ADDIS ABABA UNIVERESTY

COLLAGE OF NATURAL AND COMPUTATIONAL SCIENCES

SCHOOL OF EARTH SCIENCE

ASSESSMENT OF GROUNDWATER-LAKE WATER INTERACTION IN LAKE HAWASSA BASIN BY USING GEOCHEMICAL APPROACH

A Thesis submitted to the School of Earth Sciences, Addis Ababa University, in partial fulfillment of the requirements for the Degree of Master of Science, in Geological Engineering (Hydrogeology)

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Addis Ababa Ethiopia

Declaration page

I the undersigned approve that this thesis is my original work and data collected primary and secondary, but has not been presented in any other university. All sources of material used for the thesis have been duly acknowledged.

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This is to confirm that the thesis titled ‘Assessment of groundwater-lake water interaction in Lake Hawassa basin by using geochemical approach’ prepared by Lulu Buchule and submitted in partial fulfillment of the requirements for the Degree of Master of Science in Hydrogeology, adheres to the University's regulations and meets the accepted standards for originality and quality.

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Abstract

This study investigated the interaction between groundwater and lake water in the Lake Hawassa Basin through a geochemical approach. Utilizing field and laboratory analyses, including measurements of radon, electrical conductivity, pH, and fluoride levels, the research identifies key interaction zones, particularly along the Tikur Wuha River and the southern lake perimeter.

The findings of this research serve as critical input for groundwater drilling site planning and water resource management in the research area. Despite the presence of numerous boreholes, many are utilized for purposes other than drinking due to water quality concerns. The study identifies the eastern (Tikur Wuha river side) and southern (bottom of the lake) zones as direct interaction areas between lake water and groundwater. To mitigate water quality risks, it is recommended to establish well fields outside these interaction zones, preferably closer to Lake Hawassa.

Geochemical analysis reveals that Hawassa City and adjacent lake areas are significantly impacted by high concentrations of fluoride and salinity, particularly within the interaction zones. The observed variations in water chemistry across sampled sources are attributed to the hydrogeological and geological characteristics of the region, influencing the transmission of dissolved materials.

Keywords: Geochemical approach, Groundwater, lake water, PH, EC, Fluoride, Radon

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Acronyms	
Bq/m3	Becquerel per Meter cube
BH	Borehole
CO_3^2	Carbonate
DEM	Digital Elevation Model
EC	Electrical Conductivity
EARS	East African Rift System
E-W	East West
F^-	Temperature
GW-SW	Groundwater _Surface Water
GIS	Geographic Information System
GPS	Global Positioning System
HCO_3	Bicarbonate
N-S	North_ South
NW-SE	North West_ South East
Rn	Radon
m.a.s.l	The meter above sea level
T	Temperature
TDS	Total Dissolved Solids
WHO	World Health Organization
Δ	Delta
δ18O	delta oxygen-18
δ 2H	delta deuterium
µs/cm	micro Siemens per centimeter
A	Delta Nations
E	Total enrichment factor

CHAPTER 1

1. Introduction

1.1 Background

The Earth's hydrogeological framework facilitates dynamic exchanges between surface water and groundwater systems. Groundwater discharges into surface water bodies, sustaining base flow in streams, while surface water infiltrates subsurface layers, recharging underlying aquifers (USGS) Water Resources Mission Area, 2019). These interactions occur through two key processes which are Recharge and discharge. Surface water percolates through the soil, displacing or replenishing groundwater in recharge and Groundwater exits aquifers as base flow, contributing to lakes, rivers, and other surface water bodies is discharge. This mechanism is critical for maintaining surface water flow, particularly during dry seasons when precipitation is scarce. Variations in climate (e.g., precipitation, evaporation) and anthropogenic activities further influence these interactions.

To evaluate these processes, the study employs geochemical tracers, combining field measurements with laboratory analyses. Field observations included real-time measurements of radon, electrical conductivity (EC), temperature, and pH, while laboratory testing provided additional data on pH, Electrical Conductivity (EC, µS/cm),Total Dissolved Solids (TDS, mg/L),Carbonate (CO_3^{2-}, mg/L),Bicarbonate (HCO_3^-, mg/L) an Fluoride (F^-, mg/L).

Geochemical tracers, supported by piezometery data, are well-established tools for investigating groundwater-surface water interactions at regional scales (Kebede et al., 2021). The integration of field and laboratory data enhances the reliability of findings, particularly in assessing fluoride levels and other hydro chemical parameters.

Groundwater and surface water physically overlap at the groundwater surface, resulting in the exchange of water and chemicals in the subsurface. This exchange is an essential component of the hydrologic cycle, and surface water provides recharge to the underlying aquifer, while groundwater can be stored for days, months, years, or even centuries before it returns to the stream. The quality of the initial recharge water can change significantly before it discharges at the surface, depending on the amount of time it spends underground and the geochemical conditions within the aquifer.

Controlling how surface water and groundwater interact is essential to the sustainability of water supplies. Understanding the behavior of interactions, events, and dynamics between surface and groundwater through the use of hydrochemistry, environmental isotopes, and radon in the hydrogeological cycle is therefore essential.
The research questions were addressed in this research to identify the groundwater and lake water interaction in Lake Hawassa basin. The characterization of water chemistry result the interaction zone is found at eastern of the lake Hawassa at Tikur Wuha river side and southern bottom of the lake, on which all character of tracers due to interaction is full field. Especially in case of salinity and fluoride the highest concentration were found on which two interaction zones, these were the main questions of the research additionally the findings highlighted the importance of subsurface geology and fault systems in controlling groundwater discharge into Lake Hawassa. Water Quality Variations in Groundwater and Other Sources Geological and hydrogeological factors control the transmission of chemical elements (e.g. fluoride, salts) spatial variability: differences in rock types, aquifer properties, and flow paths lead to variations in water quality across the basin.

Thiess included mapping of the spatial distribution of Fluoride, Salinity, $P^{H,}$ radon along river segments and Electrical Conductivity (EC) in the Hawassa catchment and Lake Hawassa. The high concentration of fluoride and salinity in research area of ground water and lake water is the main challenge of the society and based this statement of problem the main object of study conducted the interaction between Lake Water and groundwater. These techniques are employed to map the geographical distribution of fluoride in the study area utilizing primary and secondary data.

1.2 Statement of problem

The presence of specific contaminants in water sources poses significant health risks, particularly concerning fluoride and salinity levels. According to the World Health Organization (WHO), excessive fluoride in drinking water can lead to dental and skeletal fluorosis, especially in regions like Ethiopia's Rift Valley, where groundwater often contains high fluoride concentrations (He et al., 2020; Wang et al., 2018). Families residing in these high-fluoride zones are particularly vulnerable to health complications stemming from prolonged exposure to contaminated water. Groundwater in the Lake Hawassa Basin is derived from various sources, including springs and wells, which receive water from precipitation and surface water infiltration. The hydrological cycle illustrates the complex interactions between these sources, yet the specific dynamics of groundwater-lake water interaction remain poorly understood. Given that both groundwater and surface water can influence each other's quality, it is crucial to investigate whether fluoride and salinity concentrations in this basin interact and how they affect water quality.

This study seeks to clarify whether groundwater feeds into Lake Hawassa or if the lake contributes to groundwater recharge. Previous research has often overlooked these critical interactions, thus highlighting the need for a comprehensive geochemical analysis to identify the sources and impacts of fluoride and salinity in the region's water supply. Understanding these interactions is vital for formulating effective water management strategies and ensuring public health safety in the Lake Hawassa Basin.

1.3 Objectives

1.3.1 General Objective

The main objective of this study is to assess the interaction between lake water and groundwater in the Lake Hawassa by Basin using a geochemical approach.

1.3.2 Specific Objectives

The research has the following particular objectives:

- To characterize groundwater chemistry
- To characterize lake water chemistry
- To study groundwater dynamics
- To analyze the signature of Rn-222 in groundwater and lake water

CHAPTER 2

2. Literature Review

The investigation of Lake Water groundwater interaction in Lake Hawassa basin is very important for water resource development and management .In this research to assess interaction deference materials were used including the published research papers which were related with the main object of the research. Seifu Kebede et al., (2021) investigated regional scale ground water surface interaction in Awash basin Ethiopia by using geochemical tracers and piezometry. For advance knowledge published papers helped them to understand about how exchange of water through ground water and surface water, their impacts on riverine ecology, and water quality, the interaction pathway for chemical exchange and specifically even small scale of exchange between ground water and lake water surface water huge effect in water chemistry (Drillings et al 1996, Telfords and Lamb 1999). Chemical tracer's piezometric observation and simple water balance that maximize the use of available datasets were conducted methodology on research.

Tsadeneya, A. (2018) investigated the interaction between surface water and groundwater along the Awash River's main course. According to the study the isotopic composition of the Upper Awash ground waters is comparable to that of the present rainfall. An examination of their isotopic compositions served as the basis for this. Although the majority of the groundwater in this area are older and come from the Middle and Lower Awash. ^{222}Rn measurements are used to measure groundwater discharge into the river in the Upper, Lower, and Middle Awash. Groundwater discharge can be observed in a number of distinct regions in the lower and middle Awash, such as the vicinity of the irrigation areas of Wonji, Metahara, and Amibara, as well as along thermal spring discharge zones downstream, such Meteka. The Pizeometeric evidence supported this observation.

The hydrology of the rift lakes is driven by highland rainfall, and the rise in water use and increased evaporation rate had a significant impact on the lakes, particularly after 2000 (after the start of large-scale water abstraction).According to Ayenew's (2004) study on the susceptibility of a few Ethiopian lakes to tectonic activity, climate change, and water consumption. The study also found that, due to significant deforestation over the previous three decades, River discharge data reveal locally increasing trends indicating an increase in runoff, even if rainfall has

somewhat decreased and temperatures have increased. Furthermore, groundwater entering and exiting the lake is facilitated or hindered by marginal normal open faults and rift valley floor faults.A thorough examination of the condition of surface-water/groundwater interaction from the headwater to the Nile Delta region is given by Kebede et al. (2017). The Nile shifts from a gaining stream in the headwater regions to mostly a losing stream in the arid lowlands of Sudan and Egypt, according to piezometric and isotopic (δ18O, δ2H) evidence. Plotting of particular Nile water leakage zones to neighboring aquifers is done using the two types of data.
Dynamics of Groundwater on the Left Bank by Tilahun A. (2014) catchments of the Upper Awash River Basin and the Middle Blue Nile, Central Ethiopia, and come to the conclusion that a unique regional groundwater flow pattern has been discovered, suggesting inter basin groundwater flow from the Blue Nile to the Upper Awash basin, which is connected to the interplay between regional faults. In addition to the horizontal annual groundwater inflow of 152Mm3 to the Upper Awash groundwater basin derived from the regional groundwater flow model, the inter basin groundwater flow conceptualized from litho-structural and hydrodynamic characterization is supported by 18O and D-depleted waters with high TDS, NaHCO3 water types, positive residual alkalinity, and low 14C activity observed along the water divide between the Blue Nile and the Upper Awash.

The Hawasa catchment was examined by Yewalaeshet T. (2015). The results of a stable isotope research show that groundwater and lake water interact in both the north and the southwest. Measurements of water level were utilized to support the stable isotope result and demonstrate groundwater flow to Lake Hawassa from all around the caldera rim. The northern side is an anomaly, as there is local groundwater flow away from Lake Shalla and groundwater flows away from the watershed. Along the path of groundwater flow, ionic concentration increases and isotopic enrichment of (2Hand18O) is noted. The results of hydrochemical investigations indicate that the area is characterized by three main types of water.

The advantages of using hydro-chemical and isotopic tracers in addition to well-head observations were illustrated by Michael et al. (2017). These tracers helped to clarify the hydrogeological characterization of the intricate rift aquifer system and the dynamics of groundwater flow with fault functioning in the intricate hydrogeological system of the Gidabo River Basin. The findings of the study may also be helpful as a foundational source of data for local groundwater exploration, conceptual groundwater flow modeling, and enhancing understanding of Ethiopia's intricate hydrogeological divide.

CHAPTER 3

3. Materials and Methodologies

Integrated methods including geological mapping, hydrogeological mapping, water point inventory, in-situ temperature, electrical conductivity, Fluoride concentration, PH measurements and radon measurement were used to comprehend the surface and groundwater interaction of Lake Hawassa.

During the initial phase of the study, prior research was gathered and examined, including scientific publications, master's theses, well completion reports, and groundwater investigation studies carried out in and around the Lake Hawassa watershed. Furthermore, these research' limitations and data gaps were noted. In order to describe the interaction between the surface and groundwater Lake Hawassa, extensive field investigations were carried out along a few chosen routes in the second phase of the project. Furthermore, every available water source, including hand dugs, springs, and both deep and shallow boreholes, was surveyed and were stocked, and water samples were taken for investigation of hydrochemical processes. In addition, several surface water bodies and boreholes were subjected to in-situ EC, temperature, pH, and radon measurements. The third phase involved analyzing data gathered from earlier studies, outdoor research, and lab findings.

3.1 Materials

The research was gathered, examined, and prepared using the following tools and resources.

Table 1 Materials/ Software

No	Description	Application
1	ArcMap 10.7	To make geological and hydrogeological map and for interpolation of point measurement
2	MS-Excel_2010	Point data, Graph, chart presentation, Calculation
3	MS-Word_2010	Report Writing
4	MS-PowerPoint_2010	Thesis Presentation

Table 2 Material/Equipment

S. No.	Description	Purpose
1	Topographic map of 1:50,000 scale	Visualization of different topographic and geomorphologic features and assessment of access routs
2	Garmin 12 channel GPS	Acquiring positions
3	Geological and Hydrogeological maps	Reference/ Base map during the field work
4	RAD-7	Continually measures radon and thoron concentration
5	Portable pH and EC meter	In situ measurement of pH, TDS (Total dissolved solid) and electrical conductivity (EC) of water samples
6	Distilled water	Washing the electrodes of pH and EC meters to prevent sample contamination
7	polyethylene sample bottles	Collecting and storing representative water Samples
8	Deep Meter	To measure Static water Level
9	Camera	Take snapshots of various features
10	Vehicle	Traveling

3.2 Samples collection and measurements

Water samples are taken from boreholes, hand-dug wells, springs, and rivers in both dry and rainy season. The sample was collected by plastic bottles and which volume holds 330 milliliters. Following that, the bottles are meticulously and correctly labeled. Included on the label are the sample ID, sampling position, sampling date, and the locality where the sample was collected, then conducted to Lab test. On-site measurements of radon (^{222}Rn) concentrations are made at a number of chosen river segments and their tributaries. The river's geographic configuration and the easiest routes to all of its eastern tributaries were taken into consideration when choosing the river segments for Lake Hawasa.

3.3 Description of the study area

3.3.1 General Description

Lake Hawassa catchment is located in the Ethiopian Rift Valley Basin, particularly Sidama regional state; it lies between 6° 50′–7° 15′ latitude and 38° 17′–38° 44′ longitude. The study area has a total area of 1385 km^2 , and it is located about 275 km south of Addis Ababa. The area will be accessed through the main asphalt road from Addis Ababa to Hawassa and has minor road in local area as presented figure 1 bellow

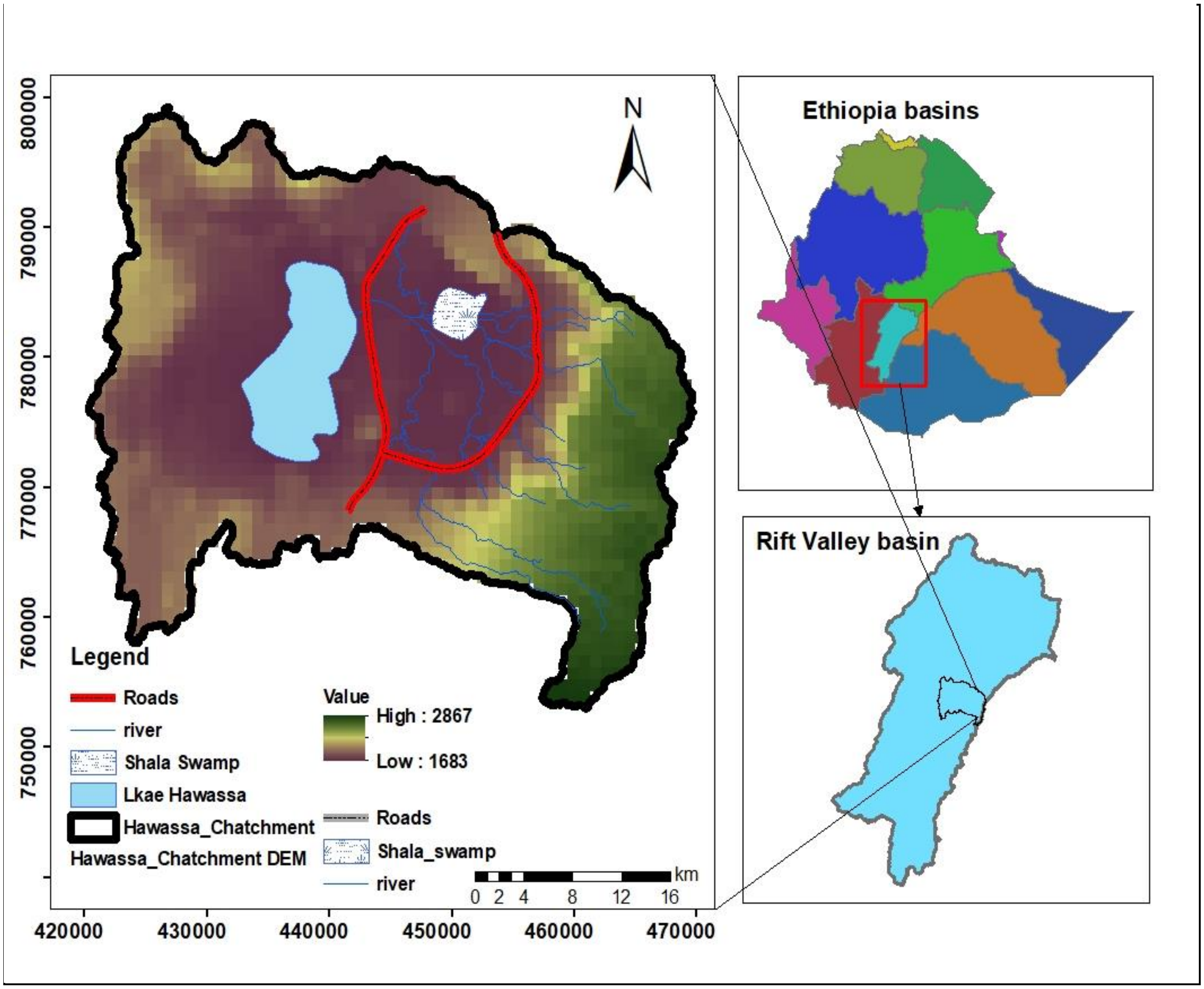


Figure 3.1 Location Map of study area

Topographically, Hawassa Lake is closed, with few streams flowing from the northwest and west to the lake. Tikur Wuha River is the Perennial River, which fed the lake from the northeast side of the catchment. According to historical data in 1999, the river discharge is high between June and October and low from October to May. Currently, the station is not functional. Rain fed farming is the primary source of income for people in the study area. Legesse et al. (2003) reported that the catchment has three seasons: (1) the primary rainy season between June and September (locally known as kiremt); (2) the dry season (lo-cally known as baga) between October and February; (3) the limited rainy season between March and May (locally known as Belg). The distribution of rainfall in the Lake Hawassa catchment area is high in kiremt between June and September, although low rainfall occurs between October and February. The belg season has mild rainfall. However, in some stations, the highest rainfalls were recorded in this season.

3.3.2 Regional Geology and Hydrogeology

3.3.2.1 Regional Geology

The East African Rift System (EARS) one of the most important tectonic structures of the earth's crust between the Africa (Nubia) and Somalia plates. In the EARS's northern section, the Main Ethiopian Rift (MER) stretches from Lake Chamo in the south to Afar in the north (Mohr, 1964). With notable dips to the E or ESE, the regional faults of the Main Ethiopian Rift System primarily run N-S or NNE-SSW. The local faults have a sharp drop. According to Kedir Yasin (2002), the eastern part of the fault travels westward. The northern section of the study corridor around the Lake facilitates the easy identification and mapping of volcanic domes, cones, calderas, faults, and significant earth cracks and fractures. At least three distinct kinds of faults, including NNE-SSW, N-S running, NW-SE, and E-W running faults/fracture zone, are present in the region.

3.3.2.2 Local Geology

Since the research area is located in the center sector of the MER, it has the same features and development history as the MER. The Lake Hawassa basin, located in the Ethiopian Rift Valley, exhibits a complex geological setting shaped by volcanic and tectonic activities which classified as the following.

1. Tectonic and Volcanic Origins

The basin is part of the Main Ethiopian Rift (MER) and formed within a collapsed caldera resulting from volcanic eruptions and tectonic subsidence. The caldera is bounded by fault systems, primarily aligned in a NE-SW direction; with escarpments reaching up to 2,700 meters above sea level (masl) .The Lake itself lies at 1,680 masl, surrounded by steep slopes and radial drainage patterns.

2. Geological Formations

Volcanic Rocks: The basin is dominated by acidic volcanic (e.g., ignimbrites, pumice flows) and basaltic lava flows, remnants of Pleistocene volcanic activity. Sedimentary Deposits: Lacustrine and fluvial sediments, including loose volcano-lacustrine deposits, cover the basin floor. These sediments are prone to erosion, contributing to sedimentation in Lake Hawassa. Fractured Aquifers: The subsurface comprises fractured ignimbrites and volcaniclastic sediments, which serve as primary groundwater reservoirs.

Figure 3.2 Basaltic lava flows on west of the Lake Hawasa

3.3.2.3 Geological Structure in the Research Area

Tectonic pressures create faults, folds, joints, and any combination of these resulting in the formation of geological formations. These constructions have the ability to change the hydrological and hydrogeological characteristics of an area, as well as the appearance of a landscape. Some environmental conditions or structural elements encourage the buildup of groundwater in an aquifer, while others function as a drain. Similar to reservoirs on the surface, natural geological conditions are essential for groundwater storage. These tectonic features, which alter the capacity of various strata to support water, could be geologic or natural dams or traps. Due to the potential for interaction between surface and groundwater, geological features have a significant influence on altering the physicochemical composition of water. The position, orientation, and density of faults and lineaments are essential for comprehending the local hydrogeological system.

Faults, calderas, fractures (cracks), and volcanic domes and cones such as strike-slip faults, shear joints, extensional joints, and faults associated with calderas are among the volcano-tectonic features that define the study area. Caldera marginal faults, caldera-related faults have an uneven surface cross-section that is primarily parallel to the caldera rim. To illustrate how the research region is conducive to recharging, the lineaments density is mapped. These faults have a steep to moderate slope that leads to the center of the caldera.

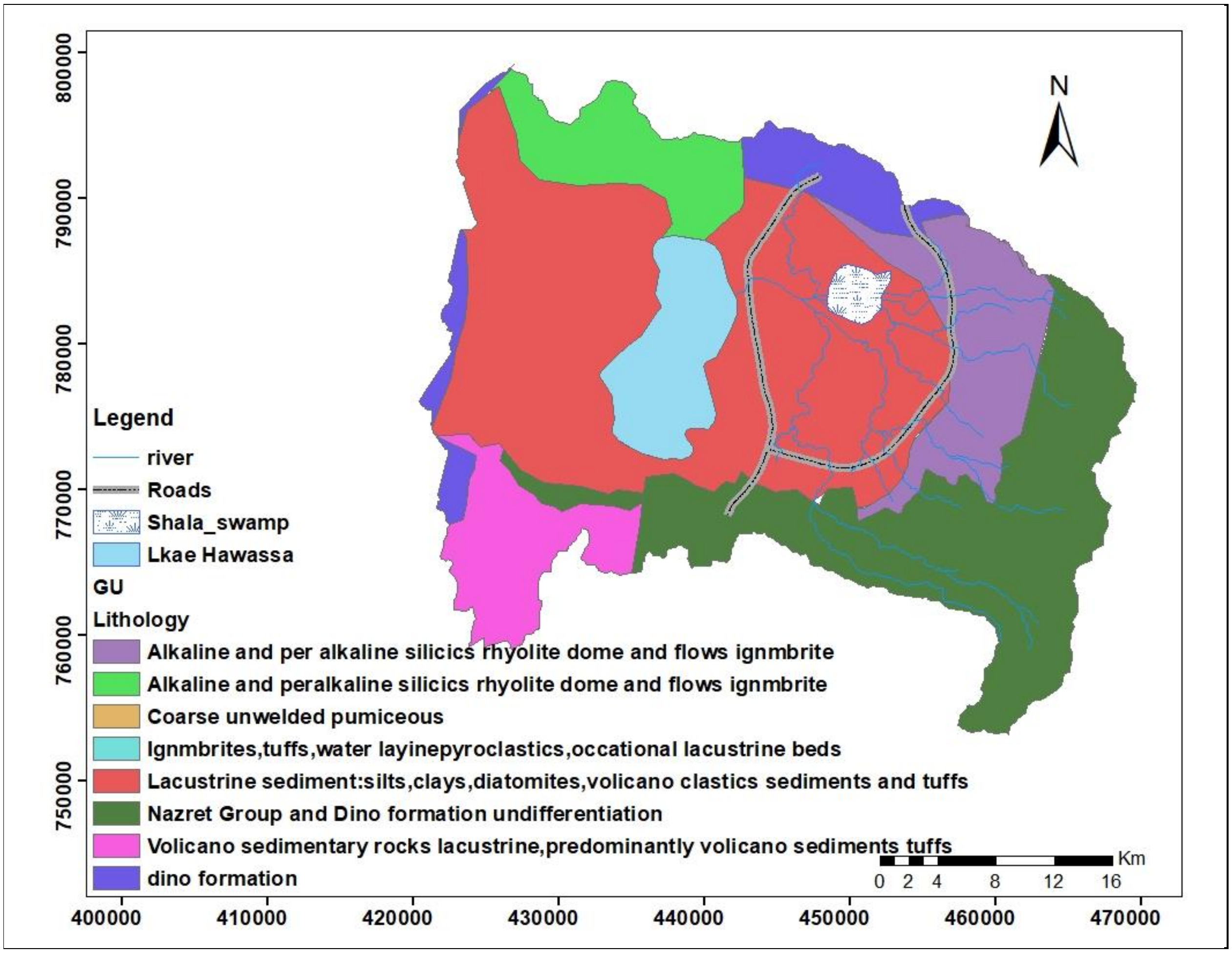


Figure 3.3 Geological Map of study area

3.3.2.4 Hydrogeological Unit

Fractured and jointed ignimbrites, as well as the volcano-lacustrine sediments that cover them, are the two primary aquifer types in the research region. Additionally, the region's primary water-bearing geothermal fluid deposit is ignimbrites (Tessema, 2003). In order to describe the various hydrogeological units in the study area, the existing water points are not dispersed equally.

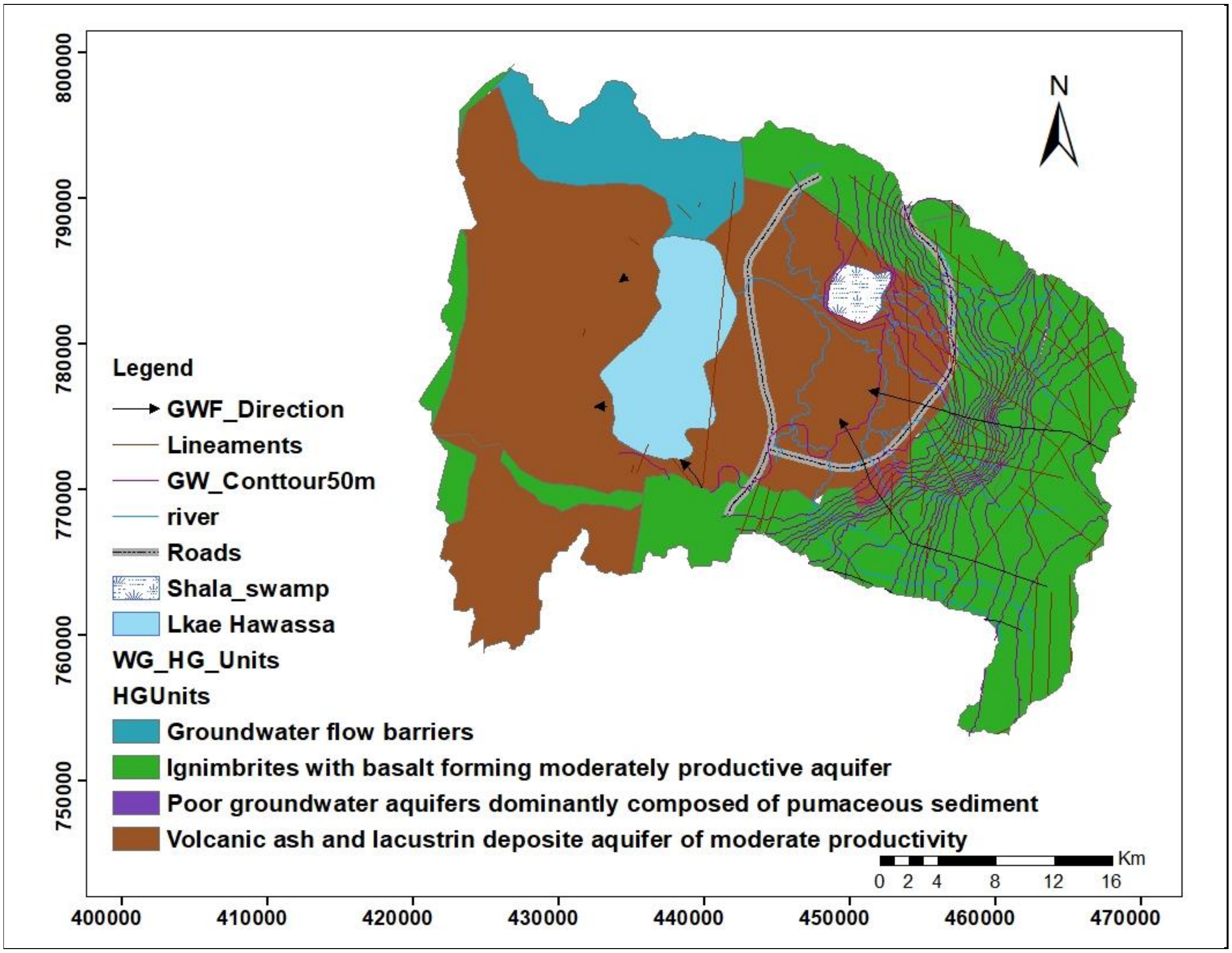


Figure 3.4 Hydrogeological Unit Map of study area

In addition to hydraulic characteristics (k and T), rocks' water-bearing qualities and recharge sources are taken into account (Tessema, 2003).However, the borehole's discharge in the eastern part of Lake Hawasa has a good discharge of 5-47 liters per second, with a depth range of 25 to 150 meters. The area northeast of the area study on the route from Shashamane to the Hawasa has low potential and the least amount of drawdown in the town and its surroundings.(Toga plain) include the mid rock farm land.

Figure 3.5 Ignimbrites rock on south the Lake Hawasa

3.4 Methodologies

3.4.1 Radon (222Rn)

Structured approach to assessing lake water and groundwater in the Lake Hawassa Basin using Radon measurements used 83 data samples, incorporating data collection and ArcGIS mapping samples collected rainy season (April) 38 samples from lake, springs, rivers and boreholes. On dry Season 24 samples total 62 data samples were collected from the same sources by direct investigation from the site or primary data collection. The other 21 secondary data samples helped to interpret the result wisely. Radon (Rn) measurement used as a natural tracer to identify interactions between lake water and groundwater. GIS Mapping (ArcGIS) sample locations were plotted using recorded Excel coordinates. Different colors were assigned based on radon concentration intervals to visualize spatial variations. A simple portable radon-in-gas monitor, the RAD-7 (Durridge Company, Inc.), is used to measure radon (^{222}Rn) (Burnett and Dulaiova, 2003). The RAD7 command list is divided into four groups: Data, Setup, Special, and Test. The Test series of instructions controls the new radon data gathering. While extracting new data from memory, the Data group removes outdated, unneeded data. When the RAD-7 detecting chamber is connected to a closed gas loop, the RAD-7 setup allows radon to be extracted from the bottle. Radon can be extracted by spraying water into a closed, airtight plastic cylinder that is part of the closed gas loop.

The entering air sample must have a low relative humidity for the RAD7 radon monitor to function at its peak; typically, the measurement is stable when the RH falls between 10 and 11%. Moisture from the incoming air is transferred to the air being blasted out of the RAD7 via the DURRIDGE pile. By the time the air reaches a drying unit en route to the RAD7, much of the moisture will have been eliminated, extending the desiccant's life span.The gradual emission of gamma rays and alpha particles that causes radioactive isotopes, which are unstable nuclides, to decay into a more stable form. To date, a large number of radionuclides have been found over 900 radionuclides with half-lives longer than one hour. There are very few known radioisotopes with half-lives appropriate for studying groundwater (Clark and Fritz, 1997). There are three naturally occurring radioactive isotopes of this radioactive noble gas (Radon): ^{219}Rn (Action), ^{220}Rn (Thoron), and ^{222}Rn (Radon). With a half-life of 3.82 days, ^{222}Rn is the most stable of these radioactive isotopes.

The natural radioactive isotope radon (^{222}Rn) is produced when the alpha decay of radium-226 occurs in the Uranium-238 decay chain. Radon (^{222}Rn) can be found in a variety of rocks, including phosphate rocks, shale rocks, igneous and metamorphic rocks like granite, gneiss, and schist, and smaller amounts of other common rocks like limestone. Apart from the radioactive decay of radon-226 and the host rocks that carry radon, riverbed sediments can also be a source of radon. Radon (^{222}Rn) is a soluble noble gas that travels with groundwater after being emitted from rocks or sediment grains that have dissolved in it. By dissolving in water or gasses, this radionuclide is partially raised to the surface. In surface water bodies, the radon (^{222}Rn) concentration are significantly a number of factors affect the amount of radon (^{222}Rn) in surface water bodies. Although geological characteristics are the main cause of radon (^{222}Rn) in surface water bodies, weather conditions also have a big role (Eilers et al., 1995).

The concentration of radon in groundwater is influenced by the quantity of these radioactive isotopes in the aquifer matrix. The mineralogy of an aquifer, the way hard rocks fracture, the porosity of the sediments, and the degree of metamorphism can all be used to determine the concentration of radon (^{222}Rn) in groundwater (Veeger and Ruderman, 1998). These radionuclides are typically measured by Becquerel's (Bq), which is equivalent to the disintegration of a radionuclide per second. The reading is then normalized to a given sample size using units of Bq/l or Bq/m3. Higher radon activity is typically observed in the area of lower temperature, and lower radon activity is typically observed in the area of lower temperature of radon into the vapor phase in higher temperature zones. Radon (^{222}Rn) transport is controlled by diffusion and it is very condensable at low temperatures (George, 1900).

Due to its numerous properties, Radon (^{222}Rn) can be used as a qualitative indicator of the interaction between surface water and groundwater (IAEA, 2000).Ideal for studying and locating the locations of groundwater and river water interactions. Therefore, a high concentration of Radon (^{222}Rn) in river water might be interpreted as an indication of a significant groundwater influx into the surface water. After a groundwater release, there will be a significant concentration of Radon (^{222}Rn) in surface water.

For a variety of reasons, radon (^{222}Rn) can still leak into the atmosphere even when it is present in surface water bodies in considerable amounts. Radon is usually an indicator of groundwater, for example, and the rapid interchange of river bottom debris and between river water, together with turbulence is typically sign of groundwater that is actively circulating also, the presence of radon in surface water always indicates that the river segment being examined is fed by groundwater. One can locate groundwater discharge zones in surface water bodies by taking measurements of Radon (^{222}Rn).

Furthermore, by serving as a signal of active groundwater circulation, radon can be used to drive hydraulic information, including rock permeability and fluid movement in a specific geologic formation (Mazor, 2004). Radon (^{222}Rn), a radioactive noble gas with a half-life of 3.8 days, is the daughter of ^{226}Ra (Radium). Its short half-life causes radioactive decay to reduce its activity when groundwater containing ^{222}Rn (radon) leaks into bodies of surface water like rivers and lakes. According to the IAEA (2000), this characteristic of radon (^{222}Rn) is a qualitative indicator of the interaction between surface water and groundwater.

Since radon entirely degasses after it is released into surface water bodies, low radon levels in rivers indicate that the water is not the result of base flow in the same or surrounding areas. Conversely, the presence of short-lived radon in surface water is always an indication that the river is receiving water from the earth at its measured reach (Tilahun A, 2014).

Figure 3.6 Radon measuring on site

3.4.2 Electrical Conductivity

Structured approach to assessing lake water and groundwater in the Lake Hawassa Basin using EC measurements used 302 data samples, incorporating data collection and ArcGIS mapping samples collected rainy season (April) 38 samples from lake, springs, rivers and boreholes. On dry Season 24 samples total 62 data samples were collected from the same sources by direct investigation from the site or primary data collection. Secondary data samples helped to interpret the result wisely. Field-measured sample locations 62 total samples were recorded with GPS coordinates in Excel with secondary data of 240 samples. Data was imported into ArcGIS for spatial analysis; EC graph was plotted by scatter plot and Color-coding applied to represent different EC value intervals.

Electrical conductivity (EC) can be a useful indicator of surface water and groundwater interaction, as it reflects the concentration of dissolved ions, which can vary between the two water sources, helping to identify mixing and exchange processes. Groundwater vs. Surface Water: Groundwater typically has a higher EC than surface water due to the longer contact time with rocks and soils, leading to higher concentrations of dissolved ions. EC values can fluctuate depending on factors like river flow, precipitation, and seasonal changes. In the stream waters and rivers, electrical conductivity is affected by the geological formations, human activities as well as climatic conditions of the region. This conductive nature of water is generally the impact of being present and the amount of dissolved inorganic solids in the water.

3.4.3 Fluoride in the Surface and Groundwater

To assesses lake water and groundwater interaction in the Lake Hawassa Basin using fluoride measurements as a key indicator. Total 151 data samples collected from Lake, springs, rivers, and boreholes within the research area. When the data was collecting at primary investigation rainy season data 36 samples, dry season data 24 samples and 91 secondary samples were used to support interpretation of lake-groundwater interaction. In laboratory analysis fluoride concentration was measured in collected samples and results were recorded in Excel with coordinates for spatial mapping. Sample locations and fluoride values were plotted in ArcGIS using recorded coordinates and the basin boundary was defined to analyze spatial trends on GIS Mapping & Spatial Analysis.In each measured value interval and plotted map the measured value separated by different colors.

The level of fluoride in the water supply is one of the problems with Ethiopia's water quality, particularly near the main Ethiopian Rift. Samples were collected for fluoride investigations from springs, hand-dug wells, rivers, and waterways in order to comprehend the spatial fluoride dispersion in the region. There were sixty-eight secondary data points and forty primary data points used. A maximum fluoride concentration of 1.5 mg/l is recommended by the WHO; in hot waters (over 25 °C) and tropical areas where drinking water is consumed often, the value drops to 0.7 mg/l. The drinking water requirements in Ethiopia are 3 mg/l. At the water source fluoride concentrations between 0.9 and 1.2 mg/l, fluoride can cause mild dental fluorosis (Moulton, 1942).

This is particularly true in warmer climates where people drink more water and dental fluorosis occurs at low concentrations in the water (Office of Drinking Water 1985; WHO 1984). The study region was found in the MER, where the primary issue with water quality is fluoride content. Fluoride can potentially have more detrimental effects on skeletal tissues (teeth and bones) if it is eaten over a longer period of time, particularly if drinking water contains 3–6 mg of fluoride per liter (WHO 1984). Mapping the spatial distribution of fluoride concentration and enrichment mechanisms in the research region was one of the objectives of these investigations.

3.4.4 P^H

To assess lake water and groundwater interaction in the Lake Hawassa Basin using pH measurement is one of other key indicators. Total 310 data samples collected from Lake, springs, rivers, and boreholes within the research area. When the data was collecting at primary investigation rainy season 38 samples, dry season 24 samples and 248 secondary samples were used to support to wisely interpretation of lake-groundwater interaction. pH values were recorded directly in the field (primary data). GPS coordinates were documented in Excel for spatial mapping. GIS Mapping (ArcGIS) Field-measured sample locations were plotted using recorded coordinates. The study area boundary was defined for spatial analysis. In each measured value interval and plotted map the measured value separated by different colors.

The interaction between groundwater and surface water (GW-SW) is a critical area of study in hydrology, and pH is often used as an indicator of these interactions due to its sensitivity to biogeochemical processes.P^H as a key parameter in identifying GW-SW exchange, particularly in hyporheic zones where biogeochemical reactions alter pH (Sophocleous 2002 Interactions between groundwater and surface water; the state of the science Hydrogeology Journal, 10(1), 52-67). PH is a useful parameter for studying groundwater-surface water interaction because it reflects the chemical characteristics of water, which often differ between groundwater and surface water due to varying geochemical processes (Winter et al. (1998) Ground Water and Surface Water, A Single Resource USGS Circular 1139). Langmuir, D.(1997).Aqueous Environmental Geochemistry. Groundwater typically has a more stable pH, often slightly acidic to neutral (pH 6–7.5) due to prolonged contact with minerals (e.g., carbonate dissolution). Stumm, W., & Morgan, J.J. (1996). Aquatic Chemistry (3rd ed.). Surface water (rivers, lakes) can vary widely (pH 6.5–8.5) due to photosynthesis, organic matter decay, and atmospheric CO_2 exchange. Mixing Zones (Hyporheic Zone) If surface water infiltrates into groundwater (or vice versa), pH values will show a gradient or an intermediate value between the two end members. A sudden pH shift along a stream or at a discharge point (e.g., springs, seeps) suggests groundwater input. Diurnal & Seasonal Variations Surface water pH fluctuates daily (due to photosynthesis/respiration), while groundwater pH remains relatively constant. Monitoring pH over time can help distinguish contributions. Nordstrom, D.K., et al. (2000). Negative pH and extremely acidic mine waters. Environmental Science & Technology, 34(2): 254-258 Anomalous pH Values: Acidic groundwater ($pH < 6$) entering a neutral surface water body may indicate pollution or natural weathering (e.g., pyrite oxidation). Drever, J.I. (1997). The Geochemistry of Natural Waters (3rd ed.). Alkaline groundwater ($pH > 8$) may suggest carbonate-rich aquifers discharging into surface water.

3.4.5 Temperature

Structured approach to assessing lake water and groundwater in the Lake Hawassa Basin using temperature measurements used 190 data samples, incorporating data collection and ArcGIS mapping samples collected rainy season (April) 36 samples from lake, springs, rivers and boreholes. On dry Season 24 samples total 60 data samples were collected from the same sources on dry season December by direct investigation from the site or primary data collection. The remain 130 secondary data samples helped to interpret the result wisely. Data Preparation for GIS Use *"XY Table to Point"* tool to plot samples from Excel by UTM Adindan Zone 37N Spatial analysis in ArcGIS mapping temperature distribution compare seasons by overlay rainy vs. dry season maps to identify thermal anomalies and Groundwater-Lake Interaction by hotspot analysis to identify areas where borehole/spring temperatures differ significantly from lake/river temps (potential discharge/recharge zones) also Buffer analysis used to compare temperatures near shorelines vs. lake center to infer subsurface exchange. To visualization & output maps created layouts showing sample points (color-coded by temperature/season) ,Interpolated temperature surfaces lake boundary and key features (rivers, boreholes) and prepared graphs by using scatter plot to identify temperature variation for each water source type. The measurement of temperature in groundwater and surface water can be a valuable indicator of interactions between these two water sources. This is because groundwater and surface water often have distinct temperature signatures due to differences in their thermal regimes. Seasonal Variations and Temperature Gradients at Interfaces indicates How to interacting Groundwater and Surface Water (Constantz, 2008; Webb et al., 2008). Surface water temperatures fluctuate significantly with air temperature and solar radiation, showing daily and seasonal variability.as well as groundwater temperatures are relatively stable, typically reflecting the mean annual air temperature of the region If surface water temperatures deviate from expected seasonal trends (e.g., being cooler in summer or warmer in winter near discharge zones), this indicate groundwater influence (Silliman et al., 1995; Kurylyk et al., 2014) . Streambed temperatures may be warmer in winter and cooler in summer compared to surface water, indicating groundwater inflow(Conant, 2004; Schmidt et al., 2007). Losing streams (surface water infiltration) Temperature profiles show surface water thermal signals penetrating into the subsurface (Hatch et al., 2006; Lautz, 2010)

3.4.6 Piezometric evidence

In contrast to surface waters, groundwater is a resource that is widely distributed and challenging to reach. An essential and easily accessible part of the groundwater flow system is surface water bodies. These days, several areas of the country face water supply problems as a result of the country's growing urbanization and population. In order to balance the supply and demand for water, many boreholes are excavated to access groundwater. Depending on the type and purpose of the well, there are several types of boreholes, such as Piezometric wells, test and production wells, and observation wells. Piezometer wells are frequently boreholes designed for purposes other than water supply. Thus, measuring water volume, flow direction, and groundwater movement velocity is the primary purpose of these wells. These wells frequently provide information on the present groundwater level in a particular area. These factors make it impossible to identify changes in subsurface water through straightforward surveys; instead, a comprehensive and integrated procedure involving well-coordinated databases, time series data, and monitoring networks is required.

Groundwater head variation and distribution aid in the identification of areas with high and low heads. The head distribution and topographic variance along a watershed can be used to create a contour map of a water table. A contour map provides a graphic representation of the hydraulic gradient of a potentiometric surface or water table. Making contour maps is an essential technique for accurately identifying the flow and movement direction of groundwater. The groundwater contours formed a "V" pointing upstream each time the line crossed a gaining stream or river. When contour lines bend downstream simultaneously, they cross a losing stream. In the two situations mentioned above, connecting the aquifer system to surface water is straightforward. The river has no effect on the potentiometric surface contour lines in other cases, where the boundary between surface water and groundwater lacks hydraulic connection. Furthermore, in locations where the water table gradient is shallow, the distance between groundwater contours will be apparent. On the other hand, if the hydraulic gradient is large, the groundwater contours will be much closer together. This suggests that the water table or potentiometric surface slopes in the direction of groundwater movement.

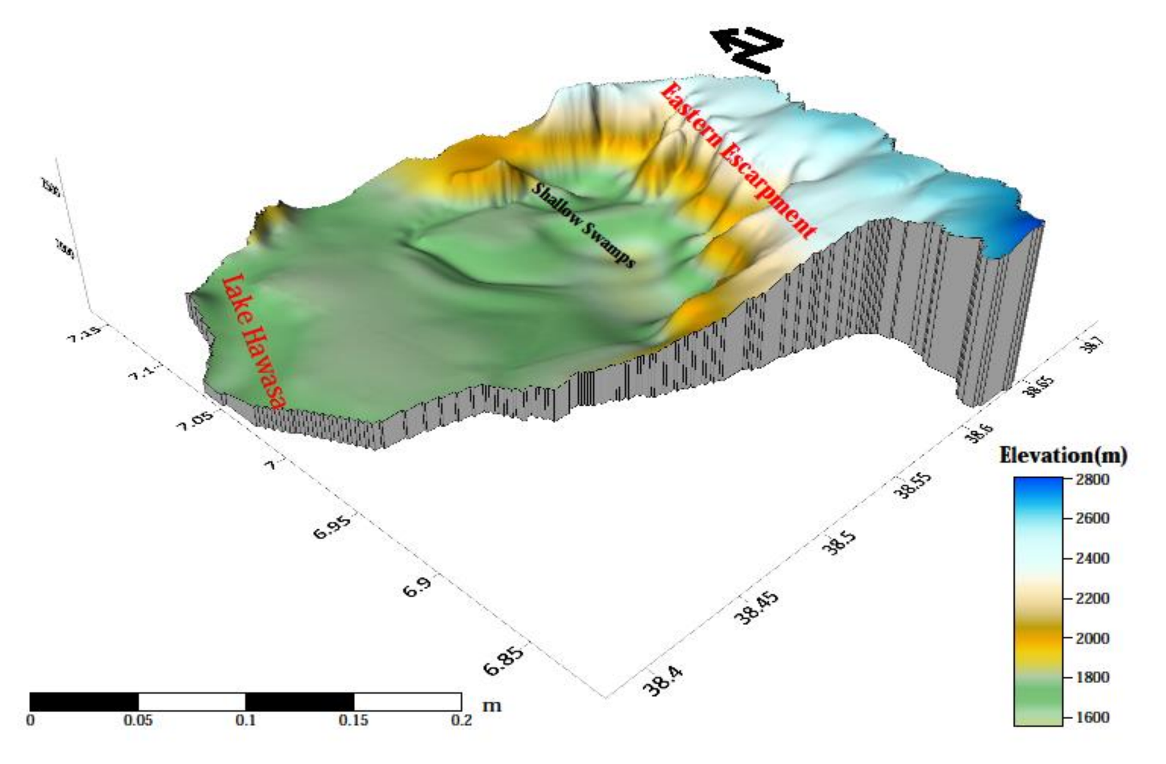


Figure 3.7 Physiography map of the study area

3.4.7 Climate condition of the study area

The climatic conditions and rainfall patterns affects a study area on the influence of altitude, vegetation, and the Inter-Tropical Convergence Zone (ITCZ). In Ethiopia climate classification as(FAO ,1965) ,Highland and cool climate (Dega) ,Mid-altitude temperate (Woinadega) ,Lowland (warm Kolla) and Very hot, arid/semi-arid (Bereha). Variations in elevation significantly influence temperature, precipitation, and evaporation. Rainfall distribution in research area as primary wet season from July to September which have main rany period and secondary wet season from march to may which is shorter extended rain the distribution is also influenced by the ITCZ, which brings moisture via southwest equatorial winds. The only metrological station in research areas are Hawasa,Wondogenet. The Variations in rainfall, temperature, and evaporation affect surface water and groundwater availability.The study highlights the importance of altitude and large-scale atmospheric systems (ITCZ) in shaping Ethiopia's climate zones and water resources. However, the limited number of meteorological stations and complex topography may affect the accuracy of regional climate assessments. Further research could benefit from additional stations or satellite-derived rainfall data to improve spatial resolution.

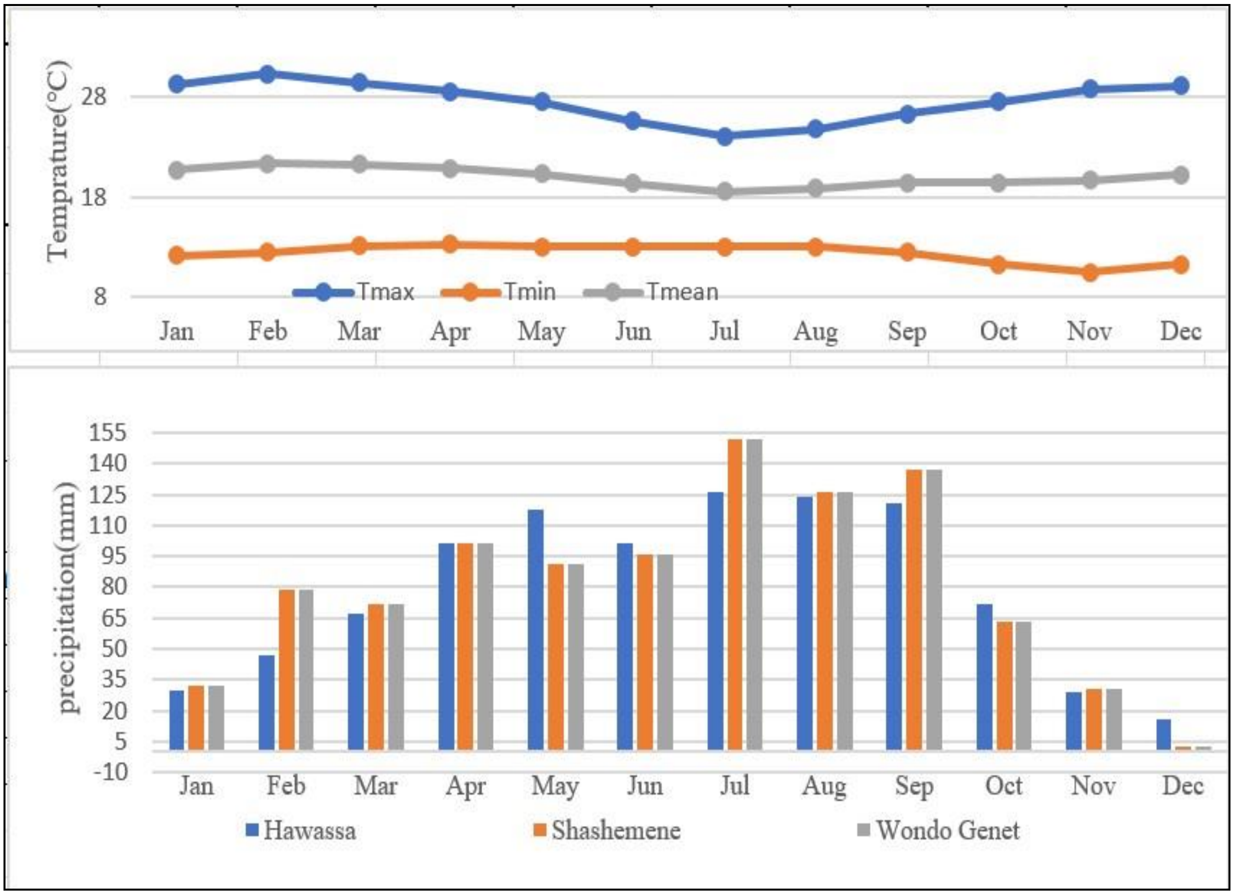


Figure 3.8 Mean annual precipitation and temperature at selected stations graph

3.4.8 Land cover land use of the study area

The land usage and land cover of a given area reveal how it is covered by flora, aquatic bodies, agriculture, and constructed structures. It illustrates how humans use the terrain for conservation, development, or both. The most common land use types in the research area are water bodies, vegetation, built environments, and farmed agricultural areas.The great majority of the Eastern tributary basin of Lake Hawasa is covered by crops and cultivated regions because of the perineal rives and groundwater availability, which make the region ideal for irrigational agricultural activity. The Easter tributary catchment's land use and land cover map shows that it is both built up and covered in mixed forest. The majority of local residents live in areas with a farming-based economy coffee, maize, sugarcane, avocado, mango, banana, tomato, and potato are grown utilizing rivers and streams that originate from a highland plateau. The area's water supply is dominated by cold springs, and they dig hand-dug wells for hygienic purposes. Sheep and goats are also common animals in the area. Because of the Shallo swamp, which the locals live on, the lower plain is a good place for farming and has plenty of grazing pasture. Bosch and Hewlett (1982) claim that stream flow is improved by the decrease in evapotranspiration brought on by forestry. Urbanization and suburbanization increase stream flow through increased runoff, but they also degrade water quality when the amount of impervious surface in a watershed exceeds 10–15% of the total land cover (Schueler, 1994).

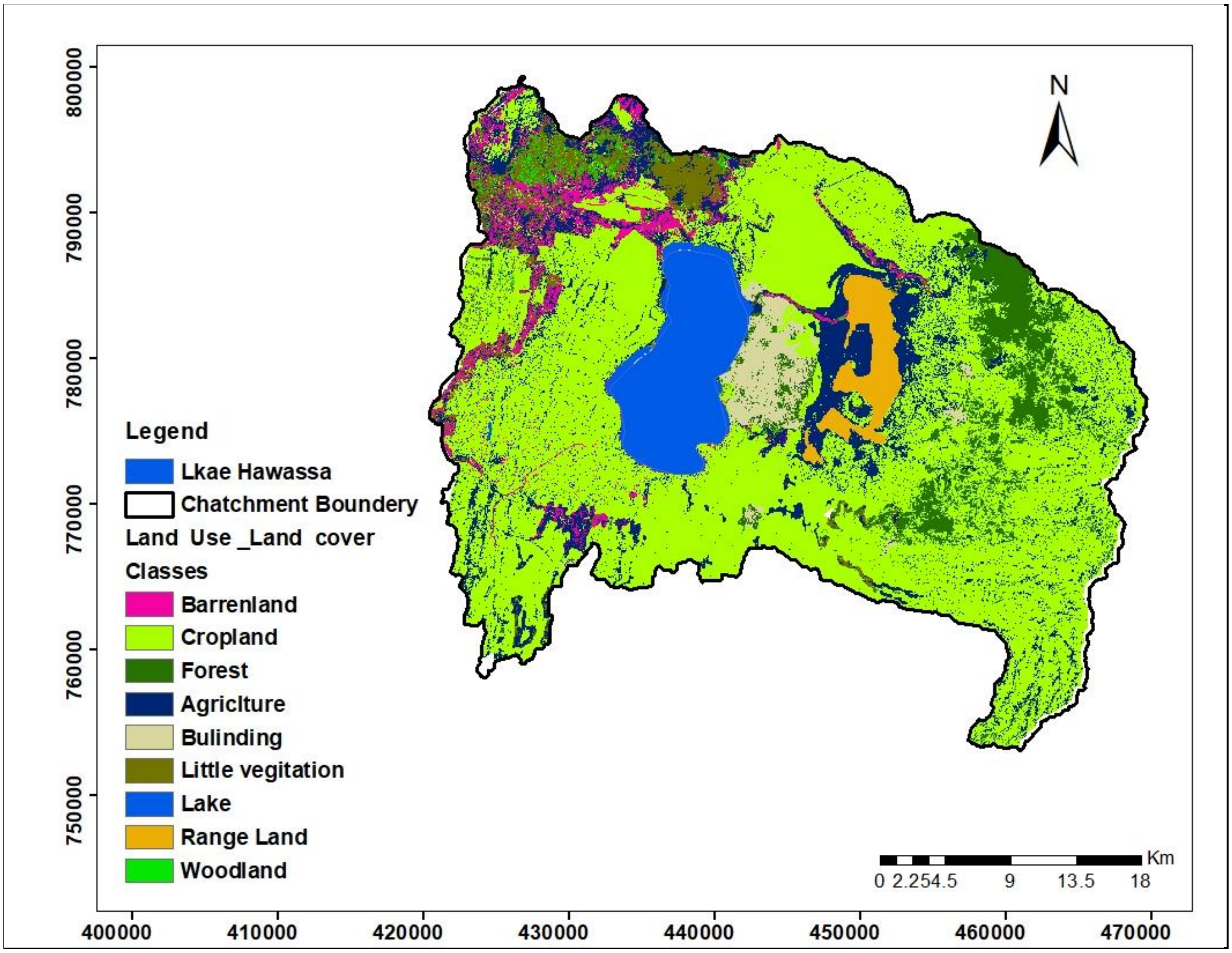


Figure 3.9 Land use land cover map of the Study area (USGS 2023)

3.4.9 Hydrology of the research areas' sprigs and surface water

A naturally occurring water source that empties into another river, lake, sea, or ocean. Because a river flows into the ground without reaching another body of water, it might occasionally serve as the main source of refilling the aquifer. If a river builds up without flowing into another body of water, it creates an endorheic river. The Eastern Tributaries Rivers that emerge from the Eastern Escarpment include the Bele Stream, Washa, Warka, Hallo, Wadesa, Gomosho, and

Boga rivers. These streams can all be reached by road from Shashamane to Wondogenet, and they all drain to the Shallo swamp, which is the source of the Tikur Wuha River, and replenish Lake Hawasa throughout the year since it has a lower level in the study region and the lake hawasa is the river's final destination in the area.

Springs are usually found at the foot of slopes and hills, in lower valleys, and close to the banks of major rivers (Zeyede Kebede and Tesfaye Gobena, 2009). Furthermore, when the artesian or aquifer pressure surpasses the hydrostatic pressure, springs may form. Thermal or hot springs, main springs (sometimes called gravity springs), and seasonal springs are the three different kinds of springs. Seasonal springs, which tend to dry up during the drier months, are one form of spring that depends on the time of year. The phrase "main springs" describes springs that form on the surface of the earth as a result of local topography and gravity.

The other kind of springs is called thermal or hot springs. Springs with a high temperature that occur on the surface of the earth are known as thermal springs. These springs undergo subterranean heating before to their surfacing (Zeyede Kebede and TesfayeGobena,2009). Deep groundwater circulation and a geothermal gradient may be the natural sources of high-temperature springs.Chemical reactions, the mixing of meteoric and magmatic water, and the flow of groundwater through fissures all contributed to the higher temperature of the springs. Kazemi M. and Muhammad Zadeh H. (2017).

Wetlands typically protect life's purity by supporting the system for long-term socioeconomic development, which leads to ecological balance in each location. Most people in the Wondogenet area depend on these wetlands and springs to support their way of life, and Shallo Swamp has the potential to be used as cow grazing pasture throughout the region during the dry season. They use the springs to purify the water supply (boro spring, tutu gudo cold spring), downstream of the watershed, and southeast of Lake Hawasa for the recreational area (Wondogenet and Bele thermal springs).

Fracture springs are the type of springs most commonly seen in the Wondogenet region. It is believed that these springs are released through joints or defects. The output and presence of these springs are significantly regulated by hydro-structures. There are several springs in the research region because the lineaments are positioned and concentrated at the eastern rift boundary of the catchment.

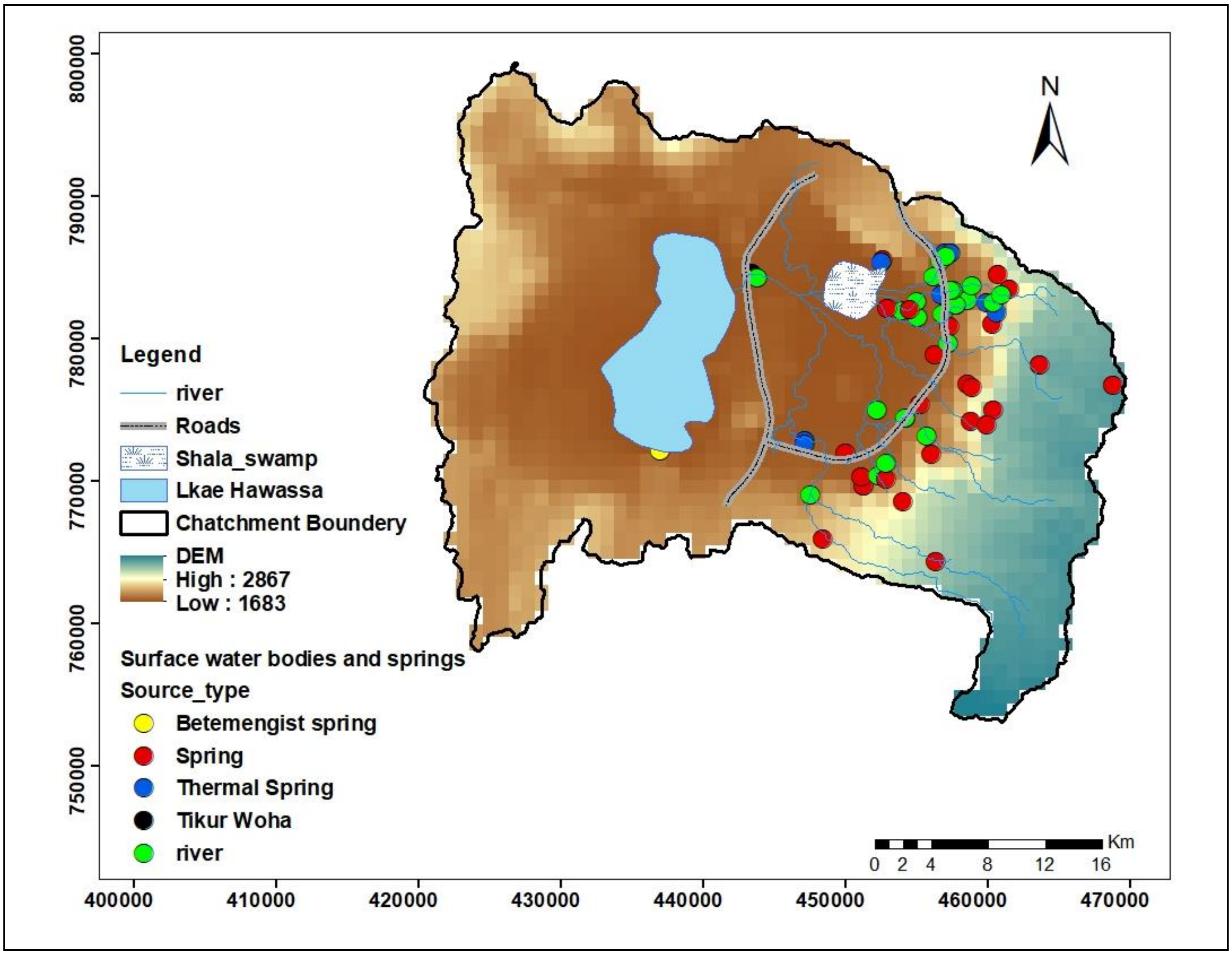


Figure 3.10 Surface water bodies and springs Used for Samples

3.4.10 Hydro chemical

Professionals were consulted regarding the water quality data based on the findings gathered. According to the laboratory, the main factors that alter and modify the water quality to comprehend the hydrochemistry of the study area are the rock-water interaction, residence time, the interval between recharge and discharge, and the level of pollution in the environment. Forty-four primary samples and sixty-eight secondary samples Data gathered from rivers, springs, boreholes, and hand-dug wells for the water quality examination that includes main ions like sodium, calcium, magnesium, and potassium as well as important ions like bicarbonate, sulfate, chloride, and fluoride. The impact of the rock-water interaction in the groundwater in that research region can also be determined based on hydrochemical data's appropriateness for irrigation in order to characterize the groundwater system, including groundwater flow direction, aquifer kinds, and depth of circulation.

CHAPTER 4

4. Results and Discussions

4.1 Result of geochemical tracers in study area for interaction

4.1.1 Radon

Radon (^{222}Rn), the daughter of ^{226}Ra, is a radioactive noble gas with a half-life of 3.8 days. Radium is easily soluble in water and is gained by dissolution from rocks. As a noble gas, it is not being absorbed by solids. Moreover, it is highly soluble in water; consequently, ^{222}Rn is likely to accumulate in groundwater. Because of its short half-life, when groundwater with ^{222}Rn discharges into surface water bodies like rivers and lakes, its activity decreases by radioactive decay. This feature of ^{222}Rn is a qualitative indicator for groundwater-surface water interaction (IAEA, 2000).

Radon degasses completely after it discharges to the surface water bodies, hence low radon count in the rivers shows that the water in the river is not the result of the base flow in the same area or nearby. On the contrary, the presence of the short-lived radon in surface water always means that the groundwater is feeding the river at its measured reach.

The study on the Lake Hawassa basin in Ethiopia provides a comprehensive understanding of the groundwater-surface water interactions in the region, utilizing geochemical approaches, particularly Radon-222 (Rn-222) measurements. Here’s a summary and interpretation of the main findings to describe the cause of interactions are , Groundwater Flow Direction, Surface Water Contribution, Geological Structures,Radon-222 Measurements, Springs and Local Recharge.

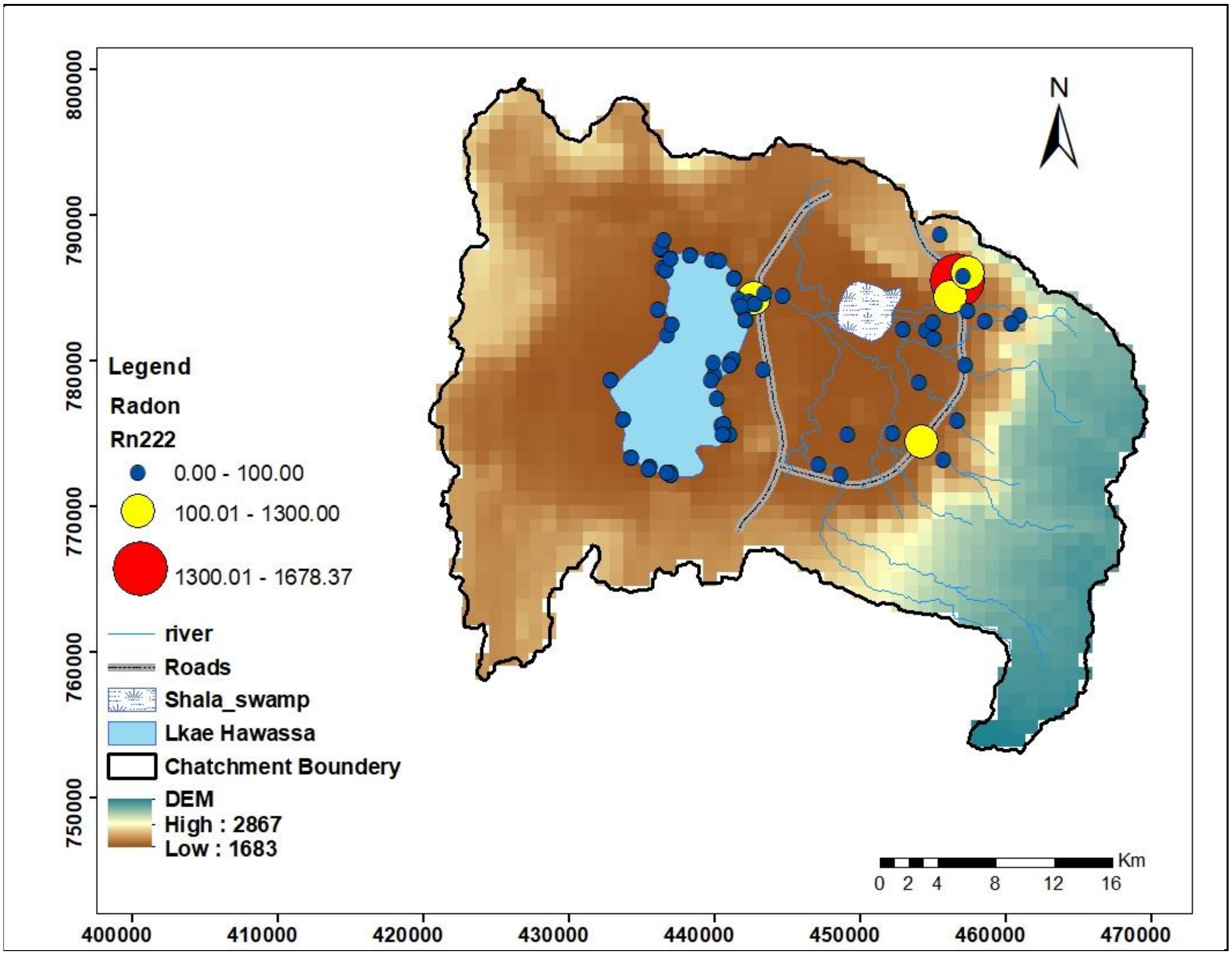


Figure 4.1 Radon map of interest area

The groundwater flow direction in the Lake Hawassa basin is from the southeast and northeast towards the lake. This indicates that the lake is a discharge zone for groundwater in the region. Surface Water Contribution the only significant river contributing to Lake Hawassa is Tikur Woha River.

This is the main perennial inflow to Lake Hawassa, contributing a significant amount of water, which flows from the northeast to the southeast of the lake. This river plays a crucial role in recharging the lake. Lake Hawassa receives water from underground springs and seepage, which contribute to its water balance as previous research findings and current assessment results as approach of Radon as tracer. Precipitation directly falling on the lake's surface also contributes to its water volume. During the rainy season, surface runoff from the surrounding catchment area can flow into the lake, although this is relatively minor compared to the Tikur Wuha River and groundwater inputs. There are smaller, seasonal streams and tributaries that may contribute to the lake, especially during the wet season. The other factor is Geological Structures. As sown bellow figure 9 the presence of lineaments (faults and joints) in the northeast to east of the lake and lied along to southern part the interest area, which also contact with river networks, facilitates the movement of water between groundwater and surface water systems. These geological structures are critical pathways for water exchange.

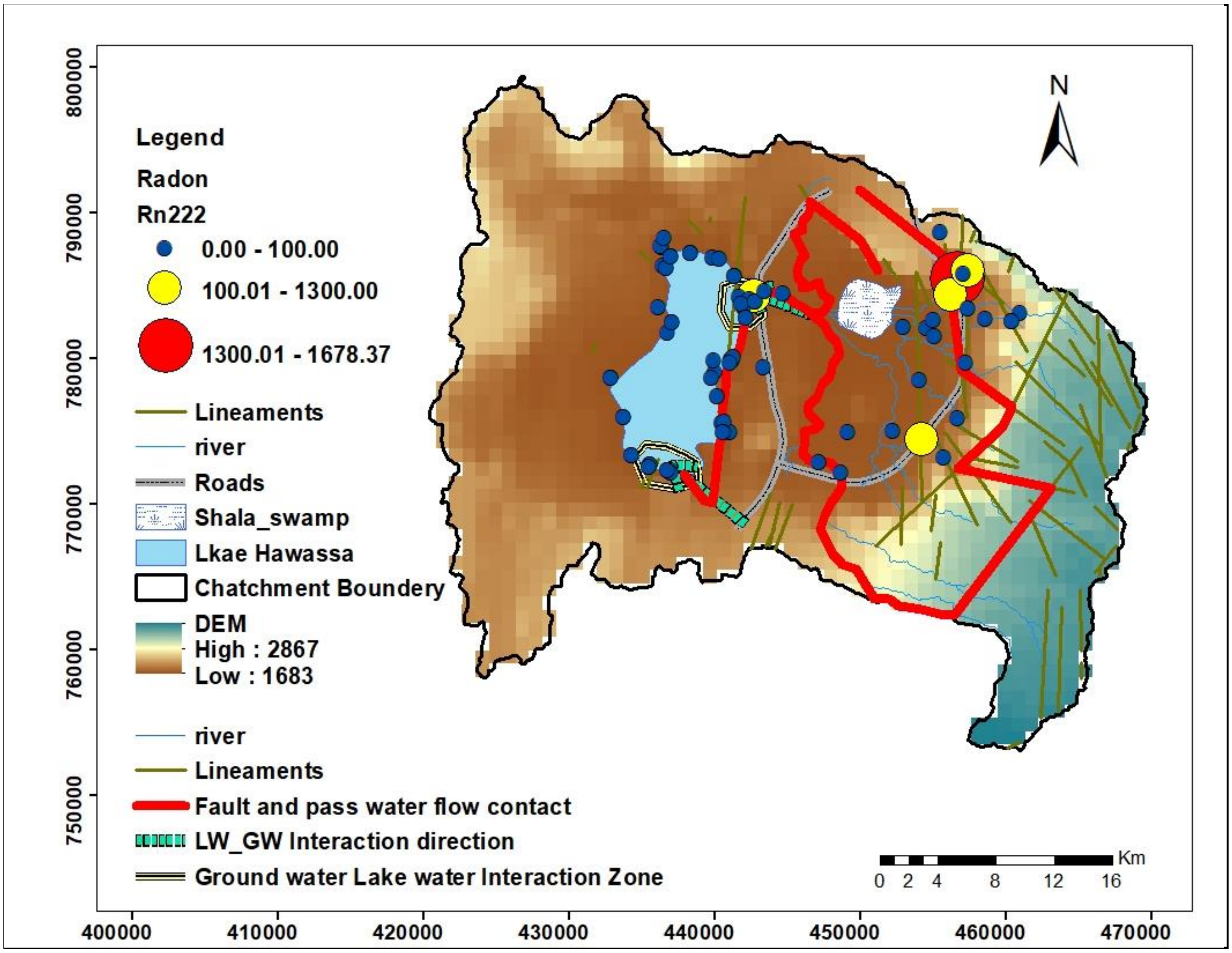


Figure 4.2 High Radon Zone with fault and flow pass contact map

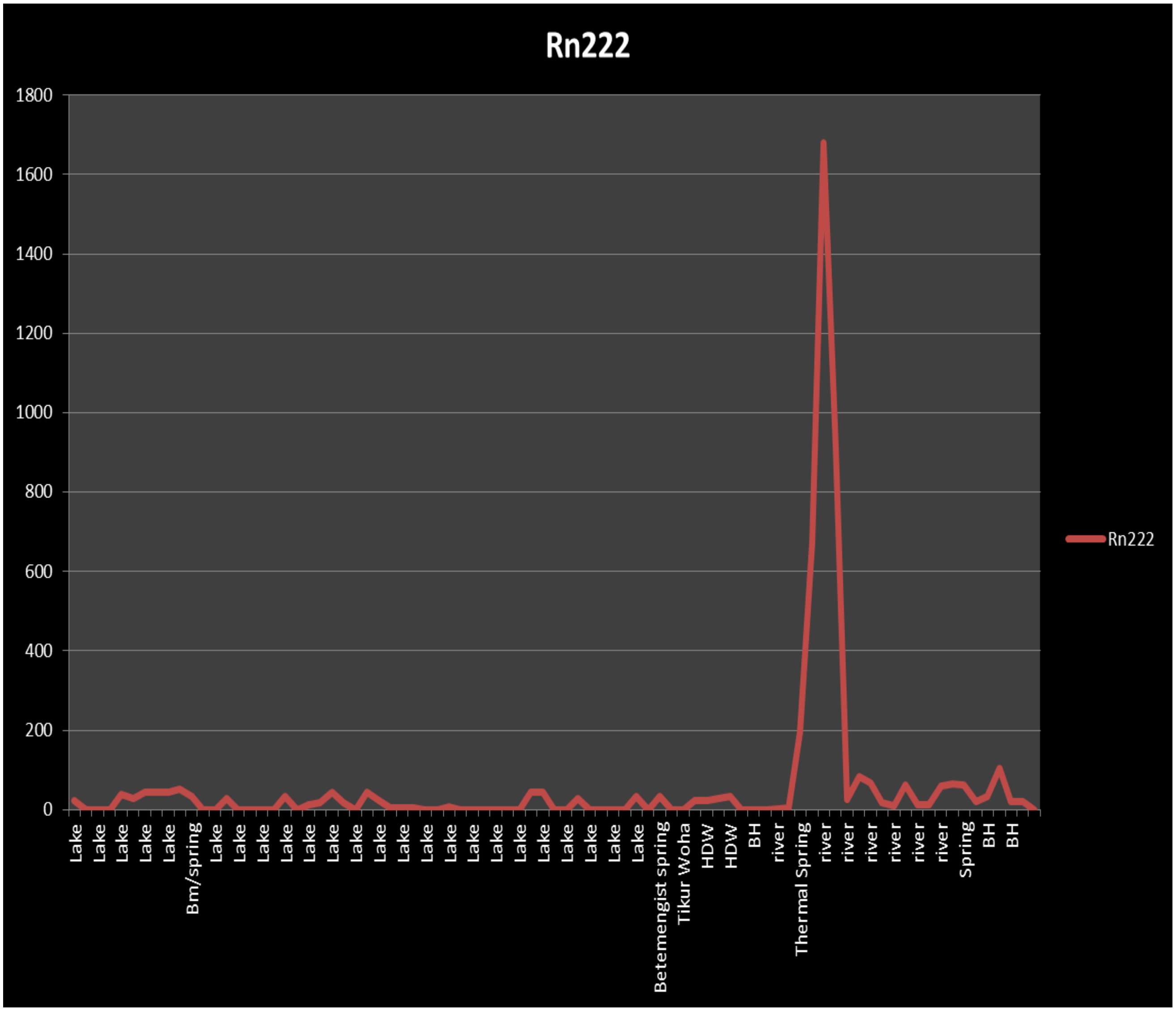
Radon-222 Measurements: Radon-222, a naturally occurring radioactive isotope, was used as a tracer to assess groundwater-surface water interactions. High Rn-222 values in groundwater indicate areas of significant interaction with surface water. The highest Rn-222 values were observed in deep wells, suggesting regional groundwater recharge from distant sources. These values were also found in the northern, eastern, and southern parts of the lake, indicating zones of high interaction between groundwater and lake water. Local springs and boreholes showed lower Rn-222 values compared to deep wells, suggesting less interaction with the lake on a local scale. Radon as a Tracer: Radon (^{222}Rn) is a naturally occurring radioactive gas that is highly soluble in water. It is often used as a tracer to identify and quantify groundwater discharge into surface water bodies (e.g., rivers, lakes).The Radon (Rn) measured values around Lake Hawassa, categorized into ranges (0-100, 100-1300, and >1300), provide insights into the interaction between surface water (lake and river) and groundwater in the region.

Here's an interpretation of the results and the regional interaction by Radon levels and their Implications Low Radon from 0-100 Radon levels typically indicate no and minimal groundwater contribution to the surface water. This suggests that the surface water (lake or river) in these areas is primarily influenced by direct precipitation, surface runoff, or other sources with limited groundwater interaction. From 100-1300 Moderate Radon levels indicate a significant contribution of groundwater to the surface water. This range suggests active groundwater discharge into the lake or river, highlighting areas where groundwater and surface water interact. Greater than 1300 have high Radon levels indicate a strong groundwater influence, often associated with direct groundwater springs or significant subsurface inflow into the surface water body. The Radon measurements around Lake Hawassa suggest a dynamic interaction between groundwater and surface water, with significant groundwater discharge contributing to the lake.

Based on the graph showing the lake-groundwater interaction zones in the Lake Hawassa basin, measured using radon values, it appears that there are significant interaction areas at two main locations:

Northeast of the Lake (Tikur Wuha Side) – This suggests that groundwater is discharging into the lake in this region, as indicated by elevated radon levels. Radon is a natural tracer for groundwater input, so higher concentrations typically signify stronger groundwater influx.

Southern End of the Lake (Around Betemengist Thermal Spring) – The presence of thermal springs here implies that deep groundwater is interacting with the lake, likely contributing to both water and heat exchange. The radon measurements likely confirm this as an active discharge zone.



Graph 4.1 Radon graph for interest area

4.1.2 Electrical Conductivity

This research provides a detailed analysis of the electrical conductivity (EC) measurements in the Lake Hawassa catchment area, including tributary streams, hand-dug wells, springs, and boreholes. The study highlights the spatial distribution of EC values and their relationship with groundwater flow, geological structures, and surface water interactions. Electrical Conductivity Measurement is one of geochemical approach to assess the interaction of lake water ground water interaction in Lake Hawasa basin. EC values were measured using a digital reader equipped with pH and temperature sensors wet and dry season of Ethiopia. Two seasonal data result of the samples have observed different result in laboratory test. Groundwater generally exhibits higher EC values compared to surface water due to prolonged contact with salt-bearing rocks during percolation and recharge processes. The groundwater flow direction in the study area is predominantly southward toward Lake Hawassa, with an eastward component along the lake's bottom boundary. In geological structure the presence of lineaments (joint and fault) structures influences groundwater movement, with a notable fault running from the northeast toward the lake an also contact with river network form north east to south west of the lake as showed fig.4.3

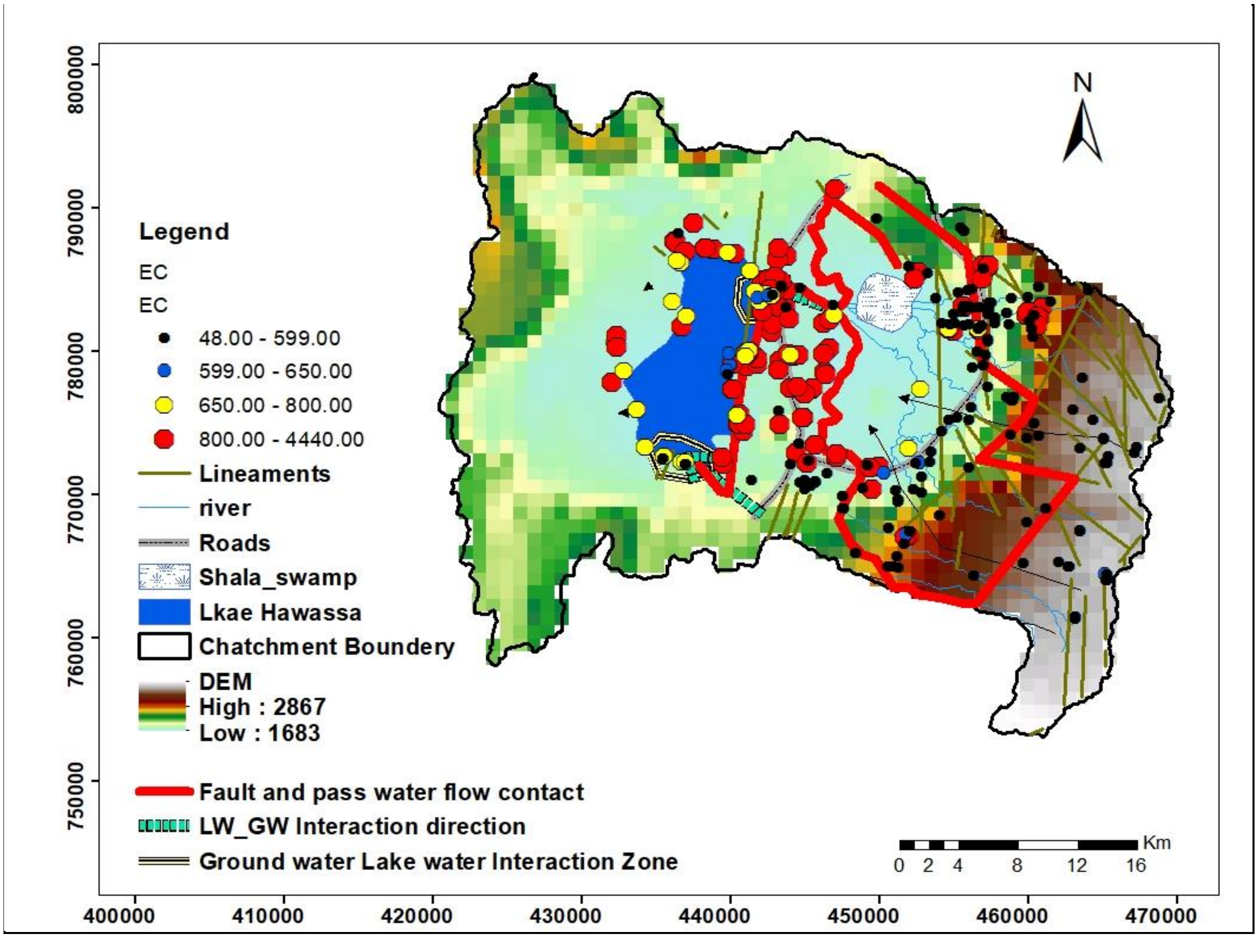


Figure 4.3 High EC Zone with fault and flow pass contact map

As result spatial distribution of EC the high concentrations are observed in the northeast direction of the lake, likely due to the influence of the fault and deep groundwater circulation that recharges the lake. The EC values in Lake Hawassa samples are consistent with those of groundwater in the northeast, indicating a connection between deep groundwater and the lake. Around Hawassa city and very near villages' to the lake are in flow to ground water at shallow depth from the lake and direct precipitation, because of the aquifer is being unconfined composed by volcanic rocks fractured basalt, which is high permeability, enabling ground water storage and flow, vesicular basalt to store water with increased porosity, weathered pyroclastic deposits including volcanic ash, tuff sufficiently weathered or fractured to allow water movement. Alluvial and lacustrine sediments like sand, silt gravel deposit by river and streams formations are directly recharging the ground water by lake and precipitation. The Betemengist spring exhibits low EC values which are contributing lower EC concentrations in the southwest region of the lake due to mixing with spring water. This suggests that the spring acts as a diluting agent, reducing the overall EC in the southwestern part of the catchment.

Near Lake Hawassa, including Hawassa City, Tikur Woha, and neighboring villages in the southeast and northeast, the EC values of groundwater and surface water are similar. This indicates that the lake recharges shallow groundwater in these areas, as evidenced by the comparable EC intervals in hand-dug wells and lake water. The lineament structures and river flow pass play a significant role in controlling groundwater flow and EC distribution. It lied in the northeast direction likely facilitates deep groundwater circulation, leading to higher EC values in this region as collected EC samples showing on interest area boundary map.

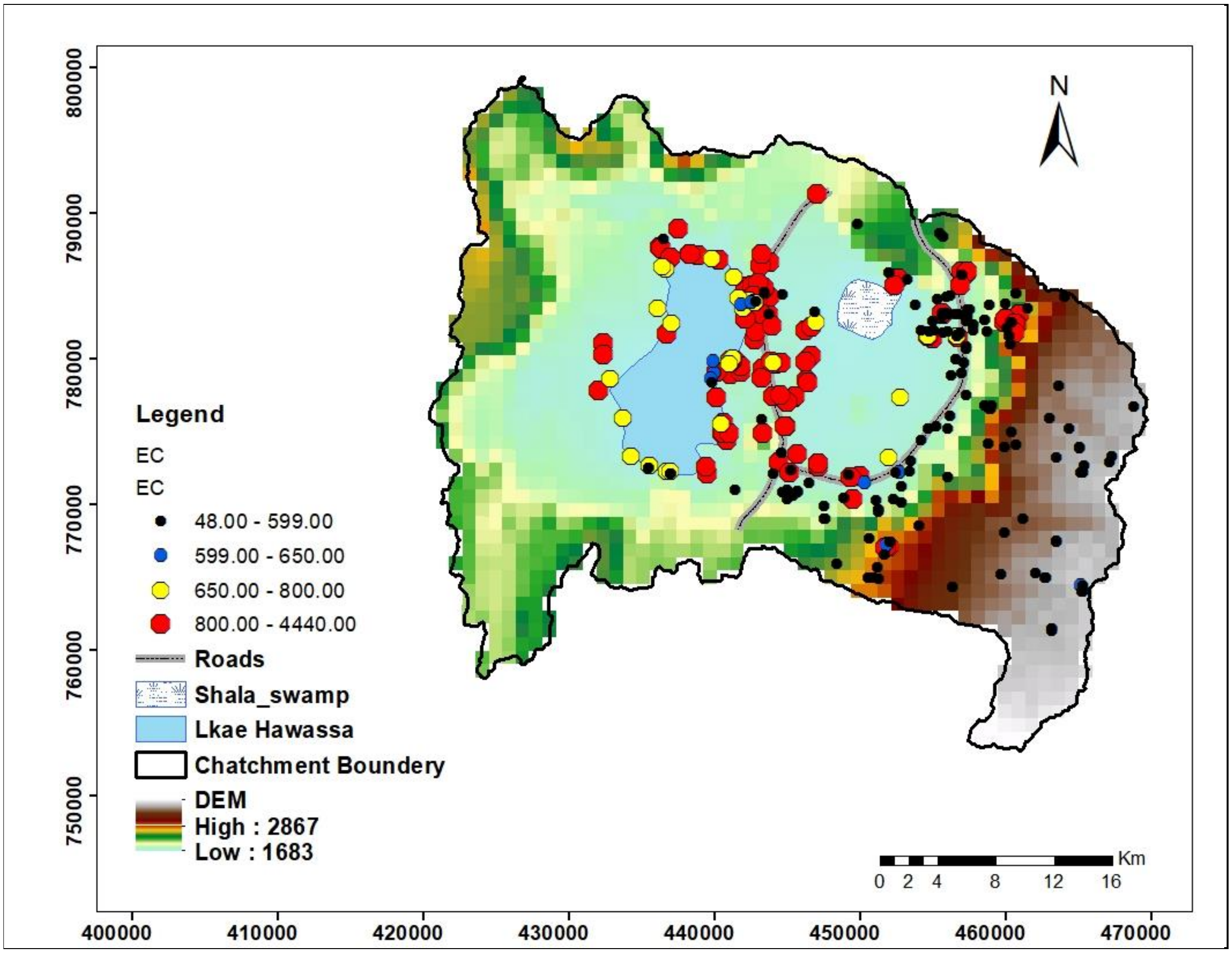
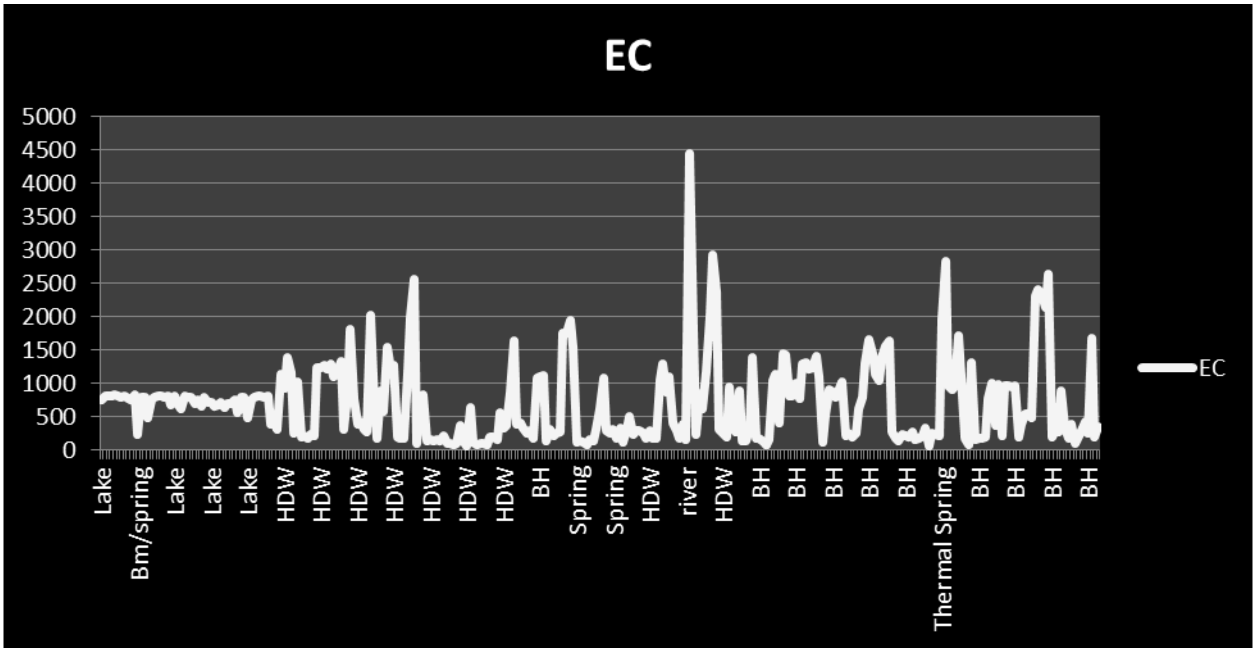


Figure 4.4 EC map of interest area

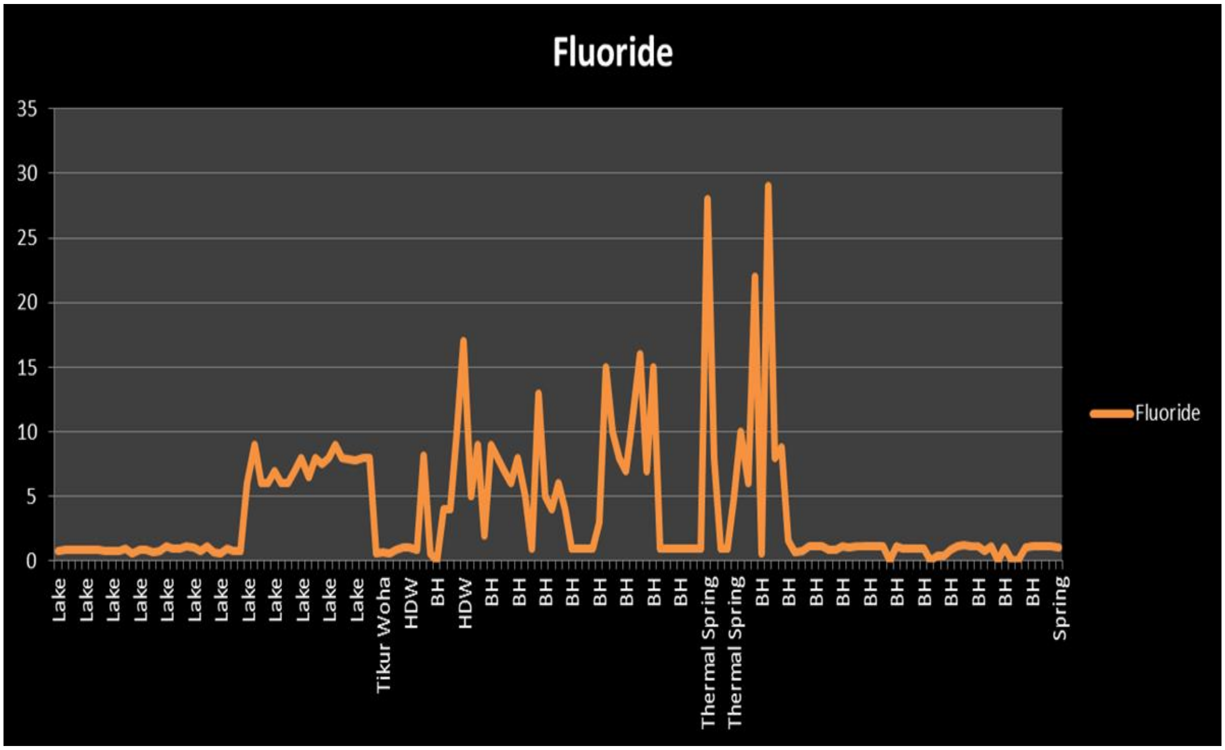
Ground water often carries higher EC compared with surface water. In this research the collected data of EC from lake Hawasa ,borehole, spring and rivers of interest area the highest value of EC observed in the lake .The interval of EC >1000.This indicate that the ground water regional discharging to the lake Hawasa. Clearly plotted on figure 4.4 the three parameters contact map describe the direction of interaction zone, based on the EC concentration result Southern Lake bottom spring and lake have directly getting discharge from the ground water .Regional groundwater flow structures likely contribute to this inflow. Northeast (Tikur Woha Area) presence of lineaments (fractures) and river flow channels facilitates groundwater movement toward the lake. Northern Lake (Fault Zone) a fault system acts as a conduit, enhancing groundwater seepage into the lake.



Graph 4.2: EC graph

4.1.3 Fluoride

Assessing lake-water and groundwater interaction in Lake Hawasa basin using fluoride concentrations involves understanding the natural distribution of fluoride in different water sources and how these concentrations can indicate interaction between lake water and groundwater in Lake Hawasa basin. Fluoride is a useful tracer for such studies because its concentration in water bodies can vary significantly based on geological and hydrological factors .The higher fluoride concentrations due to contact with fluoride-bearing minerals (e.g., fluorite, apatite) in geological formations.



Graph 4.3 Fluoride graph

According to the research result the Lake Hawassa shows lower levels of fluoride concentration when the lake water is diluted by precipitation and run off .The highest fluoride concentrations are observed in northeast river samples, aligning with groundwater discharge zones. Moderate concentrations occur near Lake Hawassa and Hawassa City. The lowest concentrations are found in southeastern villages and the lake itself.

The fluoride map (Figure 4.5) indicates groundwater flow direction from the southeast toward Lake Hawassa, suggesting regional-scale groundwater discharge into the lake. Lineaments (fault systems) and the Tikur Wuha River network likely facilitate groundwater movement, covering much of the study area. Shallow, unconfined aquifers around the lake allow localized lake-to-groundwater discharge. Seasonal water table fluctuations (wet vs. dry seasons) cause temporal variations in fluoride concentrations.

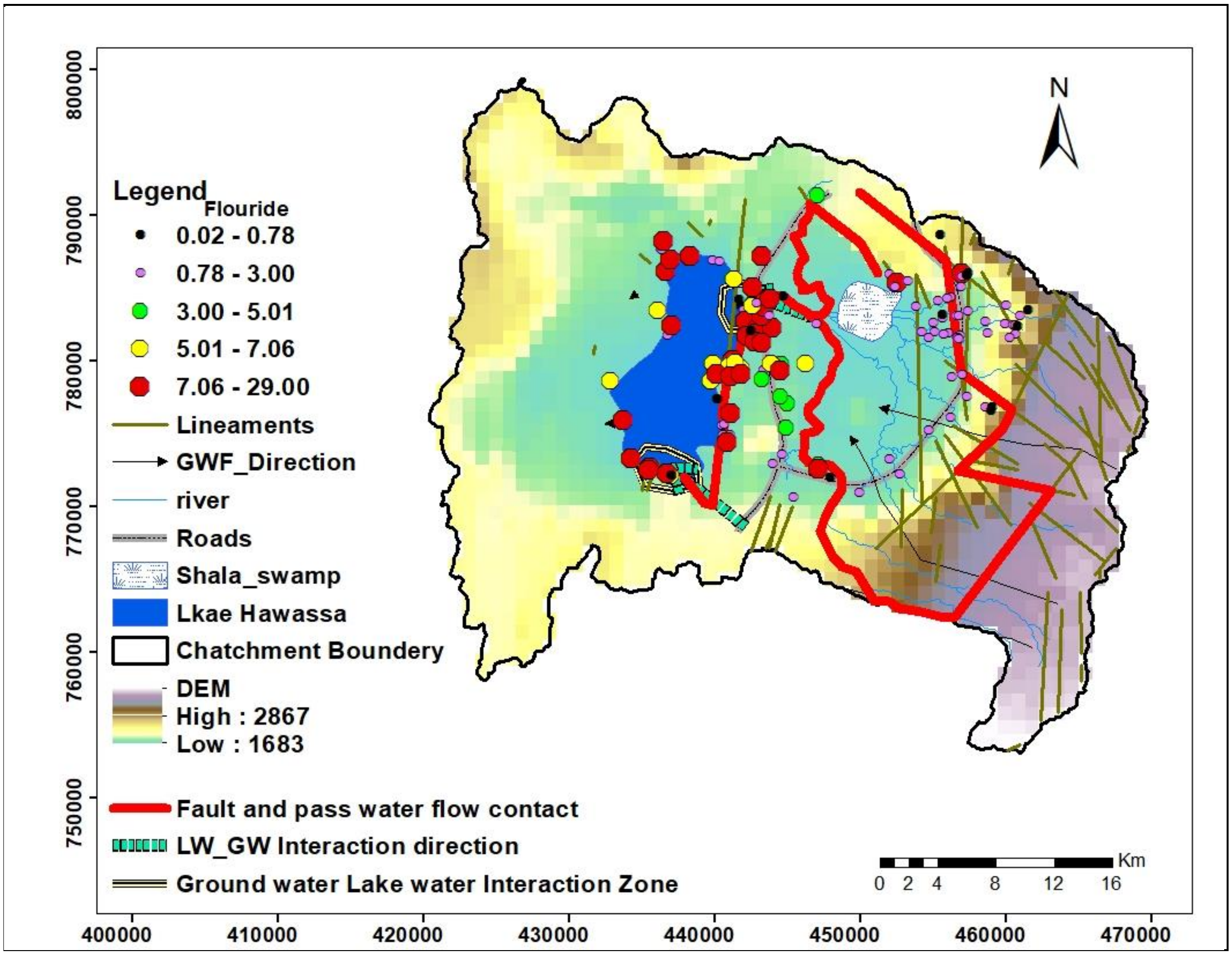


Figure 4.5 High zone for Fluoride with fault and flow pass contact map

Regional deep groundwater circulation discharges into the lake, supported by elevated fluoride in groundwater and dilution in the lake. Urban areas (e.g., Hawassa City) show moderate fluoride levels, potentially reflecting mixed sources or anthropogenic inputs. Low fluoride in the lake's southeastern boundary suggests limited interaction or recharge from low-fluoride shallow aquifers.

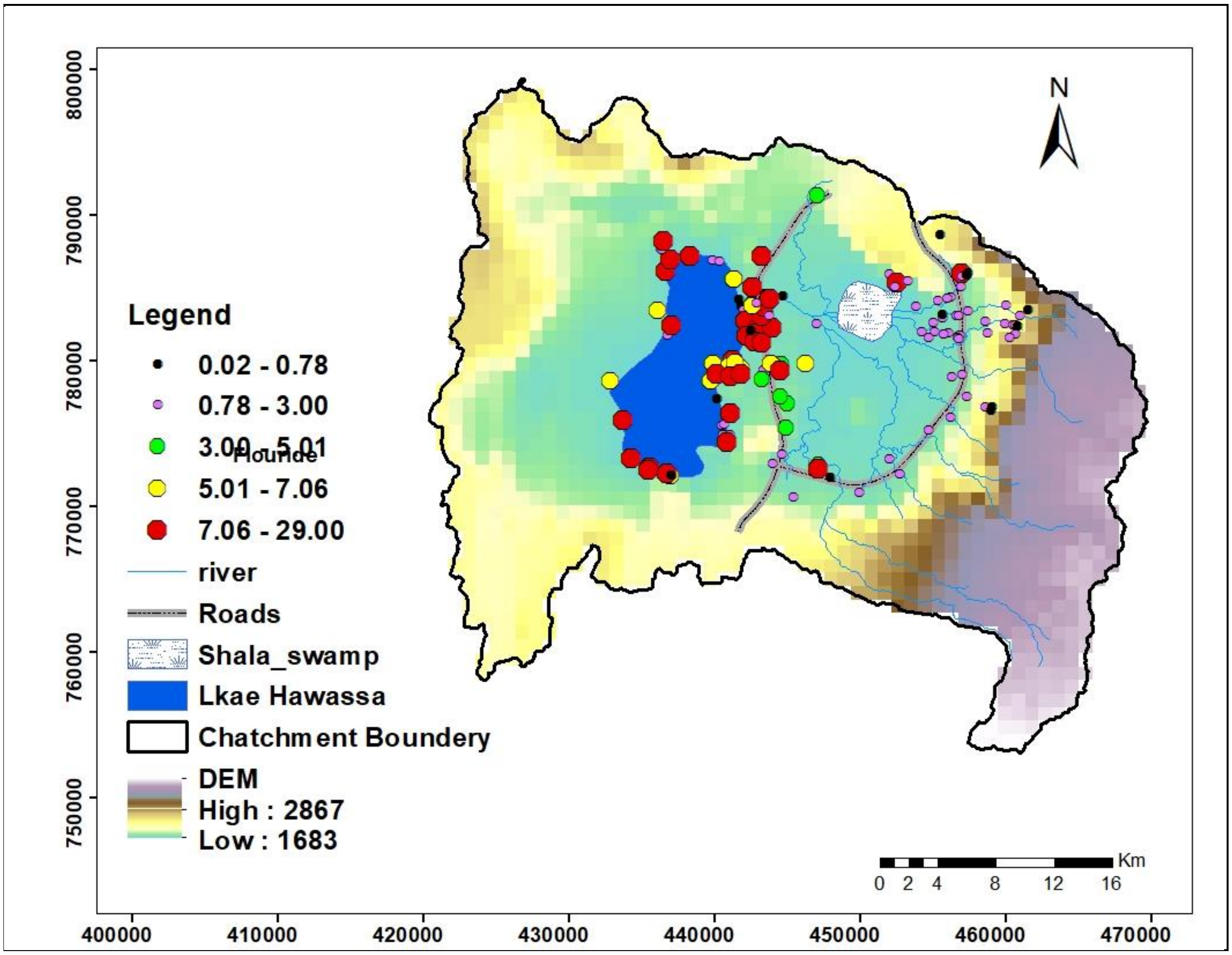


Figure 4.6 Fluoride map of interest area

4.1.4 P^H Distribution and Influencing Factors in the Hawassa Basin

The pH values of water sources in the Hawassa Basin (Lake Hawassa, rivers, groundwater, springs, and boreholes) vary spatially, reflecting geological and hydrological controls. As showed figure bellow 4.7 the transporting channel of minerals by lineament and river flow pass.

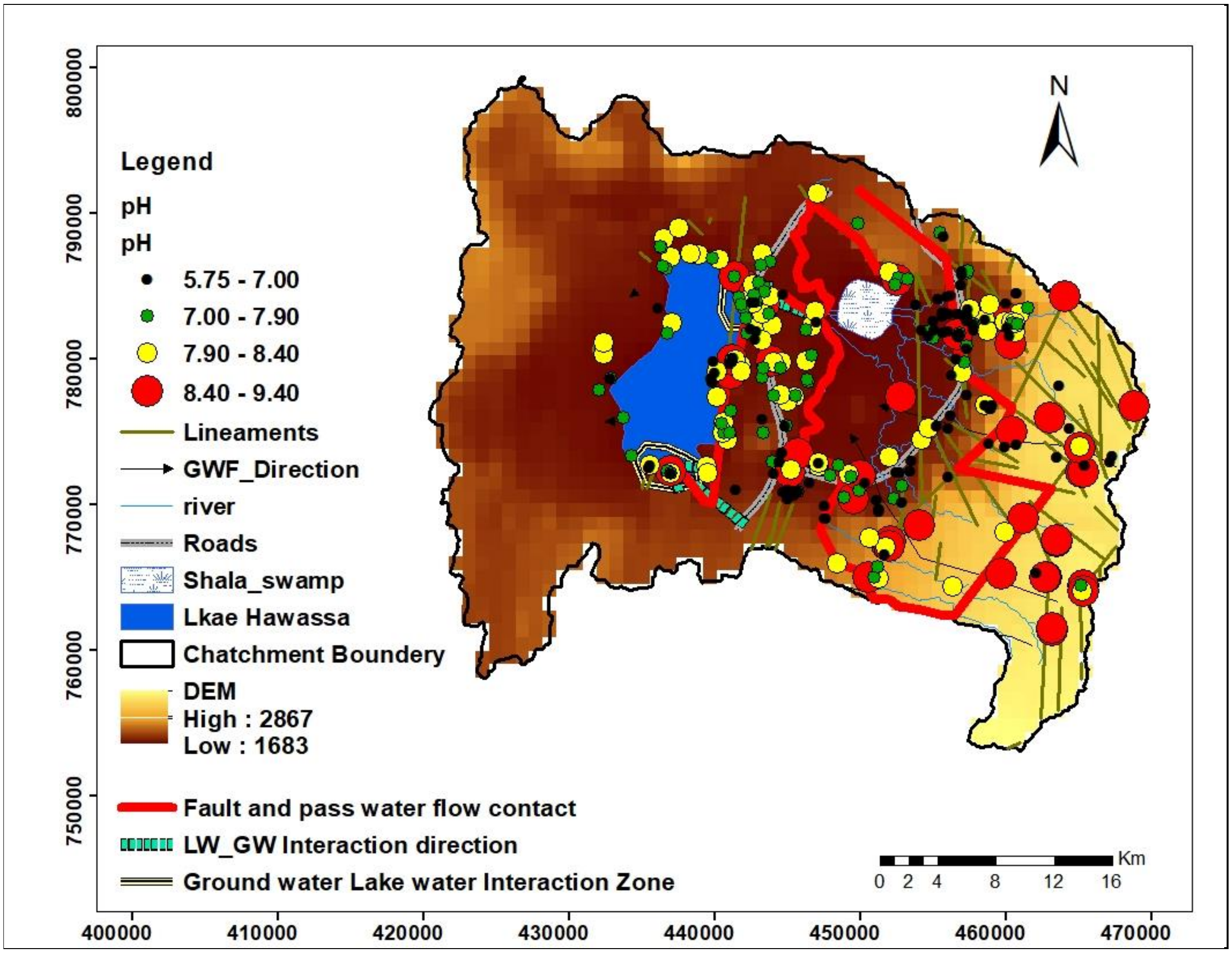
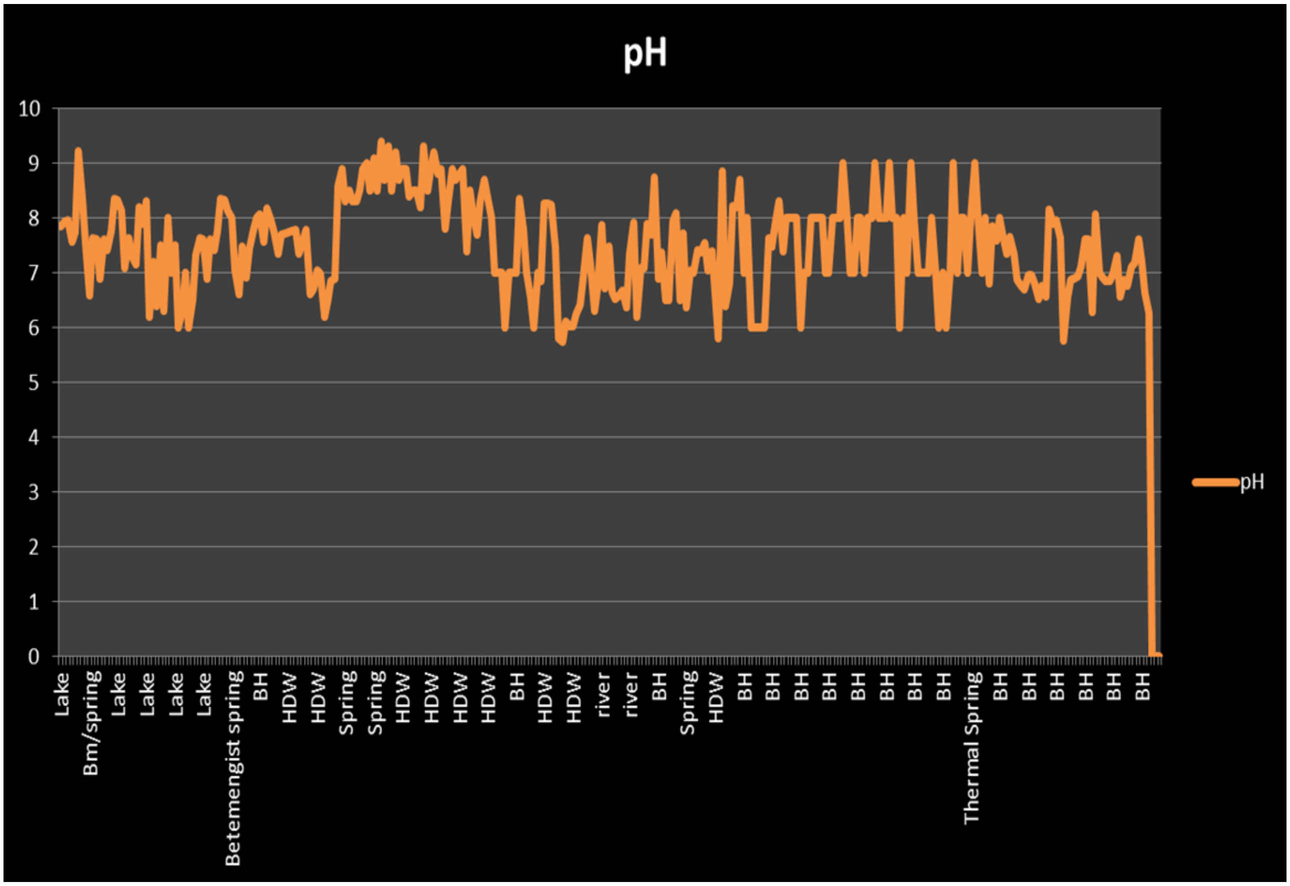


Figure 4.7 High pH Zone with fault and flow pass contact map

In this research the pH is classified into four ranges which from ranges, each associated with distinct processes as pH graph 3 presented primarily as pH 5.75-7 is slightly acidic to neutral due to groundwater inflow from acidic aquifers from surrounding geology has sulfide minerals or peat discharging to the lake Hawassa , Because of hot springs/groundwater seepage introduce acidic compounds (e.g., hydrogen sulfide, carbon dioxide) and in shallow unconfined aquifers, organic matter decomposition releases CO_2, forming carbonic acid, so no measured value of the scale above on the lake and surrounding. This indicate that the ground water lake water interaction in lake Hawasa basin due to ground water recharging to the lake. The next vale is pH 7-7.79 is neutral to slightly alkaline mixing between surface water and groundwater with some buffering capacity. The third is pH value from pH 7.79-8.40 is moderately alkaline, which has strong groundwater influence, likely from carbonate-rich aquifers like basalt weathering. This range is Widespread across all sources except Lake Hawassa because of shallow groundwater discharge due to unconfined aquifers near the lake's eastern periphery allow CO_2 from organic decay to percolate, moderating pH also hot springs/river recharge in eastern regions, hydrogen sulfide and CO_2 from thermal inputs lower pH to mid-range values. The fourth is pH 8.40-9.40 is highly alkaline as result very strong groundwater dominance with high dissolved carbonates/bicarbonates and possible hydrothermal inputs because of volcanic/geothermal activity exist in the basin.



Graph 4.4: pH Graph

Lake Hawassa (especially near Tikur Wuha River inflows) and associated groundwater because of geological weathering: Alkaline rocks (e.g., volcanic basalts, carbonates, silicates) release OH^-, CO_3^{2-}, and HCO_3^- ions, elevating groundwater pH. Tikur Wuha River recharge high-pH from groundwater via fractures/permeable lineaments which transporting alkalinity to the lake. Unconfined aquifers near the lake facilitate alkaline groundwater discharge into the ground, while lake water may infiltrate the aquifer depending on hydraulic gradients. Tikur Wuha River:

Acts as a conduit for alkaline groundwater, with pH values mirroring lake samples near its channel and also boreholes/springs are high pH in distance sources confirms regional alkalinity due to bedrock geology (e.g., volcanic/carbonate weathering).

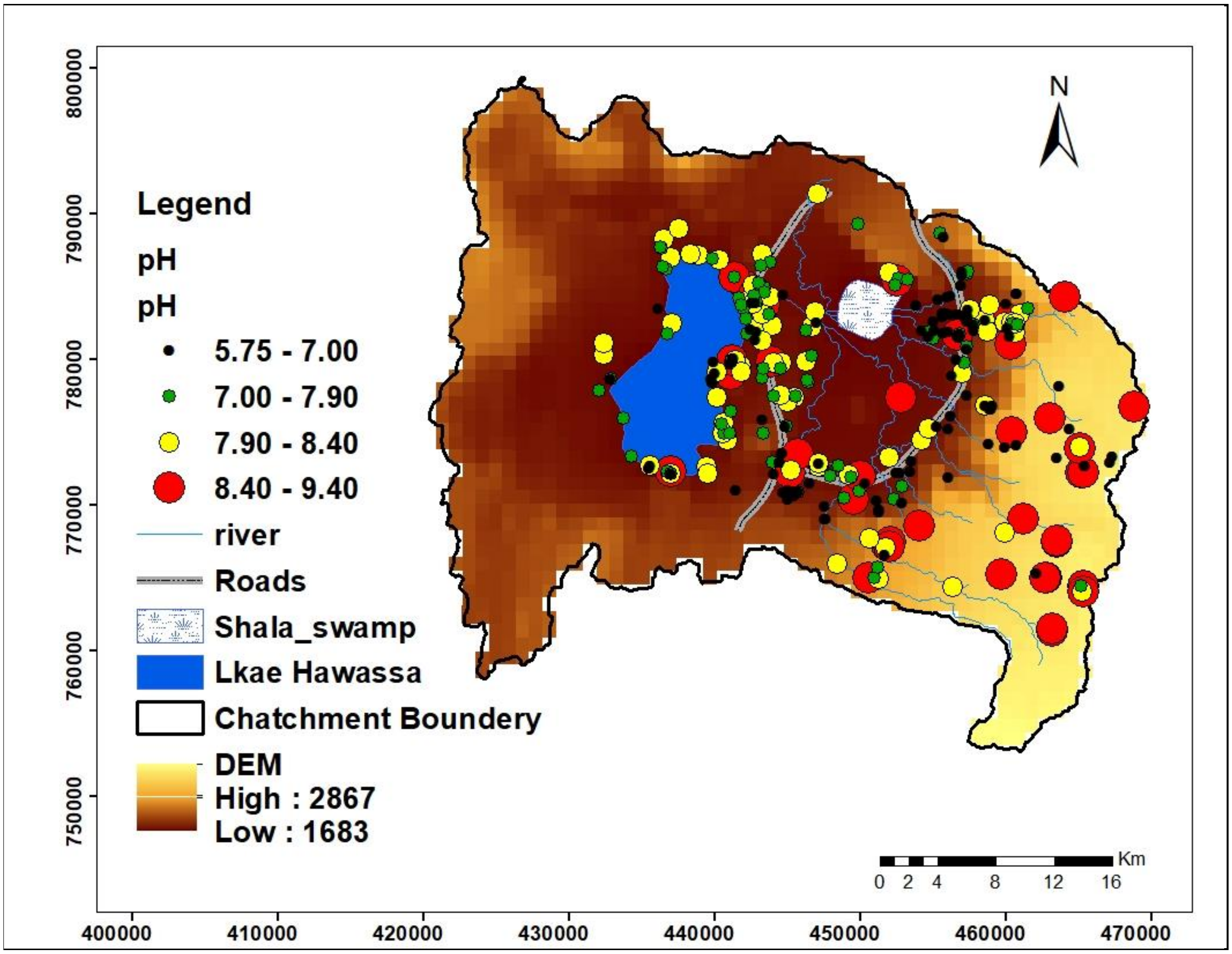


Figure 4.8 pH map of interest area

Assess lake-water and groundwater interaction in the Lake Hawassa Basin using a pH graph prepared in ArcGIS. The interaction indicators similar pH in lake & nearby boreholes/springs indicates strong interaction. Different pH in lake & rivers indicates limited interaction (if rivers have distinct sources).Gradual pH change from lake to groundwater mixing zone (discharge/recharge).

- Possible Findings in Lake Hawassa Basin:
  - High Interaction Zones:
    - Near springs & shallow boreholes with pH close to lake water.

        - Eastern/Northern shores (if geology allows seepage).
    - Low Interaction Zones:
        - Deep boreholes with different pH (isolated aquifers).
        - Rivers with distinct pH (e.g., Tikur Wuha River if it has different chemistry).

4.1.5 Temperature

In this research the interpretation of temperature data from the Lake Hawassa basin provides valuable insights into lake-water and groundwater interactions, influenced by geological and geothermal factors. Tikur Wuha Side Elevated temperatures (>32°C or higher) it indicates significant groundwater discharge into the lake via Fractures/lineaments (permeable pathways in the rift-associated geology) and river flow paths (e.g., Tikur Wuha River).The similarity in temperature between groundwater and the lake suggests direct hydraulic connectivity, with groundwater contributing to lake recharge, also in the southern of the lake (Old Sidama Betemengist Spring) the same high category temperatures was recorded ,this is because linked to thermal groundwater discharge from hot springs, driven by subsurface volcanic activity (East African Rift System) and geothermal inputs along rift faults.

Lake Hawassa Temperature Patterns Moderate temperatures (21–30°C) dominate the lake and nearby areas suggests the lake is primarily a gaining water body (recharged by regional groundwater) and come to decline by mixing with rain water at rainy season and contacting with atmospheric climate condition, so moderately cooled lake water groundwater inputs imply limited discharge from shallow aquifers near the lake. Peripheral Areas (Southern/Eastern Basin Boundaries) lower temperatures (<21°C) reflects reduced thermal spring activity away from the rift axis and correlates with diminished tectonic/volcanic influence in these zones. Regional Context Northern/Northeastern Basin (e.g., Wondo Genet) Declining thermal outputs suggest less active rift-related geothermal activity compared to the southern/western rift axis and Western/Southern Rift Axis Persistently higher temperatures due to ongoing tectonic and volcanic processes.

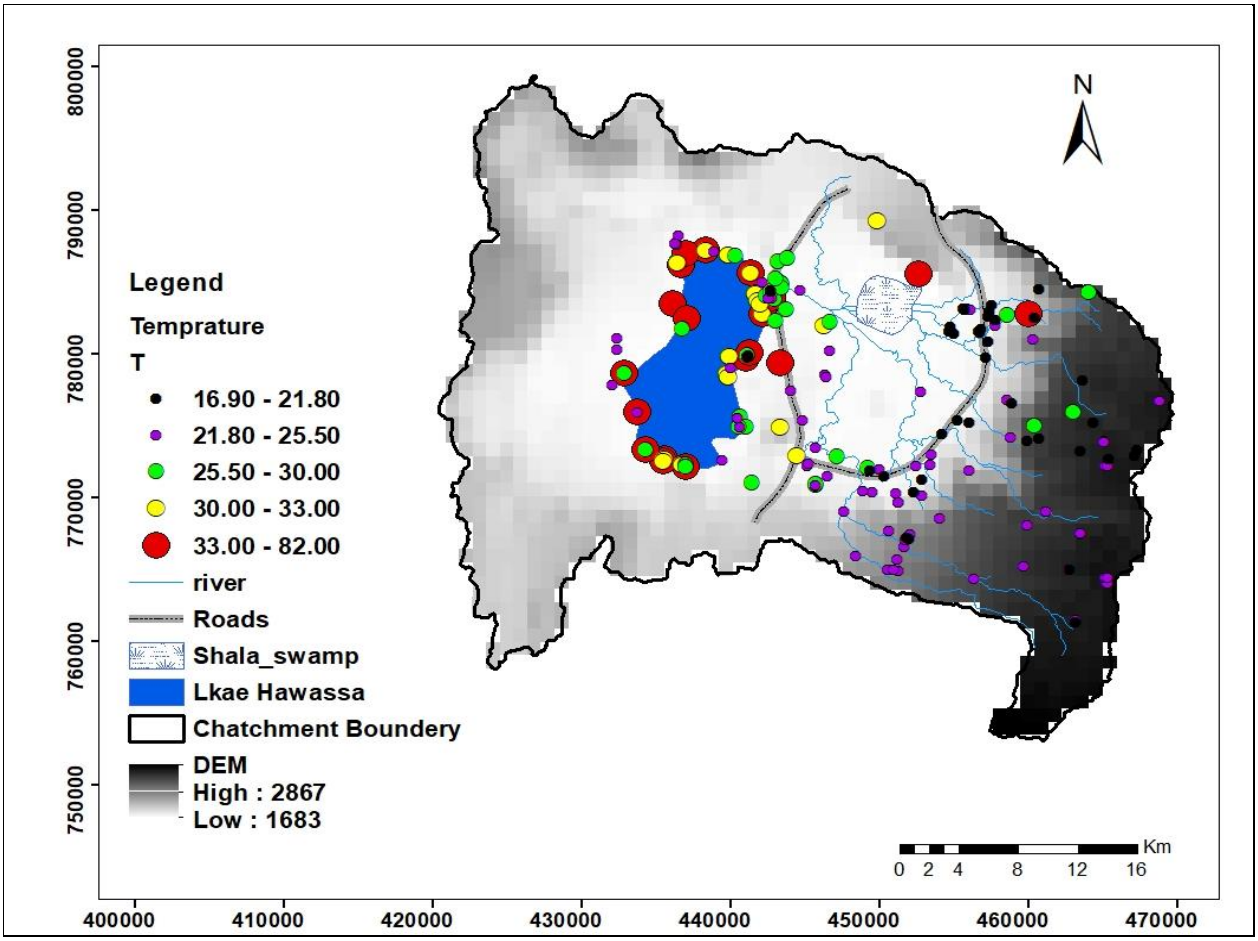


Figure 4.9 Temperature Map

4.1.6 Temperature variation and interaction

The samples were taken from a bore hole, spring, river, ground water, and Lake Hawasa. The results showed that the measurement samples varied from one location to another, indicating the lake water-ground water interaction zone. There is a range of temperature samples in the northeast of the lake, which is connected to Tickur Woha; thus, it is one of interaction zone where groundwater and lake water mix. There is another one southwest of the lake, and because of the lineament structures on both sides and the hot spring at the lake's bottom. It also shows the area where the lake and ground water interact. The interaction of geological features from the lake's northern portion in the event that the temperature in this area varies.

Both the rainy and dry seasons were used to get temperature samples for this study. Plotting the sample values on an ArcGis map revealed that temperature changes were noted in the water samples taken from rivers, springs, boreholes, groundwater, and Lake Hawassa. This finding suggested that groundwater and the lake were interacting. Consequently, the lake water ground interaction zone in the Lake Hawasa basin was determined by the temperature sample fluctuation as showed below graph 4.5

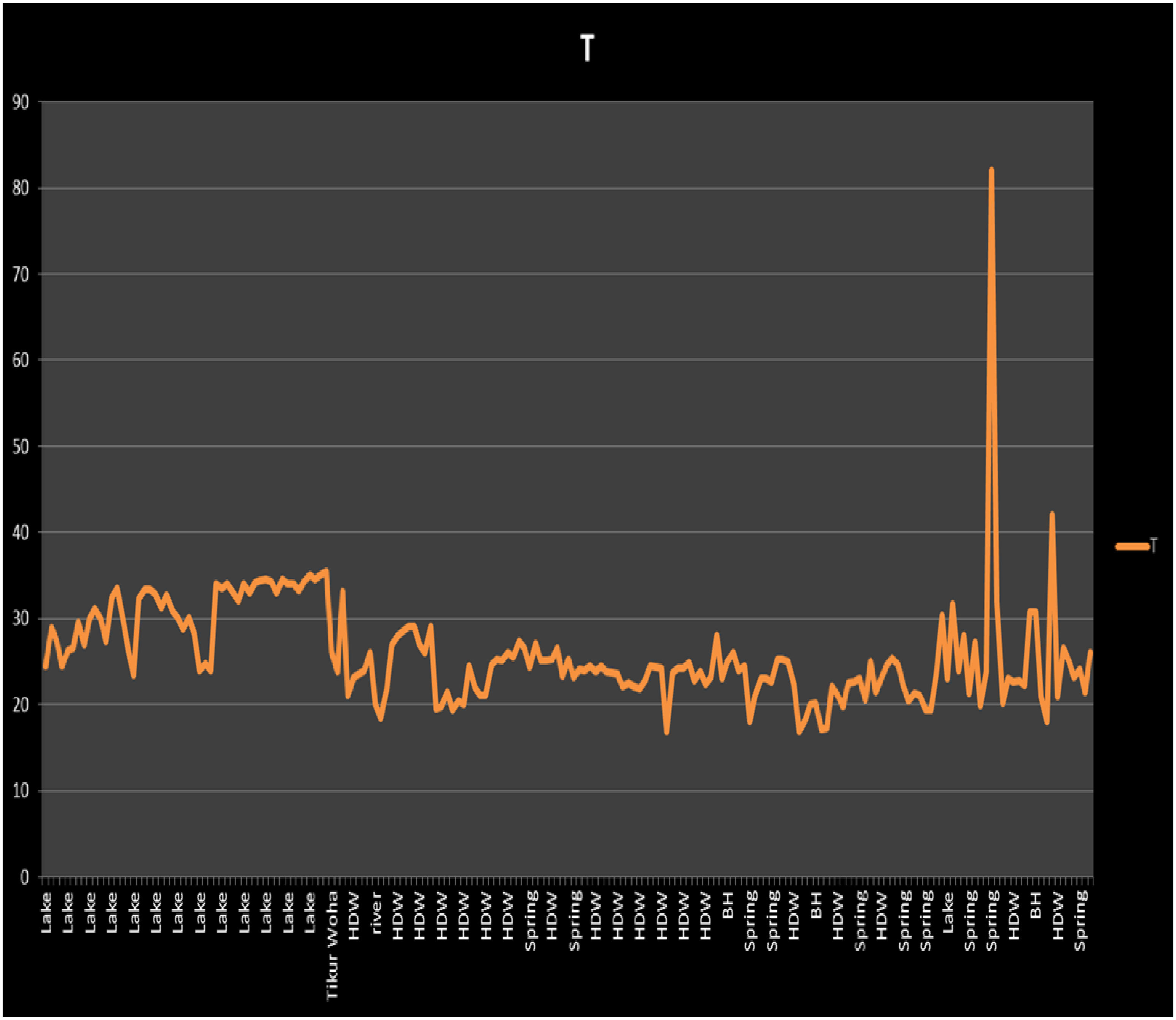


Figure 4.5 Temperature graph

4.2 Geochemical tracers indication conditions

4.2.1 Radon (Rn) anomalies

Radon is naturally enriched in groundwater but degrades quickly in surface water, so its presence suggests active groundwater inflow. The highest radon concentration was measured in the northeastern part of the lake (Tikur Woha side).The Wondogenet area (Awasa Woreda) has thermal springs, rivers, and boreholes with high radon levels. This region is likely the primary source of radon-enriched groundwater that discharges into the lake through the Fault/Lineament Structures. A geological fault or fracture zone likely connects Wondogenet to the southern part of Lake Hawasa passing by river flow paths and subsurface channels transporting radon-rich groundwater into the lake. Hydrogeological conditions allow groundwater to seep into the lake, particularly Southern lake bottom the ground water discharging to the lake. Groundwater entering via fault-controlled flow paths.in (Fig.4.10 Map) likely shows: The fault line extending from Wondogenet toward the lake. High radon locations in thermal springs and boreholes (Wondogenet) aligning with high-radon zones in the lake and river systems or preferential flow paths that facilitate groundwater movement.

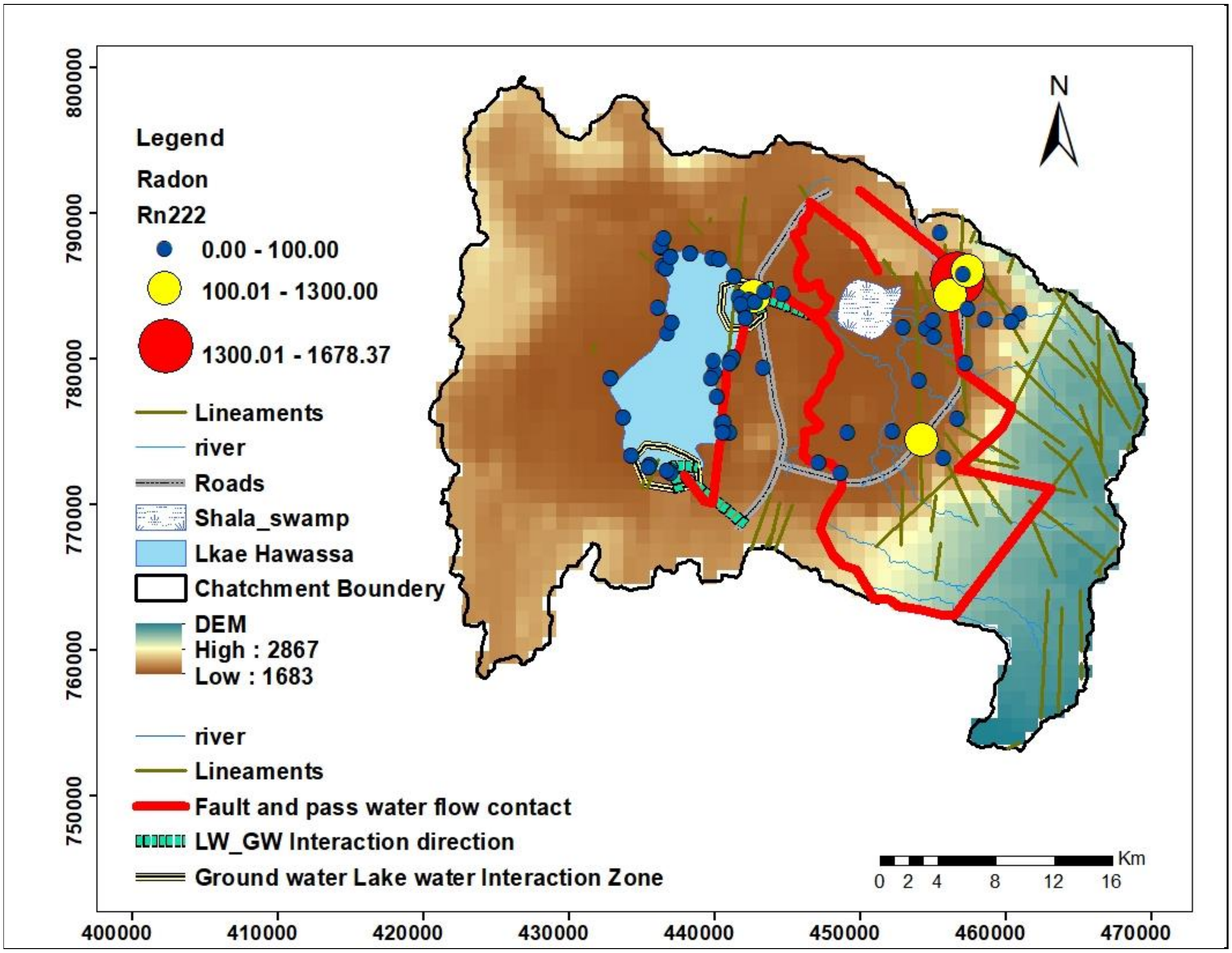


Figure 4.10 Radon Indicated Ground water lake water interactions

4.2.2 Electrical Conductivity (EC)

Elevated EC in the lake reflects the contribution of saline groundwater from deep aquifers in the rift valley, where dissolution of rift-related minerals increases salinity. The high electrical conductivity observed in Lake Hawassa and its surrounding areas, particularly in the northeast, is likely due to groundwater interaction with mineral-rich formations along its flow path. Groundwater recharges in elevated areas and flows toward the lake (discharge zone).As it moves through subsurface formations, it dissolves salt-bearing minerals (e.g., evaporates, carbonates, or weathered volcanic rocks), increasing its Total Dissolved Solids (TDS) and thus electrical conductivity (EC).The northeast region of the research area has higher permeability fractures and more soluble minerals, enhancing this process. In fig 18 below the ground water lake interaction in the EC map zone of Lake Hawasa showed clearly

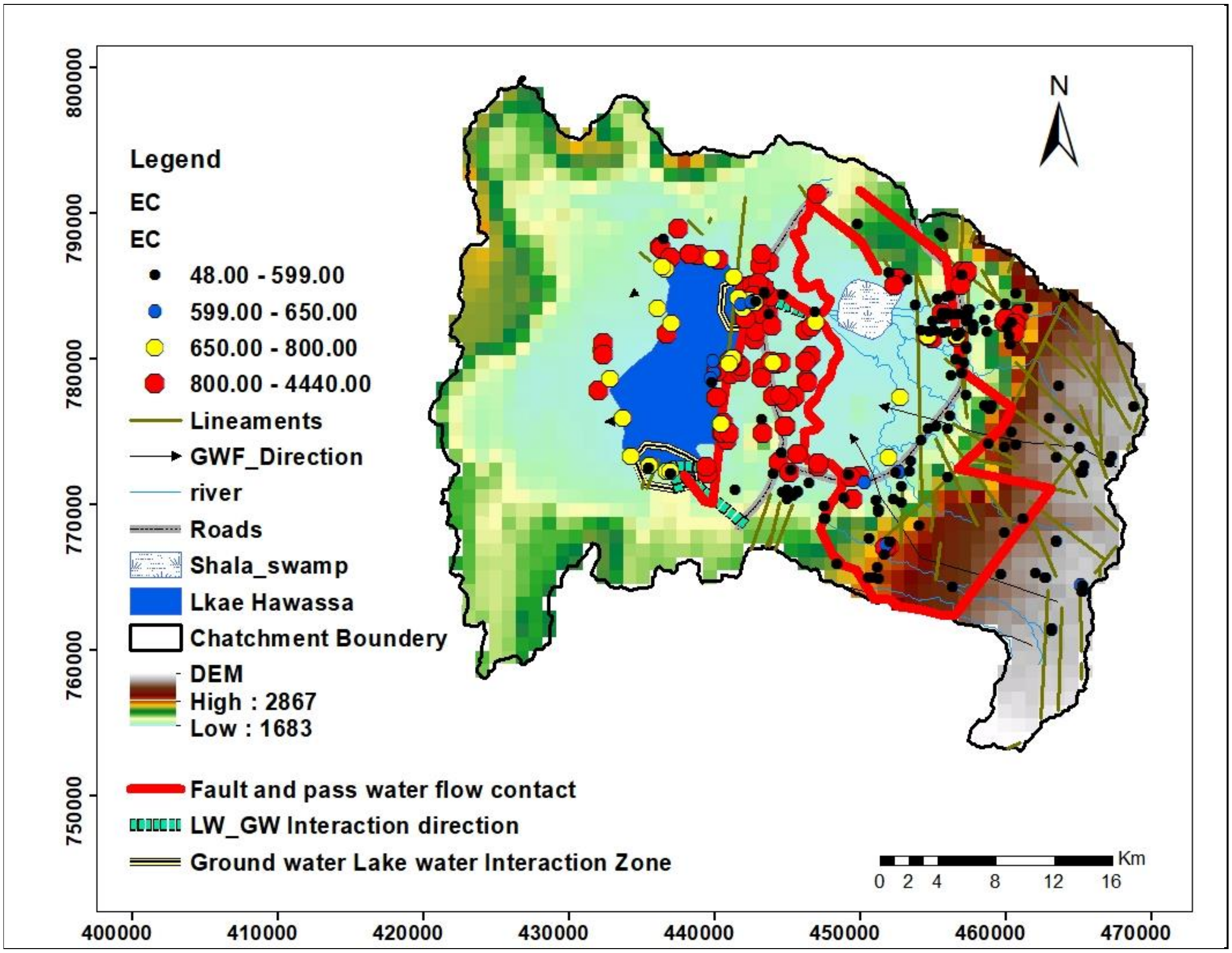


Figure 4.11 EC Indicated Ground water lake water interactions

4.2.3 Fluoride (F^-)

High fluoride concentrations in the lake are derived from regional volcanic geology and groundwater inputs, aligning with rift-related hydrothermal activity. The fluoride concentration in Lake Hawassa indicates an interaction between the lake water and groundwater, with the lake being recharged by regional groundwater circulation. Elevated fluoride levels are observed in Lake Hawassa and in groundwater from the Wondogenet area.This similarity in fluoride concentration implies a shared source or hydrological connection between the two. Groundwater in the region (e.g., Wondogenet area) likely contributes to the lake’s water budget, carrying dissolved fluoride. A map (Fig. 4.12) likely illustrates areas where groundwater and lake water mix. Discharge zones where groundwater enters the lake, Hydrological gradients indicating flow direction and geochemical evidence (like matching fluoride levels) confirming mixing.

Fluoride in water often comes from geogenic sources (e.g., volcanic rocks, hydrothermal fluids). Groundwater in the region (e.g., Wondogenet) flows through fluoride-rich aquifers; it will carry high fluoride concentrations. When this groundwater discharges into Lake Hawassa, it raises the lake's fluoride levels.

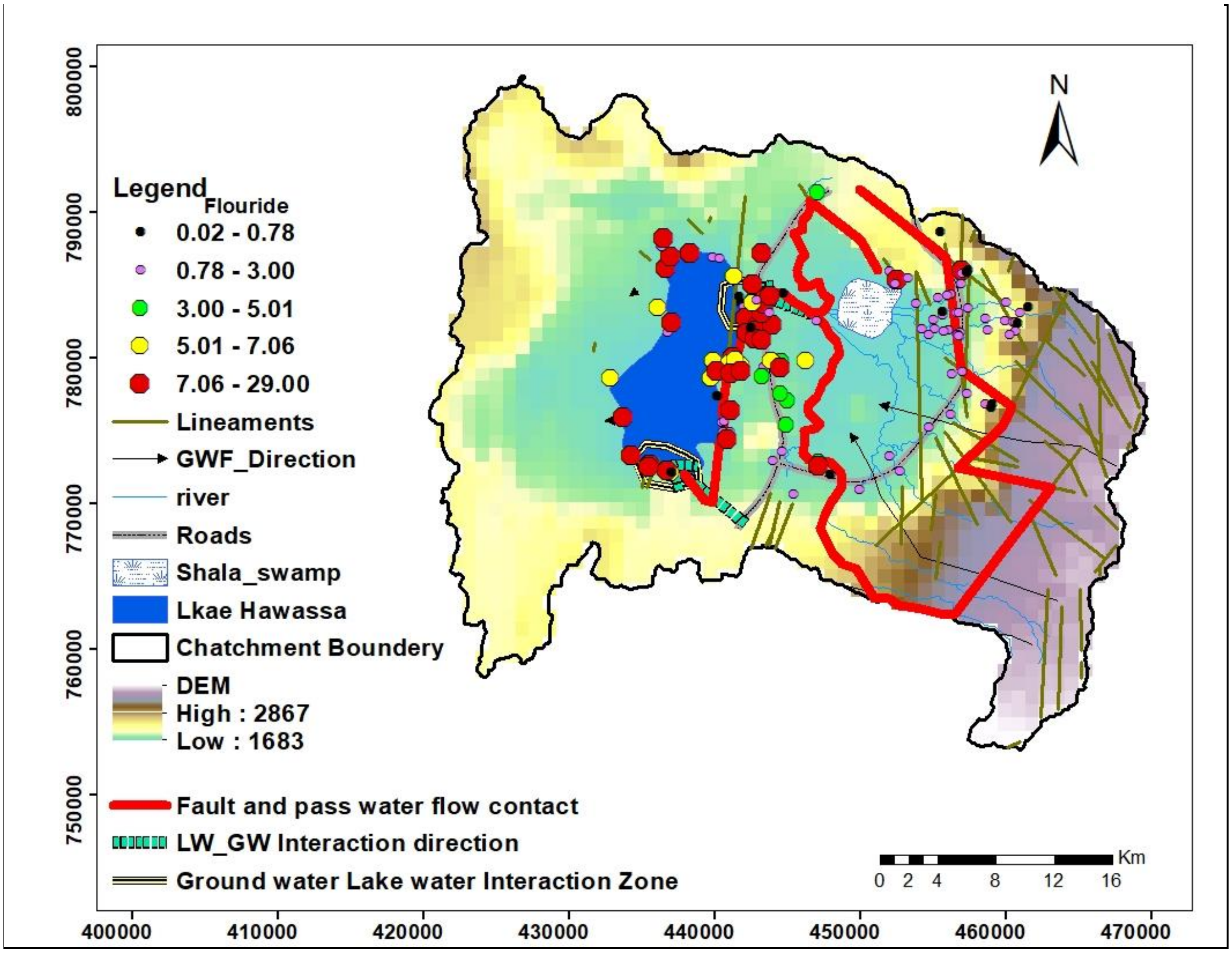


Figure 4.12 Fluoride Indicated Ground water lake water interaction

4.2.4 Thermal Groundwater Influence

High lake water temperatures are linked to geothermal groundwater discharge from the active Main Ethiopian Rift. Volcanic heat sources produce hot groundwater that migrates along faults and mixes with lake water. In the Wondogenet area, the highest temperature measurements would likely be associated with the thermal spring and boreholes that tap into deeper geothermal systems. The lake water temperature is generally lower but can be influenced by the mixing of thermal groundwater discharges, particularly in the eastern and southern bottom zones of the lake where thermal springs discharge directly into the lake in this area the temperature fluctuation was observed . The eastern side and southern bottom of the lake receive direct thermal discharges The interaction direction suggests that thermal groundwater flows toward the lake, mixing and raising local lake temperatures in these zones. Fig. 4.13 map is clearly described the interacting zone and interaction direction of both sources.

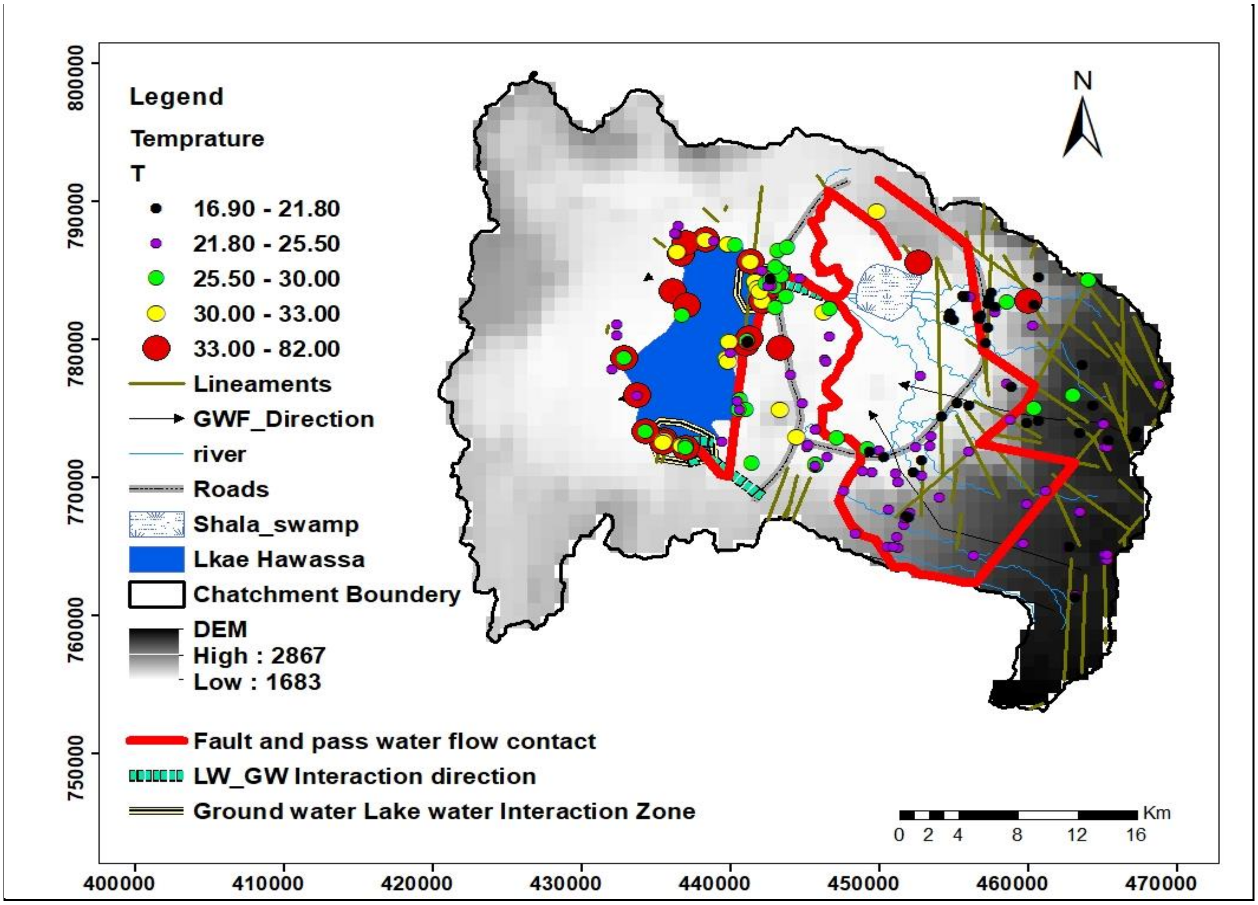


Figure 4.13 Temperature Indicated Ground water lake water interaction

4.2.5 PH

The lower pH in lake water compared to groundwater suggests mixing with atmospheric CO_2 and organic acids from surface processes. The pH values in Lake Hawassa indicate groundwater interaction, particularly from the northeastern groundwater sources, rivers, and springs .The lake water has a higher pH than the groundwater in the Wondogenet area, suggesting that the groundwater entering the lake (from the northeastern side) is more alkaline. This implies that the groundwater is not the sole source of lake water chemistry but mixes with other inputs (e.g., river inflows, springs, or lakebed interactions). Geological fractures allow groundwater to seep into the lake and hydrogeological Formations like permeable rock layers facilitate groundwater movement into the lake. Especially in the eastern (Timur Woha) and southern bottom regions on which lineaments/faults, river flow and channels, surface water also inflows contribute to pH variations. The map likely shows pH distribution, highlighting higher pH zones where groundwater enters in to eastern and southern to the lake areas as Fig.4.14 map.

- Localized reverse interaction (lake water seepage into shallow unconfined aquifers) may occur near the shoreline, but regional groundwater discharge dominates the system.

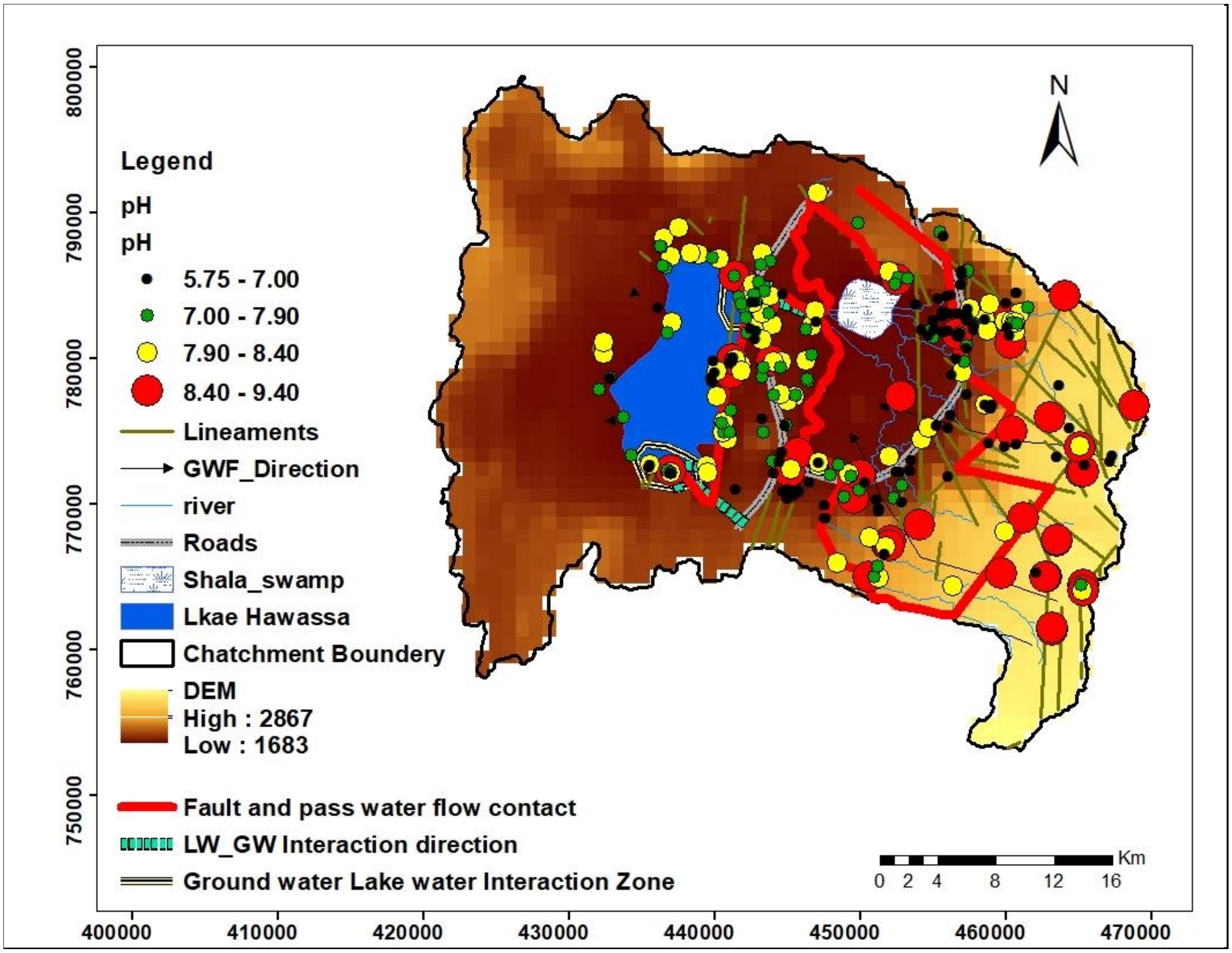


Figure 4.14 pH Indicated Ground water lake water interactions

4.2.6 Geochemical tracers source and impact on Interaction

To interpret the groundwater-surface water interaction in the Lake Hawassa Basin based on the geochemical tracers (EC, Radon, Fluoride, Temperature, and pH), we need to analyze the spatial distribution of these parameters on the provided map. Below is a structured explanation of how these tracers confirm the interaction zones, direction, and sources:

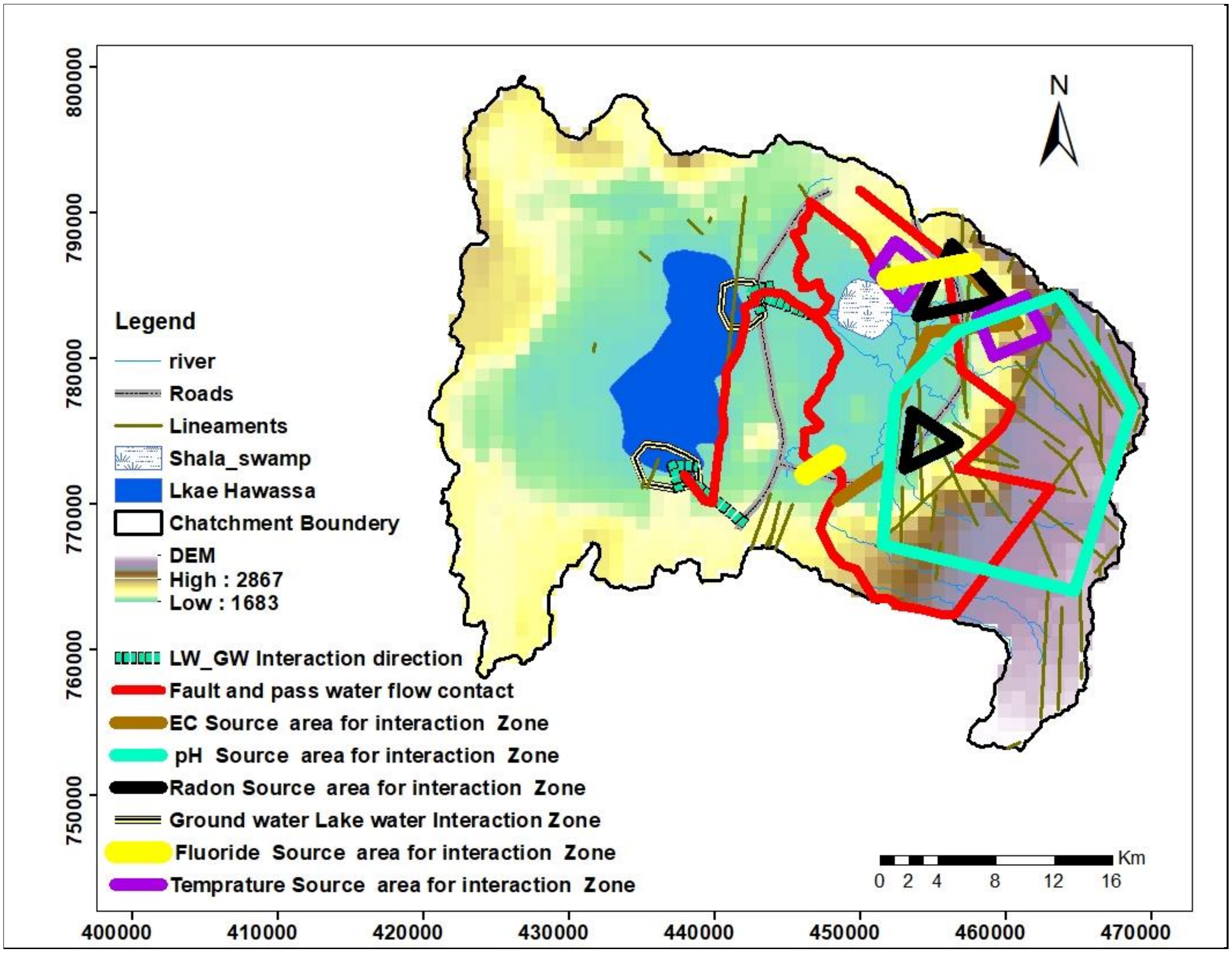


Figure 4.15 Geochemical tracers Indicated Ground water lake water interaction

CHAPTER 5

5. Conclusion

Strong Lake water-Groundwater Interaction – The highest tracer values were observed in the northeastern part of the lake, particularly along the Tikur Woha River and its channel extending from the southeast to the northeast of the lake. This suggests active mixing between lake water and groundwater in these areas. Structural Control on Interaction the presence of faults in the northeast likely facilitates groundwater discharge into the lake, enhancing connectivity between the lake and the surrounding aquifer system. Regional groundwater flow influence the regional groundwater flow direction (from the southeast boundary towards the lake) contributes to the interaction, with the lake acting as a discharge zone for the surrounding unconfined aquifer.

The study confirms active lake-groundwater interaction in the Lake Hawassa Basin, particularly influenced by geological structures and regional groundwater flow. The assessment of lake water-groundwater interaction in the Lake Hawassa basin was conducted using geochemical tracers (EC, Radon, Temperature, pH, and Fluoride) sampled from lake water, groundwater, rivers, and springs. Spatial Data Coverage of most data was collected from the East, northeast and southwest of the lake. Limited data from the western part of Lake Hawassa. The laboratory results and conducted ArcGIS plotting map suggest that Lake Hawassa receives active groundwater discharge, with spatial variability in the degree of interaction. Here's a structured interpretation of the findings

1. Radon (Rn) Concentration – High radon levels in the northeastern part of the lake suggest significant groundwater inflow in this direction, likely facilitated by fault systems and subsurface rock structures.
2. Electrical Conductivity (EC) – Elevated EC values in boreholes and around the lake confirm groundwater exchange, supporting the presence of interaction zones.
3. Fluoride (F^-) – Similar fluoride concentrations in groundwater and lake water further substantiate groundwater discharge into the lake.
4. pH Variability – Fluctuations in pH at certain locations indicate localized groundwater influence.

5. Temperature Variations – Differences in temperature in specific areas reinforce the evidence of groundwater-lake interaction.

The interaction occurs primarily in two key zones:

- Southwest (bottom of the lake)
- Northeast (along Tikur Woha)

These findings highlight the importance of subsurface geology and fault systems in controlling groundwater discharge into Lake Hawassa. Further studies integrating isotopic and hydrological modeling could enhance the understanding of flow dynamics and recharge patterns in the basin.

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Table 3 Dry Season and primary Data from November to December

FID	Fild_Id	Source_typ	X	Y	EC	Salinity	pH	T	Rn222	Fluoride	clorine	bicarbonat
1	Lake Hawassa	Lake	435554	772627	742.1	400	6.5	34.5	44.85	8	360.02	28.8
2	Lake Hawassa	Lake	436983.1	772127.3	560.7	304	7.32	34.3	44.9	6.5	358.79	0
3	Lake Hawassa	Lake	436758	772244	797.2	426	7.63	33	0	8	479.62	18
4	Lake Hawassa	Lake	436641	786179	789.6	421	7.61	34.5	0	7.5	425.92	28.2
5	Lake Hawassa	Lake	435473.5	772508.2	481.2	265	6.9	34	28	8	263.61	15.6
6	Lake Hawassa	Lake	434297.8	773286.7	743.8	403	7.61	34	0	9	375.88	46.21
7	Lake Hawassa	Lake	433702	775892	794.2	432	7.42	33.2	0	8	458.87	16.2
8	Lake Hawassa	Lake	442124	782725	801.9	435	7.76	34.3	0	7.9	396.63	47.41
9	Lake Hawassa	Lake	437010	786965	801.7	432	8.36	35	0	7.8	390.53	55.21
10	Lake Hawassa	Lake	437086	782391	793.3	428	8.32	34.5	33.65	8	362.46	64.21
11	Lake Hawassa	Lake	438348	787183	808.8	434	8.13	35	0	8	392.97	57.61
12	Beteme/spring	Betemengist spring	436983.1	772127.3	384	250	8	35.5	33.65	0.61	159.87	0
13	Lake Awassa	Lake	441388	785594	789	473	7.5	34		6	29	412
14	Lake Hawasa	Lake	441239	780024	712	463	6.3	33.5		9	12.65	85

Table 4 Dry Season and primary Data from November to December

FID	Fild_Id	Source_typ	X	Y	EL	EC	Salinity	pH	T	Rn222	Fluoride	clorine	bicarbonat
1	Lake Hawassa	Lake	435554	772627	1691	742.1	400	6.5	34.5	44.85	8	360.02	28.8
2	Lake Hawassa	Lake	436983.1	772127.3	1689.1	560.7	304	7.32	34.3	44.9	6.5	358.79	0
3	Lake Hawassa	Lake	436758	772244	1688.17	797.2	426	7.63	33	0	8	479.62	18
4	Lake Hawassa	Lake	436641	786179	1687	789.6	421	7.61	34.5	0	7.5	425.92	28.2
5	Lake Hawassa	Lake	435473.5	772508.2	1692.19	481.2	265	6.9	34	28	8	263.61	15.6
6	Lake Hawassa	Lake	434297.8	773286.7	1680.21	743.8	403	7.61	34	0	9	375.88	46.21
7	Lake Hawassa	Lake	433702	775892	1689.35	794.2	432	7.42	33.2	0	8	458.87	16.2
8	Lake Hawassa	Lake	442124	782725	1680.38	801.9	435	7.76	34.3	0	7.9	396.63	47.41
9	Lake Hawassa	Lake	437010	786965	1676	801.7	432	8.36	35	0	7.8	390.53	55.21
10	Lake Hawassa	Lake	437086	782391	1691.52	793.3	428	8.32	34.5	33.65	8	362.46	64.21
11	Lake Hawassa	Lake	438348	787183	1692.54	808.8	434	8.13	35	0	8	392.97	57.61
12	Beteme/spring	Betemengist spring	436983.1	772127.3	1689.1	384	250	8	35.5	33.65	0.61	159.87	0

Table 5 Rainy Season and Primary Data from March to April

FID	Fild_Id	Source_typ	X	Y	EL	EC	Salinity	pH	T	Rn222	Fluoride	clorine	bicarbonat
1	Lake Hawassa	Lake	440507	775489	1685.58	742.4	393	7.43	24.5	39.25	0.8	403.95	21
2	Lake Hawassa	Lake	441145	779875.9	1690	816.2	433	7.51	28.9	22.45	0.91	456.43	21
3	Lake Hawassa	Lake	440607	775572	1696	811.8	425	8.03	27.31	0	0.9	461.31	26.4
4	Lake Hawassa	Lake	440665	774877	1687.49	809.6	437	7.84	24.5	0	0.89	473.52	24
5	Lake Hawassa	Lake	440523	774920	1700.47	817.5	440	7.93	26.3	0	0.89	329.51	74.41
6	Lake Hawassa	Lake	447156	772809	1680.47	806.6	435	7.95	26.6	39.25	0.87	406.39	37.21
7	Lake Hawassa	Lake	432893	778614	1679.45	790.6	420	7.57	29.6	28.05	0.86	443.01	21.6
8	Lake Hawassa	Lake	441039.3	774915.1	1686.44	807.4	431	7.75	27.01	44.85	0.81	456.43	30.01
9	Lake Hawassa	Lake	437010	772226	1685.42	759.1	409	9.21	29.9	44.8	0.82	467.41	117.62
10	Lake Hawassa	Lake	435554	772627	1691	742.1	400	8.35	31.2	44.85	0.81	360.02	28.8
11	Lake Hawassa	Lake	436725	781729	1685.15	819.2	440	7.55	30	50.5	0.94	445.45	27
12	Beteme/spring	Bm/spring	436983.1	772127.3	1689.1	230.3	128	6.59	27.3	33.65	0.61	159.87	0
13	Lake Hawassa	Lake	436758	772244	1688.17	797.2	426	7.63	32.4	0	0.83	479.62	18
14	Lake Hawassa	Lake	436641	786179	1687	789.6	421	7.61	33.5	0	0.83	425.92	28.2
15	Lake Hawassa	Lake	435473.5	772508.2	1692.19	481.2	265	6.9	30.4	28	0.69	263.61	15.6
16	Lake Hawassa	Lake	434297.8	773286.7	1680.21	743.8	403	7.61	26.25	0	0.81	375.88	46.21
17	Lake Hawassa	Lake	433702	775892	1689.35	794.2	432	7.42	23.4	0	1.12	458.87	16.2
18	Lake Hawassa	Lake	442124	782725	1680.38	801.9	435	7.76	32.3	0	0.98	396.63	47.41
19	Lake Hawassa	Lake	437010	786965	1676	801.7	432	8.36	33.3	0	0.98	390.53	55.21
20	Lake Hawassa	Lake	437086	782391	1691.52	793.3	428	8.32	33.35	33.65	1.11	362.46	64.21
21	Lake Hawassa	Lake	438348	787183	1692.54	808.8	434	8.13	32.9	0	1.1	392.97	57.61
22	Lake Hawassa	Lake	436438.6	786303.9	1685.61	676.4	368	7.08	31.3	11.2	0.78	379.54	33.01
23	Lake Hawassa	Lake	439837	786899	1693.63	799.4	432	7.63	32.7	16.8	1.12	469.85	21
24	Lake Hawassa	Lake	441647	784147	1686.6	664.7	362	7.31	30.9	44.85	0.66	435.68	36.61
25	Lake Hawassa	Lake	441824	783702	1684.65	621.9	338	7.15	30.1	16.85	0.61	390.53	27.6
26	Lake Hawassa	Lake	440315	786823	1681.65	805.7	438	8.2	28.8	0	1	368.56	18.6
27	Lake Hawassa	Lake	441982	783457	1678.65	793.3	431	7.89	30.06	44.85	0.81	402.73	48.61
28	Lake Hawassa	Lake	442397.8	783990.6	1686	789.7	433	8.3	28.2	22.4	0.8	330.73	75.61

29	Tikur Woha	Tikur Woha	443424.4	784589.1	1680.6	399.6	222	7.05	26.2	0	0.65	253.84	0
30	Tikur Woha	Tikur Woha	444661.7	784391.3	1687.62	313.8	176	6.61	23.8	0	0.61	152.55	26.4
31	Asaminew HD/Well	HDW	443313.7	779347.5	1712.53	1131	597	7.47	33.1	22.45	0.9	543.08	38.41
32	HDW	HDW	441197.1	779778.8	1175	924	491	6.91	21	22.45	1.1	395.41	0
33	HDW	HDW	436276.8	787632.5	1687.63	1386	714	7.43	23.1	28.05	1.07	434.46	0
34	HDW	HDW	436351.9	787587.5	1686.63	1163	600	7.79	23.5	33.65	0.91	517.45	43.21
35	Wonotika M/Camp	BH	436551	788217	0	250	125	8	24	0	8.2	317	0
36	W/Arsi Zone/Shalo	BH	440152	777334	0	1010	502	8.06	0	0	0.57	301	0
37	Gonde Kerso BH	BH	455465	788638	0	188	94	7.56	0	0	0.05	95.2	0

Table 6 Secondary Data from defferent sources with grond water chemistry

FID	Fild_Id	Source_typ	X	Y	Na	K	calcium	Mg	clorine	bicarbonat	sulfate
1	Awassa agri. Res. Center	BH	444223	779650	94	1.8	24	2.4	14.56	287.92	0.49
2	abela wendo #1	BH	445381	770562	128.7	12.19	12.4	9.52	11.9	220	6.19
3	abela wendo #2	BH	445027	770369	92.6	9.56	11.9	8.67	19.1	210	3.25
4	abela wendo #3	BH	444996	770976	12.5	20.4	20.4	2.63	12.8	205	12.7
5	awassa #1(gemeto)	BH	444574	773563	118.8	13.07	7.2	7.52	18.7	150	4.23
6	awassa #2(gemeto)	BH	444086	772115	83.2	12.6	3.02	1.02	12.8	145	7.63
7	OBH-816	BH	443296	778694	190	16.5	27.36	19.61	30.94	640.5	25.7
8	Awassa Tobacco	BH	444891	775368	202	20.5	32.68	16.87	53.7	602.07	71.88
9	SW-3	BH	446878	783231	38.3	17.15	49	6.2	10.3	220	29.6
10	TBH-14	BH	445522	777337	190	15	25	15	23	615	0
11	TDW-6	BH	442202	781675	200	23	15	2	36	523	10
12	ShiferawHotel	HDW	443037	782240	328	9.4	18	2	49	755	19
13	Wondo kosha	BH	437578	788926	162.7	28.5	60.3	28.9	91.9	475	101.4
14	Toga Mosque	BH	447033	791288	148	13	24	9	26	477	0
15	MeritZer	BH	443247	787145	218	9	12	3	26	548	19
16	Chefea Komboyea	BH	446991	782483	94	11	65	12	43	375	0
17	SOS School	BH	442856	781844	285	33	30	21	45	733	3
18	Wanza Wood factory	BH	442779	781335	300	33	44	8	49	757	1

19	AwaAgriCollege	BH	441848	779460	246	17	30	24	43	743	21
20	Oasis Hotel	BH	441401	779904	232	21	30	22	44	716	26
21	Plasa Hotel	BH	440128	779062	312	21	26	16	54	887	15
22	Awassa Pepsi	BH	445009	777028	208	14	26	18	40	639	59
23	Awassa Poultry	BH	443231	775814	8	6	16	4	8	28	44
24	Gemeto	BH	444574	773563	77	7	19	9	15	286	7
25	TabourCeramics	BH	443985	782246	204	8	8	4	33	562	2
26	Awa.Agri.Research	BH	444600	779738	164	11	28	14	24	554	3
27	Agri.Col.Research	BH	444066	779743	150	9	18	9	23	493	2
28	Awassa EWWCA	BH	443874	779764	184	11	14	24	25	580	3
29	AwassaTextile	BH	444530	777465	178	14	4	24	33	630	25
30	Edol	BH	455612	782890	26	11	14	3	14	104	2
31	Wondowesha	BH	457255	782872	33	9	9	2	10	107	9
32	Wondogenet	BH	457004	779044	19	10	8	2	8	92	3
33	Busa	BH	454686	775165	25	14	15	3	7	140	4
34	Edol School	BH	452744	772218	69	30	46	8	21	331	19
35	Edol	BH	452000	773211	94	15	56	10	28	464	12
36	Loke Village	BH	440863	774376	268	47	12	6	38	748	8
37	Central Hotel	BH	441086	778907	375	30	13	23	66	858	27
38	Yamare Hotel	BH	441823	779103	264	18	32	28	69	699	50
39	Chefe Kuto Jebsa	BH	446254	779830	236	20	26	10	7	697	26
40	Total Car Wash	BH	443282	783063	144	29	66	18	30	562	54
41	Dato	BH	443429	783712	328	20	12	6	30	775	44
42	Tikurwoha	BH	442601	783759	288	35	30	10	103	574	88
43	Tikurwoha	BH	442636	785021	398	25	4	2	61	928	30
44	Medo	BH	455746	788356	40	7	7	2	13	41	15
45	Tutu (Big)	BH	451992	785880	25	5	9	3	7	81	11
46	Wondo G.F.College	BH	460747	784454	12	4	10	2	9	55	3
47	Soyema	BH	456672	781620	34	11	8	3	8	92	4
48	Cheko	BH	458776	781867	22	5	13	4	6	134	4

49	Wondowesha	BH	460084	782090	17	5	12	4	8	99	3
50	Watera-Wondo	BH	457323	780700	22	13	18	4	16	82	17
51	Waterahicho	BH	456608	779956	16	8	7	2	6	73	6
52	Ketanketa	BH	457343	777517	18	6	22	3	7	92	5
53	Wondogenet	BH	458592	776758	24	8	11	4	7	113	4
54	Melgawondo	BH	456186	776054	23	17	20	6	25	93	7
55	Girebe	BH	462037	765283	4	2	3	1	3	20	1
56	Borja	BH	451238	769452	14	5	17	9	6	149	3
57	Abella Wondo	BH	445381	770562	27	6	15	7	4	156	8
58	Gemeto	BH	444676	770823	2	5	14	4	5	124	1
59	Shalo hot spring	Thermal Spring	452526	785341	450	27	5	0	93	778	70
60	Belahot spring	Thermal Spring	456965	786018	740	40	34	5	156	1553	180
61	Wondogenet Hot Spr	Thermal Spring	459944	782463	182	41	6	3	26	564	0
62	Soyema Hot Spring	Thermal Spring	460642	781786	170	42	11	4	25	541	2
63	Gerariketa Hot Spr	Thermal Spring	447156	772809	196	15	8	5	38	467	37
64	Gerariketa Hot Spr	Thermal Spring	447189	772574	380	25	10	3	60	854	90
65	Lake Awassa	Lake	441388	785594	151	25	10	5	29	412	1
66	Wesha Rawwater	river	458869	783694	19	5	9	3	4	118	2
67	Kedo Raw water	river	447540	768999	6	6	4	1	4	49	0
68	Tikurwoha River	river	443820	784270	285	29	13	4	59	722	0
69	Hawassa	BH	442499	782033	187.06	0	24	24.3	10	644.2	1
70	HU	BH	444538	779298	8.4	11	24	17.01	2.5	183	2
71	Hawassa	BH	441095	776350	377.5	31.5	28	28.17	1.25	1244	2
72	Hawassa	BH	443283	781228	359	38	22.4	29.6	0.02	1195.6	0
73	Hawssa	BH	443968	772921	56.2	9.6	42	14.58	5	341.5	9
74	Tula Subcity	BH	447977	771948	45.2	4.6	14.4	8.2	3	195.2	5
75	Tula Subcity	BH	448528	772643	23.3	3.8	26.4	9.23	1.5	178	5
76	Tula Subcity	BH	449926	770917	18.9	4.8	24	12.15	0.25	178.1	3
77	R2	BH	458579	782688	38.5	9.3	9.9	2.5	3.1	114.7	1.2
78	R3	BH	456798	781725	23.4	5.8	7.3	1.6	5.6	99.1	2.2

79	R4	BH	455114	781945	30.6	7.9	9.6	2.1	6.6	100.1	2.8
80	HR1	BH	456023	781858	86	60.7	41.3	7.2	0	273.4	0
81	HR2	BH	456710	781543	37.8	15.1	12.2	2.7	20.9	212.4	0.9
82	HR3	BH	456773	781458	69.4	36.8	33	3.4	40.2	166	30.8
83	HR4	BH	455712	781786	24.9	12.4	16.1	1.2	0	209.9	0
84	HR6	BH	454711	781550	80.5	36.7	29.6	3.5	28.6	153.8	20.2
85	CSR1	BH	460212	781560	13.5	8.1	12.4	3	8.9	64.7	4.3
86	HSR1	BH	460462	782430	187.2	47.2	7.4	3	20	546.7	1
87	HSR2	BH	460506	782420	312.5	79.4	19.5	5.4	11.1	568.7	6.1
88	HSR3	BH	460610	782391	189.5	49.3	10.8	3.1	20.2	557.7	0.9
89	HSR4	BH	460762	782327	211.2	51.4	11.9	3.4	20.9	432	0.9
90	B1	BH	456179	784352	46.3	12.2	11.9	2.4	10.9	30.5	8.4
91	B2	BH	455971	784264	87.2	14.7	12.1	2.1	20.7	166	20.7
92	B3	BH	455289	784092	96	15.7	14.3	2.6	19.5	234.3	18
93	B4	BH	453805	783652	82.9	15.2	13.2	2.3	15.8	219.7	14.1
94	B5	BH	457024	785768	572.9	42.8	17.7	2.4	138.4	228.2	154
95	HSB1	BH	457392	785972	647.2	46.2	24	2.9	120	1482.8	150
96	HSB2	BH	457324	785907	719	53.4	34.2	3.6	147	1325.4	172.6
97	HSB3	BH	457278	785809	832.8	56.3	33	3.5	112	1325.4	132.8
98	WB	BH	456912	785067	412.2	25.6	31.2	3.3	78.7	997.1	97.3
99	W1	BH	460983	783080	16.9	4.6	9.3	2.6	2.9	657.8	1.7
100	W2	BH	460012	783769	16.5	4.3	8.6	2.5	3.1	117.2	1.8
101	W3	BH	457388	783401	19.3	5.1	8.7	2.5	3.3	146.5	1.7
102	W4	BH	454981	782586	22.1	6.2	10.2	2.7	4.1	153.8	2.1
103	HW1	BH	455671	783106	22.1	7.3	17.2	1.7	14.4	239.2	9.1
104	HW8	BH	456582	783020	28.3	21.1	28.3	6.2	18.6	145.2	19
105	Abaro spring	Spring	461498	783447	14.5	4.6	11.1	4.5	3.1	51	1.5
106	SW20	BH	456768	783051	38.8	17	15	3.7	14.8	142.8	6.5
107	KCS	BH	458941	776541	8.3	2	9.4	1.7	2.7	102.5	1.8
108	KHS	BH	459064	776769	40.1	12.1	5.7	1.3	5.1	168.4	2.4

109	BR	BH	442830	783901	68.7	7.7	10.7	2.4	12.6	191	4.4
110	HA	BH	443703	783077	338.9	17.9	14.5	3.5	64.6	685.9	3.9
111	Aboha	BH	453240	785409	32.7	6.7	10.2	1.7	6.3	133	5.4
112	hot lake	BH	452422	785064	415.1	23.6	2.1	-0.2	25	799.4	5.7
113	J.W & R	BH	454218	781941	25.7	7.2	10.2	2.6	4.8	118.4	3.3
114	G.S gisina spring	Spring	456316	778834	31	15.6	17.4	3.9	17.9	126.9	8.5

Table 7 Secondary Data from defferent sources with grondwater geochemical tracers

FID	Fild_Id	Source_typ	X	Y	EC	Salinity	pH	Fluoride
1	Awassa agri. Res. Center	BH	444223	779650	1380	1794	8	0
2	abela wendo #1	BH	445381	770562	175	227.5	6	0
3	abela wendo #2	BH	445027	770369	181	235.3	6	0
4	abela wendo #3	BH	444996	770976	125	162.5	6	0
5	awassa #1(gemeto)	BH	444574	773563	76	98.8	6	0
6	awassa #2(gemeto)	BH	444086	772115	157	204.1	6	0
7	OBH-816	BH	443296	778694	1033	965.42	7.63	4
8	Awassa Tobacco	BH	444891	775368	1127	1019.67	7.48	4
9	SW-3	BH	446878	783231	399	397	7.99	0
10	TBH-14	BH	445522	777337	1445.469	984.3	8.3	0
11	TDW-6	BH	442202	781675	0	925.1	7.4	10
12	ShiferawHotel	HDW	443037	782240	1428.375	1197.1	8	17
13	Wondo kosha	BH	437578	788926	811	487	8	0
14	Toga Mosque	BH	447033	791288	811	487	8	5
15	MeritZer	BH	443247	787145	1006	604	8	9
16	Chefea Komboyea	BH	446991	782483	760	456	6	2
17	SOS School	BH	442856	781844	1284	456	7	9
18	Wanza Wood factory	BH	442779	781335	1310	456	7	8
19	AwaAgriCollege	BH	441848	779460	1215	456	8	7
20	Oasis Hotel	BH	441401	779904	1228	456	8	6
21	Plasa Hotel	BH	440128	779062	1400	456	8	8
22	Awassa Pepsi	BH	445009	777028	1091	456	8	5
23	Awassa Poultry	BH	443231	775814	118	456	7	0
24	Gemeto	BH	444574	773563	518	456	7	1
25	TabourCeramics	BH	443985	782246	907	456	8	13
26	Awa.Agri.Research	BH	444600	779738	872	456	8	5
27	Agri.Col.Research	BH	444066	779743	792	456	8	4

28	Awassa EWWCA	BH	443874	779764	931	456	9	6
29	AwassaTextile	BH	444530	777465	1025	456	8	4
30	Edol	BH	455612	782890	211	456	7	1
31	Wondo wesha	BH	457255	782872	240	456	7	0
32	Wondogenet	BH	457004	779044	182	456	8	1
33	Busa	BH	454686	775165	254	456	8	1
34	Edol School	BH	452744	772218	613	456	7	1
35	Edol	BH	452000	773211	784	456	8	3
36	Loke Village	BH	440863	774376	1299	456	8	15
37	Central Hotel	BH	441086	778907	1654	456	9	10
38	Yamare Hotel	BH	441823	779103	1438	456	8	8
39	Chefe Kuto Jebsa	BH	446254	779830	1140	456	8	7
40	Total Car Wash	BH	443282	783063	1039	456	8	11
41	Dato	BH	443429	783712	1389	456	9	16
42	Tikurwoha	BH	442601	783759	1558	456	8	7
43	Tikurwoha	BH	442636	785021	1632	456	8	15
44	Medo	BH	455746	788356	264	456	6	0
45	Tutu (Big)	BH	451992	785880	181	456	8	1
46	Wondo G.F.College	BH	460747	784454	135	456	7	0
47	Soyema	BH	456672	781620	234	456	9	1
48	Cheko	BH	458776	781867	212	456	8	1
49	Wondowesha	BH	460084	782090	191	456	7	0
50	Watera-Wondo	BH	457323	780700	275	456	7	0
51	Watera hicho	BH	456608	779956	143	456	7	0
52	Ketanketa	BH	457343	777517	164	456	7	1
53	Wondogenet	BH	458592	776758	208	456	8	1
54	Melga wondo	BH	456186	776054	334	456	7	1
55	Girebe	BH	462037	765283	48	456	6	0
56	Borja	BH	451238	769452	242	456	7	0
57	Abella Wondo	BH	445381	770562	235	456	6	1
58	Gemeto	BH	444676	770823	218	456	7	0
59	Shalo hot spring	Thermal Spring	452526	785341	1964	456	9	28
60	Bela hot spring	Thermal Spring	456965	786018	2826	456	7	8
61	Wondogenet Hot Spr	Thermal Spring	459944	782463	965	456	8	1
62	Soyema Hot Spring	Thermal Spring	460642	781786	903	456	8	1
63	Gerariketa Hot Spr	Thermal Spring	447156	772809	970	456	7	5
64	Gerariketa Hot Spr	Thermal Spring	447189	772574	1708	456	8	10
65	Lake Awassa	Lake	441388	785594	789	456	9	6
66	Wesha Rawwater	River	458869	783694	164	456	8	0
67	Kedo Raw water	River	447540	768999	81	456	7	0
68	Tikurwoha River	River	443820	784270	1313	456	8	22

69	Hawassa	BH	442499	782033	0	456	6.81	0.59
70	HU	BH	444538	779298	0	456	7.85	29
71	Hawassa	BH	441095	776350	0	456	7.6	8
72	Hawassa	BH	443283	781228	0	456	8	8.81
73	Hawssa	BH	443968	772921	0	456	7.7	1.65
74	Tula Subcity	BH	447977	771948	0	456	7.35	0.66
75	Tula Subcity	BH	448528	772643	0	456	7.65	0.71
76	Tula Subcity	BH	449926	770917	0	456	7.35	0.8
77	R2	BH	458579	782688	158	456	6.88	1.11
78	R3	BH	456798	781725	168	456	6.77	1.19
79	R4	BH	455114	781945	172	456	6.69	1.12
80	HR1	BH	456023	781858	185	456	6.95	0.89
81	HR2	BH	456710	781543	759	456	6.95	0.89
82	HR3	BH	456773	781458	1009	456	6.8	1.13
83	HR4	BH	455712	781786	357	456	6.53	1.09
84	HR6	BH	454711	781550	981	456	6.76	1.17
85	CSR1	BH	460212	781560	208	456	6.56	1.15
86	HSR1	BH	460462	782430	956	456	8.16	1.12
87	HSR2	BH	460506	782420	952	456	7.89	1.18
88	HSR3	BH	460610	782391	935	456	7.95	1.13
89	HSR4	BH	460762	782327	960	456	7.64	0.03
90	B1	BH	456179	784352	197	456	5.77	1.16
91	B2	BH	455971	784264	386	456	6.55	0.95
92	B3	BH	455289	784092	537	456	6.88	0.96
93	B4	BH	453805	783652	537	456	6.9	1
94	B5	BH	457024	785768	474	456	6.94	0.97
95	HSB1	BH	457392	785972	2310	456	7.11	0.06
96	HSB2	BH	457324	785907	2402	456	7.61	0.44
97	HSB3	BH	457278	785809	2330	456	7.61	0.44
98	WB	BH	456912	785067	2135	456	6.28	0.91
99	W1	BH	460983	783080	2641	456	8.07	1.12
100	W2	BH	460012	783769	200	456	7	1.21
101	W3	BH	457388	783401	263	456	6.91	1.11
102	W4	BH	454981	782586	265	456	6.84	1.13
103	HW1	BH	455671	783106	876	456	6.86	0.76
104	HW8	BH	456582	783020	331	456	6.97	1.12
105	Abaro spring	Spring	461498	783447	181	456	7.31	0.04
106	SW20	BH	456768	783051	378	456	6.57	1.08
107	KCS	BH	458941	776541	102.51	456	6.88	0.1
108	KHS	BH	459064	776769	168.41	456	6.77	0.02
109	BR	BH	442830	783901	290	456	7.1	1.03

110	HA	BH	443703	783077	417	456	7.17	1.16
111	Aboha	BH	453240	785409	252	456	7.61	1.11
112	hot lake	BH	452422	785064	1678	456	7.2	1.14
113	J.W & R	BH	454218	781941	185	456	6.63	1.15
114	G.S gisina spring	Spring	456316	778834	336	456	6.26	1.08

Table 8 Secondary Data from defferent sources with grond geochemical tracers

FID	Fild_Id	Source_typ	X	Y	EL	EC	Salinity	pH	T	Rn222
1	WRKRS2	river	458579	782688	0	204	265.2	8.18	26	2.81
2	station3	river	460381	782535	0	166	215.8	7.95	20	5.2
3	station6	river	454769	781837	0	225	292.5	7.74	18.4	0
4	sample3	river	456798	781725	0	218	283.4	7.36	21.7	0
5	BGHDW1	HDW	443444	784844	0	1223	1589.9	7.69	27	0
6	BGHDW2	HDW	443408	784831	0	1239	1610.7	7.73	28	0
7	BGHDW3	HDW	443178	785016	0	1270	1651	7.75	28.5	0
8	BGHDW4	HDW	443153	786403	0	1220	1586	7.77	29	0
9	BGHDW5	HDW	443851	786603	0	1289	1675.7	7.79	29	0
10	BGHDW6	HDW	442719	784290	0	1095	1423.5	7.35	27	0
11	BGHDW7	HDW	442994	785168	0	1179	1532.7	7.59	26	0
12	AWASA HD	HDW	443707	783077	0	1321	1717.3	7.79	29	0
13	WRHDW2	HDW	456710	781543	0	304	395.2	6.6	19.5	0
14	WRHDW3	HDW	456773	781458	0	848	1102.4	6.7	19.7	0
15	WRHDW5	HDW	454972	781406	0	1799	2338.7	7.04	21.5	0
16	WRHDW6	HDW	454711	781550	0	769	999.7	6.99	19.4	0
17	WSHDW1	HDW	455671	783106	0	378	491.4	6.19	20.4	0
18	WSHDW2	HDW	455715	783082	0	420	546	6.48	20	0
19	WSHDW5	HDW	455910	783169	0	308	400.4	6.86	24.5	0
20	WSHDW7	HDW	456129	783027	0	269	349.7	6.9	22	0
21	WGC001	HDW	451987	767087	0	2020	2626	8.6	21	0
22	WGC002	HDW	451860	767159	0	646	839.8	8.9	21	0
23	WGC004	Spring	448452	765879	0	168	218.4	8.3	24.6	0
24	WGC005	HDW	445156	772214	0	876	1138.8	8.5	25.2	0
25	WGC006	HDW	445237	772325	0	579	752.7	8.3	25.1	0
26	WGC007	HDW	446669	782192	0	1535	1995.5	8.3	26.1	0
27	WGC008	HDW	445761	773460	0	1180	1534	8.5	25.5	0
28	WGC009	HDW	442923	783794	0	1268	1648.4	8.9	27.4	0
29	WGC010	HDW	463003	775932	0	195	253.5	9	26.5	0
30	WGC011	Spring	460327	780959	0	176	228.8	8.5	24.3	0
31	WGC012	Spring	460441	774945	0	180	234	9.1	27.1	0

32	WGC013	Spring	450045	771964	0	1171	1522.3	8.5	25.1	0
33	WGC014	HDW	442182	784986	0	1995	2593.5	9.4	25.1	0
34	WGC015	HDW	442693	784384	0	2558	3325.4	8.7	25.2	0
35	WGC016	HDW	464058	784255	0	93	120.9	9.3	26.6	0
36	WGC018	HDW	452788	777365	0	750	975	8.5	23.3	0
37	WGC019	HDW	449500	770360	0	823	1069.9	9.2	25.3	0
38	WGC020	Spring	468828	776680	0	136	176.8	8.7	23.2	0
39	WGC022	HDW	465168	772202	0	150	195	8.9	24.1	0
40	WGC023	HDW	465333	772178	0	126	163.8	8.9	23.9	0
41	WGC024	HDW	465081	773962	0	147	191.1	8.4	24.5	0
42	WGC025	HDW	465058	773823	0	139	180.7	8.5	23.8	0
43	WGC026	HDW	461175	769006	0	208	270.4	8.5	24.5	0
44	WGC027	HDW	459951	768092	0	91	118.3	8.2	23.8	0
45	WGC028	HDW	463504	767393	0	98	127.4	9.3	23.7	0
46	WGC029	HDW	463477	767469	0	72	93.6	8.5	23.5	0
47	WGC030	HDW	465295	764429	0	88	114.4	8.9	22.1	0
48	WGC031	HDW	463182	761459	0	362	470.6	9.2	22.5	0
49	WGC032	HDW	463185	761487	0	110	143	8.8	22.1	0
50	WGC033	HDW	463171	761282	0	65	84.5	8.9	21.8	0
51	WGC036	HDW	465168	764426	0	643	835.9	7.8	22.7	0
52	WGC037	HDW	465264	763987	0	122	158.6	8.3	24.5	0
53	WGC038	HDW	465295	763985	0	79	102.7	8.9	24.3	0
54	WGC039	HDW	462722	764991	0	96	124.8	8.7	24.2	0
55	WGC040	HDW	462760	764946	0	101	131.3	8.8	16.9	0
56	WGC041	HDW	459704	765198	0	69	89.7	8.9	23.7	0
57	WGC043	HDW	451206	765666	0	184	239.2	7.4	24.2	0
58	WGC044	HDW	450587	764948	0	184	239.2	8.5	24.2	0
59	WGC045	HDW	451296	764900	0	158	205.4	8.1	24.8	0
60	WGC046	HDW	450993	764978	0	555	721.5	7.7	22.7	0
61	WGC047	HDW	450627	767634	0	332	431.6	8.3	23.8	0
62	WGC049	HDW	452067	767449	0	356	462.8	8.7	22.4	0
63	WGC050	HDW	451788	767019	0	874	1136.2	8.4	23.2	0
64	WGC052	BH	439500	772100	0	1633	2122.9	8	0	0
65	WGC053	BH	445692	770852	0	389	505.7	7	28	0
66	WGC054	BH	446490	771490	0	400	520	7	23	0
67	WGC055	BH	447560	769845	0	322	418.6	7	0	0
68	WGC056	BH	451697	766560	0	256	332.8	6	25	0
69	WGC057	BH	441459	770953	0	285	370.5	7	26	0
70	WGC058	BH	447592	768985	0	178	231.4	7	24	0
71	WGC062	BH	444867	775396	0	1076	1398.8	7	24.5	0
72	WGC064	BH	445009	777028	0	1095	1423.5	8.34	0	0

73	WGC065	BH	445540	777450	0	1120	1456	7.79	0	0
74	WGC068	Spring	460747	784454	0	135	175.5	7	18	0
75	WGC069	Spring	455285	775356	0	315	409.5	6.55	21.1	0
76	WGC070	Spring	458592	776758	0	208	270.4	6	23	0
77	WGC071	Spring	451283	769680	0	242	314.6	7	23	0
78	WGC072	Spring	458823	774168	0	274	356.2	6.85	22.6	0
79	WWP1	HDW	432384	780275	0	1748	2272.4	8.26	25.2	0
80	WWP2	HDW	438934	787117	0	1748	2272.4	8.26	25.2	0
81	WWP5	HDW	432385	781052	0	1938	2519.4	8.24	25	0
82	WWP7	HDW	432061	777852	0	1532	1991.6	7.45	22.4	0
83	WWP8	Spring	459961	773952	0	111.3	144.69	5.8	16.9	0
84	WWP9	HDW	460748	774111	0	135.2	175.76	5.75	18.2	0
85	WWP10	BH	463520	773190	0	110	143	6.12	20	0
86	WWP11	BH	467312	773272	0	85	110.5	6.03	20.2	0
87	WWP13	HDW	467140	772886	0	155	201.5	6.02	17.1	0
88	WWP16	HDW	465379	772646	0	129	167.7	6.25	17.3	0
89	WWP19	BH	452475	772170	0	304	395.2	6.41	22.1	0
90	WWP20	HDW	450360	771469	0	620	806	6.91	21	0
91	WWP21	BH	449385	771860	0	1081	1405.3	7.63	19.8	0
92	WWP22	BH	448923	770415	0	295	383.5	7.15	22.5	0
93	WWP24	Spring	451277	769679	0	254	330.2	6.3	22.6	0
94	WWP25	Spring	451157	770264	0	300	390	6.74	23	0
95	WWP26	river	452279	770335	0	174.4	226.72	7.87	20.6	0
96	WWP27	Spring	452848	770145	0	321	417.3	6.73	25	0
97	WWP28	river	452891	771245	0	117.5	152.75	7.49	21.4	0
98	WWP29	HDW	453381	772246	0	313	406.9	6.65	23.2	0
99	WWP30	BH	453502	772956	0	501	651.3	6.52	24.6	0
100	WWP31	Spring	456042	771830	0	224	291.2	6.59	25.4	0
101	WWP33	BH	457773	781946	0	285	370.5	6.67	24.6	0
102	WWP34	Spring	457797	782335	0	288	374.4	6.38	22.2	0
103	WWP35	river	457797	782335	0	241	313.3	7.34	20.4	0
104	WWP36	river	457585	783338	0	163	211.9	7.91	21.3	0
105	WWP37	HDW	457369	782900	0	284	369.2	6.2	21.1	0
106	WWP38	Spring	457272	780864	0	163.4	212.42	7.09	19.3	0
107	WWP39	BH	457187	779743	0	163.4	212.42	7.09	19.3	0
108	WWP40	HDW	444022	777422	0	1055	1371.5	7.9	23.4	0
109	WWP41	HDW	443324	774879	0	1296	1684.8	7.7	30.3	0
110	WWP42	Lake	441175	779863	0	870	1131	8.75	23	0
111	WWP43	BH	444458	772921	0	1097	1426.1	6.89	31.7	0
112	WWP46	BH	445713	770846	0	395	513.5	7.38	23.9	0
113	WWP47	BH	445730	770874	0	287	373.1	6.5	28	0

114	WWP48	Spring	458875	776585	0	170	221	6.5	21.3	0
115	WWP51	BH	449243	772013	0	385	500.5	7.93	27.2	0
116	WWP52	river	454179	774433	0	151.1	196.43	8.1	19.9	0
117	WWP53	HDW	455724	783092	0	4440	5772	6.51	23.8	0
118	WWP56	Spring	452660	785552	0	1761	2289.3	7.73	82	0
119	WWP55	Spring	439887	778410	0	223	289.9	6.38	31.9	0
120	WWP59	HDW	442711	784287	0	843	1095.9	7.05	20.2	0
121	WWP60	Lake	442530	783888	0	612	795.6	7	23	0
122	WWP61	HDW	446435	778366	0	1182	1536.6	7.42	22.6	0
123	WWP62	HDW	446374	778550	0	2020	2626	7.38	22.7	0
124	WWP63	HDW	446664	780209	0	2930	3809	7.55	22.2	0
125	WWP64	HDW	446261	781983	0	2370	3081	7.05	30.7	0
126	WWP65	BH	449827	789222	0	315	409.5	7.4	30.7	0
127	WWP67	HDW	464351	775184	0	246	319.8	6.61	20.9	0
128	WWP68	Spring	463687	778173	0	196	254.8	5.8	18	0
129	WWP71	Spring	460005	782755	0	950	1235	8.85	42	0
130	WWP72	HDW	457302	782546	0	360	468	6.39	20.9	0
131	WWP75	Spring	436987	772131	0	274	356.2	6.81	26.6	0
132	WWP76	Lake	439450	772585	0	875	1137.5	8.21	25.1	0
133	WGC042	Spring	456357	764292	0	131	170.3	8.2	23.2	0
134	WGC048	Spring	454077	768571	0	139	180.7	8.7	24.1	0
135	WGC061	BH	456003	775232	0	320	416	7	21.5	0

Table 9 Secondary Data from defferent sources with ground geochemical tracers

FID	Fild_Id	Source_typ	X	Y	EC	Salinity	pH	T
1	WRKRS2	River	458579	782688	204	265.2	8.18	26
2	station3	River	460381	782535	166	215.8	7.95	20
3	station6	River	454769	781837	225	292.5	7.74	18.4
4	sample3	River	456798	781725	218	283.4	7.36	21.7
5	BGHDW1	HDW	443444	784844	1223	1589.9	7.69	27
6	BGHDW2	HDW	443408	784831	1239	1610.7	7.73	28
7	BGHDW3	HDW	443178	785016	1270	1651	7.75	28.5
8	BGHDW4	HDW	443153	786403	1220	1586	7.77	29
9	BGHDW5	HDW	443851	786603	1289	1675.7	7.79	29
10	BGHDW6	HDW	442719	784290	1095	1423.5	7.35	27
11	BGHDW7	HDW	442994	785168	1179	1532.7	7.59	26
12	AWASA HD	HDW	443707	783077	1321	1717.3	7.79	29
13	WRHDW2	HDW	456710	781543	304	395.2	6.6	19.5
14	WRHDW3	HDW	456773	781458	848	1102.4	6.7	19.7

15	WRHDW5	HDW	454972	781406	1799	2338.7	7.04	21.5
16	WRHDW6	HDW	454711	781550	769	999.7	6.99	19.4
17	WSHDW1	HDW	455671	783106	378	491.4	6.19	20.4
18	WSHDW2	HDW	455715	783082	420	546	6.48	20
19	WSHDW5	HDW	455910	783169	308	400.4	6.86	24.5
20	WSHDW7	HDW	456129	783027	269	349.7	6.9	22
21	WGC001	HDW	451987	767087	2020	2626	8.6	21
22	WGC002	HDW	451860	767159	646	839.8	8.9	21
23	WGC004	Spring	448452	765879	168	218.4	8.3	24.6
24	WGC005	HDW	445156	772214	876	1138.8	8.5	25.2
25	WGC006	HDW	445237	772325	579	752.7	8.3	25.1
26	WGC007	HDW	446669	782192	1535	1995.5	8.3	26.1
27	WGC008	HDW	445761	773460	1180	1534	8.5	25.5
28	WGC009	HDW	442923	783794	1268	1648.4	8.9	27.4
29	WGC010	HDW	463003	775932	195	253.5	9	26.5
30	WGC011	Spring	460327	780959	176	228.8	8.5	24.3
31	WGC012	Spring	460441	774945	180	234	9.1	27.1
32	WGC013	Spring	450045	771964	1171	1522.3	8.5	25.1
33	WGC014	HDW	442182	784986	1995	2593.5	9.4	25.1
34	WGC015	HDW	442693	784384	2558	3325.4	8.7	25.2
35	WGC016	HDW	464058	784255	93	120.9	9.3	26.6
36	WGC018	HDW	452788	777365	750	975	8.5	23.3
37	WGC019	HDW	449500	770360	823	1069.9	9.2	25.3
38	WGC020	Spring	468828	776680	136	176.8	8.7	23.2
39	WGC022	HDW	465168	772202	150	195	8.9	24.1
40	WGC023	HDW	465333	772178	126	163.8	8.9	23.9
41	WGC024	HDW	465081	773962	147	191.1	8.4	24.5
42	WGC025	HDW	465058	773823	139	180.7	8.5	23.8
43	WGC026	HDW	461175	769006	208	270.4	8.5	24.5
44	WGC027	HDW	459951	768092	91	118.3	8.2	23.8
45	WGC028	HDW	463504	767393	98	127.4	9.3	23.7
46	WGC029	HDW	463477	767469	72	93.6	8.5	23.5
47	WGC030	HDW	465295	764429	88	114.4	8.9	22.1
48	WGC031	HDW	463182	761459	362	470.6	9.2	22.5
49	WGC032	HDW	463185	761487	110	143	8.8	22.1
50	WGC033	HDW	463171	761282	65	84.5	8.9	21.8
51	WGC036	HDW	465168	764426	643	835.9	7.8	22.7
52	WGC037	HDW	465264	763987	122	158.6	8.3	24.5
53	WGC038	HDW	465295	763985	79	102.7	8.9	24.3
54	WGC039	HDW	462722	764991	96	124.8	8.7	24.2
55	WGC040	HDW	462760	764946	101	131.3	8.8	16.9

56	WGC041	HDW	459704	765198	69	89.7	8.9	23.7
57	WGC043	HDW	451206	765666	184	239.2	7.4	24.2
58	WGC044	HDW	450587	764948	184	239.2	8.5	24.2
59	WGC045	HDW	451296	764900	158	205.4	8.1	24.8
60	WGC046	HDW	450993	764978	555	721.5	7.7	22.7
61	WGC047	HDW	450627	767634	332	431.6	8.3	23.8
62	WGC049	HDW	452067	767449	356	462.8	8.7	22.4
63	WGC050	HDW	451788	767019	874	1136.2	8.4	23.2
64	WGC052	BH	439500	772100	1633	2122.9	8	0
65	WGC053	BH	445692	770852	389	505.7	7	28
66	WGC054	BH	446490	771490	400	520	7	23
67	WGC055	BH	447560	769845	322	418.6	7	0
68	WGC056	BH	451697	766560	256	332.8	6	25
69	WGC057	BH	441459	770953	285	370.5	7	26
70	WGC058	BH	447592	768985	178	231.4	7	24
71	WGC062	BH	444867	775396	1076	1398.8	7	24.5
72	WGC064	BH	445009	777028	1095	1423.5	8.34	0
73	WGC065	BH	445540	777450	1120	1456	7.79	0
74	WGC068	Spring	460747	784454	135	175.5	7	18
75	WGC069	Spring	455285	775356	315	409.5	6.55	21.1
76	WGC070	Spring	458592	776758	208	270.4	6	23
77	WGC071	Spring	451283	769680	242	314.6	7	23
78	WGC072	Spring	458823	774168	274	356.2	6.85	22.6
79	WWP1	HDW	432384	780275	1748	2272.4	8.26	25.2
80	WWP2	HDW	438934	787117	1748	2272.4	8.26	25.2
81	WWP5	HDW	432385	781052	1938	2519.4	8.24	25
82	WWP7	HDW	432061	777852	1532	1991.6	7.45	22.4
83	WWP8	Spring	459961	773952	111.3	144.69	5.8	16.9
84	WWP9	HDW	460748	774111	135.2	175.76	5.75	18.2
85	WWP10	BH	463520	773190	110	143	6.12	20
86	WWP11	BH	467312	773272	85	110.5	6.03	20.2
87	WWP13	HDW	467140	772886	155	201.5	6.02	17.1
88	WWP16	HDW	465379	772646	129	167.7	6.25	17.3
89	WWP19	BH	452475	772170	304	395.2	6.41	22.1
90	WWP20	HDW	450360	771469	620	806	6.91	21
91	WWP21	BH	449385	771860	1081	1405.3	7.63	19.8
92	WWP22	BH	448923	770415	295	383.5	7.15	22.5
93	WWP24	Spring	451277	769679	254	330.2	6.3	22.6
94	WWP25	Spring	451157	770264	300	390	6.74	23
95	WWP26	River	452279	770335	174.4	226.72	7.87	20.6
96	WWP27	Spring	452848	770145	321	417.3	6.73	25

97	WWP28	River	452891	771245	117.5	152.75	7.49	21.4
98	WWP29	HDW	453381	772246	313	406.9	6.65	23.2
99	WWP30	BH	453502	772956	501	651.3	6.52	24.6
100	WWP31	Spring	456042	771830	224	291.2	6.59	25.4
101	WWP33	BH	457773	781946	285	370.5	6.67	24.6
102	WWP34	Spring	457797	782335	288	374.4	6.38	22.2
103	WWP35	River	457797	782335	241	313.3	7.34	20.4
104	WWP36	River	457585	783338	163	211.9	7.91	21.3
105	WWP37	HDW	457369	782900	284	369.2	6.2	21.1
106	WWP38	Spring	457272	780864	163.4	212.42	7.09	19.3
107	WWP39	BH	457187	779743	163.4	212.42	7.09	19.3
108	WWP40	HDW	444022	777422	1055	1371.5	7.9	23.4
109	WWP41	HDW	443324	774879	1296	1684.8	7.7	30.3
110	WWP42	Lake	441175	779863	870	1131	8.75	23
111	WWP43	BH	444458	772921	1097	1426.1	6.89	31.7
112	WWP46	BH	445713	770846	395	513.5	7.38	23.9
113	WWP47	BH	445730	770874	287	373.1	6.5	28
114	WWP48	Spring	458875	776585	170	221	6.5	21.3
115	WWP51	BH	449243	772013	385	500.5	7.93	27.2
116	WWP52	River	454179	774433	151.1	196.43	8.1	19.9
117	WWP53	HDW	455724	783092	4440	5772	6.51	23.8
118	WWP56	Spring	452660	785552	1761	2289.3	7.73	82
119	WWP55	Spring	439887	778410	223	289.9	6.38	31.9
120	WWP59	HDW	442711	784287	843	1095.9	7.05	20.2
121	WWP60	Lake	442530	783888	612	795.6	7	23
122	WWP61	HDW	446435	778366	1182	1536.6	7.42	22.6
123	WWP62	HDW	446374	778550	2020	2626	7.38	22.7
124	WWP63	HDW	446664	780209	2930	3809	7.55	22.2
125	WWP64	HDW	446261	781983	2370	3081	7.05	30.7
126	WWP65	BH	449827	789222	315	409.5	7.4	30.7
127	WWP67	HDW	464351	775184	246	319.8	6.61	20.9
128	WWP68	Spring	463687	778173	196	254.8	5.8	18
129	WWP71	Spring	460005	782755	950	1235	8.85	42
130	WWP72	HDW	457302	782546	360	468	6.39	20.9
131	WWP75	Spring	436987	772131	274	356.2	6.81	26.6
132	WWP76	Lake	439450	772585	875	1137.5	8.21	25.1
133	WGC042	Spring	456357	764292	131	170.3	8.2	23.2
134	WGC048	Spring	454077	768571	139	180.7	8.7	24.1
135	WGC061	BH	456003	775232	320	416	7	21.5