ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF EARTH SCIENCES


# GEOLOGICAL FRAMEWORK FOR GROUNDWATER OCCURRENCE IN LAKE TANA BASIN, NORTHWESERN ETHIOPIA, AMHARA REGION

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


BY: AYALEW HUSSEN


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FACULITY OF NATURAL SCIENCES

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JANUARY 2010

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I gratefully thank organizations and individuals who directly or indirectly supported me during my study. First of all my special thank go to Samson Mengistu and Henok Endale for their daily works besides to me. Without their cooperation my research is not accomplished at to the end. Next I would like to express my deepest gratitude to as whole South Wollo Zone, Borena Woreda Water resource Office staff members, especially ato Ali Ahmed and W/ro Almaz Abebe for their support in different services.

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During the field survey and all data provided me and allowing me to pursue my master's studies, respectively.

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## ABSTRACT

The study area is found in northwestern Ethiopia, Amhara National Regional State (ANRS). It is situated in the junction of the three grabens (Gonder, Gorgora &Debretabor). The study area with 15339 $km^2$, comprising the two shield volcanoes( Guna and Choke), Lake Tana and rivers, which is delineated arbitrarily so as to determine whether the geological framework is favorable for ground water occurrence and circulation between them or not.

Irrigated methodologies are used t find out the groundwater flow system and hydrochemistry of the study area along with employing the appropriate software like global mapper, serfer, and Arc GIS that facilitate for analysis and interpretations of the data in order to get the output. The secondary data are collected from the concerned offices and same primary data are obtained during the field work.

Accordingly, groundwater flow system is considered as shallow and deep aquifer cases and the output indicate that there is the same flow trend within the two flow systems ground water flows west and to the southwest.

On the other hand, hydro chemical data analysis part also reveals, evolution of major ions, water types portability of water for human consumption, spatial distribution of some major ions including fluoride and direction of groundwater flow. For example, the water sample from the spring and hand dug well(Guzara) and bore hole(Enfraze) is $NaCHO^-_3$ type, which indicate the presence of evolution where as cold springs mostly from the high lands has the water type Na-CA-$HCO_3$ shows minor evolution. The increasing trends of the physicochemical analysis indicate that there is groundwater out flow towards the Lake area

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# CHAPTER ONE

# INTRODUCTION

## 1.1 General information

Water is one of the most prominent components for life to exist on earth. Without it life is not possible. A person requires about 3 liters of potable water per day to maintain the essential fluids of the body (Fetter 1994). Water is also used for various purposes such as municipality, commercial, irrigation, and for energy production. Although many environmental factors are determining the density and distribution of vegetation, one of the most important is the amount of precipitation.

The Lake Tana basin is an elevted region in northern Ethiopia in the headwaters of the Blue Nile (Abbay) Basin. To the east of the basin boundary, the topography is dominated by the presence of two large shield volcanies. Mt.Choke and Mt.Guna while to the west it drops sharply to the adjacent Beles and Dinder basins across the West Tana escarpment. Within the Lake Tana basin, the topography is strongly controlled by falling and there are major lineaments throughout the basin.

The main topographic feature in lake Tana, occupying an area of some 3100 $Km^2$, which drains from the South end into the Blue Nile River. Major rivers discharging the lake are the Gilgel Abbay in the South, the Gumera and Ribb on the east and the Megeche draining from the north.

The Gilgel Abbay Rivers is elevated terrain that occurs off the flanks of Mt. Choke and flows across largely basaltic terrain into Lake Tana. Close to the lake, around Bahir Dar, the Gilgel Abbay Basin landscape contains numerous well preserved Quaternary volicanic cones comprising basalt, scoria and volcanic ash. In this area there are also very rocky outcrops standing above the plains with lowlying, often swampy ground between the out crops.

The eastern and western margins of the basin are elevated above 2000m. Towards the lake, there are believed to be tilted falut blocks, largely of basalt dipping towards the lake (chorowicz et al 1998). Steep bulffs, composed of the remnants of trachyte and phenolite valocanic pluges rise above basalt in many areas and low-lying areas particularly in the eastern parts of the basin.

There are extensive flood plains in the down stream ends of the Ribb and Gumera Rivers, which are prone to long term flooding. There are also extensive flood plains surrounding the Megeche River to the north and also at the margins of the short distribution which flow form the elevated western margins of the basin in to Lake Tana.

Information on spatial and temporal variability of chemical composition of natural water is valuable to understand the different hydrological and hydro geological process in the basin. The concentration in water samples reflect their sources path, flow directions, surface water –ground interaction their travel time and age of ground water, hydraulic connection of the Lake, and ultimatelly for water management practices.

The chemical composition of natural waters and the amount of its ionic species depend on several factor: types of soil and rock through which the water passes, the degree of weathering and solubility of the mineral components of the rocks and soils, the extent and duration of the contact with rocks and soils, the temperature conditions, the type of dissolved and suspended solutes that falls with precipitation.

Climatic pattern, which produces characteristics plant communities and soil types governing biochemical processes in the hydrosphere, play also important role. The process of rock weathering is strongly influenced by temperature and the amount and distribution of precipitation.

### 1.2 previous works

Ground water well drilling programs have been initiated over the last decades, but groud water provision is often unsucessful because of poor ground water productivity of wells, difficult drilling condtions, drying of wells and springs after prolonged drought, or sometimes due to poor quality. This is hampered by lack of understanding of ground water system. Information on ground water recharge, storage, circulation, and chemical evaluation is barely known. Ground water development is being conducted without a good understanding of its role in the hydrology of the basin.

There have been a number of studies of the geology and hydrogeology in and around the Lake Tana basin, although no comprehensive assessment of the aquifers and their potential has yet been made key works used in this study to interpretet the ground water system in the area listed below.

- Geological and hydro geological map of Ethiopia 1:2,000,000 2$^{nd}$ edition (1996) and compiled by Tesfaye cherent (1998), respectively.
- Regional Hydro geological investigation of Northern Ethiopia, including 1:10,000 hydro geological maps are compiled by Bayissa Asfaw (2003).
- Abbay Basin Master plan, phase 2, sectoral studies part 3, Hydrogeology (February 1998),
- Ground water recharge, circulation and geochemical evolution in the source region of the Blue Nile River (kebede et al 2005).
- The Tana basin, intra-plateau up lift, rifting and subsidence, (chorowicz et. al 1998)
- The structure of a Mesozoic basin beneath the Lake Tana area is revealed by magento-telluric imaging. Hautot et al 2005).
- Remote sensing based assessment of water resource potential for Lake Tana Basin. Yohannes Daniel (2007).
- Engida Zemedagegnehu, Dr. Yilma Sileshi, Albert Tuinhof (2007) Groundwater Resources in Lake Tana Sub-Basin and Adjacent Areas Rapid Assessment and Terms of Reference for Further Study.

The overall extent of the ground water data in the basin is limited spatially and temporally. Many important aspects of the data which are needed to obtain comprerhnsive characterization of the ground water system are not recorded or missing, or in the possession of individuals unavailable at the time of this study. There is neither centralized ground water data base for the basin nor any mechanism to register well locations drilling details and other relevant information under the control of an individual owner. This delays and restricts aduqate data collection and inhabits the full understanding of the ground water condition in the basin.

### 1.3 objectives

The main objective of the research is:-

To investigate the geological framwork of groundwater occurence in the Lake Tana catchment.

The specific objectives are:-

- To investigate local, intermediate and regional ground water flow system based on hydrochemistry.
- To conceptualize the role of geological structures and cross-sections on the types and movement of ground water
- To conceptualize groundwater flow, recharge and discharge conditions
- To understand the rock-water interactions and the resulting impact on the natural water composition
- To asses surface water-ground water interactions in the lake water shade system.

### 1.4 Methodology and Materials

#### Sampling and laboratory analysis

A total of 18 water samples were collected from ground water wells, springs and the lake in the field, in April 2009 and kept in sample bottles and completely filled and tightened with plastic caps. TDS, conductivity temperate salinity and PH of waters measured in situ using the appropriate field kits. Locations of the sampling points are recorded during the field work using Global positioning system (GPS).

97 water chemical data points from a previous study (kebede et al 2005, 2006) were included in the data base. Some of the previous data that were compiled in this work some of them do not have a geographic coordinate.

| Parameter | instrument /analyis method/ |
|---|---|
| Major anion- | Dionex Ion chromatography equipped with autom |
| Carbonate and Bicarbonate – | Acid titration tication |
| PH,EH and Temperature- | field PH,$T^{o}$ meters |
| TDs, conductivity & salinity | field EC meter |

Table 1.1 methods applied for water samples analys

# CHAPTER TWO

# GENERAL DESCRIPTION OF THE STUDY AREA

## 2.1 Location and Accessibility

The study area is found Northwestern plateau of Amhara National Regional State (ANRS). It is located between 200000-450000E and 11000000-14000000N UTM locations.With a total area of 15339 km$^2$ with the Lake Tana at the center with 3100 Km$^2$ area coverage (Fig 2.1). The study area components BahirDar town, the capital of ANRS that is located at the distance of 560 km from Addis Ababa.

As far as the accessibility of the roads in the study area is concerned, the main asphalt road from Addis Ababa to Gondar Town crosses the entire length of the area. Generally, the northern, central and southern parts of the study area are also well access with gravel and dry weathered roads. The western part of the area is mostly accessed with weathered roads.

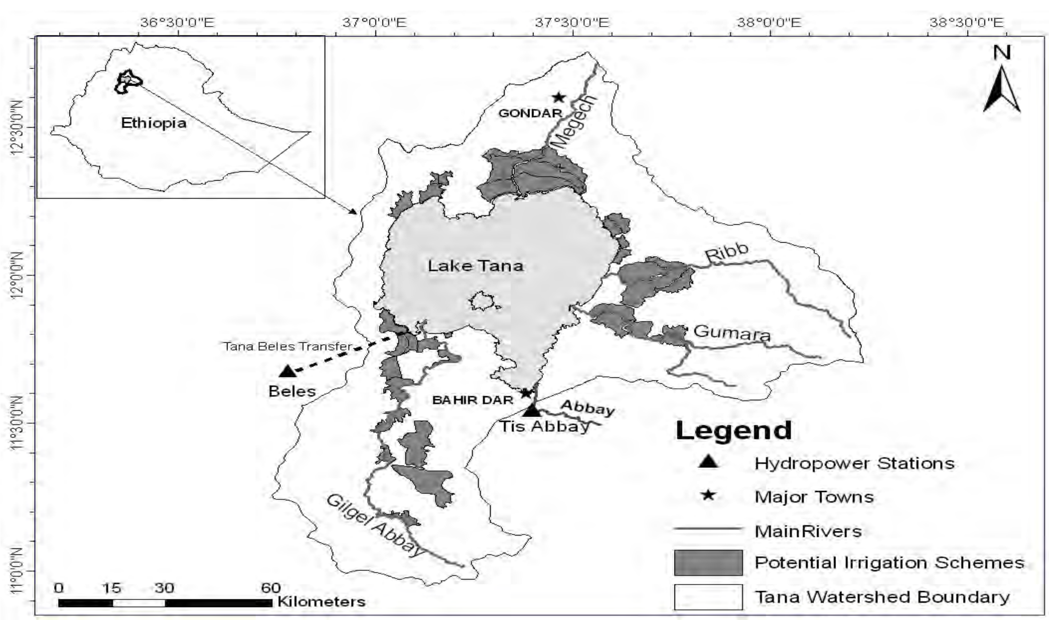



Figure 2.1 Location Map of the Study Area

## 2.2 Physiography and Drainage

The landscape of the study area is the result of volcano-tectonic and erosional processes. Generally as it observed and noticed during filed survey, and referred from the previous works the land forms in the catchments can be broadly grouped in to two; the plateau and the escarpment in which all the land forms showing a main feature of NNE-SSW alignment in line with the major tectonic line orientations.

The maximum and minimum elevations in the study area are 4135 M.a.s.l and 1790 m.a.s.l on the eastern water divide (south east) and Lake Tana, respectively. There is an elevation difference of over 2345 meter between the plateau (Mt .Guna) and the Lake floor.

.

The eastern and southern part is bounded by small caldra having elevated such as Mt. choke and Mt. Guna of 4052 and 4135 m.a.s.l, respectively. Water bodies of swampy areas and small volcanic is characterize the floor of the depression, such as Lake Tana. The plateau occupies a wide area in the study area forming a flat to undulating landscape that is slightly dissected with some depressions characterized by seasonal drainage deficiencies. The mountains escarpment on the other hand is a highly dissected terrain with desire drainage system and torrential streams compressing the entire eastern escarpment .However, the southwestern part of the corridor is characterized by local horst and graben structures forming parallel wide valleys that are poorly drained and totally water logged during the rainy seasons.

The drainage pattern in the eastern part of the study area is generally dendrite in which most of the streams originate from the eastern plateau and escarpment indicating the presence of impervious geological materials and occurrence of low infiltrating triggering high run off. On the other hand, the drainage pattern is sub parallel and sparse, and follows structural weakness zones in the central part of the study area.

The major stream in the southern part of the study area is Gigel Abbay River drains to Lake Tana that is found southwest of the study area. There are also many small streams in this sub area which are tributaries of GilGel Abbay. On the other hand, Lake Tana sub basin is a volcano tectonic depression (Caldera), the drainage pattern become radial that drains from the eastern escarprnlnt flowing west ward.

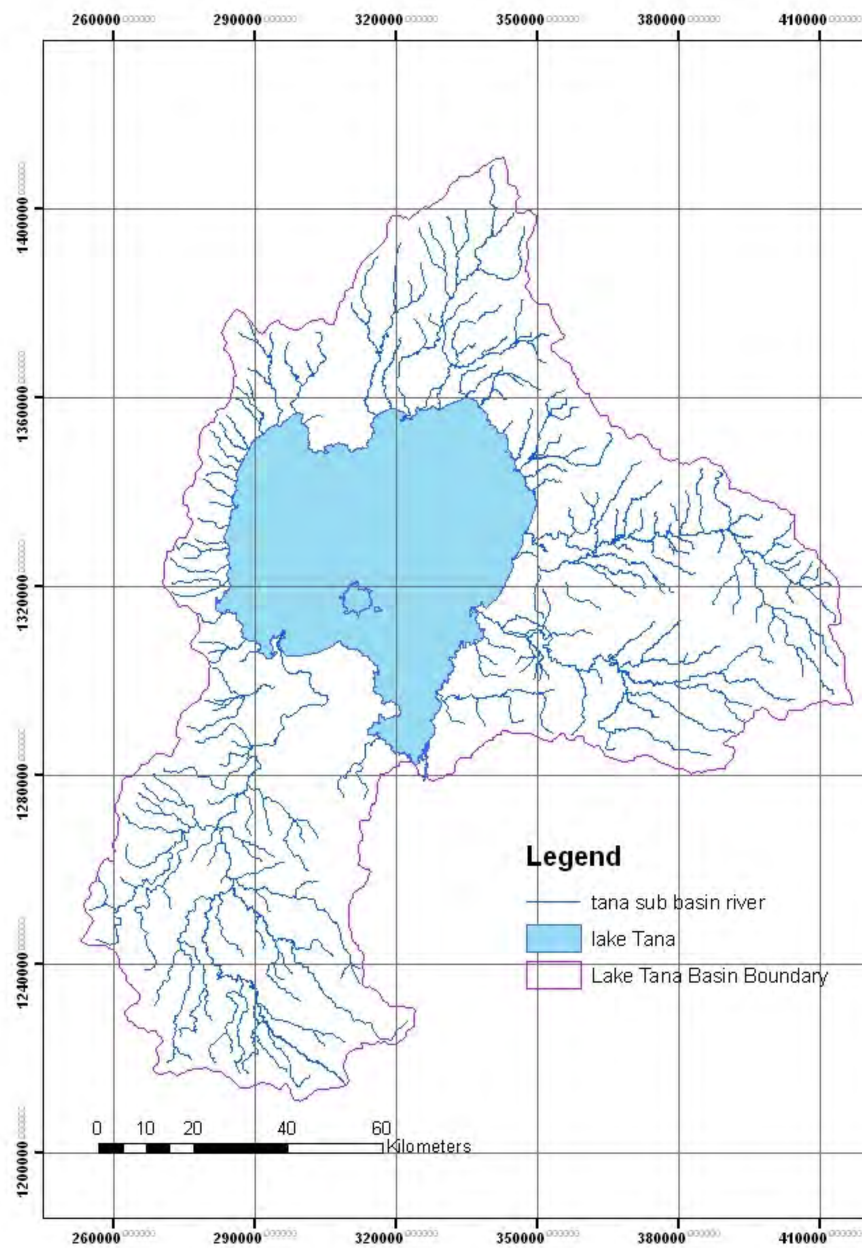



Fig 2.2 Physiography and Drainge areas of the Study Area

### 2.3 Climate

Based on the annual and monthly mean temperature and rainfall and also on seasonal changes of rainfall, type of natural vegetation associated and altitude the Climate of the study area varies among temperate to subtropical traditionally "Dega &"Woina Dega" respectively ( National Atlas of Ethiopia,1988).

In general the main rainy months are June to September; where as dry months are from October to May. In the southern parts of the sub-basin, however, the months of April and May are an intermediate season where minor rain often occurs. About 80% of the total annual rainfall occurs in the June to September. Mean annual rainfall varies from 900 mm to 1500 mm.

In general the mean annual temperature reaches up to 23 $^{o}$C in the low-lying areas (below 2000 masl) and in the range of 15 to 20$^{o}$C in the middle and high altitudes (above 2000 masl).

Estimated mean annual inflow to Lake Tana based on gauged catchments is about 3556 million $m^3$. According to Melkamu (2005) about 45 % of the total catchment excluding the Lake area is gauged. The mean annual outflow from Lake Tana is about 3750 million $m^3$, estimated over the period 1960-2001. The annual flow varies considerably; in wet year of 1998 it was 6075 million $m^3$, while in drought year of 1984 it was 1057 million $m^3$.

### 2.4 soil, land use/Land cover

The factors that control soil formation are climate, Organisms, relief, parent material, time and vegetation. The process of soil formation is those that modify the regolith and give it the acquitared characteristic which distinguishes soil from the parent material. These processes are generally governed by climate/ latitude (Bridges, 1978).

All types of chemical weathering operate most effectively in very warm and wet climate for water is essential chemical weathering operate most effectively in very warm and wet climate, for water is essential for most of the chemical reactions to increase with increasing temperature (small, 1978).

In humid tropical regions of the world (which is also characteristics of the study area) fertilization is a characteristic process of soil formation. This process involves the relative accumulation of the Oxides of iron and aluminum with the loss of Silica.

The process of fertilization is accompanied by a strong leaching of the soil so the PH values are low. The resulting soil is freely drained and red in colour (Bridges, 1978).

The soils in most of the Tana basin are derived from the weathered basalt profiles, and are highly variable. In low lying areas particularly north and east of Lake Tana, and along parts of the Gilgel Abbay, soils have been developed on alluvial sediments.

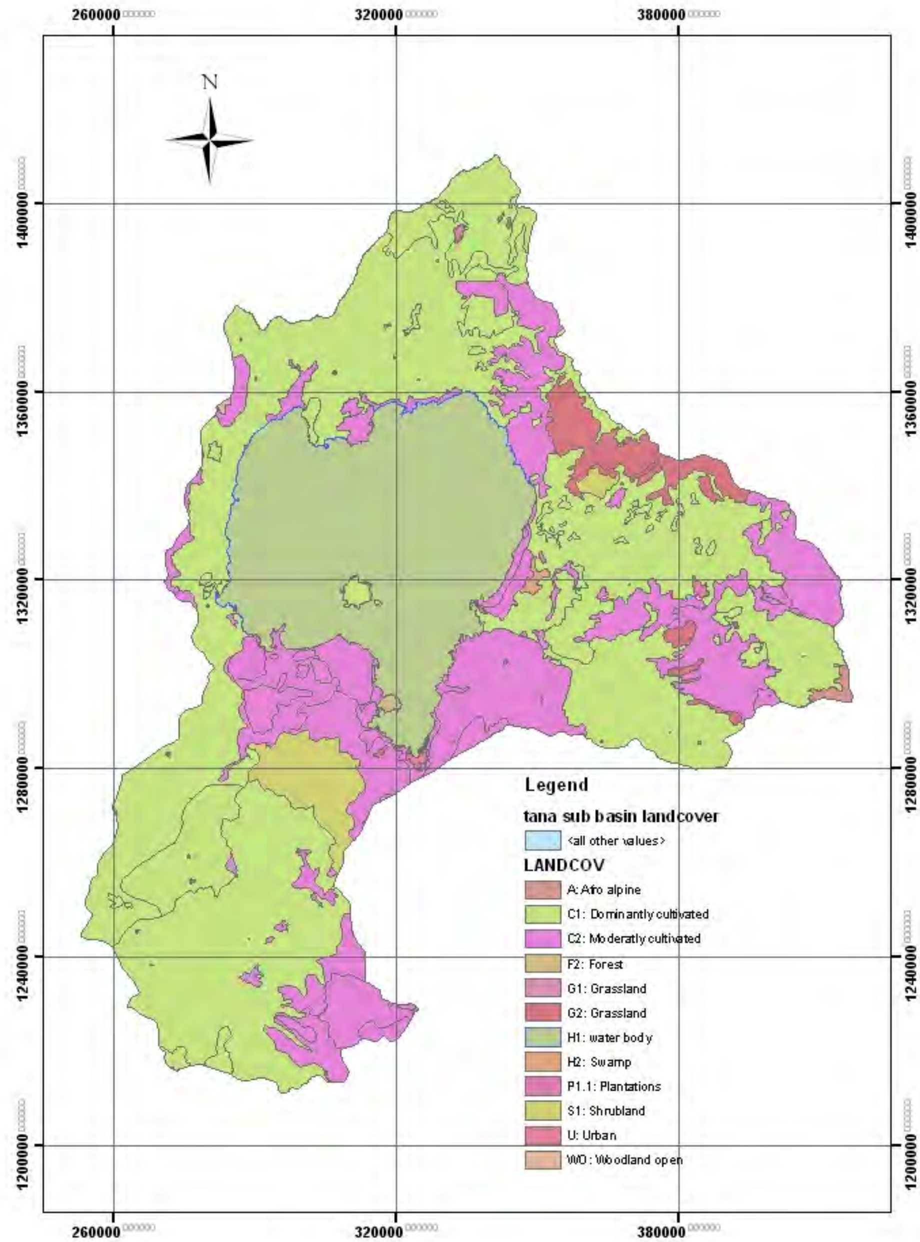



Figure 2.3 Land use/Land cover map

| Major Soil Group | Soil Texture | Drainage condition | SCS Infiltration Category | % of the Tana Basin* | General location |
|---|---|---|---|---|---|
| Eutric Regosols | Sandy loam to loam | Excessively drained | A | 0.25 | Small areas of the Gilgel Abbay near Bahir Dar |
| Haplic Luvisols | Clay to silty clay | Well drained | B | 20.72 | Flat and sloping topography on most of Gilgel Ababy, Ribb, Gumarra and Megeche catchments,<br>In the elevated areas of the Beles |
| Chromic Luvisols | Clay | Moderately well to well drained | B | 15.55 | |
| Eutric Fluvisols | Silty clay | Moderately well drained | B | 9.83 | Mid reaches of the Ribb catchment<br>Mid reaches of the Beles |
| Haplic Nitisols | Silty clay to caly | Well drained | B | 1.24 | Highest areas of the eastern Tana Basin divide<br>Bottom end of the Beles |
| Eutric Cambisols | Silty clay | Moderately to deep and well drained | B | 0.01 | Limited distribution in the Tana basin, |
| Eutric Leptosols | Clay loam to clay | Moderately deep to deep | C | 12.26 | Highest parts of the eastern and northeast catchments of the Tana basin |
| Haplic Alisols | Clay | Favourable drainage | C | 4.98 | Highest parts of the Gilgel Abbay catchment |
| Eutric Vertisols | clay | Poorly drained | D | 11.84 | Drainage lines along Gilgel Abbay Basin |
| Lithic Leptosols** | Loam to clay loam | Moderately deep to deep | D** | 3.01 | Gilgel Abbay basin near Bahir Dar |

Table 1.1: Soil Properties for the Tana Basin

Based on Yohannes Daniel (2007)

*Urban areas and Lake Tana comprise 0.07% and 20.24% of the Tana basin respectively. Emphasis on the Tana basin is because of the significance in terms of groundwater recharge**the lithic leptosols are rocky, with skeletal surface soils. Infiltration capacity may be significant.

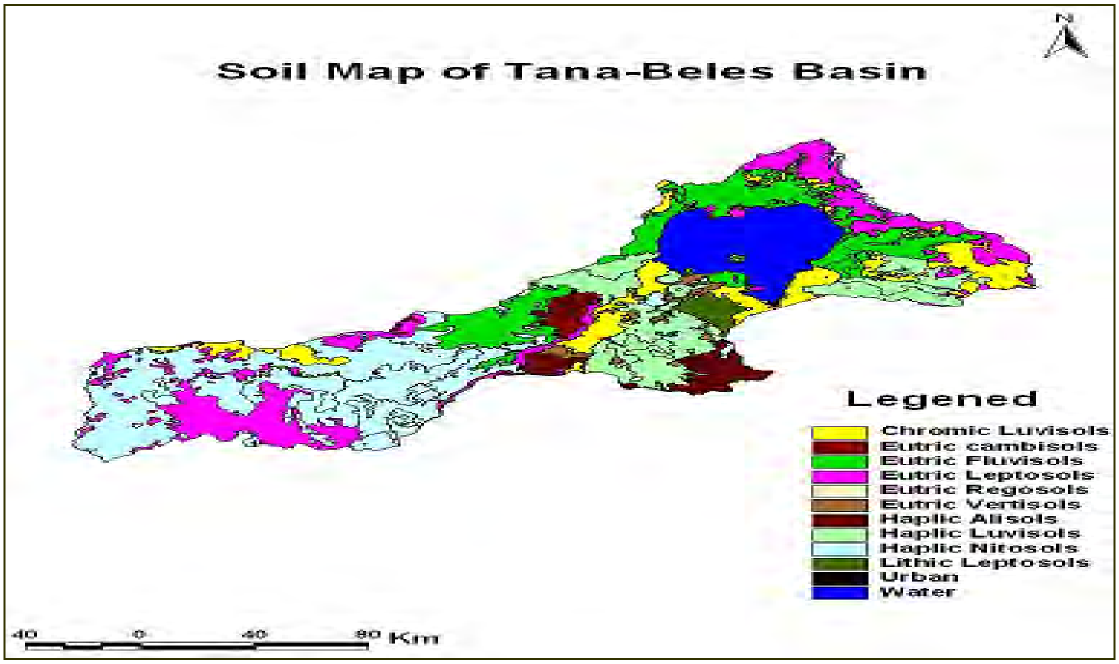



Figure 2.4 Soil Map Tana Basin

### 2.5. Public consumpiton

Groundwater is developed through the entire basin for drinking water supplies through drilling wells and capping high yield springs of the study area. The rural people who are living in these areas are using water for their day to day activities and lives stock from springs and surface water sources like rivers and streams and from hand dug wells.

Regarding to the water quality, at the vicinity of Enfraze boreholes, the fluoride concentration is beyond world Health Organization (WHO'S) guidelines, 2004 which is 1.5 mg/L. Therefore the water from this area is not potable.

#### 2.5.1Urban water supply system

The major towns in the study area are Bahir Dar, Gonder, Deberatabor, Worota, and Dangila which have the water supply from surface and groundwater sources. As the population and Business activity of the towns are growing at an alarming rate obvious by more water will be needed in the future. This additional water demand can be supplied by either increasing the number of boreholes around the towns and/or utilizing surface water resources of the study area based on detail hydro geological studies.

There are more than four boreholes drilled for each of the above mentioned towns for water supply systems. These can be sufficient for the current populations of the towns but in the future, the demand will increase therefore extra sources should be designed ahead of time.

### 2.5.2 Rural Water Supply Systems.

The groundwater developments for the rural areas are mainly concentrated on shallow and hand dug wells. Mostly, people who are living in highlands (on plateau area) are, using water for drinking and other activities from springs and streams, respectively. As there is sufficient groundwater resource in the area, the rural water supply schemes would basically depend on ground water resources like capping springs and constructing shallow wells.

# CHAPTER THREE

# GEOLOGY

## 3.1. Regional Geology

The geological framework of the Lake Tana basin as outlined on the 1:2,000,000 geological map of Ethiopia (2nd Ed, 1996) comprises a basement of Precambrian bedrock, over lain by Mesozoic sediments, Tertiary volcanic and minor sediments, quaternary volcanic and recent alluvial sediments. Ongoing tectonic activity has controlled the distribution of the rock formations and controlled the current configuration of basin (chorowicz et al.1998).

The geological interpretations have varied over the years and the early, Mesozoic sediment accumulation over the Precambrian basement rock is due to spreading of a shallow sea over much of Ethiopia as a result of land subsidence. The result of Cenozoic volcanic, tectonic and sedimentation processes is the part of the eastern Africa and Ethiopia.

The Mesozoic sequence in most part of Ethiopia consists of three major sedimentary units. The basal sandstone (Adigrat formation) is a deltaic near shore sandstone of late Permian-early Jurassic age and was deposited during the transgration. The basal sandstone unit is overlain by mid-late Jurassic limestone, shale and gypsum formations. Early cretaceous sandstone that marked the regression of the sea caps of the Mesozoic sequence (kazmin, 1972).

The general consensus is that down faulting of the Afar depression started at a much earlier age and that rifting was accompanied by a voluminous flood basalt volcanism. Following the unification of subsidence of the Afar depression and the main Ethiopian rift (MER), subsequent volcanism was refinished at first to the evolving rifts and focus of quaternary and recent volcanic activity

Lake Tana sub-basin is entirely covered by a volcanic formation of the shield group, which corresponds to the second phase of the main volcanic eruption. According to the geological map of Debre Tabor, sheet 1:250,000, it belongs to the Tarmaber series (Tarmaber basalts of the second event flow types), specifically to the second event of the Tarmaber basalt eruption at Miocene age. An interpretation of the maps indicates a north-south flow direction.

The lower basaltic formation is known as the first sequence of the Tarmaber activity in the area. Quaternary volcanics constitute the other formation in the basin, filling the paleovalley overlapping the Tarmaber series. Alluvial material is also present along riverbeds and is also expected below the Quaternary volcanic deposits as a paleosoil. Recent alluvial deposits are visible in terraces above the actual riverbed with variable thickness. The alluvium is composed of sandy gravel and clay to silty clay material.

The lower area around Lake Tana has been flattened by flood deposits giving rise to marshes and swamps and layered lacustrine deposits.

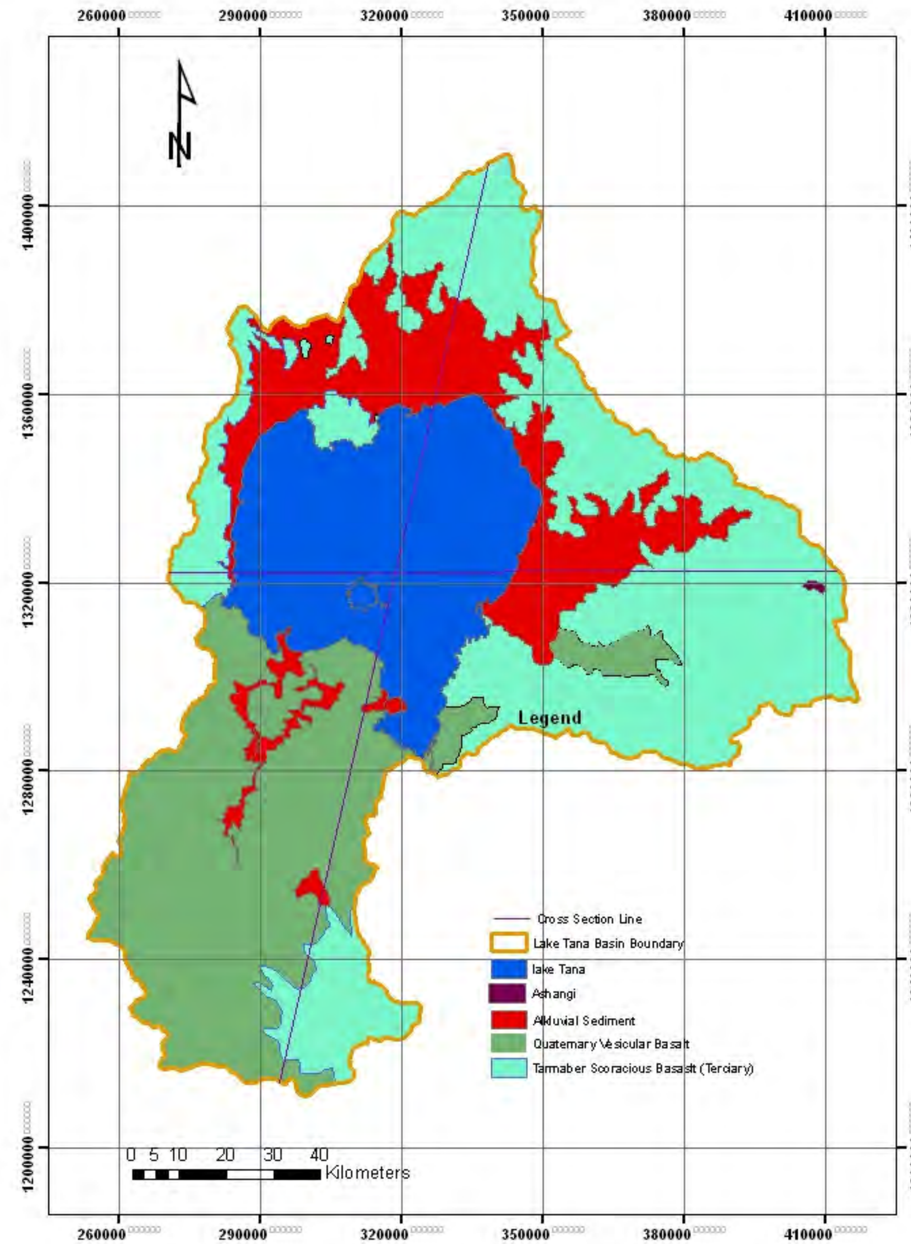



Figure 3.1 Geological Map of the study area

## 3.2 Local Geology

### 3.2.1 The Oligocene flood volcanic (Trap series)

Despite the predominance of basalts, the flood volcanic (trap series) contains significant volumes of felsic volcanic rocks usually in the upper parts of the sequence (Ayalew"D and Yirgu.G, 2003) the felisc volcanic rocks are mainly friable tuffs, rhyolite and ignimbrite interlayered wirh the flood basalt particularly in the upper parts of the sequence (Ayalew et al, 1999, Mohr 4 zaneffin, 1998, pik, et al 1998).

### 3.2.2 The Miocene, Pliocene volcanoes (Tarmaber formation)

The flood volcanism was succeeded by emplacement of large shield volcanism and continental riffing (Mohr,1983, Hoffmann et al.,1997) .A number large shield volcanoes developed on the surface of the vocanic plateau overlapping the thick sequence of the flood basalt.

Mt. choke and mt Guna are the main shield volcanoes on the northwestern Ethiopia plateau. Mt. choke has a basal diameter of 1000 km. and rises to 4052m, some 1200m above the flood volcanic and has the age of 22ma years. Guna has an age of 10.7 ma (kieffer et al., 2004) and has 4135m height, about 1500 above the flood basalts the average estimated basal diameter is about 40km.

Like the flood volcanic the shield volcanoes are bimodal and contain sequence of alternating basalts, rhyolite and trachyte lava flows, tuffs, and, ignimbrite, particularly near their summits.

### 3.2.3 Volcanic plugs and domes

These structures are relicts of central conduits of volcanic exposed by erosion of less resistant volcanic formations. They have felsic compositions and have been linked to the felsic volcanic rocks of Ethiopian plateau.There compositions are distinct from these to felsic rocks within trap sequences that are rhyolite the plugs are not the feeders to the trap volcanism but instead may be reefed to overlying shield volcanoes (deaf et al., 2001). The plugs resemble the trachitic sins and flows that are intercalated with pyroclastic, Rhyolites, tuff and ignimbrites in the upper units of shield volcanoes (Tarmaber formation)

### 3.2.4 Quaternary volcanic

Quaternary alkali basalts (Tana layer) occur related to local rift structures north-south trending extension al faults, (chorowict et al., (1998). Volcanic cones and flows of scoraceous basalts are well preserved in the Lake Tana graben these basalts are considered pliestocene in age. The volcanic rocks of the lake Tana area are usually described as alkaline basalts (Merle et al.,1979), which may have a thickness up to 1300m (Mohr,1971 ).in the recently compiled Geological map of Ethiopia,
(Tefera et al., 1996).described the rocks as plateau basalts, consisting of quaternary alkaline basalts and trachytes. .

The regions south of Lake Tana exposes quaternary rocks composed of vesicular alkali basalt and cinder cones, indicating the volatile rich nature of the host magma. The host lavas are basaltic in composition and, dated 0.03ma (Hofmann, 1997), massive, vesicular and fragmented rocks.

### 3.2.5 Quaternary Alluvial

Quaternary sediments comprises alluvial and lake deposits. The alluvial sediments occur at the lower reaches of the main Lake Tana tributaries, mainly in the north and east of Lake Tana in the Megech, Ribb and Gumera flood plains. They range in litho logy is from clay to gravel of unknown thickness and extends at woreta, up to 50m of inter bedded gravel, sand and clay was recorded in the town water supply. Lacustine deposits comprising dominantly fine silt and clay cover the bed of Lake Tana.

These deposits have been identified from high resolution seismic studies, supported by extensive analysis of cores drilled up to 9.5m deep (lamb et.al 2007). The geophysics shows that the thickness varies across the lake, from a minimum of 9m across the entire lake bed to at least 40m at the northern end of the lake.

### 3.3 Stratigraphic outlines of the area:-

In the Western Ethiopian Plateau the flood volcanic succession includes basaltic lava flows, basaltic tuffs, as well as a considerable volume of Rhyolites, trachyitic and phonolite products (Mohr and zenetfin, 1988). Intermediate lavas are lacking and the volcanism is of distinctly bimodal basalts. Rhyolites type (chazot and bertand, 1993) a feature common to most continental flood basalt provinces (eg.karoo and porana).

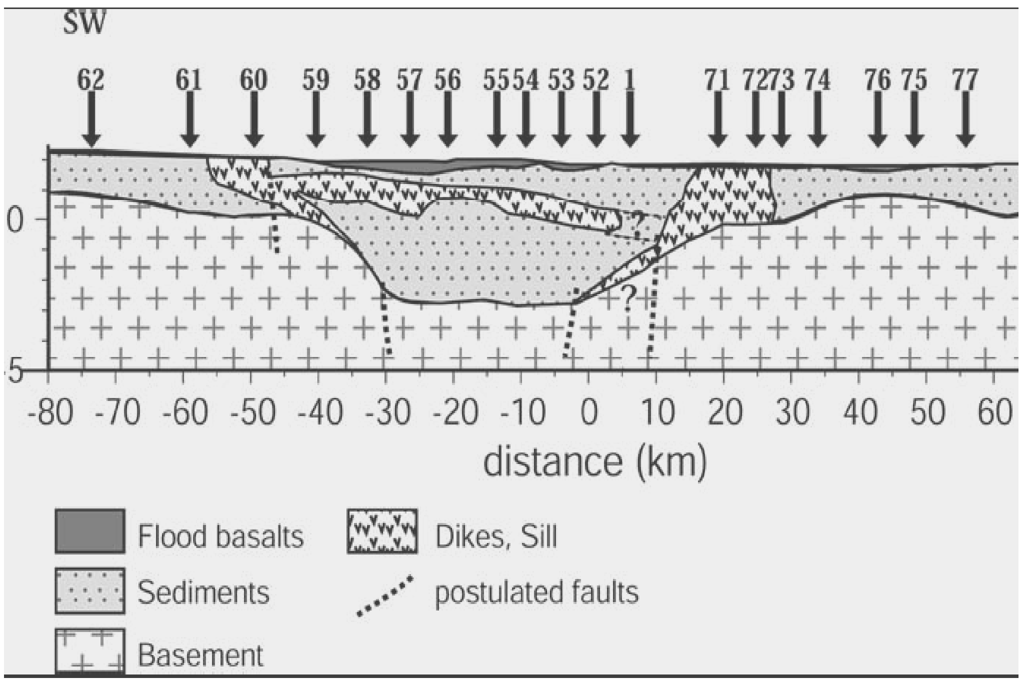



Figure 3.2 Stratigraphic Map of the basin

The Numbered Circles Show the Location of the Magnetotelluric Soundings. (Produced by the Study "The Structure of the Mesozoic Basin beneath Lake Tana Area, Ethiopia, Revealed By Magnetotelluric Imaging, 2005")

### 3.3.1. Flood basalts

The flood basalts from the base of the basin is widely exposed around the mountain for a flat- lying topography continuing up to elevation of around 2650mt, are Trachytic and phonoite products (Mohr and zonetime, 1988). Highlands are as surrounding the lake, with alluvial deposits around the lake margin.

### 3.3.2 Rhyolitic lava flows

Rhyolitic lava flows are the lower most and earliest products of the basin. They are unconformable overly the flood basalts. The contact between the flood basalts and Rhyolites lava flows is marked by red clay (paleosol) and weathered basalts. The Rhyolites are the second most abundant flows of the volcano mapped between elevations 2650 and 3000m. It is extensively exposed in the south central part of the basin while minor pyroclastic flow beds seen to associate the Rhyolites lava flows There are three types of Rhyolites lavas:- Layered Rhyolite flow, glassy and columnar jointed lavas and domes deposits.

### 3.3.3 Pyroclastic flow deposits

These are products of explosive volcanic activity from Guna felsic center. They consist of crystals and rock fragments of varying size and composition. In the southern part of the area, the pyroclastic flows are seen to overly the Rhyolites unit while in the northern part they restrict directly on the flood basalts. This unit with its different varieties is extensively exposed covering large area of the mountain. It cover in between the two lava secession separating the under lying Rhyolites and the overlying phonoite units this thick sequence includes , massive white ash bedded and laminated ash flow, welded tuff / ignimbrite and tracyite lava flows.

The basement rocks are overlain by extensive deposits of Mesozoic sediments, which are exposed in the Blue Nile gorges to the southeast. These sediments do not outcrop in the Tana basin, although they are depicted on the 1973 geological Map of Ethiopian and Somalia (merle et al 1973).

Recent geophysical studies south and east of lake Tana (Haul tot et al,2006) have indicated up to 1.5km.thickness interpreted to be Mesozoic sediments preserved in a northwest trending half grabben structure beneath the tertiary volcanic cover. The Mesozoic sediments have not been confirmed beneath the basin by intersections in bore holes but their presence is beneath the basalt layer, is inffred from the geophysical studies and the geological structure.

### 3.4 Geologic structures.

The Lake Tana basin is considered to be at the junction of three graben described from remote sensing and field studies by chorowicz et al (1998). The basin is perched with in an overall configuration of an uplifted dome which was active during the early to mid Tertiary volcanic events. Reactication of faults occurred in the late Miocene to quaternary, superimposing down faulted the North-south trending Gondar graben, which is exposed by erosion in the north of the basin. The north-south Dingle Ber buried beneath the quaternary volcanic in the GilgelAbbay and in the eastern part of the basin, the essentially East-west Debretabor Graben.

Detailed remote sensing investigations have shown the down faulting from the Gondar Graben has resulted in fault blocks 1-4km. wide dipping towards the Lake. Although, individual fault blocks, dip steeply, the staggered arrangements provide an overall relatively flat structure in to the basin for the base of the basalt (chorowicz et al, 2005).

The common structures in the area are mainly joints, fractures and faults. As it is inferred from the general geological map of Lake Tana (extracted from Kazmin, 1972), the N-S trending fault system dominates the northern part of the Lake; the southern, eastern, southwestern and northwestern parts of the lake are dominated by NE-SW trending fault system. NW-SE trending faults are also frequent in the northwestern parts of the Lake area.

Fracturing has mainly developed along two structural directions in the sub-basin. The older one is along N-S direction and is visible in the Ashangi basalt and younger one is along WNW-ESE direction and is visible in the Tarmaber basalt. The Tana graben is known to have no structural link that connects it to the main Ethiopian rift system (Kazmin, 1972).

The approximate elevation of base of the tertian basalts differs across the region. Around the eastern boundary of the Gilgel Abbay basin the base of the basalt is inferred from the magneto –telluric investigation by Hautot et.al, (2006) to be a depth of around 250m. The ground base level of the basin is around 2000m so the interprated base of the basalt is around 1750m.

The base of the Tertiary series is much lower west of the Tana basin in the Beles and Dender area at around 1100m, dipping to as low as around 600m.in the northern west.To the north east of the Tana basin in the headwaters of the Tekeze river, the base of basalt is around 1500-1700m, taking in to account the inaccuracy inherent in the broad scale of the geological map.

It appears that within the basin, the geological structure suggests inward tilting fault blocks and an essentially flat base to the basaltic sequence, while the base of the basalt dips away from the Tana basin in the areas surrounding the basin.

Mesozoic sediments up to 1.5-2km. thick are interpreted to occur beneath the volcanic in a NW-SE trending Sedimentary basin Hautot et al (2006). The structure is considered to be a half graben as the thickness increases by as much as 1km. over a 30-40km. wide section. The geophysics also describes the presence of thick dykes and sills penetrating the Mesozoic sequence.

Around the Guan volcanic massif, it is highly affected by faults expressed by intense v-shepped gullies and rugged surface. The faults are volcano tectonics and which are short and dense at the center and long but relatively sparse at the Margins. As shown on the structural map figure 3.3, the faults have different trend. However, the principal ones are NW-SE, NE-SW, and E-W trending. Generally, they have radial orientations, sometimes crossing each other. The NW-SE and E-W normal faults are commonly well developed at the Guan shield volcano.

The Lake Tana graben (LTG) is a circular depression characterized by faulted blocks dipping towards the Lake Tana from all direction (fig 3.4). The faulted blocks in the western part of the lake have an average width of 1_4km. and strike NNE-SSW. Gently inward-directed dips of the tertiary basalt toward the center of Tana basin are present to the west, north and east of the lake, in the eastern (Debretabor sub graben) and the north western chilga sub-graben sub catchments of the Lake Tana Graben.

Lake Tana was formed primarily by recent volcanic activity which made a natural dam as it poured lava across the valley outlet. However, disturbance of the crustal are evident in the faults and eastward dipping of the volcanic rocks west side of the Lake. Schematic West-east& north-south oriented geological section presented in this study show that the sedimentary beds are nearly horizontal at the north and its dip angle increases to the south. From these sections it is concluded that the sedimentary beds are nearly horizontal but a general, slightly south-easterly dip causes progressively beneath the plateau lava in south-easterly direction (USBR, 1964). The major geological formations that outcrops in Lake Tana sub-basin and its adjacent areas are Tertiary and Quaternary volcanic rocks and alluvial along the major tributaries of the Lake sub-basin (figure 2.1)

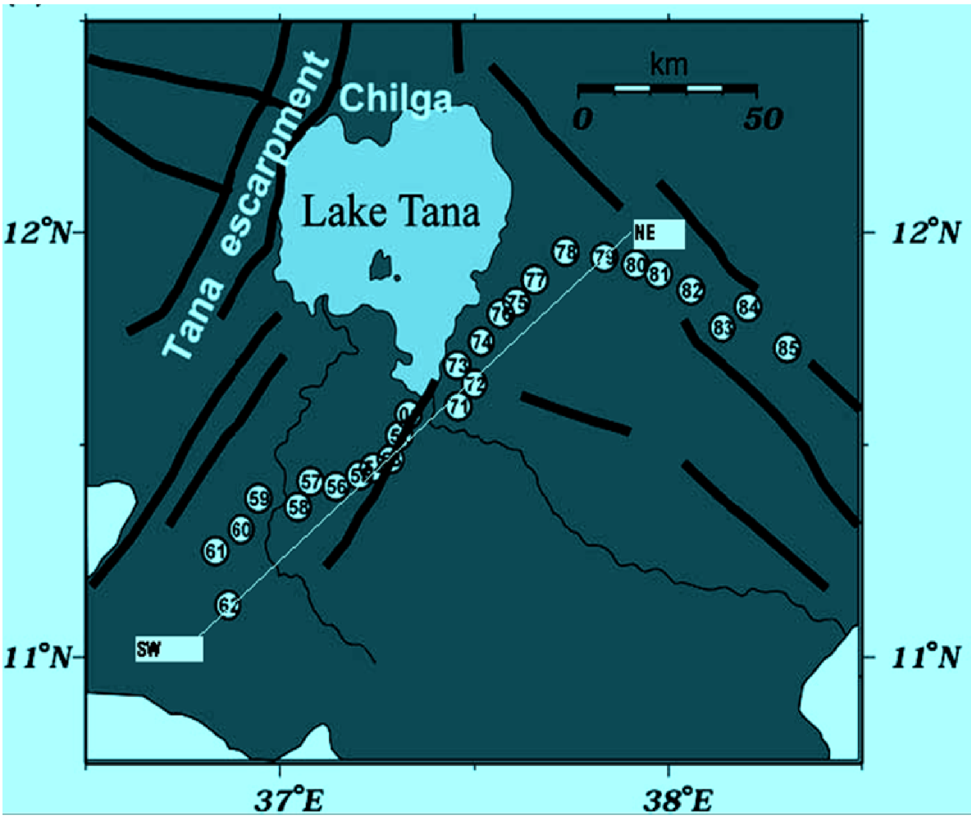



Figure 3.3 Structural Map of the Study Area

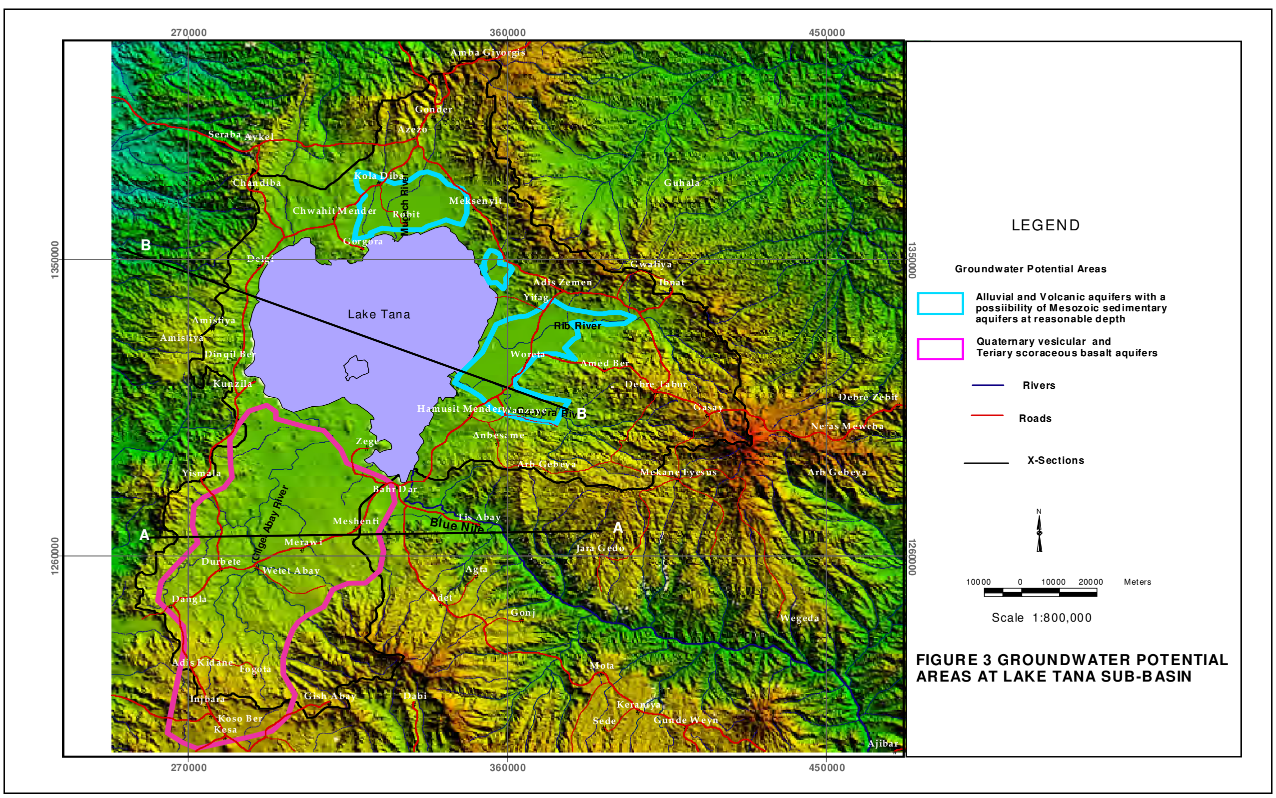



Figure 3.4ADEM showing the areas where the cracks are formed (SMEC, 2008)

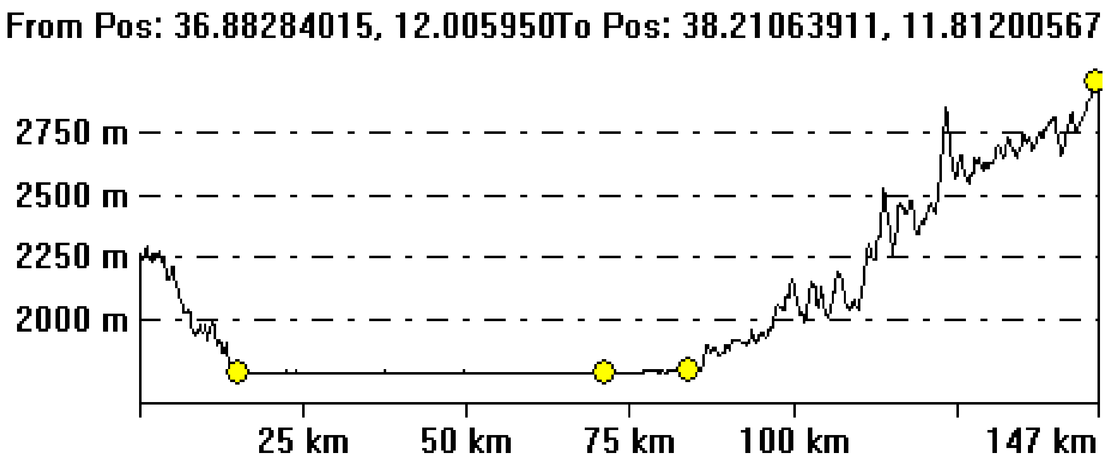



Fig.3.4 (a) Schematic E-W Geological Cross-Section of Lake Tana

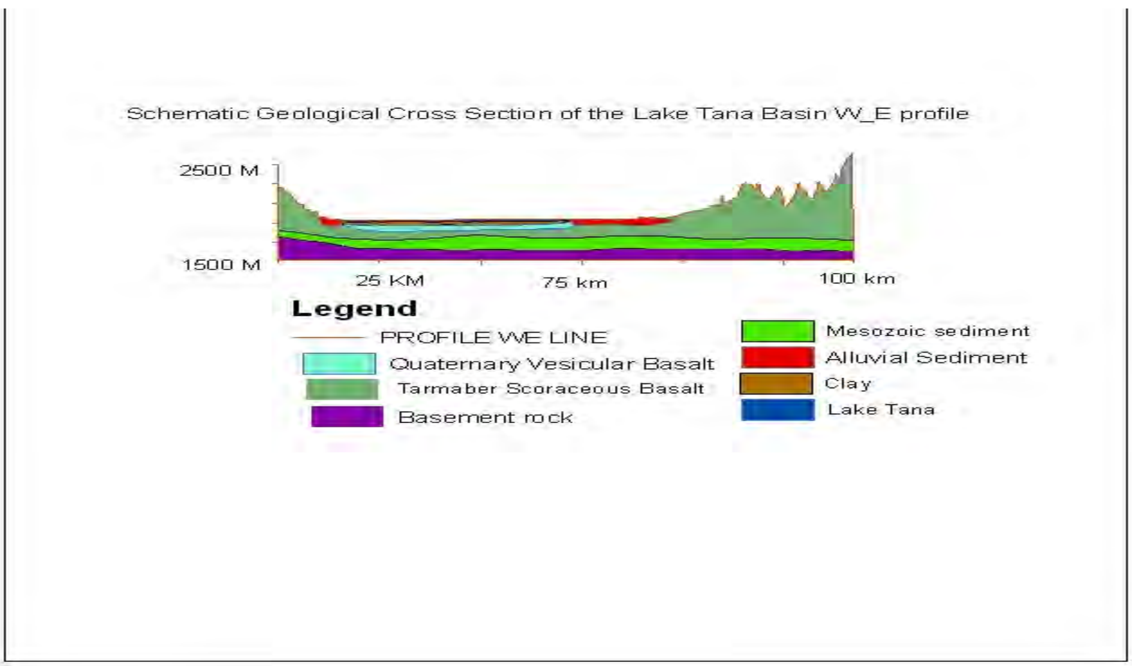
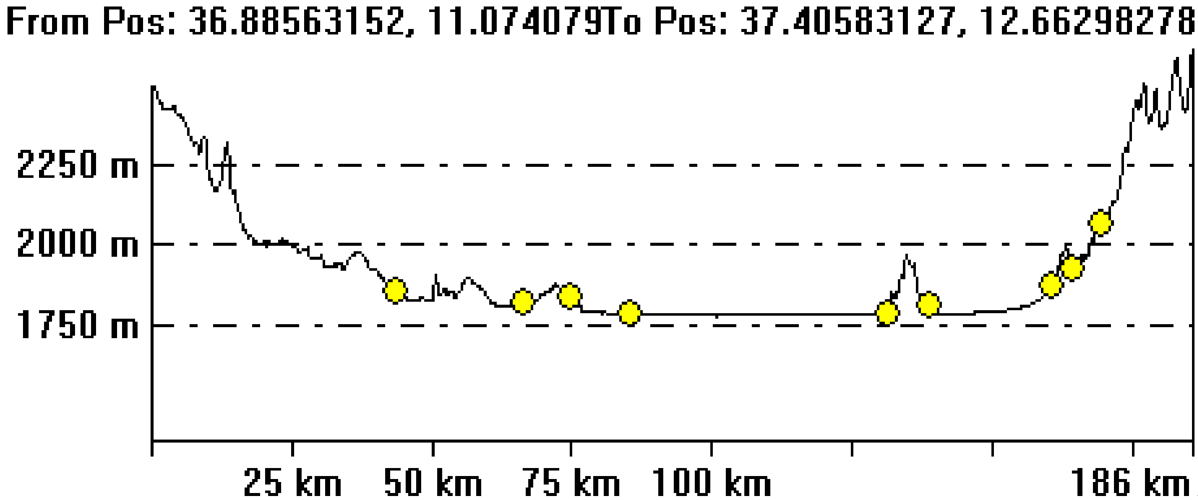



Fig 3.4 (b) Schematic Geological X-Section W-E of the Lake Tana

Figure 3.5(a) chematic geological




x-section South-North direction (line AA)

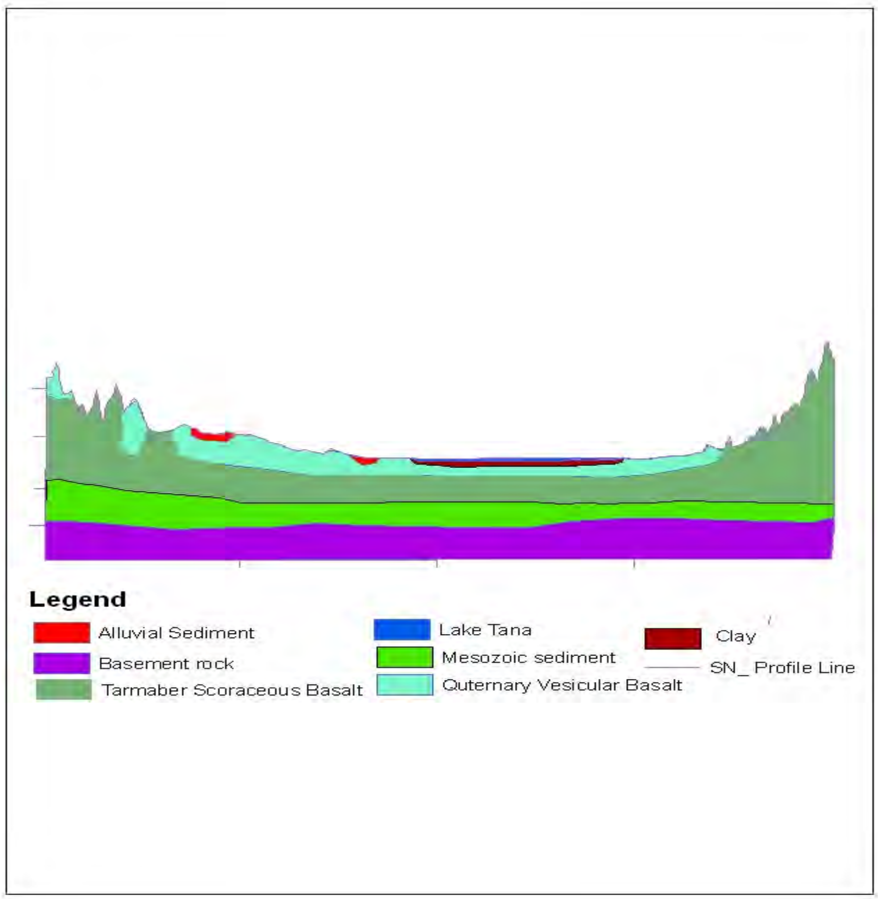



Figure 3.5 (b) schematic geological x-section South-North direction (line AA)

# CHAPTER FOUR

# SURFACE WATER HYDROLOGY

## 4.1 General

The surface water resources of the study area occurs in the form of rainfall, runoff, perennial and intermittent streams, rivers and from the Lake. The amount of annual rainfall on Lake Tana is estimated at 1248 mm/ year, which is about 7% lower than the rain fall on the surrounding catchments. The rainfall occurs nearly throughout the year with a greater portion it being received during the period April to September.

The various springs, streams and rivers that emanate from Debrtabor ridge in the north east and south east plateau (Mt. Choke) are contributing much of the surface water resources of large area of the study area. In one hand, in the northern part of the study area, converging at the downstream end streams and rivers feed the swamp in the south of Lake Tana and drained by Blue Nile River. On the other hand, in the southern part of the study area, so many tributaries those originated from eastern high land plateau end up at Nile River. In short, the perennial and intermittent streams and rivers and the lake itself are the major constituents of surface water. Quantitatively there is an adequate amount of surface and subsurface water resources in the area. Among them the major surface water bodies are discussed here below as follows.

## 4.2 Lake Tana

The Lake Tana basin is an elevated region in northern Ethiopia in the headwaters of the Blue Nile (Abbay) Basin. To the east of the basin boundary, the topography is dominated by the presence of two large shield volcanoes Mt choke and Mt Guna, while to the west it drops sharply to the adjacent Beles and Dinder basins across the west Tana escarpment. The lake covers an area of some 3100 km$^2$, which drains from the south end in to the Blue Nile River. The average annual rainfall estimated for the Tana Basin is 1326 mm/ year from inverse distant weighting (IDW) method for the period 1960-2006.

It receives in flow from streams and springs those originate from the above two large shield volcanoes and runoff from its water shade. The water quality of the lake is characterized by relatively low salinity depending on the seasons with average Ec value of162.2 µs/cm. The major ionic composition is $HCO^{-}_{3}$ mg/l.

The Lake receives untreated and improperly treated industrial wastes from the major industries of Bahir Dar and Gonder and small Towns around it that are discharged in to the wetlands. The wetlands trap much of sediment yield of the streams descending from the highland ridges.

Lacustrine deposits comprising dominantly fine silt and clay cover at the bed of Lake Tana. These deposits have been identified from high resolution seismic studies, supported by extensive analysis of cores drilled up to 9.5m deep (Lamb et at 2001).

The geophysics shows that their thickness varies across the Lake from a minimum of 9m across the entire Lake bed to at least 40m at the northern end of the Lake. Recent drilling information (Kebede, pers, comm, 2007) indicates that up to 80 m of stiff clay covers the floor of the Lake.

The regional groundwater elevation contours indicates a flow towards the Lake. Heads in the aquifers surrounding the Lake are in the order of 1790-1800 meter above sea level in the closet bore holes, approximately 700 to 1000 m from the Lake. This indicates that there is a possible upward head on the base of the lake. At an average Lake level of 1786m and even with an underlying head of say 1800m, the vertical leakage through the 80m thick clay layer, with an assumed vertical hydraulic conductivity of say 0.0001m/day would suggest a leakage rate of 7mm/year. It is not likely that the head in the aquifer beneath the lake will be of this magnitude, so vertical leakage to and from negligible.

It is therefore concludes that the interaction between the Lake and the surrounding aquifers is negligible in the context of the Lake Tana water balance. This interpretation is supported by isotope geo chemical studies of groundwater in the vicinity of the Lake, which show little evidence of mixing Lake Water with the adjacent aquifers (kebede et al 2005)

The Lake lies in a large structural basin surrounded by volcanic mountains mostly of basalt lava. It has recent tectonic origin formed by a graben system and is bordered by a set of faults. The slight subsidence and the presence of a barrier of young basalt lava flows at the lake outlet kept the water in a shallow natural basin. Structurally, the basin is characterized by NE-SW faults and dykes of younger lava on the east side of the lakes, faulted and steeply dipping volcanics along the S-W side of the lake. Some of the evidence that tectonic movements were associated with the formation of Lake Tana basin consists of NE-SW faults and dikes of younger lava on the east side of the lake, faulted, and rift fault structures northwest of Lake Tana in which several hundred feet of lakebeds were deposited. The lakebed is the only sedimentary rock formation in the vicinity of Lake Tana. It consists mostly of siliceous shale, sandstone and cherty marl (Darwin, 1960).

### 4.3 Gilgel Abbay

The Gilgel Abbay catchment includes the main Gigel Abbay and a number of tributaries such as the koga and kiliti. The Amen tributary is located in the upper catchments of the kiliti. The koga confluences with th***e*** Gilgel Abbay downstream of Marawi by far the highest runoff depth is generated in the Gilgel Abbay catchments upstream of Marawi. The Amen and the kiliti catchments have a much lower runoff depth. The runoff from koga catchments is in between those of the Gilgel Abbay and the Amen or kiliti.

It seems that the runoff of the Gilgel Abbay is far too high land the evaporations, as estimated from rainfall minus runoff for too low in relation to the average amount of runoff. However, sinse the Gilgel Abbay discsharge station is without doubt the most reliable in the entire Tana basin the observed runoff may be assumed to be correct. If the runoff is correct and the estimated evapotranspiration (rainfall minus runoff) appears far two low, there may be too possible causes: either the surface or subsurface catchments do not coincide. For a number of reasons, it is concluded that the sub-surface catchments is larger than the surface water catchments.

The runoff values of the Gilgel Abbay near Merawi, the koga and kiliti seem over-estimated by some 260, 240, and 80 mm/ year, respectively. The evapotranspiration of the Amen on the other hand or in this case better the rainfall minus runoff, seems to over –estimate the evapetranspiration. This points the direction of groundwater flowing from the Amen towards the other part of Gilgel Abbay catchments. However, the Amen is small catchments and its groundwater outflow could by far not account for the large underground in flow in to the neighboring catchments of the Gilgel Abbay catchments (SMEC Draft Report, 2008).

The area surrounding the catchments and located at higher elevation than the Gilgel Abbay gauging site is estimated to be about twice the size of the Gilgel Abbay catchments upstream of merawi.

**4.4 Gumara, Ribb and Megech**

Although the Gumara and Ribb catchments are adjacent catchments, their runoff characteristics differ much. The rainfall of the Gumara catchments is some 80 mm/year higher than the rainfall in the Ribb catchments. However, the observed runoff is about 400 mm larger.

The Ribb River is known to overflow at the gauging site upstream of the bridge during high River stages. This over flow is caused by the reduced carrying capacity of the River due to Sedimentation in combination with the obstruction of the bridge outside of the Gumara catchments and at higher elevation than the gauging site, these is about an equal area that could contribute to the underground.

It is thought that is substantial underground in flow in to the catchments of the Gilgel Abbay and the Gumara through the thick basalts from elevated areas around the volcanoes Guna and choke.

The runoff data for Megech appeared less accurate (many outliers, especially in the month of August) continue for Lake Tana.

| Catchments | Area(km$^2$) | Baseflow (Mm/s/ year ) | Discharge (mm) |
|---|---|---|---|
| Gilgel Abbay | 1664 | 507 | 305 |
| Kega | 244 | 50 | 207 |
| Ribb | 1592 | 56 | 35 |
| Gumara | 1394 | 125 | 90 |
| Megech | 462 | 26 | 56 |

Table 4.1 Estimated base flows for 5 major basins averages 1999-2004 (BOEOM 1998).

These results also indicate that there are greater discharges in the southern catchments (Gilgel Abbay and Koga) compared to the Gumara, Ribb and Megech.

Estimated amount of discharge for the catchments water balance are to be made using base flow recession for direct discharge. There is potential for water logging in low lying areas away from the drainage lines as the piezometric level approaches the ground surface. It is expected that this level will be controlled by evapotranspiration and this will accounted for the water balance.

### 4.5 Groundwater – Surface Water interactions

The degree of groundwater contribution to major tributary of Lake Tana Rivers is roughly assessed by plotting dry weather flows of gauged tributaries of Lake Tana. Figure 5.1 show that the southern and South Eastern tributaries of Lake Tana such as Koga, Gilegel Abbay, and Gummar have sustained baseflow as compared to northern and north eastern and western catchments. Furthermore, field visit and topographic map assessment have shown that nearly all of the Gilegel Abbay and Koga sub basins have undulating terrains having low density of river networks and also receive high rainfall (> 1300 mm /year)

# CHAPTERE FIVE

# HYDRO GEOLOGY

## 5.1 General

The Nature and distribution of aquifers and aquicludes in a geologic system are controlled by the lithology, stratigraphy and structures of the geologic deposits and formations. (Freeze and cherry, 1979).

Volcanic rocks due to difference in mineralogy, texture and surface, its water bearing potential varies. Groundwater circulation and storage in the volcanic rocks depend on the type of porosity and permeability formed during and after the rock formation. All rock structure possessing a primary porosity may not give rise to the primary permeability, but later connection, by means of weathering or fracturing may results a secondary permeability (Tamiru Alemayhu, 2006).

Acidic Volcanic Rocks may not contain groundwater although generally they possess interstices. The reason is that the interstices may be filled up with ash and other material and hence uncertainty pyrocastic rocks associated with lava flow are generally porous. However, their permeability varies depending on the interconnection of the pore space (Davis and De wiest, 1966.

Because volcanic rocks are crystalline at the surface, they can retain prosity associated with lava flow features and pyroclastic deposition. Hydraulic conductivity of volcanic rocks such as lava flows and cinder beds is typically quite high. However, ash beds, intrusive dykes, and sills may have a much lower hydraulic conductivity on a large scale, the permeability of basalt is very an isotropic.

The center of lava flows is generally impervious buried soils that produce high permeability develop in the top of cooled lava flows. Stream deposits occurring between the flows the zones of blocky rubble generally parallel to the flows.

The most important features governing the groundwater flow and storage in volcanic rocks are the following: (Tamiru Alemayehu, 2006)

- Vertical permeability due to primary and secondary features.
- Horizontal permeability due to horizons containing openings due to the lava flow and gas expansion during solidification.
- Occurrence of impervious horizons and dykes.

Intrusive ***i***genious and highly metamorphosed crystalline rocks generally have very little, if any, primary porosity. solid ***sa***mples of un fractured those rocks have porosity that are rarely larger than 2% (Fetter,1994).The intercrystalline voids that make up the porosity are minute and many are not interconnectivity, the primary permeability of these rocks are extremly small.

In order for groundwater to occur, there must be openings developed through fracturing, faulting, or weathering. Fractures can be developed by tectonic movements, pressure relief due to erosion of overburden rock, loading and unloading of glaciations, shrinking during cooling of the rock mass, and the compression and tensional forces caused by regional tectonic stresses.

Chemical weathering of crystalline rock can produce a weathering product called saprolite. This material has porosities of 40% to 50% and specific yield of 15% to 30%. It acts as reservior, sorting, in filtered water and releasing it to wells increases fractures in the underlying chrystalline rocks. (Wleby, 1984).

The probability of obtaining a high yield well***s*** in crystalline rock areas can be maximized if drilling takes place in an area where fractures are localized. It has been observed that zones of high conductivity in crystalline rock areas underlie linear sags in the surface topography (Le Grand 1962). Such sags are the surface features that overlie major zones of fracture concentration. These show as fracture traces and lineaments on the aerial and satellite photographs (Littm an parizek, 1964).

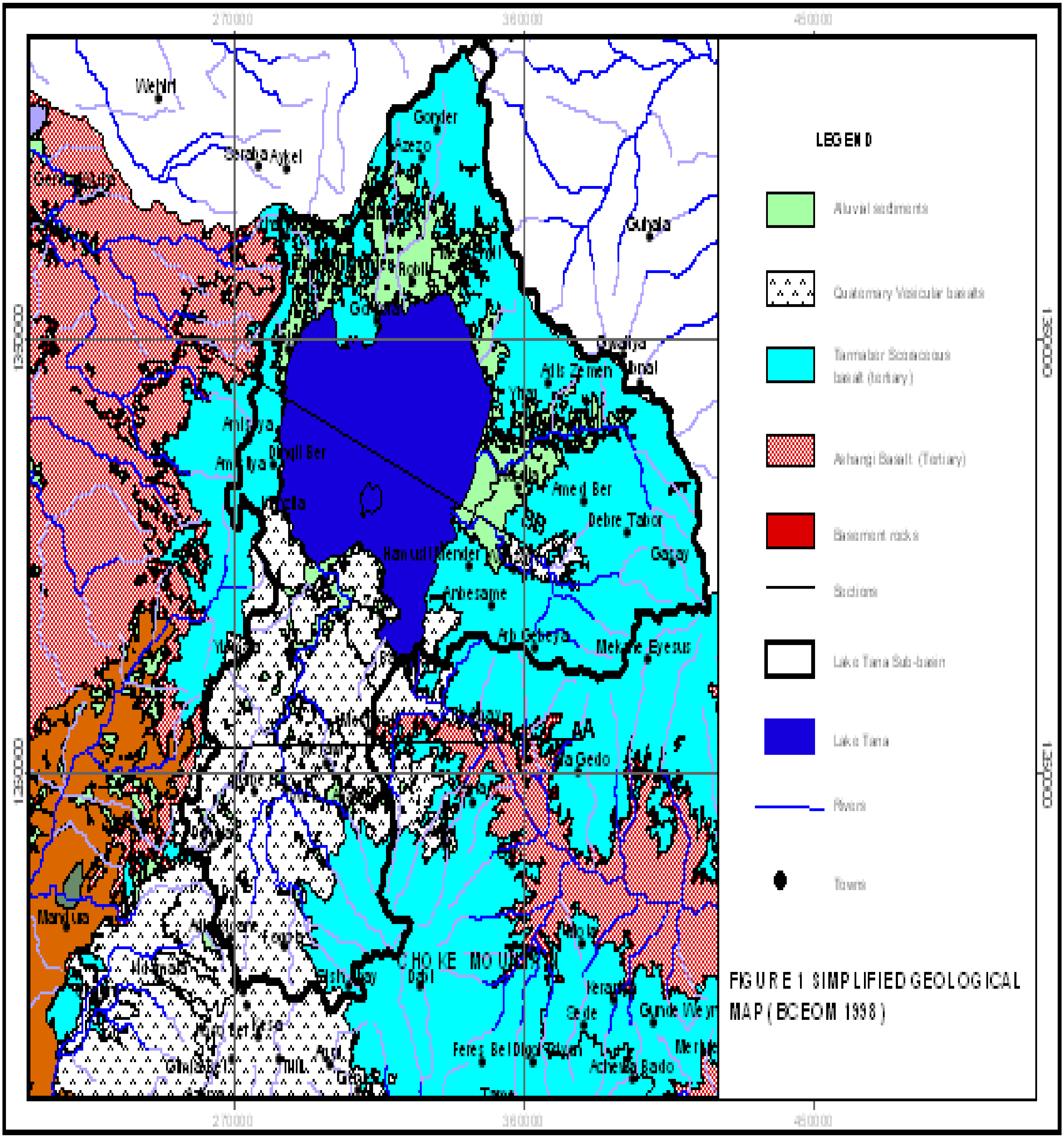



Figure 5.1 Hydrogeological map the study area

## 5.2 Hydro geological units and Aquifer system

There is no specific hydro geological study carried out in Lake Tana sub basin so far. The only recently conducted regional wise study, overviews the present area is Abay River Basin Integrated Development Master Plan Project, Phase 2, 1997, BCEOM et al. But other specific well sitting have been carried out for water supply of some towns in the study area.

In general the hydro geological units found in the study area are lacustrine sediments and volcanic rocks those have both primary and secondary porosities with high and medium permeability respectively. The secondary porosities have been facilitated through intensive physical and chemical weathering, fracturing and faulting. Comparing to the secondary structure, primary one has a significant role in the circulation and occurrence of groundwater in this sub area.This is confirmed through studying the litho logical logs of some boreholes in fig 5. 2.

Aquifer systems in Lake Tana basin are defined according to the geological units. The three major aquifer systems comprise the Tertiary volcanic (mostly Quaternary alluvial deposits.

### 5.2.1 Tertiary Volcanic

Tertiary scoraceous basalt (Tarmaber basalt) is widely distributed in the Lake Sub-basin and adjacent areas. At the southern part of the Lake basin it is overlain by the quaternary basalt and it has also wide distribution along the Choke mountain plateau. Its thickness increases from the south to the north direction with a probable maximum thickness in Gilgel Abbay River basin. Although, there are not deep bore holes drilled in this formation where it outcrops, the groundwater could be relatively deep as compared to the quaternary basalt. The only available bore holes data at Dangla shows that this formation has high discharge 25l/s with a drawdown of 12.5 m (CES and Tropics 2003).

According to the Hydro geological study of Abay River Basin Integrated Development Master Plan Project, Phase 2, 1997, BCEOM et al, the Tertiary basalts and recent lava flows which are widely distributed in the Tana sub basin are grouped as extensive aquifer with fracture permeability. There exist boreholes drilled in tertiary basalts for water supply of towns. The maximum average depth drilled in this formation is about 120 m. The water point inventory data (BCEOM,1997) shows that the average depth of boreholes drilled in this rock unit is in the order of 70-80 m. and the static water level ranges from 1-8 meter below ground level with a maximum discharge rate of 13 l/s (this is most likely the capacity of installed pump).

The characteristics of the Tertiary Basalt Aquifers are highly variable because of the range of lithologes of each unit .This variability is shown in stratigraphic logs from eight bores in the tertiary basalts at Gondar ( figure 5.2) The transmissibi***li***ty of the tertiary basalts aquifers (data only from wells described as tarmaber basalts) are relatively low. Apart from one well at Gonder with a transmissivity of 32.8 $m^2$/ day the remaining 9 have a range of < 1-11 $m^2$/day yields from the tertiary volcanic aquifers are in the order of 0.7-17 L/ sec with a mean of 3.63 L/sec. for the tramaber basalt and 4.24 ***l***/sec. for the ashangi. Transimissivity values from pumping test results are with the interval of 6 - 27 $m^2$/day (SMEC, 2008).

Many high discharging springs emerged from this rock unit act as base flow for Gilgel Abay River, which drains to Lake Tana. Areke and Lomi springs are high yielding springs, which currently serve as water supply for Bahir Dar town, have a discharge rate of 140 l/s and 50 l/s, respectively.

### 5.2.2 Quaternary Volcanic

Quaternary volcanic rocks are distributed at the southern part of the Lake basin, which has wide distribution to south beyond the Lake basin. The volcanic rock is vesicular basalt of plain topography with very low drainage network, indicating that this formation is highly pervious. Gilgel Abbay River, where almost all its watershed is found in this formation has a very big base flow. In general the static water is very shallow in this formation, which is manifested by a large number of springs that emerges from this formation. The static water level becomes shallower towards the Lake and the springs discharge increases and even forms big swampy area near the Lake shore.

The recharge estimation based on base flow separation showed that about 20% of the rainfall infiltrates to this formation (BCEOM, 1997). Big springs (Arek and Lomi), currently water supply source of Bahir Dar town discharge more than 200 l/s emerge from this formation. If the thickness of the formation is more than hundred of meters, then there could be a large stored groundwater in the vesicular basalt due its high porosity. Intensive abstraction may result more infiltration to fill the groundwater reservoir during rainy seasons. The preliminary geological section along AA shows that the quaternary vesicular basalt fills the graben of Gilgel Abay river basin (figure 3.4(a, b) and 3.5 (a, b)

### 5.2.3 Mesozoic sediments

There are no drilling data available to verify the presence of the fractured rock*s* of the Mesozoic sediments subsurface in the study area and it is not a major aquifer at the present time. However the information from Hautot et al (2005), suggests that perhaps there is a significant thickness of Mesozoic sediments beneath the basaltic sequence. These sediments have been utilized to the south east and are highly productive (Tesfaye Tadesse, pers, comm, 2007).

### 5.2.4 Alluvial sediments

Alluvial sediments have limited distribution within Lake Tana sub-basin dominantly at the eastern and northern side of the Lake. The thickness reaches more than 50 meters. The grain size of the sediment becomes coarser away the Lake. The static water level is very shallow in most areas less than one meter. Bore hole drilled (depth 53m) for Woreta town showed significant discharge with relatively low drawdown (Q = 7 l/s, drawdown =4 m) (Konoike Construction Ltd, 2001).

Alluvial sediments are commonly distributed along the Fogera Plain, Gilgel Abay River and other rivers

### 5.2.5 Lacustrine deposit

The Lacustrine deposit extensively lies in the northern part of Lake Tana and occupies the localities known as Chilga graben. This sediments are composed of clay, silty claystone, silty sandstones volcanic ashes, and lignite beds (Mulugeta, 2002). Bore hole drilling result shows that the thickness of Lacustrine deposit reaches 90m and it is underlain by volcanic rocks. Wells drilled in this sediments found dry.

| Boreholes with Log Data | Log Data |
|---|---|
| BH D1- | Basalt and pyroclastics below 78 m |
| BH D2- | Basalt, silt and rhyolite layer from 26 to 36 m |
| DurebetBH2- | Grey to bluish grey lime, altered plagioclase, limonite (minor aquifer), decomposed basalt |
| BahirD. Seed | Vesicular or scoriaceous basalt |
| BahirD. Hyke | Vesicular basalt and scoriaceous basalt and basalt |
| BahirD. K3W2 | Vesicular basalt, slightly weathered basalt and sandy silt, gravel, silt and vesicular basalt |
| BahirD.K3W3 | Vesicular basalt, slightly to highly weathered basalt |
| GisheA. BH1 | Vesicular basalt |
| Adete W1 | Weathered basalt, vesicular basalt |
| Adete W#2 | Fractured basalt |
| Andessa BH2 | Vesicular and weathered basalt, gravel, sand and scoriaceous basalt, gravel |

Table 5.1.Log Data (BCEOM, 2000 and 1998)

### 5.3 Aquifer Formation type Depth and Lateral Extent

Form hydro geological classification of rocks, the distribution, type and discharge of springs, hand dug wells and bore holes, in the study area, it can be deduced that two types of aquifer systems: shallow and deep are present.

The shallow aquifer system is mainly localized and occupies the lake area. This can be observed from werota, Tseda and Durbete areas. The shallow aquifer system is believed to be characterized by the shallow wells, their depth ranges from 30 to 70m and have shallow groundwater circulation system. The existence of this aquifer system is related to climate and topographic conditions. In high rainfall areas with a more or less flat topography the shallow aquifer is found to be prominent.

Thus in the some cases, from pre knowledge of the aerea un productive wells are encountered from deep aquifer systems, the existence of this aquifer is raise, which is witnessed by boreholes drilled at Humus sit and Debre tabor (depth 118 and 122m respectively) localities in the same area on the central, southern and northern part of the study area as well as the eastern part.

The aquifer is mainly composed of Tarmaber, Ashangi, basalt, Quaternary basalt, Aiba Basalt and Alluvium deposits of fractured and weathering conditions. From the lit logic log of some shallow wells it is observed that the range of depths of aquifers is 9to 50 meters at angua mesk, fog era and Guzara Hand dug wells To Tseda (with depth 45m Yechereka (with depth 42m). respectively. There numerous low yields in the highland emanating from the content of this aquifer system with the underlying low permeability unit Groundwater generally exists in unconfined or semi-confined condition, the low permeable paleosols that are present between the successive eruption and flows acting as semi-confining layers.

As far as the deep aquifer system is concerned the depths of the aquifers ranges from 70 to 210 meters. This shows it is being deep confined aquifers with regional extension. The aquifers are mainly composed of tarmaber basalt Ashangi basalt, & Quaternary basalt deposits. There are more than 50 boreholes tapping from this aquifer system.

Some of the high discharge structurally controlled springs those emanate from the foot and neck of the Debere Tabor ridge and the shield volcanoes of mt Guna and mt choko of Andesa high TDS and merawi (UTM 03709054E and 12490ZN), and Addis kedan (UTM 03652474E and 1105539N) springs with eestimated yield 40, 30, 10, L/s,respectively. are belived to get their water sources from this aquifer.

The highest and lowest yileds of bore holes tapping from this aquifer are found at Angerb 7 (Gonder) with UTM location lat 126170N and long 374667E) with 17L/sec and Hamusit (UTM location 3736321 E and 1149276N) with 2.1 L/sec. They are located at the recharge and discharge areas of the study area, respectively.

In general it can be said that there is deep and shallow circulation of groundwater giving different aquifer system and various high and low yield springs Groundwater in the study area is of good yield in low relief areas along the major structures mainly at the Lake Tana Graben easterly & southern graben.

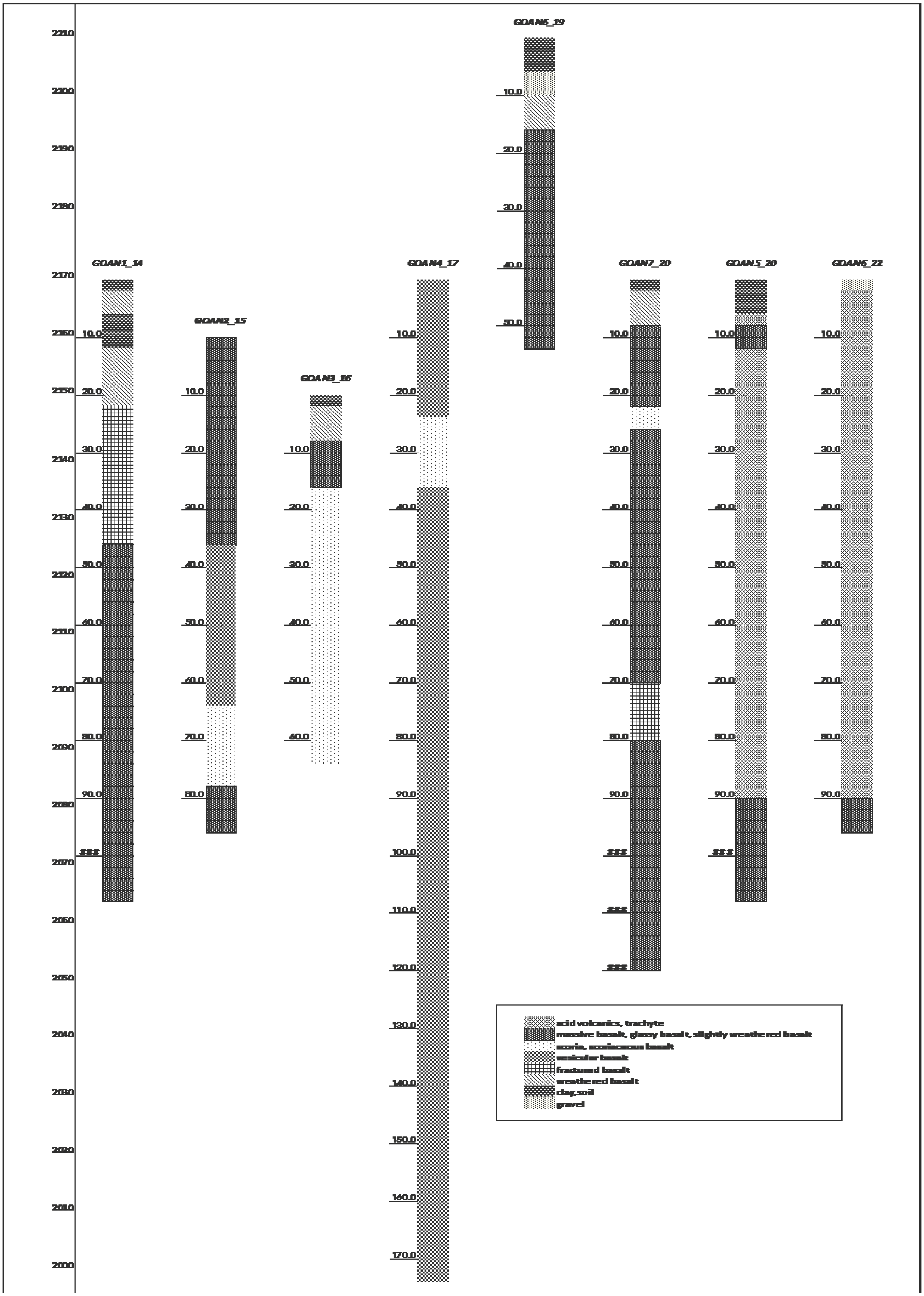



Figure 5.2 Lithologiccal logs of some selected boreholes

## 5.4 Groundwater source Inventory

### 5.4.1 Hand dug wells

There are numerous dug wells within the study area these are mainly used for public and live stock consumption. Among which around 5 dug wells have been collected from secondary data sources and inventoried for hydro chemical analysis purpose. Depth and static water level of the majority of dug wells could not be obtained due to lack of the information and problem faced to measure them since they are fitted by hand pump however from the existing data, the range of their depth is from 3 to 15 with available static water level of 1 to 10 M.

The dominant aquifer formation is known to be quaternary basalts and alluvial deposits in the Northern, Easter and southern of the Lake Tana basin.Most of the dug wells provide a perenial source of water and however, yield is substantially decrease during the dry season. The seasonal fluctuation of the static water levels in most of the wells is highly attributed to the direct recharge condition from precipitation in to the wells which intern indicates the unconfined nature of the aquifers. Dug wells are constructed in both recharge and discharge zones of the study area.

### 5. 4.2 Boreholes

Both shallow and deep boreholes are drilled in the study area by Government, Non Government and private Drilling companies. There are about 50 deep boreholes where the depth varies between70 to 210meters and 40 shallow bore holes with the range of 30 to 70 in depth. The deepest bore holes a depth of 208 m drilled at Negade Bahir with SWL 11.7m and a yield 1L/sic, Most of the deeper bore holes are fitted with submersible electrical pumps and the others bore holes are equipped with Indian Mark II

The main aquifer formation of the boreholes are weathered vesicular basalts, volcanic sediments, pycoclastic, weathered and fractured basalt, tracyite and alluvial deposits having a variable thickness, weathering and fracture intensity. The static water level of the wells ties within the range of artesian Angers 7 (Gonder) to 59.02 M depth for deep well.

### 5.4.3 Springs

Springs are the most conspicuous forms of natural returns of groundwater to the surface; they come in all sizes from trickles to large streams. The three principal variables that determine spring discharge are aquifer permeability, area contributing recharge to the aquifer and amount of recharge (Davis and Dewiest 1966)

Springs and seeps occur where down gradient parts of aquifers martial are exposed to the surface, as in out crops aquifers at mountain sides or canyon walls, or shallow water table reaching the surface at the base of long slopes. Springs also form where discontinuities like faults or dykes present hydraulic barriers and force groundwater to flow upward. In fractured rocks fissures can be filled with rainwater, which then flows through the same fracture system to form springs at lower points.

Springs can be generally grouped in to two as gravity and artesian springs. The gravity springs result from water flowing under hydrostatic pressure, where as artesian (non-gravity) springs are results of fractures extending to great depths in the crust and are called thermal springs (Todd.1980)

#### 5.4.3.1Cold Spring

There are abundance of cold springs in the study area, The type of these springs are generally contact and depression. Contact springs occur between the more permeable overburden and the low permeable rocks. These types of springs are common in the southern part and eastern part of the lake on the plateau. They have variable discharge depending on the seasonal variation of precipitation. They have low Ec value indicating the shallow groundwater circulation. The Burka spring with, known Ec value of 217µ s/cm and the Addis kedam cold spring has Ec value of 360 µc/cm have an estimated yield of 5-20 l/sec on the other hand, structure controlled springs are found along eastern sub graben of lake Tana Graben with high yield greater than 20l/s Jiga and Gish Abbay cold springs. Cold springs from Lake Tana graben (South) emanate NW-SE transfer faults.

Depression springs formed when the ground surface intersects the groundwater table. It occurs when the underlying bed rock unit exposed on the open channels, they are common in the southern part of the study area along valley outs. They have variable discharge mostly less than 1.5l/sec and characterized by drainage brain.

The majority of cold springs emerged from the basaltic plateau, because of dissection and fragmentation by river erosion. The high discharge springs emerge at the foot of choke shield volcano.

#### 5.4.3.2 Hot Springs

The distribution of thermal springs in Ethiopia was first presented by kurdo (1967) where thermal springs are largely clustered in the Rift due to its peculiar characteristic of thermal anomaly. The concentration of major ions and trace elements is high in thermal springs than in the cold springs. Thermal springs that are associated with volcanic activity are loaded with $Na.HCO^{-}_{3}$, ol (Tamiru Alemayhu, 2006)

Non-volcanic thermal springs get temperature from deep circulation of water, where the temperature of the rocks is high because of the normal temperature gradient of the earth, where as the Volcanic thermal springs attain their temprature from underlying hot acidic magma chamber that is located at shallow depth. Thermal springs of both volcanic and non-volcanic type are part of deep-seated water. The association of volcanic springs with acidic magma chamber could impiety their origin. It is either the water expelled from the magma or the surface water that come in contract with highly heated rocks. . In a volcanically non-active area, extension fractures and normal faults are important thermal conducts to the surface.

Volcanic thermal springs are strictly associated with acidic volcanic centers that could have shallow magma chamber. Faults play important role by acting as conduits to transport thermal water to the surface .Even in this case, the addition of recharge water comes from precipitation, and Non volcanic springs that are structurally controlled in central Ethiopia are generated from water having variable depth of circulation. .

The high discharge thermal springs of wanzaye and Andesa hot springs are located along fault zone and in the lake Tana Graben (LTG) which are non volcanic and with temperatures ranging from 20 to 70 $^{o}C$

As hot groundwater comes to the surface and colls, it may precipitate some of its dissolved ions as minerals. Travertine is a deposit of silica that often forms around hot springs, while dissolved silica precipitates a sinter which deposited by a gyster . The composition of subsurface rocks generally determines which type of deposit forms, although sinter can indicate higher subsurface temperature than travertine because silica is harder to dissolve than calcite (Plummer et al, 2004).

As long as the concentration of the hot springs of the study area is concerned, relativejy they have high values and the water types is $Ca\text{-}HCO_3$. The hot springs which have the water type similar to that of other water bodies (boreholes, hand dugs and rivers) and finding by Tenalem Ayenew, (1998) and Tamiru Alemayhu (2006) Seifu Kebede (2005) mentioned above lead to the conclusion of internal highlands, in turn this indicates the presence of groundwater circulation from Mt. Guna and Mt. choke to lake Tana basin.

### 5.5 Wetlands

There are a number of wetlands and groundwater dependent ecosystem in the Lake Tana catchemnt. Most of these wetlands remain green even in the dry seasons. Most of the wetlands are depressions formed by volcanic topography or by tectonic depressions.

The plains surrounding the lake (i.e. the Dembiya, Fogera and Kunzila plains in the north, east and southwest, respectively) form extensive wetlands during the rainy season.

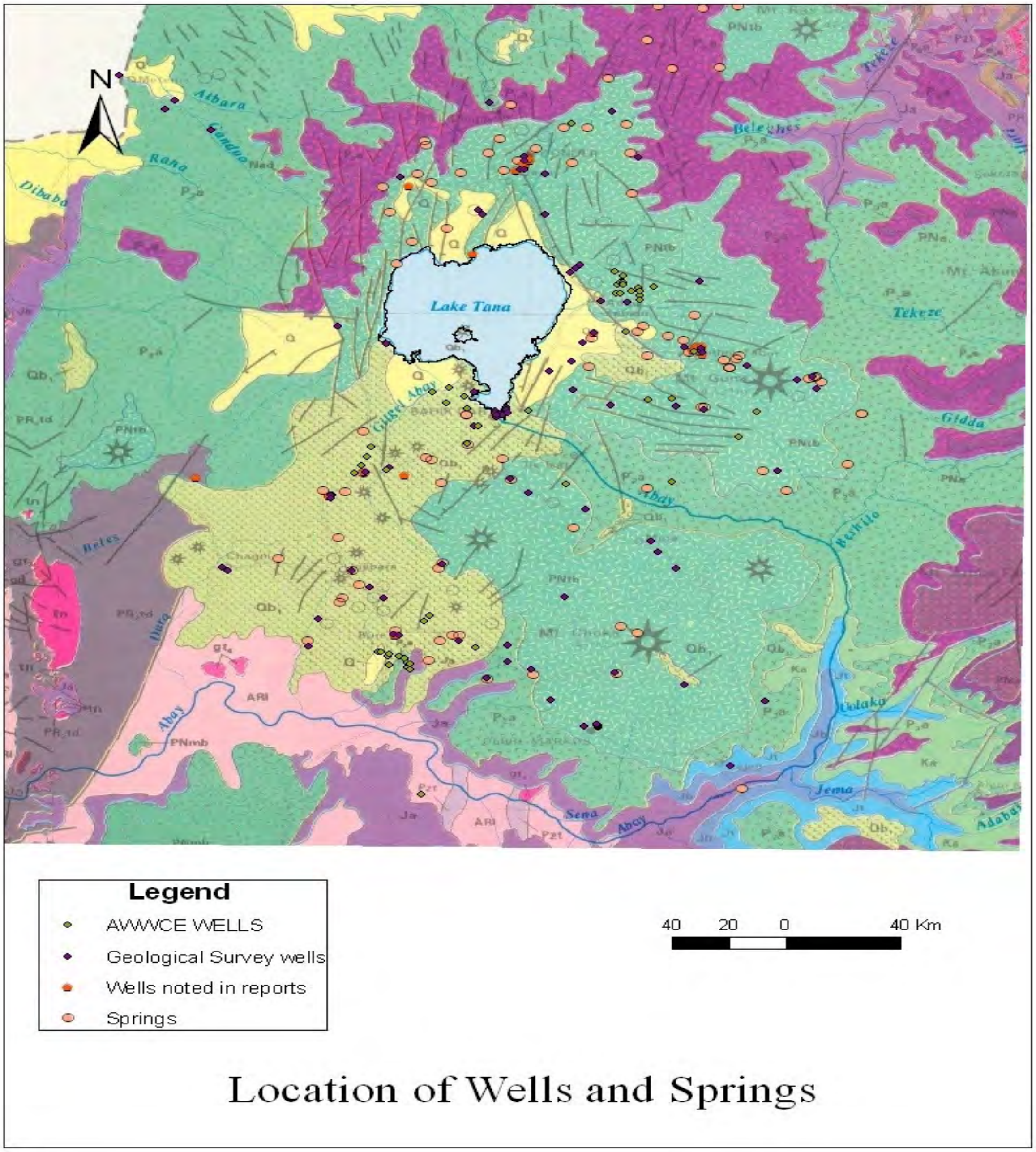



Figure 5.3 Locations of Wells and springs

# CHAPTER SIX

# GROUNDWATER FLOW SYSTEM

## 6.1 General

Chebotarev (1955) recognized that groundwater tends to chemically evolve in long flow chemically changes within flow systems toward a more concentrated solution similar to the composition of seawater. The systematic changes in anion composition in aquifers of this type have become known as the chebotarev sequence. In the direction of flow from the recharge area, the sequence can be illustrated as follows:

$HCO_3^- \rightarrow HCO^-3 \; +SO_4^{-2} \rightarrow SO_4^{-2} + HCO^-_3 \rightarrow SO_4^{-2} + C1^- \rightarrow Cl^- + SO4^{-2} \rightarrow Cl^-$.

The relationship between water chemistry and flow system can be considered in two ways.

1. Chemical differences between types of flow system
2. Chemical changes within flow system (Kehew 2001).

The basic classification of groundwater flow system was set forth by Toth (1963), who recognized local, intermediate and regional flow systems.

The size of these flow systems is governed by the topography in the drainage basin relative to the depth of the flow system. High relief undulating or hummocky surface topography will increase the depth of local flow systems, and if the depth to a regional aquiltard is shallow, the drainage basin may contain only local flow systems. By contrast, in basins of great depth in which the surface relief is small compared to the depth of the base of the flow system, a reginal flow system will predominate.

Local flow systems recharge at topographic highs on the water table and discharge in adjacent topographic lows. Intermediate flow systems recharge at topographic highs and discharge in topographic lows further down gradient than the adjacent low. The regional flow system recharges near the drainage divide in the basin and discharges at the topographic low point of the basin.

The chemical composition of groundwater in flow systems is a function of aquifer mineralogy and the rate at which groundwater moves through the system. Local flow system display vigorous flow that flushes soluble mineral salts out of the aquifer in a relatively short period of time. As a result the groundwater may never progress past the bicarbonate hydro chemical fascies on the Chebotarev sequence.

Flow velocity is progressively more sluggish with depth in a drainage basin, and intermediate and regional systems are therefore move likely to evolve in to the surface or chloride fascies, depending on the availability of evaporate minerals in the drainage basin. Because of the sluggishness of groundwater circulation, particularly in regional flow systems, soluble salts are flushed out of the system very slowly and persist for thousands or millions of years.

Changes in water chemistry with in a flow system are highly variable. In small, local flow systems in permeable aquifers with uniform litho logy, very little change in the chemical composition of groundwater may take place. If carbonate minerals are present equilibration may occur under open system conditions in the vadose zone. Few changes occur after the water reaches the water table and moves through the groundwater flow system to the discharge area. In any flow system in which the aquifer mineralogy changes, corresponding water chemistry changes will be noticed (Kehew, 2001)

### 6.2 Ground Water Flow

Groundwater is an important source of water; it may provide the base flows for rivers, or act as an underground reservoir from which water can be pumped as a location in to which water can be drained. Consequently, it is the flow of groundwater which must be examined, usually, groundwater travels very slowly: one hundred meters per year is a typical average horizontal velocity and one meter per year is a typical vertical velocity. Where these velocities are multiplied by the cross sectional areas through which the flow occur, the quantities of water involved in groundwater flows are essential.

Consequently, the essential feature of an aquifer system is the balance between the inflows, out flows and quantity of water stored (Rush ton and Kruse, 2004)

Unlike a surface reservoir the upper surface of the groundwater (the water table or phreatic surface) is not horizontal, a slopping water table results from the resistance to flow caused by the hydraulic conductivity. Due to the slow movement of groundwater, care is necessary when positioning any man-made outflow, such as pumped boreholes, to ensure that they collect water efficiently from the aquifer system.

The direction of flow of groundwater is depicted from groundwater contour maps. Hence groundwater contour maps for the shallow and deep aquifer systems are constructed from water level elevatons of boreholes in the study area. However, the water level data used is collected at different times and this will be affected by the seasonal fluctuation of water level.Moreover, the collected data are not fully geo referenced and the construction of the groundwater contour was based on the on the following assumption, which are characterstics of the study area under consideration.

- There is hydracids connection because the different litho logic unit
- The fractures in the study area are extensional and they will acct as conduits of ground water.
- The groundwater is continuous across the fractures.

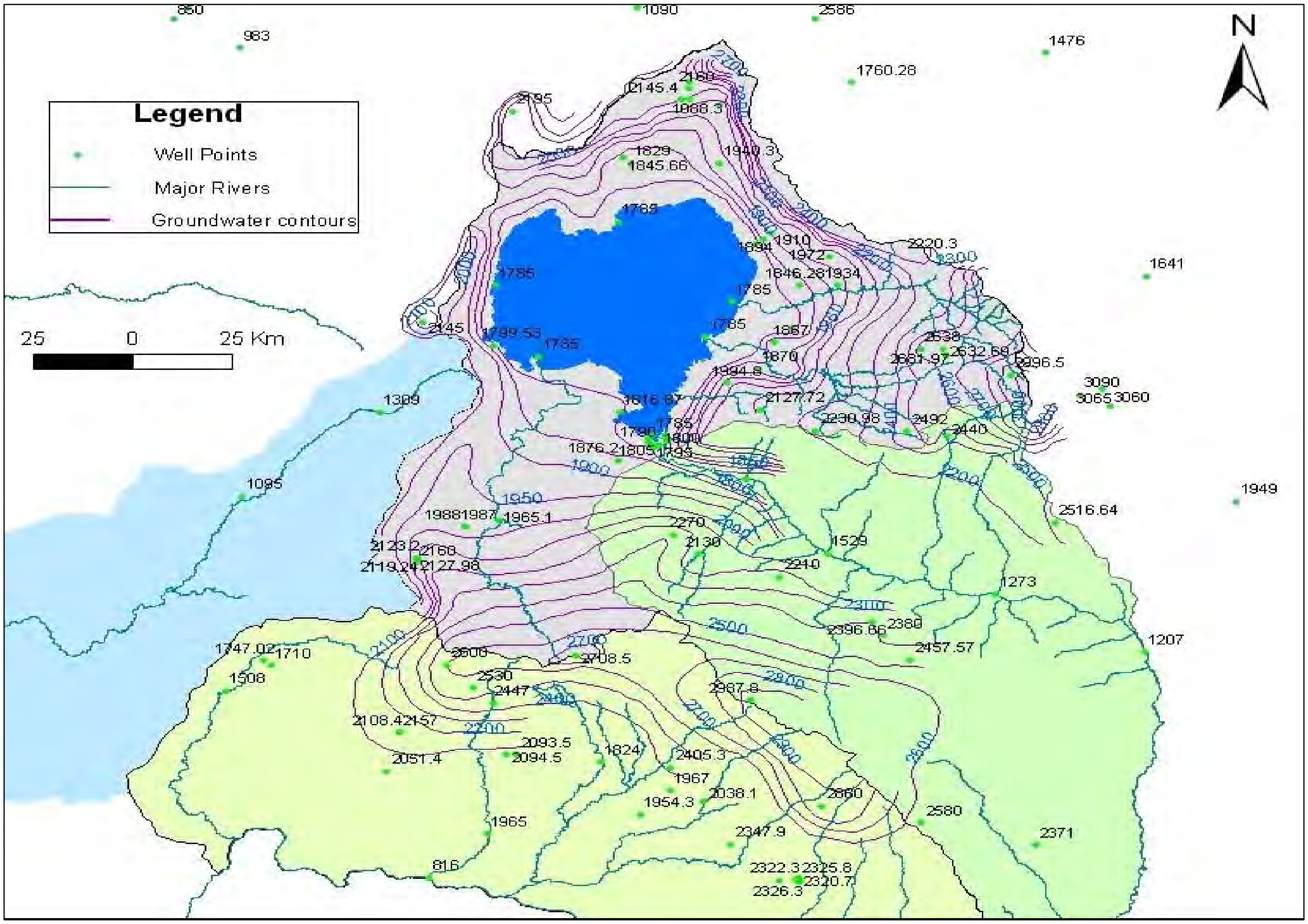



Figure 6.1 Groundwater counter Map of the study area (SMEC, 2008)

Note: The contour intervals vary from 50m contour separations in areas around Lake Tana where there are well details, to only 100m in elvated areas.

The groundwater elevation contour as shown in

5.5 Wetlands

There are a number of wetlands and groundwater dependent ecosystem in the Lake Tana catchemnt. Most of these wetlands remain green even in the dry seasons. Most of the wetlands are depressions formed by volcanic topography or by tectonic depressions. The plains surrounding the lake (i.e. the Dembiya, Fogera and Kunzila plains in the north, east and southwest, respectively) form extensive wetlands during the rainy season.

High groundwater heads occur in the south and east around the two shield volcanoes of Mts Choke and Guna, with the hydraulic gradient radiating from these points. Elsewhere around the eastern and western basin margins, there is a steep hydraulic gradient towards Lake Tana flattening on the plains adjacent to the lake.

### 6.3 Groundwater source, recharge & Discharge

#### 6.3.1 Groundwater source

A study of the groundwater flow within aquifer requires information about in flows and out flows. The term recharge is used for the in flow to an aquifer system arising from precipitation; return flow, irrigation and flows from various surface water bodies such as rivers, canals and lakes. The magnitude of the recharge is likely to change significantly with time.

The estimated precipitation around Gondar and Bahir Dar stations are 1389mm and 1326mm (SMEC, 2008 drft, 2008), respectively. Out flows from the aquifer system can be divided in to natural outflows and man-made out flows. Natural out flows occur when water levels in the aquifer is at spring or into rivers. Other natural out flows include low-lying areas which act as sink to groundwater systems; this form of out flows may be associated with areas of evapotranspiration especially from deep-rooting vegetation. One further natural out flow occurs when water flows into other aquifers. There are also man- made out flows, pumped wells and boreholes are the main means of withdrawing water from an aquifer.

The main groundwater source of the study area is radiating from the south and east around the two should volcanoes of Mt choke, and Guna. Elsewhere around the eastern and western basin margins, there is a steep hydraulic gradient towards Lake Tana flattening on the plains adjacent to the lake.

#### 6.3.2 Ground water Recharge

Natural source of freshwater that become ground water are:

1/ aerial recharge from precipitation that percolates through the unsaturated zone to the water table and

2/ loses of water from streams and other bodies of surface water such as lakes and wetlands.

Aerial recharge range from a tiny fraction to about half to average rates of recharge (for example, a few inches per year) represent significant volumes of inflow to ground water.

Streams and other surface water bodies may either gain water from groundwater or lose water to groundwater. Streams commonly are a significant source of recharge to groundwater downstream from mountain fronts and steep hill slopes in arid and semi arid areas and other soluble rocks.

Recharge can be broadly defined as water that reaches an aquifer crossing the water table from any direction, which contributes an addition to the groundwater reservoir (Lerner 1997).

There are three principal mechanism of recharge defined by Lerner et al (1990) as:

- Direct recharge (Diffuse): water added to the groundwater reservoir in excess of soil moisture deficits and evaporation by direct vertical percolation from precipitation or irrigation.

- Indirect recharge: recharge to the water table through the beds of surface water resources, such as beneath rivers and lakes.

- Localized recharge: an intermediate form of groundwater recharge resulting from the horizontal near surface concentration of water in the absence of well defined channels such as small depressions, joints and rivulets.

The above mechanism usually do not occur individually rather in combination which makes the assessment complex .On the other hand, the recharge and discharge conditions of an area is controlled by several factors such as climate, topography, drainage, geological framework, soil condition, land use/ land cover and vegetation etc.

For instance semi-arid areas where potential evapotranspiration exceeds average precipitation, the groundwater recharge depends on high rain fall events. Besides, this process is also controlled by soil infiltration capacity, hydraulic nature of subsurface material, and the presence of Surface fractures, joints and depression so as to escape evapotranspiration, etc. For example poor vegetation cover on a permeable soil cover along with high rain fall can favor the recharge process.

Regarding topography, in areas of steep slopes and rugged terrains, it favours runoff and evaporation rather than infiltration, Where as in flat land, it creats favourable condition for infiltration. On the contrary, in humid areas recharge is mainly controlled by precipitation surplus (rainfall minus potential evapotranspiratin) other factors being present.

The studied area gets large amount of recharge from the south and east of two large shield volcanoes called Mt. choke and Mt Guna, which possesses the most elevated area with the characteristics of high rain fall and flat topped hills that facilitate infiltration than surface run off. The Lake Tana Graben margin area is also affected by faults which produce fracture zone and joints on the volcanic rocks. In addition to these, the drainage densities of the areas are very high.

The fracture and joint along with open channels facilitate the, recharge process. The areas get relatively high amount of rain fall. Cold springs of Jiga, Gish Abbay and Bahir Dar water, supply spring are emanate from these high land areas have a characteristics of low EC value . This implies fast infiltration and shallow circulation of groundwater, where the area gets substantial amount of direct recharge. The central area has radial flow and gets medium to high rain fall.

### 6.3.3 Groundwater Discharge

Groundwater discharge can be defined as the release of water from the saturated zone across the water table togather with associated flow towards the water table with in the saturated zone (Freeze and cherry, 1979). Groundwater discharge areas can be manifested by surface water features such as springs, swamps and seepages.

Surrounding the Lake Tana especially south and east and the downstream of Gilgel Abbay areas are the main discharge areas zones on the study area. These comprises north eastern and south western parts of the study area which are getting relatively low amount of rain fall comparing to that of the high Land plateau and have higher evapo transpiration.

The manifestation of discharge areas with minor amount Lake Tana, Berta chera chara, Gundobrihan swamp and other swamp areas, springs (hot and cold) and depressions are clearly observed in the study area. The high yield cold spring like Gish Abbaya and Bahir Dar water supply springs are found around the Choke shield volcano in the center of the basin where as low yield cold springs are abundantly found on the near top of the volcanoes and the ridges in the study area. The non-volcanic hot springs (Andessa and Wanzaye) are discharged from the floor of Lake Tana Graben (LTG).

On the other hands, swamps occur on low lying depressions when the groundwater table coincides with the surface of the ground. The Berta Chara-Chara has been covered with vegetation is already become the form of this type of discharge area.

## 6.4 Groundwater Movement

Groundwater movement takes place from highlands (recharge area) to low lands (discharge area). Since the study area is concerned, groundwater flow is strongly controlled by structures like faults and fracture. Darcy's law shows that for flow to occure there must be difference in hyayraulic head, providing that has been referred to as a hydraulic gradient. From a field perspective, it follows that a value for hydraulic head can be defined and measured at every point with in some regions. The term filed is generally used to describe a region where some physical quantity can be described in terms of space coordinate system and time.

The water level record in wells in the region is generally with in 10m of the ground surface and often much shallower, with some wells being artesian. The abundance of springs, and the overall coincidence of groundwater level with the topography, particularly in steep landscapes, suggests that the shallow groundwaters operate under local flow systems controlled by ground elevation. Deeper groundwaters also exist.

Groundwaters generally discharge to springs and streams. Geochemical and isotope data (Kebede et al., 2005) supports the short flow paths of recharge waters through the aquifers. These groundwaters are low salinity and dominated by Ca-Mg-HCO3.

The deeper regional systems have longer flow paths through the aquifers. This has led to hydrolysis of minerals in the basaltic aquifers and in some locations enrichment by $CO_2$ from underlying rocks, resulting in groundwaters with higher salinity dominated by Na-$HCO_3$ waters (Kebede et al., 2005).

Groundwater surface elevation contour shows that groundwater elevation generally follows the ground surface contours with the groundwater flow directions largely consistent with the surface water catchement boundaries.

High groundwater heads occur in the south and east around the two shield volcanoes of Mt Choke and Guna with the hydraulic gradient radiating from these points. Elsewhere around the eastern and western basin margins, there is a steep hydraulic gradient towards Lake Tana flattening on the plains adjacent to the lake.

The hydraulic gradient in the Ribb and Gumera catchements is relatively steep at around 0.02 although it appears to be a relatively even grade in the direction of the Lake. In low lying areas, particulary the Fogera plain there is a sharp reduction in head and lower hydraulic gradient (approximately 0.01) beneath the plain. This is consistent with a model of groundwater discharge to the streams as well as a possible increase in hydraulic conductivity in the alluvial deposits.

A similar situation occurs in the Megech valley where the hydraulic gradient flattens out in the lowlyng areas from 0.02 around Gondar to 0.006 beneath the plains.

In the Gilgel Abbay, the groundwater gradient reduces from around 0.02 in the south to around 0.005 in lower lyaing areas approaching Lake Tana. East of the Gilgel Abbay, as the topography drops sharply into the Abbay River, the hydraulic gradient steepens. As noted previously, it is expected that groundwater is close to the ground surface in the downstream parts of Gilgel Abbay, with discharges to high volume springs and also to low lying swampy areas.

The groundwater elevation flattens in the lowland areas around the Lake and it is considered that groundwater level in these areas is likely to be controlled by the discharge to streams. There is a potential for water logging in low lying areas away from the drainage lines as the piezometric level approaches the ground surface. It is expected that this level will be controlled by evapotranspiration. Areas prone to flooding largely coincide with areas in which the groundwater gradient decreases.
Groundwater flow in the study are can be categorized as shallow and deep aquifer system in the study corridor.

### 6.4.1 Groundwater flow from shallow Aquifer system.

In order to depict the groundwater flow in the study area from shallow aquifer system, surface and together (with shallow) wells data were used southern and eastern parts of the study areas are generally the main sources of water that migrate to deferent direction. There is also some localized source from west of central part. Addis zemen ridge (yifag area) is located and groundwater flows from this area towards the lake is clearly observed.

After having high amount of recharge from southern and eastern shield volcanoes, which shows high flows, groundwater moves both south western of Lake Tana and western parts following Belles catchments. However, the magnitude of flow is concerned high flow is observed in the central part of the three graben towards the Lake Tana. Local groundwater flow leads to regional flow in most part of the area, the local flow disturb the regional one like in the divergent zone.

Groundwater flows from the highlands to the lake and depth to the water table varies from less than 5 meters to more than 50 meters. A number of groundwater fed wetlands are also observed in the cathement of the three command sites. The most prominent ones are found in the Gilgel Abay subbasin. The eventual discharge zones of the regional groundwater flow are the rivers, springs and diffuse discharge to the wetlands. The influence of groundwater in the water balance of Lake Tana is minimal and is in the order of less than 5 percent of the total inflow. The Permanent water logged plains are also common in the region and these plains host wild life and are used as grazing lands.

### 6.4.2 Groundwater flow the study area from Deep Aquifer

Deep aquifer system can be characterized by data obtained from boreholes which have high depths. Generally the groundwater flow direction from deep aquifer system has entirely similar triend from that of shallow aquifer system. Besides to groundwater flow direction divergent and convergent zones and groundwater divide found in the same place and characterized in the same manner to that of the shallow aquifer system this can be observed on both shallow and deep aquifer.

## 6.5 Conceptual Groundwater Models

In this preliminary understanding three possible conceptual models of the groundwater of Lake Tana sub basin, which are developed based on the available data and regional geological set up of the area.

The hydrogeological and hydrological investigation in the area showed that the base flow Rivers of Beles and Goang west and southwest of Lake Tana is very small. In the west and southwest sides of the Lake there is a very sharp drop in elevation. If the groundwater flow was in that direction there could be big springs on the escarpment and the base flow the rivers should be significant. This indicate that the geological set up of the area do not favour the groundwater movement in that direction.

In addition, at the northern part of the Lake, especially in Chilga graben, which is found about 30 km from the Lake and elevation lower than the lake by more than 100 meters, drilling of a number of wells up to 230 meters in this are was found to be dry. This condition can be interpreted either the groundwater flow through area is very deep from the lake to the north direction which may form the base flow of Angreb river or may recharge the deep aquifer in the northern direction or there is a barrier (groundwater divide or impervious volcanic rocks that block the groundwater flow in that direction).

Most of the researchers in the area agree that Precambrian rocks in northwestern Ethiopia are overlain by Jurassic sandstones, which were formed during the transgression of the Indian Ocean over East Africa. Jurassic seaways transgressed from the east and southeast of Ethiopia as far as the present day Lake Tana. The different geological sections constructed by USBR 1964 in west-east direction concluded that the sedimentary beds are nearly horizontal but a general, slightly south-easterly dip causes progressively beneath the plateau lava in south-easterly direction (USBR, 1964).

The recent Magnetotelluric imaging carried out south and east of Lake Tana revealed that there is a consistent NW-SE trending sedimentary basin beneath the lava flow (Sophie et al., 2005). The major volcanic geological formations that outcrop in Lake Tana sub-basin and its adjacent areas overlying the sedimentary formation may follow the dipping of the sedimentary formation. Based on the above preliminary findings three conceptual groundwater models are developed. .

Conceptual Model I: The groundwater of Lake Tana is bounded by the Lake Tana Escarpment in the west and south east of the lake and the volcanic barrier or groundwater divide between Lake Tana and Chilga graben, and dominantly recharged from the south of Lake. Gilgel Abay river catchment and Adjacent areas like Choke Mountains, and in the east, southeast, east and north east Gumera, Rib and Megech rivers Catchment and from deep percolation of the Lake itself. The most likely interaction of Lake Tana and the groundwater system in the sub-basin is conceptualized based on the available previous studies and preliminary analysis of the data and information as shown in figure 6.2 and discussed as follows:

- ❖ The alluvial aquifer is recharged from the volcanic aquifers from the upper catchments and also from Lake Tana during high Lake level periods. The aquifer is discharged to Lake Tana during low Lake Level and partly to the underlying volcanic aquifer.

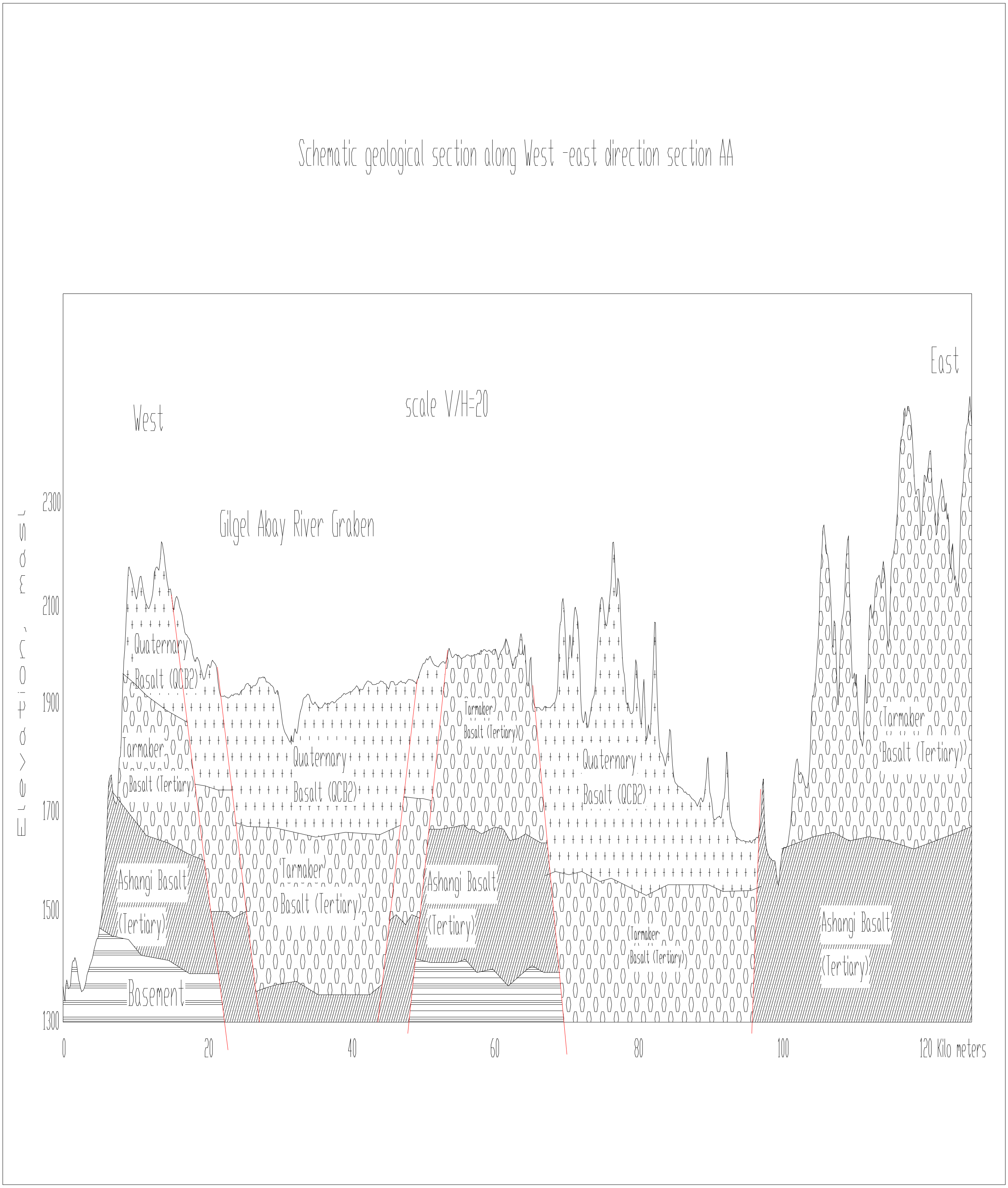
- ❖ The volcanic aquifer of quaternary vesicular basalt is recharged from rainfall and most of its recharge is discharged as springs and base flow to Lake Tana and some part could recharge the scoraceous basalt underlying it.

- ❖ The Tertiary scoraceous basalt is recharged from rainfall within the Lake Sub-basin and adjacent areas (Choke mountain plateau) and partly from the vesicular basalt and it conceptualized that it is mainly discharged to the underlying Mesozoic sedimentary aquifer along the southeast direction (dipping of the sedimentary formation).

Conceptual Model 2: The second conceptual model is similar to the first conceptual model except that there could be a deep groundwater flow in the north direction from Lake Tana sub-basin through Chilga graben that may form the base flow of Angereb River or the deep groundwater system of the area.

Conceptual Model 3: All the groundwater of the alluvial and volcanic aquifers is drained to Lake Tana from all direction and gets lost by surface water outflow and evaporation due to the impermeable bed of the lake. To evaluate this conceptual model it was tried to construct the schematic hydrogeological section along south-north direction.

The schematic hydrogeological x-section(figure 6.2) showed that the possibility that all the quaternary and tertiary volcanic aquifer could not be drained to the Lake due to the following condition i.e. the depth of the lake is not greater than 20 meters and the thickness of the quaternary and tertiary volcanic rocks is more than 250 meters around the lake and it is believed to be distributed below the impermeable lake bed and the faults and fractures transmit from quaternary and tertiary rocks of the lake catchment and from the lake itself to the tertiary volcanic rock underlying below the lake bed.



Schematic geological section along West -east direction section AA
scale V/H=20
West
East
Gilgel Abay River Graben
Elevation, masl
2300
2100
1900
1700
1500
1300
Quaternary
Basalt (QCB2)
Tarmaber
Basalt (Tertiary)
Ashangi Basalt
(Tertiary)
Basement
0
20
40
60
80
100
120 Kilo meters

From the three conceptual models developed here, the most likely conceptual groundwater flow system of Lake Tana sub-basin is assumed to be the first conceptual model. However, the Terms of reference is prepared to evaluate the groundwater condition taking into consideration all the three conceptual models and determine the appropriate model through investigation. During the progress of the study the conceptual models will be tested, modified or changed or new model may be identified upon the result of the study and investigation out come.

Figure 6.2 The schematic hydrogeological x-sectionalong W_E direction (produced by the Rapid Assessment Report)

### 6.6 Groundwater Potential of the Lake Tana basin

Stream hydrograph analysis results of Asmerom (2008), in the upper Blue Nile basin shows that about 15% of annual flow is derived from shallow groundwater. However, for some catchment it reaches 44%. In the same work, it is also indicated that about 45mm/year of the total flow (total flow 303mm/year) is derived from ungauged basins.

The annual recharge into the basin, which is obtained from integrated methods (chloride mass balance, base flow separation, etc.), varies between 70mm/year and 120mm/year. Hence, the groundwater potential with uneven distribution in the basin could be estimated to be in the range of 1.2 billion $m^3$ to 2 billion $m^3$. Based on conventional water balance models, the estimated storage volume in the basin is about 1.855 billion $m^3$, which is close to the above-indicated value.

Regardless of the total volume of groundwater recharging the aquifers and the billions of meter cube of storage groundwater use for irrigation largely depends on the properties of the aquifers to transmit readily to wells (i.e. transmisivitiy and hydraulic conductivity of the aquifers).

According to SMEC report, the aquifer transmissivity and yields are relatively low and the aquifer properties are highly variable laterally. It is considered that even with a combination of wells, the yields required to meet the demands of a large scale irrigation development are unlikely to be achieved from the aquifers in most areas. The general conclusion is that there would be inadequate resources available for large scale, sustainable groundwater based irrigationdevelopment.

# CHAPTER SEVEN

# HYDROCHEMISTRY

## 7.1 General

The fundamental concepts relating to chemical process that are most useful in developing unified approaches to the chemistry of natural water are mainly related to chemical thermodynamics and to reaction mechanisms and rates. Thermodynamic principles may also be useful in correlating chemical processes with biological or physical processes. Thermodynamics principles applied to chemical energy transfers form a basis for evaluating quantitatively the feasibility of various possible chemical processes in natural water systems, for predicting the direction in which chemical reactions may go, and in many instances for prediction products that should be present in the water.

The chemical reactions in which elements participate involve changes in the arrangement and association of atoms, molecules and interactions among electrons that surround the atomic nuclie. The filed of natural water chemistry is concerned principally with reactions that occur in relatively dilute aquous solution, although some natural waters have rather high solute concentrations. The reacting systems of interest are generally heterogeneous (ie they involve both a liquid phase and a solid or a gaseous phase, or all three). As a check on the chemical analysis a cation-anion balance is usually performed. This is accomplished by converting all the ionic concentrations to units of equivalents per liter. The anions and cations are assumed separately, and the results are compared. If the sum of the cations is not with in a few percent of the sums of the anions, then either there is a problem with the chemical analysis or one or more ionic species that have not been identified are percent in insignificant amounts (Fetter, 1994)

Recognition of the anion evolution sequence as a characteristic feature of many groundwater systems resulted from the compilation and interpretation of chemical data from regional flow systems. The anion evolution sequence and the tendency for total dissolved solids to increase along the paths of groundwater flow are generalization that when used in the context of more rigorous geochemical reasoning, can provide considerable information on the flow history of the water. Large variations in the major cat ion commonly occur in Groundwater flow systems. Since cation exchange commonly causes alternations or reversals in the cation sequences, generalization of cation evolution sequences in the manner used by chebotarev for anions would be of little use because there would be so many exceptions to the rule.

For major cation and anion data to provide greatest insight into the nature of groundwater flow systems, interpretations must include consideration of specific hydro chemical processes that can account for the observed concentration (Freeze and cherry, 1979).

### 7.2 Sampling and Methods

Due to the natural and unexpected in conveniences and problem faced to sample and analyses water bodies during filed survey, which was intended to do so in regional water bureau, the primary data was not collected in so far as expected confirming for some physical parameters. However the, secondary data were collected as much as possible that may represent the entire study area. Accordingly, the physico-chemical analysis those were analyzed mostly by regional water bureau.

The method was involved the withdrawal of water from pumping boreholes sufficiently in order to insure that the sample represents the groundwater that feeds the well and in situ measurements of PH, EC, TDS and Temperature has been conducted .

### 7.3 In Situ Parameters

The physical parameters of natural water like pH, Eh, Temperature, conductively and TDS should be measured on the filed for that they will easily be changed due to environmental dynamics. These parameters are measured in the filed using conductivity meter to measure conductivity and TDS, while PH meter was used to measure pH and tempraturet and few of them were also confirmed during the field survey. The geo chemical analyses also measured in the laboratory as obtained from secondary data, eve though, the cat ion data were get error in the value measured due to the problem faced in the measuring device. They are discused below:-

**7.3.1 PH**

Although water molecules are quite stable chemically they still tend to break down or dissociate in to their component parts, $H^-$ (Hydrogen) ions and $OH^-$ (Hydroxy) ions.

$H_2O= HOH= H^+ +OH^-$

Water is said to be either acidic or alkaline (Basic), depending on the relative concentration of hydrogen ions. Hydrogen ions in water cause it to act as an acid. The capability of water to neutralize acid, that is reduces the number of hydrogen ions in solution, is called alkalinity. The acidity –alkalinity characteristics of water are basic to an understanding of water chemistry (Driscoll. 1995). The hydrogen ion concentration of water is expressed as PH. The PH is equal to the logarithm of the inverse of the hydrogen ion concentration, or

$$PH= Log\ 1/H^+$$

This particular equation is used because the actual number of ions is very small. The PH ranges is from 0 to 14, with a PH value of 7 at 25 $^0$C ( 77 $^0$F) indicating a neutral solution in which $H^+$ and $OH^-$ ions have the same concentration. A PH less than 7 indicates an acid solution, where as a PH greater than 7 indicate an alkaline solution. Temperature play a vital role in determining the PH at which neutrality occurs, Fore example, at 0 $^0$C (32 $^0$F) the concentrations of positive and negative ions are equal at PH= 7.53, whereas at 50 $^0$c (122 $^0$F) neutrality occurs at PH =6.65 (Freeze and Cherry, 1979).

According to Hem (1992) hydrogen ion of natural waters mainly fall between 6 to 8.5 and it is controlled by interrelated chemical reactions that produce or consume hydrogen ions. The main once are the reaction of acidic solutes and hydrolysis reaction. River water in areas not influenced by pollution generally has a PH in the range 6.5 to 8.5. Consequently, from the existing water bodies data the PH values of water in the area can consider as neutral and it is potable.

When the PH value increment trend is concerned, the lowest value is observed at the southern central part (Durbete, Merawi, and yibab) of the study area and the highest one is found at Gurdema and the lake water. The PH spatial distribution is increasing towards the north Debretabor, Infraze and Maksegite which follow the groundwater flow trend.

### 7.3.2 EC (Electrical conductivity)

Electrical Conductivity of water is its ability to conduct an electric current at a specified temperature and it is usually measured in micro siemen's per centimeters or micromohs per centimeter (Weast, 1968). The value of EC increase with temperature, between 20 $^{0}$C and 30 $^{0}$C, an increase in 1 $^{0}$C increase the EC by two percent on the average (Hem, 1992).

The American society for Testing and Material (1964, P.383) defined electrical conductivity of water as" the reciprocal of the resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specified temperature". Pure liquid water has a very low electrical conductance a few hundredths of a micro mho per centimeter at 25 $^{0}$C. This value has only theoretical significance, because water has pure is difficult to produce. The presence of charged ionic species in solution makes the solution conductive. As ion concentration increases, conductance of the solution increasses, therefore, the conductance measurement provides an indication of ion concentration. Electrical conductivity values show significant variations with the different sources of water. A gradual increment in EC from south (Addis kdam, Dangela) part towards northern (Enfraze) part of the study area and at the time, the highest Ec value 917µs/cm is found at Enfraze area (UTM 373718E and 121533N). This Ec value reduces towards the lake Tana is also strengthened the existence of groundwater flow from the Gonder Graben towards south.

### 7.3.3 Eh (Red ox potential)

The electrochemical evolution sequence that founded on geochemical theory refers to the tendency for the red ox potential of groundwater to decrease as the water moves along its flow paths. This tendency was first recognized by Germanov et al (1958). As water from rain and snow enters the subsurface flow system, it initially has a high red ox potential as a result of its exposure to atmospheric oxygen. The initial red ox conditions reflect high concentrations of dissolved oxygen, with pH values close to 13, or, expressed as Eh, close to +75mv at PH ( Freeze and cherry).

Although there is no enough measured as well as complete secondary data concerning this parameter, based on the limited data, there is high Eh value in the Recharge Zone and low value, at Discharge Zone.

### 7.3.4 Temperature

Temperature has remarkable influence on certain physical, chemical and bacteriological characteristics of groundwater. The solubility of $CO_2$ in water at atmospheric pressure, the variability of dissolved oxygen important for water life, and microbiology are all affected by change in temperature (Hem, 1989).

Temperature also like other parameters measured in the filed by using conductivity meter. In most cases, shallow groundwater is normally characterized by a temperature which is strongly affected by the type of over lying surface environment. In the area, almost all wells have the same depth with the same climatically solution but shows temperature variation. Temperature of the area is ascending when moving to Lake Tana surrounding area with maximum of 23.3 $^{O}$C at werota bore holes and the lake itself.

### 7.3.5 Total Dissolved Solids (TDS)

Total dissolved solids (TDS) can be determined by evaporating a known volume of the sample and weighing the residue. TDS can be estimated by summing the concentration of the individual ions. This method does not account for any dissolved substances. For example, dissolved silica, $SiO_2$, may not be reported but contribute to TDS.

One basic measure of water quality is the TDS, which is the total amount of solids, in milligram per liter that remain when a water sample is evaporated to dryness. Water naturally contains a number of different dissolved inorganic constituents. The major cations are Calcium, Magnesium, Sodium, and Potassium; the major anions are Chloride, Sulfate, Carbonate and Bicarbonate. Although not in ionic form, silica can also be a major constituent.

These major constituents constitute the bulk of the mineral matter contributing to total dissolved solids. In addition, there may be minor constituents present, including iron, manganese, fluoride, nitrate, strontium and boron (Fetter, 1994).

The surface water may be adversely impacted by human activity. If Organic matter, such as untreated human or animal waste, is placed in to the surface water body, dissolved oxygen levels diminish as microorganism grow, using the organic matter as an energy source and consuming oxygen in the process. The total dissolved solids may increase owing to the disposal of waste water, urban runoff, and increased erosion due to land –use change in the drainage basin. The natural quality of ground water varies substantially from place to place. It can range from total dissolved solids contents of 100 mg/l or less for some fresh groundwater to more than 100,000 mg/l for some brine in deep aquifer (Fetter, 1994).

A Groundwater moves along its flow paths in the saturated zone, increase of total dissolved solids and most of the major ions normally occur. As would be expected from this generalization it has been observed in groundwater investigations in many parts of the world that shallow groundwater in recharge areas is lower in dissolved solids than the water deeper in the same system and lower in the discharge areas (Freeze and cherry, 1979).

TDS values of the studied area show their spatial distribution with in the area. The concentration has entirely the same trend with that of Ec. It increase from southeast towards northwest part of the study area and also has a highest value at the same location (at Enfraze ) with amount 551mg/l ), which is mentioned above and as well coincided with groundwater flow direction. This is probably due to high rock- water interaction at the course of long groundwater flow (long residence time). Since this area is highly affected by tectonic effect like fractures and faults, which may also favor the interaction. Natural geological processes and/ or ma made effects can add some contribution for high TDS concentration around Lake Tana area.

From TDS and major cations and anions relationships, it can be seen that there is more or less a liner relationship between TDS-$HCO^{-}3$ and TDS-$Cl^{-}$ through the contribution of the $HCO^{-}3$ and Cl ions for TDS concentration is far different (more in HCO3).

**7.4 Classification of Laboratory Analyzed Parameters.**

The spatial variability observed in the composition of the major ions can provide highlight the aquifer heterogeneity and connectivity as well as the physical and chemical processes controlling water chemistry. Generally the approach is to divide the samples in to hydro chemical group, which are group of samples with similar chemical characteristics that can be fitted with location. Verifaction that are systematic variations along the flow path are relates to reactions between groundwater and surround formation which can provide the hydro chemical evolution trend for the study area. This is vital for interpreting the spatial variations of water chemistry that helps to determine potability of water and defining ground water flow direction along the study area and characterization of the hydrologic systems.

### 7.4.1 Chlorine (Cl)

chlorine ions do not significantly enter in to oxidation or reduction reactions, from no important solute complexes with other ions unless the chloride concentration is extremely high , do not forms sates of low solubility, are not significantly absorbed on mineral surfaces, and play few vital biochemical roles. The circulation of chloride ion in the hydrologic cycle is largely through physical processes (Hem, 1986).

Chloride is present in all natural waters, but mostly the concentrations are low. In most surface streams, chloride concentrations are lower than those of sulfate and/ or bicarbonate. Exceptions occur where streams receive in flows of high chloride groundwater or industrial waste or are affected by oceanic tides. Chloride that is not accounted by rain and snow fall is most logically assignable to leaching of sedimentary (evaporates). Pollution caused by human is a major factor in some basins. \

The most common type of water in which chloride is the dominant anion is one in which sodium is the predominant cation. Water of this type has a range from dilute solutions influenced by rainfall near the ocean to brines near saturation with respect to sodium chloride (Hem, 1986). Shallow unprotected hand dug wells of Anguamesk with, 16.57 mg/L and Amed Ber with 21.57 Mg/L has chloride concentration greater than the sulfate but less than $HCO^{-}3$. This happened perhaps due to effluents, released from the treatment of industrial wastes from the recharge area.

On the other hand, Cl ion concentrations show an increase from south to north of the study area. The highest concentration value for both the hand dug wells and bore holes are found to be at woreta (UTM 373632 E and 114928N) with 20.57 mg/L and Guzara (UTM 373775E and 120858N) with 22.06 mg/L, respectively. The range of chloride ions collected in the study area is in between 1.85 to 22.06 mg/L. According to WHO gridlines for drinking water quality 2004, the concentration of Cl has to be less than or equal to 250 mg/L. As these in terms of chloride, all parts of the area are safe for the drinking water supplies point of view.

### 7.4.2 Fluorine (F)

Fluorine is the highest member of the halogen group of elements. It is the most electronegative of all the elements. In solutions it forms $F^-$ ions. Fluoride ions have the same charge and nearly the same radius as hydroxide ions, thus the ions may replace each other in mineral structures. A significant fact noted in geochemistry of chlorine is that more than 75% of the total amount of those elements known to be present in the outer part of the earth is contained as chloride, as a solution form in the ocean. Fluorine on the other hand, is almost all tied up in rock minerals, and only a small percentage of the total is contained in sea water (Hem, 1926).

In nature F comes from chemical weathering product of igneous rocks, magmatic emissions, atmospheric dusts from continental sources and industrial pollution (Hem, 1970). Sources of fluoride in water are, Fluorite in water are, fluorite ($CaF_{2}$), this is a common one that has rather low solubility and occurs in both igneous and sedimentary rocks.

There is no agreement among researches as to how the high F is introduced into the groundwater and surface water bodies. According to Gerasimovskiy and savinava (1969) the volcanic rocks of East parts of the world the most important sources are acidic volcanic rocks such as tuff, pumice and obsidian and emanations from geothermal system (Tesfaye, chernet, 1982, Tesfaye cherent et al, 2001).

High F is observed in few water points issuing from acidic volcanic rocks of the quaternary and in the groundwater associated with thermal system. The high F in groundwater associated with acid volcanism has its source from leaching of F bearing accessory minerals.

There is the high concentration of fluoride at Enfraz bore hole with 2.95 mg/l that is fall beyond WHO standard for fluoride optional level of 1.5 mg/L, 2003 for safe drinking water. The concentration in Lake Tana is 0.41 mg/L where as the rest of areas, which comprising the eastern, central, & south of the lake basin have fluoride value at safe limit. These areas have also been identified as a major groundwater recharge zones on the basis of its low Ec < 500 µs/ sec.

High concentration of fluoride causes the known problems of dental and skeletal fluorosis. Nevertheless, flouoride is an essential nutrient to health dental growth provides its concentralion is in the range of 0.5 to 1.5 mg/l.

Generally the study area can be subdivided in to two on the basis of fluoride concentration high fluoride area Norther part >0.5 Mg/l and low fouoride area in the rest of the basin. Knowing the spatial distribution of the fluoride ions is very useful to locate the productive wells for safe and potable water development.

### 7.4.3 Bicarbonate

The Bicarbonate concentration of natural water generally is held within a moderate range by the effects of carbonate equilibria. The concentration in rain water commonly is below 10mg/l and some time is much less than 1.0mg/l depending on pH. Most surface streams contain less than 200mg/l but in groundwater some what higher concentration are not uncommon. Concentrations over 1000mg/l occur in some waters that are low in calcium and magnesium especially where processes releasing carbon dioxide (such a sulfate reduction) as occurring in the groundwater reservoir.

Ground water associated with recharge is represented by water dominant in calcium, magnesium and sulfate with lesser amounts of sodium and bicarbonate. As the groundwater flows from the source of recharge towards the discharge area, their is an increase interaction between water and rock. Sodium bearing litho logic units are encountered as the groundwater moves along the flow path and calcium and magnesium ions are exchanged for sodium ions attached to aquifer solids.

Anaerobic sulphate reducing reaction also act on the groundwater as it moves along a flow path. Therefore, both reactions result in a decrease in calcium, magnesium and sulphate and a corresponding increase in $Na^+$ and $HCO^-_3$ as groundwater flows away from the source of recharge and results in water that evolves to a sodium bicarbonate type in the deep geochemical zone.

Bicarbonate ions have exactly the same spatial distribution trend in the basin with that of sodium ions as described above. Accordingly, they are increasing from south Addis kedan cold spring (with 87.84 mg/l) at the south to the higher bicarbonate concentration at the north Entraze (with 628 mg/l).

# CHAPTRE EIGHT

## CONCLUSIONS AND RECOMMENDATIONS

According to litho logic logs described under chapter five and by under standing that the area was affected by dormant volcanism it has a similarity in litho logy types in the study area. From this and by studying the structures and cross_sections in the area, generally it can be concluded that the ground water circulation is controlled by both litho loges and structures. The following conclusions have been drawn.

- The alluvial aquifer is recharged from the volcanic aquifers from the upper catchments and also from Lake Tana during high Lake level periods. The aquifer is discharged to Lake Tana during low Lake Level and partly to the underlying volcanic aquifer.

- The volcanic aquifer of quaternary vesicular basalt is recharged from rainfall and most of its recharge is discharged as springs and base flow to Lake Tana and some part could recharge the scoraceous basalt underlying it.

- The Tertiary scoraceous basalt is recharged from rainfall within the Lake Sub-basin and adjacent areas (Choke mountain plateau) and partly from the vesicular basalt and it conceptualized that it is mainly discharged to the underlying Mesozoic sedimentary aquifer along the southeast direction (dipping of the sedimentary formation).

- Aquifers in the study area have two systems the shallow and the deep. The shallow aquifer system is mainly composed of latcustrine, alluvial sediments and pyroclastic materials such as fractured rhyolite and its weathering product. From the litho logic log of some shallow wells it is observed that the range of aquifer depth is 30 to 70 meters. Groundwater generally exists in unconfined or semi-confined conditions, the low permeability paleosols that are present between the successive eruptions and flows acting as semi confining layers.

- For the deep aquifer system, the depth of the aquifer ranges from 70 to 200 meters. This shows it is being deep confined aquifers with regional lateral extension. The aquifer is mainly composed of fractured rhyolite, pyroclastic deposits, scororacious materials and basalts, Based on the hydro geologic map and the permabilities of rocks, the aquifers show variation and classified as high, high to moderate, moderate, low to moderates and low, respectively.

- In general, it can be said that there is deep and shallow circulation of groundwater giving rise to different aquifer system and various high and low yield springs. Groundwater in the study area is of good, in low relief areas along the major structures mainly at the eastern escarpment of the Lake.

- The studied area gets large amount of recharge from the south and east of two large shield volcanoes called Mt. choke and Mt Guna, which possesses the most elevated area with the characteristics of high rain fall and flat topped hills that facilitate infiltration than surface run off. The Lake Tana Graben margin area is also affected by faults which produce fracture zone and joints on the volcanic rocks. In addition to these, the drainage densities of the areas are very high.

- The fracture and joint along with open channels facilitate the, recharge process. The areas get relatively high amount of rain fall. Cold prings of Jiga, Gish Abbay and Bahir Dar water, supply spring are emanate from these high land areas have a characteristics of low EC value . This implies fast infiltration and shallow circulation of groundwater, where the area gets substantial amount of direct recharge. The central area has radial flow and gets medium to high rain fall.

- Some of the high discharge structurally controlled springs those emanate from the foot and neck of Debretabor ridge are (Deberatabor spring, Wanzaye thermal spring) and choke mountain chain (Gish Abbay cold spring, Jiga cold spring) are believed to get recharge internally from eastern high lands (upper lake Tana-basin).

- The water level record in wells in the region is generally with in 10m of the ground surface and often much shallower, with some wells being artesian. The abundance of springs, and the overall coincidence of groundwater level with the topography, particularly in steep landscapes, suggests that the shallow groundwaters operate under local flow systems controlled by ground elevation.

- The groundwater flow systems from both shallow and deep aquifers have the same flow trends. After having high amount of recharge from eastern high plateau, groundwater moves both towards north western (Lake Tana sub-basin) and western parts following Gilgel Abbay River flow Direction with in the north western part (Amba Giorgis with discharge 16-18 L/sec. Azezo,Gtwz with 9.9 l/sec and Baher Dar Kebele 15 with 10L/sec). There are also some artesian source of recharge from west (Angerb WN o7) the mean discharge areas are northern and south western part of the study area when the Gilgel Abbay River leaving the study area.

- In the Gilgel Abbay, the groundwater gradient reduces from around 0.02 in the south to around 0.005 in lower lyaing areas approaching Lake Tana. East of the Gilgel Abbay, as the topography drops sharply into the Abbay River, the hydraulic gradient steepens. As noted previously, it is expected that groundwater is close to the ground surface in the downstream parts of Gilgel Abbay, with discharges to high volume springs and also to low lying swampy areas.

- Groundwater surface elevation contour shows that groundwater elevation generally follows the ground surface contours with the groundwater flow directions largely consistent with the surface water catchement boundaries.

- The field measurements of pH values of the study ranges between 6 to 8.44 and therefore, PH values of water in the area can be considered as neutral. The spatial distributions of the PH values are increasing from south towards the northern part of the studed areas that, reflecting the direction of groundwater flow in the Lake region.

- Electrical conductivity values show significant variations with different sources of water. Generally as it is seen from there is a gradual increament in Ec from south eastern part towards the north western ( Lake Tana) part of the study area at the time the highest Ec value 917 µs/cm is found at Enfraze area

- TDS, total dissolved solids, have entirely the same trend with that of Ec. It increases from south east towards northwest part of the study area and also concentrated (has highest value) at the same location which is maintained above that is also coincide which groundwater flow direction. This may be due to high rock-water interaction at the course of long groundwater flow and has long residence time.

- Water types for different source are also determined, boreholes, hand dug wells and rivers have the same water type as Na- $HCO_3$ and ca Mg $HCO_3$. Lake and Hot springs have also possessed the same types of water composition as Na- $HCO_3$ type in the study area.

- Chloride (Cl), Fluorine (F) and Bicarbonate ($HCO_3$) distribution in the studied area also investigated in a separate way so as to observe their evolution and confirm whether the water fits WHO guideline, 2004.

- In the study area, Cl ion concentration shows a general increase from south to north. On the other hand, around the Lake, it radically increases at the water point of borehole (Durbete) with GPS location in South west (value 13.2 mg/l) and Worota northeast of Lake Tana. The highest values from these area are and 22.06 Mg/l, respectively. The ranges of the chloride ions in the study area are in between 1.85 to 22.06. According to WHO guidelines for drinking water quality 2004, the concentration of Cl has to be less than or equal to 250 mg/l. As of these in terms of chloride, all parts of the area are safe for the drinking water quality.

- Bicarbonate ions are increasing from south of Lake Tana Addis kedam with GPS location towards North, Enfraze. The highest bicarbonate ion concentrations are found at north of Enfraze boreholes (628.3mg/l) $HCO_3$ varies from 103.7mg/l (Lake Tana Water) to 628.3 mg/l. Generally cold springs have lower values and Hand dug wells have higher values around the Lake.

- The Fluoride ion concentration of Lake Tana and its vicinity is greater than 0.12mg/l that is far below WHO standard for fluoride optional level of 1.5 Mg/L, 2003 far safe drinking water. The highest value encountered in enfraze deep boreholes.2.95 mg/l. Where as the rest of areas have fluoride value at safe limit. High concentration of fluoride causes the known problem of dental and skeletal fulorosis.

**Based on the findings obtained so far from this research work the following recommendations have been given.**

- Data base organization about well history, physicochemical analysis, pumping test etc. should be done well for newly construction water schemes.On the other hand, collecting and documenting data for the old wells from the concerning offices, drilling campanies and organization should be done.

- Observation pipes should be installed in the existing and newly constructed boreholes or that almost of all wells exist in the area do not have such pipes.

- For the existing boreholes static water levels, depths if possible and hydro chemical analysis have to be carried out and well documented.

- Further quantification of the groundwater flow amounts should be done with detail investigation methods through systematic sampling and measurements of all springs those are found along Mt Guna and Mt choke chain.

- According to this study there are two aquifer systems, concerning the groundwater flow direction both of them show the same trend? This is also be left for further verification through detail shallow hand dug and deep wells inventory depth and litho logic log characterization.

- Other methodology like isotopes should be employed in further works for analysis of groundwater flow system along the study area to confirm the out put of this work.

- Regional major ions evaluation needs to be conducted to observe variation of water types which strongly indicated groundwater flow direction.

- Lateral distribution of fluoride should be assessed and mapped especially at enfraze well field and including entire study area with detail hydro chemical trend analysis approaches as it has been observed from fluoride distribution that is beyond WHO'S guideline,2004 (1.5Mg/l) there fore, the other alternatives should be searched out with detail studies.

- Appropriate environmental protection measures should be done on the escarpment and on the central part of the study area along which there is high groundwater flow is expected.

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# ANNEX 1

Table of well locations

| S. No | Bore Location | Elivation (m) | (Lat) | long | Depth (m) | Aquifer | SWL(m) | DWL(m) |
|---|---|---|---|---|---|---|---|---|
| 1 | Addis Zemen 1 | 1980 | 121330 | 377833 | 137 | Tarmaber Basalt | 8 | 1972 |
| 2 | Angerb 1 | 2170 | 126330 | 374667 | 108 | Ashangi Basalt | 10.78 | 2159.22 |
| 3 | Angerb 2 | - | 126330 | 374667 | 86 | Ashangi Basalt | 17.05 | - |
| 4 | Angerb 3 | 2159 | 126330 | 374667 | 65 | Ashangi Basalt | 6.05 | - |
| 5 | Angerb 4 | 2170 | 126340 | 374667 | 174 | Ashangi Basalt | 0.8 | 2152.95 |
| 6 | Angerb 5 | 2160 | - | 374667 | 72 | Ashangi Basalt | 18.5 | 2169.2 |
| 10 | Angerb 6 | 2210 | 12630 | 374667 | 56 | Ashangi Basalt | 13.56 | - |
| 7 | Angerb 7 | 2160 | 126170 | 374667 | 120 | Ashangi Basalt | Artesian | 2141.5 |
| 8 | Angerb Gw5 | - | 126250 | 374667 | 109 | Ashangi Basalt | 10 | 2160 |
| 9 | Angerb Gw6 | - | 126320 | 374667 | 95 | Ashangi Basalt | 16 | - |
| 12 | Arbaya | 1770 | 126330 | 37833 | 87.4 | Alluvium Basalt | 9.72 | 2230.98 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 11 | Arbgebeya | 2290 | 116310 | 377508 | 95.6 | Tarmaber Basalt | 59.02 | 2196.44 |
| 13 | Aykel | 2195 | 125500 | 370667 | 50 | Aiba basalt | Artesian | 1760.28 |
| 14 | Azezo 6tw2 | - | 124170 | 373160 | 107 | Tarmaber Basalt | 24 | 2195 |
| 15 | Azezo 6tw3 | - | 125660 | 373170 | 150 | Tarmaber Basalt | 20 | - |
| 16 | Azezo MF | - | 125670 | 374167 | 156 | Tarmaber Basalt | 4.87 | - |
| 20 | Bahir Dar | 1790 | 11610 | 374133 | 50 | Quateranary | 3.49 | 1786.51 |
| 17 | Bahir Dar 07 | 1800 | 115830 | 373828 | 72 | Quaternary Basalt | Artesian | 1795.13 |
| 18 | Bahir Dar 08(1) | 1790 | 115910 | 374000 | 81 | Quaternary Basalt | Artesian | 1790 |
| 19 | Bahir Dar 08(2) | 1800 | 115880 | 373994 | 106 | Quaternary Basalt | Artesian | 1800 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 21 | Bahir Dar 11 (3) | 1820 | 116000 | 374150 | - | Quaternary Basalt | Artesian | 1820 |
| 22 | Bahir Dar 13 (1) | 1800 | 116060 | 373750 | 72 | Quaternary Basalt | 7 | 1793 |
| 23 | Bahir Dar 13 (2) | 1800 | 116050 | 373750 | 53 | Quaternary Basalt | 2.45 | 1791.55 |
| 24 | Bahir Dar 13 (3) | 1805 | 115990 | 373750 | - | Quaternary Basalt | Artesian | 1805 |
| 25 | Bahir Dar 14 | 1795 | 115810 | 373828 | 70 | Quaternary Basalt | Artesian | 1795 |
| 26 | Bahir Dar 15 | 1800 | 115910 | 373822 | 55 | Quaternary Basalt | 1.15 | 1798.85 |
| 27 | Bahir Dar peda | 1790 | 115690 | | 60 | Quaternary Basalt | Artesian | 1790 |
| 28 | Debretabor (1) | 2690 | 118560 | 380153 | 110 | Tarmaber basalt | 8.03 | 2681.97 |
| 30 | Wanzaye | 1870 | 118080 | 376222 | - | Allavium | Artesian | 1870 |
| 31 | Dangla (1) | 2150 | 112630 | 368517 | 104 | Quatenary Basalt | 26.8 | 2123.2 |
| 32 | Dangla(2) | 2150 | 112640 | 368478 | 57.9 | Quatenary Basalt | 30.76 | 2119.24 |
| 33 | Dangla (3) | 2150 | 112640 | 368478 | 122 | Quatenary Basalt | 22.02 | 2127.98 |
| 34 | Dangla (4) | 2152 | 112730 | | 120.5 | Quatenary Basalt | 5 | 2147 |
| 35 | Dangla (5) | 2160 | 112510 | 368486 | 124 | Quatenary Basalt | Artesian | 2160 |
| 36 | Debretabor (3) | 2640 | 118660 | 379889 | 72 | Tarmaber Basalt | 2 | 2638 |
| 37 | Debretabor (4) | 2640 | 118460 | 380458 | 122 | Tarmaber Basalt | 7.31 | 2632.69 |
| 38 | Durbete (1) | 2000 | 113550 | 369600 | 30 | Quaternary Basalt | 12 | 1988 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 39 | Debretabor (2) | 2570 | 118640 | 380153 | 72 | Tarmaber basalt | 3.5 | 2566.5 |
| 39 | Durbete (2) | 2000 | 113550 | 369600 | 30 | Quaternary Basalt | 13 | 1987 |
| 40 | Enfraz (1) | 1910 | 121830 | 376333 | 100 | Alluvium | 16 | 1894 |
| 41 | Bahir Dar | 1790 | 116130 | 374133 | 23 | Quaternary | 2.2 | 1787.8 |
| 42 | Enfraz (2) | 1910 | 122000 | 376500 | 54 | Alluvium | Artesian | 1910 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 43 | Gonder W1 | - | 125830 | 374500 | 65.9 | Tarmaber Basalt | 6.32 | - |
| 44 | Gonder W2 | - | 125830 | 374500 | 120 | Tarmaber Basalt | - | - |
| 45 | Gonder W3 | - | 125830 | 374500 | 90 | Tarmaber Basalt | - | - |
| 46 | Gonder W4 | - | 126000 | 374500 | 91.7 | Tarmaber Basalt | 3.24 | - |
| 47 | Gonder W no 1 | 2150 | 125830 | 374500 | 92 | Tarmaber Basalt | 4.6 | 2145.4 |
| 48 | Gonder W no 2 | 2190 | - | 374500 | 140 | Tarmaber Basalt | 6.67 | 2183.33 |
| 49 | Gonder W no 3 | 2170 | - | 374500 | 92 | Tarmaber Basalt | Arte sian | 2170 |
| 50 | Gorgora (1) | - | 122500 | 372833 | 72 | Tarmaber Basalt | - | - |
| 51 | Gorgora (2) | - | 122330 | 372833 | 92.5 | Tarmaber Basalt | 0.75 | - |
| 52 | Gorgora (3) | - | - | 372833 | 72.5 | Tarmaber Basalt | - | - |
| 53 | Hamusit | 2000 | 117680 | 375511 | 118 | Alluvium | 5.2 | 1994.8 |
| 54 | Kola Diba $GtW_1$ | 1829 | 124000 | 373333 | 96 | Tarmaber Basalt | Arte sian | 1829 |
| 55 | Kola Diba $Gtw_2$ | 1851 | 124170 | 373167 | 44 | Alluvium | 5.34 | 1845.66 |
| 56 | Kunzila | 1805 | 118760 | 370256 | 70 | Quaternary Basalt | 5.47 | 1799.53 |
| 57 | Maksegnit | 1945 | 124000 | 375333 | 72 | Tarmaber Baslalt | 4.7 | 1940.3 |
| 58 | Tseda # 1 | 1970 | 125670 | 375333 | 45 | Tarmaber Basalt | 5.75 | 1964.25 |
| 59 | Wada yessus | 1960 | 105250 | 373544 | 80 | Tarmaber Basalt | 5.7 | 1954.3 |
| 60 | Wotet | 1970 | 113730 | 376964 | 38 | Quaternary Basalt | 4.9 | 1965.1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Abbay | | | | | | | |
| 61 | Woreta (1) | 1810 | 119240 | 376603 | 60 | Alluvium | 20 | 1790 |
| 62 | Woreta (2) | 1870 | 118840 | 377167 | 55 | Alluvium | 3 | 1867 |
| 63 | Yifar | 1850 | 120500 | 373083 | 60 | Alluvium | 3.72 | 1846.28 |
| 64 | YenYenessa | 1820 | 115450 | | 61 | Quaternary Basalt | 3.80 | 1971.2 |
| 65 | Zege | 1820 | 116830 | 373083 | 62 | Quaternary basalt | 3.13 | 1816.87 |
| 66 | Aykel BH1 | - | 129250 | 384000 | 186 | Ashengi basalt | - | - |
| 67 | Debre taber W5 | 2547 | 111220 | 383828 | 150 | Tarmaber basalt | 4.5 | 2542.5 |
| 68 | Debre taber W6 | 2555 | 111191 | 383696 | 140 | Quaternary basalt | 197 | 2535.3 |
| 69 | Debre taber W7 | 2569 | 111160 | 383598 | 141 | Quaternary basalt | 28.6 | 2540.4 |
| 70 | Debre taber W8 | 2538 | 111240 | 384055 | 150 | Quaternary basalt | 43.56 | 2494.44 |
| 71 | Bahir dar Zuria(Achfer) | - | 129200 | 373010 | 40 | Quaternary basalt | 6.00 | - |
| 72 | Bahir dar Zuria (meshenty ) | - | 126900 | 373130 | 52.4 | Quaternary basalt | 15.0 | - |
| 73 | Bahir dar Zuria (ZelemaN2) | - | 129000 | 373100 | 27 | Quaternary basalt | 14.50 | - |
| 74 | Bahir dar Zuria (lata) | - | 129400 | 373070 | 52.4 | Quaternary basalt | 6.0 | - |
| 75 | Bahir dar Zuria | - | 128350 | 373350 | 57.45 | Quaternary basalt | 3.50 | - |
| 76 | Bahir dar | - | 128450 | 373130 | 64.4 | Quaternary | 13.00 | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | basalt | | |
| 77 | Bahir dar Zuria (Yigoda) | - | 128700 | 373060 | 64.4 | Quaternary basalt | 12.00 | - |
| 78 | Bahir dar Zuria (Egodi) | - | 127700 | 373170 | 67.4 | Quaternary basalt | 0.60 | - |
| 79 | Bahir dar Zuria (Gonbat) | - | 117800 | 373160 | 96.55 | Quaternary basalt | 27.00 | - |
| 80 | Bahir dar Zuria (Wonjita) | - | 129000 | 373120 | 27.0 | Quaternary basalt | 14.50 | - |
| 81 | Dashin Brewery WNo2 | - | - | - | 150.0 | Tarmaber basalt | 37.10 | - |
| 82 | Dashin Brewery WNo3 | - | - | - | 151.0 | Tarmaber basalt | 3.92 | - |
| 83 | Negadebahir | 1100 | 125830 | 374667 | 208.00 | Ashangi | - | - |
| 84 | Addis Zeman WNo6 | - | 134000 | 366000 | 31.00 | Tarmaber Basalt | 4.0 | - |
| 85 | Ambomeda | - | 133900 | 379000 | 43.00 | Tarmaber Basalt | 9.00 | - |
| 86 | Wotet Abbay, BH2 | 1790 | 113730 | 370360 | 61.00 | Quaternary Basalt | 4.45 | 1785.15 |
| 87 | Hamusit No2 | 1804 | 114927 | 373631 | | Allvial | | |
| 88 | Woreta WNo6 | 1810 | 119240 | 376964 | | Allvial | | |
| 89 | Yibab Eyesu | 1831 | 113270 | 371845 | | Quaternary | | |
| 90 | Dangela | 2068 | 111644 | 364849 | | Quaternary | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | WNo7 | | | | | | | |
| 91 | Durbet WNo3 | 1981 | 112133 | 365773 | | Quaternary | | |
| 92 | Addis Zemen Wo2 | 1803 | 120473 | 374510 | | Tarmaber | | |
| 93 | Enfra 2 WNo3 | 1882 | 121530 | 373712 | | Aluvial | | |
| 94 | Maksegnit BH2 | 1906 | 122353 | 373344 | | Tarmaber | | |
| 95 | Berta chera chara | 1786 | 113681 | 372486 | | Quatemary | | |
| 96 | Gurdema {Kb14} | 1795 | 113372 | 372308 | | Quaternary | | |
| 97 | GundoBrehan | 1805 | 113487 | 372129 | | Quatemary | | |

# ANNEX II

Hand dug wells and springs chemical data

| Name | Na | K | Cl | Ca | Mg | $NH_4$ | $NO_3$ | $HCO_3$ | F | Hardness ($CaCO_3$) | Conductance (µS/cm) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K-1 | 3 | 0.9 | 1.93 | 12 | 7.3 | 0.039 | 1.76 | 73.2 | 0.04 | 60 | 128.64 | 7.35 |
| K-2 | 3.4 | 1.4 | 0.96 | 13.6 | 4.86 | 0.271 | 2.2 | 68.32 | 0.06 | 54 | 139.36 | 6.92 |
| K-3 | 5.3 | 2 | 0.96 | 26.4 | 10.7 | 0.16 | 1.32 | 136.64 | 0.28 | 110 | 233.64 | 6.48 |
| K-4 | 3.1 | 0.6 | 3.86 | 17.6 | 8.8 | 0.17 | 1.32 | 100.04 | 0.17 | 80 | 170.56 | 6.66 |
| K-6 | 2.4 | 1 | 9.64 | 13.6 | 3.89 | 0.05 | 11.88 | 29.28 | 0.01 | 50 | 128.64 | 5.36 |
| K-7 | 3.3 | 0.7 | 2.89 | 8.8 | 2.43 | 0.13 | 3.96 | 34.16 | 0.23 | 32 | 74.9 | 6.45 |
| K-10 | 1.6 | 1 | 0.96 | 4.8 | 6.32 | 0.16 | 5.72 | 14.64 | 0.18 | 38 | 53.5 | 5.19 |
| K-11 | 1.3 | 0.6 | 1.96 | 4 | 3.4 | 0.08 | 0.88 | 14.64 | ND | 24 | 42.56 | 5.2 |
| K-12 | 12 | 3.9 | 3.86 | 24 | 8.75 | 0.03 | 4.84 | 139.08 | 0.13 | 96 | 265.5 | 6.95 |

Note: All concentrations are in mg/l

Key:

K-1: Denmeni Spring
K-2: Merkurios Spring
K-3: Burka Spring
K-4: Label Spring
K -6: Abagaro Spring
K-10: Hand-dug well
K-11: Hand-dug well
K-12: Wetet Abbay borehole

## ANNEX III

Samples collected from the study area during field survey

| Type | Cond (µs/cm) | Temp ($^0C$) | TDS (mg/L) | pH | $F^-$ (mg/L) | $Cl^-$ (mg/L) | $NO_3^-$ (mg/L) | $SO_4^{2-}$ (mg/L) | $CO_3^{2-}$ (mg/L) | $HCO_3^{2-}$ (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| BH1 | 505.0 | 23.3 | 303 | 7.4 | 0.42 | 20.57 | 1.57 | 10.09 | 0.00 | 323.30 |
| HDW1 | 456.0 | 22.7 | 273 | 7.34 | 0,66 | 16.57 | 3.82 | 10.30 | 0.00 | 284.26 |
| BH2 | 360.0 | 22.8 | 217 | 7.76 | 0.49 | 6.79 | ND | 7.67 | 0.00 | 240.34 |
| HDW2 | 524.0 | 23.3 | 314 | 7.17 | 0.17 | 21.57 | 24.32 | 3.10 | 0.00 | 305.00 |
| BH3 | 241.0 | 22.2 | 144.4 | 6.84 | 0.25 | 6.37 | 16.69 | 0.89 | 0.00 | 152.50 |
| CS1 | 217.0 | 22.5 | 130 | 6.55 | ND | 2.08 | 9.57 | ND | 0.00 | 147.62 |
| CS2 | 143.8 | 22.7 | 86.2 | 7.05 | ND | 1.85 | 17.13 | ND | 0.00 | 87.84 |
| BH4 | 233.0 | 22.3 | 140.4 | 8.07 | 0.28 | 2.43 | 0.59 | 0.70 | 0.00 | 161.04 |
| BH5 | 358.0 | 22.3 | 215 | 6.61 | 0.2 | 13.2 | 47.48 | ND | 0.00 | 162.26 |
| HDW3 | 694.0 | 23.4 | 416 | 7.65 | 0.72 | 22.06 | 1.41 | 52.47 | 0.00 | 466.04 |
| BH6 | 917.0 | 23.2 | 551 | 7.8 | 2.95 | 16.06 | 50.23 | 21.63 | 0.00 | 628.30 |
| BH7 | 622.0 | 22.7 | 373 | 7.23 | 0.32 | 10.6 | 7.24 | 6.19 | 0.00 | 451.40 |
| BH8 | 421.0 | 23.1 | 253 | 7.74 | 0.43 | 20.51 | 1.05 | 9.89 | 0.00 | 257.42 |
| BH9 | 310.0 | 22.4 | 186.9 | 6.67 | ND | 2.22 | 15.64 | 0.44 | 0.00 | 206.18 |
| BH!0 | 344.0 | 22.4 | 207 | 8.44 | 0.45 | 9.00 | ND | 3.18 | 21.6 | 242..78 |
| BH11 | 212.0 | 22.5 | 126.9 | 6.91 | 0.26 | 2.52 | 19.06 | 0.61 | 0.00 | 120.78 |
| HDW4 | 369.0 | 22.3 | 221 | 7.17 | 0.12 | 6.64 | 8.21 | 2.06 | 0.00 | 234.24 |
| Lake | 162.2 | 23.3 | 97.2 | 7.7 | 0.41 | 6.07 | 0.12 | 6.64 | 0.00 | 103.70 |

ND not determined

BH -borehole

HDW –hand dug well

CS –cold spring

DECLARATION

I, the undersigned, declere that this thesis is my original work and has no have been presented for a degree on any other university.

All sources of materials used for the thesis have dully acknowleged.

Ayalew Hussen

.........................

Signature

Place and date of submission: School of Graduate studies, Addis Ababa University

January 2010