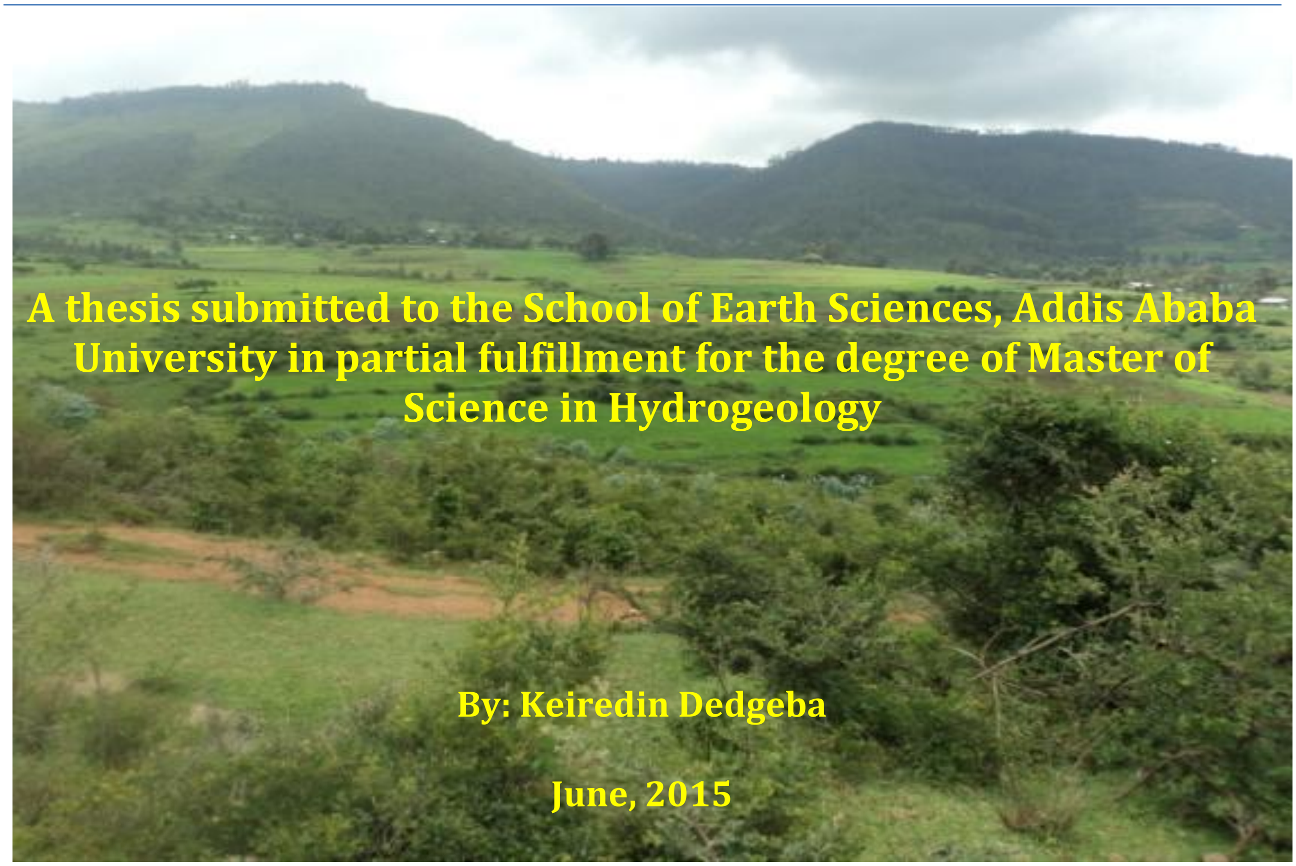
ADDIS ABABA UNIVERSITY
SCHOOL OF EARTH SCIENCES

Urban Aquifer Management with Special Reference to Sebeta Town and Its Vicinities (Oromia)



ADDIS ABABA UNIVERSITY
SCHOOL OF EARTH SCIENCES

URBAN AQUIFER MANAGEMENT WITH SPECIAL REFERENCE TO SEBETA TOWN AND ITS VICINITIES (OROMIA)

By

Keiredin Dedgeba

A Thesis Submitted to the School of Earth Sciences of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science (Hydrogeology)

Approved by board of examiners:

Dr. K.V. Suryabhagavan ______________________________
(Chair Person)
Prof. Tenalem Ayenew ______________________________
(Advisor)
Dr. Dessie Nidaw ______________________________
(Examiner)
Dr. Worash Getaneh ______________________________
(Examiner)

DECLARATION

I, the undersigned declare that this Thesis is my original work and has not been presented for any degree in any university and all the sources of materials used for the thesis have been duly acknowledged.

Keiredin Dedgeba___________________

This Thesis has been submitted for examination with my approval as university advisor

Prof. Tenalem Ayenew __________________

Date and place of submission:

School of Earth Sciences, Addis Ababa University.

June, 2015

Dedicated to:

My mother, Kedija Ousman
&
My father, Dedgeba Musteffa

For their unforgettable Support and Inspiration in all my Educational Life. With Love and Gratitude!

Acknowledgement

First of all, my special thanks goes to my advisor Prof. Tenalem Ayenew, Department of Earth Sciences, Addis Ababa University, for the fruitful discussions and guidance during the course of the research.

This work would have not been completed without the contribution of various institutions, organizations and individuals; among which Oromia Water Mines and Energy Bureau; particularly Obbo Motumma Mekasa (Bureau Head) and Fekadu Lebecha (Process owner for water resources management), Ministry of Water, Irrigation and Energy; Water Works Design and Supervision Enterprise (Ato Engida Z. and Ato Dawit Nir'e), National Meteorological Agency, Sebeta Hawas Woreda Rural Water Supply Office, Taye Alemayehu and Kassahun Yaie (my lifelong friend) are greatly acknowledged for their encouragement, support and valuable data provision.

Words are found inadequate to express my bottomless gratitude to my wife, Teyba Mohammed, who is source of strength in every aspect of my life, her kind-hearted treatment and love and her endless support, brought me to this day, I thank you Mamy. My sincere gratitude also goes to my daughter Iman Keiredin (Imuka) and my younger son Bilal Keiredin and all my brothers Seid Dedgeba....and Sisters Leila Dedgeba....for their tireless inspiration and encouragement.

My classmates, friends, and colleagues in and outside the University are all acknowledged for their friendship and support during my stay at Addis Ababa University. My deepest thanks goes to my friends Kinfe Atsbeha and Yonas Teshome that we share all the academic and social life together in the two years stay during this study.

Last but not least I offer my special thanks for those who involve directly or indirectly in this study and their names are not listed. THANK YOU ALL!

Abstract

The study area, Sebeta town and its vicinities, is characterized by recently expanding urbanization, huge industrial activities and groundwater dependent agricultural practices. All these activities have a tremendous effect on the water resource utilization and a polluting potential of the system. Groundwater is the only major source for all kind of water uses and supplies in the area.

This study mainly deals with the groundwater resource assessment and sustainability problems of the resource in Sebeta town and its vicinities. The area has mean annual precipitation, potential evapotranspiration and actual evapotranspiration of 1239mm, 1355.7mm and 873.4mm respectively. The overall water balance of the study area is computed with an aim of estimating the amount of annual recharge to the groundwater. Accordingly, annual recharge to the groundwater of the study area is approximated to be 146mm. The main aquifer formations of the area are weathered and fractured basalt, ignimbrite, rhyolite, and scoria. The general trend for groundwater flow as observed from pieziometric heads is from the northern and north eastern highlands towards the southern direction of the study area. Moreover, groundwater type of the area evolves from Ca-Na-HCO_3 water type in the northern and north eastern highlands to Ca-Mg-HCO_3 on the high and intermediate productive aquifers of southern part of the study area.

This study reveal that, all streams around Sebeta town, the underlying unconfined shallow aquifers groundwater and alluvial aquifers along Sebeta river may be generally considered as highly vulnerable to any type of pollution. There is no clear and regular system for monitoring and supervision of water supplying schemes and sources by the concerned offices. It is therefore crucial to note implementation of local water regulations and appropriate legislative integrated framework for the protection and sustainable use of groundwater and pollution prevention on the surrounding aquifers.

Keywords: groundwater, pollution, urban development, sustainable use and management

List of Abbreviations and Acronyms

m:	meter
l/s:	liter per second
m/s:	meter per second
mg/l:	milligram per liter
pH:	hydrogen ion activity
mm:	millimeter
EC:	electrical conductivity
TDS:	total dissolved solids
R:	recharge value
LU/LC:	land use/land cover
ITCZ:	Inter Tropical Convergence Zone
UK-GWF:	United Kingdom Groundwater Forum
WWDSE:	Water Works Design & Supervision Enterprise
AAWSA:	Addis Ababa Water Supply Authority
WHO:	World Health Organization
GIS:	Geographic Information System
PPT:	precipitation
PET:	potential evapotranspiration
AET:	actual evapotranspiration
SRO:	surface runoff
ΔG:	change in groundwater level or recharge
W:	withdrawal
Q:	discharge
K:	runoff coefficient
SW:	shallow wells
HDW:	hand dug wells
DW:	deep wells
SP:	spring
MCM:	million cubic meters
M. Max. T.:	mean maximum temperature
M. Min. T.:	mean minimum temperature
M. Mon. T.:	mean monthly temperature
OBS:	observatory

Table of Contents

Content Page

List of Figures

List of Tables

List of Plates

1. INTRODUCTION

1.1 Background

Water resources are increasingly strained due to population growth, development, and environmental degradation with policy makers and planners often facing serious challenges in ensuring the long-term sustainability of existing resources and meeting future water demands for various sectors. Similarly, the increasing scarcity of water along with rapid population increase in urban areas provides huge challenge in urban water supply and sanitation sector, especially in the towns of developing nations of the world. Groundwater storage formed by aquifers is invaluable for water supply and storage. However, natural replenishment for these aquifers is very slow. Artificial groundwater recharge using wastewater effluent accomplished through infiltration via spreading basin or direct injection is supply augmentation practice that is already used in some arid and semi arid regions (Eusuff and Lansey, 2004).

According to some literatures, groundwater potential in Ethiopia is shaped by complex geological formations and the diversity of the topography, climate and soil. Recent studies indicate that groundwater reserves may be far greater than the commonly used estimate of 2.5 billion cubic meters (BCM). Studies for irrigated agriculture in Kobo, Raya, and Ada'a Becho suggest that regional aquifers are deep and water movement crosses surface basin boundaries. It is estimated that the groundwater reserve of the Kobo Girana Valley alone is in the order of 2.5 BCM, that of Raya 7.2 BCM and Ada'a Becho, in which this research area is included has a groundwater reserve of 965 million cubic meters (WWDSE, 2009).

No doubt that, rapid urbanization demands for improved urban infrastructures for better economic growth and environmental safety. Adequate and potable water supply facilities are one of these basic infrastructures. Lack of potable water supply results in huge social and economic problems, but most of the time provision of adequate and potable water supply demands huge capital investment that resulted in major challenges for many towns in providing their increasing populations with adequate and potable water supply. As a result, the demand for adequate water supply for industrial, commercial and domestic purposes continues to rise while the financial and technical capacities of most towns are limited. Mean while, more industry requires more water, and prosperity raises expectations for the quality of water services. A projected increase in the size of the middle class might lead to a demand for better governance and more water services (World Bank, 2012).

Most of the projected global population growth will take place in third world countries that already suffer from water, food and health problems. Municipal wastewater can be an important water resource but its use must be carefully planned and regulated to avoid adverse health impacts (Bouwer, 2000).

According to European Commission (2012) assessment, urban growth has been leading to reduction of groundwater availability. As the population increased so did water deficiency. The study also suggest that rather than assuming growth, urban planners should consider no growth or reduced growth scenarios for economic development in areas dependent on groundwater.

It is known fact that, groundwater offers numerous socioeconomic advantages to both developed and developing nations. In contrast to this strategic role for groundwater, it has remained a poorly understood and managed resource (BGR et al., 2007; FAO, 2003). Pollution of the vital underlying groundwater sources in African cities as well as in many rural communities has reached critical levels (Xu and Usher, 2006). This has become a clear threat to water service delivery and meeting the MDGs on water. The overarching challenge has therefore become the sustainable utilisation of local groundwater resources. Generally its development and sustainable use require proper management, and that is the core theme of this research work.

Like in many developing towns, Sebeta town, on which this research work focuses, has a rapid population growth and high rural-urban and urban-urban migration also poses many social and environmental challenges for the town resulting in a growing industrial and commercial centre in the town. It also faces a critical shortages of water and sanitation services to meet the critical demands of its expanding population, manufacturing industries and commercial enterprises.

Sebeta town and its surrounding is among the highly populated urban as well as industrial centers in the country. Consequently a considerable amount of waste is generated every day from different sources. Since the town has inadequate and inefficient waste (solid and liquid) management facilities, all point and non point sources in the study area discharge their effluents directly or indirectly to the nearby rivers and streams. In addition to this, wastes dumped on an open ground join the river after a while via surface runoff.

Furthermore, the prevailing situation of insufficient and unsafe water in the town of Sebeta and its surrounding resulted in communities, which have no access to yard or community tap, using unprotected sources and is believed to result in poor environmental conditions and an ever-present risk of epidemics. This situation in turn present a formidable threat to health and productivity of the citizens. The dynamics of urbanization processes accompanied with other water resource management constraints are threatening the entire water supply system of the town & often make the daily distribution planning very difficult.

As it is common in several towns and rural areas of our country, groundwater is a primary source of fresh water in Sebeta town and its surrounding. But many of the groundwater sources (production wells) that were supplying water sufficiently for the town of Sebeta in the past years getting dry and others face a problem of declining water level chronically.

Moreover a higher potential of water quality deterioration is observed in the surface water bodies as well as shallow groundwater resources of the surrounding area.

1.2. Groundwater Management Issues

Groundwater management can be defined in brief as the planned and coordinated management of groundwater basin with a goal of long-term sustainability of the resource. The management of a groundwater basin implies a program of development and utilization of subsurface water for some stated purpose, usually of a social or economic nature. In general, the desired goal is to obtain the maximum quantity of water to meet predetermined quality requirements with the least cost. Groundwater can be regarded as a renewable natural resource, if there exists to a balance between the recharge and abstraction from the basin. If pumping exceeds the total amount of recharge, groundwater depletion may occur and the aquifers are no longer sustainable. Generally, groundwater is a flow resource, a scarce one and also prone to negative externalities (over pumping and pollution). Hence, proper groundwater management is vital for the implementation of sustainable water resource development and conservation.

Understanding the quantity and quality of groundwater resources along with identifying the existing groundwater constraints are the fundamental issues for proper groundwater management over a given basin. Without considering such concerns, the effects of past development and prediction of the influences of future development can't be adequately determined. Identification of major constraints related to groundwater resource is the main driving force for the commencement of groundwater management actions.

According to Hescock (2006) as cited in Tizro et al. (2007) has explained that the assessment and development of groundwater resource can be conceived by the application of water balance method that equates demand for water against abstraction requirement needs. A water balance represents the total amount of surface and groundwater entering and leaving a given basin over a specific period of time. It is used to evaluate whether the quantity of groundwater abstracted is at safe condition or not. The estimation of groundwater balance is essential in order to assess the safe yield of the aquifer systems and therefore to establish their rational exploitation and sustainable management (Voudouris, 2006).

In groundwater management the concept of safe yield has been used to indicate the limits of pumpage from an aquifer. Safe yield is the rate at which groundwater can be withdrawn from an aquifer without producing an undesirable adverse effect (Dottridge and Jaber, 1999). The rate depends on the hydraulic parameters of the aquifer and the location of boreholes. Safe yield should be less than the average annual recharge in order to compensate for minor groundwater losses. Any withdrawal in excess of safe yield is an overdraft (Freeze and Cherry, 1979). The traditional definition of the safe yield assumes the pumpage rate is equal to the total recharge, but Feng-Xiang (2001) as cited in Voudouris (2006) assumed that the safe yield is 50% of the total natural recharge of groundwater.

The quality of groundwater had been given little attention in groundwater management issues in the past. However, it is now recognized just as important as its quantity. The quality of water is used to determine whether the water is satisfactory for the proposed use or not. Once groundwater has become polluted, it usually requires a very long, complex, and expensive task to restore the water quality in to its original condition. For these reasons, identification and assessment of threats to groundwater quality, and monitoring and prevention of groundwater pollution are considered as one component of groundwater management issue. Groundwater quality management can be implemented to avoid groundwater pollution through assessing pollution hazards and risks, delineating groundwater vulnerability zones, controlling effluent discharges and constructing contaminant structures. Complete groundwater management describes the above mentioned groundwater management theories, of which some will be addressed in this paper work.

1.2.1. Groundwater Management issues in Ethiopia

Policy, laws and regulatory tools

Central objective of the Ethiopian water resources management policy (1999) is "to enhance and promote all national efforts towards the efficient, equitable and optimum utilisation of the available water resources of the country for significant socio-economic development on a sustainable basis". The fundamental principles of the policy are:

- Water is a natural endowment commonly owned by all the people of Ethiopia;
- Every Ethiopian citizen shall have access to sufficient water of acceptable quality to satisfy basic human needs;
- Water shall be recognized both as an economic and social good;
- Water resources development shall be underpinned on rural-centered, decentralized management, participatory approach as well as integrated framework;
- Management of water resource shall ensure social equity, economic efficiency, system reliability and sustainability; and
- The participation of all stakeholders, user communities especially that of women, shall be promoted in water management.

The water resources management policy is a framework document that needs to be translated into specific laws, regulations, plans and strategies as well as appropriate administrative set ups for its proper implementation.

Among recent developments, empowerment of regional governments to administer, develop and protect the natural resources of their region (Proclamation No. 7/1993) and the empowering of Regional Natural Resources and Environmental Protection Bureaus to manage and develop their natural resources including water resources (Proclamation No. 41/1993) are some of the important moves in recent years.

The Ethiopian Water Resources Management Policy (1999) and the Ethiopian Water Resources Management Proclamation No. 197/2000 are the two most important achievements in modern day Ethiopia. According to these tools water is put 'to the highest social and economic benefit of the Ethiopian people'. The federal arrangement that gave large autonomy to regional government, according to the above mentioned proclamations and the constitution seems as if overlooked by the active proclamation that leads to weak implementation of the policy and enforce water laws.

Generally speaking, regulatory responsibilities are not clearly defined as yet, which is understandable given the limited extent of groundwater development until very recently. The other main challenge in regulation is clarity and effectiveness. Several regulation provisions exist but they are not widely known and implemented. Another shortcoming is that they are limited to licensing individual wells – particularly with an eye to well location and water quality – but are not geared to the sustainable management of groundwater. According to the comments forwarded by World Bank, 2013, the priority actions in regulations hence are:

(1) clarifying the institutional framework,

(2) activating existing regulation, and

(3) developing standard drilling procedures.

Groundwater management in Ethiopia has not yet been considered as decisive task to be done in such vulnerable groundwater relying project area. This is mainly linked with the development stage and utilization level of the groundwater itself. As explained above, although the country, particularly the highly populated and socio-economically dynamic part of the country (study area) is highly dependent on groundwater for its water supply, little has been done to manage it.

1.3. Previous Works

Though there is no detail work done so far on the groundwater resources management of the specific study area, there are few unpublished thesis research works and geological and hydrogeological investigations that are found valuable to be mentioned in this area.

Among the unpublished thesis research papers, the work of Deshu Mamo, 2004 on the assessment of pollution of Sebeta River has some contribution but this study covers a very small portion of the catchment, about 10 km^2 and it strictly deals only with the pollution of the surface water and soils in and around Sebeta town.

The MSc Thesis work of Solomon Kenea, 2007 on GIS-based groundwater vulnerability mapping of Atebela river catchment, Sebeta area is the first detailed work that covers Sebeta town and its surrounding. He applied the DRASTIC MODEL to the assessment of groundwater vulnerability to contamination to produce the intrinsic, specific and hazard vulnerability maps of Atebela catchment. He has assessed the specific vulnerability of groundwater to contamination for nitrate. He has also explained that these maps are useful to develop an appropriate legislative framework for the protection and sustainable use of the groundwater resources and for water pollution prevention of the groundwater of Atebela River catchment and hence, the vulnerability maps can serve as one tool to achieve the Millennium Development Goals by ensuring environmental sustainability. Some datas are adapted and used in this thesis from this work.

Similarly the work of Tamiru Alemayehu et al. (2005), with the title of Hydrogeology, Water Quality and the Degree of Groundwater Vulnerability to Pollution in Addis Ababa, Ethiopia has applied the DRASTIC model and has shown both the intrinsic vulnerability of the area and specific vulnerability assessment for population density and hazard centers such as industries and health centers.

The other most important work to be mentioned in this area is that of Water Works Design and Supervision Enterprise (2009) on 'Evaluation of Water Resources of the Ada'a Becho Plains Groundwater Basin for Irrigation Development Project'. This work has identified that, the hydrogeological set up of the basin is governed by the lithological stratigraphy of the area and tectonic. In this investigation it is confirmed that, the recharge condition, groundwater flow and aquifer parameters in these plains is highly governed by the general bedding of the sedimentary formation underlying the volcanic unit, the tectonic condition and the hydraulic properties of the different volcanic units that outcrops in the basin. From the maps it clearly understood that the Ada'a and Becho plains regional groundwater is recharged from large areas (Abay plateau and Upper part of Awash River basin). The groundwater flow concentrates in these plains and the potentials in these plains are significant. Moreover, in recent years a continuous investigation is being undertaken using integrated method and drilling of a number of production test wells. The indication for the availability of large amount of groundwater has also prompted the government to look for additional water for irrigation. The Ada'a and Becho Plains Study project is aimed to meet this objective (WWDSE 2009).

Regarding the title of this particular research work only few related works can be mentioned in the surrounding region. The first one is the work of MetaMeta and Associates on established framework for integrated water resource protection & water quality monitoring and improved control of waste water discharges with special focus on larger area of Upper Awash River Basin in its specific project entitled 'Source to Tap and Back'. This work describes the baseline situation on **water resources and governance** in the project area. It gives a detailed overview of all involved institutions, stakeholders and their responsibilities. It also describes understanding of water resources and governance are necessary to establish a framework for integrated water resource protection (AAWSA, 2014).

In all studies conducted so far, there is limited consideration of the role of urban aquifer management in affecting the sustainable dynamics of the catchment of the surrounding under consideration. Moreover, the current study considers these factors to critically estimate direct groundwater recharge and discharge. This research work after incorporating recent data to the existing ones and assessment of recent changes in hydrology and hydrogeology of the area are new works that supplement the existing ones to provide useful information for Policy makers and general public to manage the resource on sustainable basis.

1.4 Statement of the Problem

The Regional Government of Oromia is operating targeting Sebeta Town and its surrounding as an investment center for industrial and agricultural development. Most of the activities carried out are a potential threat to the groundwater since the industries (textile, tannery, alcohol factories, brewery, soap factory, etc) release their effluents into the surrounding rivers. In addition, agricultural practices with the application of fertilizers and pesticides are also potential causes of groundwater pollution. Boreholes estimated to be 150 in number, are found within the study area especially in the town of Sebeta and its surrounding. Hence the combined effect of over-pumping of the groundwater with its contamination needs special attention.

Several changes are noted at the existing groundwater resources of Sebeta town and its surrounding, especially in the highly populated and industrialized parts, due to land use alterations, urbanization, shrinkage of wet lands *etc*. These changes are attributed predominantly to human activities in conjunction with poor management practices, which have caused numerous negative consequences such as development of deficient water balance and reduction of groundwater resources, groundwater level decline, and surface and groundwater quality deterioration.

Bearing in mind these issues, this research is driven by the need to understand the effects of human and natural impacts and it will largely focuses on the assessment of causes of sustainability challenges of water supply schemes of the town. Finally recommendations on some possible solutions for sustainable utilization and management of the resource are forwarded.

1.5. Research Objectives and Scope of the study

1.5.1. Research Objectives

General Objective:

- The primary objective of the proposed study is to suggest appropriate urban aquifer management tools/systems by assessing the groundwater potential of the area along with its sustainability for domestic, agricultural and industrial water supply.

The specific objectives include:

- Quantify the amount of annual recharge
- Estimate the exploitable groundwater resource and the safe yield of the aquifers of the study area
- Assess the degree of vulnerability of the groundwater for major groundwater pollutants and provide information on the groundwater resources management options of the surrounding catchment.

1.5.2. Scope of the study

The scope of the study incorporates the analysis of primary data and 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 future sustainable management of the surrounding aquifer supported with the existing situation.

1.5.3. Limitations

Like many other research works, this study has also faced a number of limitations in the process of convening the work. The main obstacles were:

- The absence of time series data that could show successive trends of monitoring data on groundwater level decline and pollution in the study area.
- Severe financial and instrumental constraints that greatly restrict the number of samples that could have been incorporated in the analyses performed for the effluents discharge scenarios.
- The time bound set for the thesis work coupled with the financial constraint forced me to incorporate important temporal data from previous works.
- Limited number of literatures specific to the objectives set in this project and the study area.

For these reasons it is not possible to draw a clear picture on the scale of groundwater depletion and pollution but a number of indications, administrative and technical reports confirmed that the situation is critical and needs immediate solution.

1.6. Research Methodology

The methodology on which the research worked comprises of three major components, namely, office work (pre-field work), field work and post field work. These methodologies are thought to be useful to attain the above mentioned specific objectives.

1.6.1. Office Work (Pre-field Work)

This includes collection of secondary data such as meteorological data, geological map, topographical map (detailed 1:50,000), hydrogeological map, geophysical data, pump test data, Satellite data and Population size, livestock distribution, commonly cultivated crops and current water supply of the study area. Moreover, published and unpublished research works, geological and hydrological, hydrogeological report and information on socio-economy of the area has been reviewed in the office work. In general, major works done during Desk study/Data inventory stage includes:

a) Collection and analysis of relevant reports of previous studies and development activities related to water resources
b) Collection and analysis of hydrometeorological data
c) Collection and interpretation of digital images
d) Collection of different maps (geological, hydrogeological, soil, land use etc)
e) Preparation of checklist for data to be collected from different sources

1.6.2 Field Work

During the field work, all data on population size, current water supply of the study area, current water use of the area, investment plan of the regional state, geological and hydrogeological conditions of the area and other relevant information from the field, local institutions and individuals has also been gathered.

In addition to these, 10 water samples has been collected from the surrounding streams (3 samples), wells (4 samples) and springs (3 samples) for analysis. Discharge data from some selected springs, wells and current water use and management practices of the study area has been collected for the purpose of analysis.

1.6.3. Post Field Work

After the field work, the following approaches and methodologies has been applied to assess the water supply sustainability and quality problems of the proposed study area. These are:

- Data and information about the beneficiary's perception of water supply sustainability problems has been collected using different methods of data collection; like interviews and discussions with beneficiaries, technical staff members, and personal observations was employed to produce primary data.
- Data and information from private well (deep and motorized wells) owners has been collected to estimate the daily abstraction rate and the distribution of such wells.
- Water quality test has been conducted on thoroughly selected streams, springs and groundwater wells.
- An interview was undertaken with the concerned technical persons and possible stakeholders whom their responses are very important to understand the sustainability problems of the water supply schemes in the area under discussion.
- Informal discussions with key informants about the sustainability problems of existing water-supply schemes and their management has also been conducted.
- The analysis and interpretation of data has been carried out by using convenient mechanisms.
- In general, the research methodology employed is summarized as shown in a flow chart below (Fig 1.1.)

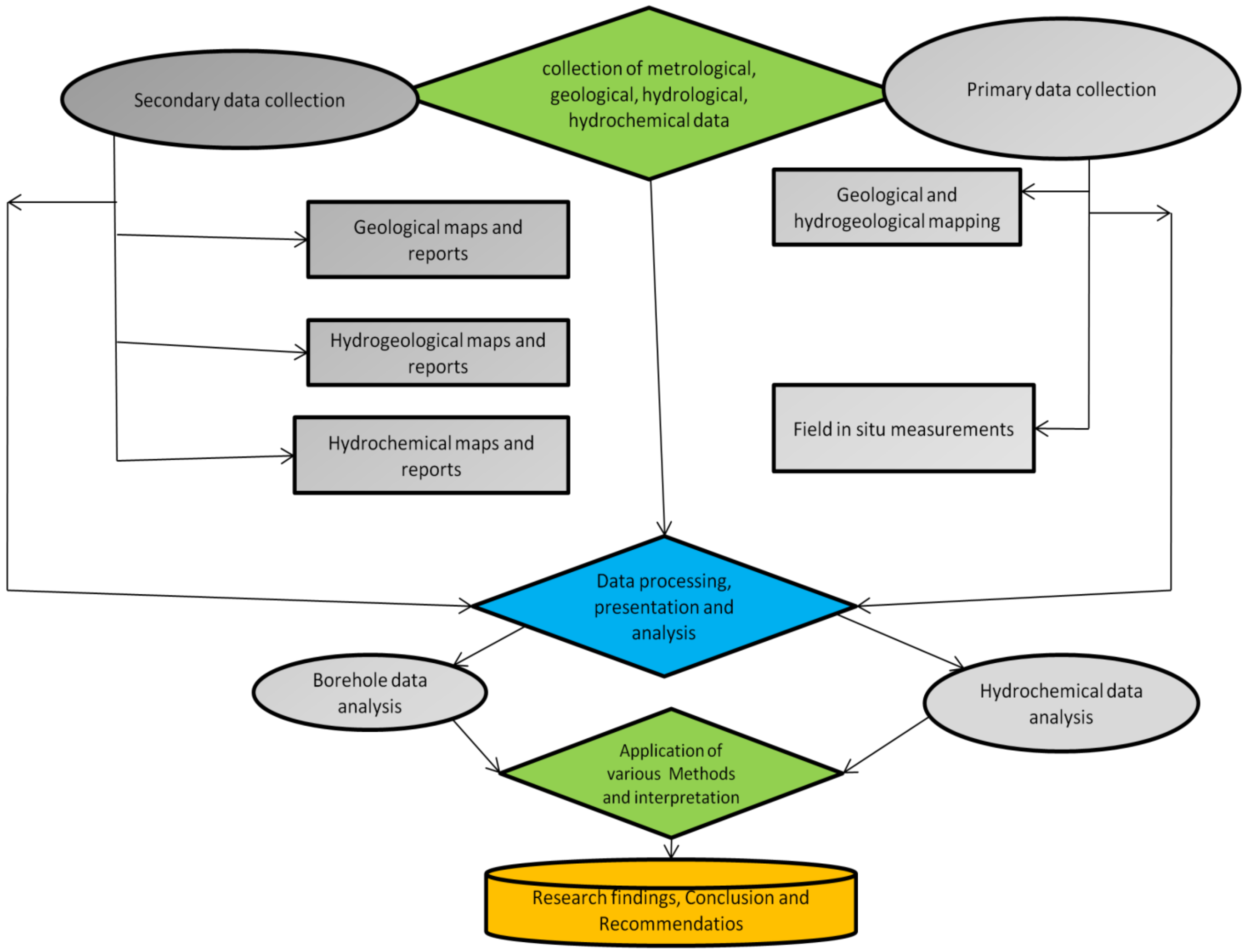


Fig. 1.1: Flow chart of the research methodology

2. GENERAL OVERVIEW OF THE STUDY AREA

2.1 Location and Accessibility

The study area is part of the central landmass of Ethiopia, found in the upper Awash Basin specifically situated on the northwestern shoulder of the Rift Escarpment. It is located at about 20-35 km southwest of Addis Ababa in Oromia National Regional State, Special Zone of Oromia Surrounding Finfinne, in the District of Sebeta Hawas as well as Sebeta town Administration. The two major all weather asphalt roads, namely the Addis Ababa – Jimma asphalt road and the Alemgena – Butajira asphalt road passes through the study area (Fig 2.1).

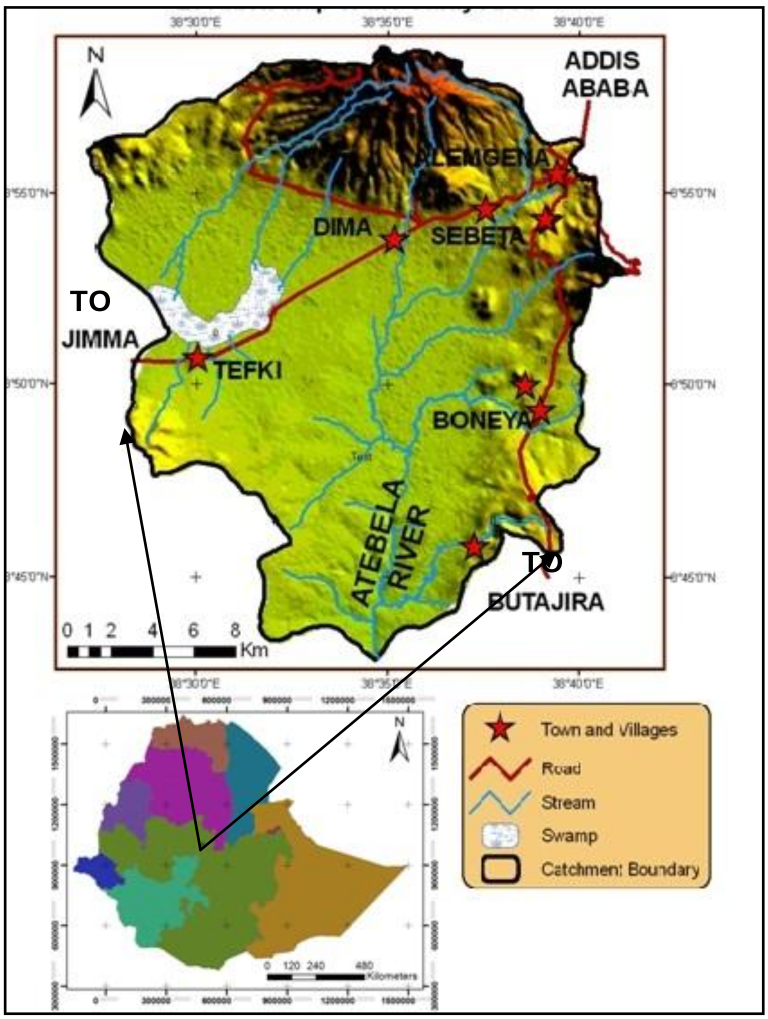


Fig 2.1 Location map of the study area

The area of interest is specifically bounded by geographical coordinates of 38^0 29' 55.3" - 38^0 41' 30" E Longitude, and 8^0 50' 52.4"- 8^0 59' 57.2" N latitude, having an average elevation of 2260m a.s.l. and covers a total area of over 361.2 km^2 but the catchment has a little bit wider area having an area of 495km^2. It is bordered by Ilu District from the southwest, Welmera/Holeta district from the north, Akaki District from the East, Addis Ababa from the northeast, and Kersa Kondaltiti district from the South.

Major towns and/or villages that lie within the study area include Sebeta/Alemgena, Boneya, Dima and Tefki. They are all found on the major asphalt roads.

2.2 Climate

The climate of the area is predominantly humid to sub-humid with a total annual rainfall of about 1239.1mm, whereas the mean annual temperature is about 15.7 ^{0}C. The effect of orography on the climate is observed that it is on the wind ward side receiving the greatest amount of rainfall. The mountain of Wechecha is experiencing lower humidity during the hot season. The topography of the study area ranges in altitude from 2000 – 3380 m above the mean sea level.

2.3 Physiography and Drainage Pattern

The study area is characterized by very diverse spatial variation of topographic features. It ranges from very steep high mountains to flat plains with the general slopping direction being from south towards the north. The mountainous areas are located in the northern and eastern parts of the study area with higher peaks of hills. Such features are also found in the southwestern part around Tefki. The altitude reaches a maximum of 3380m (at Wechecha mountain) to 2000m at the mouth of the surrounding river catchment. Most part of the area is covered by flat land which extends from the foot of Wechecha and Daleti to the mouth of Sebeta/Atebela River and that also goes beyond Tefki town. It lies mainly on the southern, western and central part of the catchment at an altitude of 2000–2362 m with slope of 0 – 7 percent. The streams meander in this flat land especially in the southern part of the study area with gorges forming slope of 2 – 7 %.

The study area is found in two physiographic divisions. The first physiographic division is the plateau area which consists part of the Central Ethiopian Highland adjacent to the northwestern shoulder of the Rift Escarpment. It is part of extensive landmass of Tertiary Plateau Basalt (Trap Series). The mountain chain of Wechecha whose elevation peak of 3380 meter is found in the plateau located along the Rift Margin area. The mountainous ridges of Wechecha to the north of the study area are covered by eucalyptus and the indigenous coniferous forest of Suba.

The second physiographic division is the relatively flat plain which forms the major part of the study area (Fig 2.2). It is found following the north-western shoulder of the Main Rift system. Young basaltic lava flows and jointed ignimbrite-sheets dominate geology of the areas under this physiographic division. Becho plain, situated west of Mt. Wechecha, is included in this part where no significant topographic changes other than planar surfaces are exhibited. Elevation in this part of the study area varies from 2000 to 2080 m. The ridge of Daleti along the road to Butajira is covered by dense forest of smaller areal extent, and with lowering of elevation bushes, grass and scattered trees of mostly man-made (coniferous, and eucalyptus trees) characterize the area. Most of the flatland areas within this physiographic division are grass lands as well as agricultural land due to presence of fertile soil and favorable climatic conditions (Gelana Gadissa, 2005).

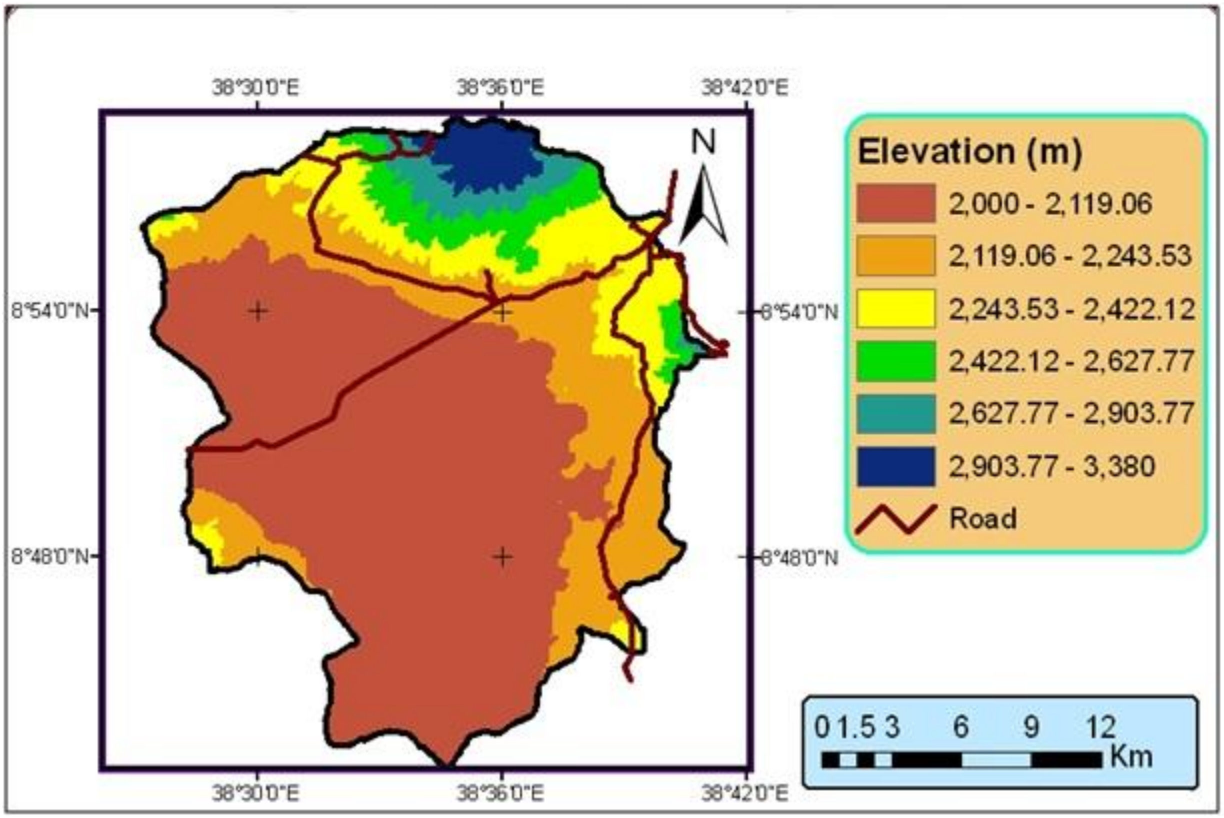


Fig 2.2. Topographic and elevation map of the study area

The alluvial plain of the study area is an area of active deposition due to its subdued relief and consequently low stream gradients. Erosion gullies are common where steeper slopes occur.

The surface drainage of the study area is characterized by radial and parallel pattern on the hillside and foot of Wechecha Mountain, respectively and rectangular pattern is observed in the southern part of the catchment. Streams that discharge from the northern and eastern part of the catchment including those in the southwest discharge into Atebela river which in turn discharge into Awash river while streams that flow from the west and northeast remain in the catchment forming swamp during the rainy season (Fig 2.3).

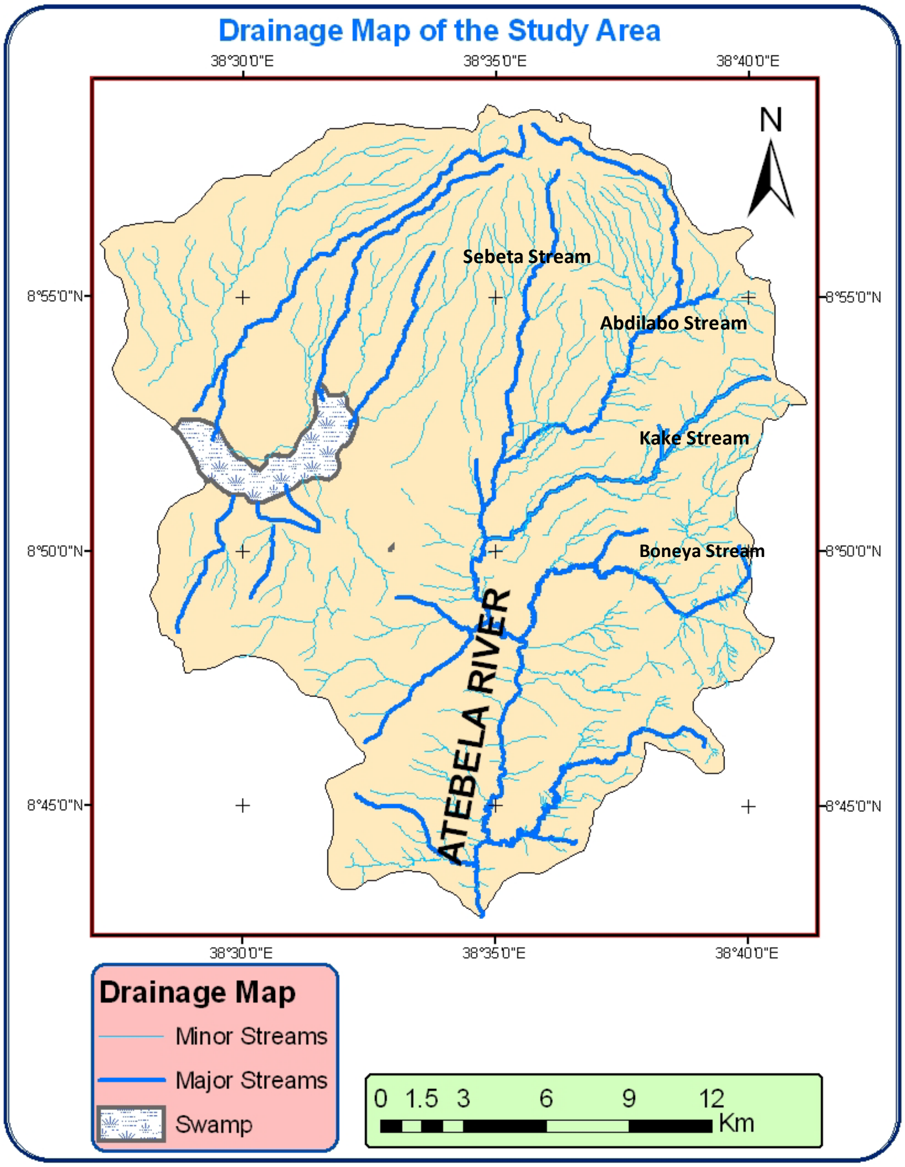


Fig 2.3 Drainage map of the study area

2.4 Soil Type and Properties

Soil is a dynamic natural body that involves external and internal soil forming processes acting on different geomorphic surfaces in relation to different soil forming factors such as parent materials, climate, relief/topography, organisms, and human influences over a period of time. These resulted in the formation of various soils in the study area.

Soil map of the study area is found from the report of Becho Plain groundwater survey in which soil classification is based on air photo interpretation and description of soil auger borings and pits carried out according to FAO guidelines. Vertisols are the dominant soil class of the study area, and including all the upland plains, all the seasonal swamps, and most of the alluvial cover flood plains and terraces. They are black clays characterized by the dominance of the clay mineral, montmorillonite, which expands when wet and contracts when dry, giving rise to wide surface cracks.

According to Solomon Kenea (2007), five soil groups are identified in the study area. The first soil unit comprises of the gentle foot slopes of volcanic hills fringing the alluvial plain. The soils are eutric vertisols which frequently have calcareous nodules at depth in the profile. They are susceptible to rill and gulley erosion on the prevailing slopes of 1.5 – 3.0%. In the study area, they are manifested starting from the northwest part at the foot of Mt. Wato Dalecha rounding along the foot of Wechecha and also along the road taking to Butajira. In addition, these soils are found at the southern part extending up to the foot of Mt. Debel then to Tefki. The second type of soil comprises very gentle foot slopes of less than 1.5% gradient, which occur extensively to the north of the entire alluvial plain and also to the south of the road southwest of Tefki town. The eutric Vertisols are less susceptible to erosion on these slopes but are subject to periodic flooding by slow moving water. The back swamp soil units are subject to the most prolonged flooding are characterized by stagni-calcic vertisols with significant accumulation of calcium carbonate at depth.

Soil morphology is related to the appearance of the soil in the field in terms of depth, color, texture, structure, consistence, drainage and the presence or absence of stones, and carbonates. The soil units have been grouped into the following classes for a generalized description of their soil morphology:

- Very shallow-to-shallow soils – these soils occur in the study area most prevalently in areas of steep slopes and are red to reddish brown in color. They are dominantly, in the southwestern, northern, eastern and southeastern hills/mountainous areas.
- Moderately deep to deep, poorly drained soils – these soils occur at receiving sites of runoff from the surrounding elevated terrain. They are heavy clay soils with a characteristic of montmorillonite dominated clay fraction which causes them to shrink and swell and occur in the vicinity of Tefki town.
- Alluvial soil – these soils are young soils that are often found on low-lying plains and near river stream courses. They constitute sand and gravel with varying thicknesses

Different land/soil degradation types were encountered within the basin area. They are mainly evident as moderate to severe erosion, flooding and landslides. The main contributors for the phenomena are steep slopes, very little vegetation cover, indiscriminate use of the land, etc. All these situations aggravate (accelerate) the degradation processes. The textural map of the soil in the study area is shown in Fig 2.4.

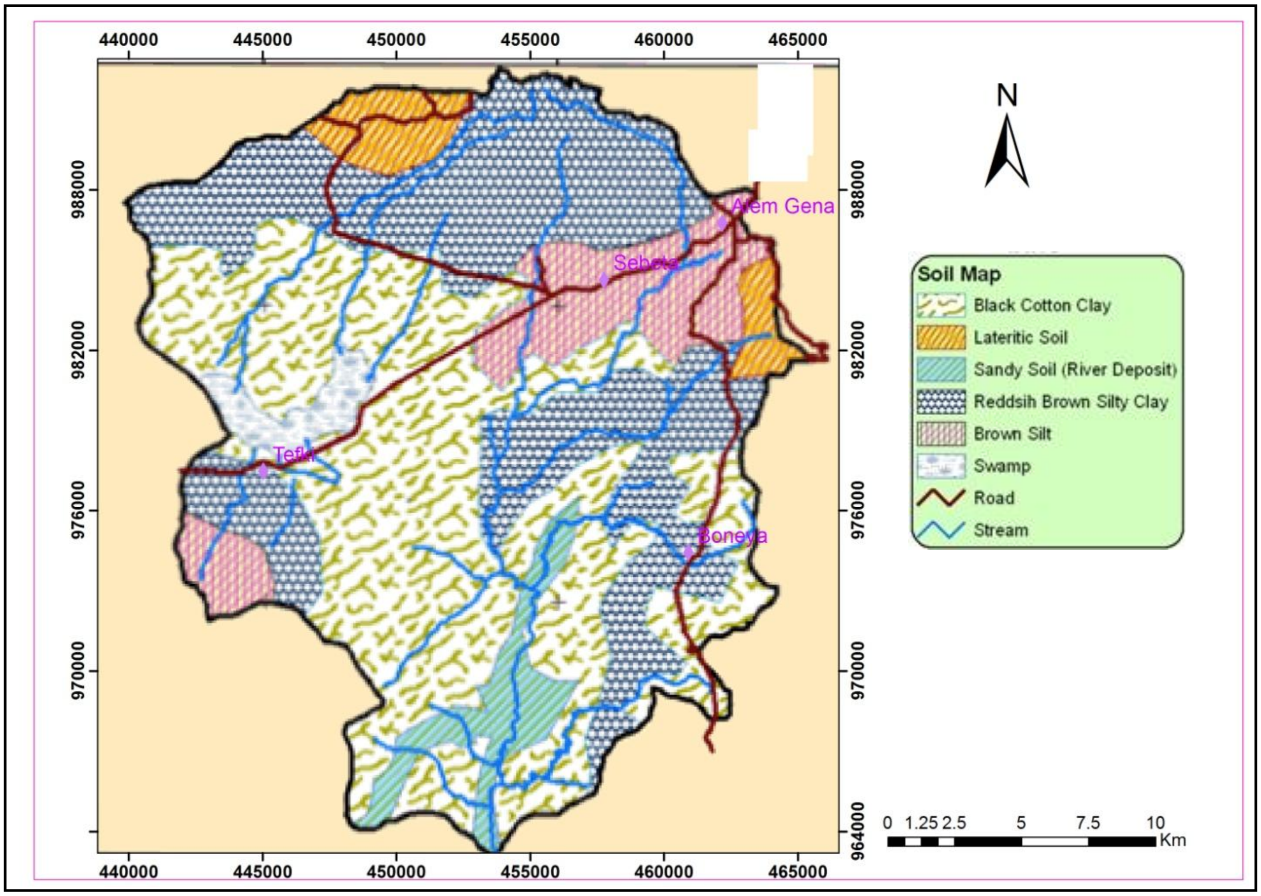


Fig 2.4 Soil map of the study area (after Solomon Kenea)

2.5 Land Use and Coverage

The land cover of the study area is classified as forest, bare rock, agriculture and grassland, swamp, bushes and shrubs, and built up areas (towns, all weather and asphalt roads, etc). The land use pattern of the area is dramatically changing annually due to urbanization, population growth, industrialization and irrigation based agriculture which includes big size flower farms. Eventually these differences will have direct impact on the groundwater and surface water resources of the area. The relative percentage of the land cover is given in Table 2.1. below

Table 2.1. Spatial distribution of land use /land covers in the study area

Group	Major Classes	Area (Km^2)	% Coverage
1	Forest	20	4.04
2	Bare land (Rocky)	15	3.03
3	Cultivated and Grassland	237	47.88
4	Bushes and Shrubs	105	21.21
5	Swamp	14	2.83
6	Built up areas (Towns + Road)	104	21

The major classes are sub-divided into mapping units (Fig 2.4). The main purpose of this sub-division is to reduce the variation within a given land use/land cover types by breaking heterogeneous into more homogeneous land use/land cover types in relation with the hydrography of the basin.

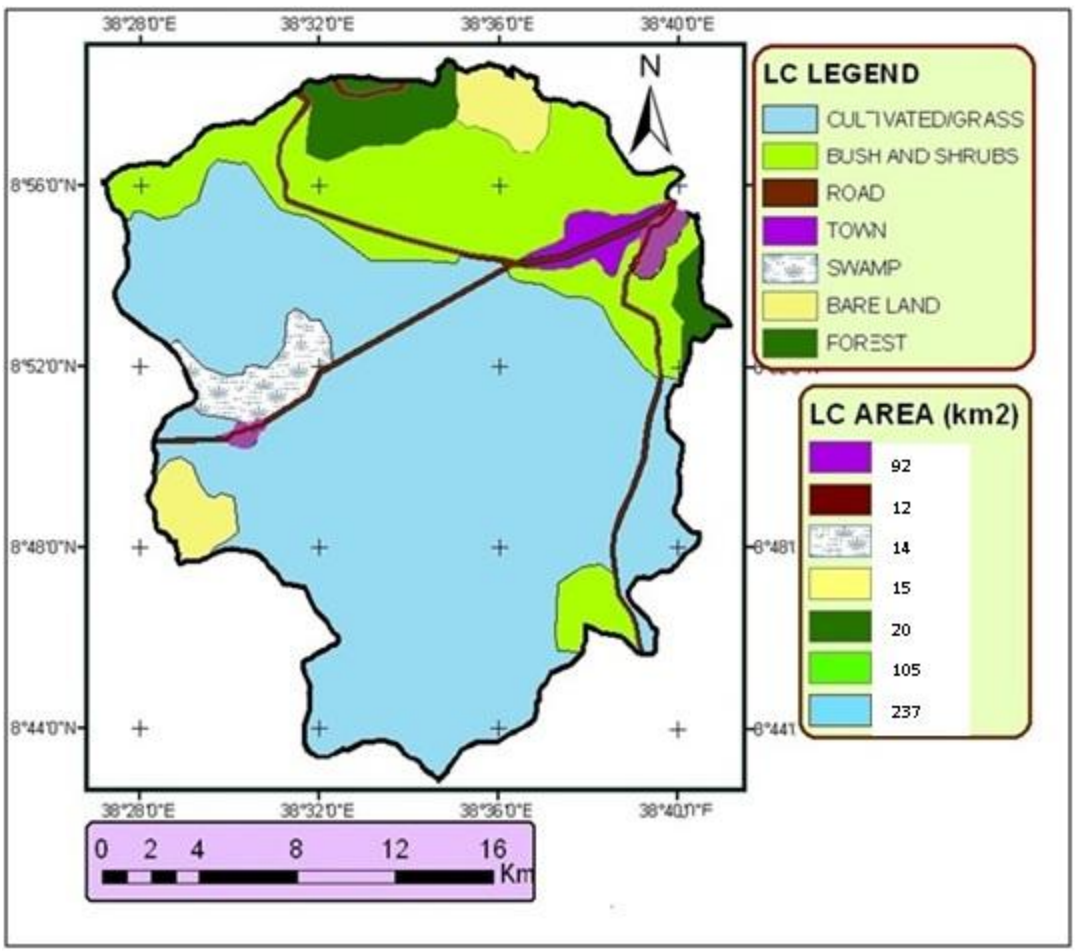


Fig. 2.5. Land cover/land use map of the study area

3. HYDROMETEOROLOGY

Groundwater resource investigation of a given area is highly based on its hydrometeorological parameters. Hydrometeorological variables of the study area is determined from A.A (Bole), Sebeta, and Holeta Meteorological Stations. Moreover, Food and Agriculture Organization (FAO) of United Nation Local Climate Estimation database that estimates the variables by weighing the values of the nearby stations based on their distance from a given point of interest is used. Accordingly, these variables are presented briefly as follows:

3.1 Precipitation

In water resources development and management, rainfall (precipitation) is the most important climatic variable, and its temporal and spatial variability determines the range of human activities. Seasonal rainfall in Ethiopia is driven mainly by the migration of the Inter-Tropical Convergence Zone (ITCZ) (C. Mc Sweeney, 2008), particularly influencing the main season during the second half of the year; and offshore winds originating in the Arabian Sea (The Livelihoods Integration Unit), which affects the minor season during the first half of the year. Moreover, rainfall pattern is spatially correlated to topographical variations in the country (Cheung et.al, 2008). Consequently, three rainfall regimes (Abebe, 2010) are commonly identified. Hence, the movement of ITCZ in the northward direction brings moisture from the South Atlantic Ocean, which results in high rainfall in the study area.

Monthly mean precipitation distribution of the study area is estimated using the arithmetic mean value of the long term historical rainfall data of Holeta, Sebeta, and A.A (Bole) meteorological stations. Accordingly, the study area receives mean annual precipitation of 1239mm.

Table 3. 1. Monthly mean precipitation records of the meteorological stations around the study area

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Holeta	24.8	61	72.1	90.9	79	151.9	285.7	330.3	198.3	23.3	14.7	14.5	1346.7
Sebeta	17.4	50.3	71.6	100.9	94.3	148.4	298.8	337.6	141.1	29.2	7.7	10	1307.3
A.A (Bole)	12.6	33.5	64.3	86.9	66.2	123.5	243.3	256.3	131.4	35.8	2.7	6.9	1063.2
Average	**18.3**	**48.3**	**69.3**	**92.9**	**79.8**	**141.3**	**275.9**	**308.1**	**156.9**	**29.4**	**8.4**	**10.5**	**1239.1**

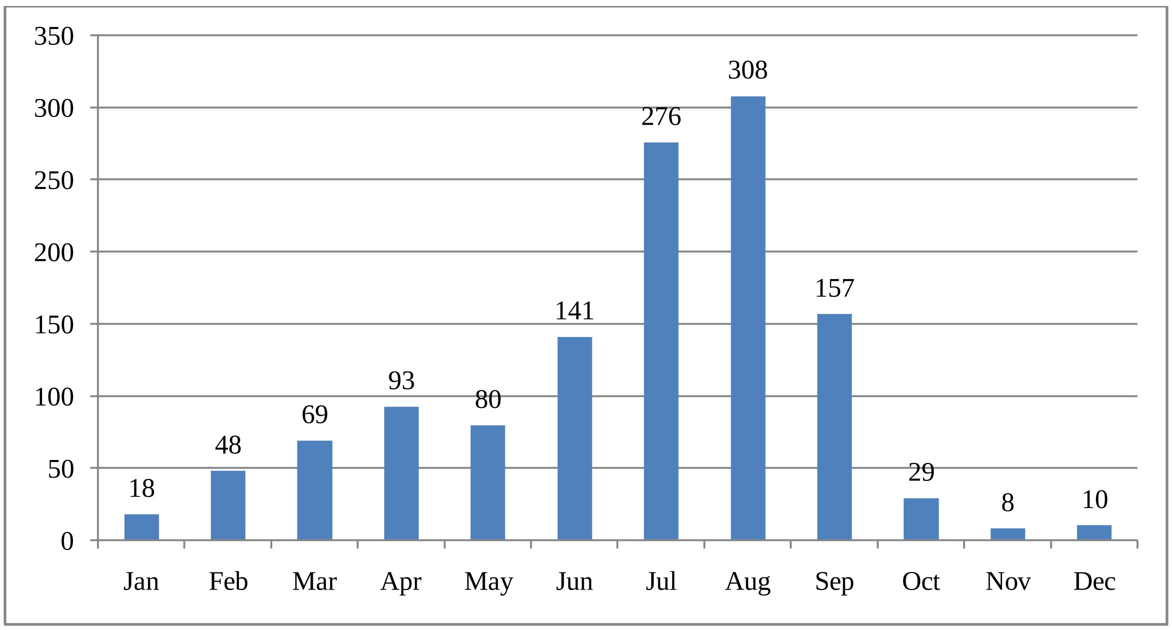


Figure 3.1. The arithmetic mean monthly rainfall distribution of the study area for the period of 1985-2014 (Source: NMA)

3.2. Temperature

The higher the air temperature, the more water vapour it can hold, and similarly if the temperature of evaporating water is high, it can more readily vaporize. For this research, the temperature data for Addis Ababa Observatory and Holeta are used since there is no meteorological station in the study area that records temperature data. The study area has low variation in mean monthly air temperature. It has low mean value of 13.6^{0}C in the month of November while it attains the highest mean value of 17.3⁰C during the month of May as shown in table 3.2 below.

Table 3. 2. Mean daily temperature in the study area in months (1985-2014)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A.A (Bole)	15.8	16.95	18.2	18.5	18.6	17.3	16.3	16.15	16.25	16.05	14.85	15
Holeta	13.5	14.7	15.75	15.95	15.95	15.1	14.4	14.35	14	13.55	12.35	12.35
Mean T(⁰C)	**14.7**	**15.8**	**17.0**	**17.2**	**17.3**	**16.2**	**15.4**	**15.3**	**15.1**	**14.8**	**13.6**	**13.7**

Source: NMA

3.3. Evapotranspiration

Evapotranspiration is one of the most important climatic variables due to the fact that a considerable amount of moisture is lost from a watershed through such processes. It is affected by other climatic factors such as temperature, relative humidity, wind speed, soil moisture availability, solar radiation and land cover (crop) types. Potential evapotranspiration is the amount of water that could be lost under conditions with adequate precipitation and soil moisture supply and it is useful in predicting the evapotranspiration of an area and in monitoring potential water scarcity situations. The water budget (moisture surplus or deficit) of a watershed is determined by balancing the incoming water (mainly precipitation) and the water leaving the watershed the significant proportion of which is contributed by evapotranspiration.

In this case the monthly potential evapotranspiration of the area is adapted from FAO local climate estimator which gives potential evapotranspiration of point of interest by proximity weighing the nearby stations. Actual evapotranspiration is determined by soil moisture balance of the area in the process of groundwater recharge estimation. Accordingly, the mean annual potential evapotranspiration and actual evapotranspiration of the study area are 1355.7mm and 873.4mm respectively.

Figure 3.2 and table 3.3 show the relationship between precipitation and evapotranspiration. Accordingly, groundwater recharge is expected when precipitation is significantly exceeding the evapotranspiration during the months June to September.

Table 3. 3. Mean monthly and annual precipitation, potential evapotranspiration and actual evapotranspiration of Sebeta area

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
P(mm)	18.3	48.3	69.3	92.9	79.8	141.3	275.9	308.1	156.9	29.4	8.4	10.5	**1239.1**
PET (mm)	116.3	113.4	136.4	126.0	128.7	100.5	83.7	86.8	97.5	127.1	121.5	117.8	**1355.7**
AET (mm)	27.3	51.3	71.3	93.9	80.8	100.5	83.7	86.8	97.5	101.4	50.4	28.5	**873.4**

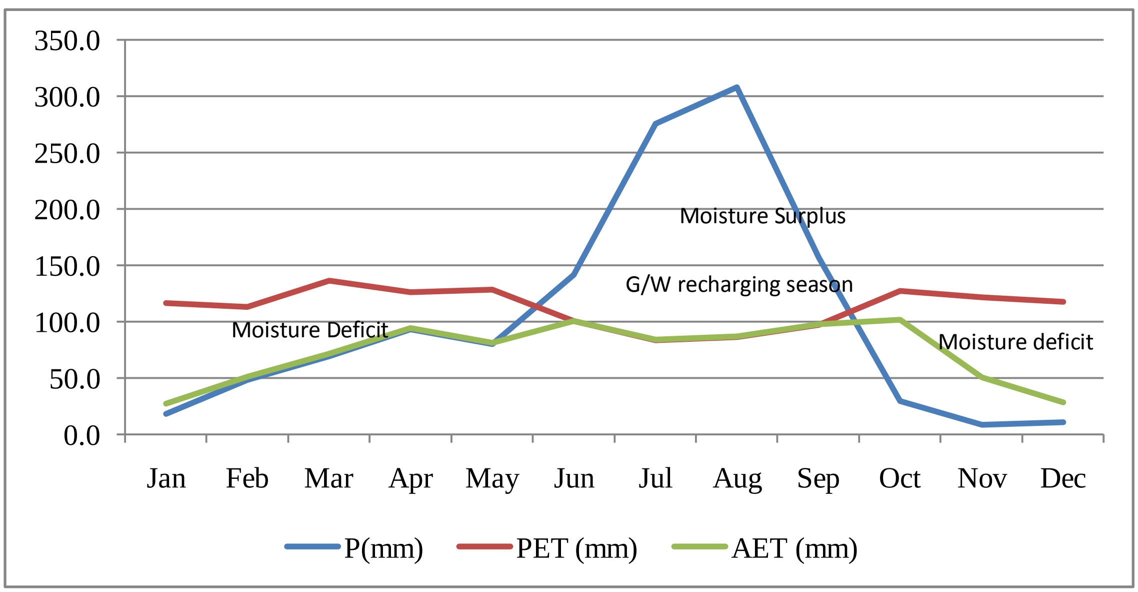


Figure 3.2. Relationship between Precipitation and Evapotranspiration of the area

4. GEOLOGY AND HYDROGEOLOGY

4.1 Geology

4.1.1 Regional Geology

The regional geological setting of the area consists of one major rock group, namely Rift/Post-Rift Volcanic Products and Sediments (Fig 4.1). The Rift/Post-Rift Volcanics and Sediments, mostly confined to the zone of the Main East African Rift System generally stretching in the northeast direction across the area, comprise a rather complex geology with diverse rock units of basic to acidic composition. These are results of series of different volcano-tectonic activities in the Quaternary Period. Details of the regional geology, as extracted from previous workers' reports (mainly from a compilation work of GEODEV–AFREDS (1999)), are provided in the following subsections.

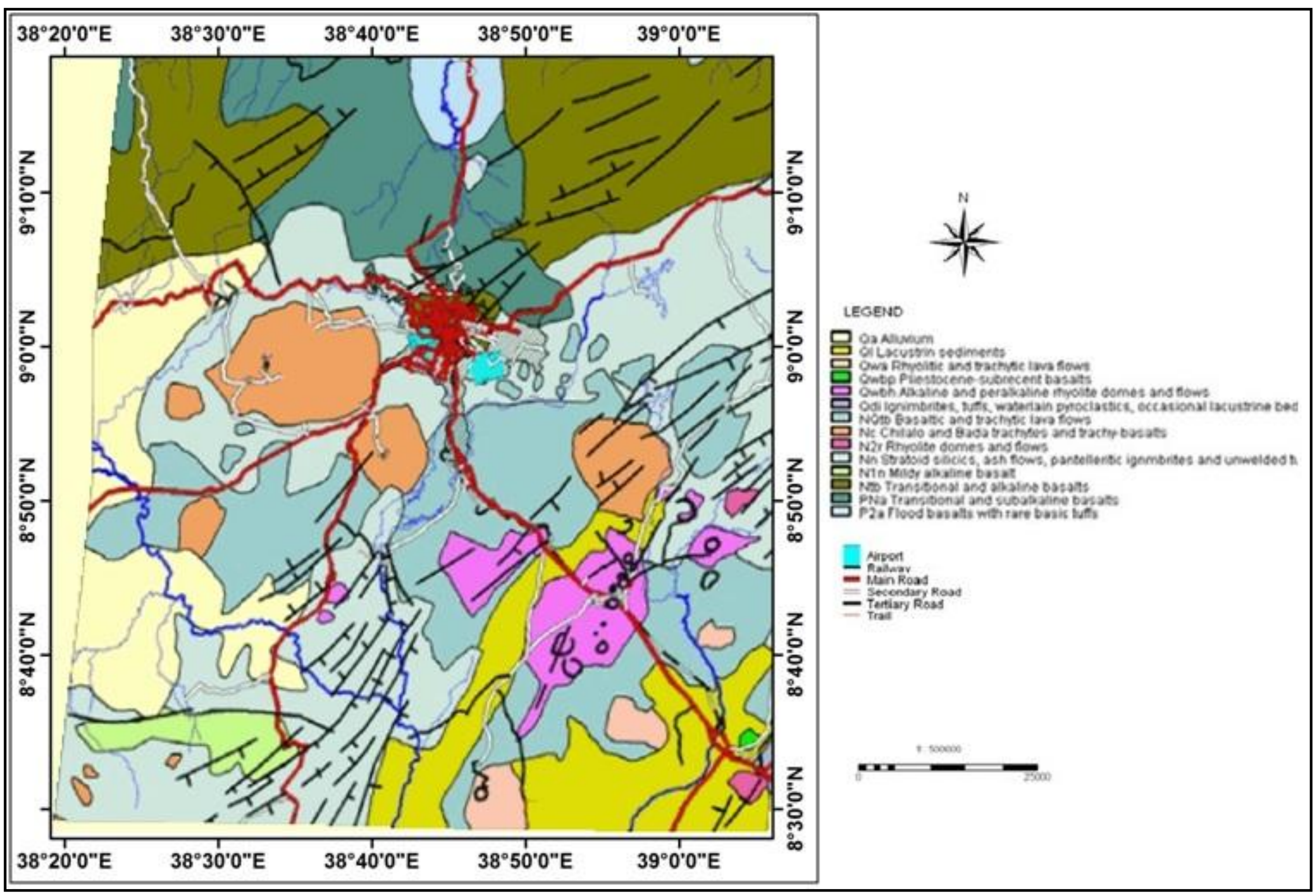


Fig 4.1 Regional geological map of the study area (Source: Gelana Gadissa, 2005)

4.1.1.1 Post Rift Volcanics and Sediments

4.1.1.1.1 Nazret Group

The name Nazret Group (Nn) was assigned to a thick succession of stratoid silicics of the Rift Valley floor with some occurring along Rift margins and adjacent plateau (Kazmin & Seifemichael Berhe, 1978, 1981; Kazmin et al., 1979). The stratoid silicics consist of rocks such as fiamme ignimbrites, pumice, ash, trachyte and rhyolite flows and domes with rare intercalations of basalt flows. In the Rift floor they reach a thickness up to 250 m or more, and tend to thin towards the escarpment. On the plateau margins they range in thickness from 1 to 30 m. The map unit had been assigned different local names by different authors. Mohr (1971) included the Nazret Group in his "Twit Series" for the peralkaline silicics of central and southern Oromia which include not only acidic rocks of the Rift but also the Alaji Formation. Zanettin and Justin-Visentine (1974c) used the name Balchi Rhyolites that predominantly consisted of tuffs and rhyolite. Juch (1975) called the same unit Pliocene Silicics a misfit for the actual age range of the unit. Later Meyer et al. (1975) introduced the name Nazret Series, which was later, replaced by Nazret Group (Kazmin & Seifemichael Berhe, 1978). An area of maximum thickness of the silicic rocks occurs in the central part of the Rift. The thickness decreases sharply from the center of the Rift due north and south. In the study area the Nazret silicics appear beneath the younger volcanics.

4.1.1.1.2 Afar Group

a) Chilalo Formation

Several large trachytic volcanoes occur along both the eastern and western outer margins of the Rift Escarpment (Seifemichael Berhe & Kazmin, 1978; Kazmin 1979; Kazmin et al., 1981). These groups of complex shield volcanoes which developed on both sides of the Rift shoulders and margins of the Rift were described as Chilalo Trachytes, Chilalo & Bada Trachytes, Chilalo volcanics. They are Pliocene in age and are later named as Chilalo Formation (Mengesha et.al., 1996). Complex central volcanoes such as Chilalo, Bada, Kaka, Enkolo, Gara Gumbi, Asebot, Afdam, Boset, Gash Megal and other smaller volcanoes in the vicinity of Addis Ababa are well known volcanic centers. Kazmin et al. (1981) identified two clear volcanic units in a number of these complex volcanoes including Chilalo, Bada and Kubsa volcanoes.

The lower unit consists of peralkaline ignimbrite and trachyte intercalations. The trachytes show clear flow structures. Highly porphyritic, dark grey trachyte with phenocrysts of sanadine represents the major rock types. Rhyolites are the first products of the Chilalo Volcano followed by trachytes, whereas basalts followed by trachy basalts and trachytes are the products of the Beda Volcano. These flows are synchronous with younger ignimbrites of the Nazret Group, and partly inter-finger with them, making it part of the Nazret Group.

To date the following K-Ar ages are available: for the Wochecha 4.5 MY (Miller & Mohr, 1966), for Yerer 3.5 MY (Morton & Rex., 1979), for Chilalo 3.5 MY (Kuntz et al., 1975) and for Menagesha 3.0 MY (Morton & Rex., 1979). A relatively recent age of 1.4MY was reported by Di Paola (1976) for mugearitic flow on the western slope of Chilalo volcano, suggesting that some of the volcanic activity has probably continued into the Pleistocene. Di Paola (1972) has related the origin of these volcanoes to the opening of the Main Rift System of the area. The formation of these volcanoes coincided with the important stage of the opening of the Rift which is around 4 to 4.5 MY even though the Rift started opening much earlier (Kazmin et al., 1981). This rifting corresponds to the peak of the silicic volcanism in the Rift (Morbidelli et al., 1975; Kazmin et al. 1981.

b) Bishoftu Formation

An area in East Shewa Zone, south and southeast of Addis Ababa, is covered by Pliocene to Pleistocene alkali basalt and trachyte lava flows with well preserved scoria cones. They occur on the western escarpment of the Main Rift System and were named as Bishoftu Basalts (Zanettin and Justine-Visentin 1974), which considered them as younger than 2 MY old.

These basalts are later named as Bishoftu Formation (Mengesha et al., 1996). Field investigation (Kazmin et al., 1981) has proved that these flows originated partly form at least the large Pliocene basaltic and trachytic volcanoes such as Yerer, Wechecha, Furi, etc. This proposition was similarly supported by age similarity of 2-8 MY on the basalt between the towns of Akaki and Bishoftu, southwest of Yerer Mountain (Morton, 1979).

4.1.1.1.3 Wonji Group

In the Main Rift System, in East Shewa and adjacent zones, Meyer et al. (1975) named Wonji Series to the volcanic succession younger than 1.6 MY and lying along or close to the Wonji Fault Belt (Mohr, 1967). It was pointed out that the latest volcanism in the Rift is related to crustal extensions along the axial zone of the Wonji Fault Belt (Mohr, 1967a; Meyer et al., 1975; Gibson, 1970; Dakin and Gibson, 1971).

Although some volcanic activities occur outside the Wonji Fault Belt, bulk of the Pleistocene to recent volcanic activity is controlled by this tectonic feature. The Wonji Group includes the entire Rift volcanics formed after the last major event of rifting. One of the major complexes that has been identified within the Wonji Group in the vicinity of the study area (Kazmin and Seifemichael Berhe, 1978; Kazmin et al., 1981) is fissural basaltic eruptions - sub recent and / recent fissural basalt flows. The recent fissure basalts are mainly concentrated along the Wonji Fault Belt, and also occur in western margin of the rift (Kazmin and Seifemichael Berhe, 1978; Kazmin et al., 1981). The flows are controlled by extensional fractures and exhibit fresh surface that took place during the historical period. Relatively older basalt flows synchronous with early stages of formation of the pantelleritic volcanoes are fissural products whereas the youngest are of central type eruption. Lines of well-preserved scoraceous cones follow fractures in the Wonji Fault Belt, which cut across the pantelleritic volcanoes. Recent flows followed low topographic features, or followed over the fault escarpments as shown on Fig 4.1 along the road to Butajira in the vicinity of the study area.

4.1.1.1.4 Alluvial and Lacustrine Deposits

a) Lacustrine Deposits

Although sinking of the main Rift System was dominantly accompanied by volcanic activity, sedimentation was also an integral part of the Rift formation. In the Rift, Quaternary sediments and mostly of lacustrine origin are intercalated with Pliocene to Pleistocene ignimbrites both in the Rift floor and Rift shoulders. The oldest sediments are lacustuine diatomites, tuffaceous clays and silts interbedded with basal ignimbrites of the Nazret Group. These sediments are named Chorora Formation (Sickenburg Schonfeld 1975) and the age ranges between 9 and 7 MY (not show on the accompanying map due to scale).

The current Lakes that spread over the entire Rift Valley are remnants of once larger lakes, which used to cover major part of the developing rift floor. Pleistocene- Holocene lacustrine sediments are known in the central and southern part of the Rift in East Shewa Zone and were deposited in the huge ancestral lake whose level before 3500 to 2100 years used to be 100 meters higher than its level (Kazmin et al., 1981).

b) Alluvial Deposits

Quaternary sediments of fluvial origin are widely spread all over the area. Only the larger, more continuous areas of Quaternary deposits are shown on the map (Fig 4.1). Alluvial deposits are mostly recent, but it may include older Pleistocene sediments. Alluvial sediments cover an extensive area of western part of Ethiopia in West Wellega Zone and along the upper reaches of the Gibe River. Alluvial sediments also occur along the Tinishu Gibe River course. The alluvial sediments are mainly represented by sand, silt and clay.

4.1.1.2 Rift Structure

The Main Rift System in Ethiopia as part of the East African Rift System is a fault bounded depression which extends from northern Afar to south up to Borena in Oromia. It generally trends SW-NE forming an elbow shape. The Rift splits the country almost into two equal parts. In the north it displays fanlike feature descending into the Afar Depression. The structural trend of the Main Ethiopian Rift continues up to the point of the Triple Junction, near Lake Abe, where the East African, Red Sea and the Gulf of Aden Rifts meet. Rift Escarpment rises up to 1500 m above the Rift Floor. North of the latitude of Finfinne, both eastern and western escarpments are approximately at the same altitude, and both have rather complicated structure. A major normal fault with considerable down throw can be traced at the foothills of the escarpment. In the lower slopes antithetic faults predominate separating blocks tilted down towards the Rift Floor. In the upper part of the escarpment there are several normal faults with rift ward downthrows of several hundred meters. This type of structure can be clearly seen in the eastern escarpment west of Mechara.

At the latitude of Addis Ababa, the Rift Valley appears to be crossed by a major east west transverse lineament and south of this the structure of the western and eastern escarpments is different. The Western Escarpment is generally higher in elevation and steeper than the Eastern Plateau. The western escarpment consists of three to five steps, either horizontal or slightly tilted away from the rift and separated by normal faults. West of Butajira, the escarpment is formed by a single fault of about 1000 m displacement.

4.1.1.3 Transverse Faults

Several transverse faults cross the Main Rift System (Kazmin et al., 1981; Kazmin & Seifemichael Berhe, 1978; Tadewos, 1995). They displace the escarpments and are also marked by clear alignment of volcanic centers along the faults. These faults trend predominantly NW or NNW, however, E-W faults are also common. Christiansen et al. (1975) indicated that the northwesterly trending fault line joining Ayelu and Amosa Volcanoes continues to the western escarpment of the Rift. This fault clearly displaces the segment of the Axial Wonji Fault Belt and is considered as a transform fault. Mohr (1967a) recognized that at the latitude of Addis Ababa the Rift is crossed by a major E-W system of faults. They are marked by alignment of Pliocene trachytic volcanoes, such as Yerer, Wochecha and Menagesha.

4.1.2 Local Geology

4.1.2.1 Ignimbrite of the Nazret Group (Ngi)

Nazret Group in general consists of fiamme ignimbrites of light greenish gray to reddish brown varieties, and un-welded tuffs. Rocks of this map unit usually occur one intercalating the other; the relatively thick deposit of un-welded tuffs and volcanic ash are most of the time blanketed by ignimbrite sheets of up to about 30m thick in areas close to the rift margin of Northwestern Main Rift System, mainly in the vicinity of Addis Ababa and NE wards from the city; the whole system generally becomes thicker towards the Rift Axis (Fig 4.2).

It is unconformably overlies faulted blocks of Plateau Basalt Formations of Tertiary Volcanics in areas along the Rift Shoulder, and partly over the Entoto Silicics in the vicinity of Addis Ababa. Younger volcanic products of the Rift Volcanics, mostly the younger basalts and trachyte flows, in areas of their occurrence covered the unit.

4.1.2.2 Trachyte Formation of the Wechecha Group (Qwt)

Large trachyitic volcano of Wechecha occurs along the rift escarpment close to the rift margin north of Sebeta town. This unit is also found southwest of the study area south of Tefki town. In addition, it is found along the road to Butajira. Gelana Gadissa (2005) explained that this volcano is of trachyte formation and generally forms mountain ranges and domes/plugs, with highly rugged surface characterizing the larger volcano of Wechecha. Wechecha Group is generally younger than Rocks of Nazret Group, as products of the former overlie the later unit. It in turn is overlain by products of younger volcanisms. Total thickness of the unit is more than 1000 m in the larger of volcano of Wechecha.

Wechecha Group (Qwt) in few cases has intercalations of rhyolites and ignimbrite, and rarely unwelded tuffs. The trachyte formations of Wechecha grade from more trachytic to rhyolites as one goes from base of the mountain to its top where a number of volcanic necks and plugs occur at the vents. Detail rock sampling and laboratory analysis was conducted by Gelana Gadisa (2005). The rock generally is porphyritic with large euhedral phenocrysts of feldspars. Some of the other minerals observed are biotite, pyroxene, iron oxide and plagioclase. It sometimes consist rocks of andesitic flows and/or associated tuff intercalations. Jointing due to cooling of the magma, and complex flow fold structure commonly occur in the rocks (Fig 4.2).

4.1.2.3 Rhyolite Flow of the Bilbilo Group (Qwr)

Rhyolitic flows occur mainly in the southeastern part of the study area. These include rhyolitic flows in Geja area. Most of these central volcanoes have little associated flows of the unit around the domes and cones. Similarity in many aspects of the associated rocks and the relation they have with the rest of the map units identified in this study led the authors to group the unit in to one category of Bilbilo Group (Qwr).

The rhyolitic rock of Bilbilo Group (Qwr) overlies and/or cut through older formations of namely the Nazret Group. Sometimes it is covered by recent basalt flows and scoria. It consists of rhyolitic rocks with cryptocrystalline to fine grained brittle rocks that have reddish to white color play in fresh and almost light brownish grey to white soft material when weathered. Sometimes it is difficult to distinguish the rock from equivalent units of various tuffs (trachyitic crystal tuff, andesitic crystal tuff, rhyolitic tuff, ignimbrites, etc.), perhaps, due to the effect of weathering – devitrification (Fig 4.2).

4.1.2.4 Recent Basalt Flows (Qb)

Recent basalt flows which are closely associated to the scoria cones occur mostly in the area along the road to Butajira and the central part of the catchment. The recent basalt flows occur found erupted through localized fractures across the mountain ridges of Wechecha, Furi, Entoto, etc., located along the rift shoulder. In these particular cases, the basalts flowed down the topography over the Mountain flanks and all the older units in areas of its occurrence (along its floor of eruption). The basalt commonly occurs in boulder forms perhaps due to smaller volume of the lava, and thus has a limited thickness (less than 20m) and smaller extent. In areas of ancient depressions and stream valleys, the basalt has a relatively thick and more massive deposit with a tendency to develop columnar joint structures. The rock consists of porphyritic and rarely aphyric olivine basalt with olivine and sometimes plagioclase phenocrysts. The unit is more of basic, rarely andesitic, and usually scoraceous type (Fig 4.2).

4.1.2.5 Quaternary (Alluvium) Deposit (Qa)

Quaternary sediments of fluvial origin take the biggest portion of the study area and the surrounding neighboring catchments. The alluvial deposits are recent sediments occurring in areas of flood plains and river terraces. It covers wide area of the Flood Plain of Awash in Becho district. The Alluvium Deposit (Qa) consists mainly of sand, silt and clay (Fig 4.2).

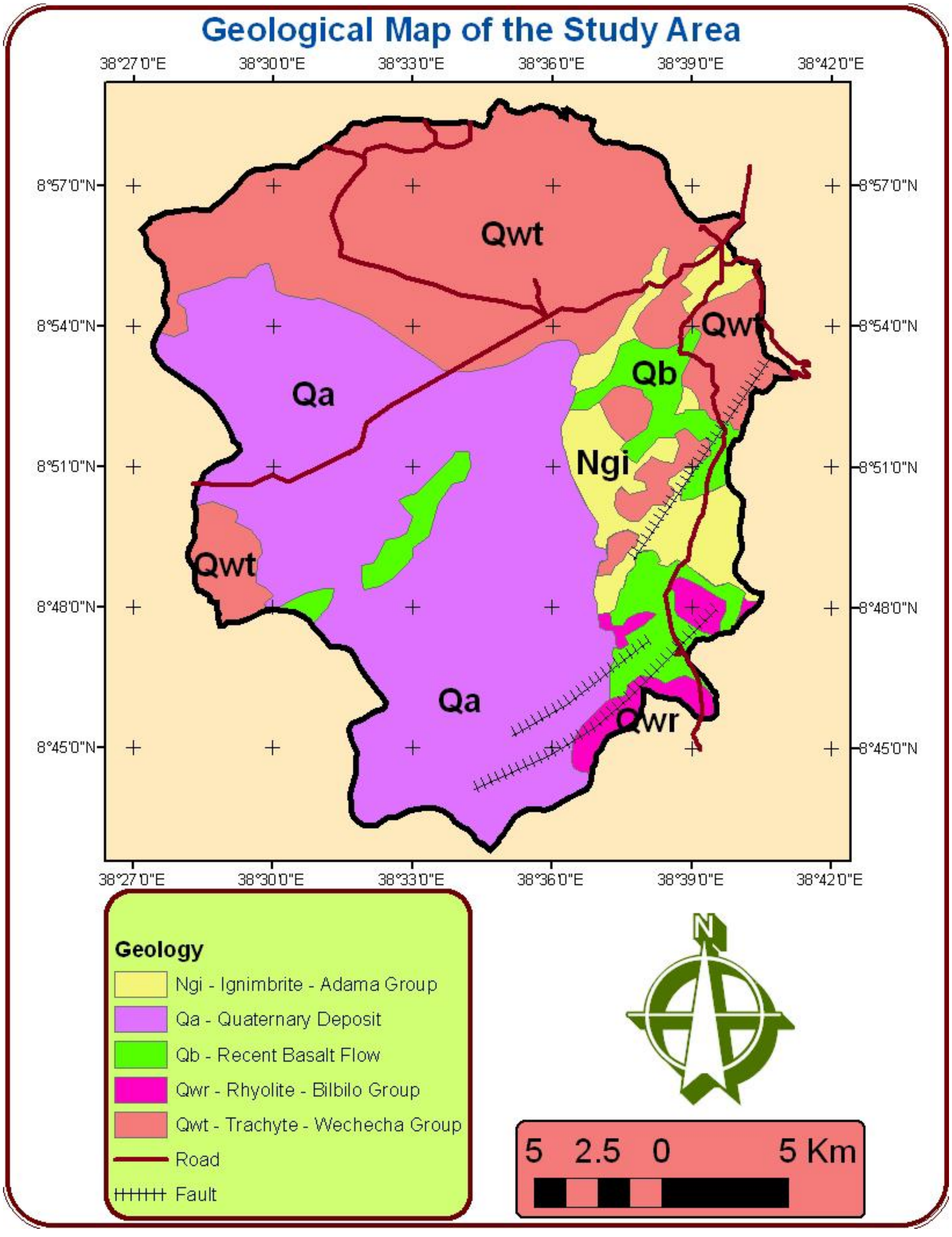


Fig 4.2 Geological map of the study area (Adapted from Gelana Gadissa, 2005)

4.2 Hydrogeology

The main hydro-geologic units in the study area are extrusive volcanics, pyroclastic units and alluvial deposits. The various rock units are subjected to varying degrees of secondary activities such as weathering, erosion and deposition. Some of the relatively hard formations are undergone fracturing, faulting and jointing.

The groundwater system of the area is inferred from water point data (Fig 4.3 and Annex 1) and it could be classified into the deep groundwater system found on the eastern and northern hillside and plateau groundwater system characterizing most of the flat land and the shallow groundwater system.

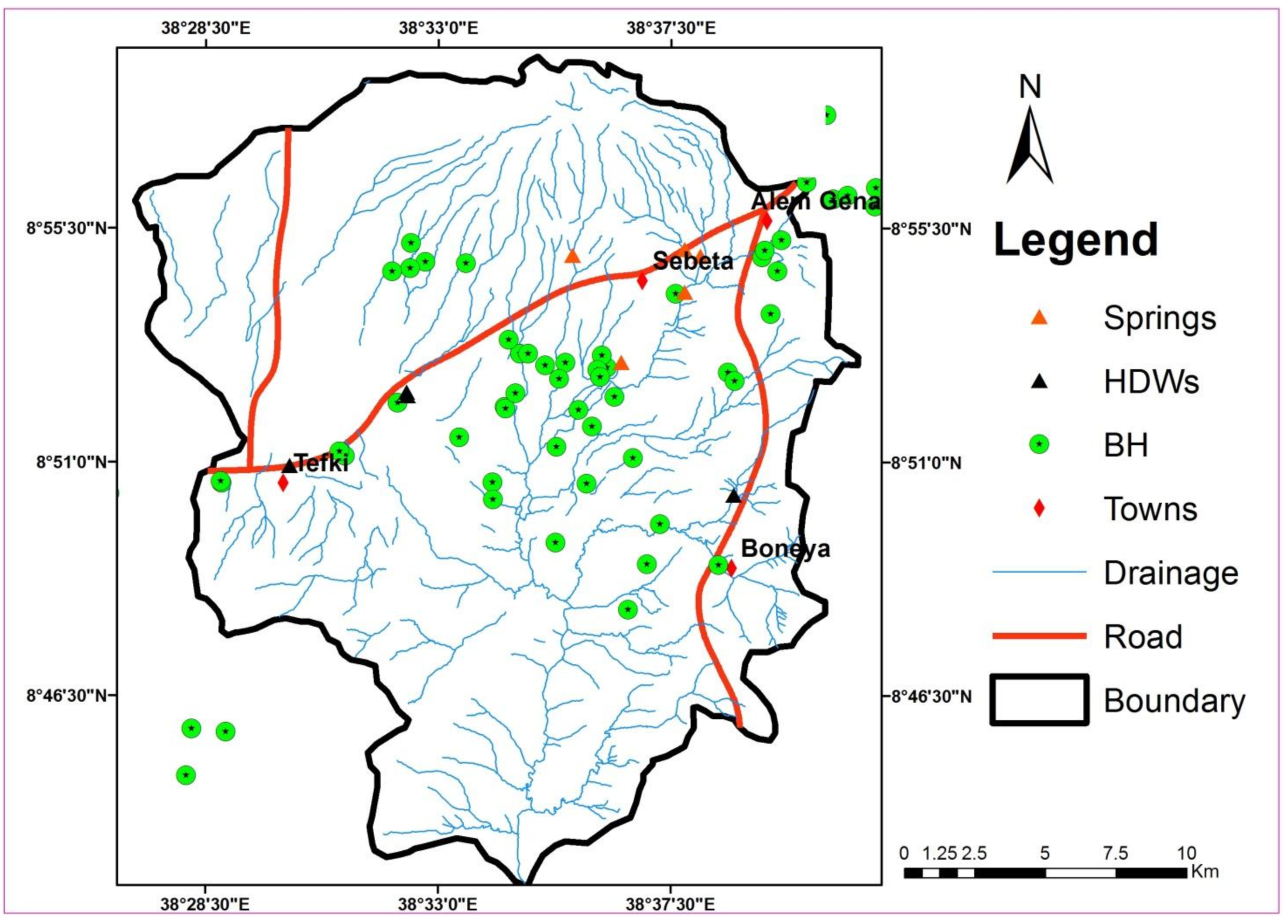


Fig. 4.3: Water Point distribution of the study area

As can be seen from fig 4.3 above, the dominant scheme types are boreholes and shallow wells that have moderate yielding capacity, although the aquifers are relatively good. Based on the recent knowledge about the deeper aquifers, penetration of deep test wells is also happening by AAWSA, on the peripheries of the study area. On spot developed springs with good discharges are also common within the catchment of the study area for the town's water supply.

4.2.1 Hydrostratigraphy

In general, the study area has two hydrostratigraphic units consisting of:

- Extensive fracture aquifers with moderate to high groundwater productivity and
- Localized inter granular aquifer with low groundwater productivity

4.2.1.1. Extensive fracture aquifers with moderate to high groundwater productivity

Fractured aquifer of the area consists of fractured basalt, fractured ignimbrites and tuff units. From the general hydrogeologic characteristics, high water storage and transmitting capacity of basaltic lava flows is due to joints caused by cooling, lava tubes, vesicles that are interconnected, tree moulds, fractures caused by buckling of partly congealed lava (*aa* lava surface) and voids left between successive flows. On the other hand, the water circulation and storage capacity of welded tuff depends on the secondary porosity and permeability developed through fracturing and weathering processes (Davis, 1966).

From the existing boreholes, it is evident that deep boreholes in Sebeta and Alemgena areas struck the lower basalt and scoria are found to have yields more than 10 l/s However, those boreholes completed in fractured ignimbrite and tuff units are found to have slightly lower yield.

4.2.1.2 Localized inter-granular aquifer with low groundwater productivity

Inter-granular porosity in the study area is mainly associated to the weathering and erosion processes. Alluvial sediments are deposited in the southern and southwestern parts of the study area along close to Sebeta and Kariko streams. These aquifers are considered to form localized aquifer with low productivity.

Plate 4.1 Road cut outcrop of fractured ignimbrite (Photo on the road Alemgena-Butajira)

Plate 4.2 Tuff unit overlying the fractured ignimbrite

4.2.2. Evaluation of the Existing Boreholes

The groundwater potential of the area has been analyzed based on boreholes data collected in the study area. Accordingly, data has been collected from six boreholes having almost all required information and eleven additional wells with few data. The six wells that represents most part of the study area have location, depth, yield, lithological logs, SWL and aquifer information (Data Annexed). Analysis of the existing boreholes show that the area has fractured tuff, fractured ignimbrite, fractured basaltic and scoria aquifers. Boreholes penetrated basaltic aquifer (lower basalt), fractured rhyolite and scoria are found to have more yield than other aquifer units. For instance, Daleti new borehole, Origin new well and Dima boreholes are found to be high yielding wells. Accordingly, the ground water system of the area can be evaluated as follows:

4.2.2.1 The Deep Groundwater System

The deep groundwater system extends northern, eastern and southeastern part of Sebeta town. Ignimbrite is a dominant formation in the central part and trachyte in the northern. The groundwater system in the elevated area is characterized by springs of higher yields. High yield springs (up to 5 l/s) are measured in the basalt formation affected by faults.

The groundwater of high yield is obtained by drilling more than 150 m in this part of the study area; especially for areas characterized by trachyte and ignimbrite and very shallow groundwater is possible only in the weathered part of the rocks.

4.2.2.2 The Shallow Groundwater System

It extends from Sebeta north-central to the mouth of Atebela River and from the slope break in the east to Tefki Town in the west. The area is considered to be high groundwater potential. In general, the hydrogeological situation of each layer in the catchment is described in Table 4.1. below

Table 4.1 Productivity of the geological formation in shallow aquifers

Aquifer	Areal Extent	Aquifer Type	Yield (l/s)	Productivity
Alluvial	Extensive	Very shallow	-	Low
Basalt	Localized	Fractured	5-10	Moderate
Trachyte	Extensive	Fractured	1-3	Low

a. Alluvial Aquifers

Alluvial aquifers include the upper aquifer system of the flat portion of the Sebeta catchment which extends mostly from the north-central to the south direction. They are composed of clay, silt, sand, gravel and rock fragment deposits. They are also manifest along the river banks. Shallow groundwater is the characteristic of these aquifers in which the saturated thickness ranges from 2 to 8 m. Groundwater depth varies from 6 to 16 m. The groundwater occurrence is limited to river channels and depressions where relatively thicker deposits are created.

b. Ignimbritic Aquifers

Ignimbritic aquifers are found underneath the alluvial aquifers in which the top part is weathered yielding water for hand dug wells in the flat part of the catchment. The depth of water strike in this case ranges from 8 – 14 m. On the other hand, they form deep aquifers of confined nature in the relatively elevated eastern part of the study area.

c. Basalt Aquifers

Basalt aquifers are found underneath the ignimbrite in most part of the study area. They are the most productive aquifers but are relatively small in area extent; they yield water for shallow wells of depth 60 to 70 m. The vesicular basalt and scoria are also found in some localities around Sebeta-Alemgena and along the road to Butajira.

Secondary processes play a significant role in the localization and controlling of the groundwater systems of the catchment. This can be observed from the lithological logs of boreholes drilled within and the surroundings of the catchment. A number of boreholes to a maximum depth of 502 m and a minimum of 39 m are bored in and very near to the study area. The major water bearing formations in all of the boreholes are weathered and fractured ignimbrites, weathered and fractured basalts, sediments associated with unwelded tuff and trachytes and rhyolites.

4.2.3. Groundwater flow

Water point inventory in the study area shows that static groundwater level varies from 2m to 166.5 m.b.g.s. In general, groundwater table in the area is found to be lower than the surface topographic gradient. In some cases, unlike topographic elevations, gradient of static water level has slight variation in the study area. It most likely shows that the area has intermediate groundwater flow system with less influence by local flow. Figure 4.4 shows the relationship between topographic and static water level elevations of some selected boreholes.

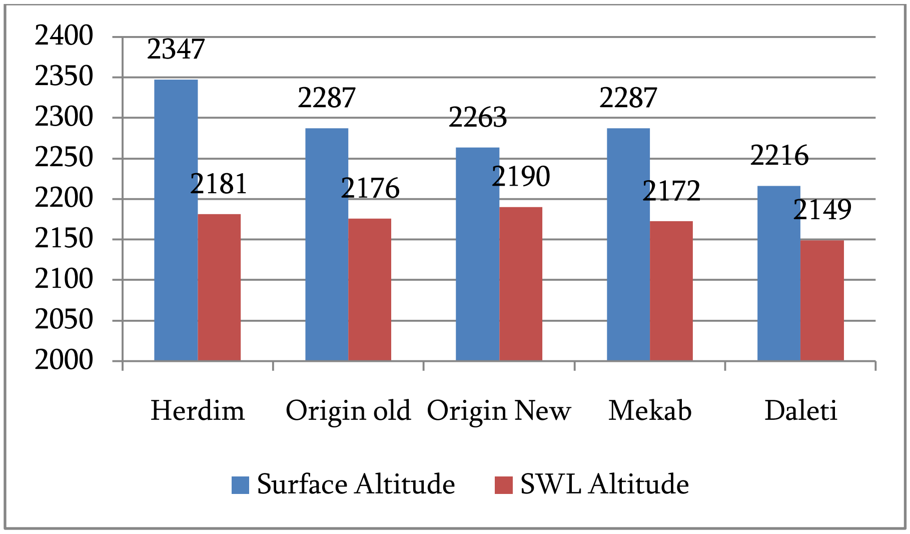


Fig. 4.4: Relationship between land surface and static water level altitudes

The variation in SWL anomaly is related to the hydrostatic head. (i.e. water table at lower elevation has higher hydrostatic head which makes rise of water table in the well). Accordingly, groundwater flow of the study area is towards south and south west direction following surface topography and drainage. Figure 4.5 shows the distribution of groundwater table contour and groundwater flow directions.

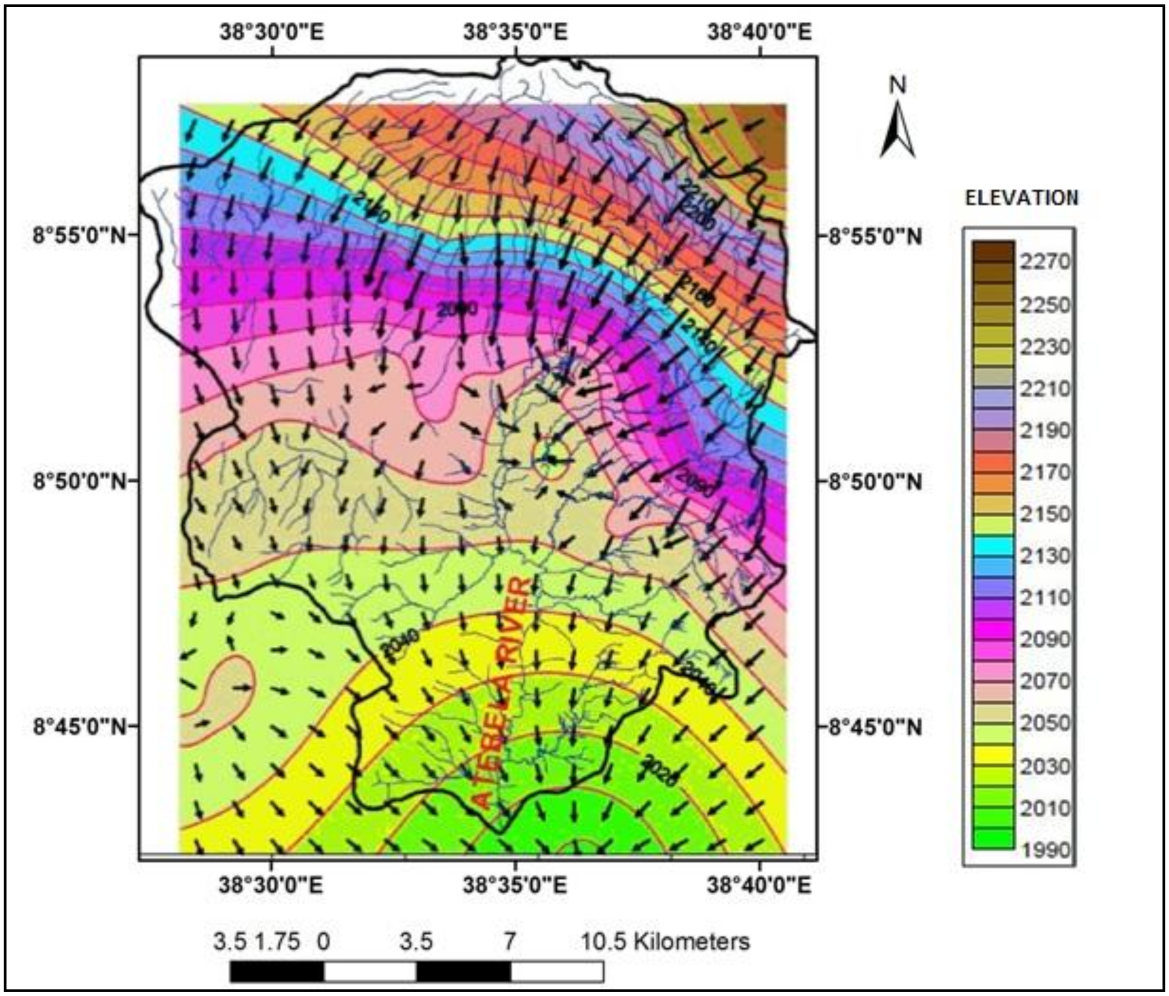


Figure 4.5. Groundwater table contour and flow system of the study area

The hydrogeological map of the study area is presented in Fig 4.6. It is prepared by utilization of borehole data (lithological logs, well yield, water level, and groundwater chemistry) and geological map of the study area. The well yields of the boreholes in the study area vary between 38 l/s at Awash Sheba Flower Farm (56 m deep) in the southern margin of the study area on the periphery of the study area characterized by gravel deposit, fractured ignimbrite and sand deposit and 0.75 l/s around Tefki characterized by weathered jointed ignimbrite. High yield is found in vesicular basalt as observed from lithological logs and this is grouped into high permeability aquifer class together with the fractured and weathered basalt and gravel. The fractured and weathered ignimbrite and weathered trachy basalt are mapped as intermediate permeability aquifer class and this class yields discharge in the range of 2 – 5 l/s. The third class of aquifer is the low permeability aquifer which yields 1 – 2 l/s and it constitutes weathered trachyte and rhyolite.

The TDS is also grouped into two and mapped based on the borehole data with highest characterizing the central and southern part of the catchment. The lowest TDS values (117–236 mg/l) are characterizing the trachyte and rhyolite aquifers. The water type on the other hand shows Ca-HCO3 or Ca-Na-HCO3 on the low permeability aquifer while it is Ca-Mg-HCO3 on the high permeability and intermediate permeability aquifers

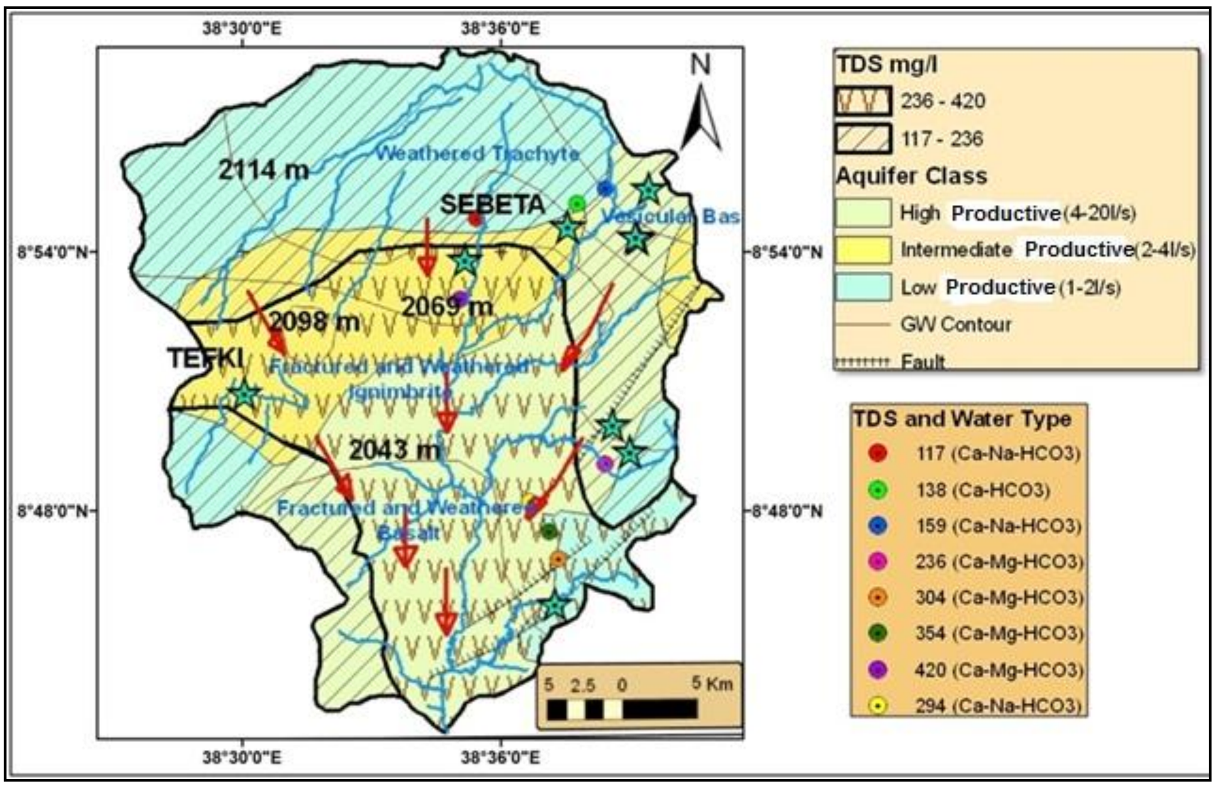


Fig 4.6. Hydrogeological map of the study area

4.2.4 Groundwater Recharge and Discharge

4.2.4.1. Groundwater Recharge

Groundwater recharge is a function of the volume of residual rainfall, surface infiltration, and geological percolation rates (Malin, 1989). Accordingly, part of the rainwater that falls on the ground is infiltrated in to the soil. A part of this infiltrated water is utilized in filling the soil moisture deficits, while the remaining portion percolates down to reach the water table forming groundwater recharge from rainfall. In addition, groundwater can be recharged from rivers/ streams, irrigation, municipal sewers, etc.

Groundwater Recharge Estimation using Soil – Water Balance Method

In this study, groundwater recharge of the area is estimated using soil moisture balance method which is essentially a book-keeping procedure estimating the balance between the inflow and outflow of water. It is applied using mean monthly precipitation, mean monthly evapotranspiration of the project area, land cover and soil type of the area under consideration.

The soil water balance is represented by:

$$Gr = P - Ro - Ea \pm \Delta S$$

Where, Gr : recharge

P : precipitation

Ro : runoff

Ea: actual evapotranspiration

ΔS: change in soil water storage

According to this approach, water is held in a soil moisture store; precipitation adds to the store, evapotranspiration depletes it. When full, excess precipitation is routed to groundwater as recharge. The surplus amount determined in this process after deduction of surface runoff represents direct groundwater recharge for a given soil and vegetation condition.

The study area has mainly sandy clay to loam soil type and covered predominantly by short rooted crops, grass and bushes. Assuming the area has an average water holding capacity of 150mm, the soil moisture balance of the area is presented in table 4.2 below.

Table 4. 2. Long term monthly average moisture balance of the study area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
P	18	48	69	93	80	141	276	308	157	29	8	10	1239
PET	116	113	136	126	129	101	84	87	98	127	122	118	1356
P-PET	-98.0	-65.1	-67.1	-33.1	-48.9	40.8	192.2	221.3	59.4	-97.7	-113.1	-107.3	
ACC Pot WL	-416.2	-481.3	-548.4	-581.5	-630.3	0.0	0.0	0.0	0.0	-97.7	-210.8	-318.1	
SM	9.0	6.0	4.0	3.0	2.0	42.0	150.0	150.0	150.0	78.0	36.0	18.0	
^SM	-9.0	-3.0	-2.0	-1.0	-1.0	40.0	108.0	0.0	0.0	-72.0	-42.0	-18.0	
AET	27.3	51.3	71.3	93.9	80.8	100.5	83.7	86.8	97.5	101.4	50.4	28.5	873.3
D	-89.0	-62.1	-65.1	-32.1	-47.9	0.0	0.0	0.0	0.0	-25.7	-71.1	-89.3	
S	0.0	0.0	0.0	0.0	0.0	0.8	84.2	221.3	59.4	0.0	0.0	0.0	365.7

Where :

P: Precipitation

Ref PET: Reference Potential Evapotranspiration

APWL: Accumulated Potential Water Loss

SM: Soil Moisture

dSM: Change in soil moisture during the month indicated

AET: Actual Evapotranspiration

D : Soil moisture deficit

S : Soil moisture surplus

Soil moisture surplus (S in the above table) determined in this process consists of direct runoff and groundwater recharge. Determination of surface runoff needs many factors which are not readily available during this study. Many authors have proposed the range between 0.2 to 0.8 based on geology, slope, rainfall intensity etc. As previously mentioned, the study area has rolling flat topography with slight ups and downs mainly covered silty loam soil. In addition, fractured, ignimbrite, tuff, basalt and sediment are the main geologic units in the area. Therefore, it is reasonable to take 60% of the total annual surplus (S) moisture as surface runoff and the rest 40% of 365.7 (i.e. 146mm) as annual groundwater recharge.

Accordingly, the total annual recharge into the groundwater system of the catchment is estimated to be: **495Km^2 X 146mm = 72.27 MCM**

4.2.4.2. Groundwater Discharge

Groundwater of the area and its surrounding is generally discharged through pumping from a number of boreholes and hand pumps. For instance, Sebeta town boreholes, Addis Ababa City boreholes, boreholes for different organizations and private companies around Alemgena and Sebeta are exploiting groundwater from the catchment this study pertains to. There are also springs, streams and rivers naturally discharging the groundwater of the catchment.

5. HYDROCHEMISTRY

The chemical composition of surface and groundwater is controlled by many factors that include composition of precipitation, mineralogy of the water-shade and aquifers, climate, and topography. These factors combine to create diverse water types that change spatially and temporally. The quality of water is also an issue due to the variations both in the natural geology and hydro geological conditions and to human impact. Water-rock interaction plays an important role in controlling water quality. The main mineral characteristics of water, especially groundwater are determined by weathering reactions taking place close to the earth's surface and there is a wide diversity of chemical composition related to the geology of the catchment or aquifer. Geochemical reaction along groundwater flow paths can lead to regional variations in water composition that involve in the direction of flow.

Moreover, hydrochemical information can be used to interpret the origin and mode of groundwater recharge, refine estimates of time scales of recharge and groundwater flow, decipher reactive processes, provide paleo-hydrological information, and calibrate groundwater flow models. Hydrochemistry can also assist in understanding the evolution of water chemistry (quality), to examine natural base line conditions against which human impacts can be recognized and to take a look at some ways in which the protection and management of groundwater resources can be achieved.

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

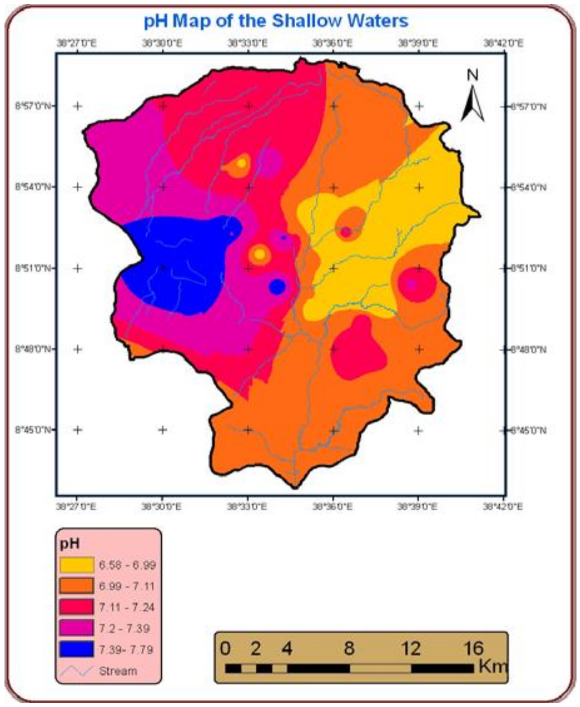
Sample collection is done from some bore holes, hand dug wells and springs, and in addition utilization of previously analyzed water chemistry data from boreholes and shallow wells as well as springs are also done in order to avoid redundancy in sampling. In situ parameters such as pH, TDS and Temperature have been collected for the sake of crosschecking the laboratory results after proper calibration of pH and TDS meters.

Presentation of the results using Piper diagram has been made to facilitate the interpretation and analyses. Trend and concentration analyses have been made by mapping a number of variables separately, such as EC, TDS, pH, Cl^-, Na^+, Ca^{2+} and Mg^{2+} that greatly help interpret flow paths, recharging and discharging zones, local, intermediate and regional flow systems in the study area. Some of the basic physical and chemical characteristics of the water are discussed below.

5.1 Physical Parameters

5.1.1 pH

The pH of an aqueous system is a measure of the acid-base equilibrium achieved by various dissolved compounds. It is controlled by inter-related chemical reactions that produce or consume hydrogen ions and the geo media. In most natural waters it is controlled by the CO_2^- - HCO_3^- - CO_3^- equilibrium system (WHO, 1984). Biochemical processes are also among the factors that control the pH-levels of natural waters. The groundwater from the different sources in the study area has pH values ranging from about 6 to 7.9 and is associated with the high bicarbonate contents of the water. The pH levels of the shallow groundwater including those sampled for the hand dug wells increase to the west as these are the most feasible areas for shallow groundwater exploration. In the same way, the deep groundwater has its pH increasing towards the west and south. In either case, the pH levels tend to increase toward south and west parts of the study area which are the discharging zones.



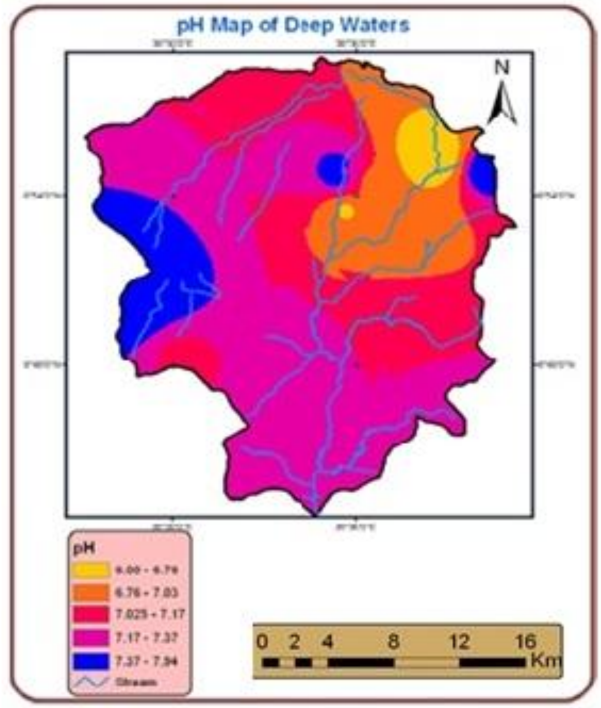


Fig 5.1 pH map of shallow groundwater **Fig 5.2 pH map of deep groundwater**

5.1.2 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

The presence of charged ionic species in solution makes a solution conductive. As ion concentrations increase, conductance of the solution increases; therefore, the conductance measurement provides an indication of ion concentration. It is apparent that the relationship between electrical conductivity and ionic concentration of water is direct, and most of the data set fit a straight-line regression closely (correlation coefficient = 0.65). EC vs. TDS relations for the four types of water sources, namely, shallow wells, springs, hand dug wells and deep wells show no significant difference. The hand dug wells have shown high TDS which could indicate the susceptibility of the groundwater to external application of materials through different mechanisms which involve contamination. But the deep waters have higher TDS than the shallow waters which may indicate a relatively longer residence time (rock interaction). As for the springs, the available data don't show a good relationship between the two parameters, may be due to technical errors in data collection.

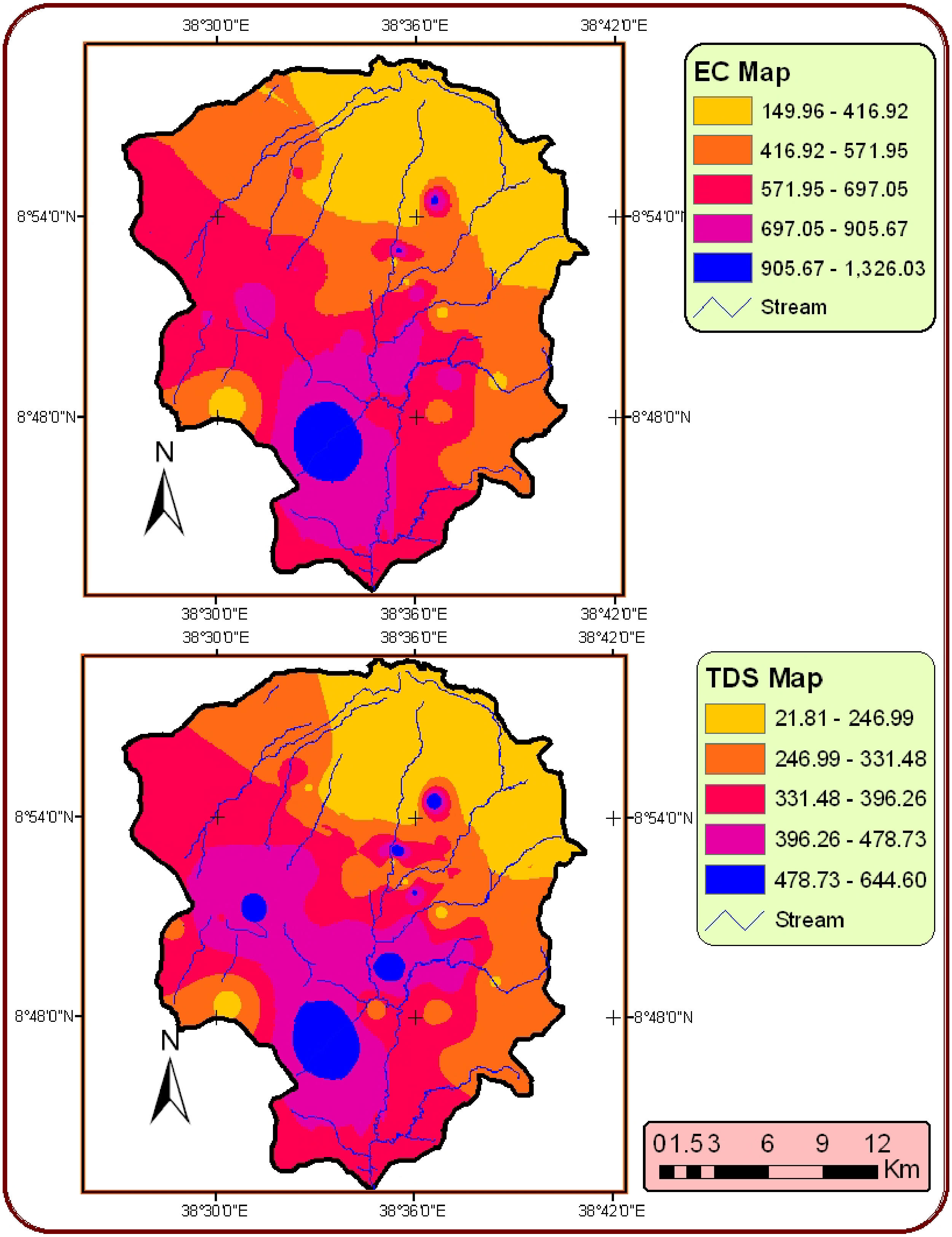


Fig 5.3 EC and TDS map of the study area

A 2D interpolated map of the EC values from all the water sources show an increase towards the south and the center of the catchment i.e. EC values are getting higher and higher towards the discharging zones and their values are generally lower in the recharging zones at the southwest, north and east. The trend shows the general increase of both parameters in the direction of groundwater flow (Fig 5.3).

5.2 Chemical Parameters

5.2.1 Ca^{2+}, Mg^{2+}, HCO_3^- and Na^+

The well chemistry data is mapped separately for the different ions. The Ca^{2+} map shows low values (0.18-43.28 mg/l) characterizing the northeastern and western part of the catchment. It is observed to increase to the south and the maximum value ranges between 87.75-121.68 mg/l. The evolution of Mg^{2+} on the other hand shows an increase towards the west and central while low values are characterizing the northeast and the southwest. As for Na+, the trend shows entirely low values on the north, south and eastern part of the catchment and it is observed to evolve to the west. The HCO_3^- ion on the other hand evolves towards the south and central part of the catchment (Fig. 5.4).

The opposite direction of evolution of the Ca^{2+} and Na^+ ions may indicate cation exchange. 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 in higher sodium concentrations (Hem, 1985). The increasing trend in the Ca^{2+} ions concentration down the discharging zone may be highly attributed to the effect of the geo-media in that some of the minerals forming rhyolites and trachytes (such as plagioclase feldspar and amphiboles) bear significant amount of Ca. On the other hand, the typically lower concentrations in Na^+, HCO_3^- and Ca^{2+} near recharge sources is the low residence time which increases as groundwater flows away from the source of recharge.

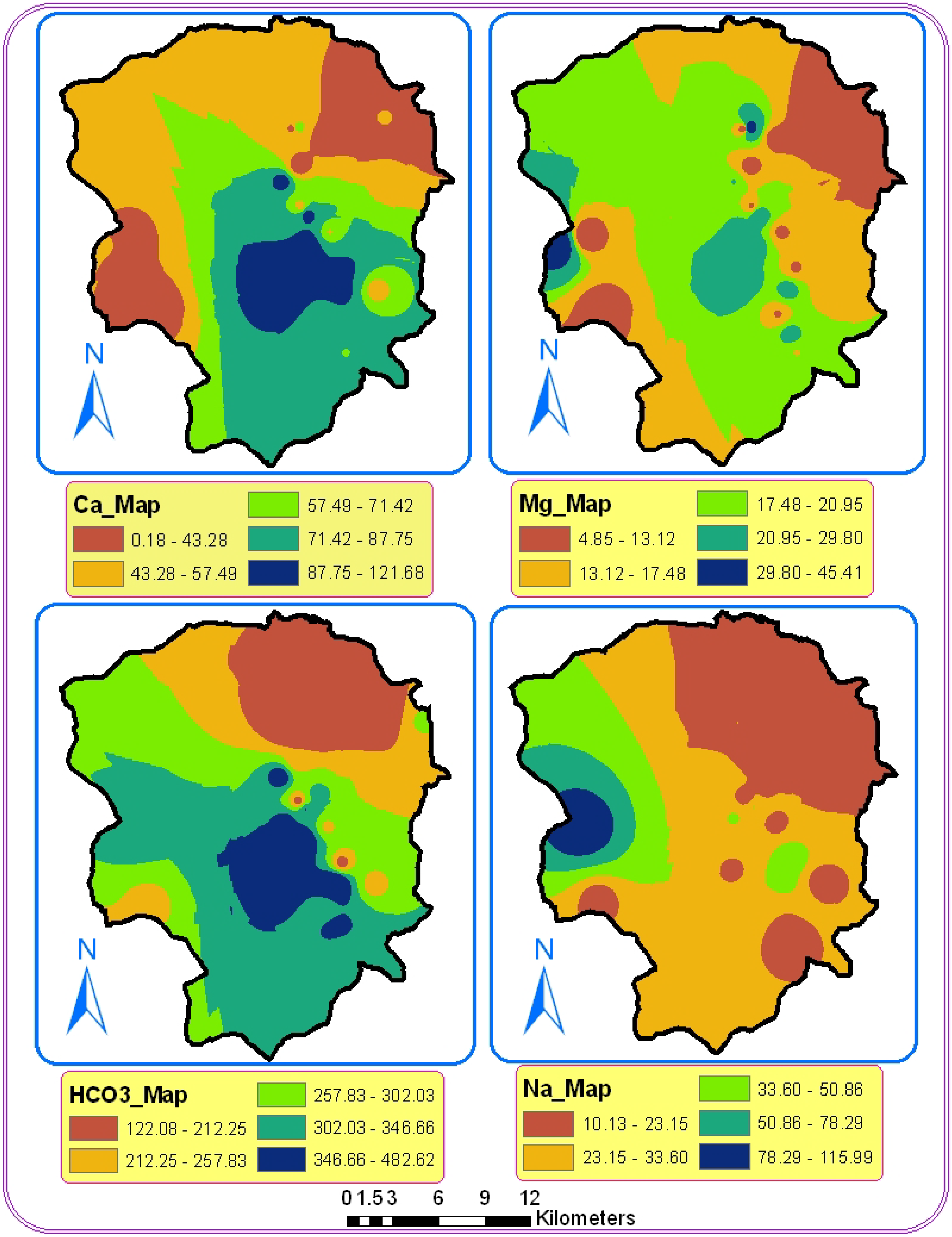


Fig. 5.4. Ca^{2+}, Mg^{2+}, HCO_3^- and Na^+ Maps

5.2.2 NO_3^-, PO_4^{3-}, SO_4^{2-} and NH_3^-

Maps of NO_3^-, PO_4^{3-}, SO_4^{2-} and NH_3^+ are stated on Fig 5.5 below. The nitrate, mapped for the groundwater chemistry data available boreholes shows increase towards the south and it decreases towards the west. The PO_4^{3-} and NH_3^+ maps however show a different trend in which they lower in concentration towards the south. The SO_4^{2-} map on the other hand is generally increasing to the west and central part of the catchment.

The increasing trend of nitrate towards the south can be attributed to anthropogenic effect such as application of agricultural fertilizers and infiltration of river water into the groundwater through stream beds.

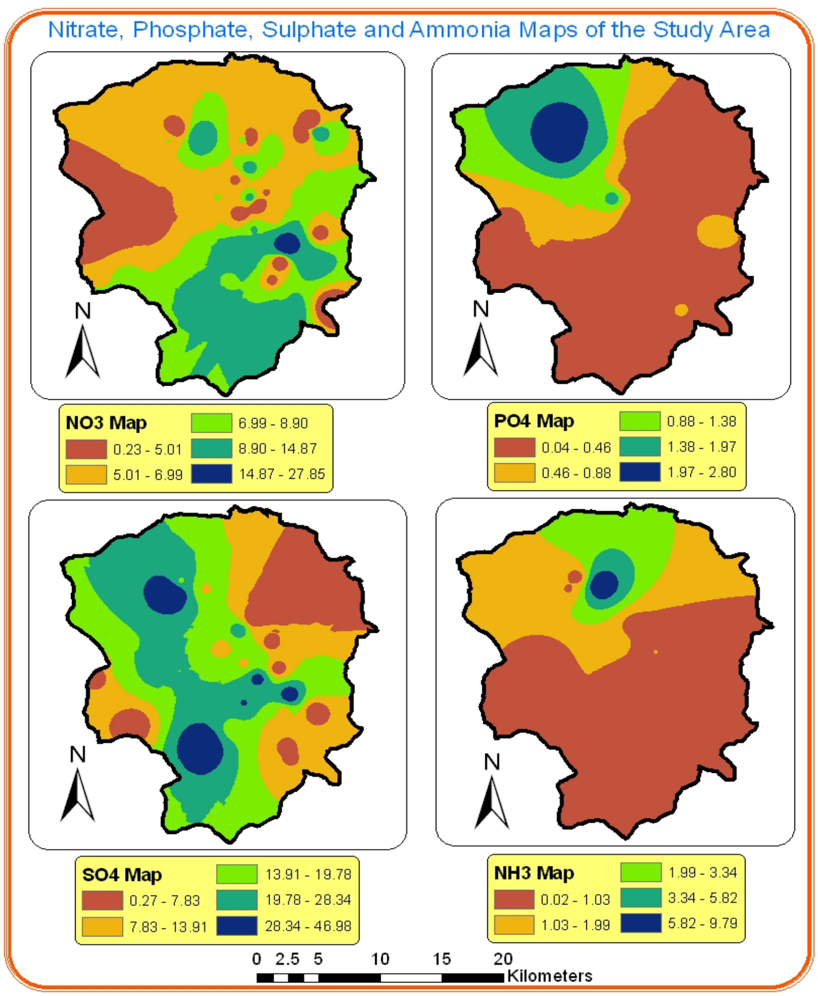


Fig 5.5: NO_3^-, PO_4^{3-}, SO_4^{2-} and NH_3^- Maps

5.2.3 Graphical Presentations

Most of the graphical methods are designed to simultaneously represent the total dissolved solid concentration and the relative proportions of certain major ionic species (Hem, 1985) and all the graphical methods use a limited number of parameters, usually the available data, unlike the statistical methods that can utilize all the available parameters.

Piper Diagram

The piper diagram displays the relative concentrations of the major cations and anions on two separate tri-linear plots, together with a central diamond plot where the points from the two tri-linear plots are projected. The central diamond-shaped field (quadrilateral field) is used to show overall chemical character of the water.

The piper plot for the study area is done for all water sources (boreholes, hand dug wells, springs and shallow wells) and it shows that the majority of the water samples are of calcium-magnesium-bicarbonate and type of waters of borehole water samples are of calcium-bicarbonate (Fig. 5.6).

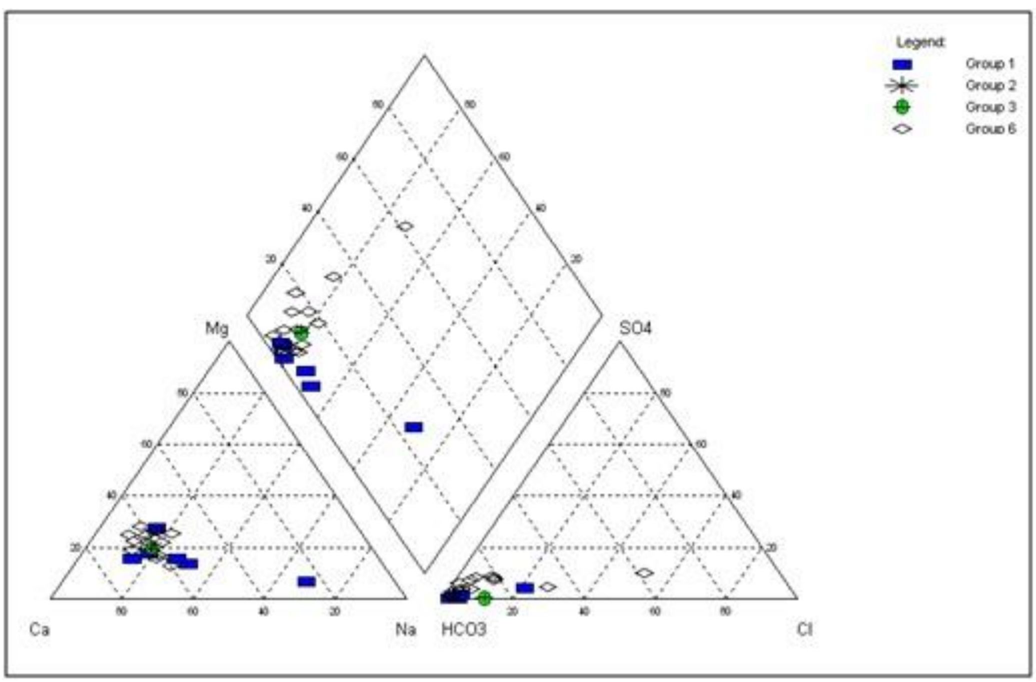


Fig 5.6 Piper plot of all sources (Group 1 – **BH**, Group 2 – **HDW**, Group 3 – **SP**, Group 6 – **SW**)

6. WATER POLLUTION RISK ASSESSMENT

Water pollution is a contamination of water by sewage, toxic chemicals, metals, oils or other substances. It can affect such surface waters as rivers, lakes, as well as the water beneath the earth's surface, groundwater. Water pollution can harm many species of plants and animals. According to the World Health Organization (WHO, 2000), about 5 million people die every year from drinking polluted water.

6.1 Point and Non-point Sources of Pollution

Two types of water pollutants exist; point source and non-point source. The direct chemical discharge to a certain water body best illustrates point source water pollution. A non point source delivers pollutants indirectly through environmental and land use changes. An example of this type of water pollution is when fertilizer from a field is carried into a stream by rain, in the form of run-off which in turn affects aquatic life. Non point source pollution is much more difficult to trace back to the original source of the pollutants because it enters waterways from many points across an area of land, where point sources enter waterways at an identifiable point.

6.2 Industrial activities

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

The large and medium scale-manufacturing sub-sector in the study area is dominated by five major consumer goods producing industrial groups, such as, food and beverage, chemical, steel, textile and leather groups. A number of pollution related studies have confirmed that about 90% of industries in Ethiopia, which is also true in the case of the study area, are simply discharging their effluent into nearby water bodies, streams and open land without any form of treatment. The harmful industrial waste liquids are those mixed with organic or heavy metals, with corrosive, toxic or microbiologically leaded substances.

6.3 Sewage, domestic wastewater

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

6.4 Water Quality Standards

Water quality standards are fundamental tools that help protect valuable surface and ground water resources and serve as the foundation for the water-quality based approach to pollution control and are a fundamental component of watershed management. Water quality standards should have objectives like: restoring and maintaining chemical, physical, and biological integrity of waters providing, wherever attainable, water quality for public water supplies, recreation, agricultural and industrial purposes. The term "water quality standards" is sometimes used more broadly to include minimum wastewater treatment requirements, effluent limits for point-source dischargers, and all the provisions and requirements in the state's water quality rules. The suitability of the existing water supply for domestic use, industrial purpose, and agriculture has been analyzed by comparing the water quality analysis with international and local standards.

6.4.1 Domestic Water Quality Criteria

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

a) Physical or appearance test

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

b) Bacteriological Test

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

c) Chemical Test

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

Chemical tests identify impurities and other dissolved substances that affect water used for domestic purposes and are needed to detect water contaminants such as nitrates, sodium, chlorides and the hardness capacity of water. The analysis result of the water sample collected in the area have been compared with the Ethiopian Standards (ESA, 1990) and with the standards established by WHO and EU (Annex 4)

A number of samples were collected from the groundwater (borehole, hand dug well and spring) in the area, some are unfit for domestic use due to high concentration (above maximum allowable limit) of NO_3, or total coliform bacteria count. As for the surface water in the area, present data set indicate that Sebeta River water is totally unfit for domestic use, because of high organic pollutant (which is indicated by high BOD, COD and low DO), high total coliform bacteria count, suspended solid and high turbidity and bad color (Refer the Annexed Quality Test data).

6.4.2. Industry water quality criteria

The three primary users of water are industry, irrigation, and municipal. Water quality criteria generally include the following components:

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

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

6.5 Impact of industries on water quality

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

Plate 6.1 Industrial effluents from a textile industry 6.2. Untreated effluents from a tannery (Sebeta)

Tanneries are one of the biggest pollutants that use the rivers as a dumping ground in Sebeta area (Plate 2). Out of a number of factories only few of them have some form of treatment for their liquid waste while the rest discharge their effluent without any treatment directly in to the surrounding river. Tannery waste has got a high heavy metal content and comes from sources that are not too easy to control. Tannery wastewaters are characterized by being strongly alkaline with a high oxygen demand, a high salt content and contain large quantities of organic and inorganic compounds, including toxic substances such as Sulfides, Cadmium and Chromium salts. According to the physico-chemical tests done, the effect of the industrial waste on the river quality has been dramatic.

6.6 Impact of Urbanization on water quality

The water in river reservoir comes from a variety of sources including direct rainfall, local runoff, and imported water. The chemical composition in the local runoff reflects the urban, industrial, rural, and natural land-use activities in the watershed (Lopes and Dionne, 1998). Hydrologic impacts due to urbanization cause water quality problems such as increased sediment loadings, increased temperatures, habitat changes, and the loss of fish populations, changes in stream physical characteristics (channel width and depth), and decreased base flow. There is widespread recognition that these problems are caused by increased runoff volumes and velocities from urbanization and associated increases in watershed imperviousness. And it is generally understood that diminished water quality comes with increased urban intensity of the watershed. In general, urban development is bound to:-

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

Plate 6.3. Waste disposal on river banks   Plate 6.4. Polluted River below Sebeta Abattoir

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

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

All components (physical, chemical, biological) in a stream can be influenced by changes in the hydrologic regime (characteristic behavior and quantity of stream flow). The major flow related impacts of urbanization include:-

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

In general, all the rivers around Sebeta are found to be under high impact and is impaired. On the other hand, the river water is used for a variety of purposes such as irrigation, cattle drinking (Plates 6.5 & 6.6) and domestic purposes without prior treatment. For sustainable management of this water resource, environmental protection agencies at different levels and other concerned administrative and/or nongovernmental bodies should take strict as well as technical measures.


Plates 6.5 & 6.6.: animals drinking diverted polluted water of the area

6.6.2 Temperature related impacts of Urbanization

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

In general, stream flow and water temperature can be altered as urban intensity in a basin increases. In this study, water temperature and stream flow were used to compare sites along a gradient of urban intensity from low to high and to determine the relation to other physical, chemical, and biological factors. As it has been observed from ten years (2005-2014) temperature data of the area that has been obtained from the National Meteorological Agency, on the preferred months, January, February and March, the temperature increases with urban intensity (Fig. 6.1).

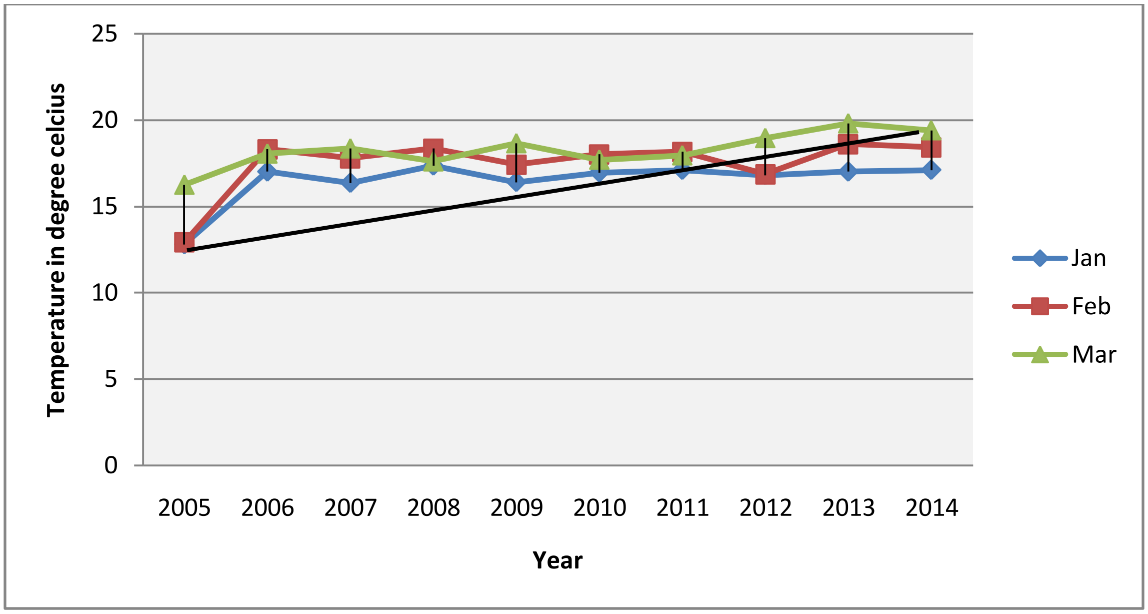


Fig. 6.1 Temperature pattern with Urbanization (Data as shown on table 3.2 page 24)

Problems of stream channel erosion and suspended sediment have developed in Sebeta area because of land use changes in the drainage basin. Urbanization in this area has consisted of residential, industrial, agricultural and commercial developments. Urban development would double the mean annual flood peaks in portions of the streams. This result was not surprising and is un expected result of urbanization, which typically decreases the quantity of water that seeps into the ground to replenish ground water supplies. It is the level of ground water, not rainwater runoff that is primarily responsible for keeping streams running during periods of low rainfall. Increased evaporation during these years could also have contributed to the low flows.

7. RESULTS AND DISCUSSION

Like many other urban centers of the country, in Sebeta town and its surrounding, groundwater is the prime source of water for all purposes. As observed from the number of available boreholes in the study area, the groundwater of the area is exploited for water supply of the towns, industries, factories, for rural water supply and in some cases for small scale irrigation by hand dug wells and springs. There are also about 15 big projects of flower farming (floriculture) which involve groundwater exploitation for their farm. The groundwater of the area is intensively exploited and polluted without considering its sustainability.

Currently, approximately more than 150 boreholes (mainly concentrated in Sebeta and Alemgena towns) and a number of dug wells exploit from the catchment groundwater reserve with an average pumping rate of 5 l/s per borehole.

The pollution of the surrounding river is highly aggravated since the town has no sewerage conveyance and waste treatment plant. Many of the shallow wells, springs and hand dug wells that are found near the river banks are at risk for the near future use. Currently there are two shallow wells in the western side of the town, at a locality called Bole, with high pollutant load and supposed to be abandoned.

7.1. Results from Hydrometeorology

The meteorological analysis of the study area catchment has been carried out based on the long term meteorological data (1985 – 2014) from three stations that are found at Sebeta, Addis Ababa and Holota. Accordingly, the monthly mean maximum and minimum temperature are calculated to be 13.6 °C and 17.3 °C with annual average value of 15.7°C.

The distribution of precipitation in the catchment is not uniform both in space and time. The main rainy months of the catchment last from June to September. Accordingly, the estimated mean areal depth of precipitation of the catchment is 1239mm/year.

The monthly potential evapotranspiration of the area is adapted from FAO local climate estimator which gives potential evapotranspiration of point of interest by proximity weighing the nearby stations. Actual evapotranspiration is determined by soil moisture balance of the area in the process of groundwater recharge estimation. Accordingly, the mean annual potential evapotranspiration and actual evapotranspiration of the study area are calculated to be 1355.7mm and 873.4mm respectively. Accordingly, groundwater recharge is expected when precipitation is significantly exceeding the evapotranspiration during the months June to September.

7.2. Results from Analysis of Hydrogeology

In this study, conventional hydrogeological investigation has also been carried out in order to define the basic hydrogeological factors controlling the occurrence, movement and storage of groundwater in the surrounding Atebella/Sebeta sub-basin. The main aquifer formations of the area are weathered and fractured basalt, ignimbrite, rhyolite, and scoria. Estimation of water balance and calculation of actual and potential evaporation using FAO's local climate estimator software gave important contribution for the calculation of groundwater recharge of the catchment.

According to the thornthwaite and mather soil water balance model, the total recharge of the study area is 146mm/year. Considering the total area of the catchment as 495 km^2, the total annual recharge was estimated to be 72 MCM.

The general groundwater flow direction has been determined by construction of groundwater contour map on the basis of the hydraulic head distribution from various boreholes and wells in the same aquifer system. The groundwater flow of the area seems to be topographically controlled. The sub surface barriers as intrusions and fracture conduits also play an important role in the local and regional groundwater circulation. Groundwater flow can be said fairly follow the surface drainage pattern from north and north east towards southwest and south.

7.3. Results from Analysis of Hydrochemistry

Sample collection has been done from 5 bore holes (shallow and deep), 1 hand dug well and 4 springs, and in addition utilization of previously analyzed water chemistry data from boreholes and shallow wells as well as springs are also done in order to avoid redundancy in sampling. In situ parameters such as pH, TDS and Temperature have been collected for the sake of crosschecking the laboratory results after proper calibration of pH and TDS meters. Trend and concentration analyses have been made by mapping a number of variables separately, such as pH, EC, TDS, Cl^-, Na^+, Ca^{2+} and Mg^{2+} that greatly help interpret flow paths, recharging and discharging zones, local, intermediate and regional flow systems in the study area. Finally, presentation of the results using Piper diagram has been made to facilitate the interpretation and analyses.

Accordingly, among the physical parameters pH, EC and TDS of the study area groundwater system has been analyzed. The groundwater from the different sources in the study area has pH values ranging from about 6 to 7.9 and is associated with the high bicarbonate contents of the water. Likewise, EC vs. TDS graph for the four types of water sources, namely, shallow wells, springs, hand dug wells and deep wells show no significant difference. The hand dug wells have shown high TDS which could indicate the susceptibility of the groundwater to external application of materials through different mechanisms which involve contamination. But the deep waters have higher TDS than the shallow waters which may indicate a relatively longer residence time (rock interaction).

After analyzing both physical and chemical parameters, the result has been presented graphically on a piper plot. The piper plot for the study area is done for all water sources and it shows that the majority of the water samples are of calcium-magnesium-bicarbonate and type of waters of borehole water samples are of calcium-bicarbonate

7.4. Results from Analysis of Pollution Risk

Management of groundwater quantity and quality requires both the protection of aquifers and groundwater from over abstraction and entrance of pollutants, and also the remediation or treatment of polluted resources. However, treatment of polluted groundwater is complex, expensive, and often only partially successful and it may take many years. Groundwater quality management should be pro-active and attempt to prevent the contamination of groundwater resources.

Sebeta and its surrounding, is highly exposed to activities which possibly cause pollution. The pollutants identified in surface and shallow groundwater bodies in the study area include organic wastes, inorganic constituents, nutrients and micro organisms. The increase in the amount of discharges and types of pollutants in the Atebela/Sebeta River catchment is due to population growth, intensive urbanization, as well as increased industrial and agricultural activities and more importantly lack of frequent monitoring.

In Sebeta area, most of the surrounding industries dispose untreated wastes directly into streams or rivers. Sources of industrial effluent range from small scale cottage industries to abattoirs, tanneries, textile manufacturing using dyes and noxious cleaning chemicals, and steel industries and others. These industrial processes produce large quantities of different kinds of pollutants (Plates 8.1 and 8.2).


Plate 8.1:Effluent from an alcohol factory


Plate 8.2: Downstream water appearance

Physical characteristics of the samples collected from surface water show that Sebeta River has dark green color, offensive odor, high turbidity and a lot of suspended materials due to industrial and sewage waste. The amount of total dissolved solids for surface water samples in the area range from 130 mg/l to 3,800 mg/l. Most of the values are below 1000mg/l for relatively deeper groundwater sources and in the case of surface water higher values of TDS is recorded at Sebeta River (Annexes 2 and 3).

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

The only possible means of the town's municipal and industrial water supply is from deeper groundwater systems and well developed springs otherwise any form of surface water in its current status, in the catchment can't be utilized even for urban irrigation based agriculture (Plates 8.3 and 8.4). The surface water alternative source of the area is totally not advisable in its current condition.

Plate 8.3 Polluted river diverted for irrigation Plate 8.4 Effect of polluted water on vegetables

7.5. Groundwater management challenges and prospects

In recent years, the growth of industry, technology, population and water use has increased the stress upon both land and water resources. Consequently it is high time to manage these resources in a regular basis for sustainable use of the resource. Like in many other parts of the country, in the study area there is no well-organized surface- and ground water quantity and quality monitoring system and centralized database for these parameters. Except the drinking water quality guidelines, there are no prepared standards for the purpose of controlling drilling activities, effluent discharge, irrigation and industrial water qualities.

Lack of training for the professionals, water managers, community and local operators is another reason for the sustainability problem of the area. Result of the study shows that ninety percent of interviewed technical staffs clarify that the existing training and staff mobility strategy doesn't allow professionals to improve their skills. Eighty percent of the respondents explain, they didn’t obtain any kind of training so far. In addition there is high shortage of skilled human resource, budget, and logistics in the rural water supply office of Sebeta woreda. Some of the technical staffs couldn't read GPS and locate water schemes on a map properly.

8. CONCLUSION AND RECOMMENDATIONS

8.1. Conclusion

The results of this study revealed that the area receives ample recharge, nearly 146mm per annum. This result coincides with the previously published reports of hydrogeological map of Ethiopia, which classified the area as region 2 as water resource zone, implying that the area receives 150mm-250mm recharge from rainfall annually and the groundwater possible discharge is moderate or high level. Compared with the existing all purpose demand of the area, i.e. for domestic, industrial and irrigation based agriculture, there is still a big potential of groundwater reserve that could serve partly the capital, Addis. In the mean time a number of public water supply wells that has been sufficiently used in the past years getting dry in many parts of the study area. This was the main reason that initiated the researcher to deal on the groundwater management issues.

In fact urbanization increases surface storm water runoff and modifies its quality. As land urbanizes, it will be covered by impervious surfaces such as paved roads, parking lots, and roofs which prevent rainfall from infiltrating into the ground. It is not yet clearly identified the root cause of the dry wells of the area because of the fact that there are no substantial information on the following issues:

- Lateral flows in the aquifer are determined by the gradients of the groundwater surface and properties of the aquifer material; information on these, in particular aquifer properties, is lacking and difficult to obtain, hence there are substantial uncertainties in assessing these flows.
- To determine the effects of land use changes it is necessary to assess the variations in groundwater recharge over a period of many years; sufficiently long and reliable field measurements are not available.

- It also lacks recorded data of the groundwater levels over a long period of time

But the possible causes for the drying public water supply wells in the study area is that these wells has been drilled some ten years before having relatively shallow depth (<100m). However, the recently drilled water supply wells in the very neighbor of these dry wells are comparatively deeper (200m and above) with higher capacity. These deep wells are the possible causes for the dry out relatively shallower wells of the surrounding since the deeper onesare still serving the community sufficiently. Unless it is properly managed, the same problem will arise on these functional wells too.

Moreover, even if the regional water resource bureau of Oromia has the right to monitor and give a water use permit to regulate the distribution of wells with the appropriate well spacing, there are a good number of wells the researcher encountered randomly distributed in the area without having a proper water use permit from the licensing authority. Most of the water supply boreholes in the area do not have any hydraulic calculation result at hand. They simply consume the groundwater resource unwisely until it stops without considering its capacity/yield. Due to the dramatic increase in population and urbanization in conjunction with enormous socio-economic activities in the field of agriculture, floriculture and industry with limited capacity of involved institutions to enforce regulation are the main factors which aggravates the situation in this area.

8.2. Recommendations

As the problem of water resource management in the study area is getting to its chronic stage the following recommendations are forwarded as an immediate and long term solutions:

- ❑ Sustainable groundwater management requires a good understanding of the groundwater system, based on data collected through monitoring programs and groundwater assessments/studies/research. Hence there must be a regular monitoring system and installing groundwater monitoring wells on some parts of the study area.

- The groundwater data needs to be stored, analyzed and presented using appropriate information management systems to facilitate decision making by various stakeholders.
- The above two needs to be supported by relevant policies, laws, institutions and capacity building programs
- A combination of three main elements; demand management, recharge enhancement and alternative supplies can sustain or prolong groundwater resources and maximize the value of their utilization.
- Effective management strategies are required based on the concept of groundwater being a common pool resource.
- Integrated management approaches are required that are designed to change the way people view and use the resource.
- Instruments such as setting entitlements, volumetric allocations and use conditions, assist with demand management and allow trading to maximize the utility of the groundwater resource
- In some cases new institutions such as catchment water management board, water banks and water user associations may assist in implementing and sustaining the resource.
- Industrial effluents discharges, which are the main causes of surface and ground waters pollution, must be regulated and monitored regularly by the concerned environmental bureaus. They must be forced by law to comply with provisional discharge permit limits whenever they violate.
- The waste water collection system must be improved and proper waste disposal or sewage treatment prior to discharge to surface waters has to be practiced by the

municipality and industries so as to minimize the pollution loads emanating from domestic, industrial and other sources.

- Vegetation cover alongside streams has to be maintained and enhanced so as to shade the water and filter pollutants from the runoff or nonpoint sources.
- Anthropogenic activities such as, agricultural practices, livestock rearing, construction, chemicals storage and handling and waste disposal in the project area should be carried out in such a way that impacts to the river system and or the whole environment is minimal.
- Drilling companies should be enforced to respect the existing laws and regulations and should request groundwater use permit before the launching the drilling work.
- Therefore, the most effective, least expensive and quickest means must be identified and urgently implemented to preserve the environment or at least to minimize the undesirable damage to it within the area.

REFERENCES

Abebe, D. (2010). Future climate of Ethiopia from précis regional climate model experimental design Ethiopia, presented climate strategies forum, Nov. 2010, http://www.metoffice.gov.uk/

Aller L., Bennet T., Lehr J.H., and Hackett G. 1987. DRASTIC: a standardized system for evaluating groundwater pollution potential using hydrogeologic settings. U.S. Environmental Protection Agency, Ada, OK, EPA/600/2-87-036,455 p.

Alley, W. M., Reilly, T. E., & Frank, O. L. (1999). Sustainability of Ground-Water Resources: U.S. Geological Survey Circular 1186. Available at http:// pubs. usgs.gov /circ/ circ1186/.

Bachmat Y, and M. Collin (1987). Mapping to Assess Groundwater Vulnerability to Pollution, Proceedings of the International Conference on Vulnerability of Soil and Groundwater to Pollutants, March 30- April 3, 1987 at Nordwijk aan Zee / (ed. By W.van Duijven-booden and H.G.van Waegeningh)- The Hague. (p 297-307),

Behailu Berhanu, (2007) Impact of Industries and Urbanization on Water Resource in Modjo River Catchment, unpublished Msc Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

BGR, CAP-NET, WATERNET, WA-NET (2007) Capacity Building for Groundwater Management in West and Southern Africa. Geozentrum: Hannover.

Bouwer, H. (2000) Integrated water management: emerging issues and challenges. *Agricultural Water Management*, **45**(3), 217-228

C. Mc Sweeney, M. N. (2008). http://country-profiles.geog.ox.ac.uk. Retrieved November 15, 2013, from http://country-profiles.geog.ox.ac.uk

Chernet,T.,1993. *Hydrogeology of Ethiopia and water resources development*. Ethiopian Institute of Geological Surveys, Addis Aababa, 222pp.

Cheung, W. H., Gabriel Senay and Singh, A. (2008). Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. INTERNATIONAL JOURNAL OF CLIMATOLOGY .

Civita, M., and De Maio M. (2000). SINTACS R5, a New Parametric System for the Assessment and Automating Mapping of Groundwater Vulnerability to Contamination, Pitagora Editor (Bologna).

Davis S. and De Wiest R. (1966). Hydrogeology. John Wiley & Sons, Inc., New York, 463 p. [This book stands out for the emphasis placed on the geologic aspects of groundwater].

Di Paola, G.M., 1976. Geological Map of the Tulu Moye volcanic area CNR, Italy

Dottridge, J. and Jaber, N. A. (1999). Groundwater Resource and Qulaity in Northeastern Jordan: Safe yield and Sustainability. Journal of Applied Geography 19: 313–323.

Eusuff, M. M., and Lansey, K. E. (2004) Optimal operation of artificial groundwater recharge systems considering water quality transformations *Water Resources Management*, **18**(4), 379-405.

FAO (1985). Water Quality for Agriculture. Irrigation and Drainage Paper, No. 29. FAO, Rome, Italy.

FAO (1992). CROPWAT; Computer Program for Irrigation Planning and Management. Irrigation and Drainage Paper, No. 46. FAO, Rome, Italy.

Focazio, M.J., A.H. Welch, S.A. Watkins, D.R. Helsel, and M.A. Horn, 2000. A retrospective analysis on the occurrence of arsenic in ground-water resources of the United States and limitations in drinking-water supply characterizations. USGS Water Resources Investigations Report. 99-4279. Reston, Verginia.

Food and Agricultural Organization of the UNs(2003) Groundwater Management – The Search for Practical Approaches. Water Reports 25. Rome: FAO.

Foster S.S.D. 1987. Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy. In Vulnerability of soil and groundwater to pollutants (W. van Duijvenbooden and H.G. van Waegeningh, eds.), TNO Committee on Hydrological Research, The Hague, Proceedings and Information No. 38, p. 69-86.

Freeze R. and Cherry A. (1979). Groundwater. A Simon and Schuster Company Eaglewood Cliffs. New Jersey. USA.

Gelana Gadisa, 2005 Final Report on Construction Material Assessment for major towns of Oromia surrounding Finfinne, Oromia Mineral Resources Development Study Project, OMEB; Finfinne.

Golwer A. 1983. Underground purification capacity. Groundwater in water resources planning, Proc. UNESCO Intl. Symp., Koblenz, Germany, Aug. 28-Sept. 3, 1983, UNESCO/IAH/IAHS, National Committee of the Federal Republic of Germany for the IHP, vol. II, p. 1063-1072.

GEODEV–AFREDS PLC Consortium, 1999. Final Report on Geology and Mineral Resources of Oromia,

Global Water Institute for Africa climate change, environment & security (2011). Water Security in Ethiopia: Risks and Vulnerabilities' Assessment. Website: www.gwiwater.org/en/node/174

Hem, J.D. (1985). Study and Interpretation of the Chemical Characteristics of Natural Water, U.S. Geological Survey Water Supply Paper 2254, 263pp, 3rd ed.

Kazmin, V. 1979. Relationship between rifts and Precambrian basement in East Africa Annals of Geological Survey of Egypt V. 19 pp 54-60.

Kebede Tshehayu, Solomon Waltenigus, Shiferaw Lulu, Abebe Gebrehiwot (2004). Groundwater management using groundwater modeling; Case study Akaki well field, Addis Ababa, Proceeding of the International Conference and Exhibition on Groundwater in Ethiopia.

Kukuric, N. (1999). Development of a Decision Support System for Groundwater Pollution Assessment, PHD dissertation, A.A. Balkema Publishers, Rotterdam, The Netherlands.

Lopes, T.J., and Dionne, S.G., 1998, A review of semi volatile and volatile organic compounds in highway runoff and urban storm water: U.S. Geological Survey Open-File Report 98-409, 64 p.

Manahan Stanleye (1991). Environmental Chemistry, 5th Edition, Lewis Publishers, USA.

Mengesha Teferra, Tadiwos Chernet and Werkineh Haro (compiler), 1996. Geological Map of Ethiopia, scale 1:2,000,000, 2nd edition and explanatory note, Bulletin No. 3, GSE.

Meyer W. Pilger A Rosler A and Stels J, 1975. Tectonic evolution of the northern part of the Main Ethiopian Rift in southern Ethiopia in Afar Depression of Ethiopia Eds A Pelger and A Rosler schweizerbart schverlag Stuttgart PP 375- 360.

Mohr P. A., 1971. Ethiopian rift and plateaus: Some volcanic petrochemical differences. J. Geophys. Res., 76, 1967-1884.

MoWIE, (2013). Ethiopia: Practical Framework for Managed Groundwater Development In the Greater Addis Ababa Area. Supplement to Task Force Report on Aquifer Management for Addis Ababa and its Vicinity. Metameta Research. Addis Ababa: 41.

Morbedelli L. Nicoletti M. Petrucciani C. and Peclrillo E. M. 1975. Ethiopian southeastern plateau and related escarpment: K-Ar ages of the main volcanic events (Main Ethiopian Rift from 8^0 10' to 9^0 00' lat N) In Afar Depression of Ethiopia Eds A plgert and A Roslet Schweizerbart schevErlag. Stuttgart, PP 362-369.

Morton, W. H., Mitchell J.G. Rex, D.C and Mohr P., 1979. Rift ward younging of volcanic units in the Addis Ababa region, Ethiopian Rift Valley, nature, 280, pp 284-288.

National Research Council (U.S). 1993. Groundwater vulnerability assessment— predicting relative contamination potential under conditions of uncertainty. Committee on Techniques for Assessing Groundwater Vulnerability, National Research Council, National Academy Press, Washington DC, 52 p.

Ogbanna, D.N., Ekeweozor I.K.E. and Igwe F.U. 2002. Waste Management: A tool for Environmental Protection in Nigeria. Synopsis, Ambio, Vol. 31, No. 1, February2002.

Rao, P.S.C., and W.M. Alley, 1993. Pesticides. In W.M. alley (ed.). Regional groundwater quality. Van Nostrand Reinhold, New York.

Rao, C.S (1996). Environmental Pollution Control Engineering, Newage International (P) Limited, Publishers, New Delhi.

Robins, N.S. (1998). Groundwater pollution, Aquifer Recharge and Vulnerability, published Geological Society, Special Edition No. 130

Robbins, N. S., Davies, J., Farr, J. L., Calow, R. C. (2006). The changing role of hydrogeology in semi-arid southern and eastern Africa. Hydrogeology Journal (2006) 14: 1483-1492

Seifemichael Berhe and Kazmin V. 1978. Geological Map of Nazret map sheet (NB37-15) Eth Inst of Geological Survey. Addis Ababa.

Seifemichael Berhe and Kazmin V., 1987. Geology, Geochronology and Geodynamic implications of the Cainozoic Magmatic Province in west and southeastern Ethiopia, Journal of the Geol. Soc. of London, vol.144.

Shaw, E.M. 1988. Hydrology in Practice. Chapman and Hall London.

Solomon Kenea, 2007. GIS – Based Ground Water Vulnerability Mapping of Atebela River Catchment, Sebeta Area. Unpublished Msc Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Tamiru Alemayehu, 2004. Assessment of Pollution Status and Groundwater Vulnerability mapping of the Addis Ababa Water Supply Aquifers, Ethiopia.

Tamiru Alemayehu, Dagnachew Legesse, Tenalem Ayenew, Yirga Tadesse, Solomon Waltenigus and Nuri Mohammed, 2005. Hydrogeology, Water Quality, and the Degree of Groundwater Vulnerability to Pollution in Addis Ababa, Ethiopia. UNEP/UNESCO/UN-HABITAT/ECA

Taye Alemayehu, 1988. Pollution of the Hydrogeologic system of Dire Dawa groundwater Basin,

Tesfaye Berhe, 1998. The Degradation of the Abo-Kebena River in Addis Ababa, Ethiopia. MSc Thesis, School of Graduate Studies, Addis Ababa University, June 1998.

Thornthwaite, C.W., 1944. Report of the committee on transpiration and evapotranspiration, 1943-1944. Transactions American Geophysical Union 25, 683-693.

Thornthwaite, C.W., 1948. An approach toward a rational classification of climate. Geographical Review, 38, 55-94, 1948

Thornthwaite, C.W. and Mather, J.R., 1957. Instructions and tables for computing potential evapotranspiration and the water balance, Publication 10, 185–311. Centeron, N.J.: Laboratory of Climatology

Tizro, A.T., Voudouris, S.K. and Eni, M. (2007). Groundwater Balance, Safe yield and Recharge Feasibility in a Semi- Arid Enviroment: A Case Study from Western Part of Iran. Journal of Applied Sciences 7(20): 2967- 2976.

UK Groundwater Forum 2004. Groundwater Basics

Van Bavel, C.H.M., 1996. Potential evaporation: the combination concept and its experimental verification. Water Resources Res. 2: 19-31.

Vowinkel, E.F. and Clawges, R.M., 1996. Variables indicating nitrate contamination in bedrock aquifers, Newark Basin, New Jersey. Water Resources Bulletin 32: Vol. 32. N5. 1055-1066.

Voudouris, S.K. (2006). Groundwater Balance and Safe yield the Coastal Aquifer System in NEastern Korinthia, Greece. Journal of Applied Geography 26(2006): 291- 311.

Vrba, J. and Zaporozec, A., 1994. Guidebook on Mapping Groundwater Vulnerability. International Contribution to Hydrogeology. IHP-IV, Project M-1.2 (a). Verlag Heinz Heise. Vol 16, 1994

WHO (2000). Global Water Supply and Sanitation Assessment 2000 Report. Available in full at http://www.who.int/water_sanitation_health/Globassessment/GlobalTOC.htm.

World Bank (2013). Sustainable Development and Management of Groundwater in Ethiopia: Issues, Challenges and Opportunities, Natural Resources Management Unit (AFTN2), Sustainable Development Department: 110.

XU Y and USHER B (eds.) (2006) Groundwater Pollution in Africa. Published by Taylor & Francis / Balkema, ISBN 10: 0-415-41167-X. UK.

Zaporozec, A. (ed.), 1985. Groundwater protection principles and alternatives for Rock County, Wisconsin. Wis. Geological and Natural History Survey, Madison, WI, Special Report 8, 73 p.

ANNEXES

ANNEX 1: Inventoried and Secondary Water Point datas used for interpolation of depth to water map

No	Site Name (Code)	X_UTM	Y_UTM	Elev (m)	SWL	GW_ Elev
1	Sebeta(SPW-1)	456511	981649	2072	18.35	2053.65
2	Sebeta(SPW-2)	456326	982067	2080	11.53	2068.47
3	Sebeta(SPW-3)	456177	981556	2078	14.8	2063.2
4	Sebeta Town(BH-1)	456265	981309	2075	19.3	2055.7
5	Alemgena -3	466044	988018	2248	31.7	2216.3
6	Alemgena -1	464528	987613	2256	28.55	2227.45
7	Alemgena - 2	465052	987733	2250	29.2	2220.8
8	Alemgena - 4	466018	987363	2244	21.6	2222.4
9	Hardim	462313	983537	2347	166.15	2180.85
10	Origin New BH	462013	985552	2263	73.42	2189.58
11	Origin old	462555	985053	2287	111.5	2175.5
12	Daleti Community BH	460800	981461	2216	67.1	2148.9
13	Daleti New BH	461033	981164	2200		2200
14	Mekab	462707	986167	2287	115	2172
15	STTW1 (Test Wells)	438871	977186	2061	12.65	2048.35
16	STTW2	447224	978514	2055	13.44	2041.56
17	STTW3	449082	980399	2066	10.67	2055.33
18	Eth. High Land Flower 1	453428	982135	2089	15.64	2073.36
19	Eth. High Land Flower 2	453720	982141	2090	15.68	2074.32
20	Daleti	462109	985789	2252	56	2196
21	Boneya	460464	974637	2095	38.14	2056.86
22	Awash Melka	456740	962388	2000	3	1997
23	Darge-Suq	464300	990600	2277	14.4	2262.6
24	Gen.Gebre	463600	988200	2278	27.5	2250.5
25	Fulaso (Harojila)	451518	985340	2141	2.45	2138.55
26	Bole	450080	985388	2132	6	2126
27	Qocha	449527	985178	2121	10	2111
28	Makalo	448899	985053	2116	7.5	2108.5
29	Hordofi	449558	986067	2149	9	2140
30	Mt. View	453035	982639	2101	17	2084
31	Haro jila1 (HDW)	449434	980645	2075	7	2068
32	Haro jila2 (HDW)	449407	980765	2071	6	2065
33	Dairy (Tefki)	447020	978672	2067	6	2061
34	HDW (Tefki)	445254	978171	2066	9	2057
35	Gora-1	452891	980250	2071	4.5	2066.5
36	Gora-2	452924	980195	2069	3.5	2065.5

37	Mango Gora	453268	980729	2076	1.8	2074.2
38	Matali	451276	979174	2077	3.5	2073.5
39	Gora Harkiso-1	452457	977565	2073	11	2062
40	Gora Harkiso-2	452466	976970	2067	4.5	2062.5
41	Mehal Atebela	455035	981813	2090	13	2077
42	Andode Sp-HDW	461003	977106	2110	2	2108
43	Cholo	441773	968843	2062	21	2041
44	Lilu	441578	967182	2079	27	2052
45	Gila	454714	978831	2062	9	2053
46	Gombore	454683	975426	2064	11	2053
47	Mehal Sefera	455784	977521	2059	13	2046
48	Malima & Deti	455988	979556	2072	9	2063
49	Bebeli	457439	978436	2077	8	2069
50	Tiliqu Sefer	457922	974666	2073	10	2063
51	Berga-1	455502	980145	2073	22	2051
52	Berga-2	458390	976091	2075	14	2061
53	Turo	457253	973055	2057	8	2049
54	Koticha	456773	980613	2072	10	2062
55	Dima Mango-1	454809	981251	2083	9	2074
56	Dima Mango-2	454323	981723	2085	7	2078
57	Bure	442993	968724	2082	28	2054
58	Tafki Golden Rose-1	442842	977555	2074	14.15	2059.85
59	Tafki Golden Rose-2	442811	977625	2073	9.9	2063.1
60	Mukerbi	458956	984255	2172	6.8	2165.2
61	HADMES Hotel	463580	988814	2290	30	2260
62	Yes Mineral Water	463633	988634	2286	26.82	2259.18

ANNEX 2: Chemistry Data for Boreholes, HDWs and Springs

	Location																					
Site Name	X_UTM	Y_UTM	Elev (m)	Temp ^{0}C	PH	EC	TDS	Alkal.	Na	K	Ca	Mg	HCO_3	SO_4	Cl	NO_3	NH_4	NH_3	PO_4	F	Mn	Fe
Fulaso (Harojiia)	451518	985340	2141	21.2	7.3	296	192.4	130					158.6	13		13.6	10.4490	9.8	1.75		0.45	1.18
Bole	450080	985388	2132	21.8	6.94	634	236.6															
Makalo	448899	985053	2116	20.9	7.11	520	338	160					195.2	47		7.04	0.2064	0.9	2.8		0.1	0.03
Hordofi	449558	986067	2149	21.4	7.22	610	396.50	260					195.2	19		2.64	0.5160	0.5	2.8		2.2	0.01
Haro Jila (HDW)	449434	980645	2075	21	7.33	681	442.65															
Haro Jila (HDW)	449407	980765	2071	19.8	7.55	703	456.95															
Tefki Dairy	447020	978672	2067	19.5	7.79	805	523.25	316					385.5	25		1.32	0.1290	0.1	0.56		0.1	0.02
Tefki (HDW)	445254	978171	2066	19.7	7.46	599	389.35															
Gora 1	452891	980250	2071	20.6	7.49	505	328.25															
Gora 2	452924	980195	2069	20.1	7.32	444	288.60	162					197.6	12		7.04	2.0640	1.9	1.71		0.01	0.08
Mango Gora	453268	980729	2076	20.2	7.03	429	278.85															
Matali	451276	979174	2077	20.7	6.94	523	339.95															
Gora Harkiso 2	452466	976970	2067	20.6	7.48	733	476.45															
Mehal Atebela	455035	981813	2090	23.3	6.98	980	637.00															
Andode Sp-HDW	461003	977106	2110	23	7.26	488	317.20	192					234.2	18		3.52	0.0645	0.6	0.84		0.1	0.06
Cholo	441773	968943	2062		6.6	294	174.00	144	9.4	2.8	42	7.02	175.7	8.99	1.92	13.2		0.5	0.16	0.7	0.05	
Lilu	441578	967182	2079		6.7	440	270.00	187	22.5	4.2	56	8.64	228.4	17.9	17.3	1.5		0.3	0.33	0.3	0.05	
Gila	454714	978831	2062		7.05	640	364.00	312	36	7.1	79	22.7	380.6	12.4	15.4	2.6		0.4	0.12	1.4	0.17	
gombore	454683	975426	2064		6.96	810	542.00	336	20	4.9	122	28.1	409.9	28.9	31.7	14.2		0.6	0.26	1	0.13	
Mehal Sefera	455784	977521	2059		6.89	776	468.00	362	25	6.4	117	24.3	442.1	33.6	15.4	9.1		0.6	0.45	0.3	0.1	
Melima & Deti	455988	979556	2072		6.75	837	500.00	286	34	5.7	100	28.1	348.4	18..6	81.6	0.62		1.1	0.12	0.9	0.07	
Bebeli	457439	978436	2077		6.7	381	220.00	197	18	2.4	56	10.8	240.1	2	2.9	5.94		0.3	0.27	0	0.02	
Tiliqu Sefer Adea)	457922	974666	2073		7.19	771	442.00	396	42	3.2	106	24.3	483.1	11.9	10.6	0.74		0.2	0.09	1	0.15	
Berga #1	455502	980145	2073		6.84	386	226.00	149	16	4.2	49	11.9	181.5	15.1	12.5	11		0	0.41	0.6	0.02	
Berga #2	458390	976091	2075		6.58	676	458.00	152	48	1.2	92	11.9	185.5	38.3	146	28		0.3	0.25		0.02	

Turo	457253	973055	2075		7.2	523	294.00	295	30	3	74	12.4	304.5	10.5	6.72	4.09		0.4	0.35	1.2	0.02	
Koticha	456773	980613	2072		7.18	523	302.00	269	22	5	7.1	19.4	327.9	2.2	3.84	4.78		0.6	0.19	1	0.1	
Balchi Medianelem	458457	970573	2113		7.08	509	304.00	254	19	2.7	71	17.3	310.4	7	2.9	14.2		0.4	0.5	0.4		
Gichichi	458061	971737	2080		7.18	606	354.00	312	18	3.5	85	23.8	380.6	4.65	4.8	8.31		0.5	0.33		0.02	
Dima Mango_1	454809	981251	2083		6.86	338	214.00															
Dima Mango _2	454323	981723	2085		6.9	697	420.00	331	32	3.6	101	21.1	404.1	25.8	11.5	4.03		0.3	0.12	0.6	0.15	
Kontoma	453850	973096	2060		7.23	632	303.00							15.9	21	8.5	0.2700		0.18	0.9		
Dobi	451420	971692	2063			1327	645.00							46.2	103	10.5	0.2300		0.19	0.6	0.12	
Boneya	460464	974637			7.1	376	236.00		15.5	1.8	47	13.8	226.5	0.55	5.8	11.5	0.4000		0.16	2.6	0	
Boneya (BH)	460464	974637		22.5			337.35	224					273.3	2		131	Nill	Nill	3.7		0.1	0.06
Awash Melka	456740	962388			7.19	510	350.00		42	9.8	63	9.4	333.1	2.64	6.7	7.5	0.0600		0.18	1.3	0	
Awash Sheba F1	454852	962780																				
Tefki	444624	978143			7.44	726	455.00		116	6.6	36	6.1	345.9	15.6	56.6	4.8	0.1130		0.29	3.6	0	
Tefki Golden 2	442811	977625	2066		7.94	653	313.00					44		4.7	5	0.26	0.0017		0.39	1.1	0.18	
Tefki Golden 1	442842	977555																				
Daleti	460810	981473	437		6.97	344	222.00		15	4.8	44	13.2	217.8	0	0	7.5	0.0600		0.12	0.2	0	
Sebeta BH12	463742	985378			7.9				20.4	4	56	9.7	268.4		7.1		0.4600			0.7		
Meta Abo Brewery	455000	985200			7.7	191	117		23.8		24	3.9	122		14.2	9.3			0.12			
Alemg Jafar Tannery	459676	984947		20		291																
G.Gebre kebede	463600	988200		19.7			220															
Sebeta Dragados	457030	984617			6.85	979	597		16	3.4	36	9	178	2.6	5	8.69				0.5		
Healthy Water	463572	988693			6.92				8.6	11				2.9					0.34	0.4	0.03	
Sebeta Shooting	463599	988583																				
Geja Dera	461930	970844			7.37	507	243							0	0.9	0.01	0.0014		0.16	0.6	0.08	
Seb Agro #1	460850	985850			6.65	244	159		16	3.1	29	4.84	141.5	1.8	3.88	14						
Seb Agro #2	460500	986500		21.8	6	211	136								3.5	1.1			0.35	0.7		
Debele Yohanes	445643	973409			7.06	333	219		17	4.2	50	8.3	235.7	0.53	2.9	7.5	0.0250		0.31	0.8	0	
Debela Kajima	443843	969974																				

Meta A Bre BH5	455300	985250		21.6	7.3		139		14	6.6	20	46	122		7.1	0.1			0.04	0.7	0.2	
Meta A Bre BH8	455525	984000		24.7			140															
Meta A Bre BH7	455350	985100		25			144															
Yes W. Bottling	463572	988693			6.92	488	232		8.6	11				2.9					0.34	0.4	0.03	
A/G Hafde PLC	461412	986324		20		288																
A/G ODA Flow	460937	986565																				
Sebe.Tal Flow #1	455450	983014																				
Seb. Tal Flow #2	455426	982736			6.7	422	273		17	4.2	68	9.4	218.4	1.32	4.8	10.5	0.250		0.22	0.4	0	
Sebeta WS	459831	985582	2227	21.5	6.56	201	138		9.1	4.6	26	5	123	0.26	9.6	3	0.025		0.6	0.8		
Meta Abo Bre	455287	985619	2200			148	18.8															
Kelecha 1	445354	969451																				
Kelecha 2	445144	969045																				
Sebeta WS1	456511	981649	2072		7.32	460	296	260	57	11.6	28.12	9.12	317.20	0.57	5.31	1.64		0.2	0.13	0.88	0.28	0.03
Sebeta WS2	456326	982067	2080		7.12	396	260	208	34.5	9.9	38	9.12	253.76	0.19	5.46	4.28		0.16	0.17	0.63	Trac	0.08
Sebeta WS3	456177	981556	2078		7.67	360	218	180	31.5	8.6	32.68	9.12	219.60	15.43	3.64	3.26		0.5	0.6	0.82	Nill	0.01
Sebeta WS4	456265	981309	2075		7.02	508	320	274	24	7	59.28	19.15	334.28	0.1	2.73	5.46		0.17	0.23	0.74	Trac	0.02
Geme Spring	457023	981813	2087	24.4	6.89	467	303.55															
Debele Spring	459268	984313	2164	22.1	6.78	513	333.45															
Sebeta Spring 1	459268	985817	2217	22.4	6.67	306	198.9															
Sebeta Spring 2	459831	985582	2227	21.5	6.56	138	201															
Meta Abo Spring	455287	985619	2200	18.8	6.75	148																

ANNEX 3: Potential Pollutants identified on Sebeta Stream (on 3 different stations-moving down stream)

Site Name	Geographic Coord.		Elev (m)	Temp ^0C	pH	TDS (mg/l)	DO (mg/l)	COD (mg/l)	BOD (mg/l)	TN	SO_4	NO_3	NH_3-N	PO4	SO_4	S	Cr	Pb	Zn
	X_UTM	Y_UTM																	
Stream (SRS1)	459860	985700	2228	32.2	5.4	3,800	0.39	38100	11064	1000	2093	176.3	614.5	130.7	2093	2.2	0.35	<0.1	3.25
Stream (SRS2)	459690	985090	2203	22.6	5.84	3,100	0.42	22962	5361	446	4060	21.7	335	43.6	4060	2.2	0.3	0.1	1.3
Stream (SRS3)	458436	982873	2132	23.3	8.49	1,950	0.41	4043	1289	163	1162	0	93.83	10.3	1162	0.6	0.25	0.1	-

ANNEX 4: Recommended ranges of concentration for industrial process water (mg/l) (Todd, 1980)

Industry & process	Turbidity Unit	Color Unit	Taste & Odour	Dissolved Solid	Hardness as $CaCO_3$	Alkalinity	pH	Maximum Total Alkalinity
Food Processing Factory	1-10	5-10	Low	850	10-250	30-250	>7.5	300
Tanning	20	10-100	Low		50-500	130	6-8.0	135
Textile	0.3-25	0-70	Low	0-50				50-200

ANNEX 5: Maximum allowable concentration of some water quality parameters.

Constituents	WHO (Max. Al. Con)	EU	Ethiopian Standard (Max)
P^H	6.5-8.5	7	6.5 - 9.2
Colour (TU)	50	20	50
Turbidity (NTU)	5		25
TDS (mg/1)	1000	500	1500
Total alkalinity as $CaCO_3$, (mg/l)	500	-	
Total Hardness as $CaCO_3$, (mg/g)	500	-	500
Calcium hardness as $CaCO_3$, (mg/l)	300	-	
Na (mg/l)	200	150	
K (mg/l)	10	-	
Ca (mg/l)	100	-	200
Mg (mg/l)	30	-	150
Cl (mg/l)	250	25	600
SO_4 (mg/l)	250	250	400
F (mg/l)	1.5	-	
NO_3 (mg/l)	50	50	
Mn (mg/l)	0.1	0.05	0.5
Fe (mg/l)	0.3	0.2	1
Microbiological Variables			
Faucal coliform	No per 100ml	No per 100ml	No per 100ml
Total coliform	No per 100ml	No per 100ml	No per 100ml

ANNEX 6: Rain fall data for the surrounding meteorological stations (1985-2014)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Sebeta Monthly RF (30 Years)						Geog Co	**458824**	**985569**		Elev.	2220
Total	522	1509	2148	3027	2829	4452	8964	10128	4233	876	231	300
Mean	17.4	50.3	71.6	100.9	94.3	148.4	298.8	337.6	141.1	29.2	7.7	10
	Addis Ababa (OBS) Monthly RF (30 Years)						Geog Co	**472616**	**998662**		Elev.	2408
Total	378	1005	1929	2607	1986	3705	7299	7689	3942	1074	81	207
Mean	12.6	33.5	64.3	86.9	66.2	123.5	243.3	256.3	131.4	35.8	2.7	6.9
	Holeta (Research C. Monthly RF (30 Years)						Geog Co	**443219**	1E+06		Elev.	2380
Total	744	1830	2163	2727	2370	4557	8571	9909	5949	699	441	435
Mean	24.8	61	72.1	90.9	79	151.9	285.7	330.3	198.3	23.3	14.7	14.5

ANNEX 7: Technical expert's questionnaire prepared to understand water supply sustainability problems of Sebeta Area

Experts and technical persons survey questionnaire

Survey area: region ___________ Zone ______________ Woreda __________________

Date of interview: _______________ Name of interviewer: ________________________

Respondent's Name and profession: ____________________________Age _____ Sex ____

1. Describe the most important water supply development activities carried out in the past till to date through government /or other organizations support. Discuss what is working well and what not, including suggestion for improvement and change: ____ ____ ______________________________

2. What are the major water supply sustainability problems in order of importance?
   a. Quality b. Quantity c. Skill d. Policy e. Institutional structure f. Hydrogeological knowledge g. Water use management h. Others specify ______________________

3. How can water supply sustainability problems be minimized?

   a. improving institutional structure

   b. prevention of the resource from contamination

   c. Investing on knowledge of professionals

   d. Revising policy

   e. Improving awareness of the resource to management committees and administrators

   f. understanding the resource

   g. other specify ____________________

4. What major natural disasters have occurred in Sebeta area that affects sustainability of the water supply scheme?

a. Drought b. Flooding c. Conflict over water resources d. Water born diseases e. Presences of hazardous chemical constituents f. Other specify ____________

5. What prevalent problems encountered in the developed water supply schemes?

a. Imbalance between supply and demand b. Poor administration

c. Conflict over water resources d. Failure of developed schemes

e. No problem f. Others specify ____________________

6. Do you have legal frameworks for promoting participation of various stakeholders?

Yes ________ No _______

7. What are the major benefits of sustainable water supply schemes for your community?

a. Improved health b. Reduce conflict over resources

c. Improved productivity d. Safe, adequate and clean water for domestic supply

e. Other specify _____________________

8. What criteria's are considered when planning sites for water supply development schemes?

a. Settlement b. Transport accessibility

c. Hydrogeological feasibility d. Policy makers decision

e. Other specify _________________

9. Is there continuous supervision during water supply scheme development?

a. Yes b .No c . Intermittent supervision

10. Is there any monitoring system after development of water supply schemes

a. Yes b .No

11. What is the extent of community participation in deciding the site and design of the water supply scheme projects?

a. Involved in site selection b. Involved in planning

c. Involved in implementation d. Involved in administration and management

e. others specify ______________________

12. Out of the developed groundwater sources, how many are failed to meet their objectives? (In percent)

Bore holes __________________

Shallow wells _________________

Springs _______________

13. How many water supply development scheme projects are delayed than the planned time? (In percent)

Ground water development scheme projects __________________

Surface water development scheme projects __________________

14. What are the causes of groundwater development failures? (Put in order of importance)

a. Quality problem

b. Quantity problem

c. Financial problem

d. Conflict

e. Institutional structure problem

g. Lack of proper investigation

h. Management problem

i. Policy

j. others specify ____________________

15. What are the cause for the delay of water supply project schemes?

    a. Financial problem

    b. Conflict

    c. Management problem

    d. Policy

    e. Others specify ________________

16. Who organize the water supply scheme management?

    a. Water committee   b. Professionals   c. Community

    d. Administrators   e. Others, specify __________________

17. Does the existing training and staff mobility policies allow professionals to improve their skills?   Yes _____________   No _______________

18. Do you think staff is enough and capable?

    a. Yes   b. No

19. Do you train village level operators?

    a. Yes   b. No

20. Do you give training to households and water committee?

    a. Yes   b. No

21. Do you have Zone-level/woreda level organization(s) for management of multiple water resources?

    a. Yes   b. No

22. What are possible solutions to improve water sustainability in your woreda?

____

____

23. What are your main recommendations regarding water supply sustainability problems?

____

ANNEX 8: Format prepared for Groundwater Source Data - FORM 1

Location (Woreda/Town/Kebele): ID :

Location (taken by GPS): X : Y : Z : UTM zone : 37

Date of completion(dd/mm/yyyy): Type of source:

Constructed by: Operated/Owned by:

Report the current operational use and condition of the source and site:

Reported yield of the source: L/s m^3/d Verified at source(y/n):

If not verified, who provided information?:

Abstraction infrastructure – note if this is spring source then complete only relevant information:

Pump installed (y/n): Make: Model:

Depth of installation: m Rising main type, dia. & length:

Delivery main (y/n): Delivery main type, diameter & length:

Enter any other comments about the installation:

Water Quality Is there water quality information available for this site? (y/n):

If so, what date(s) was this analysed: and by whom:

Key comments on this analysis, if it has been made available:

Any other comments about the site:

Groundwater Source Details - FORM 2, Well details

Type of source: ______ ID: ______

Datum point: Borehole mouth True elevation point of datum: ______ m.a.s.l

Construction dates: *From :* ______ *to :* ______

Contractor: *Name:* ______ *Contact :* ______

Yield of the source: (pumping) L/sec ______ m^3/d. Verified at site: Yes/no

If the yield of the source was not measured, state why not and the source of above information:

Briefly describe the construction method and details:

Total well depth: ______ Measured on site: Yes/No

Type of aquifer: ______ Confined/Unconfined/Leaky: ______

Reported water strikes: m b.g.s.

Surface casing type: ______ Diameter: ______ Length: ______

Production casing: ______ Diameter: ______ Length: ______

Screen casing type: ______ Diameter: ______ Length: ______

Screen slot size: ______

Gravel pack (y/n): ______ Type: ______ Volume : ______

If any details pertaining to the well construction are not known please indicate with n/a.

Water level information: SWL: ______ Date measured: ______

Is there historic information about SWL available: Yes/no *If so then data must be reported.*

DWL: [m b.g.s] Date measured: [ ] at what yield: [l/s]

Has there been a pumping test conducted at this site? [Yes/no]

If so can any of the following be reported?

Transmissivity [m^2/d] Storativity [ ] Specific Capacity [$m^3/d/m$]

Form 3: Well Lithology - Description

Drilled depth (m)		Lithological Description	Thickness	Remarks
From	To		(m)	

Form 4: Well Construction (casing design) - Description

Installed depth (m)		Casing type (plain/screen)	Length	Remarks
From	To		(m)	

ANNEX 9: Some of the available Borehole data with all informations

No	Well Location	GPS Location		Major Aquifer	Depth (m b.g.s)	Yield (l/s)
		Easting(m)	Northing(m)			
1	Herdim	462313	983537	Fractured tuff	252	4.8
2	Origin New	462013	985552	Ignimbrite	180.33	8.7
3	Origin old	462555	985053	NI	251	1.5
4	Daleti Old	460800	981461	Fractured ignimbrite	102	4
5	Mekab	462707	986167	Fractured basalt	300	5.8
6	Daleti New BH	461033	981164	Scoria, basalt and rhyolite	192+	~10-15
7	Well around Origin New BH	462109	985789	Fractured basalt	147	11.3
8	Dima Borehole	450359	981037	Scoria	282	~19

ANNEX 10: Atebela River Discharge Measurements

Measurement coordinate and elevation

X_UTM	Y_UTM	Elevation
453614	963655	2009

Dimension- Cross-sectional distance = 1.4 m

Average depth = 0.4 m

v = 5.1091x + 0.2727

Date	Time	Rotor Rev.	Counts	Water Velocity		Area (m^2)	Q (m^3/s)
				cm/s	m/s		
7/4/2015	9:20	8.90	89.00	454.98	4.55	0.546	2.484
7/6/2015	9:20	10.33	103.33	528.21	5.28	0.5572	2.943