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Institute of Technology, School of Biosystems and Environmental Engineering

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Groundwater Characterization of Tikur Wuha River Catchment, Southern Ethiopia

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I, Gulilat Gebrechristos Ergena, declare that this thesis is my original work and that it has not been presented and will not be presented by me to any other university for similar or any other degree award.

Signature: __________

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Abbreviations

EC	Electrical Conductivity
FAO	Food and Agricultural Organization
MER	Main Ethiopian Rift
NNE	North North East
SNNPR	South Nations and Nationalities People Region
SSW	South South West
TDS	Total Dissolved Solids
WHO	World Health Organization
WWDSE	Water Works Design and Supervision Enterprise

Table of Contents

List of Tables

List of Figures

ABSTRACT

The development of balanced plan for water resource utilization requires assessment of the water resources in terms of quality, quantity, spatial distribution and the land use land cover condition of the entire catchment area. This thesis work is aimed to characterize different aquifer systems and their hydrochemistry in Tikur Wuha River catchment which is located in South part of Ethiopia particularly in Sidama Zone. The catchment area of Tikur wuha River 625 km$^{2.}$ The area is located in central part of MER and generally characterized by two topographic features. which is the high land near the rift escarpment and the rift floor. The study area is covered by Recent lacustrine and alluvial deposits, scoria cones, rhyolitic lava flows and associated ignimbrites, tuffs and volcanic ash. The escarpment and the mountains of the eastern margin of the catchment are made up of Nazeret series, which is composed of ignimbrite, unwelded tuff, ash flow, rhyolitic flow, domes and trachyte. The low laying area which is the rift floor is covered with lacustrine and alluvial deposits. The hydrogeological classification is done using qualitative and quantitative approaches based on the hydrogeological characteristics of lithological unit and different data collected from different organization, based on this the study area is classified in to the following aquifer aquiclude system. Extensive and highly productive porous aquifer (T=110-2000 m2/day, K=5-400 m/day and Q= 17-70 l/s). Highly to moderately productive mixed porous and fissured aquifers (T=500-2700 m2/day, K=15-560 m/day and Q= 10-30 l/s). Extensive moderately productive fissured aquifer (T=10-110 m2/day, K=0.5-5 m/day and Q= 5-10 l/s). Extensive low to moderately productive mixed porous and fissured aquifer (T=10-55 m2/day, K=0.1-1 m/day and Q= 2.5-5 l/s). Low potential aquifers and aquicludes also cover some parts of the study area. Aquachem software has been employed to identify the different water types. From the analysis of hydrogeochemical data different water types are identified of which the majority of the cold springs, dug wells and boreholes from the highlands and escarpments are Ca-Mg-HCO3 type and Ca-Na-HCO3 type. The majority of waters from the rift floor boreholes and shallow wells; sodium is the dominant cation and the dominant anion is bicarbonate. These ground waters are Na–Ca-HCO3 and Na- HCO3 type.

1. INTRODUCTION

1.1 Background and Justification

Water is essence food and the basic component of life. The need for water is strongly ascending and has diversified purpose, which is not only important for drinking purpose but also vital for any development activities. It is the most essential resource affecting municipal, agricultural and economic activities. Any development is related either directly or indirectly to water utilization. Persistent drought and population growth together with the need for water to domestic, irrigation and industrial development brings high demand in water resources. It is therefore of great importance that they should be developed and used in a sustainable manner so as to maintain adequate water resources and preserve the environment.

More than 98% of the available global fresh water is ground water (Fetter, 1994), which is one of the most precious resources that nature has provided and occurs under the ground in rock unit (s) that can store and transmit water at the rates fast enough to supply reasonable amount to wells. There are various types of aquifer which are composed of various types of rocks. An aquifer in a given area could be a rock of sedimentary, igneous, or metamorphic origin depending on the degree of interconnection of fractures, joints, bending; planes grain size, grain sorting (degree of assortment), orientation of grains and the prevailing hydro geological condition, etc. Ethiopia consists of a large variety of metamorphic, sedimentary and igneous rocks with diverse aquifer characteristics. The study area dominantly consists of volcanic rocks.

Water which is absolutely pure is not found in nature. Even water vapor condensing in the air cations solids dissolved salt, it seeps up other materials from the air and becomes more contaminated on reaching the ground, running on the surface and percolating through the various strata of the soil and rock. Some contamination may be removed by passage through the soil as result of infiltration and adsorption and exchange reactions, some may be removed in the surface water by sedimentation and biological activity; specific engineered processed in the treatment plants may remove some of them.

In the study area, surface and ground water are the most important water supply sources for the community. But information on ground water recharge, storage, circulation and factors that influence ground water circulation and its chemical evolution is not well known. This study tries to address the hydrogeological setup of Tikurwuha catchment, by giving attention to the qualitative and quantitative aquifer characterization and hydrochemistry of the catchment.

1.2 Statement of the Problem

The concept of groundwater regions is a very important generalization in the study of hydrogeology. These are geographical areas of similar occurrence of groundwater. If an area is subdivided into several smaller regions, useful comparisons can be made between areas of well-known hydrogeology and areas that are geologically similar but have not been as well studied (Fetter, 2001).

Many of us depend on ground water for our very existence. Ground water is a precious and most widely distributed resource of the earth. It is obvious that for the full utilization of existing water resources, good understanding of hydro geological systems, ground water flow direction, recharge and discharge condition and hydrochemistry is highly important.

Tikur Wuha river catchment is located in SNNPR Zone, Southern Ethiopia. The catchment is drained by Tikur Wuha river and its tributaries covering Wondogenet and Malga Woredas of Sidama Zone and Hawassa town itself. Hawassa well field is part of this catchment, which is the most important well field for ground water supply of Hawassa town.

For the study area is part of the main Ethiopian rift, it is highly affected by the uplift and subsequent rifting phenomena that created localized and regional fractures and faults, (the rift floor and escarpments are highly faulted); the complex spatial and temporal distribution of the volcanic rocks, their different intricate stratigraphic and structural relationships, wide compositional variability, different degree of weathering and topographic position complicate the hydrogeological behavior of the volcanic aquifers and the hydro chemical signature requires systematic and scientific approach of investigation to determine the groundwater potential,) in the area.

It is common to have problem in exploitation of groundwater in that unsuccessful rate of well production encounter and requires huge amount of investment cost to utilize this precious resources. Improper evaluation of groundwater and site selections is mostly expected to pose the problems. Since the groundwater occurs out of our sight, deep in the subsurface, there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the groundwater occurrence and distribution controlling parameters.

In the study area, groundwater is the most important water supply for the community. But information on ground water recharge, storage, circulation and chemical evolution is barely known. A picture of ground water recharge and factors that influence ground water circulation and its chemical evolution is lacking. The ground water development in this study area was conducted without a good understanding of its role in the characterization of aquifer and hydro chemistry of natural water.

In area where surface water is not available, ground water is the second alternative for irrigation purpose, if the demand for the irrigation and ground water potential is promising without negative environmental effect. To use water for drinking purpose, the water should be analyzed in terms of quality and quantity. The water supply needs chemical, physical and bacteriological analyses.

Despite water requirement is increasing very rapidly with the growth of human and animal population, and irrigation in the area, analysis of water resources has been fragmentary. Thus, as a part of filling the gap, the present study may give insight to the hydrogeological conditions of the catchment as well as, the hydrochemistry of the aquifer systems.

1.3 Objective

1.3.1 General Objective

The main objective of this research is to undertake groundwater characterization of Tikur Wuha river catchment.

1.3.2 Specific Objectives

1. To characterize aquifer systems and aquifer units in the study catchment
2. To identify the hydrogeology of the catchment in terms of water bearing layers using qualitative and quantitative parameters
3. To determine groundwater flow direction of the study catchment
4. To examine the hydrochemistry of the aquifer systems

2. LITERATURE REVIEW

2.1 Aquifer characterization

2.1.1 Hydrogeological units.

An aquifer is defined as a saturated permeable geological unit that stores and transmits economic quantities of water to wells. The excellent aquifers are unconsolidated sands and gravels of alluvial deposits, but permeable sedimentary rocks such as sandstone and limestone, and highly fractured and/or weathered volcanic and crystalline rocks can also be classified as aquifers.

An aquitard is a semi-permeable geological unit that store but transmit very small amount of water. When viewed over large areas and long periods, its permeability is not sufficient to justify production wells being placed in it. But they are equally important like aquifers, because they retain the groundwater by overlaying and underlying. Clays, loams, and shales are typical examples of aquitards.

An aquifuge is an impermeable geological unit that neither store nor transmit water at all. Dense unfractured igneous or metamorphic rocks are typical examples of aqufuges. However, in nature truly impermeable geological units seldom occur. All of them leak to some extent, and must therefore be classified as aquitards. In practice, however, geological units can be classified as aquifuges when their permeability is several orders of magnitude lower than that of an overlying or underlying aquifer.

2.1.2 Aquifer Types

2.1.2.1 Confined Aquifer

A confined aquifer is bounded above and below by an aquiclude. In a confined aquifer, the pressure of the water is usually higher than that of the atmosphere, so that if a well taps the aquifer, the water in it stands above the top of the aquifer, or even above the ground surface. We then speak of a free-flowing or artesian well.

2.1.2.2 Unconfined Aquifer

An unconfined aquifer, also known as a water table aquifer, is bounded below by an aquiclude, but is not restricted by any confining layer above it. Its upper boundary is the water table, which is free to rise and fall. Water in a well penetrating an unconfined aquifer is at atmospheric pressure and does not rise above the water table.

2.1.2.3 Leaky Aquifer

A leaky aquifer, also known as a semi-confined aquifer, is an aquifer whose upper and lower boundaries are aquitards, or one boundary is an aquitard and the other is an aquiclude. Water is free to move through the aquitards, either upward or downward. If a leaky aquifer is in hydrological equilibrium, the water level in a well tapping it may coincide with the water table. The water level may also stand above or below the water table, depending on the recharge and discharge conditions.

In deep sedimentary basins, an inter bedded system of permeable and less permeable layers that form a multi-layered aquifer system, is very common. But such an aquifer system is more a succession of leaky aquifers, separated by aquitards, rather than a main aquifer type.

2.2 Determination of aquifer parameters from pumping test data

2.2.1 Hydraulic Parameters

Hydraulic conductivity (K), Transmissivity (T) and Storativity(S) (specific yield for unconfined aquifers) are the hydraulic properties of aquifers and soil materials that determine how fast water moves into, and out of subsurface materials and how piezometeric surfaces or water tables are affected. Much of the success in predicting underground movement depends on how accurate the pertinent hydraulic parameters can be evaluated.

Hydraulic conductivity is a measure of the ability of a fluid to move through interconnected void spaces in the sediment or rock. It is a function of both the medium and the fluid.

Transmissivity is the rate at which water flows through a vertical strip of the aquifer. Or it can also be defined as the product of the average hydraulic conductivity and the saturated thickness of the aquifer (Tenalem and Tamiru, 2001).

2.2.1.1 Hydraulic conductivity

This is the most important parameter, because the other parameter as Transmissivity is obtained as a function of hydraulic conductivity; i.e. by multiplying K with aquifer thickness. Storativity is mostly the prominent character of unconfined aquifers and it ranges from 0.01 to 0.3, for confined ones storativitity is very negligible and ranges from 0.00005 to 0.005; because in confined aquifers, assuming the aquifer remains saturated change in pressure produce only small change in storage volume (Tenalem and Tamiru, 2001); because the water is under pressure, and when it is removed, other pressurized water nearby replaces. Thus, Hydraulic conductivity is the most important character of all aquifer types (i.e. confined, unconfined and leaky).

Hydraulic conductivity is governed by the size and shape of the pores, the effectiveness of the interconnection between pores, and the physical properties of the fluid. If the interconnecting pores are small in size, the volume of water passing from one pore to the other is restricted and the resulting hydraulic conductivity is quite low. Similarly, if the fluid is viscous due to dissolved materials, the hydraulic conductivity will be low.

2.3 Hydrogeology

The assessment of groundwater resources entails broad understanding of various parameters in relation to ground water occurrence, movement, distribution in prevailing hydrogeologic environment. It involves identification and characterization of hydrogeologic units, recharge discharge conditions, aquifer type, property and set up, ground water flow system as well as surface and ground water interaction.

The dominant volcanic rocks in the earth's crust are basalts, andesites, trachytes, dacites, rhyolites and volcanic pyroclastic rocks such as welded tuffs (ignimbrites), unwelded tuffs, surge deposits, pumice and scoria fall deposits. Groundwater in these rocks is the major source of water for large parts of the world's population. They have extremely variable hydrogeological characteristics. Since they differ in their mineralogy, texture and structure their water bearing potential vary accordingly.

The groundwater circulation and storage capacity of volcanic rocks depend on the nature of the porosity and permeability of the aquifers (Permeable geological formation which contains saturated pores and fractured media to store and transmit significant amount of groundwater). In these rocks the occurrence of water bearing structures is conditioned by the primary and secondary porosity and permeability of the lithological units.

All rock structures possessing primary porosity may not have necessarily a primary permeability; i.e. non connected vesicles possess a large primary porosity, but no or little primary permeability. Their later connections, due to weathering or fracturing, may give rise to secondary permeability. Primary porosities are peculiar characteristics of the volcanic textures and structures such as vesicles, flow contacts or interflow spaces, lava tubes or tunnels, clinker or rubble layers in the aa lavas, tree molds and shrinkage cracks. Whereas, secondary porosities are due to tectonic fractures, inter trappean beds, weathering zones (Tenalem and Tamiru,2001).

Both porosity and permeability of volcanic rocks tend to decrease slowly with time. Some of this decrease is owing to compaction, but the filling of the pores with secondary minerals is the most important cause of the decrease. On the other hand, faulting and fracturing will increase the permeability of the volcanic rocks.

An interaction of geologic and geomorphic factors governs the movement of water from the time it reaches the land surface till the time of leaving it. Geomorphic features control the distribution and amount of precipitation that contributes to run off and ground water recharge.

The nature, distribution and structure of geologic formation control the occurrence, movement and availability of ground water. Of all, the primary importance is the occurrence and distribution of aquifers and their relationship with the associated relatively impermeable beds that act as leaky or non-leaky confining layers and barriers to ground water movement. The geologic structure has a marked influence on the lateral and vertical extent of aquifers and associated less permeable rocks.

The surface and subsurface run off are governed, in part, by geology on which depend the development of land forms, infiltration characteristic of zone of aeration and transmissive characteristics of aquifers. The porosity and permeability of consolidated rocks are attributed to process of rock fracturing and weathering controlled by topography, lithology, structure and climate. The depth of fracturing and weathering as well as the nature of weathered product, together determine availability of ground water and its supply to wells.

The principal hydrogeologic properties of rocks are porosity, effective porosity or specific yield and permeability. These properties control the entrance of water in the water bearing formations. Hydrogeologic properties depend chiefly on porosity, size of openings or interstices and their shape arrangement, interconnection, continuity. Rock formations and the openings there in are the results of primary geologic processes which form the rocks and secondary processes that modify them by either increasing or decreasing their porosity and permeability.

2.4 Occurrence of groundwater/ sub surface water

Most water on our planet occurs as saline water in the oceans and deep underground or is contained polar icecaps and the permanent ice cover of the high mountain ranges. So, only 30 million km^3 of fresh water, that’s only 2 percent of all water, plays an active part in the hydrological cycle and in the maintenance of all life on the continents. The water vapor turns in to fresh water precipitation (rain, hail, snow) on the earth's surface (seas, land), then flows over the land surface (glaciers, runoff, streams) and infiltrates into the soil (soil water) to be used by the vegetation (evapotranspiration), or to recharge the groundwater bodies. Sub sequentially, most groundwater returns either by being pumped or by natural outflow, to surface water bodies which subsequently discharge back into the sea.

Subsurface water is generally divided into two major types; phreatic water or soil moisture in the unsaturated zone and groundwater in the saturated zone.

Groundwater is part of the earth's water or hydrological cycle. When rain falls, a part infiltrates the soil and the remainder evaporates or runs off into rivers. The roots of plants will take up a proportion of this moisture and then lose it through transpiration to the atmosphere, but some will infiltrate more deeply, eventually accumulating above an impermeable bed, saturating available pore space and forming an underground reservoir. Underground strata that can both store and transmit accumulated groundwater to outlets in rivers, springs and the sea are termed aquifers.

In the major aquifers, the rock matrix provides a certain proportion of the total storage capacity of the system, while the fractures provide the dominant flow-path. The most widespread aquifers combine these features and are known as dual permeability aquifers, where regional flow can occur through the matrix and some through structural features such as joints or fault planes. This situation is common in many sand stones.

The effect can be enhanced during aquifer development where individual boreholes/well fields may become extra productive after prolonged pumping through preferential near-well development of local fracture system (Chow, 1988).

2.5 Groundwater mapping

A complexity of factors: hydrogeological, hydrological and climatological, control the groundwater occurrence and movement. The precise assessment of recharge and discharge is rather difficult, as no techniques are currently available for their direct measurements. Hence, the methods employed for groundwater resource estimation are all indirect. Groundwater being a dynamic and replenish able resource is generally estimated based on the component of annual recharge, which could be subjected to development by means of suitable groundwater structures (Kumar, 1997).

The occurrence of groundwater is mainly influenced by the geology, geomorphology, tectonics and climate of the country. The variability of these factors in Ethiopia strongly influences the quantity and quality of the groundwater in different parts of the country (Tamiru, 2006).

Many water wells drilled or dug in Ethiopia are abandoned due to low yields or as dry. In most cases lithologic units of Ethiopia have heterogeneous hydro-geological characteristics and therefore each site need to be treated separately for water well sitting.

2.6 Groundwater flow system and directions

It is important to determine the position of the water level and the direction in which ground water moves because many water related projects and constructions are highly influenced by ground flow system. Ground water is driven by lateral variation in topography in water table or phreatic aquifers. Local relief in topography is high that causes local system of ground water flow. Due to pronounced local relief various condition of ground water flow in local and intermediate flow systems possibly exists. However, in phreatic aquifer the regional system of ground water flow may be considered similar to surface water flow condition. In the study area the flow system generally follows the topographic variation. The local ground flow direction varies within small areas depending on the topographic effect at the shallow depth whereas the regional ground water flow shows the general direction at a depth.

Unlike many sedimentary basin aquifers, which are characterized by similar groundwater flow pattern and continuity over vast regions; the groundwater dynamics and recharge mechanism in volcanic terrain remains challenging system. This is confirmed by the presence of highly variable groundwater flow patterns, chemistry, groundwater depths, occurrences, and discharge mechanisms. The general implication is that the dominant and even in some cases the sole source of recharge to the aquifers or thermal waters of the area comes from groundwater inflow from the surrounding highlands (Seifu *et al.,* 2001).

By means of field measurements of the water table or piezometric surface, representative contour maps can be drawn for the various types of aquifers within the hydrogeological basins (Tenalem and Tamiru, 2001).

The groundwater flow lines, sketched perpendicular to the groundwater level contour lines (equipotential surfaces), show the direction of groundwater flow. Equipotential surfaces are groundwater level contour lines of equal head.

Contour maps of groundwater levels (i.e. groundwater elevation levels) and flow lines provide very useful data for locating new productive wells in a given area. Diverging contour lines indicate regions of groundwater recharge, while converging contour lines are associated with groundwater discharge areas (Tenalem and Tamiru, 2001).

Furthermore, areas of favorable hydraulic conductivity can be ascertained from the spacing of the contour lines. In fact, for areas with uniform groundwater flow, the portions having wide water table contour spacing and consequently flat gradients are characterized by higher hydraulic conductivity or permeability. In other words, dense contour map does not tell us high productivity of the aquifer; the closer (denser) the groundwater contour lines, the lower the hydraulic conductivity and the farther the groundwater contour lines the higher will be hydraulic conductivity.

2.7 Ground water recharge and discharge

Groundwater in unconfined aquifers moves from topographically high areas (recharge) to topographically low areas (discharge). In a recharge area, the potential energy decreases with depth, this results in downward movement of water. Between the recharge and discharge areas, groundwater flow is primarily horizontal. In a discharge area, the potential energy increases with depth, this results in upward movement of groundwater.

In humid areas with porous soils, 25% of annual rainfall may recharge the aquifer. In contrast, in desert regions recharge is very small — 1% of rainfall or less. Although commonly displayed on a two-dimensional surface, hydraulic-head distribution is generally a three-dimensional phenomenon i.e., hydraulic head varies vertically as well as laterally. The vertical distribution of hydraulic head can be determined by drilling wells near each other (nested) but open to different depths. If hydraulic head increases with increasing depth, groundwater flow is upward and, in general, indicates an area of discharge. If hydraulic head decreases at a given location with increasing depth within the aquifer, then groundwater flow is downward, indicating an area of groundwater recharge (Fetter, 2001).

For a local-scale flow system, the distance between recharge and discharge points is relatively short and groundwater travel times through the system may be on the order of days to years. For regional-scale flow systems, the distance between recharge and discharge points is much greater and travel times for groundwater are also much greater, on the order of decades to centuries. The determination of groundwater flow rates and directions is frequently difficult because of local variations in hydraulic conductivity, changes in stream stage, well withdrawals, and rainfall, just to name a few factors.

Many surface-water bodies (lakes, rivers, springs, and seeps) are “outcrops” of the water table, similar to the outcrops of rocks. Especially in humid regions, these surface-water bodies are useful for inferring water-table elevations where no wells exist. A stream into which groundwater naturally discharges are called a gaining stream. In arid regions, streams commonly lie above the water table and, therefore, recharge the groundwater systems; these streams are called losing streams. A spring is a place of natural groundwater discharge from a natural opening at the land surface. Springs may be classified according to the geologic formation. They may also be classified according to the amount of water they discharge (large or small), their water temperature (thermal, warm, or cold), or by the forces from which they are formed (gravity or artesian pressure). A spring is the result of an aquifer's being filled to the point that the water overflows onto the land surface. Springs may also flow from fractures (or other openings) connected to confined aquifers. Withdrawing groundwater from shallow aquifers that are connected to streams can have a significant effect on streams. The withdrawal can diminish the surface-water supply by capturing some of the groundwater flow that otherwise would have discharged to the stream or by inducing from the stream to the aquifer (Toth, 1963).

The amount of water that is extracted from an aquifer without causing depletion is primarily dependent upon the ground water recharge. Thus, a quantitative evaluation of spatial and temporal distribution of ground water recharge is a pre-requisite for operating ground water resources system in an optimal manner. Quantification of the rate of natural ground water recharge is basic for efficient ground water resource development and management. It is particularly important in regions with large demands for ground water supplies, where such resources are the key to economic development.

Rainfall is the principal means for replenishment of moisture in the soil water system and recharge to ground water. Moisture movement in the unsaturated zone is controlled by capillary pressure and hydraulic conductivity. The amount of moisture that will eventually reach the water table is defined as natural ground water recharge. The amount of this recharge depends upon the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth and the soil type.

Groundwater is naturally recharged upstream and discharged downstream. Recharge areas are close to mountain peaks, where precipitation is likely to be higher than in the adjacent lowlands. Shallow groundwater discharges in the valleys and other low-lying zones of the Earth's crust. Deep groundwater discharges directly into the ocean.

Through human intervention, groundwater is subject to artificial discharge, that is, the process of pumping groundwater from an aquifer to satisfy a socioeconomic need. In some instances, groundwater may also be subject to artificial recharge. Some progressive communities are presently accomplishing the artificial recharge of their aquifers in order to conserve the groundwater resource.

Excessive pumping can lead to groundwater depletion, wherein groundwater is extracted from an aquifer at a rate faster than it can be replenished. Depletion can have significant effects on surface and unsaturated subsurface (vadose) waters, and on the terrestrial, riparian, and other ecosystems which depend on these waters. There is often advantage to storing water under ground where evaporation losses are minimized. Underground storage also serves to replenish ground water resources in areas of over draft. Any process by which man fosters the transfer of surface water in to the ground water system can be classified as artificial recharge. The most common method involves infiltration from prodding to high permeability, unconfined, alluvial aquifers. When planning the management of ground water system, one need to know the limits to which water can be drown of safe yield should be introduced. Safe yield is usually desired as the annual drafts of water that can be withdrawn without providing some undesirable result. Numerous undesirable results can be produced by ground water withdrawal.

2.8 Groundwater divides and groundwater interactions

Groundwater divides are imaginary and vertical impermeable boundaries across which there is no flow (Freeze and Cherry, 1979) or the groundwater flow is away from this ideal line. The regional groundwater divide is the divide that separates one catchment basin from the other.

Groundwater and surface water are not isolated components of the hydrologic system, but instead interact in a variety of physiographic and climatic landscapes. In many regions ground water and surface water resources are connected and most surface water features (rivers, lakes, dams, wetlands) generally interact with groundwater. The exploitation of, or quality of one resource, can therefore affect the other. Groundwater and surface water bodies such as rivers most of the time interact in such a way that they are gaining, losing or acting as both.

A typical stream or river of humid region receives groundwater discharge: therefore, as one goes downstream the base flow increases, even if no tributaries join the river. This is a gaining or effluent stream type. In such a case, the water table slopes toward the stream, so that the hydraulic head (groundwater flow direction) of the aquifer is towards the stream (Tenalem and Tamiru, 2001).

In arid regions, many rivers are fed by overland flow, interflow and base flow at high altitudes. As they wind their way to a lower elevation, the local rainfall amount decreases, consequently, there is less infiltration and a lower (deeper) water table elevation. There may also be a dramatic change in the depth of groundwater when a stream draining a high altitude basin of lower permeability flows out onto coarse alluvial materials. For whatever reasons, if the bottom the stream channel is higher than the local water table, water may drain from the stream into the groundwater at depth. As one goes downstream of a given river of such a type, less and less water will be found in the channel. This is a losing or influent stream. The rate of water loss is a function of the depth of the flowing water and the permeability of the Underlying alluvium. Fine grained alluvial deposits on the channel will retard the rate of loss into the groundwater (Birhanu, 2009).

2.9 Hydrochemistry

The groundwater in the Ethiopian rift is both anthropogenically and naturally affected. In some cases, the chemistry of groundwater is controlled by the quality of surface water due to hydraulic connection. This will be true in urban centers. The main quality controls are: geomorphological and geographical conditions, climate, geology (geological structures, rock composition, weathering, magmatism, geothetrmal activities, etc.) Physico-chemical factors (temperature, pressure, chemical properties of elements, solubility of chemical compounds, pH, Eh, etc.) biological factors (effects of micro-organisms, plants and animals) and Anthropogenic influences *(*Tamiru, 2006).

Organic matter in the soil is degraded by microbes, producing high concentration of dissolved carbon dioxide (CO_2). This process lowers the PH by increasing carbonic acid (H_2CO_3) concentration in soil water. The production of carbonic acid starts a number of mineral weathering reactions, which result in bicarbonate (HCO^-_3) commonly being the most abundant anion in the water.

As a result of chemical and biological interaction between groundwater and geological materials through which it flows, and to a lesser extent because of contribution from atmosphere and surface water bodies, groundwater contains a wide variety of dissolved inorganic chemical constituents in varies concentrations (Freeze and Cherry, 1979).

The objectives of chemical hydro geological investigations are to determine the sources, concentration and fate of dissolved constituents within the physical frame work of flow and transport. The term “water chemistry” (or water quality) refers to the quantities of these various substances (commonly called solutes) that are present in a particular water sample, making up its chemical composition water acquires very small quantities of some solutes from dust and gases when it falls through the atmosphere as precipitation, but it typically acquires the majority of its solvents once it reaches the land surface. Solutes that were already present in the water increases in concentration because of the processes of evaporation and transpiration, for the most part, remove water while leaving the solutes behind.

Hydrochemistry can also assist in understanding the evolution of water quality, to examine natural base line conditions against which human impacts can be recognized and to take a look at some ways in which the protection and management of groundwater resources can be achieved. Some information on key minor and trace elements (Fe, Mn and F, for example) is also a requirement for understanding the geochemical environment of water, as well as, its portability.

Chemical reactions in which elements participate involve changes in the arrangement and association of atoms and molecules and interactions among electrons that surround the atomic nuclei. The field of neural water chemistry is concerned principally with reactions that occur in relatively dilute aqueous solution, although some natural waters have rather high solute concentrations. The reacting systems of interest are generally heterogeneous-that is, they involve both a liquid phase and a solid or a gaseous phase, or all three.

The scale of changes of the dissolved constituents is dependent on the physical and chemical properties of the surrounding rocks, the water temperature, salinity of water and its chemical content, the volume of water in movement and its velocity, periodic change of recharge water and the hydrologic and human factors. The way in which solutes are taken up or precipitated and the amount present in solution are influenced by many environmental factors, especially climate, structure and position of the rock strata and biochemical effect associated with life cycle of plants and animals, both microscopic and macroscopic (Hem,1992).

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 summed separately, and the results are compared. If the sum of the cations is not within 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 present in significant 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 generalizations 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 cations commonly occurs in groundwater flow systems. 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 concentrations (Freeze and Cherry, 1979)

Physical and chemical properties of the waters.

In recent years it has been recognized that the quality of groundwater is of nearly equal importance to quantity (Todd 1980). Physical characteristics of water that can be altered after sampling due to the physical and chemical changes of water and storage conditions should be measured during the field survey. These physical (water quality) parameters measured in the field are Temperature, pH, EC, TDS and Eh.

Temperature

Temperature of groundwater is reported in 0C and obviously must be measured immediately after collecting the sample (Todd, 1980).

This high range of temperatures is caused by a variety discharge mechanisms and, to a larger extent, by differences in the depth of circulation and local heat gradient values. Groundwater colder than local annual surface temperature occurs at high altitudes and is caused mainly by snowmelt recharge. Groundwater with a temperature close to the local average annual surface temperature belongs to the shallow active water cycle, circulation being limited up to 100m, and rarely 200m depth. Groundwater that is more than 6^0C above local average annual surface temperature circulates to appreciable depths, deducible from the heat gradient.

Electrical Conductivity (EC)

Electrical conductivity of water is its ability to conduct an electric current at a specified temperature and it is usually measured in micro siemens per centimeter or micromhos per centimeter. The values of EC increase with temperature, between 20ºC and 30ºC, an increase in 1ºC, increases the EC by two percent on the average (Hem, 1992).

Total Dissolved Solids (TDS)

Total Dissolved Solids include all solid materials in solution, whether ionized or not. As it is related to the sum of the concentrations of all ions, it is directly related to the electrical conductivity.

All natural surface waters and some groundwater carry both dissolved and suspended particles. The amount of the latter present in groundwater before it is brought to the land surface generally is small. But, in river water the concentration of suspended material may be large, and at high stage of flow in many streams it generally exceeds the Total Dissolved Solids concentration (Tenalem and Tamiru, 2001).

Graphical presentations

Over the years, a considerable number of techniques for graphical representation of analyses have been proposed. Some of these are useful principally for display purposes that is, to illustrate oral or written reports on water quality, to provide means for comparing the analyses with each other, or to emphasize differences and similarities. Graphical procedures do this much more effectively than numbers presented in tables (Hem, 1989).

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

In addition to the types of graphs suitable for displays and comparison of analyses, graphical procedures have been devised to help detect and identify mixing of waters of different composition and to identify some of the chemical processes that may take place as natural waters circulate. Graphing techniques of the latter type may be useful in the study of data prior to preparing reports or arriving at conclusions.

3. MATERIALS AND METHODS

3.1 Location, accessibility and description of the study area

The study area is enclosed between $6^0$47' 33" and 7^0 10' 6" N latitude and 38^0 28' 13" and 38^0 43' 51" E longitude and covers a total area of 625 km^2. The town lies on the Addis Ababa - Nairobi road 275 kms from Addis Ababa. It is located in the SNNPR which is about 275 km from Addis Ababa. The main asphalted road from Addis to Hawassa reaches the study area. Tikur wuha cathment is part lake Hawasa catchment and it covers nearly half of the lake Hawassa catchment.

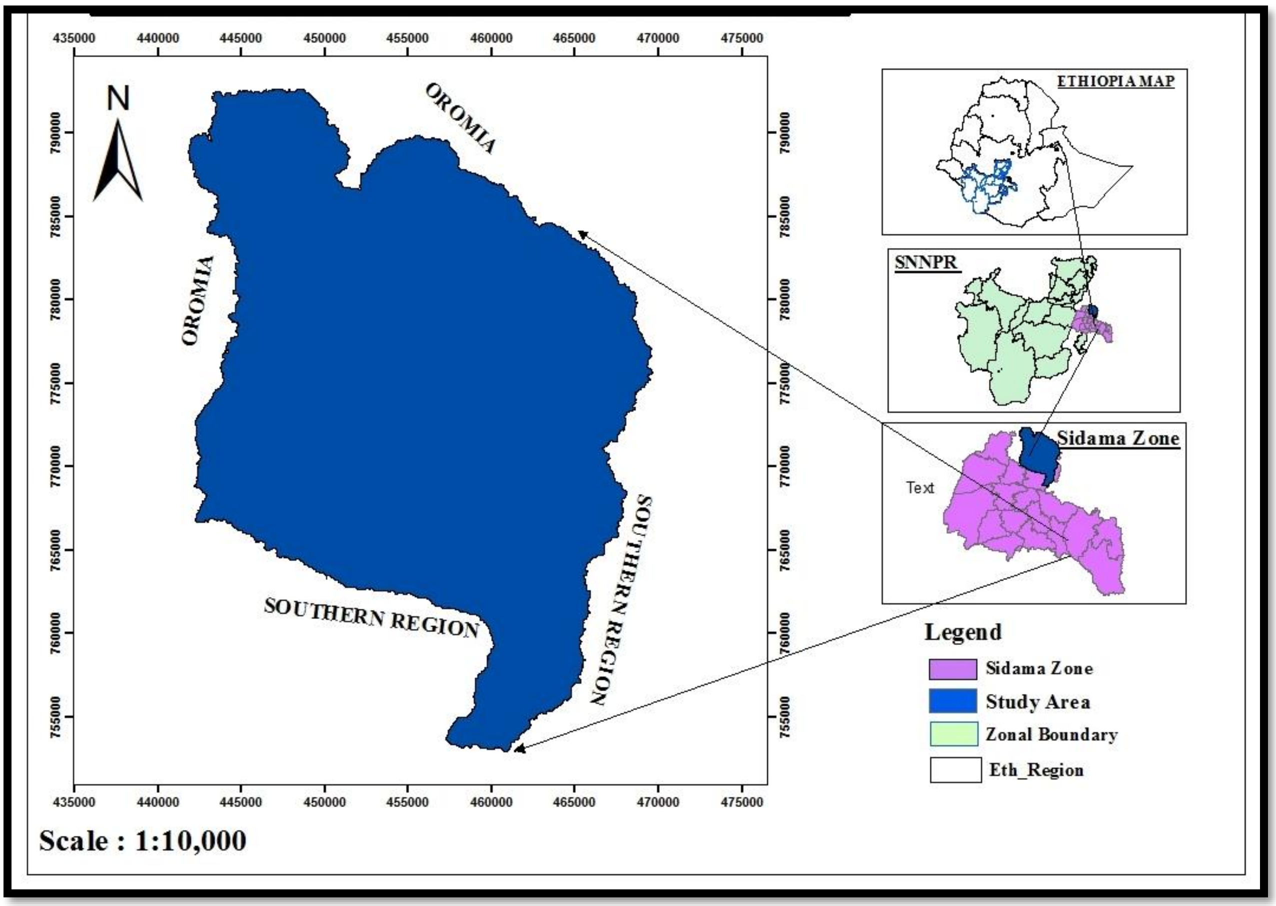

Figure 1.Location of the study area

3.2 Physiography and Drainage

The catchment area of Tikur Wuha River 625 km^2 that is 48 % of the lake Hawassa catchment area. There is a high elevation difference within the area ranging from 2900m to 1700m above sea level. The area can be divided in to two geomorphic zones, the eastern and south eastern highlands and the rift floor. Tikur Wuha river is the only perennial and gauged stream, which flows into lake Hawassa. There are eleven perennial streams which have their headwater in the eastern highland and flow to the west, Hawassa Caldera, crossing the Wodogenet escarpment that finally join together to form Tikur Wuha river which subsequently leads into Lake Hawassa.

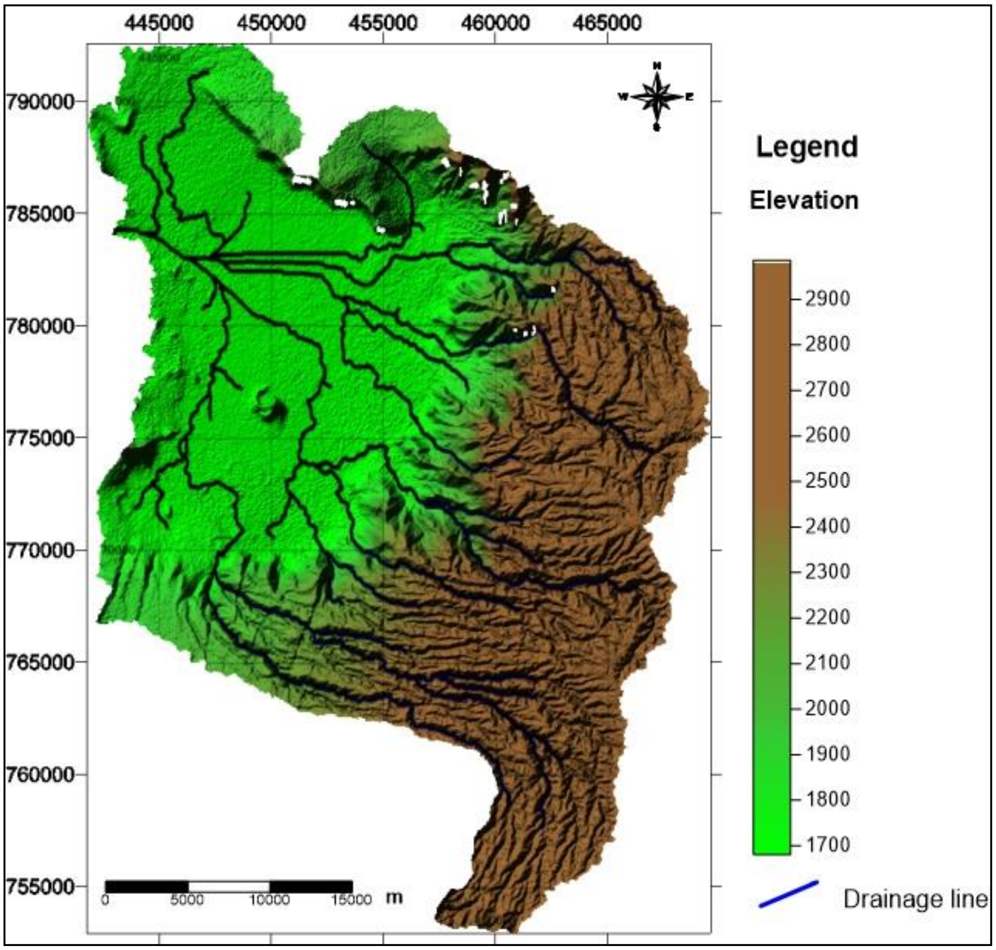

Figure 2.Physiograpy and drainage map of the study area

3.3 Climate and Hydrology

3.3.1 Climate

The Hawassa area has a sub-humid climate (FAO, 1984) and gets a mean annual rain fall of 1032mm over the entire catchment. The area is characterized by an eight month long rainy season from March to October where the big rain (Kiremet) occurs from July to September with rain fall range from 70-140mm and the dry period is from November to February that gets less than 20mm rain fall. The mean annual temperature at Hawassa is 19.5^{0}C and the mean annual temperature ranges from 12-260C. Maximum temperature occurs in January, February and March that reaches around 29^{0}C whereas minimum temperature occur during months of

November and October which decreases up to 10^{0}C. Daily sunshine hours range between 4-9 hrs, where the minimum occurs during rainy seasons and the maximum during dry months. The mean monthly relative humidity at Hawassa ranges between 54-76% which depends on the variation of dry and wet seasons. There is an eight month long rainy season from March to October with mean monthly range of 50-150 mm where in the remaining months less than 25 mm and the area gets high amount of rainfall in July, August and September (Wondwesen,2005).

Table 1. Annual rain fall of the study area

Station name	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Hawassa	27.3	36.3	79.0	112.2	119.4	103.7	121.4	118.6	121.3	68.3	32.4	21.0	960.8
wondogenet	31.1	41.4	101.9	145.0	130.5	107.5	128.3	138.8	143.2	100.4	42.9	24.0	1134.8
Haissawita	24.3	39.4	107.9	142.5	139.2	89.6	106.8	111.2	149.6	79.6	34.8	28.3	1053.1
Shashemene	21.0	26.6	71.5	110.2	107.4	73.1	98.3	88.7	116.2	66.5	27.9	19.4	826.9
Mean Monthly RF of the cathment	26.0	38.2	92.1	131.7	130.2	93.3	109.4	114.0	135.4	81.9	35.3	24.6	1012.1

In the study area, there are two stations recording maximum and minimum daily temperatures. These stations are used to calculate representative monthly and annual average temperature of the area. Accordingly, the average monthly and annual maximum and minimum temperatures of the catchment are shown in the table below.

Table 2. Mean monthly temperature of the study area

Temperature in ^{o}c	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual Temp.
Mean Max	26.4	27.6	27.3	25.9	24.9	23.4	22.4	22.7	23.4	24.4	25.5	25.7	25.0
Mean Min	11.2	11.7	12.6	13.3	13.1	13.0	13.0	13.0	12.6	11.9	10.5	10.3	12.2
Mean Monthly	18.8	19.7	20.0	19.6	19.0	18.2	17.7	17.9	18.0	18.2	18.0	18.0	18.6

The mean annual minimum temperature of the study area is 12.2 ^{o}C and the mean annual maximum temperature is 25.0 ^{o}C. The mean annual air temperature of the study area is 18.6 ^{o}C

Maximum temperature value was recorded in the month of February while minimum temperature record was obtained in December.

3.3.2 Hydrology

There are eleven perennial streams which have their headwater in the eastern highland, which are Bela, Wesha, Werka, Sole, Shenkora woha, Gomesha, Wodesa, Abosa, Kedo and Bogete flow to the western part of the catchment crossing the Wodogenet escarpment that finally join together to form Tikurwuha river which subsequently leads into Lake Hawassa.

Tikur Wuha River

This river is the only perennial river that enters in to the lake with a drainage catchment of 625km2. It has been gauged since 1981 at Dato village.

Lake Shallo

This Lake is found on the floor the caldera east of Lake Awassa where they were united as a single lake before (Mohr, 1971). Now this Lake becomes a swampy area and covered by papyrus like grasses, however it was about 12km2 covered by water during 1972.

3.4 Soil Land Use and Land Cover

Soil and land use/land cover map was prepared by Water Works Design and Supervision Enterprise. Based on this work the major soil units are cambisols, andosols, alisols and leptosols where they are classified based on the physical and chemical characteristics which include depth, color, structural development, texture and evidence of profile development such as presence of diagnostic horizons, reaction to 10% HCl, pH value and others. These soil units have characteristics of their parent material where they are developed. The soils on the floor are developed in recent alluvial deposits specially the eastern part where as the others are associated with lacustrine sediments and volcanic material. Generally based on their dominant characteristics these soil types are classified in to four groups. These are clay loam, fine sand, fine sandy loam and silty loam (WWDSE, 1999).

As far as land use is concerned, the main land use of the catchment is rain fed agriculture with agro-forestry practices. On the floor of the area mechanized farms such as Shallo basic seed and Hawassa state farm exist. Private small holding farms are also occupying a considerable large portion on this area surrounding the lake. Swampy area south of Lake Shallo is found and serves as a very important grazing land. Almost all of the rural populations are farmers and their living standard is based on farming with a considerable income generated from cattle production and cash crops. In addition, other important land uses in the area are fishing and recreation on the Lake and collection of firewood and charcoal production at the northwest hilly areas.

The Land use/land cover condition of the area are open bushy woodland with cultivated land found on the floor and southern part of the area; Cultivated land with exposed bare rock and soil found on southwest corner of the area; Open grassland with bare soil covering the eastern escarpment western caldera rims; Open grassland with open bushy woodland on the volcanic hills.

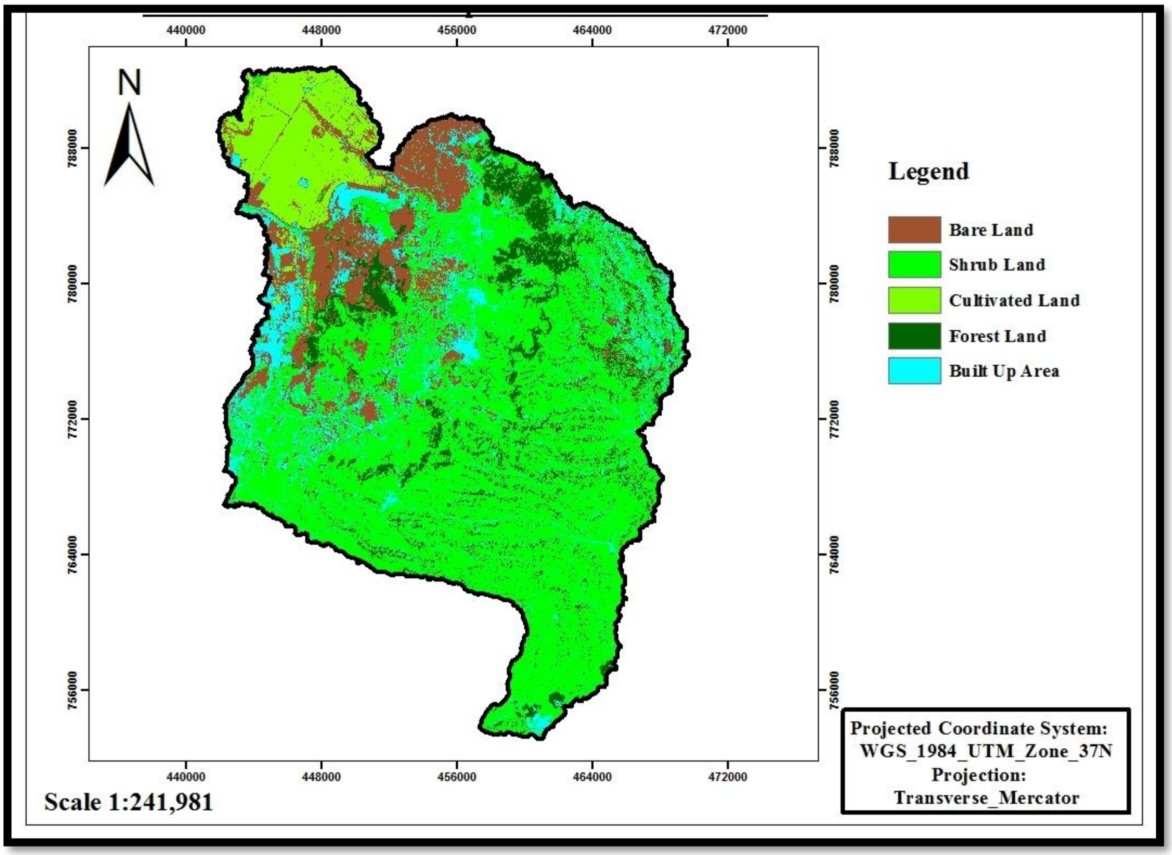

Figure 3. Land cover map of the study area

3.6 Regional Geologic Settings and Structure

The MER is the northern segment of the Great East African rift system running NNS-SSW direction, which is a fault bounded trough bordered by the plateaus in the east and west. It is the result of Cenozoic volcano-tectonic and sedimentation processes. It extends from Lake Abe, Afar-triple junction and dies out southward into Lake Turkana and south of Lake Chamo. It is about 80km wide and 700km long.

The MER is characterized by active extensional tectonics. Two main fault systems have been distinguished in the MER: N 30 O E - N 40 O E trending fault which characterizes mainly the rift margins and a N-S to N 20 O E trending fault system, the Wonji Fault Belt (WFB), which exhibits a number of sigmoidal, overlapping right-stepping en-echelon fault zones obliquely cutting the rift floor (Boccaletti *et al.,* 1998).

Tertiary volcanic rocks dominate most of the geologic sections exposed along the rift margins. The MER is divided geographically in to three sectors: Northern, Central and Southern. The central sector of the MER in which the study corridor is a part is more than 175 km long and 75 km wide extending from the north of Lake Ziway in the north to Lake Abaya in the south. The central sector of the MER is a symmetrical rift mostly characterized by well-defined synthetic rift margins having variable throw along the strike of boundary faults. The rift escarpment is subdued at places due to weathering and accumulation of pyroclastic falls along the margins.

The plateau areas overlooking the rifts probably originate during the Oligo-Miocene when an immense volume of Trap basalts and minor ignimbrites were out poured on top of an up-domed esozoic and Precambrian basements. Volcanism, plateau uplift and development of the Main Ethiopian Rift have been attributed to a mantle hot spot beneath the Ethiopian plateau (Ebinger *et al.,* 1993).

Uplifting and fissuring under tension and volcanism was followed by rifting of the red sea at first which was then followed by rifting in the Afar depression and finally in the Main Ethiopian Rift. Migration of volcanism controlled by regional structural development has been documented within the tertiary flood basalt province in Ethiopia (Mengesha *et al.,* 1996).

The earliest volcanic sequences mainly representing the Ethiopian Flood Basalt Province are found typically overlying the Precambrian, Paleozoic or Mesozoic sediments and also found inter-bedded with Cretaceous regressive sandstones along the southern and western margins of the Afar Depression.

The earliest flood basalts are known by the name as Ashangi Basalts (54 to 36 Ma), Jima Volcanics (42.7 to 30.5 Ma), Aiba Basalts (34 to 28 Ma), Arsi and Bale Basalts (Oligocene to Miocene), Mekonen Basalts (34.8 to 23.1), Alajae Formation (36 to 13 Ma), Tarmaber Gussa and Tarmaber-Megezez Formations (26 to 9 Ma). This flood basalt volcanism culminated by the formation of alkaline basaltic shield volcanoes such as Tarmaber Formation (Mengesha *et al,* 1996).

Jima volcanics are the earliest volcanics, which cover most part of the southern Ethiopia, are considered analogous with the main flood basalts volcanic sequences. It covers major part in the south and southwest Ethiopia in the areas extending between Hagre Selam and Mizan Teferi in the east to west direction being dissected by the rift and covered by silicic volcanics in the rift proper and in the north to south direction extends between Bedele and Jinka. This volcanics form a thick succession of basalt and felsic rocks with dominating its lower part.

In the course of the development of the rift system, a variety of continental sedimentary basins were developed, in the MER lacustrine sedimentation is wide spread during the pluvial period of quaternary resulting the present rift valley lakes where they are the remnants of one mega ancestral lake. The Pliocene age Awassa caldera is a result of this tectonic and geologic evolution and is by far the largest in the east African rift system, covering half the width of the rift floor, approximately 50x40 km (Gidey,1987). The caldera is composite, containing the younger 15km wide nested Corbetti caldera with in it in the northern margin. The main Hawassa caldera is asymmetrically overlapped against the eastern rift escarpment causing this rift margin arcuate, while Corbetti is along the rift axis. The oldest volcanic rocks, which are the plateau trap series are exposed on the western escarpment and consists of about 1000m of basaltic lava flows, with interbedded ignimbritic beds, overlaid by massive rhyolites and intervening tuffs and basalts.

3.6.1 Geological Setting of the study area

3.6.1.1 Old Alkaline and Peralkaline silicic rocks (Late Pliocene-middle Pleistocene)

This unit constitutes the rift pyroclastics and the old rhyolitic lava flows that includes unwelded to moderately welded tuff, pumaceous pyroclastics, ignimbrites, and ignimbrites & tuffs. It covers large parts of the periphery of the caldera where it is widely distributed on the eastern wall of the caldera. The large part of the eastern caldera wall is covered by ignimbrites underlying moderately welded coarse tuff of this unit. The ignimbrite usually forms low relief flat-topped hills, porphyritic with rock fragments of various size and intercalating weak tuff layers.

The northeastern part of the area is covered by ignimbrites and tuffs of this unit, with age range of 3.7-1.6Ma (Gidey, 1987). This unit is also exposed on the southern, southwestern and northwestern parts of the area. Pyroclastic deposits containing silty-gravely sand with angular coarse pumaceous pyroclastics and lava rock fragments characterize the southern & southwestern part. The Pumaceous pyroclastics on the southwestern periphery is composed of pumice fragments with lapilli tuff of fragmental texture. The rhyolitic ridges at Wendogenet, with age 2.45Ma (Gidey, 1987) and the rhyolitic necks on the floor of the caldera south east of lake Hawassa area also included in this unit, having vertical sheeting and flow folding structures.

3.6.1.2 Ignimbrite

Ignimbrite generally forms low relief, flat topped hills. It is light grey, porphyritic with visible lath shaped plagioclase feldspar and rock fragments of various size and composition. Fiamme and glass shards are also common constituents. Weathering ranges from slight to moderate. Weak tuff layers up to 2-3m are sometimes found intercalating this unit. The ignimbrite consists of two joint sets; the first joint set strike is north south with 1.5 to 2m joint spacing. The second one strike is East West also with 1.5to 2m joint spacing. The localities Baja, gemecho, Weteragendo and Wijigra village are all covered with ignimbrite.

3.6.1.3 Volcano-lacustrine deposits (Pleistocene to recent)

This unit is the only non-volcanic formation in the area covering almost all parts of the floor of the catchment, deposited as a result of the recession of the lake. These sediments are volcanic in origin and covered by alluvium along river beds. Their thickness estimated to be 30-50m, but it reaches 100m (on south east of L. Hawassa observed from well logs of boreholes) when they are covered by relatively thick alluvium. These lacustrine deposits have variable lithology which is related with their mode of origin (Tenalem,1998), i.e. they are either quiescent lake deposits, water deposited volcanic ejecta or coarse sediments intruded into the lake by flood events. From well logs observation they are mixed with sediments, locally inter bedded with volcano-clastics and rock fragments of rhyolites, ignimbrites, basalts & tuff and the grain size of the sediments ranges from fine to medium sand but increases with depth.

3.7 Methodology

3.7.1 Aquifer characterization data collection and methodology

Existing data, indirect and direct approach was used in order to characterize the different aquifer units in the area. The characterization involves the use of existing pumping test data, lithology obtained from well logs, water table depth, structures and topography so as to see the vertical and lateral distribution and the nature of the aquifers.

Characteristics of different aquifers in the study area is done by collecting all the secondary and primary data available. The secondary data are the well completion reports of Boreholes. The well completion report includes all the necessary drilling history of the well and pumping test data.

Aquifer characterization was made by using surface geology, borehole lithological log and pumping test data analysis. To identify the surface geology, the geological map of the scale 1:

250,000 were used and digitized on the Arc GIS software. From these map different lithological units and fault lines were produced and identified.

A total of 30 borehole pump test data is taken and have been put into Aquitest Software for execution of aquifer parameter like Transmisivity. The hydraulic conductivity is then determined from transmissivity as the aquifer thickness is known.

Hydro Geological Classification /Characterization

The classification of different lithological units is made based on hydrogeological characterization of various rock types. This study used the qualitative and quantitative parameters to classify the hydrogeological units.

Qualitative Parameters

Units with porous permeability

In this types of hydrogeological unit groundwater accumulated in and flows through pores of an unconsolidated or semi-consolidated material. Porous materials of Quaternary age are represented either by lacustrine sediments with subordinate alluvial, colluvial and eluvial sediments developed in depressions of lakes and/or along valleys of former and existing rivers or by pumiceous pyroclystic, re-sediment pumice and unwelded tuff materials.

Units with fissured permeability

In this types of hydrogeological unit groundwater accumulated in and flows through the weathered and fractured part of volcanic rocks. The porosity of lava flows may be high but the permeability is largely a function of a combination of the primary and secondary structures (joints and fissures) within the rock. The weathered and fractured surfaces play a significant role in ground water accumulation and flow.

Units with Mixed Porous and Fissured permeability

The aquifer consists of various types of permeability; inter granular and fractured permeability. The intercalated sediment does not act as an independent aquifer but rather it contributes to the safe yield of the wells.

Quantitative Parameters

The quantitative data division of lithological units is based on the hydrogeological characteristics of various rock types, such as hydraulic conductivity, Transmissivity, aquifer thickness and yield obtained from different organizations.

3.7.2 Groundwater level and flow direction mapping materials and methods

Groundwater contour map has been generated based on the available secondary well log data from appropriate offices. This map has been constructed to show the groundwater flow direction.

Topography, geology and structures are the primary controlling factors on the flow system of the groundwater.

To map the groundwater table static water levels and altitude of the water point data is used. A well inventory is prepared during the preliminary phase of the investigation. Essential data included are the surface elevation of all boreholes, their total depths, water levels, and screen or perforation schedules. If direct or indirect observation of the groundwater elevation is available, the surface topography is assumed to reflect the direction of groundwater flow. The Digital Elevation Model provide the basic drainage patterns and topographic variations of the given area. Then the flow lines and the equipotential lines (i.e. groundwater contours) were made by Global Mapper 12 and Surfer 13 software.

3.7.3 Water quality analysis materials and methods

Representative water samples were collected from selected water points (spring, shallow wells and boreholes). Field parameters of the samples (pH, EC, Temperature) were measured at the time of sampling. Such measurements are always important for confirmation between field and laboratory measurements and are good indicators about sample preservation or change of chemical constituents during transportation. Physico-chemical analysis has been carried out in the Regional Water and Irrigation Development laboratory. A total of one hundred two (102) water sample data from boreholes, hand dug wells and springs were collected. Most of the sample used in this study collected from South Water Works, SDCSE and South Region Water and Irrigation Development Bureau. To fulfill the gap where there were data scarcity, fifteen samples have been collected and analyzed in the regional water and irrigation development bureau laboratory. The samples consist of five from springs, five from boreholes and five samples from hand dug wells. Measure of Electrical Conductivity (EC) and PH were made during the field.

Water Type and Piper Diagram

Piper diagrams permit the cations and anions composition of many samples to be represented on a single graph in which major groupings or trends in the data can be discerned visually. Piper trilinear diagram plots the major cations and anions as percentage of milli-equivalent on two separate base triangles, and project the plotted points from the two base triangles on one central diamond plot. It is convenient for showing the effect of mixing two waters from different sources; the mixture of two different water will be plotted on the straight line joining the two points (Freeze and Cherry, 1979).

4. RESULT AND DISCUSSION

4.1. Aquifer classification of the area

The classification of different lithological units made based on hydrogeological characterization of various rock types. This study used the qualitative and quantitative parameters to classify the hydrogeological units.

The hydraulic characteristics of the area are defined for 30 data points; most of them lie on the lacustrine sediment. Hydraulic conductivity and transmissivity values are highly variable due to complex geological and hydro geological situation of the area and it is demonstrated on the results of the analysis of pumping test data. The results are used to characterize hydrogeological units of the study area together with the qualitative data, such as borehole lithological log.

the aquifer system in the study area is found to be in unconfined condition except aquitard layers of clay and ash deposits exists on some parts of the area. For example, free flowing well is found southeast of the lake (Melga Wendo). The presence of multi-layered aquifer system with variable permeability is also the characteristics of the area. This is the nature of the lacustrine sediment in the area, which composed of clay, sand to gravel, ash, pumice, tuff, and volcanic fragments of rhyolites, ignimbrites and scoraceous basalt.

Regarding the thickness of the aquifers, it is highly variable as the lithology. It ranges from 20-30m in the lacustrine sediment, even reaches 40m when the well penetrates the underlying ignimbrite, the scoraceous basalt and in areas of thick lacustrine covers. All the analysis results are summarized below:

Table 3.Aquifer parameter of the study area

No	Easting	Northing	Elevation	Depth (m)	K (m/day)	T (m^2/day)	SWL	Draw Dawn (m)	Discharge (l/s)	Aquifer
1	432476	760825	1840	192	0.144	11.5	73.44	44.61	5	sand
2	446574	770241	1754	90	0.5	8.2	38.5	35.8	5	pumice and sand
3	440747	768424	1833	180	6.23	113.6	103.2	30.5	7.1	Ignimbrite and sand
4	433977	762572	1876	250	0.4	24.2	102.26	42.8	13.84	sand and gravel
5	454724	792524	1961	247	0.429	17.1	202.5	95.8	3	
6	437317	767645	1848	208	1.008	50.544	119	10.9	5.36	pumcice and basalt
7	437337	764453	1881	223	2.635	210.24			10	pumice and

					2					sand
8	445269	773012	1701	70	5.4	103.4	4.9	22.65	26	pyroclastics sand and pumice
9	444775	778878	1714	58	4.5936	110.304	30.17	12.36	20	basalt
10	448528	772643	1705	168	5.5	751.2	4.46	10.33	64.5	pumice and sand
11	444538	779298	1714	48	0.14712	2.64	24.8	4.91	20	pumice and basalt
12	444042	771978	1691	210	10.3	741.6	11.86	4.99	26.8	
13	442971	780703	1669	65	16.56	416.16	18.5	6.04	22	pumice and sand
14	447977	771948	1714	186	18.8	1351.2	10.69	2.3	63.6	pumice and sand
15	444045	777859	1729	71	28.08	758.88	46.9	0.15	6.1	Basalt and pumice
16	445205	779257	1716	46	39.456	711.36	28	2.08	22	
17	448118	772982	1705	175	55.9	2678.4	4.28	4.52	75	sand and pumice gravel
18	449926	770917	1714	193	69.6	2090.4	2.87	2.02	66	sand
19	441715	779318	1695	100	82.512	2476.8	9.73	0.02	18	
20	448915	777121	1732	90	82.944	580.32	45.47	1.03		
21	443283	781228	1707	50	115.632	2764.8	16.4	1.1	20	
22	445082	772614	1700	185	130.9	627.8	4.2	0.55	73.35	sand and pumice gravel
23	441095	776350	1699	40	417.6	2174.4	7.6	0.1	22	
24	443592	780212	1700	71	254.88	917.28	20.35	0.01	29.7	sand pumice Ignimbrite
25	444873	779434	1707	86	279.36	1008	25.39	0.07	20	Scoria and pumice
26	442876	779278	1176	52	285.12	744.48	25.6	0.01	22	scoracious basalt
27	443968	772921	1704	101	417.6	1254.2	9.27	0.13	27	
28	449214	771791	1711	200	0.0	2664.0	5.63	7.19	61	pumice and sand
29	442215	778191	1720	86	408.48	21.168	37.02	0.02	27.5	Scoria and basalt
30	441796	779759	1688	41	540.96	1972.8	13.54	0.01	20	

Hydraulic conductivity and transmissivity data derived from pumping test analysis and collected from various organizations show that a high variability spatially in the catchment, this might be as a result of the presence of structures (faults and fractures), the degree of fracturing of the volcanic rocks and/or the complex/reworked nature of the lacustrine sediment. Based on the qualitative and quantitative hydrological criteria and geomorphologic setting the different lithological units are classified in the following aquifer and aquiclud system.

4.1.1 Extensive and highly productive porous aquifer

This hydrogeological unit consists of lacustrine sediments with alluvial, colluvial and elluvial sediments and pumacious pyroclastics of quaternary age. The lacustrine sediments are characterized by variable thickness and texture. The texture varies from clay, silt, to sand and gravel, ash, tuff. In the study area it is observed in the existing boreholes that more than one highly permeable water bearing unit of sand, pumice, coarse tuff, and volcano clastic sediments which is separated by clay aquitards. Volcano clastic sediments are associated with volcanic eruptions which have the characteristics of sedimentary materials. These are clastic sediments of volcanic origin in alternate layers of lacustrine units and pumice and tuff. High runoff from escarpment and eastern highlands in the study area transports material and deposits at the bottom of the rift. This porous aquifer in the study area is exposed in the rift floor and it is highly developed. Aquifer parameters calculated by using pump test data from existing boreholes is presented in table below:

Table 4.Aquifer parameters in porous aquifers of study area

No.	Parameter	Value
1	Transmissivity	110-2000 m^2/day
2	Hydraulic conductivity	5-400 m/day
3	Discharge	17- 70 l/s

4.2.2 Highly to moderately productive mixed porous and fissured aquifers

This unit is composed of volcano-lacustrine sediments, including scoria, scoraceous basalt, pumice, un-welded coarse tuff and ash which are associated with lacustrine sediments of fine to medium grained sand and gravel. This unit is characterized by porous permeability of sediments and fractured permeability of scoraceous basalt underneath the sediments. The unit is exposed near lake Hawassa and have limited lateral extent within the study area. Water from boreholes in this unit is saline because of high evaporation from near surface water table. High concentrations of fluoride and sodium is also a big quality problem. The pump test analysis result shows that aquifer parameters vary highly in this unit and the result is presented in the table below:

Table 5.Aquifer parameters in highly to moderately productive mixed porous and fissured aquifers of study area

No.	Parameter	Value
1	Transmissivity	500-2700 m^2/day
2	Hydraulic conductivity	15-560 m/day
3	Discharge	10- 30 l/s

4.2.3 Extensive moderately productive fissured aquifer

This type of unit occurs in the study around Wondogenet escarpment slopes and piedmont area. Tertiary ignimbrites are the most widespread formation. Basalts, scoria, and recent alluvium are also formation exist in this type of units. The ignimbrite formation is productive as a result of secondary fracture porosity and permeability. The formation is often inter bedded with volcano clastic and even sedimentary materials. The major aquifer in boreholes in this area is thick unit of weathered and fractured ignimbrite with alternating layers of scoraceous basalt, pumice, tuff clay aquiqlude. In this unit groundwater flows through joints, fractures and faults, this are the major source of secondary porosity. open faults and fault system may also provide significant ground water flow path. This unit are the major source of hot and cold springs. A number of good quality cold springs emanate from Wondogent area and some of the springs are thermal. Aquifer parameters calculated by using pump test data from existing boreholes is presented in table below:

Table 6.Aquifer parameters in moderately productive fissured aquifers of study area

No.	Parameter	Value
1	Transmissivity	10-110 m^2/day
2	Hydraulic conductivity	0.5-5 m/day
3	Discharge	5- 10 l/s

4.2.4 Extensive Low to moderately productive mixed porous and fissured aquifers

Quaternary Peralkaline rocks of mainly welded tuffs occurs in the eastern highland, adjacent to the rift margin. This unit form extensive low to moderately productive mixed porous and fissured aquifers. This unit ranges from un welded to moderately welded fine to coarse tuff and pumaceous deposits of acidic volcanics with characteristics of very deep water table and massive nature. The area, in general, receives high rainfall, but favors high runoff, because of its hilly topography. Considerable volume of rainfall is lost as run off to rift floor with very small proportion of water left for infiltration. This more of a recharge area rather than an aquifer.

One borehole from Wujigra area shows an alternating layers of welded tuff, sand, volcanoclastic deposit and ignimbrite.

Table 7.Aquifer parameters in Low to moderately productive mixed porous and fissured aquifers of study area

No.	Parameter	Value
1	Transmissivity	10-55 m^2/day
2	Hydraulic conductivity	0.1- 1 m/day
3	Discharge	2.5 - 5 l/s

4.2.5 Low Potential Aquifers

A thin layer of top clay soil and volcanic ash with very low permeability that covers the area have impeded the free percolation of water, resulting in very low recharge amount. As a result, water table is very deep and poor quality.

4.2.6 Aquicludes

This unit mainly comprising of domes of the old rhyolite lava flows and trachyte.

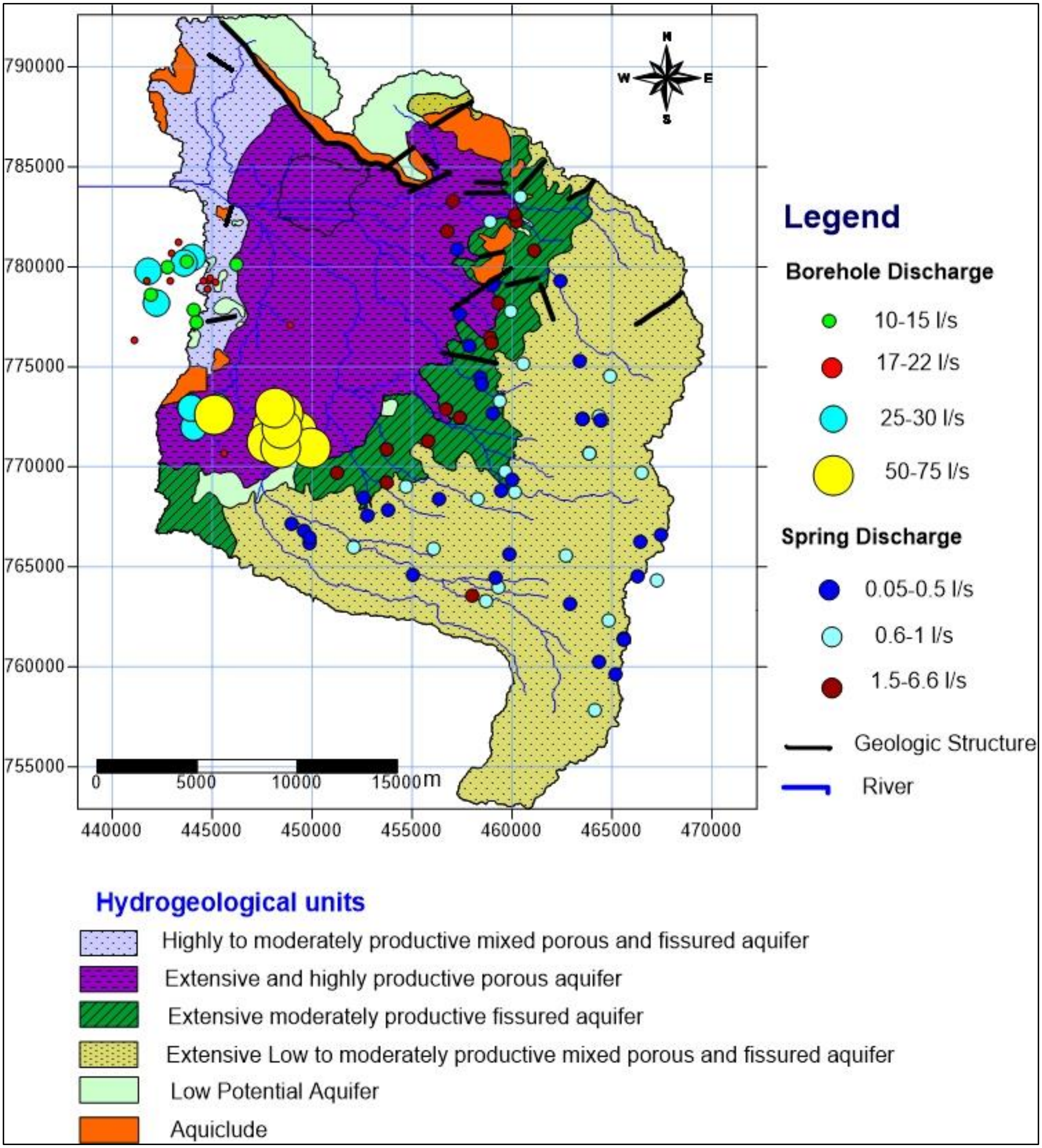

Figure 4.Hydrogeological map of the study area (Modified after Geological survey of Ethiopia)

4.4 Aspects of Groundwater Recharge and Discharge

4.4.1 Ground Water Recharge

Recharge estimation requires accounting the different factors. These include climate, topography, drainage, geologic frame work, soil condition, land use/land cover and vegetation etc. For instance, in semiarid areas where potential evapotranspiration exceeds average precipitation, the ground water recharge depends on high rainfall events. Besides, this process is also controlled by soil infiltration capacity, hydraulic nature of sub surface material, the presence of surface fractures, joints and depressions so as to escape evapotranspiration, etc. For example, poor vegetation on a permeable soil cover along with high rainfall can favor the recharge process. Regarding topography, in areas of steep slopes and rugged terrains, favor run off and evaporation rather than infiltration. Where as in flat land, it creates favorable condition for infiltration. On the contrary, in humid areas recharge is mainly controlled by precipitation surplus (rainfall minus potential evaporation) other factors being present.

By considering the various factors controlling the recharge processes, qualitative recharge and discharge characterization is done, which allows a relative zonation of recharge-discharge condition in the area. Figure 7 shows the relative ground water recharge and discharge area and the characteristics of the area are discussed as follows:

Escarpment and highland volcanic mountains of the eastern margin: The studied catchment gets large amount of recharge from this part of the area. It is the most elevated with the characteristics of flat topped hills, which favors infiltration than surface run off. As it is the rift margin, the area is highly affected by rift fault, which produces fracture zone and joints on the volcanic rocks. In addition, the drainage density is high in the area. The fracture and joint along with dense open channels facilitate the recharge processes. The area gets relatively high amount of rainfall. Cold springs emanate from this area have a characteristics of low EC value and similar isotopic composition as the meteoric water. This implies fast infiltration and shallow circulation of groundwater, where the area gets substantial amount of direct recharge.

The foot of escarpment:

This area is characterized by steep slope and undulating topography, which minimizes infiltration relative to the highland. The eastern part gets relatively higher amount of rainfall than the western part, which allows direct recharge. The major contribution of recharge is through direct precipitation and indirect infiltration from perennial rivers that drains the eastern escarpment. Similar to the above, this area is affected by faults that permit localized recharge.

The hot springs from this area (Wendogenet) shows low EC value relative to waters of the floor, which indicates fast and shallow circulating groundwater, comes from direct recharge of this area and the highland.

The Rift floor: The floor is characterized by relatively lower amount of rainfall and higher evapotranspiration. Direct recharge in this area depends on high rainfall events and fast infiltration occurs through the permeable lacustrine sediments. It also gets indirect local recharge through the riverbed of Tikur Wuha and associated open channels. The Presence of lake, swamp and shallow ground water table forms discharge area on this part of the floor.

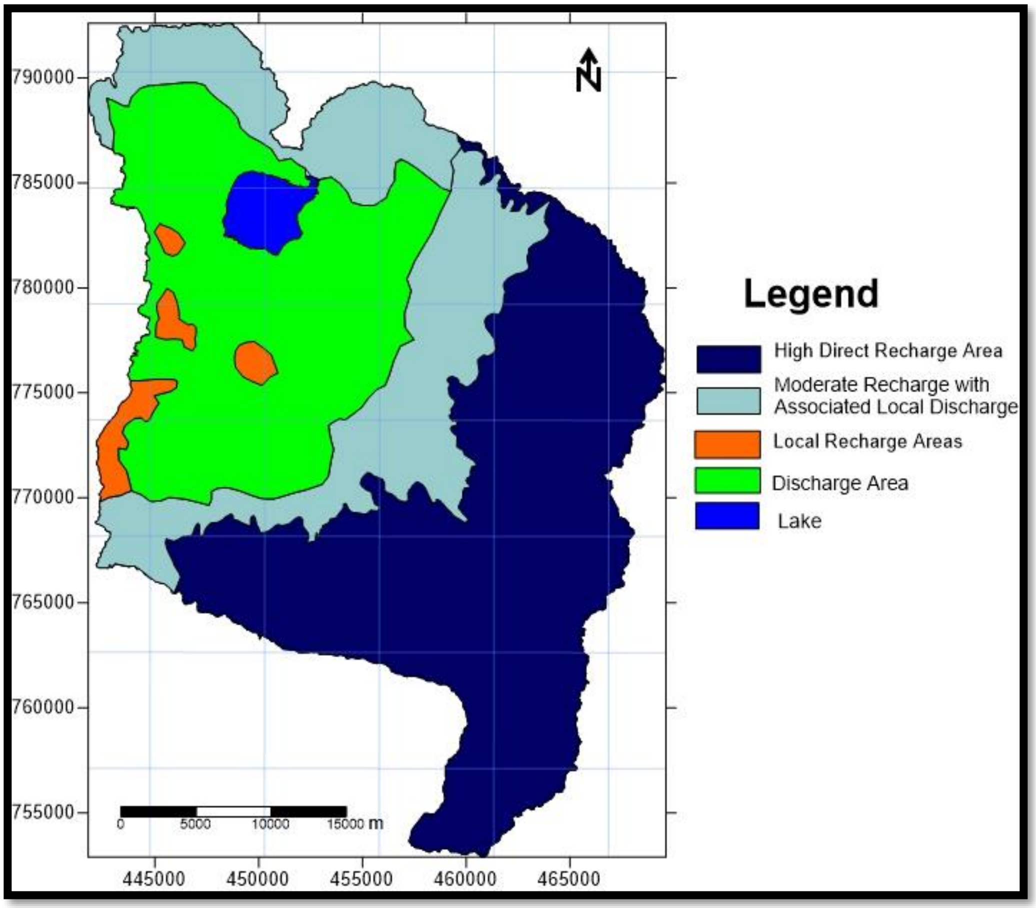

Figure 5. Recharge and Discharge areas

Groundwater discharge areas can be manifested by surface water features such as springs, swamps and seepages. In addition, in arid and semi-arid regions discharge areas can be identified by topography, vegetation covers, soil and land surface features. Here along with these features it is supplemented by hydrochemical and isotopic results. Therefore, there are discharge areas in the catchment with characteristics of springs (hot and cold), swamps, and depressions. All of the cold and hot springs are found on the eastern, south eastern and southern parts of the area, where as swamps occur on low lying depressions when the groundwater table coincides with the surface of the ground.

Most of the cold and hot springs are fault controlled, for instance cold springs of the escarpment and hot springs of Wendogenet where these faults may act as a barrier. Cold springs from the escarpment emanate from NNE-SSW faults of the eastern margin of the rift. Hot springs of the floor are also controlled by faults and fracture zones. Shallo hot springs where emanates from NW-SE trending fault (at the foot of Werensa ridge, northeast of the Lake). Hot springs found south east of the lake comes out from fractures at the foot of scoria cones. This recent volcanic necks of the scoria are aligned in N-S direction where they are on a regional fracture zone. Hot springs from this area are characterized by low temperature and discharge.

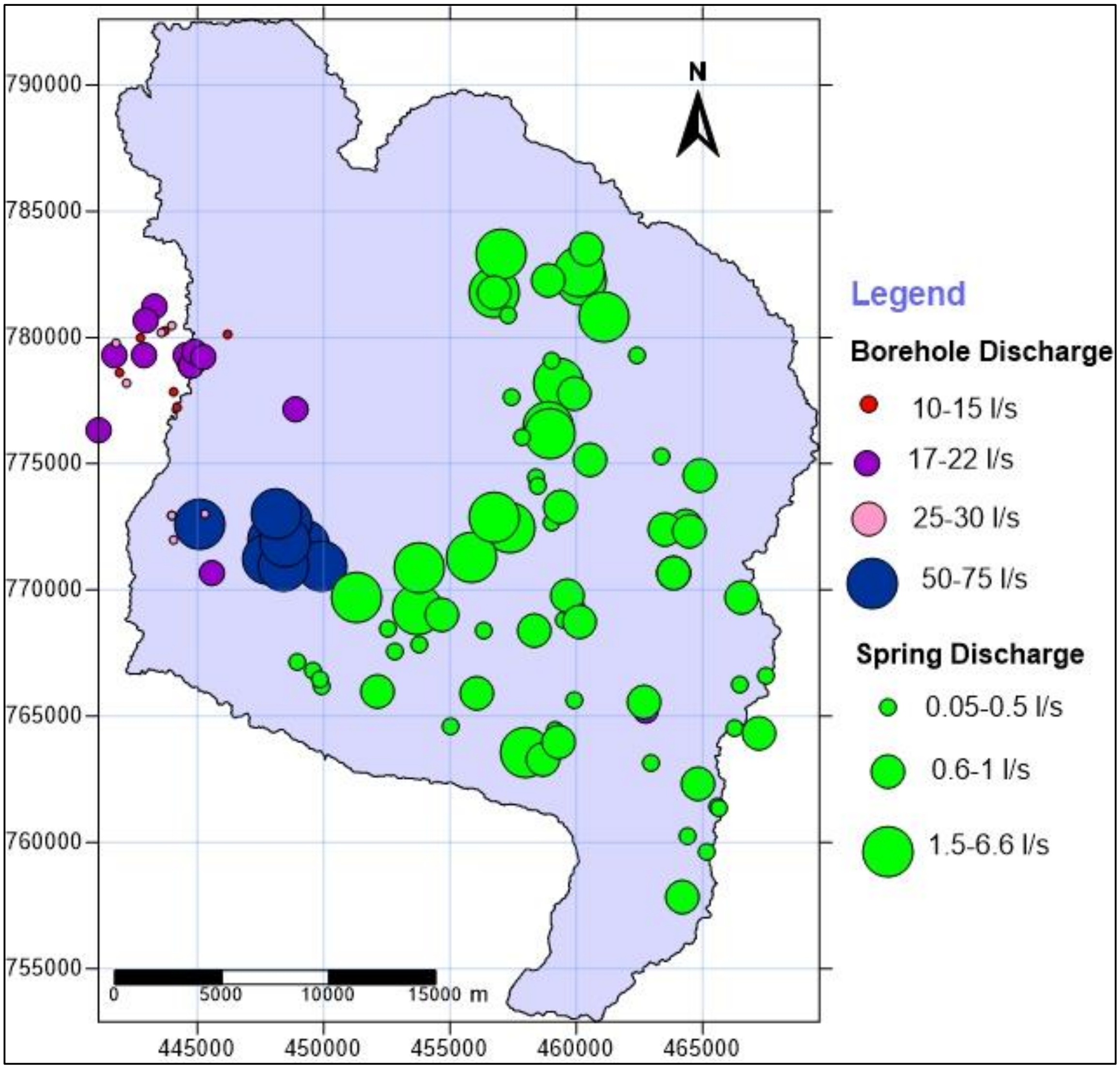

Figure 6.Discharge map of the study area

These fault controlled springs, as supplemented by their hydrochemical and isotopic signature, they are fast, shallow circulating groundwater where the faults may act as a barrier for groundwater flow. Some cold springs with very low discharge less than 1 l/s are found on the south eastern highland near the watershed boundary. These springs are formed when the groundwater table coincides with the surface at low depressions and open channels. It occurs when the underlying bed rock unit exposed on the open channels. Swamps and low depressions covered by vegetation are also characteristics of groundwater discharge areas in the catchment. For instance, swamp containing Lake Shallo, depression of Wendokosha area is one of them. Boreholes developed on lacustrine deposits of the rift floor yield up to 75 l/s which also indicate discharge area, borehole and spring discharges of the study area is shown in figure above:

4.5. Groundwater level and flow direction mapping

It is desirable, wherever possible, to determine the position of the water table and the direction of groundwater movement. To do so, it is necessary to determine the altitude, or the height above the datum plane, of the water level in well. However, in most areas, general but very valuable conclusion about the direction of groundwater movement can be derived from observation of land surface topography.

Gravity is the dominant driving force in groundwater movement. Under natural conditions, ground water moves “downhill” until, in the course of its movement, it reaches the land surface at a spring or through a seep along a side or bottom of a stream channel. Thus, if we ignore minor surface irregularities, in the study area we find that general slope of the land surface is toward the south west, suggesting that the groundwater flow is in the same direction.

To know the actual groundwater flow it requires sufficient data of water tables in the study area. Accordingly, several water level measurements were collected and the ground water elevations were calculated and ground water contour map has been constructed using the Surfer 13 software to verify and present the resulting water level contours distribution.

In the study area the wells are concentrated in the same area therefore it is difficult to get evenly distributed wells which represent the whole catchment. Existing wells also lack access for water level measurement.

In order to make a groundwater level map, one needs water level readings made in a number of wells, each of which is open only in the aquifer of interest. But in many areas of the country in general and the study area in particular, it is very difficult to get wells which fulfill the mentioned requirements fully.

Despite the above mentioned problems and constraints it is possible to show the general trend of the ground water flow direction using the existing data. As such the general ground water flow of the catchment is towards west from south eastern part of the catchment.

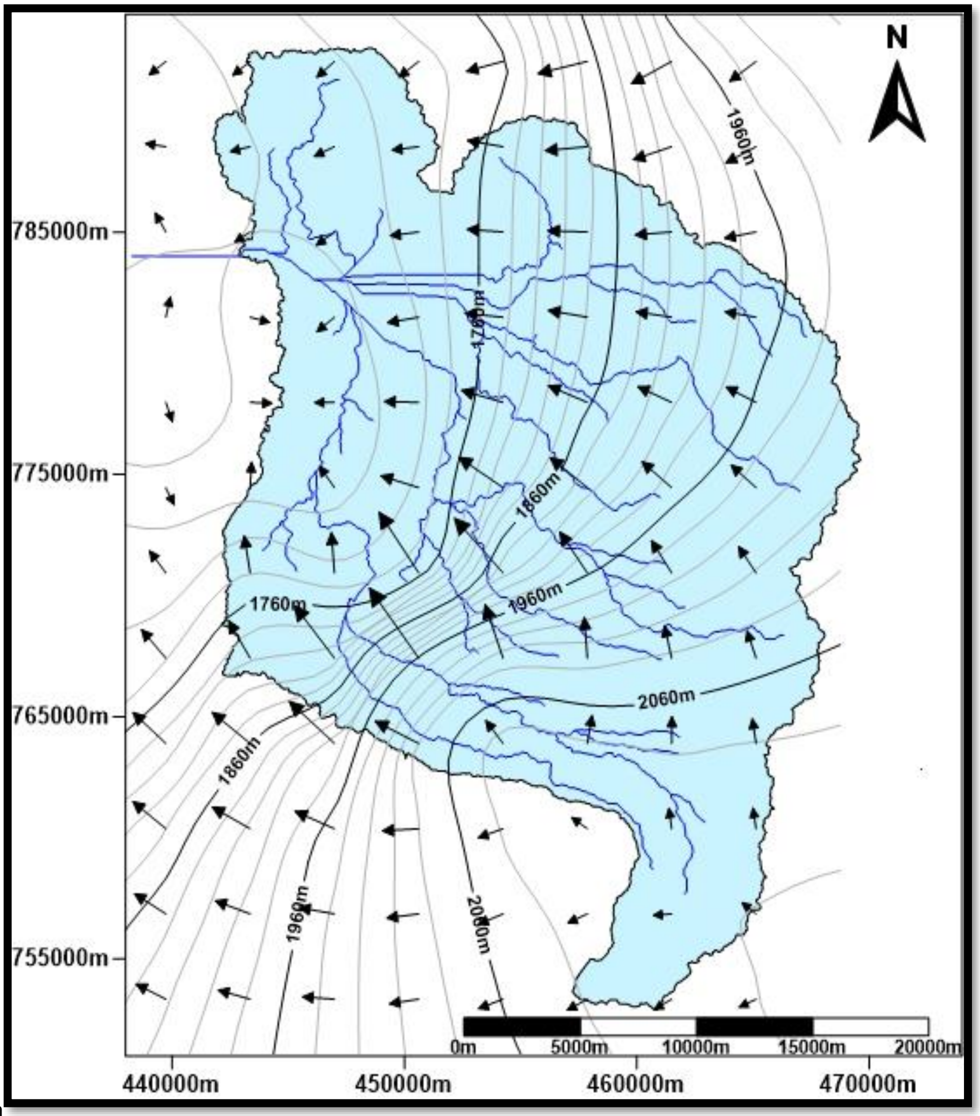

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Figure 7.Ground water flow direction map of the study area

4.5 Water quality analysis

Water Sampling and Analysis

The main hydrochemistry of natural water characteristics of the study area can be expressed by some physical parameter like PH, TDS, conductivity and major constituents, (HCO3, SO4, Cl, Na, Ca and Mg) and secondary constituents (K, F, NO3, and CO3) have been used. Figure 10. Shows the location of the water samples.

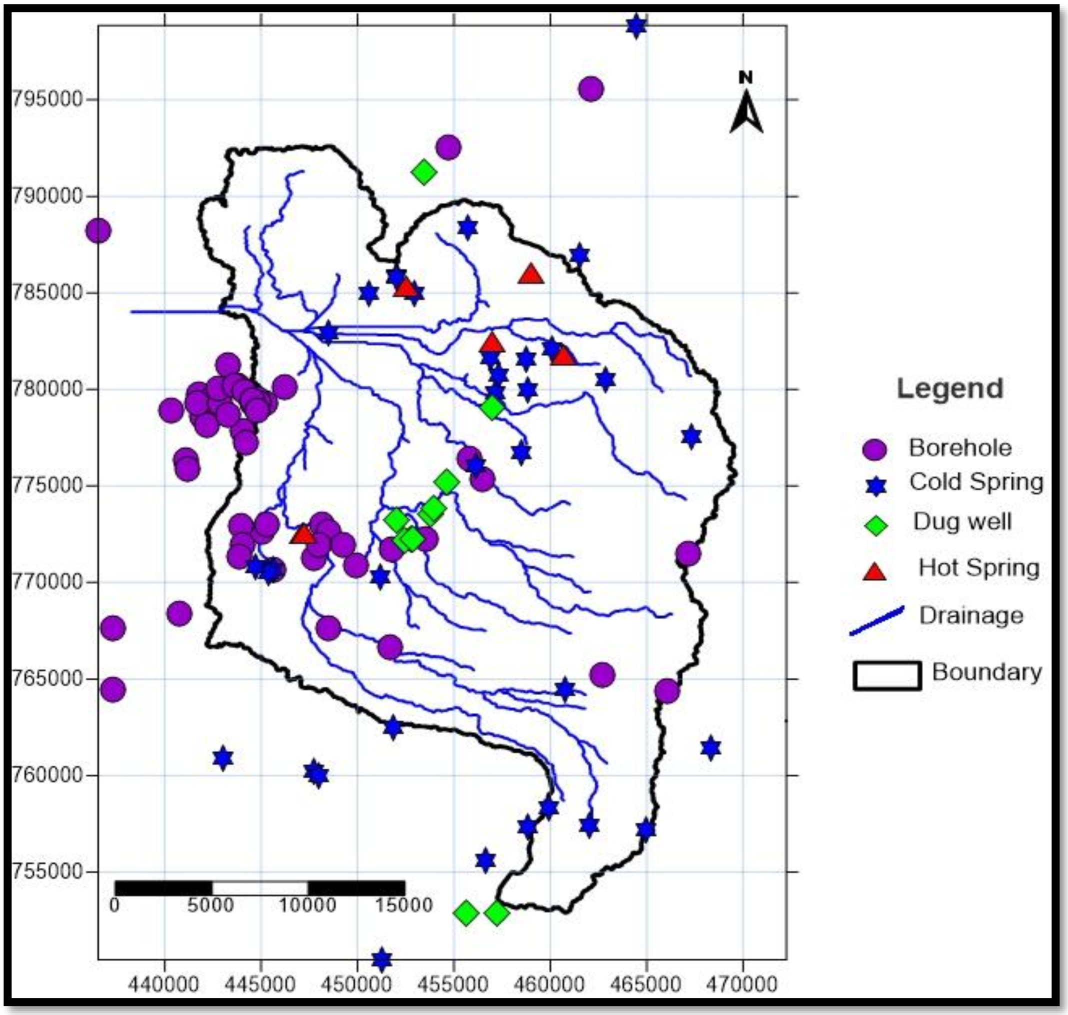


Figure 8.Location of water sample points

Physical Parameters

Hydrogen Ion Activity (PH)

In the study area 100 samples have been taken for pH sampling and the pH values of the sample lie between 5.04- 9.43. Water samples taken from East and South highlands, which is the recharge area, show acidic condition. Generally, water in recharge areas have low PH values because of the oxidizing condition and increases towards down gradient along the flow path because of reducing condition in deeper groundwater environment. PH can indicate the ground water flow direction in this particular case from East and South highland areas (Wondogent and Malga Woreda) towards lake Hawassa. According to WHO standard less than 6.5 is acidic, 6.5-8.5 is normal and greater than 8.5 is basic water.

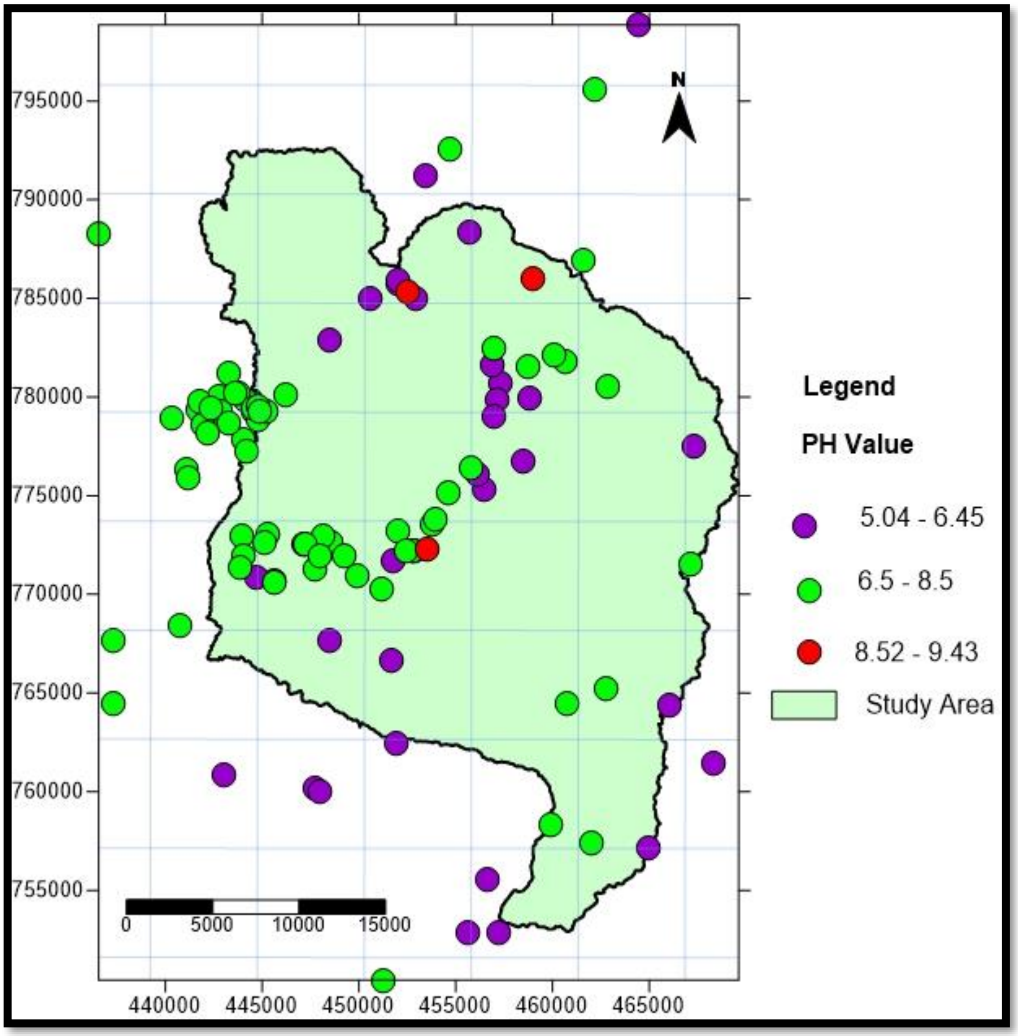


Figure 9.PH distribution of the study area

Electrical conductance (EC)

In the study area the values of the measure of the electrical conductivity shows high variation ranging from 4 μS/cm to 2825 μS/cm. Thermal springs located north eastern part of the study area HSP 1 and 2 have high EC values 1964 & 2825 μS/cm due to high temperature and TDS. The lowest value is registered in a spring sample around south eastern highlands. The electrical conductance is low in the eastern and southern escarpment of the study area, this may indicate an area of recharge. EC values increases towards the rift floor this may suggest the direction of ground water flow direction. In general, the larger the value of specific conductance, the greater the concentration of dissolved solids in the water sample and the poorer the water quality. In the study area high EC is registered in Hawassa Town and the lowest value is registered in south eastern rift escarpment.

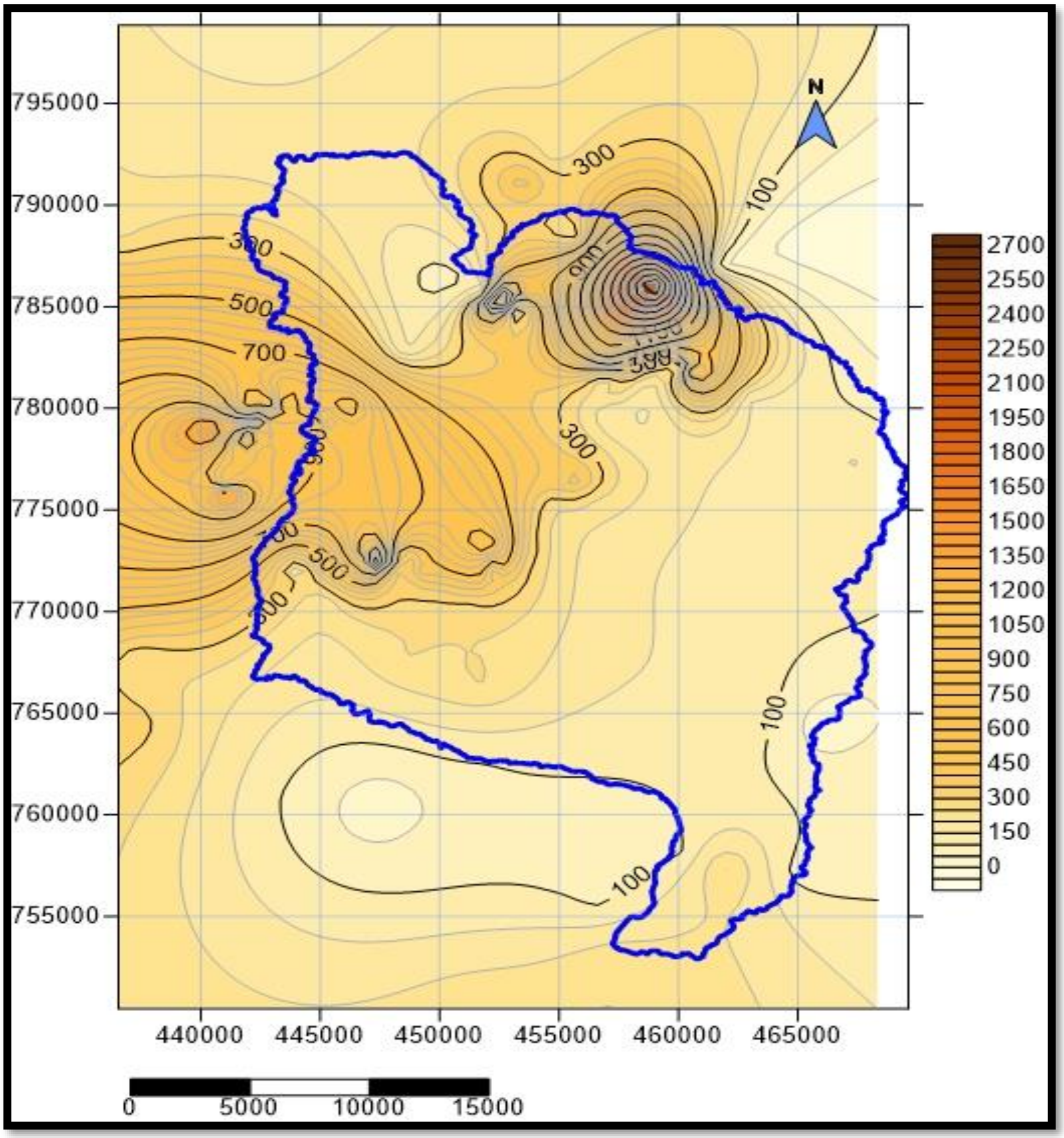


Figure 10.Electrical conductivity map of the study area

Hardness

Hardness level greater than 500 mg/l is generally unacceptable for domestic use. Samples in the study area have a hardness level ranging from 5.8 mg/l to 240 mg/l. Hardness level of springs is generally low compared to boreholes. Hardness of water is one factor of water quality. water sample rich in calcium are categorized as hard water. High calcium concentration is associated with basic rocks. Acidic rocks dominated by Na characterized by low hardness water.

Table 8 Hardness classification of water samples of the study area

Description	% of samples
Soft	23
Moderately Hard	30
Hard	37
Very Hard	10

Total Dissolved Solids

The term TDS describes all solids (usually mineral salts) that are dissolved in water. The TDS is usually measured in mg/l. Water naturally contains a number of different dissolved inorganic constituents. Several processes may cause an increase in TDS content of ground water. The TDS of natural water range from less than 10ppm of dissolved solids for rain and snow, to more than 300,000 ppm for some brine.

TDS concentration also varies with altitude. TDS values increase with decreasing altitude, plateau areas or topographically high areas show low TDS values and low topographic areas show high TDS values because high altitude is recharge areas.

The TDS values in the south east of the study area, which is rift escarpments show lower values of TDS indicating the low rock-water interaction or recharge zone. The Value increases towards the rift floor. The TDS values in the study area ranges from 2 - 725 mg/l, the lowest record is found in the south east escarpments and the highest value is recorded near lake Hawassa. Hot springs around wondogenet area show high concentration of TDS ranging from 1025 - 1696 mg/l. The increase in TDS from high land area to lowland is attributed to the increase in evapotranspiration of the low lands and possibly the dissolution of mineral constituents by ground water during its movement through geologic media. Based on the classification below the water source in the catchment is fresh and TDS value under the permissible limit except hot spring 1, 2, and 6 which have TDS concentration greater than 1000 mg/l.

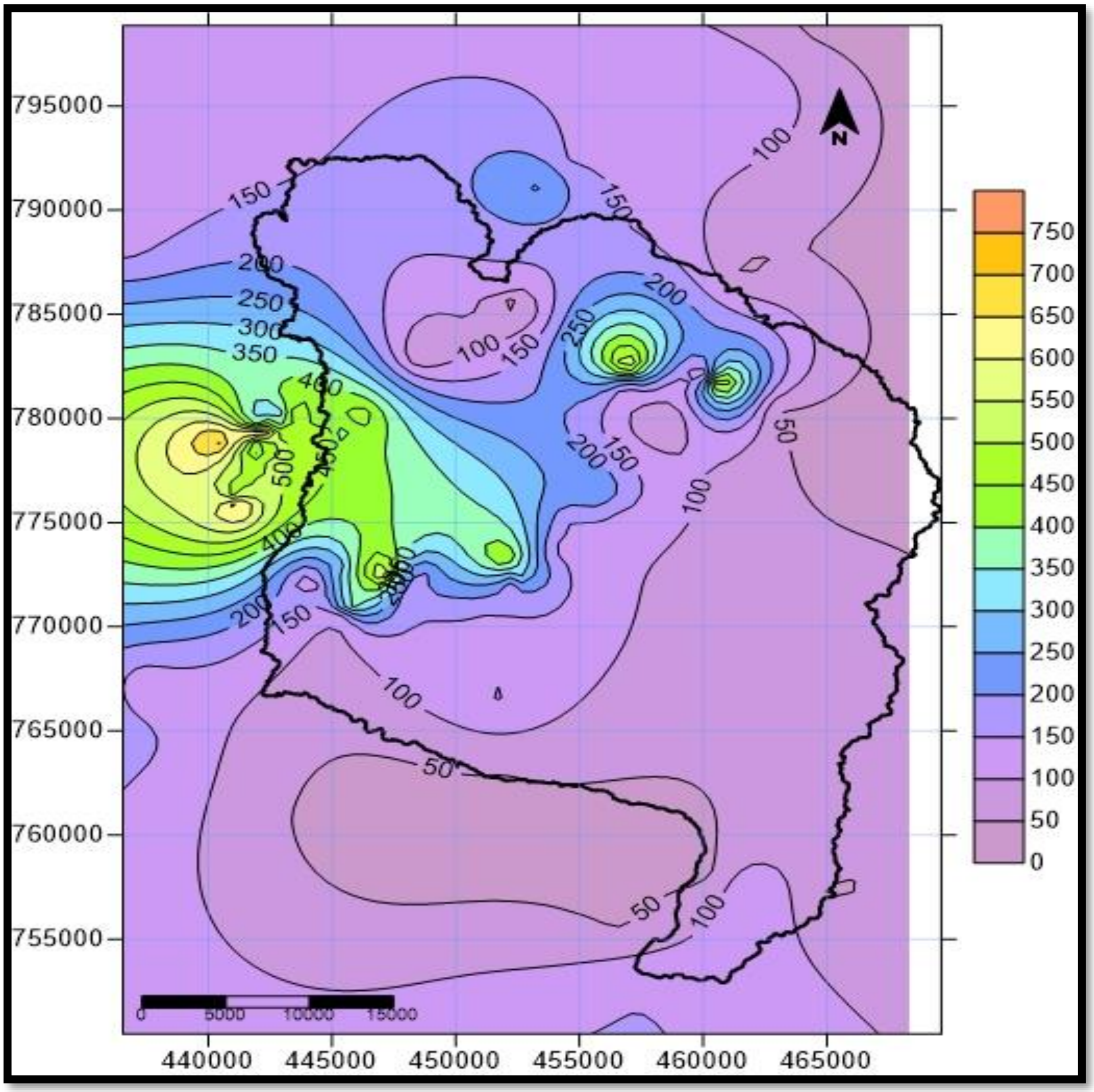


Figure 11.TDS map of the study area

Major cations and anions.

The major cations and anions that have been analyzed for the collected samples are sodium, calcium, magnesium, potassium, iron, manganese, bicarbonate, sulfate, nitrate, chloride and fluoride.

Sodium

Sodium shows significant variation whose values range between 1.4 to 377.6 mg/L. The (Na^+) concentration ranges from minimum values in the high land and rift escarpments to maximum values in the rift floor close to Lake Hawassa. Samples taken near Hawassa town and near lake Hawassa exceed the maximum desirable and permissible limit ranging from 213.2 - 377.6 mg/l. The WHO limit for sodium in drinking water is 200 mg/l. The dominance of Sodium in the study area is likely to be attributed to the dominance of the acidic volcanic rocks, mainly ignimbrite, rhyolite and pumice. In addition, this Na dominance could be attributed because of long time of water-rock interactions. Sodium is commonly measured where the water is to be used for drinking and agricultural purpose particularly irrigation.

Calcium

The concentration of calcium in the study area is generally low ranging from 1 - 64 mg/l all the analyzed samples are within the range of the permissible limit of WHO guidelines which is 100mg/l. Ca is essential to all organisms. It is considered to be non-toxic. It has long been suspected that a causal link exists between water hardness (dissolved Ca and Mg) and cardiovascular disease. It appears that there exists a weak inverse relationship between drinking water hardness and cardiovascular disease mortality. This would suggest that a lower, minimum acceptable concentration of Ca in drinking water would be more appropriate than an upper limit.

Magnesium

The concentration of Magnesium of the water sample in the study area ranges from 1-29.6. The WHO limit for drinking water is 30 mg/l. All the samples analyzed are within the range.

potassium

Potassium is slightly less common than sodium in igneous rock. Although potassium is an abundant element and its common salts are highly soluble, it seldom occurs in high concentrations in natural water. Potassium is an essential element in humans and is seldom, if ever, found in drinking water at levels that could be a concern for healthy humans. WHO guideline says there is no established guideline value for potassium because it occurs in drinking-water at concentrations well below those of health concern for healthy humans.

The concentration of potassium of water samples from study area ranges between 1.6 mg/l to 42 mg/l. In the study area 53 water samples are taken for sampling of potassium and sodium concentration and in most cases the concentration of sodium is greater than that of potassium.

Iron

A number of samples from the study area shows concentrations of Iron greater than 0.3 mg/l. The concentration the sample taken from the study area ranges from 0.008- 2.96. The is no noticeable pattern in the increasing or decreasing of iron concentration but Samples taken from springs Shallow wells and boreholes from the high lands of Wujigra, Gorche and areas near the escarpment shows iron concentration greater than 0.3 mg/l, a few borehole samples from Hawassa town also show concentrations between 0.37 - 1.5 mg/l.

In drinking water, it is toxic to humans at Concentrations greater than 200 mg/L. Iron deficiency is widespread. Drinking water, however, is not the main source of iron to humans. Water with high Fe concentrations is usually unpalatable in terms of odor, taste, staining of laundry and discoloration of food.

Manganese

The concentration of Manganese of the study area ranges from trace to 1.4 mg/l. Like the Iron Concentration Manganese also does not show any patter in the study area but samples from the highland areas who has high concentration of Iron which are mention under topic Iron, also has manganese concentration greater than 0.4mg/l which is health based value. A couple of boreholes in Grarariqeta and one borehole from Hawassa also show values greater than 0.4 mg/l.

Bicarbonate ion

In the study area bicarbonate concentration ranges from 15 mg/l - 1244 mg/l. The highest value is registered in a borehole sample around Hawassa Town and the lowest value is registered in the spring sample from the highland areas. Spring samples from high land area range between 15 - 166 mg/l and borehole samples have value ranging from 70 to 1244 and borehole samples in the lowland areas of the study area show relatively high concentrations ranging 342 - 1244 mg/l.

Sulfate

The concentration of sulfate ion in the study area is generally low, ranging between 0- 40 mg/l, with one exception, 95 mg/l is registered in one borehole around Hawassa town.

Chloride

The concentration of chloride in the study area is generally low ranging from 0 mg/l to 100 mg/l. All water samples analyzed are within the permissible limit, the maximum limit of WHO drinking water standard for chloride concentration is 250 mg/l.

Fluoride

Most of the fluoride in groundwater comes from acidic volcanic rocks such as pumice, obsidian, pyroclastic deposits, ignimbrite and rhyolite. The natural concentration of fluoride depends on the geological, chemical and physical characteristics of the aquifer, the porosity, the acidity of the soil and rocks and the temperature and the action of other chemical elements. The high permeability and large rock water interaction makes the leaching process more effective in pumice. As pumice fall deposits are wide spread in the study area, these rocks represent first order potential reservoir of fluoride. Groundwater with high fluoride content is found mostly in calcium-deficient groundwater.

The fluoride guideline values for World Health Organization and Ethiopian drinking water quality guidelines are 1.5 mg/l. It has to be noted that fluoride concentrations above 1.5- mg/l causes dental fluorosis, concentrations ranging from 1.5-10 mg/l results in skeletal fluorosis and concentration greater than 10 mg/l results in crippling fluorosis with nerve disorder. Fluoride toxicity may be acute or chronic, with effects ranging from superficial damage, to disability and even death.

The eastern and southern side of the study areas shows very low concentration of fluoride (<1.5 mg/l). This is the area, which has been identified as major ground recharge zone on the basis of its low EC and high Eh values. Most of groundwater samples have shown a fluoride concentration in the range of 0.03 to 8.9 mg/l. The study area can be sub divided in to two, on the basis of fluoride concentration: high fluoride area, (north western part) and low fluoride area (east and south). Fluoride zoning is helpful, to guide people where to develop water resource for domestic purposes or to design appropriate remedial measures.

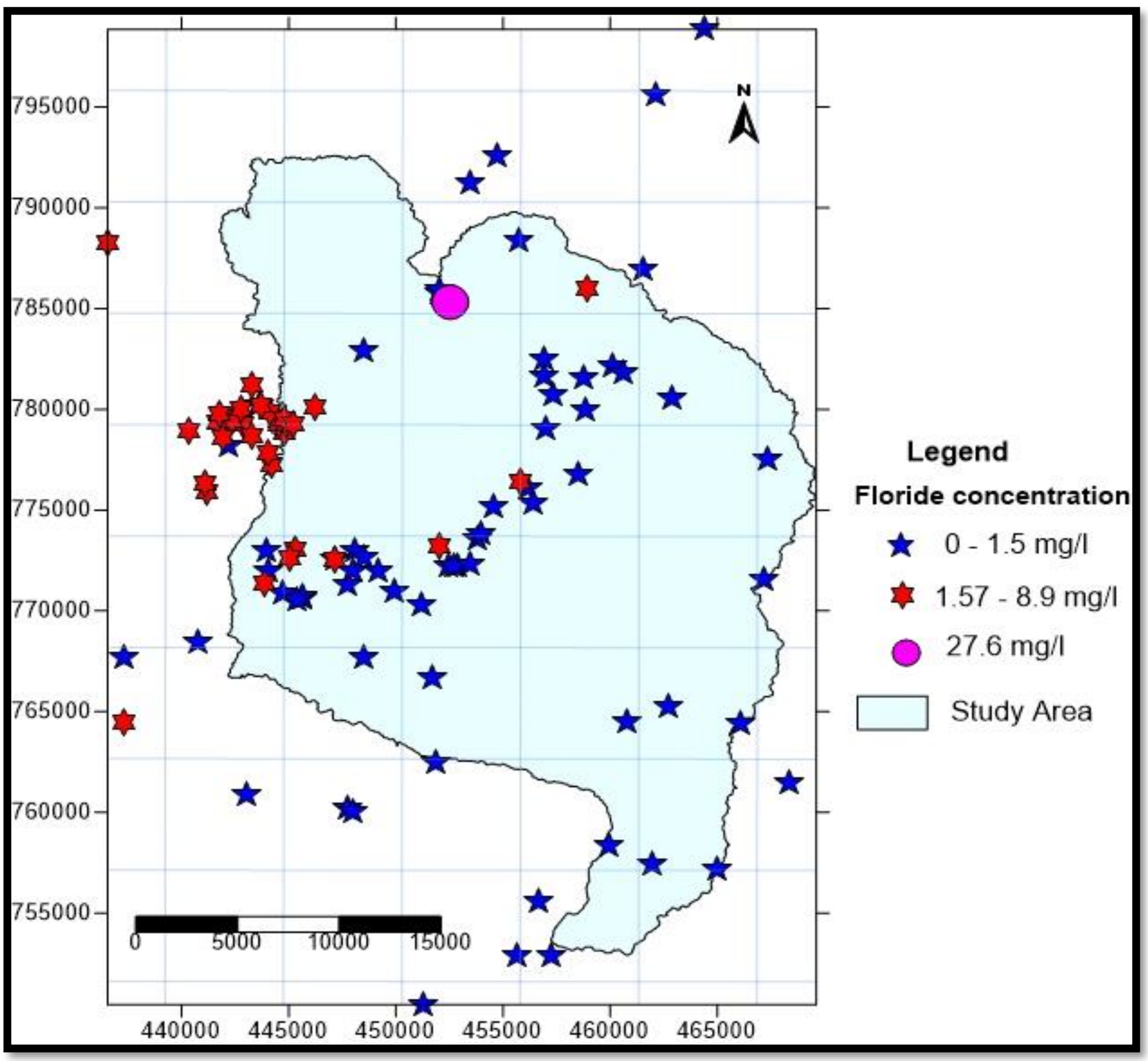


Figure 12.Fluoride distribution of natural waters

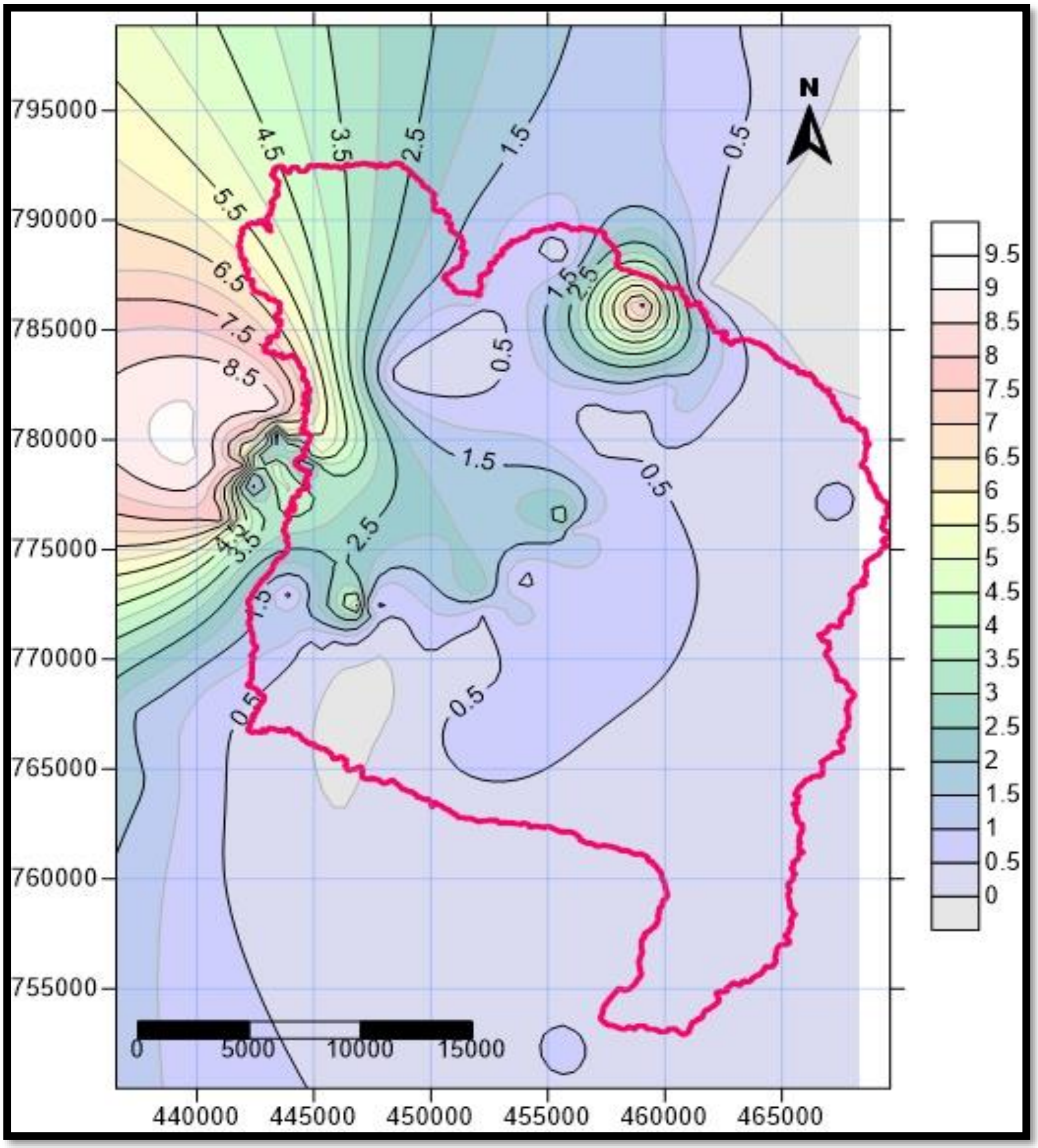


Figure 13. Fluoride map of the study area

Nitrate (NO3)

The Nitrate concentrations in the water samples of the study area ranges from 1.4 to 43.9 mg/l. All the waters are below the Nitrate guideline values of World Health Organization and Ethiopian drinking water quality guidelines, which is 50 mg/l. Nitrate is commonly used as a quality indicator of potential contamination of groundwater. The relatively lower concentration of Nitrate is related to the absence of aquifers affected by anthropologic source related to agricultural fertilizers (in organic) and animal manures (organic sources). Nitrate concentration in the area is generally low.

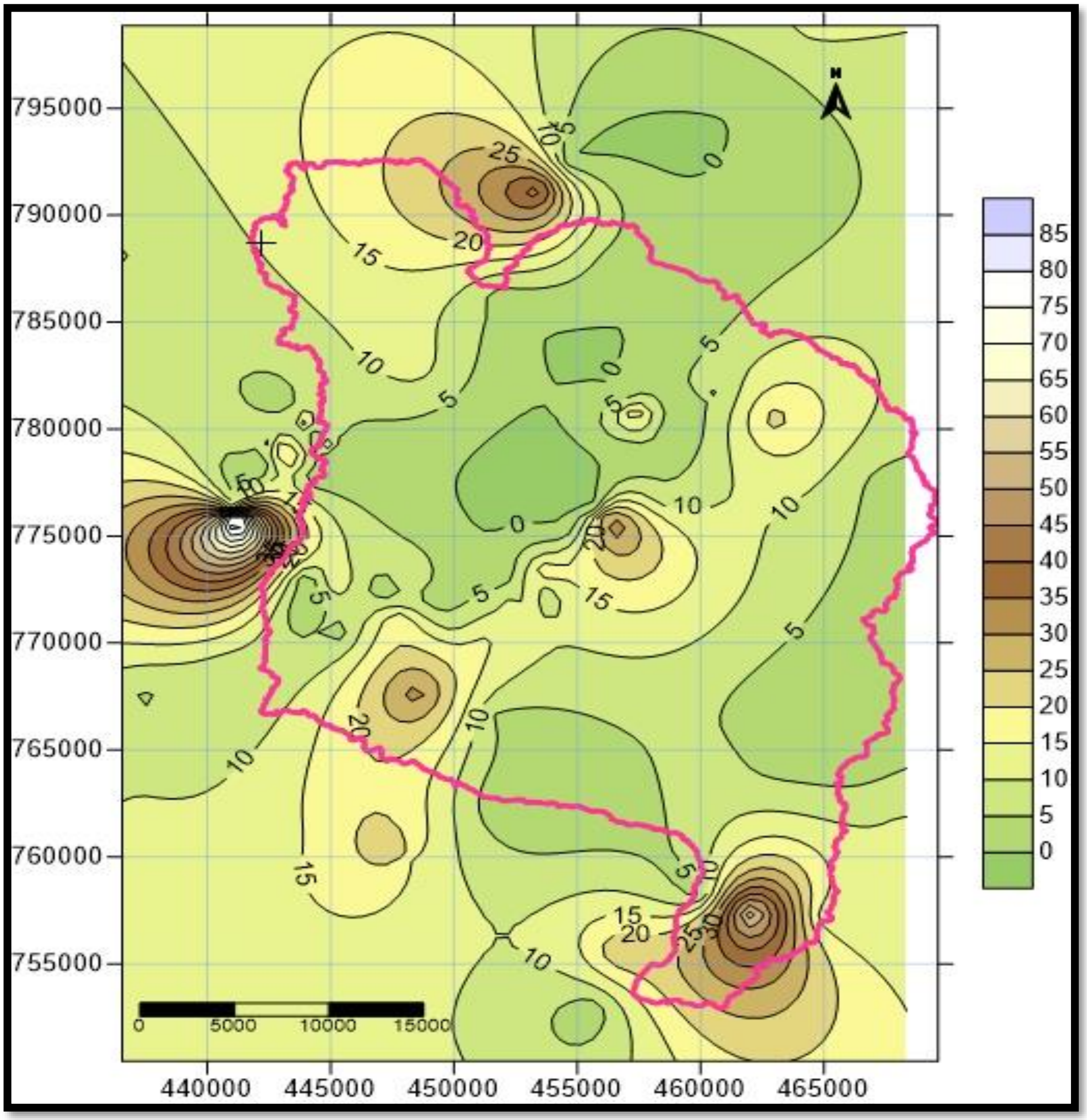


Figure 14.Nitrate concentration of the study area

Classification of natural waters

The classification of natural waters of the study area is made using Aquachem software and presented as follows. In the study area there is a variation of concentration of major ions. The analysis shows that the dominant water type of the study area is bicarbonate type this indicate that the ground water system in the study area is hydro chemically homogenous system. and the dominant cation is sodium followed by calcium. The cation groups associated with bicarbonate are Ca, Ca-Na, Na-Ca, Mg-Ca, Na-Mg-Ca, Ca-Na-Mg and Na-Mg. The classification is made by construction Piper plot by using Aquachem diagram and from this plot the water types of the study area are presented as follows based on the dominant cations and anions the water samples of the study are classified in three main water types:

- Na-HCO3 (Sodium Bicarbonate type)
- Na-Ca-HCO3 (Sodium-Calcium Bicarbonate type)
- Ca-Na-HCO3 (Calcium -Sodium Bicarbonate type)

Sodium Bicarbonate type

In this type of water Sodium ion is a dominant cation and Bicaronate ion is a dominant anion. In the study area these types of water found in Hawassa Town and near lake Hawassa which is a rift floor. Boreholes near Lake Hawassa and Hawassa Town, hot springs of the floor and foot of the escarpment, boreholes around Hawassa well field (Gemeto and Gara Riqeta) contain this type of water.

Sodium-Calcium Bicarbonate type

In this type of waters Sodium and Calcium are dominant cations and Bicarbonate is a dominant anion. It is a characteristics of waters of escarpment and foot of escarpment. This type of water is a characteristic of cold springs and hand dug wells at the foot of the escarpment (Wondogent area) and cold springs from south eastern highlands of the study area.

Calcium -Sodium- Bicarbonate type

In this type of water, the dominant cation is calcium followed by Sodium with Bicarbonate as the dominant anion. However, this type of water is rare in the catchment. Two hand dug wells and four cold spring samples from the foot of eastern escarpment and highlands have this types of water.

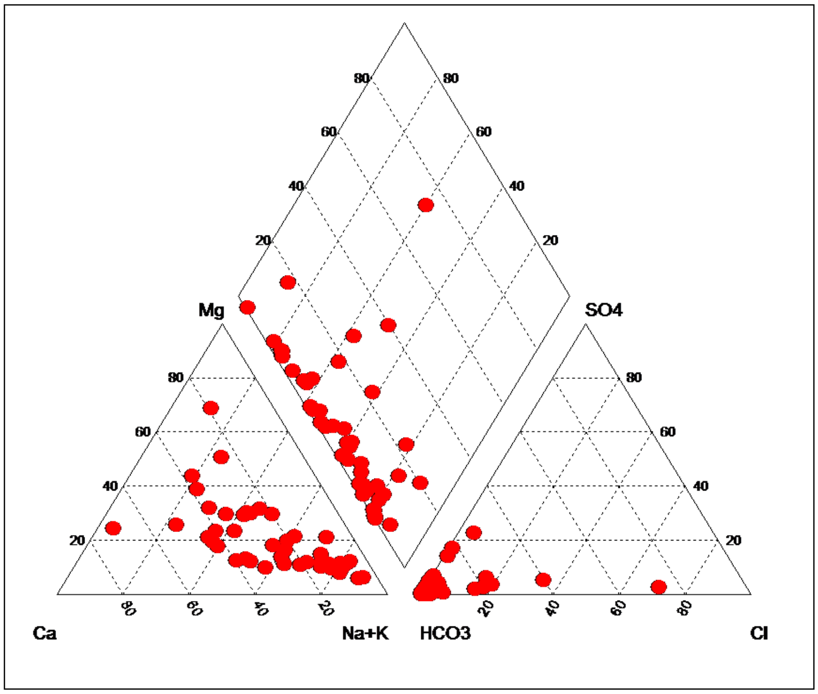
Magnesium- Calcium- Bicarbonate type

A few boreholes in the catchment have this types of water. Three boreholes from the rift floor, one borehole from Gemeto area and two boreholes from south eastern highlands show this property.

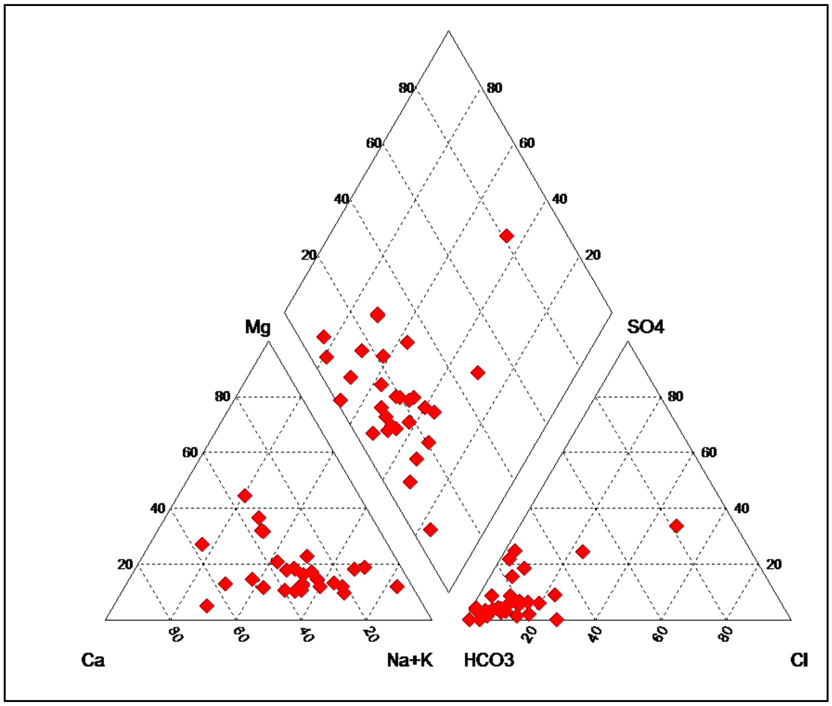
Generally, sodium bicarbonate is a dominant water type in the catchment, 35 water samples out of 97 show this type of water. The rift floor is dominated by this types of water. A large number of boreholes and all hot spring samples belong to this group. One hand dug well from escarpment and a couple of cold spring samples from Cheleka area also belong to this group. Most of the cold spring and hand dug wells from the escarpment and high land areas belong to sodium-calcium-bicarbonate water type group.

Table 9.Water types of all samples of study area

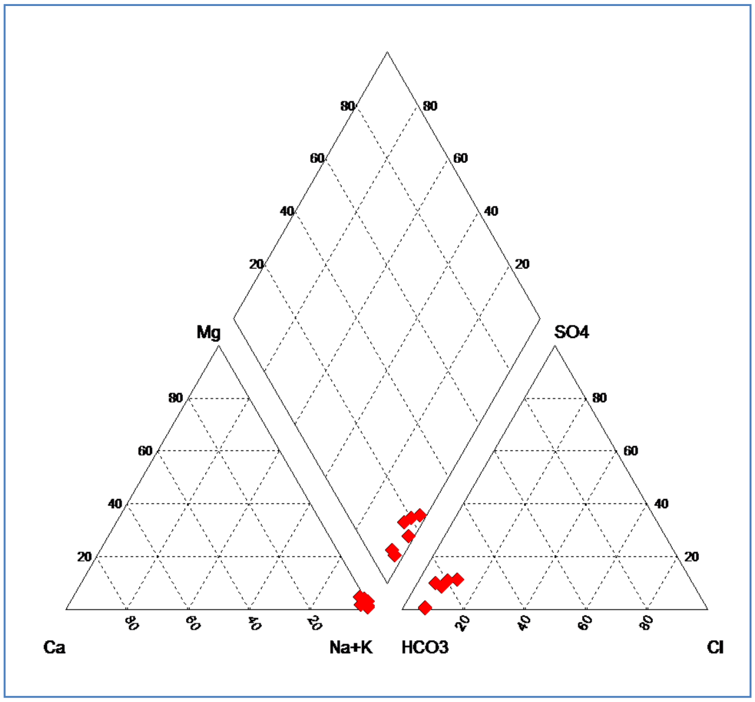
No	Water types	Number of water types for wells	Number to water types for springs	Total
1	Na-Hco3	27	8	35
2	Na -Ca -Hco3	12	13	25
3	Ca -Na-Hco3	2	4	6
4	Mg -Ca -Hco3	6	0	6
5	Na -Mg-Ca-Hco3	3	0	3
6	Ca -Na-Mg-Hco3	2	1	3
7	Na-Mg-Hco3	3	0	3
8	Ca -Mg - Hco3	1	0	1
9	Ca-Na-Mg-Cl-No3	1	0	1
10	Ca-Hco3	1	0	1
10	Na-Hco3-Cl	1	0	1
12	Na-K-Hco3	1	0	1
13	NH4-Mg-Ca-No3-Hco3	0	1	1
14	Na-Ca-Cl	0	1	1
15	Mg-Ca-Hco3-No3	0	1	1
16	Ca-Mg-Na-Hco3	0	1	1
17	Mg-Ca	0	1	1
18	Na-Ca-Mg	0	1	1
19	Ca-Hco3	0	1	1
20	Ca-K-Hco3	0	1	1
21	Ca - Mg- Na - Hco3	0	1	1
22	Na-Hco3-So4-Cl	0	1	1



(a) Borehole



(b) Spring



(d) Hot Spring

Figure 15.Piper plots of different water types of the study area (a), (b) and (c)

Piper diagrams permit the cations and anions composition of many samples to be represented on a single graph in which major groupings or trends in the data can be identified visually and also showing the effects of mixing two waters from different sources. The mixture of the two waters will plot on the straight line joining the two points. The intersection of lines extended from the two sample points on the triangles to the central rectangle gives a point that represents the major-ion composition on a percentage basis. From this point, lines extending to the two adjacent scaled rectangles provide for representation of the analysis in terms of two parameters selected from possibilities, in this case, total major-ion concentration.

In Fig.18, in one hand, all cations concentrated nearly on calcium and sodium bar line and slightly go to the center of the triangle that reflected to almost evenly in the central diamond shaped rectangle, at left lower bar. On the other hand, all anions nearly concentrated to bicarbonate bar line reflected to the central diamond shaped rectangle.

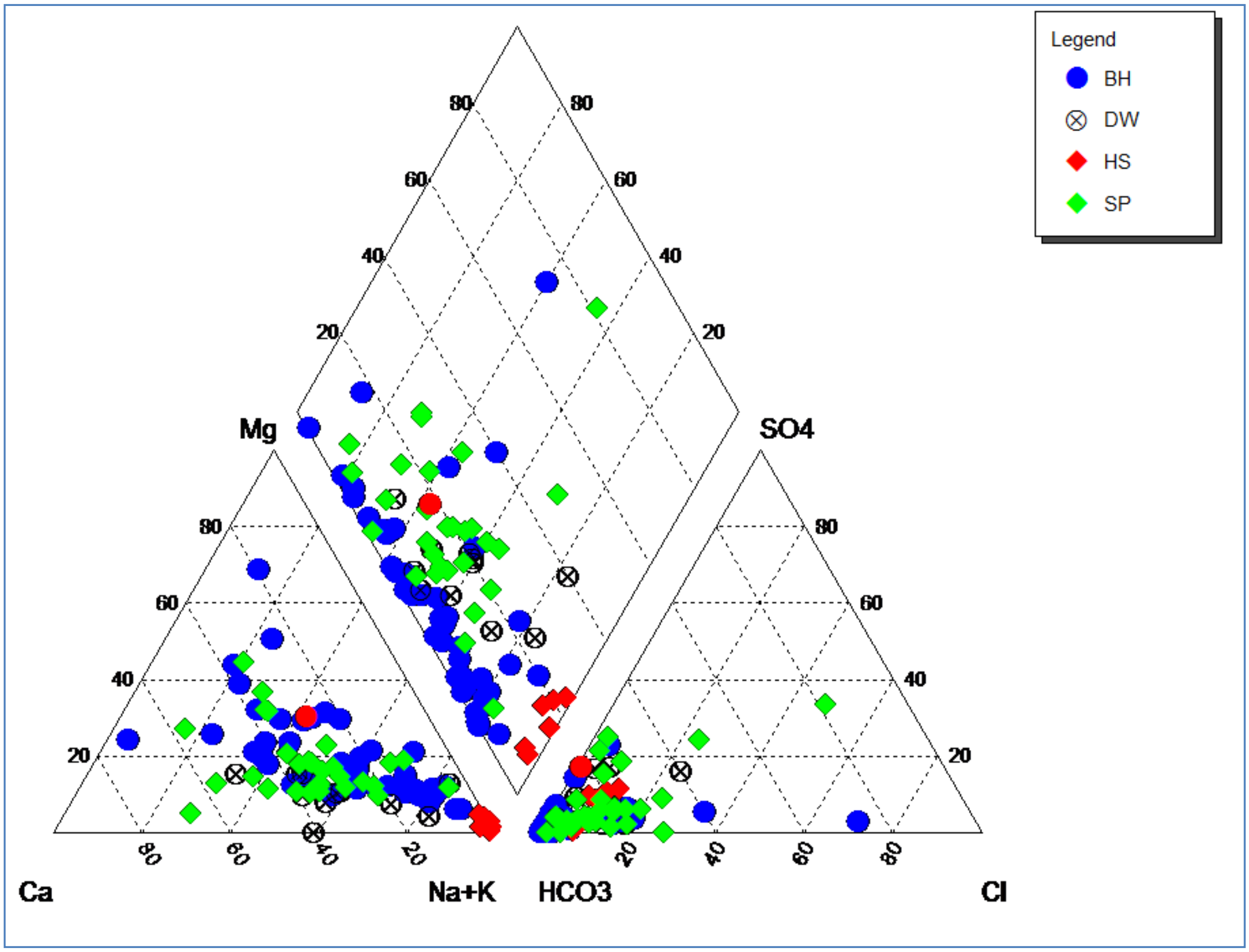


Figure 16.Piper Diagram of all natural waters of the study area

The two major cations and anions simultaneously reflected on the rectangle and forming intersection which is representing of water point. The reflection values in the central rectangle concentrated on its entire left side bar, which shows the Na + K + HCO3 and Ca +Mg+ HCO3. Accordingly, the water is Na-K-HCO3 and Ca-Mg- HCO3 types.

In addition to represent all water source together, piper diagram also important to display each water source of more than one sample. In the figure below, six piper plots observed which are representing Borehole; Hand dug well, Hot and cold springs.

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Tikurwuha River Catchment is mainly composed of lacustrine deposits and volcanic rocks of Tertiary and Quaternary age. The silicic rocks of the Dino Formation are not only confined to the rift floor but are extensively developed in escarpments and on the adjacent plateau. The Nazareth group includes ash flow tuffs, pantellritic ignimbrites and un-welded tuffs while the Dino formation is made up of Dino ignimbrites. The surface geology of the study area is composed of this type of formation as it is indicated in geological map of the Country. The rift ignimbrites are highly faulted and outcrop in most parts of the rift. It is made up of lithic and pumaceous tuff alternating with highly weathered reddish brown ash.

Porous aquifers of lacustrine sediments with alluvial, colluvial and elluvial sediments and pumacious pyroclastic of quaternary age have good groundwater holding and bearing capacity. this unit are consisting of more than one highly permeable water bearing unit of sand, pumice, coarse tuff, and volcano clastic sediments which is separated by clay aquitards and classified as Extensive and highly productive aquifer.

Highly to moderately productive mixed porous and fissured aquifers composed of volcano-lacustrine sediments, including scoria, scoraceous basalt, pumice, un-welded coarse tuff and ash which are associated with lacustrine sediments of fine to medium grained sand and gravel. This unit is characterized by porous permeability of sediments and fractured permeability of scoraceous basalt underneath the sediments. Groundwater in this is saline because of high evaporation from near surface water table. High concentrations of fluoride and sodium is also a big quality problem. This unit is classified as highly to moderately productive mixed porous and fissured aquifer.

Tertiary ignimbrites make extensive moderately productive fissured aquifer. In this unit groundwater flows through joints, fractures and faults, this are the major source of secondary porosity. open faults and fault system may also provide significant ground water flow path. This unit are the major source of hot and cold springs.

Quaternary Peralkaline rocks of mainly welded tuffs occurs in the eastern highland, adjacent to the rift margin. This unit form extensive low to moderately productive mixed porous and fissured aquifers. This unit ranges from un welded to moderately welded fine to coarse tuff and pumaceous deposits of acidic volcanics with characteristics of very deep water table and massive nature.

Groundwater flow direction in the study area is mainly controlled by structures and geomorphology. The general ground water flow of the catchment is towards west from south eastern part of the catchment.

Analyses of spring and borehole sample show considerable differences in the amounts and dominance of major ions. Chloride, Nitrate, Fluoride and total dissolved solids (TDS) are commonly used as groundwater quality indicators of potential contamination of groundwater.

A number of samples from the study area shows concentrations of Iron greater than 0.3 mg/l. The concentration the sample taken from the study area ranges from 0.008- 2.96. The is no noticeable pattern in the increasing or decreasing of iron concentration. Like the Iron Concentration Manganese also does not show any patter in the study area but samples from the highland areas who has high concentration of Iron also has manganese concentration greater than 0.4mg/l which is health based value.

The eastern and southern side of the study areas shows very low concentration of fluoride (<1.5 mg/l). This is the area, which has been identified as major ground recharge zone on the basis of its low EC and high Eh values. Most of groundwater samples have shown a fluoride concentration in the range of 0.03 to 8.9 mg/l. The study area can be sub divided in to two, on the basis of fluoride concentration: high fluoride area, (north western part) and low fluoride area (east and south).

The dominant water type of the study area is bicarbonate type this indicate that the ground water system in the study area is hydrochmically homogenous system. and the dominant cation is sodium followed by calcium. Based on the dominant cations and anions the water samples of the study are classified in three main water types: Na-HCO3 (Sodium Bicarbonate type), Na-Ca-HCO3 (Sodium-Calcium Bicarbonate type) and Ca-Na-HCO3 (Calcium -Sodium Bicarbonate type). Boreholes near Lake Hawassa and Hawassa Town, hot springs of the floor and foot of the escarpment, boreholes around Hawassa well field (Gemeto and Gara Riqeta) contain sodium bicarbonate type of water.

5.2 Recommendations

- 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 Wondogenet ridge.
- Further hydrological investigation is needed to quantify and estimate the recharge of the catchment.
- Other methodology like isotopes should be employed in future works for analysis of groundwater flow system along to confirm the output of this work.
- Regional major ions evolution (including the study area) needs to be conducted to observe variation of water types which strongly indicated groundwater flow direction.
- Lateral distribution of fluoride and iron should be assessed and mapped especially around Gemeto well field and in the vicinity.
- The source of iron and manganese in some part of the study area requires detail investigation.
- Appropriate environmental protection measures should be done on the eastern rift escarpment (upper parts of the Wondogenet ridge) and on the central part of the study area along which there are high groundwater flow is expected.

REFERENCE

Birhanu D. 2009. Groundwater Resource Assessment in The Gidabo River Catchment in The Southern Main Ethiopian Rift Province. Un Published Msc Thesis Addis Ababa, University, Ethiopia.

Boccaletti M., BoniniM., Mazzuoli R., Bekele A., Piccardi L. and Tortrici L. 1998. Quaternary oblique extensional tectonics in the Ethiopian Rift (Horn of Africa), Tectonophysics, 287, 97-116.

Chow V.T. 1988. Applied hydrology.

Ebinger C., Yemane T., Giday W., Aronson J. and Walter R., 1993. Late Eocene-Recent Volcanism and Faulting in Southern Main Ethiopian Rift System. J. Geol. London 150, 99-108pp.

FAO. 1984. Agro-climatological data for Africa: Food and Agricultural Organization of the United Nations, Rome, Italy.

Fetter C.W. 1994. Applied hydrogeology, Mir publishing com., 691pp.

Fetter C.F. 2001. Applied Hydrogeology 4th edition, Prentice Hall Upper Saddle River, New Jersey, U.S.SA. pp 82, 88-90, 151, 154-155, 169

Freeze R. & Cherry A. 1979. Groundwater. A Simon and Schuster Company Englewood cliffs. New Jersey, USA.

Geological survey of Ethiopia. 2014. Technical hydro geological and hydro chemical report of Dilla.

Geological survey of Ethiopia. 2014. Technical hydro geological and hydro chemical report of Hosaena.

Gidey W. 1987. Volcanotectonic history of the Central sector of the MER: A geochronological, geochemical and petrological approach, Unpub. Ph. D. Thesis, Clevland, Ohio, Case Western Reserve University, 410pp.

Hem J.D. 1989. Study and interpretation of the chemical characteristics of natural water. Third edition, US Geological Survey water supply paper 2254, United States government printing office, Washington, 253pp.

Hem J.D. 1992. Study and interpretation of chemical characteristics of natural water. Third edition. United States Geological survey water supply paper 2254, United States government printing office, Washington, 264pp.

Kumar P. 1997. Ground Water Assessment Methodology. National Institute of Hydrology

Roorke-247667 (Uttaranchal).

Marcel D. 1997. Chemical and isotopic groundwater hydrology.

Mengesha T., Tadwos C. and Workinesh H. 1996. Geological map of Ethiopia, Scale 1:2000000. Second Edition and explanatory note Bullitin number 3 GSE.

Mohr P.A. 1971. The Geology of Ethiopia. University College of Addis Ababa press, Addis Ababa, Ethiopia, First printing, 1961.

Piper A.M. 1944. A graphic procedure in the geochemical interpretation of water Analysis. Trans. Am. Geophys. Union 25, 914-923

Seifu K., Tenalem A., and Mohammed U. 2001. Application of isotopes and water balance approaches for the study of hydrogeological regime of the Bishoftu Crater Lakes, Ethiopia, Sinet: Ethio. J. Sci., 24(2), 151-166.

Tamiru A. 2006. Groundwater Occurrence in Ethiopia. Addis Ababa University. pp 88

Tenalem A. 1998. The hydrogeological system of the Lake district basin, Ethiopia, Unpub. Ph.D. Thesis, ITC, Enschede, The Netherlands, 259pp.

Tenalem, A. and Tamiru, A. 2001 Principles of hydrogeology, Department of Earth Sciences, AAU, Addis Ababa.

Todd D.K. 1980. Groundwater hydrology. Second edition, John Wiley & Sons, Inc.,New York, 535pp.

Toth J. 1963. A theoretical analysis of groundwater flow in small drainage basins. J. Geophys. Res. 68, 4795-4812.

Water Works Design & Supervision Enterprise. 1999. The study of Awassa Lake level rise, Interim Report, Addis Ababa, Vol. I-III, 265pp.

WHO 2017. World Health Organization, Guidelines for drinking water quality, 4th edition, Geneva.

Wondwosen M. 2005. Conceptualization of groundwater flow system and aquifer characterization in Awassa Lake catchment. Unpublished MSc Thesis Addis Ababa University, Ethiopia

Annexes

Annex 1. Selected lithological logs

Grarariqeta well 1

Depth (m)	Descriptions
0_2	Black Cotton Soil
2_32	Fine Grained Sand
32_70	Highly weathered Pumice
70_86	Medium Grained Sand
86_90	Silty Sand
90_100	Coarse Grained Sand
100_114	Fine Grained Sand
114_120	Pumice
120_124	Fine Grained Sand
124_138	Weathered Pumice
138_162	Fine Grained Sand
162_182	Weathered Pumice
182_200	Fine Grained Sand

Grarariqeta well 2

Depth (m)	Descriptions
0_4	Black Cotton Soil
4_10	Light Gray Silt
10_46	Dark Silt
46_61	Dark Coarse Grained Sand
61_94	Gray Silty Sand
94_156	Silty Pumice
156_171	Coarse Grained Sand
171_193	Silty Sand

Grarariqeta well 3

Depth (m)	Descriptions
0_2	Black Cotton Soil
2_22	Sandy Pumice
22_42	Coarse Grained or Fractured pumice
42_48	Silty Sand
48_58	Weathered Pumice
58_76	Fine Grained Sand
76_88	Weathered Rhyolite
88_94	Sandy Silt
94_102	Fractured Pumice
102_108	Silt
108_114	Coarse Grained Sand
114_148	Silty Sand
148_154	Medium Grained Sand
154_160	Silt
160_172	Coarse Grained Sand
172_186	Silty Sand

Grarariqeta well 4

Depth (m)	Descriptions
0_10	Light Gray Soil
10_30	Fine Grained Sand
30_58	pumice
58_62	Sand
62_74	Pumice
74_94	Fine Grained Sand
94_110	Slightly Weathered Pumice
110_114	Weathered Pumice
114_150	Coarse Grained Sand
150_154	tuff
154_166	Medium Grained Sand
166_168	Massive Rhyolite

Grarariqeta well 5

Depth (m)	Description
0 -20	Clay
20 -40	Silty sand
40 -60	Tuff
60 -100	Pumice

Grarariqeta well 6

Depth (m)	Description
0 -6	Silty clay
6 -24	Sandy clay
24 -42	Fine sand
42 -51	Clay
51 -72	Weathered and fractured basalt with sand
72 -108	Sand
108 -120	Sand and gravel

Grarariqeta well 7

Depth (m)	Description
0 -64	Clay
64 -76	Course Sand
76 -94	Pumice
94 -108	Fine Sand
108 -120	Tuff
120 -132	Silty Clay
132 -150	Clay

Gemeto well 1

Depth (m)	**Geological Description**
0-6	Top soil
6-12	Sand with weathered pyroclastic
12-30	sand
30-60	Highly weathered Pyroclastic
60-70	highly weathered pumice

Gemeto well 2

Depth (M)	Description
0 – 12	Dark Clay
12 – 34	Sand
34 – 40	Tuff
40 – 50	Silty Sand
50 – 57	Medium Grained Sand
57 – 70	Coarse grained Sand with some Gravel

Gemeto well 3

Depth (M)	Description
0 – 3	Top soil
3– 21	Fine Sand
21 – 39	Weathered pumice
39 – 66	Weathered pyroclastics
66 – 84	Fresh Basalt
84 – 120	Weathered pumice
120- 126	Fresh Basalt
126- 192	Sand
192- 200	Welded tuff

Gemeto well 4

Depth (M)	Description
0 – 6	Black cotton soil
6– 12	Sand
12 – 18	pumice
18– 24	Highly weathered coarse sand with pumice
24 – 27	Pumice
27 – 33	Medium size gravel with sand
33- 39	Weathered pumice
39- 54	Highly weathered Trachyte, Ignimbrite, sand and gravel
54- 63	Medium size sand with gravel
63- 66	Welded tuff
66- 84	Highly weathered sand with gravel

84- 87	Welded tuff
87- 129	Coarse sand and gravel
129- 132	Highly weathered ignimbrite
132- 171	Sand with gravel
171- 200	Highly weathered pumice with coarse gravel

Hawassa Town Adare Hospital

Depth (m)	Descriptions
0-3	Loam soil
3-9	Ash
9-12	Pumice
12-71	Scoria

Hawassa Industrial Park

Depth (m)	Descriptions
200-199	Highly weathered basalt
199 -188	Slightly weathered basalt
188-148	Highly weathered scoria & sand
148 -65	Highly weathered scoria with sand
65 -61	Coarse sand
61-54	Very fine sand
54 -39	Sand with weathered scoria
39 -36	Black scoria with pumice
36 -32	Weathered sand with pumice
32 -21	Sand with little scoria
21 -10	Sand with little gravel
10-7	Sandy clay with gravel
7-0+1m	Top soil

Annex 2. Water quality test results

SampleID	X	Y	pH	Cond	TDS	Na	K	Ca	Mn	Fe	SO4	HCO3	NO3	F
SP-1-1	447756	760183	5.8	4	2	1.4	3.5	3.6	0.5	0.37	3	15	23.8	0.04
SP-1-2	456639	755568	5.8	94	47	1.4	5	6.4	0.6	0	0	32	24.6	0.06
SP-1-3	448015	759981	5.9	36	18	10.7	5.5	3.9	0.7	0.07	1	37	15.8	0.07
SP-1-4	451154	770267	6.9	278	139	16.6	7.7	20	0	0.02	0	153	15.8	0.17
SP-1-5	464441	798855	6.43	183	38	17	5	11			10	45	11.4	0.28
SP-1-6	455740	788356	6.29	264	158	10	7	2			15	41	5.9	0.26
SP-1-7	450572	785000	6.17	175	105									
SP-1-8	451992	785880	6.18	181	109	25	5	9			11	41	0	1.07
SP-1-9	452973	785004	5.6	125	75									
SP-1-10	461987	757382	6.95	254	152	16	7	22			6	39		0.1
SP-1-11	461555	786954	7.08	76	46	10	2.3	23			0	22	3.3	0.07
SP-1-12	462875	780510	6.55	157	54	11.4	5	13.4			5	50	22.2	0.1
SP-1-13	460747	764454	8.29	135	61	12	4	10			2	55	7.5	0.27
SP-1-14	456872	781620	6.27	234	140	34	11	2			4	112	0.03	0.4
SP-1-15	458776	781557	7.8	212	127	22	5.3	13			4	134	1.33	0.57
SP-1-16	460084	782090	8.25	191	115	17	5.4	12			3	99	7.97	0.3
SP-1-17	457323	780700	5.04	275	105	22	13	16			17	12	20.5	0.36
SP-1-18	458808	779958	6.27	143	64	16	1	7			6	73	0.68	0.48
SP-1-19	457122	779857	5.96	162	97									
SP-1-20	467343	777517	6.19	154	28	10	6.1	22			5	92	3.1	0.59
SP-1-21	458502	776750	6.33	208	126	24	1	11			4	113	6.65	0.75
SP-1-22	456156	776054	6.34	334	200	20	17.2	20			7	93	29.1	0.55
SP-1-23	452037	785783	5.3	48	29	4	2	3			1	20	7.09	0.07
SP-1-24	451235	750452	6.61	242	145	14	5.3	17			3	149	9.75	0.29
SP-1-25	445646	770671	6.11	274	364			17.5			0	12.2	5.28	0.12
SP-1-26	445381	770502		235	141	27.2	5	14			1	15.73	2.24	0.54
SP-1-27	444675	770823	6.35	238	133	2.3	4	14			1.3	124	6.3	0.35
SP-1-28	443002	760880	5.77	107	54	7.4	6.4	6			3	49	12.85	0.16
SP-1-29	448464	782924	5.77	142	55	12	6.3	3			1	51	12.29	0.16
SP-1-30	451888	762462	5.65	98	41	8.1	4.3	3			1	40	0.5	0.24
SP-1-31	468348	761450	5.26	99	59	7	5	6			1	46	11.09	0.15
SP-1-32	459945	758292	6.73	85	29	1	5	3			0.4	37	3.1	0.14
SP-1-33	458852	757314		100	50									
SP-1-34	464996	757188	5.71	79	47	8	3	4			2	32	11.52	0.15
BH-1-1	447762	771246	6.5	384	192	31.3	6.3	20	0.5	0.14	27	166	19.4	0.03
BH-1-2	445082	772614	7.7	545	273	47.5	3.7	30	0	0.07	1	293	12.8	2.07
BH-1-3	448118	772982	6.7	565	283	26.7	4.5	32	0.2	0.1	5	190	11.4	0.43

BH-1-4	443968	772921	6.5	402	201	50	5.9	38.4	0.6	0.59	2	293	0.4	0.31
BH-1-5	444042	771978	6.5	168	84	54.2	7.6	16	0.2	0.07	1	98	2.2	1.13
BH-1-6	448528	772643	6.5	360	180	25.1	3.8	26.4	0.003	0.3	5	183	6.16	0.71
BH-1-7	447977	771948	7.35	360	180	45.2	4.6	14.4	0.014	0.26	5	195.2	4.84	0.66
BH-1-8	449926	770917	7.35	330	170	18.9	4.8	24	0	0.04	3	178.12	7.04	0.8
BH-1-9	449214	771948	7.55	470	230	164.6	4	27.2	0	0.08	8	585.6	2.64	0.65
BH-1-10	445269	773012	7.1	530	265	46.2	6.8	22	0	1.72	4	268	13.2	1.94
BH-1-11	443886	771378	6.87	324	200	47.5	6.7	18.4	0	0.03	0.55	197.64	0.95	1.57
BH-1-12	455827	776385	7.76	432	259	54	3	13			2	272	0.3	3
BH-1-13	456449	775340	6.04	241	145	16	9	20			1	13	33.6	1.33
SampleID	X	Y	pH	Cond	TDS	Na	K	Ca	Mn	Fe	SO4	HCO3	NO3	F
BH-1-14	453503	772256	8.52	330	221	38	13	22			11	177	4.43	1.5
BH-1-15	451752	771715	6.44	508	205									
BH-1-16	440747	768424	6.9	299	150	29.8	7.8	28	0	0.1	4	232	5.3	0.83
BH-1-17	446191	780125	7.3	985	493	189.9	18.3	22	1	0.08	0	647	4.4	4.78
BH-1-18	437337	764453	6.8	329	165	37.9	8.4	14	0	0.32	1	171	9.7	1.66
BH-1-19	437317	767645	6.5	250	130			24.8	0.014	0	0	183	4.4	1.5
BH-1-20	445633	770637	6.8	277	139	24.7	6.1	15.2	1	0	0	166	6.6	0.03
BH-1-21	448486	767636	6.3	252	126	18.9	7.4	16.8	0.8	0.48	10	41	32.6	0.02
BH-1-22	451702	766658	6.4	256	154.8	42.06	3.15	44	1.4	2.96	7	292.8	4.4	0.85
BH-1-23	467137	771511	7.15	131	70	13	3	9.3			1	15	2.56	0.24
BH-1-24	466072	764373	6.17	14	51	3.3	1.9	6			1	56	1.77	0.22
BH-1-25	444538	779298	7.85	989	497	7.5	11	24	0.01	0.37	0	183	2.2	2.9
BH-1-26	445205	779257	8.1	725	363	165.6	12	29.2	0.4	0.7	1	598	4	4.94
BH-1-27	441095	776350	7.6	919	460	377.6	31.5	28	0	1.2	2	1244	8.4	8
BH-1-28	443283	781228	8	890	445	359	38	22.4	0	0.44	0	1196	3.5	8.71
BH-1-29	441796	779759	8	674	337	290.2	25	28.8	0.1	1.5	0	952	6.6	6.58
BH-1-30	444046	777856	7.1	959	480	128.2	26	36	0.2	0.08	23	573	3.5	4.13
BH-1-31	444224	777249	8.1	929	465	262.1	2.1	36.8	0.01	0	23.5	673	5.28	4.1
BH-1-32	443745	780233	7.7	920	460	213.3	2	38.4	0.1	0.214	0	644.16	20.68	5.8
BH-1-33	441936	778609	7.8	567	284	124.6	18	8	0	0.3	8	366	1.24	8.61
BH-1-34	442212	778191	8	1004	502	125.9	12	48	0.1	0.04	31	537	0.4	0
BH-1-35	442333	779452	8.3	1336	670	251.8	16	36	0	0.3	40	756.4	0.92	4.8
BH-1-36	440370	778898	7.75	1443	725	254.4	2.3	24	0.7	0.022	30.2	755.18	5.72	8.9
BH-1-37	441715	779318	6.6	1445	723	35.2	7.4	14	0	0.04	1	177	9.7	6.53
BH-1-38	442876	779278	7.44	983	498	69.69	12	45.6	0.3	0.04	16	603	15.81	2.54
BH-1-39	442765	780010	6.8	545	273	28.6	8	64	0.1	0.03	8	342	8.8	7
BH-1-40	443592	780212	8.1	1016	508	156.4	12	16	0.1	0.06	6	580	4.4	0

BH-1-41	444827	779531	8.42	870	440	181.5	11	20	0.1	0	2	488	7.48	4.8
BH-1-42	441168	775893	8.32	1411	707	304.3	9.5	36	0	0.02	95	732		5.2
BH-1-43	444096	779891	7.14	893	449	172.2	10.5	28	0.01	0.008	1.6	622.2	4	4.2
BH-1-44	443296	778649	8.36	997	500	227.5	2.4	32	0.3	0.1	34.3	629.5	22.88	5
BH-1-45	444865	779285	8.5	940	470	217.3	5	24	0	0.1	0.7	573.4	14.52	4.45
BH-1-46	444568	779434	8.1	842	422	6.85	11.5	20	0.006	0.12	0	152.5	1.32	1.71
BH-1-47	444775	778878	8.03	923	462	11.5	10.5	16	0.01	0.08	1	183	4.4	1.64
BH-1-48	462146	795570	6.9	236	144	29	8.7	13.6	0	0.12	4.52	132.54	0.69	0.82
BH-1-49	462737	765210	6.8	152	76	20	3.9	1	0	0	1.82	70	0.56	0.41
BH-1-50	454724	792554	7.38	219	138	59.5	1.6	2.4	0	0.51		176.95	0.01	1.24
BH-1-51	436551	788251	8.5	250	125	0	6	44.8	0.9	0.35	1	317	4.8	6.8
DW-1-1	453430	791221	6.45	436	262	69	14	10.4			26	124	43.9	1.26
DW-1-2	455612	752890	6.15	211	127	26	11	14			2	104	1.77	0.58
DW-1-3	457255	752872	6.23	240	144	33	9	9			2	107	12.3	0.43
DW-1-4	457004	779044	6.28	182	109	19	10.4	1			3	17	1.56	0.56
DW-1-5	454588	775165	6.51	254	152	25	14	15			4	140	2.59	1.4
DW-1-6	452744	772218	6.76	613	368	59	30	46			19	231	0.16	1.3
DW-1-7	452000	773211	6.74	784	470	34	15.2	56			12	464	0.89	2.51
DW-1-8	453808	773518	6.5	333	167	28.5	12	24.1	0	0.14	5	165	20.7	0.31
DW-1-9	453988	773816	6.5	302	151	30.7	10.5	24	0	0.01	3	166	12.8	0.37
SampleID	X	Y	pH	Cond	TDS	Na	K	Ca	Mn	Fe	SO4	HCO3	NO3	F
DW-1-10	452474	772165	7.1	301	151	30.4	7.3	18	0	0.08	19	116	11.4	0.31
DW-1-11	452875	772232	6.5	485	243	26.4	30	28	0	0.11	15	185	23.8	0.51
HS1-1	452550	785341	8.63	1964	1178	450	27	5			70	778	0.63	27.6
HS1-2	458965	786015	9.43	2825	1696	740	40	4			180	1563	0.04	8.1
HS1-3	456944	782483	7.72	965	579	182	41	0			0.51	564	0.74	1.2
HS1-4	460642	781766	8.16	903	542	170	42	1.1			2	541	4.23	1.4
HS1-5	447158	772549	5.6	970	582	196	15	3			37	467	0.39	5.39
HS1-6	447189	772554	6.76	1708	1025	380	25	10			90	854	0.12	0.6