Addis Ababa University
School of Graduate studies
Faculty of science

Groundwater Dynamics in Tributary Streams of Muger and Holota River Catchments

A Thesis Submitted to School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the requirements for Degree of Master of Science in Hydrogeology

By:

Kidist Hailu

Advisor:

Tilahun Azagegn, PhD

June, 2016
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Acknowledgement

Before all, I would like to praise God who made possible for me to begin and finish my education.

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My heartfelt thanks go to my beloved family because of their advice and support I am here today and my deepest love shall be to my husband (Yordanos) and my sons (Leul and Maraki).

Abstract

Integrated hydogeological study using major ion hydrogeochemistry and environmental isotope tools were employed to characterize groundwater dynamics in tributary streams of Muger River Catchments in the north and Holota River Catchments in the south. Hydrogeochemical study reveals that water types vary from early stage of geochemical evolution (CaHCO3 type) to the highest level of geochemical evolution (NaHCO3) and from low TDS to high TDS and $NaHCO_3$ type are observed only in the downstream part of Holota River catchment. In relation to stable isotopes, highly enriched groundwater from deep wells were also observed in the downstream part of Holota River catchment. Radon concentration has been observed in the main Holota River and low in tributary streams. However, Radon concentration is low in main Muger River but high in its tributary streams that flow through acidic rock units. The stable isotopes signature of the deep aquifer in Holota River catchment illustrates that, the groundwater is recharged through long subsurface path relative to the deep aquifers found in Tributary streams of Muger River catchment. Radon signature shows that main Holota River is recharged from the groundwater at some segments whereas it is not the case for Muger River. And finally, groundwater level map together with isotopic signature show that groundwater divide shifts from surface water divide towards Muger River catchment and the groundwater flow converges towards Holota River flow direction.

Key Words: Groundwater dynamics, Muger River, Holota River, Stable isotopes, Radon

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Acronyms

Bq/m3	Becquerels per cubic meter
Ca	Calcium
DEM	Digital Elevation Model
EC	Electrical Conductivity
EW	East West
GMWL	Global Meteoric Water Line
GNIP	Global Networking of Isotopes in Precipitation
GPS:	Global positioning system
IAEA	International Atomic Energy Agency
LMWL	Local Meteoric Water line
m.a.s.l	Meter above sea level
Na	Sodium
NE	North East
M	Meter
Ra	Radium
Rn	Radon
SE	South East
SWL:	Static Water Level
TDS:	Total Dissolved Solids
VSMOW	Viena Standard Mean Oceanic Water
WWDSE:	Water Works Design and Supervision Enterprise

Chapter 1- Introduction

1.1 Back Ground

Though two-third of our world is covered by water, freshwater is not more than 2.7%. Out of this, more than 77% occurs in the form of ices capes & glacier which is not suitable for domestic consumption while the rest occurs in the form of surface water and groundwater (Fetter, 1994).

Groundwater is a vital resource in steadily increasing demand by human. In history of water use in the country in general in Addis Ababa in particular, groundwater is one of the major resource supplies for domestic, industrial and agricultural consumption. In the suburbs of Addis Ababa; Urbanization, major industries, horticulture-floriculture and animal husbandries are extensively established and demand huge amount of water. Due to this reason, most of the above mentioned industries and agricultures have their own boreholes.

The lithological parameter is one of several parameters that control groundwater quality. Other factors include evaporation at the surface prior to infiltration, transpiration and wash-down of sea spray. Water moves underground, and its salt or mineral content is determined by all soil and rock types it passes through.

Hydrogeochemistry and environmental isotope study were used to investigate groundwater flow system, surface water ground water interaction and to estimate the groundwater residence time. Isotope methods when introduced in to catchment hydrology is a complementary tool to conventional hydrologic methods for addressing questions of where water goes when it rains, what pathways it takes to the stream and how long water resides in the catchment.

Chemical composition of water samples collected from surface water and groundwater is valuable in identification of mixing, sources, groundwater flow path and the similarity and difference of subsurface waters.

Inter-basin groundwater transfer between Abay River Basin and Awash River Basin was very crucial issue and different professional researchers have been undertaking several researches and investigations. Although, different researchers quantify the amount of groundwater coming from Abay River Basin towards Awash River Basin is extremely variable. The mean annual recharge of the Ada'a-Becho aquifers system is estimated to be 687 Mm^3 with 70% of recharge contributed by Upper Abay River Basin (WWDSE, 2008), A regional groundwater flow model for the Upper Awash groundwater basin gives a total volumetric annual inflow of nearly 590Mm^3 into the system of the Upper Awash groundwater basin. Out of the total recharge to the Upper Awash groundwater basin, nearly 26% (153Mm^3) is an inflow from the Blue Nile basin through horizontal exchange (Tilahun Azagegn, 2015). The annual out flow from Abay River Basin towards Upper Awash River Basin is 25Mm^3 (M. Rhazac, 2015).

This research will give detail understanding on the previous researches which were done on the inter-basin groundwater transfer between Abay Basin and Awash basin by using hydrogeochemistry and isotopic evidence with large scale investigation. (Tributary streams of Muger River Catchment and Holota River Catchment).

The investigation will be approached through the integrated work of hydrogeochemistry and environmental isotope evidences by weekly and spatial monitoring of groundwater and surface water in the study area.

1.2 Statement of the Problem

Several researches have been carried out by different researchers about inter-basin ground water flow between the Abay River basin and Awash River basin. some address ground water flow direction in the upper Awash River Basin coincide with surface water flow path whereas, some researches point out that there is an inter basin groundwater flow from Abay River basin towards Awash River basin. It is for this reason that, this work has been carried out between Abay River basin and Awash River basin with large scale investigation by taking the catchments, tributary streams of Muger River Catchment from Abay River Basin and Holota River Catchment from Awash River Basin using geochemical (major ions) and environmental approaches.

1.3 Description of the Area

1.3.1. General

The study area is fall in part of Abay River basin and in part of Upper Awash River basin and found from 40km up to 100 kms radius from Addis Ababa to Holota River Catchment and Tributary streams of Muger River Catchment respectively. The study area confined within an approximate coordinate of 432518-466751UTME and 985925-1047929UTMN and covers total area of 1080 km^2, out of which about 553km^2 falls in Abay River Basin (Tributary streams of Mugger river catchment) and the remaining 527 km^2 falls in upper Awash River Basin (Holota River Catchment).

According to 20 years record of data collected from National Metrological agency, the mean annual rainfall in the study area is 986.13 mm. The annual maximum and minimum precipitation during this period varies from 1661.98 mm to 641.81 mm. The rainfall pattern in the study area generally is bi-modal nature with high rainfall in July and in August. Minimum and maximum monthly temperature of the study area varies from 15.26 ^{o}C in April to 18.07 ^{o}C in December.

The topography of the study area is varied. Based on the map developed from DEM (Digital Elevation Model) the area has an overall elevation difference that ranges between 1500 m.a.s.l up to 3300 m.a.s.l. The topography of tributary streams of Muger River Catchment has rolling topography and the elevation difference ranges between 1500 m.a.s.l up to 3234 m.a.s.l, whereas Holota River Catchment of the study area has almost flat topography except the high elevation of Wochecha mountain, the elevation difference ranges between 2052 m.a.s.l up to 3300 m.a.s.l.

Drainage pattern depends on the topography and geology of the study area. Both river catchments have dendritic drainage pattern. In Holota River catchment there are different contributing streams join together in to Holota River and then flows towards the main river Awash. In another side, different tributary streams join Muger River then flows towards the main River Abay.

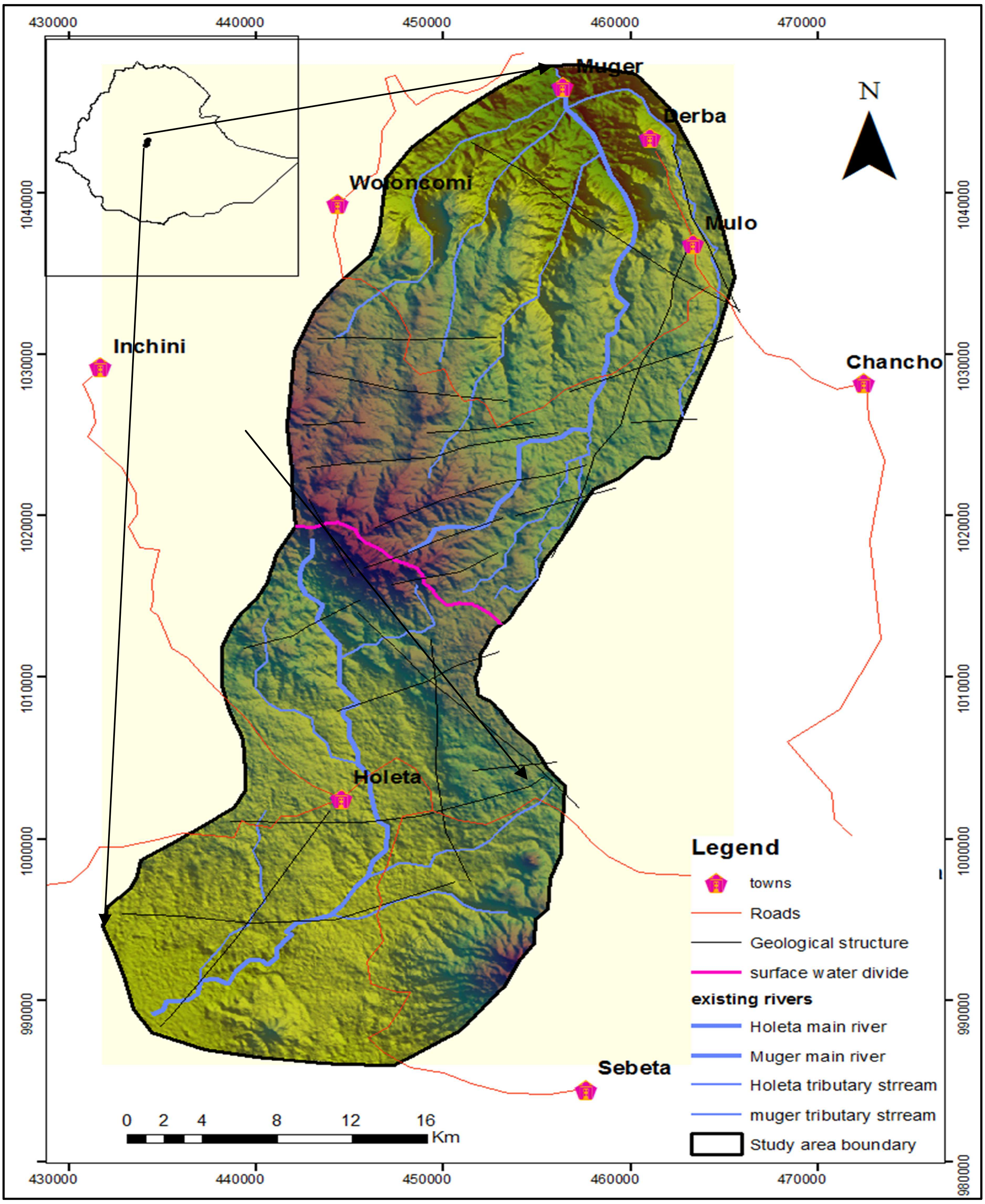

Figure 1: Location map of the study area

1.3.2 Geology

According to WWDSE, 2008, various geological units ranging from Mesozoic sedimentary succession and Tertiary age groups of acidic and basic volcanic rocks are described. The main rock units in tributary streams of Muger River Catchment are consists of Ambaradam sandstones which is in the age of Mesozoic sedimentary rock, Blue Nile basalt, Amba aiba basalt, Alaji rhyolite and tarmabner basalt which has the age of teritiary volcanic rock. Whereas, Holota River Catchment consists of central volcanoes unit of trachyte and rhyolite, Addis Ababa ignimbrite and Tarmaber basalt which are in the age of teriatiary volcanic rock. Brief descriptions of geologic units in the study area are described below from oldest to youngest;

Amba Aradam Sandstone

The Amba Aradam sandstone is widely known as upper sandstone is outcropped in the northern part of the study area within the tributary streams of Muger river catchment and conformably overlying the Antalo limestone. It is consisting of shale and marl at the bottom and quart sand stone at the top. The sandstone is grayish to pinkish white in color and fine to coarse grained in texture. The age of the Amba Aradam sandstone is probably of Late Cretaceous and represents a regressive facies of Cretaceous sea (Kazmin, 1975).

Blue Nile Basalt

This unit is thick basaltic flows and outcrops in the Northern part of tributary streams of mugger river catchment. It is alkaline basalt with columnar joints of wider spacing forming vertical cliff. In hand specimen it is massive and dark in color. According to Kazmin (1975), the age of this unit is Paleocene-Oligocene (69-23 Ma).

Amba Aiba Basalt

This unit is exposed overlying the Blue Nile Basalt in part of tributary streams of mugger river catchment. It is flood basalts in thick flow with closely spaced columnar joint. In hand specimen it is aphanitic in texture and dark grey color. The age of this unit is Oligocene-Miocene (36-18 Ma).

Alaji Rhyolite

This unit is exposed in part of tributary streams of mugger river catchment. It is consisting of rhyolites, ignimbrites and subordinate trachytes. Obsidian bearing rhyolites are common in the project area. It is grayish to pinkish brown in color. The obsidian composition at Segnogebeya area gives rise to the dark gray color. The age of this rock unit is Miocene, 33-15Ma (Kazmin, 1979).

Tarma Ber Basalt

The Tarma Ber Basalt which is the dominant unit exposed in central part of the study area (in both Tributary streams of Muger River catchment and Holota River catchment). It is consisting of mainly scoraceous lava flows and at places it is columnar olivine bearing basalt as pockets within the scoraceous components. It is highly weathered, fractured and pinkish to grayish in color. The age of this unit is Miocene, 27-5Ma.

Addis Ababa Ignimbrite

This Ignimbrite is outcropped in the South western part of Holota River catchment. It is composed of welded tuff (ignimbrite) and non welded pyroclastics fall (Ash and tuff). It is grayish to white color and when welded it exhibits fiamme textures, elongated rock fragments of various color. The age of this unit is 5.11-3.26 Ma (Morton et al 1979).

Trachyte

The Central Volcanoes units are mainly trachytic lavas exposed at Wochecha, Southeastern part of the study area (in Holeta river catchment) forming an elevated ridges or mountain picks. It is grayish color fine to medium grained trachyte with subordinate ash falls and ignimbrite. The age of this unit is 4.6-3.7 Ma (Chernet et al 1998).

Rhyolites

The central volcano unit of rhyolite is exposed in the northern part of the study area (in Holota River catchment). In fresh hand specimen it is grayish pink and reddish brown to yellowish grey color when weathered. Data on the ages of the rhyolites are not available; however from the cross-cutting relationship they can be younger than the adjacent ignimbrite.

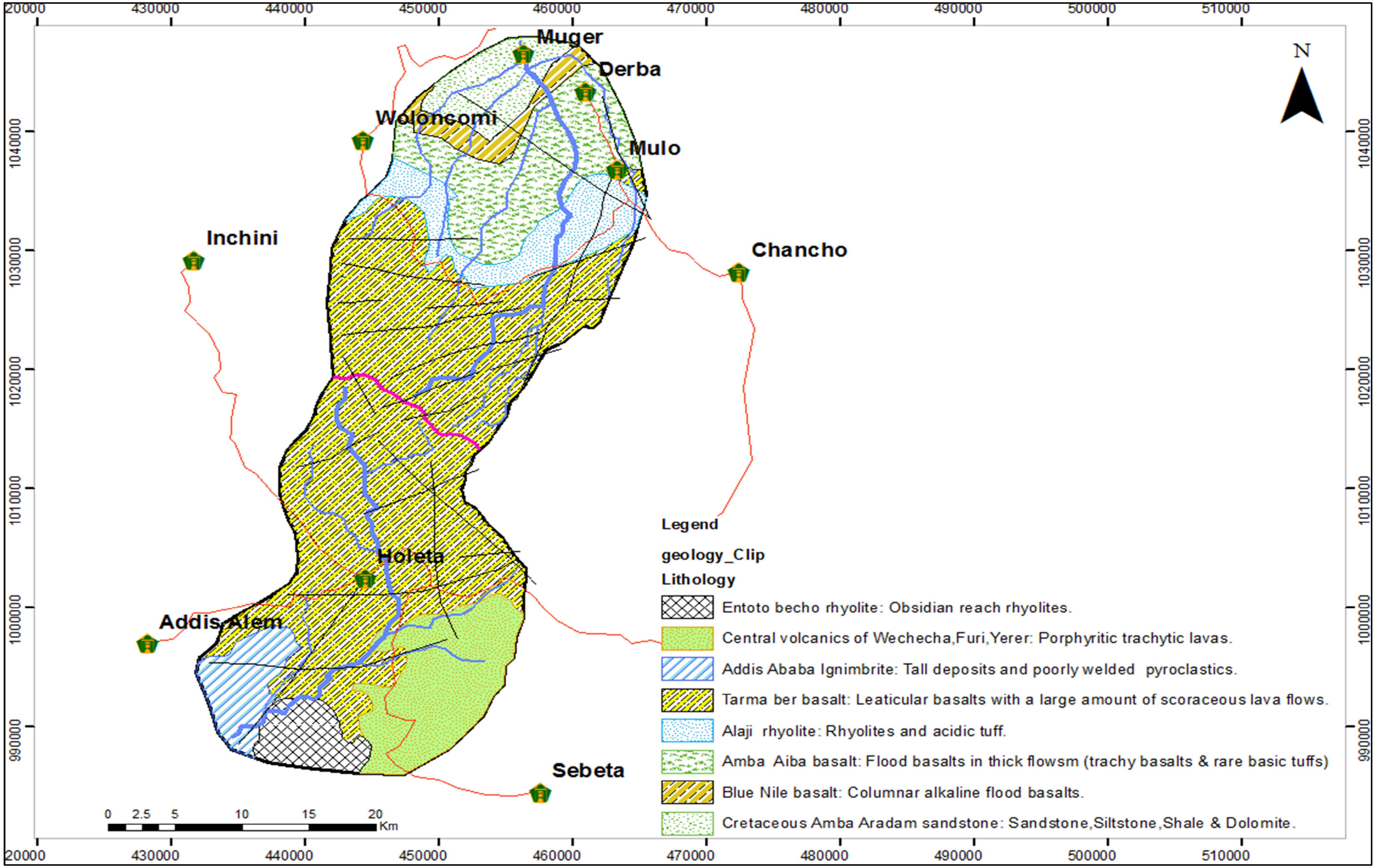

Figure 2: Geological map of the study area (Source: WWDSE, 2008)

1.3.3 Hydrogeology

According to Tilahun Azagegn, 2015, various regional aquifer units and groundwater flow barriers have been identified in the study area and describes below:

Upper Coarse grained Sandstone aquifer

This aquifer unit is found in the northern part of tributary streams of Muger River catchment. It dominantly composed of cemented, coarse grained sand and layers of conglomerates, with thin lenses of mudstone and shale. The sandstones and conglomerates have high primary porosity. This aquifer unit receives direct recharge from precipitation or from flood water draining the surrounding volcanic highlands. This unit is overlain by impermeable mudstone, forms cliff where direct recharge to the aquifer system is low.

Trap series Basalt and Trachyte aquifer

The unit is found in the tributary streams of Muger River catchment. It comprises columnar basalts, weathered basalts, trachytes, ignimbrites and rhyolites. The aquifer unit outcrops and forms flat to gentle topography and receive direct recharge from precipitation. Groundwater circulation is shallow along stream courses but relatively deep at ridges.

Scoriaceous Basalt aquifer

This aquifer unit is found in upstream of both Holota River catchment and tributary streams of Muger River catchment. The aquifer unit is composed dominantly of scoria, scoriaceous basalt and boulders of basalt with very thin layers of trachytes, rhyolites, and palaeosols. Depth to ground water in this unit is shallow except at volcanic peaks. This unit is characterized by high primary porosity and secondary porosity.

Rift Basalt and Ignimbrite aquifer

This unit if found in Holeta river catchment. The Rift Basalt and Ignimbrite aquifer unit is composed of vesicular basalts with high primary porosity and ignimbrites with lower primary porosity. Receive direct recharge from precipitation. Groundwater circulation in this unit is generally shallow.

Pyroclastic deposit aquifer

This unit is found in the south western part of Holota River catchment. This aquifer unit comprises the pyroclastic rocks within the Trap series volcanic from the plateau, and the volcanic ash and tuff deposits from the rift. Hydraulic conductivity of the unit is low, dominantly attributed to the low secondary porosity. It receives direct recharge from precipitation but with very slow infiltration rate.

Groundwater flow barriers

Unless the trachyte and rhyolite domes are affected by fractures and faults, they form groundwater flow barriers. The NW-SE trending fault affected the dome and causes for groundwater flow towards downstream of Holota River catchment.

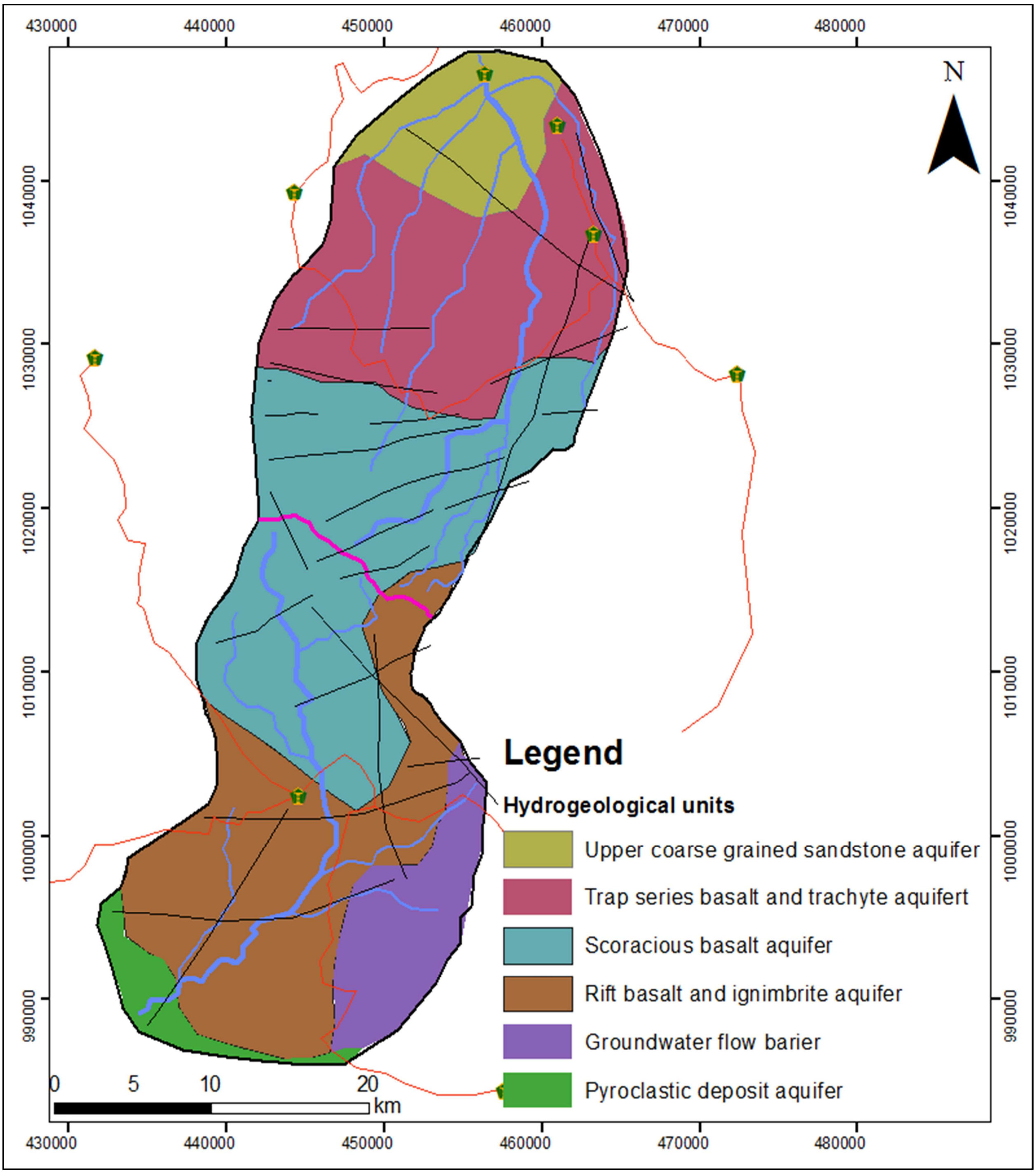

Figure 3: Hydrogeological unit map of the study area (source: Tilahun Azagegn, 2015)

Chapter 2- Previous Works

Several researches and investigations have been undertaking in the area. Those are;

Andarge Yitbarek (2009). Hydrogeological and hydrochemical framework of complex volcanic system in the Upper Awash River basin, Central Ethiopia: with special emphasis on inter-basins groundwater transfer between Blue Nile and Awash rivers. This work, from available data identified two aquifer systems (Upper basalt and Lower basalt aquifers).

Ketema Wogari (2006). Water resource potential evaluation of Holota River Catchment, central Oromia, West Shewa.

The research found that from direct and indirect investigation of the study area, the area revealed that it has enormous potential of surface water and subsurface water. The work estimated that the annual recharge to ground water from rainfall is about 24% of the mean annual rainfall of the catchment, in other words, the annual recharge to ground water is estimated to be about 160Mm3/year

Mola Demile et.al (2005). Groundwater recharge in the Akaki catchment, central Ethiopia: evidence from environmental isotopes (d^{18}O, d^{2}H and 3H) and chloride mass balance.

The research showed recharge patterns, possible flow paths and the relative age of groundwater in the Akaki catchment, by using stable environmental isotopes d^{18}O and d^{2}H and radioactive ^{3}H coupled with conservative chloride measurements.

The work showed that, the stable and radioactive isotope measurements further revealed that groundwater in the Akaki catchment is compartmentalized into zones and it appears that a complete mixing following the flow paths is lacking and commensurate with lithologic complexity.

Seifu Kebede et.al (2007). Ground water origin and flow along selected transects in Ethiopian rift volcanic aquifer.

The most important factor that controls the groundwater flow continuity between the high rainfall region in the plateau and the rift floor aquifers is the geological architecture of the interface zone.

Seifu Kebede et.al (2010). Ground waters of the Central Ethiopian Rift: diagnostic trends in trace elements, d^{18}O and major elements.

From geochemical trend, it shows a continuity of groundwater flow from the western highlands to the rift valley floor following the regional groundwater flow path. And it summarized, regional flows are not evident in the volcanic aquifers of the region because of faulting, heterogeneity in permeability and dissection of aquifers, and groundwater levels and their development is largely unknown, in the studied region, Central Ethiopian Rift, there is a clear regional trend in groundwater flow and geochemistry. The fact that this region falls at the intersection between an E–W running fault zone and the NNE–SSW running fault zone may be responsible for the flow of groundwater's from the highlands to the rift floor.

Tenalem Ayenew.et.al (2007). Environmental isotopes and hydrochemical study applied to surface water and groundwater interaction in the Awash River basin

The dominant source of recharge to the rift aquifers comes from shallow groundwater inflow from the adjacent highlands.

However, the presence of variable groundwater chemistry, depth and groundwater occurrence in the region suggests complex groundwater dynamics, often governed by the intensity and attitude of the rift faults and the volcanic stratigraphy and its relation with the various water bodies.

Tilahun Azagegn (2008), Hydrogeochemical characterization of aquifer systems in Upper Awash and adjacent Abay plateau using geochemical modeling and isotope hydrology.

From geochemical data, stable isotope data and tritium data, the work addressed schematic conceptual models for spatial geochemical variations, evolution and recharge area zonation for shallow and deep aquifer systems.

The regional groundwater flow system of the area is controlled by the structural and stratigraphic relationship of rock formations which constitute confining beds, traps and aquifer systems in the study area. Recharge area for the aquifer systems of a given river basin can either be within the same basin and/or as inter-basin groundwater flow from adjacent basins.

Tilahun Azagegn (2015), Groundwater Dynamics in the Left Bank Catchments of the Middle Blue Nile and the Upper Awash River Basins, Central Ethiopia.

From the data of δ18O and δD signature collected from shallow aquifer systems in all the sub-basins shows that the aquifer system is locally recharged from modern precipitations. On the other hand, the highly depleted waters from deep wells in the Upper Awash and Guder sub-basins including those located very close to and along the water divide between the Blue Nile and the Upper Awash basin supports the inter-basin groundwater flow determined from the evidence-based litho-structural model.

WWDSE (2008). Evaluation of ground water resource potential of Ada'a and Becho plains

The investigation result showed that, comparison between $\delta^{18}O$ and δD content of the ground waters of the Upper Awash basin with the rainfall shows for the shallow aquifers recharge takes place from modern rains. The same line of evidence also shows recharge takes place principally from summer rains and that the spring rains have minor importance in recharging the aquifers in the Upper Awash basin.

Deep ground waters are depleted in $\delta^{18}O$ and δD and are highly depleted with respect to the modern day rainfall. These ground waters must therefore represent relatively older and regional ground waters. Recharge to these aquifers must have taken place at higher altitude. However shallow ground waters in the highland are more enriched than deep ground waters in their $\delta^{18}O$ and δD contents. This suggests the recharge to the above mentioned $\delta^{18}O$ and δD depleted aquifers must have taken place under colder climatic conditions and/or at higher altitude.

Chapter 3- Objective of the Research

3.1 General objective

General objective of this thesis is to provide detail information on the ground water dynamics in tributary streams of Muger River Catchment and Holota River Catchment and to provide surface water and ground water interaction characteristics with large scale using geochemical and environmental isotope techniques.

3.2. Specific Objective

The specific objectives of the thesis are:-

- Determine geochemistry (major ions) of ground water and surface water in the study area
- Isotopic signature characterization of surface water and ground water and to investigate groundwater connection to modern day infiltration from rainfall.
- Identify groundwater discharge zones from measurements of ^{222}Rn
- Determine ground water flow condition from water level measurement

Chapter 4- Methodology and Materials

4.1 Methodology

To understand the inter basin groundwater transfer between the two river catchments, different methodologies have been applied:

- Review of previous works which includes geological, hydrological, hydrogeological studies, published and unpublished academic thesis conducted in the study area, journals that are related to the study area and the methodology to be applied (^{222}Rn, ^{2}H and ^{18}O)
- Measuring in-situ field parameters of water samples like electrical conductivity and temperature, Radon -222 (^{222}Rn) in different parts of the study area, laboratory chemical analysis for chemical parameters, environmental isotopes, measurements

4.2 Materials

Different materials were used for the research work like;

- Geological map, hydro geological map and DEM (digital elevation model)
- Software's ;
    - ✓ Arc-GIS 10.2,
    - ✓ Global Mapper 15,
    - ✓ Microsoft Office, (MS-word, MS-excel), Aquachem 3.5
- GARMIN GPS- Vista (hand GPS).
- Bottles for collection of representative water samples.
- EC meter (for measurement of temperature and electrical conductivity).
- RAD-7 with its accessories, such as desiccants /drying unit (for extracting the humidity from the gas loop before interring to the RAD-7 machine), water pump (for pumping water from the water body into the extraction module.
    - ✓ The portable radon-in-gas monitor RAD-7 (Durridge Company, Inc.) was used for measuring radon in the atmosphere and in water (Burnett and Dulaiova, 2003). The RAD-7 setup allows radon extraction from a continuously running water pump stream into a closed gas loop which is pumped through the RAD-7 detection chamber. Radon extraction is

accomplished by spraying the water into a closed air tight plastic cylinder that is part of the closed gas loop.

- ✓ The following diagram shows the set up of RAD-7 detector

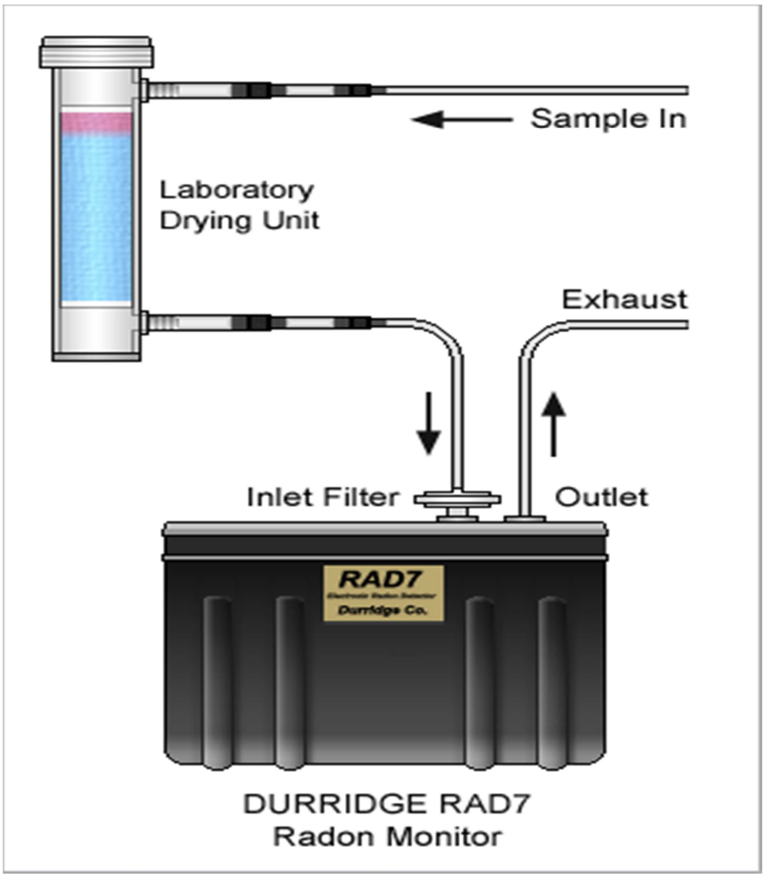

Figure 4: RAD- 7 detector setup

The research work was executed by using all the above methodologies and materials in such a way that they are implemented in an appropriate manner.

Chapter 5- Result and Discussion

5.1 Hydrogeochemistry

5.1.1. General

Water is replenished by precipitation. Amount and rate of rainfall, runoff and evaporation are important factors in the control of water composition. Solutes contained in groundwater represent the net effect of a serious of antecedent chemical reactions that have dissolved material from another phase, have altered previously dissolved components, or have eliminated them from solution by precipitation or other processes. The processes to which solutes are taken up or precipitated and the amounts present in solution are controlled by different factors, like, climate, geological activities, and biochemical effects. Composition of atmospheric precipitation, sources of solutes in the atmosphere and anthropogenic activities (Hem, 1985). There are also several factors that control groundwater chemistry like, mineralogy of the geologic units, structural set up, geomorphology, residence time and interaction with surface water bodies (Freeze and Cherry, 1979).

Chemical composition of groundwater and surface water is used to construct groundwater flow path and groundwater interaction between the host rocks. Accordingly, this section of the research work deals with the major geochemical processes, the changes undergoes along the flow path and the factors that are responsible for the changes.

5.1.2. Data availability, quality and analysis method

Water samples were collected for chemical analysis from different representative points of the study area during field work (Figure 6). Existing chemical data of boreholes, springs and rivers in the study area from previous studies and organizations were collected. During the field work in-situ measurement of:

- Electrical conductivity
- Temperature and
- Radon was made.

Water samples were collected and analyzed for the following parameters: pH, EC, TDS,NH_4^+ Na^+, K^+, Ca^{2+} and Mg^{2+}, total Fe, Cl^-, F^-, NO_2^-, NO_3^-, CO_3^{-2}, HCO_3^- , SO_4^{2-}, $PO4^{-4}$, total hardness and alkalinity.

Water samples were analyzed by the following methods:

- titration methods: Ca^{+2}, Mg^{+2}, alkalinity, hardness, CO_3^{-2}, HCO_3^- and Cl^--
- flame bottom method for Na^+ and K^+;
- gravimetric method for TDS;
- direct measurement for EC and pH;
- sulfamer method for SO_4^{-2};
- Phosphobar method for PO_4^{-4};
- ferrobar method for total Fe;
- Standness method for F^-;
- cadmium reduction method for NO_3^- and
- Deionization method for NO_2^- (NEERI, 2014).

Many organic compounds and some inorganic compounds exist in solution in water as uncharged molecules but most inorganic solids dissociate when they go in to solution in water. The closely knit structure of the solid is broken in to positively charged cations and negatively charged anions that are separated by solvent molecules. On macro scale, the positive and negative charges must be in balance (Hem, 1985).

The collected Hydro chemical data has to be checked according to the principle of electro neutrality; the sum of cations in meq/l should nearly be equal to the sum of anions in meq/l for the chemical data to be reliable for further geochemical characterization and interpretation (Freeze and Cherry, 1979).

There must be an overall balance between cations and anions in solution to maintain electrical neutrality (Hem, 1985). In a given volume of water sample that has been analyzed for inorganic constituents, the sum of all the cations (meq/l) nearly equal to the sum of all the anions (meq/l). If the analysis reveals the presence of cations and anions in solution, an equation for the electro neutrality condition may be written as:

$$\text{Electro neutrality} = \frac{\text{sum of cations} - \text{sum of anions}}{\text{Sum of cations} + \text{sum of anions}} \times 100$$

When the results of a water analysis are close in to the above equation, it should prove to be close to equality. If the two sides of this equation differ by more than a few percent, either the analysis is erroneous or one or more significant ions were omitted from the analysis. Thus, after charge balance (electro neutrality) calculation, those hydro chemical analysis results with charge balance error less than 5% is regarded as acceptable (Fetter, 2001). In this study, all of the data's falls in the acceptable range (Figure 5).

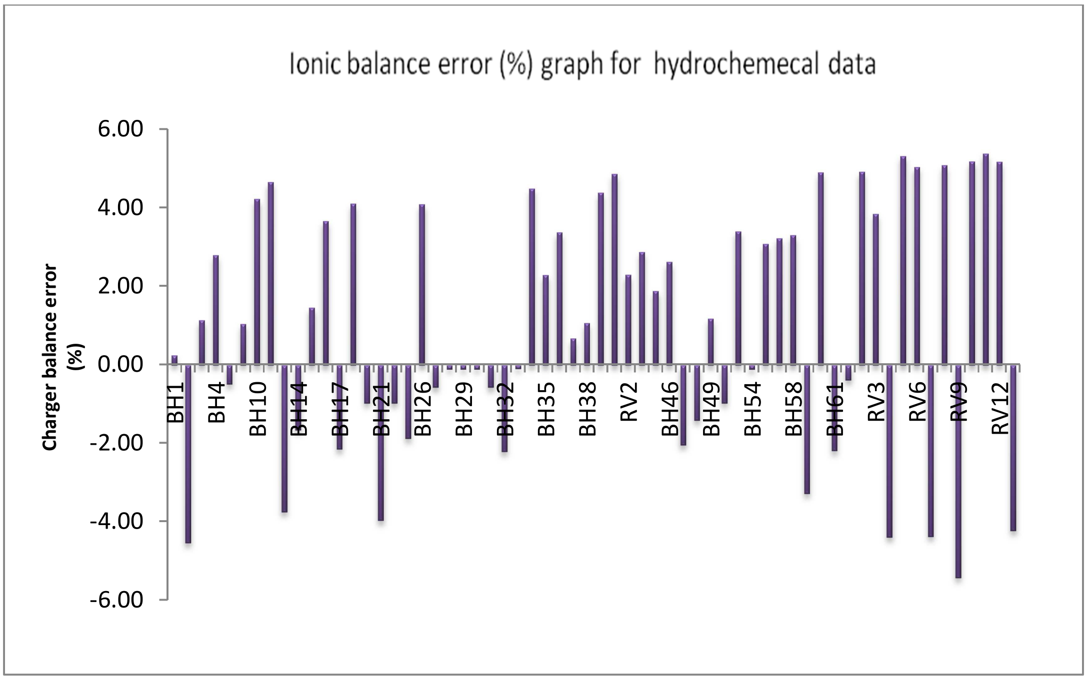

Figure 5: Ionic balance error (%) graph for hydro chemical data

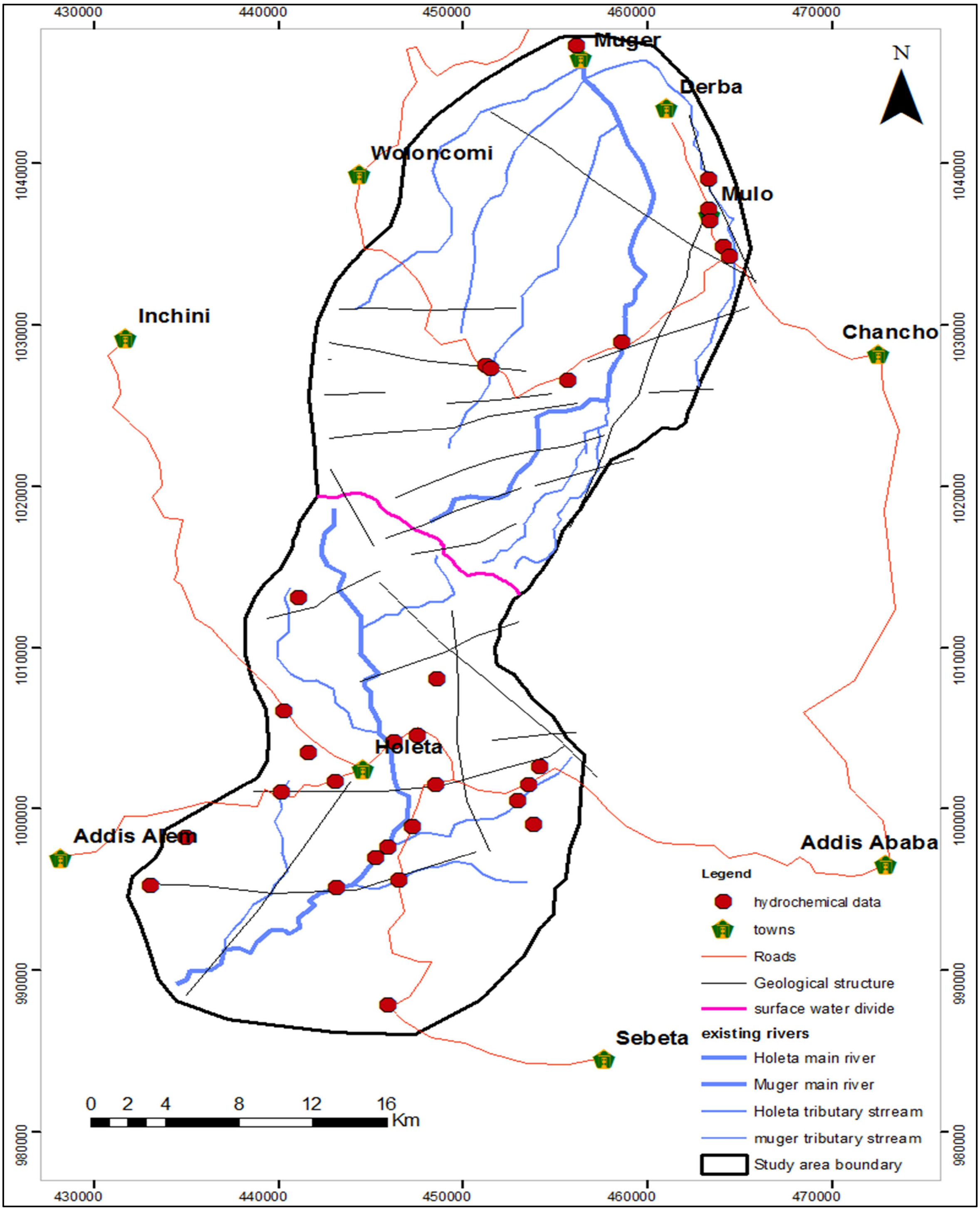

Figure 6: Hydrochemical data availability map

Various units are in use in the expression of data obtained in the chemical analysis of water. The units of concentration used in the text are mg/l. The EC values are given in µS/cm Different ratios were calculated using meq/l unit.

Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} are the major cation constituents and HCO_3^- dominates the negatively charged species. F^-, Cl^-, NO_3^- and SO_4^{-2} are not common anion. TDS value ranges between 100 mg/l to 990 mg/l and pH values ranges between 6.27 up to 8.68 ppm. To interpret groundwater flow system of the area from geochemical evidences, distribution of ion and TDS and groundwater type distribution in the area have been evaluated.

Important hydro chemical parameters of groundwater and surface waters of the study area are discussed below;

5.1.3 Total Dissolved Solid (TDS)

Thirty three field measurement of electrical conductivity have been taken during field work. Electrical conductance or conductivity is the ability of substance to conduct an electric current. Electrical conductivity is a measurement of how well an aqueous solution can carry an electrical current. It is commonly used to determine the levels of impurities in the water, typically the more impurities in the water, the higher the conductivity value will be.

Electrical conductivity is the degree of salinization of groundwater. Measurement of EC of a solution will also give a relative indication of the amount of dissolved salts. The more salts that are dissolved in the water have the higher electric conductivity. The relationship of electrical conductivity versus total dissolved solids for all hydrochemical data gave the equation expressed by $TDS = 0.601EC$ (Figure 7).

The concentration of dissolved solids in the river is related to many factors. The more direct and important factors is the variable volume of liquid water from rainfall available for dilution and transport of weathering products.

The texture and structure of rocks are significant for water composition because they determine the surface area of solid rock that may be exposed to attack. Groundwater may be recovered in large amounts of rocks that contain shrinkage cracks and other joints, interflow zones, or other openings through which water may move. Concentrations are likely to be a function of contact time and area of solid surface exposed per unit volume of water. Groundwater has better opportunity to participate in reactions with the rock minerals. However, solute load in a dilute river may be related to solutes in rainfall or dust and other atmospheric fallout transported from other localities (Hem, 1985).

The water carried in rivers is often considered to consist of base flow fraction made up of groundwater that infiltrates in to the channel and direct runoff fraction that enters the drainage system during and soon after precipitation. The direct runoff presumably has had no residence time in the groundwater reservoir and only short contact with soil or vegetation. Reactions in the soil zone, however, are commonly extensive enough that the direct runoff has a considerably higher dissolved solids concentration than the original rain. The base flow has a still greater dissolved solids concentration. The solute concentration of river water thus tends to be inversely related to flow rate. At very high flow rate, the water may be nearly as dilute as rainwater. (Hem, 1985)

TDS in water is an important parameter to characterize the changes groundwater undergoes along the flow path and widely used method for categorizing groundwater.

Based on the classification of total dissolved solids, Freeze and Cherry (1979), Fresh water is the water that contains less than 1000 mg/l of dissolved solids accordingly, all primary and secondary hydro chemical data of the area fall within this range.

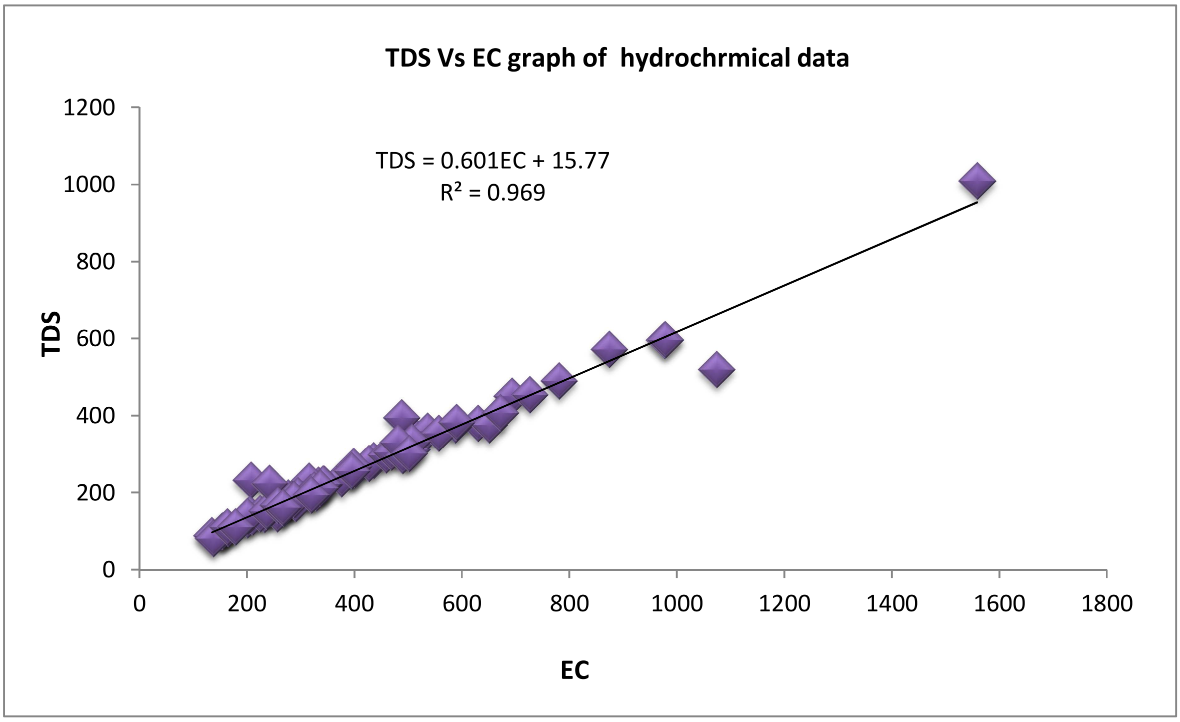

Figure 7: TDS versus EC graph of hydro chemical data

Distribution of TDS gives important implication on groundwater dynamics like flow direction, recharge area, discharge area and interaction between groundwater and surface water bodies.

The result showed from the spatial TDS distribution map (Figure 8), the upstream of both River Catchments has lower TDS value and increases along the flow path towards the downstream of the River Catchments with some exceptional boreholes found in the middle of Holota River Catchment along EW fault zone. Although, in the middle of tributary streams of Muger River Catchment, there is very low TDS concentration is shown in the spatial distribution map of TDS (Figure 8).

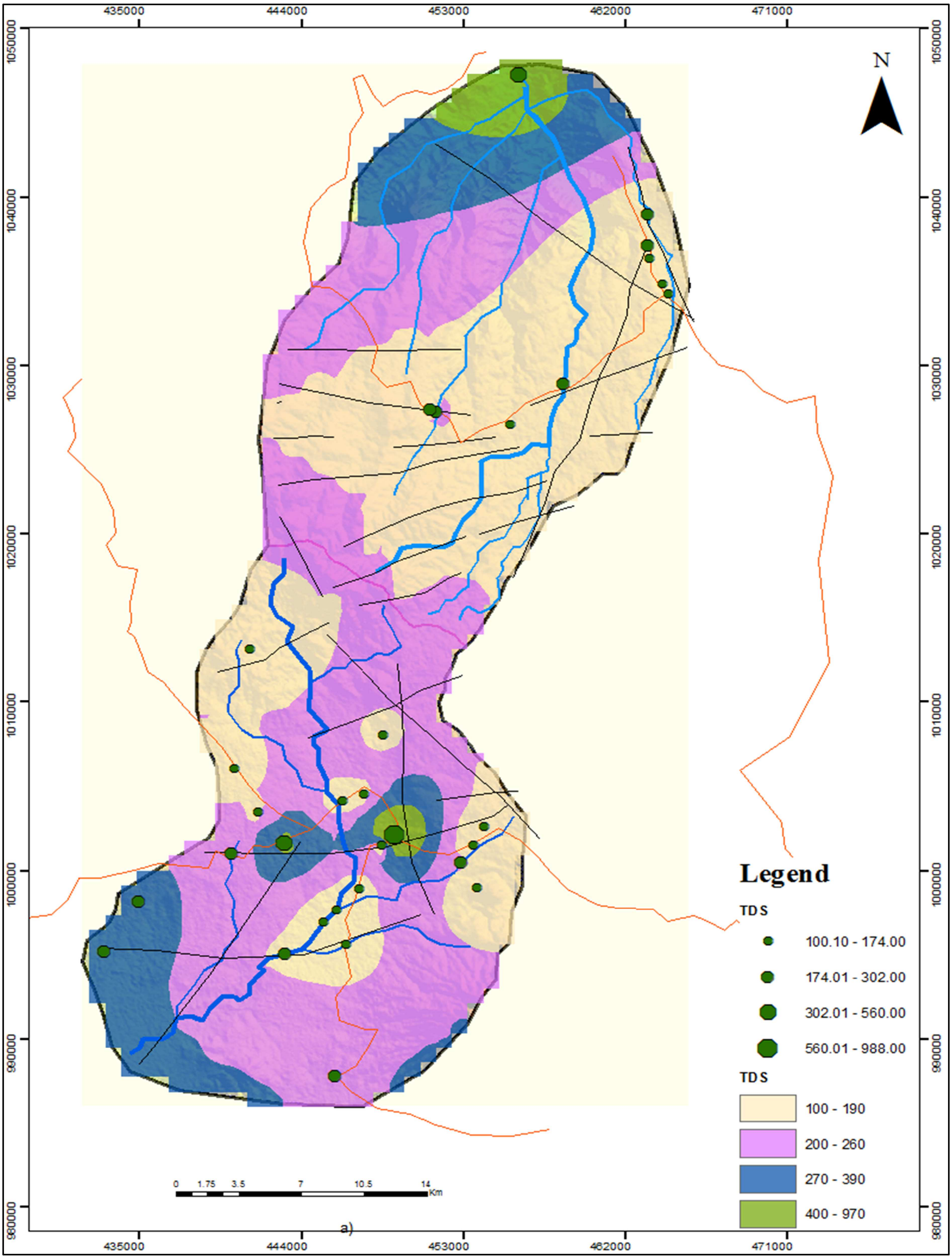

Figure 8: Spatial distribution map of TDS

TDS concentration increases towards the downstream of the river catchments and high along the east west fault zone in Holota River Catchment (Figure 8). The sources of recharge in evolved groundwater in the EW fault zone and downstream of river catchment could be recharge from deep circulation with long sub surface path with considerable rock-water interaction.

Table 1: Location of field measurement water points

Sample ID	Source	UTME	UTMN	EC	Aquifer geology
HR-1	Holota river tributary	447894	1009131	188	Scoracious basalt aquifer
HR-2	Holota main river	445399	1008379	191	Scoracious basalt aquifer
HR-3	Holota main river	445407	1005268	189	Scoracious basalt aquifer
HR-4	Holota main river	445374	1004738	193	Scoracious basalt aquifer
HR-5	Holota main river	446105	1003873	166	Scoracious basalt aquifer
HR-6	Holota main river	446101	1002833	172	Rift basalt and ignimbrite aquifer
HR-7	Holota main river	446465	1001086	189	Rift basalt and ignimbrite aquifer
HR-8	Holota main river	445913	997622	185	Rift basalt and ignimbrite aquifer
HR-9	Holota river tributary	452911	1000512	226	Rift basalt and ignimbrite aquifer
HR-10	Holota river tributary	454221	999759	157	Groundwater flow barrier
HR-11	Holota main river	443118	995089	206	Rift basalt and ignimbrite aquifer
HR-12	Holota river tributary	433040	995231	258	Rift basalt and ignimbrite aquifer
HR-14	Holota river tributary	434984	998212	265	Rift basalt and ignimbrite aquifer
HR-15	Holota river tributary	446492	995599	173	Rift basalt and ignimbrite aquifer
HR-17	Holota main river	445231	996952	187	Rift basalt and ignimbrite aquifer
HR-18	Holota river tributary	447638	1012559	186	Scoracious basalt aquifer
HR-19	Holota main river	443517	1014536	193	Scoracious basalt aquifer
HR-20	Holota river tributary	446596	1013226	185	Scoracious basalt aquifer
HR-21	Holota river tributary	440295	1013053	228	Scoracious basalt aquifer
HR-22	Holota river tributary	439322	1010213	231	Scoracious basalt aquifer
MR-1	Muger main river	458600	1028944	196	Trap series basalt and trachyt aquifer
MR-2	Muger river tributary	451485	1027273	255	Trap series basalt and trachyt aquifer
MR-3	Muger river tributary	456140	1021714	193	Scoracious basalt aquifer
MR-4	Muger river tributary	455762	1020665	191	Scoracious basalt aquifer
MR-5	Muger main river	458689	1030535	201	Trap series basalt and trachyt aquifer
MR-6	Muger main river	457900	1027032	199	Scoracious basalt aquifer
MR-7	Muger main river	454540	1024628	198	Scoracious basalt aquifer
MR-8	Muger river tributary	455718	1019251	200	Scoracious basalt aquifer
MR-9	Muger river tributary	463275	1038355	355	Trap series basalt and trachyt aquifer
MR-10	Muger river tributary	464619	1033828	352	Trap series basalt and trachyt aquifer
MR-11	Muger main river	456078	1047291	286	Upper coarse grained sandstone aquifer
MR-12	Muger river tributary	462392	1041185	369	Trap series basalt and trachyt aquifer

5.1.4. Sodium and Calcium

Spatial distribution of major ions from groundwater in silicate, carbonate and clastic rocks help to characterize groundwater dynamics, and related Hydrogeological characteristics of the given area. In order to characterize Hydrogeological features of the study area, sodium and calcium concentrations in water samples are have been used.

Sodium is the most abundant member of the alkali metal groups of the periodic table. In igneous rocks, sodium is mostly more abundant than potassium. Moreover, sodium dominates groundwater from acidic volcanic rock units while calcium dominates basic rock units. . When it comes to sedimentary terrain, calcium is a dominate cation in groundwater from limestone while sodium dominates waters from evaporits rocks.

From the spatial distribution map of sodium, it is observed that sodium concentration decreases towards downstream of the river catchments. Along the east west fault zone at the middle of Holota River Catchment, sodium concentration becomes exceptionally high. And in the middle of tributary streams of Muger River Catchment, a relative increment of sodium concentration showed along the flow path. (Figure 9) The maximum concentration of sodium identified in the study area is 370mg/l with high EC (1454µS/cm) and TDS (988mg/l) value , in a borehole found in EW fault zone.

From the spatial distribution map of calcium, Calcium concentration increases downstream of the flow path. However, in Holota River Catchment, some points have been shown relative increment of calcium concentration which fall down on EW fault zone and in Wochecha mountain (Figure 9). Maximum concentration of Calcium in the study area is 180mg/l at the downstream of tributary streams of Muger River Catchment.

Generally, the spatial distribution of Na^+ is inversely related with the spatial distribution of Ca^{2+} concentration in the study area (Figure 9).

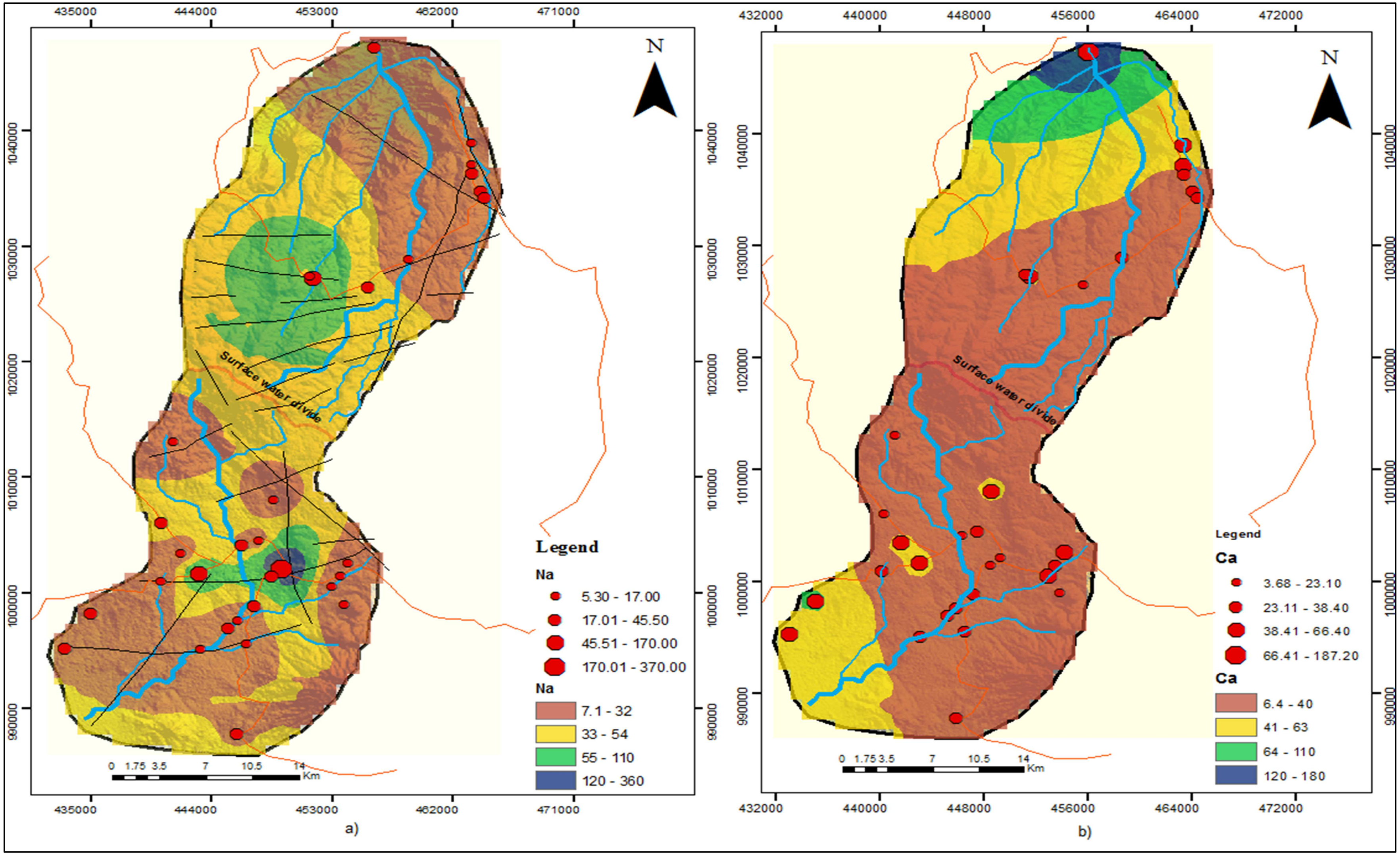

Figure 9: Sodium (a) and Calcium (b) distribution map

The spatial distribution map of major cations (Sodium and calcium) concentration shows the inverse relationship of sodium and calcium (Figure 9). Calcium concentration increases towards downstream of the river catchments along the flow path associated with contact between basaltic rock with water. Sodium concentration is high around the groundwater divide and decreases towards downstream of river catchments along the flow path associated with contact between basaltic rock with water. Concentration of sodium is very high along the EW fault zone which is the result of cation exchange reaction along the groundwater flow path.

5.1.5. Groundwater types

Elements not available in the rock minerals contacted by water cannot be expected to be present in the final solution. Non availability can be related to the structure of the rocks as well as to their composition.

From chemical analysis result and by using Aquachem 4 software five groups of water types are identified in the study area (CaHCO3, CaNaHCO3, NaCaHCO3, NaHCO3 and others). The classification of the waters into group of groundwater types is based on major and minor cations and anions in the water samples.

$CaHCO_3$ water type is water with calcium as the dominant cation and bicarbonate as the dominant anion that includes $CaHCO_3$ and $CaMgHCO_3$ and it observed in both River Catchments. This groundwater type is characterized by low TDS; often less than 240 mg/l, hence they represent early stage of geochemical evolution in recharge area and shallow depths of rapid circulation, relatively low residence time in sub surface, without significant water–rock interactions. Water type of most river samples in the study area shows $CaHCO_3$ water type chemistry.

The second and third group of water type is $CaNaHCO_3$ and $NaCaHCO_3$ respectively. These groups represent groundwater circulating in intermediate zones (depth and travel distance from recharge areas). Water samples in this group were obtained from wells ranging from 100m up 275m depth. Relative increment of TDS value occurs in this water types exceptionally in a single sample point within Holota River Catchment with TDS value 450mg/l. The water type in this group represents intermediate stage of geochemical evolution, with considerable travel distance from recharge area and/or at a relatively deeper part of the aquifer or mixing effect of local recharge with regional flow system. This in turn signifies that the groundwater belonging to this group is in the intermediate zone between the recharge and discharge areas. This water type is found in Wochecha Mountain and downstream of the River catchment.

The forth water type group in the area is $NaHCO_3$ which is water with sodium as dominant cation and bicarbonate as the dominant anion. The group includes wide range of TDS values (144 – 990 mg/l). This groundwater type is found only in Holota river catchment along the EW fault zone with high TDS and in the eastern boundary of Holota River Catchment (Figure 10).

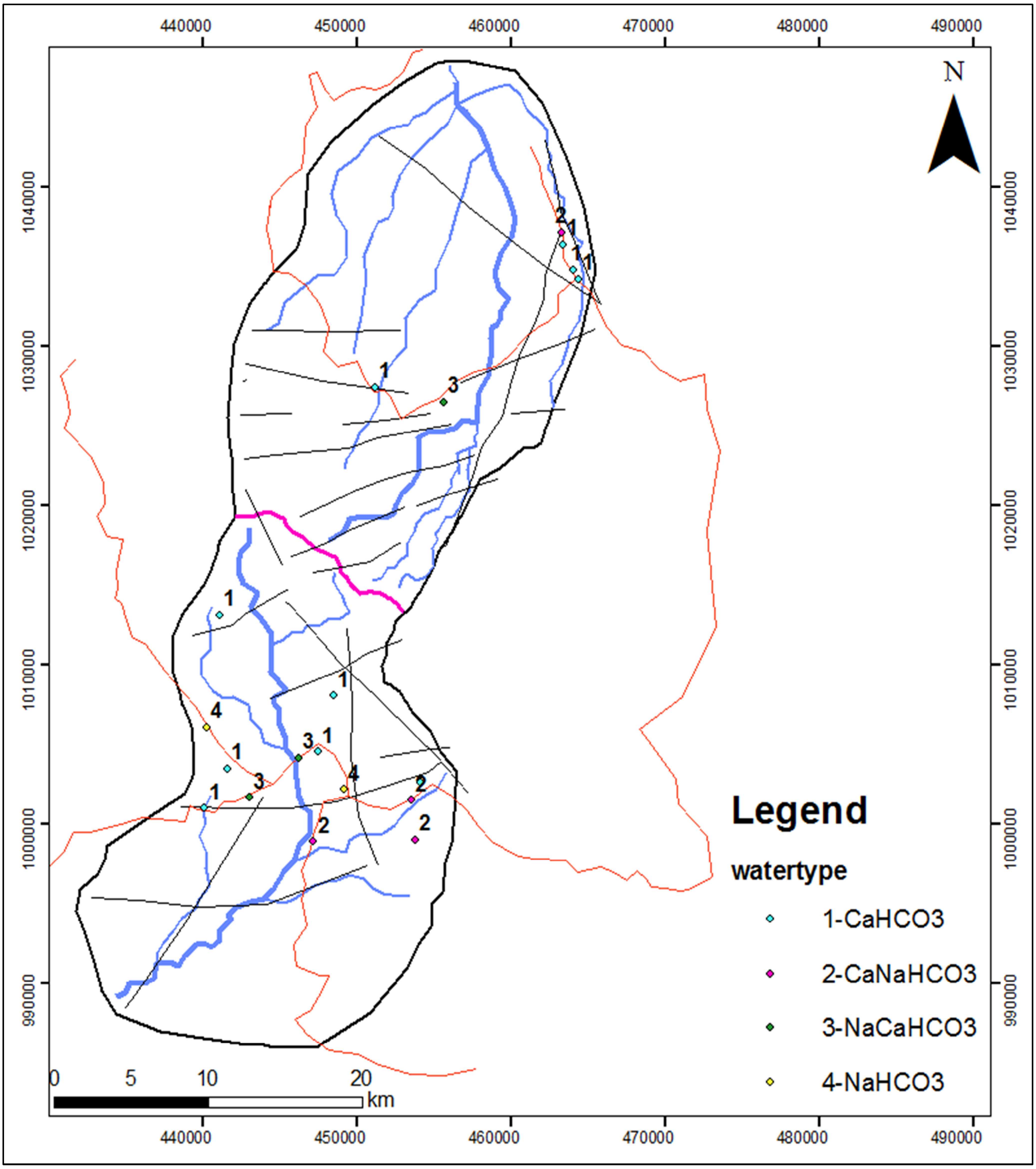

Figure 10: Groundwater type distribution map

From the spatial distribution map of groundwater type verses TDS, $CaHCO_3$ groundwater type is characterized by low TDS; this type of groundwater represents early stage of geochemical evolution in recharge area and shallow depths of rapid circulation, relatively low residence time in sub surface and without significant water–rock interactions.

CaNaHCO3 and NaCaHCO3 groundwater type is characterized by considerable travel distance from recharge area and/or at a relatively deeper part of the aquifer or mixing effect of local recharge with regional flow system.

This groundwater type in the study area also characterised by low TDS concentration except relative increment of TDS concentration is observed in Holota River Catchment which could be related with the mixing effect with deep circulation.

NaHCO3 groundwater type is observed only few points around the western boundary of Holota River catchment with low TDS concentration; this is due to cation exchange at deeper zones. And this groundwater type also observed along the EW fault zone in Holota River catchment with high TDS concentration. The presence of such type of groundwater observed only in Holota River catchment could be as a result of significant rock water-rock interaction, long subsurface path and long residence time.

Table 2: Hydrochemical data

No.	Sample ID	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	SO4
1	BH1	465410	1002944	135	89	6.83	11.5	4.6	9.6	3.4	1.99	1.5	1.68	76.86	1.6
2	BH2	465161	1003103	201	130	7.8	18	4.9	21.6	4	8	0.5	0.9	136.6	3.2
3	BH3	433779	1000228	436	283	6.9	12.8	2.5	63.6	15.3	5.15	6.6	0.3	286.9	0.2
4	BH4	430267	987498	630	380	7.36	42	3.6	82.7	14.3	19.2	7	1.68	350	21.7
5	BH5	487089	997218	401	261	7.71	35	4	40	7	4	0.44	0.98	261	4
6	BH6	460464	974637	376	236	7.1	15.5	1.8	46.98	13.8	5.8	11.5	2.58	226.5	0.55
7	BH7	460810	981473	344	222	6.97	15	4.8	43.7	13.2	0.5	7.5	0.15	217.8	0
8	BH8	445643	973409	333	219	7.06	17	4.2	50	8.3	2.9	7.5	0.8	235.7	0.53
9	BH9	466662	970715	427	276	7.28	24	6.1	67.3	6.1	5.8	7	0.8	284.4	1.32
10	BH10	464607	973547	507	312	7.8	20	6.1	68.7	17.5	3.8	8.5	1.24	316.1	0.55
11	BH11	466690	976790	588	376	7.36	67	9.5	41.8	13.8	20.2	32.5	0.8	266.3	17.3
12	BH12	474740	1028068	342	222	7.45	8	0.7	45	15	6	17.28	0.13	195	25
13	BH13	427126	971361	874	572	7.27	160	23	9.68	2.7	63.36	0.11	2.17	366	44.06
14	BH14	453776	998997	154	100	7.45	9	0.8	20	3	1	0.44	0.08	95	6
15	BH15	456740	962388	510	350	7.19	42	9.8	62.8	9.4	6.7	7.5	1.25	333.1	2.64
16	BH16	456402	962608	536	360	7.25	41	11	65.32	12.32	8.64	2.39	1.36	311.47	18
17	RV1	456699	962400	316	230	8	27	6.2	41.8	12.5	5.7	8	0.41	233.9	1.1
18	BH17	451196	1027438	278	181	7.46	10	0.6	36	7	2	2.7	0.31	173	1
19	BH18	418679	988365	977	596	8.5	235	3	6	4.56	41.86	1.2	1.74	525	13.79
20	BH19	423439	988990	557	354	8.15	128.5	3.1	10.4	4.8	53.11	1.04	0.59	256.2	11.9
21	BH20	420071	983317	781	490	7.4	140	12.8	12	4.8	48.27	0.67	1.31	368.93	5.92
22	BH21	411777	989671	1559	1010	6.45	230	24	35.04	4.8	18	0.74	0.84	811	0.06
23	BH22	551014	1052479	329	200	7.33	21	4.7	42	7.56	11.83	6.81	0.73	173.1	8.71
24	BH23	550872	1054157	208	232	7.3	10	2.3	27	3	4	3.99	0.37	113	5
25	BH24	479695	1073212	488	395	7.01	13	2.2	57	16	14	18	0.31	215	11

No.	Sample ID	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	SO4
26	BH25	473911	1031930	166	108	7.61	30	0.7	5.34	0.54	1.92	0.8	0.225	90.28	7.15
27	BH26	471304	1027754	257	146	6.54	20.5	0.9	32.2	4.2	1.9	2.93	0.41	154.3	0.83
28	BH27	463292	1037141	295	192	7.5	13.6	1.3	46.5	10.7	28.4	4.6	0.16	183	0
29	BH28	463376	1036389	156	101	7.8	21.5	9.5	32.2	7.4	5.8	8	0.5	189.1	0.83
30	BH29	464070	1034816	156	101	7.8	21.5	9.5	32.2	7.4	5.8	8	0.5	189.1	0.83
31	BH30	464387	1034248	156	101	7.8	21.5	9.5	32.2	7.4	5.8	8	0.5	189.1	0.83
32	BH31	463286	1038986	295	192	7.5	13.6	1.3	46.5	10.7	28.4	4.6	0.16	183	0
33	BH32	406469	1009401	395	257	7.83	10	2	50	13	3	3	0.62	250	1
34	BH33	443048	1001649	693	450	7.77	94	9	48	9	18	2	4	390	26
35	BH34	489927	1000153	507	332	7.89	93	3.3	19.32	12.75	16.48	9.14	1.29	297.2	6.6
36	BH35	446260	1004149	211	137	8.58	24	0.3	18	3	7	6.65	0.4	107	2
37	BH36	440274	1006055	233	144	8.68	45.5	1.7	3.68	0.56	6.72	2.22	0.5	111.6	2.3
38	BH37	453522	1001474	206	144	7.67	7.6	1.8	29.4	7	3.8	4.8	0.41	133.2	1.32
39	BH38	447200	998889	225	146	7.91	24.5	2	24.9	3.8	5.8	10	0.41	138.3	1.32
40	BH39	448532	1008047	258	174	6.27	6	1.4	44.5	4.9	7.8	25	0.41	117.9	6
41	BH40	421795	1040108	244	160	7.25	30.5	2.5	19.36	5.4	7.68	0.12	0.28	143	0.53
42	BH41	533663	1047803	399	268	7.5	10	1.2	69	12	8	13.3	0.33	239	11
43	BH42	473800	1024726	319	200	7.32	17	1.1	44	11.04	4.55	5.86	0.47	200	1.14
44	RV2	413753	1076600	138	82	7.52	5.4	3.3	16	3.89	1	1.32	0.82	70.27	8.5
45	BH43	441584	1003445	263	170	7.13	6.6	1.5	46.3	7.6	0.96	7	0.41	179.3	0.53
46	BH44	438871	977181	651	376	7.86	136	4.8	3.8	4.1	70.99	0.38	1.29	230	35.41
47	BH45	447224	978514	590	383	7.1	91	8.7	36.8	8.83	42.77	0.78	0.73	229.48	72.49
48	BH46	449082	980399	480	312	7.3	78	8.1	29.64	6.84	23.66	3.18	0.93	259.62	18.24
49	BH47	459831	985582	201	138	6.56	9.1	4.6	26.4	5	9.6	3	0.8	122.98	0.26
50	BH48	460850	985850	244	159	6.65	16	3.1	28.8	4.84	3.88	14	0.5	141.5	1.8
51	BH49	457030	984617	979	597	6.85	16	3.4	36	9	5	8.69	0.49	178	2.6
52	BH50	455620	1026514	237	152	8.16	34	1.5	16	1.1	6.72	2.46	0.34	118.9	13.2
53	BH51	474421	1013070	291	172	8.56	54	1	1.8	1.05	21	0.2	0.09	86	24

No.	Sample ID	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	SO4
54	BH52	473621	1013070	277	186	7.82	46	1.2	12.9	4.6	10	1.58	0.09	141	11.3
55	BH53	444624	978143	726	455	7.44	116	6.6	36.4	6.1	56.6	4.8	3.6	345.9	15.58
56	BH54	448502	978502	1074	520	7.37	53	7	118.8	59.8	99	0.01	1.55	258.2	306
57	BH55	441088	1013105	164	112	7.38	6.5	1.4	23.1	6.5	0.5	8.5	0.41	105	1.06
58	BH56	468227	1081132	242	224	8.3	24	0.6	16	6	4	5	0.26	137	5
59	BH57	473576	972821	498	305	7.8	45	7.7	60	7.3	7.2	8.8	0.8	302.6	4.5
60	BH58	484475	975622	672	408	7.5	40	3.5	96.8	18	7	9.7	0.3	444	0.5
61	BH59	442661	1079441	395	257	7.83	8	2	50	13	3	3	0.62	250	1
62	BH60	483800	1065398	459	298	7.3	16.5	1.2	67.16	16.01	15.14	25.91	0.626	231.8	13.52
63	BH61	447488	1004519	258	168	7.96	12	1.2	30	8	3	5.32	0.17	159	3
64	BH62	415726	995659	469	305	6.9	75	2.8	37.24	4.1	14.4	0.4	1.07	312.6	1.81
65	BH63	448467	1001475	179	112	8.46	32.5	0.4	12.8	4.32	4.97	0.86	0.93	75.4	38.6
66	RV3	458600	1028944	280	180	7.54	14	1.4	38.4	3.84	5.96	1.4	0.41	150.79	0.3
67	RV4	451485	1027273	325	206	7.24	17	2.6	43.2	7.68	5.96	0.4	0.39	201.06	22.3
68	RV5	445913	997622	269	160	7.99	10.6	1.2	36	9.6	5.96	0.78	0.39	150.79	6
69	RV6	452911	1000512	337	212	7.39	9.5	1.4	46.4	5.28	4.97	27.17	0.34	87.96	42.2
70	RV7	443118	995089	288	182	7.48	11.1	1.9	32	6.24	5.96	2.73	0.38	150.79	10
71	RV8	433043	995231	490	296	7.88	27.5	2.5	53.6	20.64	15.09	1.03	0.51	278.16	5
72	RV9	455104	989707	481	330	7.23	28.5	6.4	48	14.4	18.64	53.64	0.46	254.98	0.02
73	RV10	434980	998207	502	302	7.98	26.5	1.9	66.4	17.76	18.64	1.38	0.55	266.57	23.3
74	RV11	446492	995599	267	162	7.28	17	2	33.6	10.56	9.76	1.21	0.4	141.4	18.82
75	RV12	445890	987801	320	194	7.17	28	4.8	32	9.6	7.76	4.28	0.51	139.08	38.5
76	RV13	445231	996952	267	162	7.69	20	1.5	32	7.2	9.76	1.29	0.4	134.44	42.2

5.2. Isotope Hydrology

Water is a chemical compound of hydrogen and oxygen. In the gaseous state, at least, it has the molecular formula H_2O. Although the same formula also represents the compositions of liquid water and ice, the molecules in these two forms are associated structurally and it is a good idea to think of the condensed phases in terms of these associations rather than as simple aggregates of molecules. Because three isotopes of hydrogen and three of oxygen exist in nature, 18 varieties of water molecules are possible.

Isotopes are forms of a given chemical element that have different atomic masses. For a particular element, the isotopes have the same numbers of protons, and so have the same atomic number. However, each isotope has a different number of neutrons and therefore has a different atomic mass. Stable isotopes are those isotopes that do not undergo radioactive decay; so their nuclei are stable and their masses remain the same. However, they may themselves be the product of the decay of radioactive isotopes. In hydrological studies, the stable isotopes of interest generally relate to hydrogen, carbon, nitrogen and oxygen. In terms of the water molecule itself, oxygen has three stable isotopes, ^{16}O, ^{17}O, and ^{18}O; and hydrogen has two stable isotopes, ^{1}H and ^{2}H (deuterium). The relative abundances of the lighter isotopes of hydrogen (1H=0.999) and oxygen ($^{16}O=0.997$) are naturally high. The stable isotopes of ^{18}O (oxygen-18) and ^{2}H (deuterium) are used to provide information on hydrological processes, including groundwater-surface water interactions (Fritz and Fontes, 1980).

Stable and radioactive environmental isotopes are useful for understanding groundwater systems. Applications of stable isotope ratios of hydrogen and oxygen in the study of groundwater system are based up on isotopic variation in atmospheric precipitation and the general concept of tracing in which either intentionally introduced isotopes or naturally occurring environmental isotopes are employed. An environmental tracer will be useful for estimating groundwater inflows to rivers when the concentration of the tracer in groundwater is relatively uniform and significantly different to that in the river. One of the most powerful tracers for this purpose is radon (^{222}Rn). Generally, among the most important applications where isotopes are useful in groundwater system; flow path, interconnection between aquifers and groundwater are common.

Isotope data availability and analysis methods

Fifty four water samples were collected and analyzed for stable isotopes of water ($\delta^{18}O$ and δD) in the study area. Out of these, thirty one samples were collected from different reach of the study area, ten samples were collected at a particular location of Holota River for ten consequent weeks starting from August 2015 up to October 2015, four samples were collected at a particular location of Holota River during raining with an interval of 30 minutes and the remaining eleven samples were collected from different shallow and deep boreholes in the study area. Around 70 primary and secondary isotopes data are collected and analyzed in the study area and surrounding of it.
In situ measurement was conducted for ^{222}Rn at 39 different reaches of both Holota River Catchment and tributary streams of Muger river catchment (Fig.13).

Laboratory measurement for $\delta^{18}O$ and δD were conducted by using equipment called LOS Gatos Research DLT-100 leaser instrument configured with auto sampler together with standards at 10 sample intervals.

For ^{222}Rn counting, relatively simple counting device called Rad7 has been used to measure the radon activities at different selected reaches of the study area. Radon activities were counted at thirty nine selected representative points at both Holota River Catchment and tributary streams of Muger River Catchment along the flow path. Each measurement was carried out for forty five minutes including three cycles of 15 minutes duration. Twenty six measurements are located at the representative points in Holota River Catchment whereas thirteen measurements are taken at the representative points of tributary streams of Muger River Catchment of the study area.

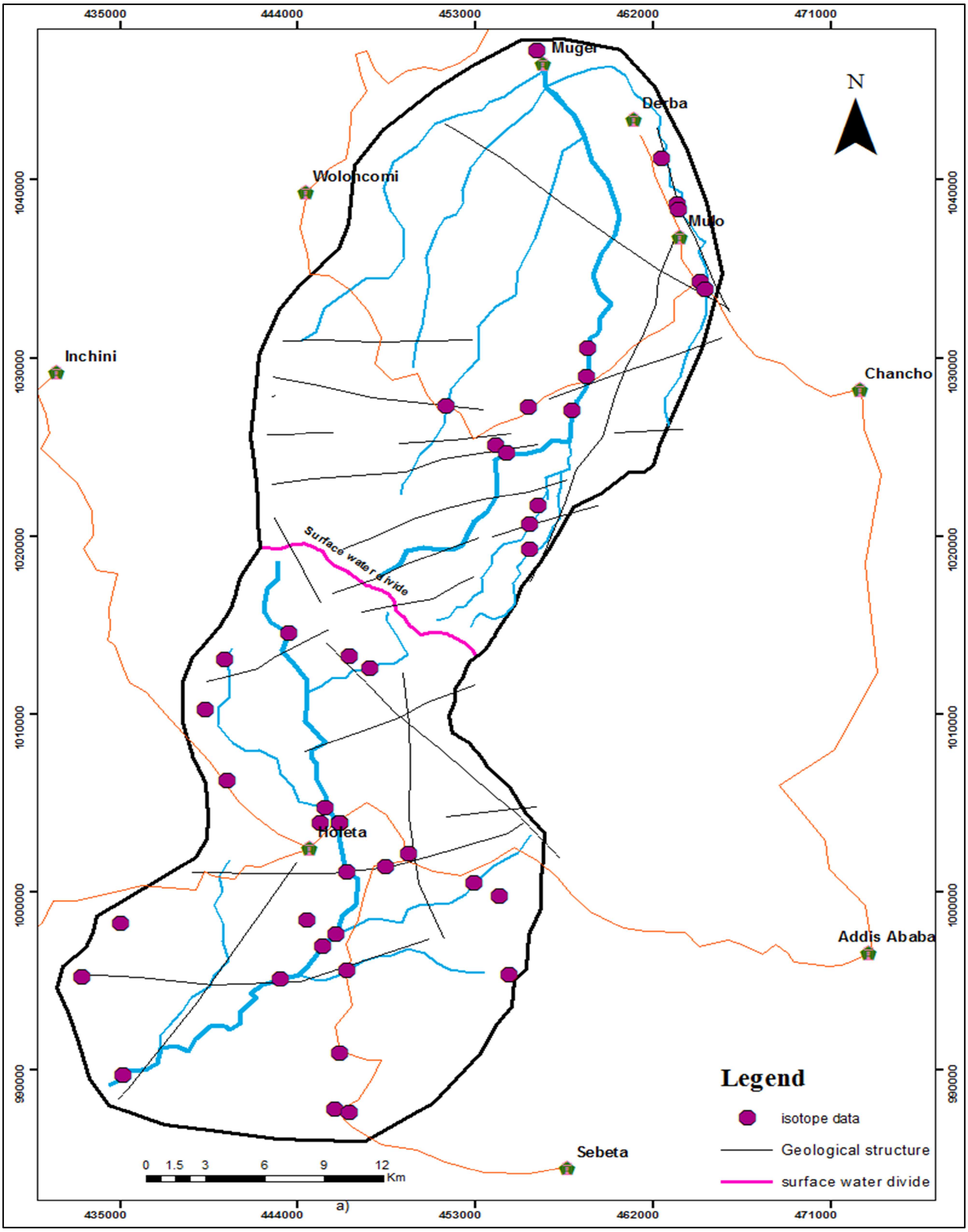

Figure 11: Stable isotope data availability map

Stable isotope

Elements are defined by the number of protons in the nuclei of their atom. Hydrogen has one proton and oxygen has eight protons. Isotopes are defined as variations of a given element, differing from each other by the number of neutrons.

The hydrogen isotopes are H (common hydrogen-1protone), ^{2}H (deuterium-1protone and 1 neutron) and ^{3}H (tritium-1protone and 3neutrone), common hydrogen and deuterium are stable and tritium is radioactive isotope. Oxygen isotopes are ^{16}O (common oxygen-8 protons and 8 neutrons), ^{17}O (heavy (very rare) oxygen-8protone and 9 neutron) and ^{18}O (heavy oxygen-8 protons and 20 neutrons).

Water is composed of hydrogen and oxygen, and it occurs in different isotopic combinations in its molecules. Most common isotopic combinations are; $^{1}H_2{}^{16}O$ (common), $^{1}HD^{16}O$ (rare) and $^{1}H_2{}^{18}O$ (rare). The water molecules divided in to light molecules (1H216O) and heavy water molecules ($^{1}HD^{16}O$ and $^{1}H_2{}^{18}O$).

The isotopic composition of water expressed in the composition to the isotopic composition of ocean water which is called Vienna Standard Mean Ocean Water (VSMOW) (Craig, 1961)

The isotopic composition of water, determined by mass spectrometry, is expressed in per mil ($^{0}/_{00}$) deviation from the VSMOW. These deviations are written δ D for deuterium and **δ** ^{18}O for ^{18}O:

$$\delta D‰ = \frac{(D/H)_{\text{sample}} - (D/H)_{\text{SMOW}}}{(D/H)_{\text{SMOW}}} \times 1000$$

and

$$\delta^{18}O‰ = \frac{(^{18}O/^{16}O)_{\text{sample}} - (^{18}O/^{16}O)_{\text{SMOW}}}{(^{18}O/^{16}O)_{\text{SMOW}}} \times 1000$$

Water with less deuterium than VSMOW has negative δ D and water with more deuterium than VSMOW has positive δ D for. The same is true for δ ^{18}O. (Emanuel M., 2004)

Isotopic composition of local meteoric water line of Addis Ababa station precipitations data (δ18O (‰) against δ2H(‰)) are plotted and resulted with a linear trend represented by the equation δ2H(‰)= 7.2δ18O(‰)+11.9 is known as the local meteoric water line(LMWL).

The LMWL is the reference line to study the surface and subsurface water recharge sources, mechanism, interconnection between different aquifer units, interaction between the rivers with groundwater and that of precipitations from all over the world plotted to give δ2H (‰)= 8δ18O (‰)+10 which is given by Craig (1961)known as Global meteoric water line(GMWL) (Figure 13). The monthly rains of Addis Ababa at IAEA station plot, gives a local meteoric line (LMWL) defined by: δD = 7.2 δ18O + 11.9 with weighted mean summer precipitation for δ18O and δD composition of -1.56 and +1.48, respectively and spring precipitations of +0.47 and +17.36, respectively (Seifu Kebede et al., 2012). The δ18O and δD values of various water groups from the area (surface waters and groundwater) were plotted against the GMWL and the LMWL.

The LMWL of Addis Ababa precipitation is plotted above the GMWL with d-excess of 11.9‰ which could be related with the source of rainfall, temperature and topographic effects.

Different ranges of values were observed for the water groups categorized into surface waters and groundwater. Based on the observed value ranges, fractionation processes attributed to evaporation of meteoric water before recharge are highlighted and the effects of mixing from different sources within the hydrologic system are also addressed.

Sampling and in-situ measurements of surface waters for isotopic study are used to characterize interaction between surface water and groundwater of the area. Precipitation on the Ethiopian highlands is generally a result of the clouds from oceans, which arrive after several rainout effects (Seifu Kebede et al., 2012). Evaporation from surface water causes enrichment in δD and δ18O and the trend line of surface waters plots with slope less than slop of LMWL (Fig. 14).

From the distribution plot of stable isotope, sample collected during the raining time from Holota River on September 2015 fall on the LMWL and have almost parallel trend line with the LMWL. Weekly (10 weeks) collected Samples for 10 weeks starting from August 2015 up to October 2015 show that the samples collected around October fall below the LMWL, while the samples collected in August and early September fall above the LMWL. Samples collected from different reaches of the rivers in the study area on February 2015, lain down below the LMWL and fall nearly along the evaporative line. Samples collected from deep and shallow ground water shows deviation from the LMWL and trending parallel with the evaporative line.

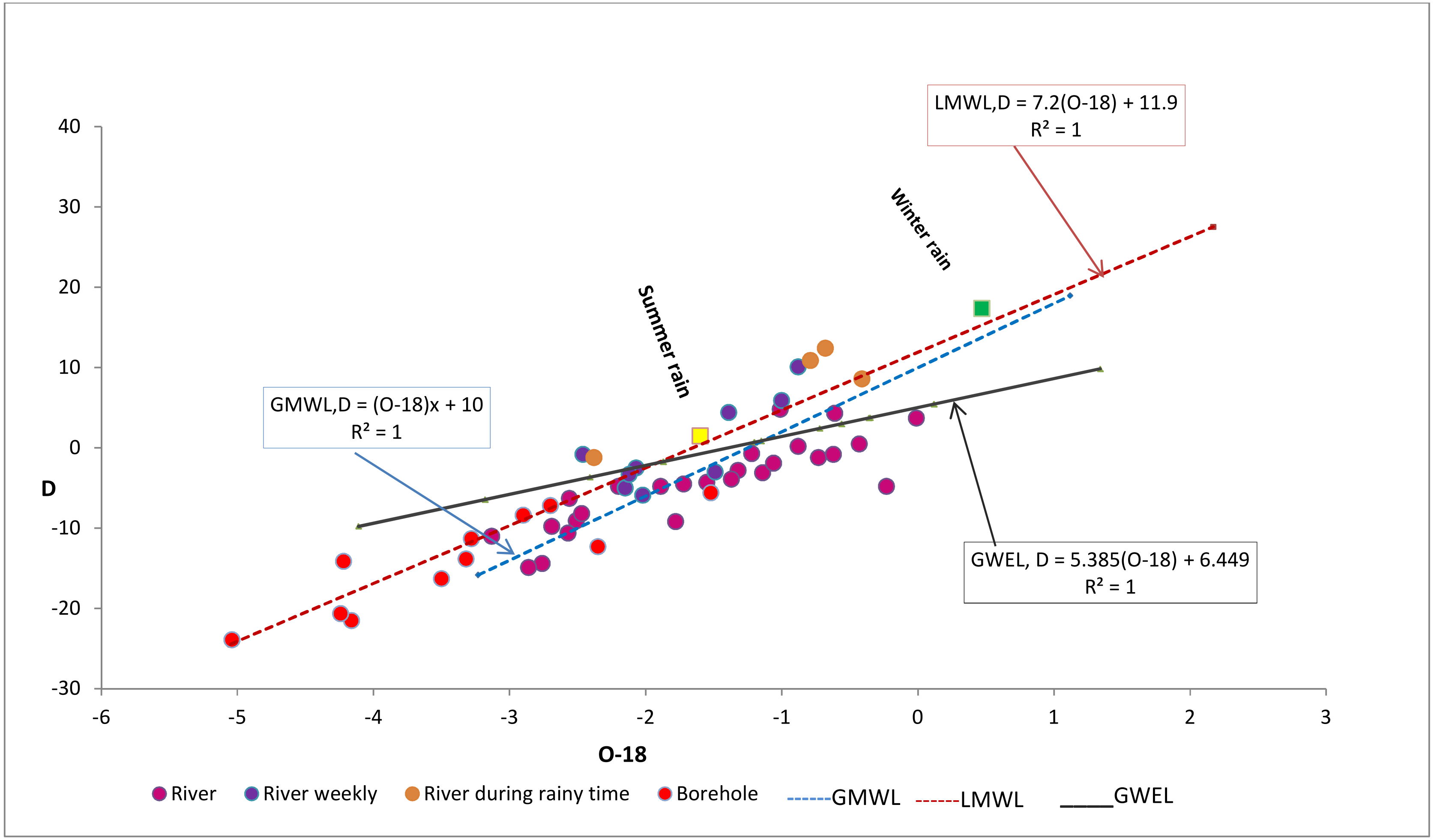

Figure 12: Distribution of stable isotope of water in the study area

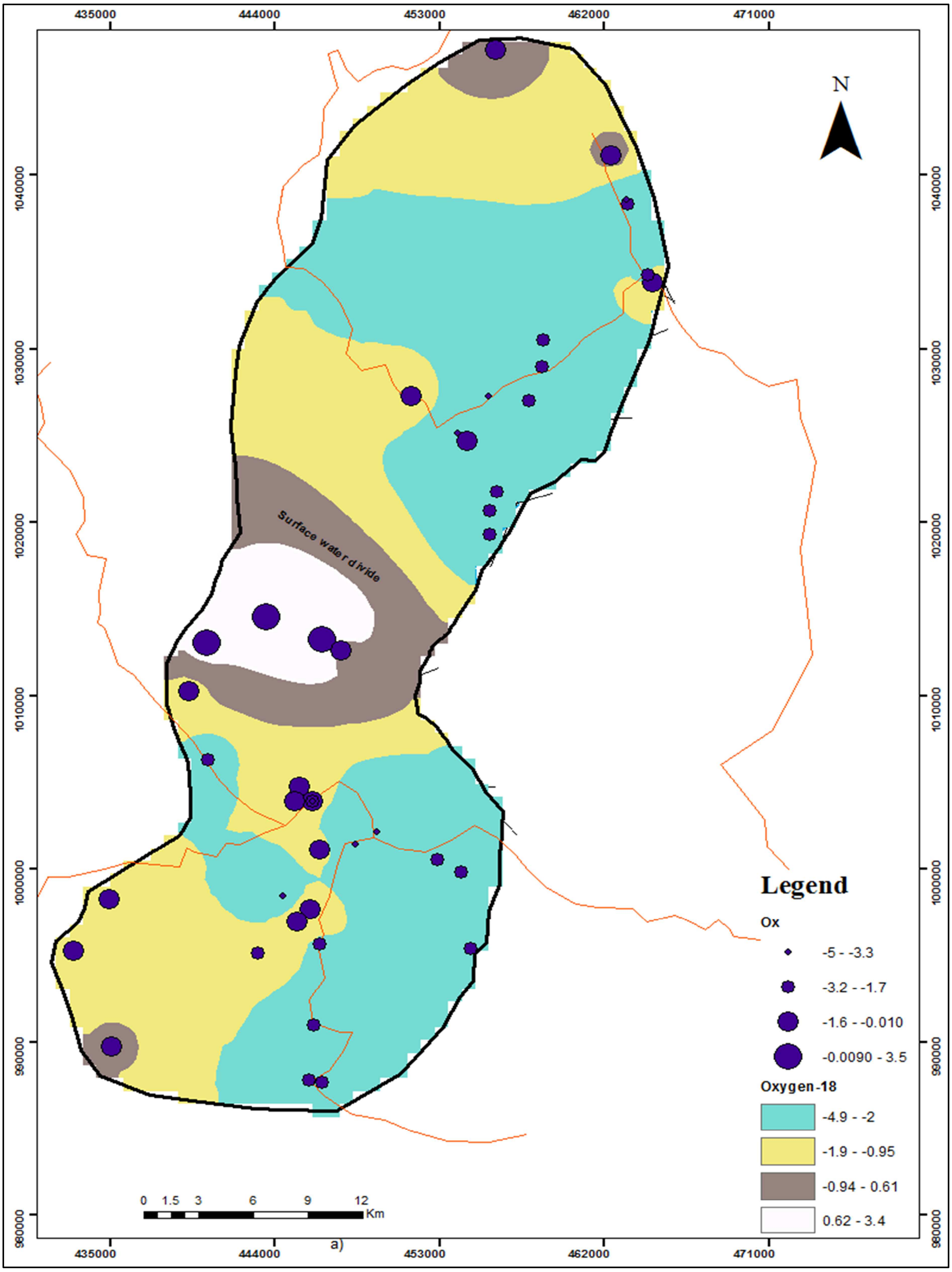

Figure 13: Distribution map of Oxygen-18 isotope

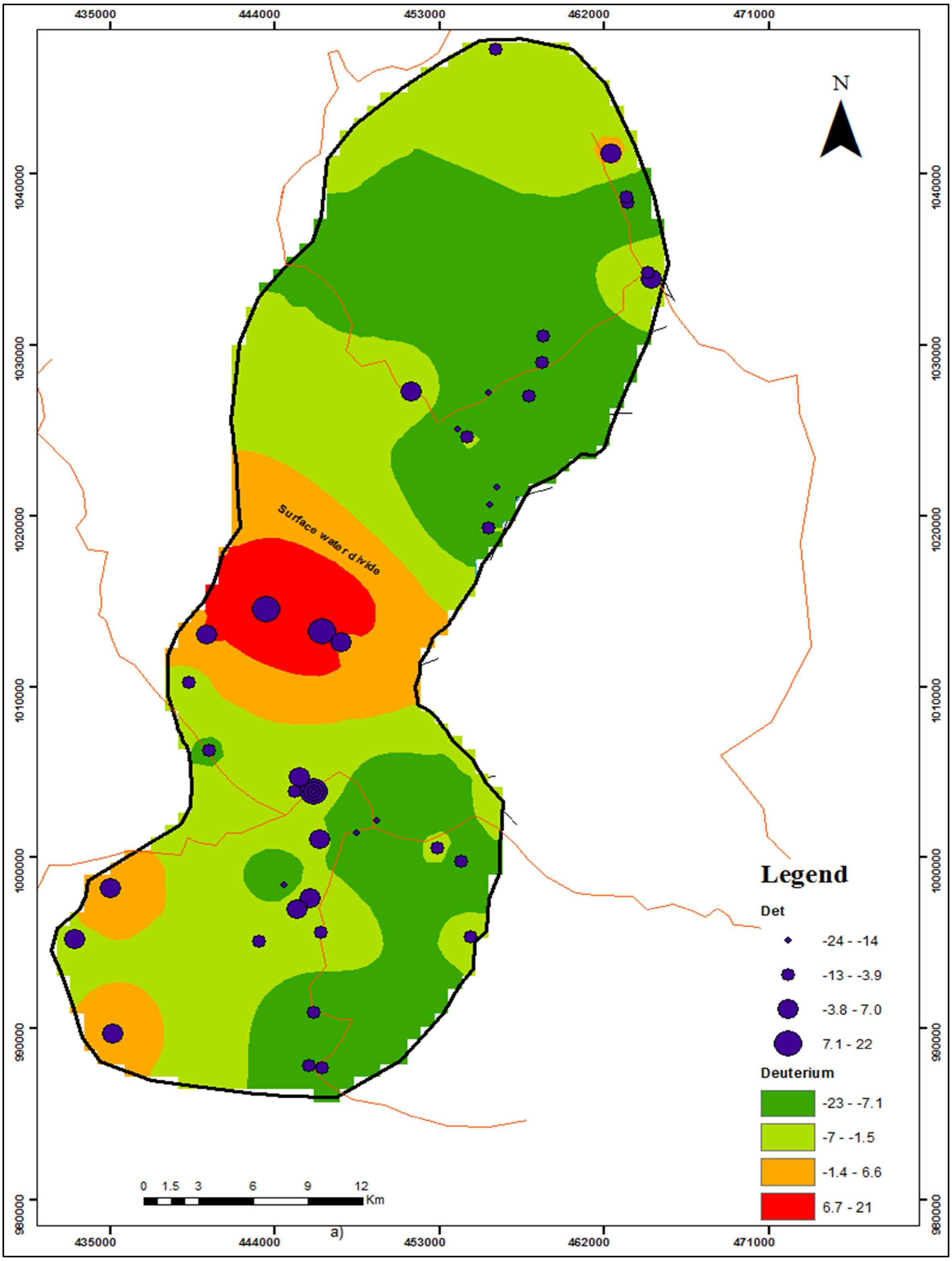

Figure 14: Distribution map of Deuterium

From Isotope distribution plot (Figure....), surface water points which were taken during the raining time shows parallel trend line with LMWL with slope value 6.289 and D-excess 14.37, weekly collected water points fall along the LMWL except some points which fall near to evaporative line were collected at the end of October. The river water points collected at different reaches of the study area are nearly plot to the evaporative line with the slope of 5.027 value corresponding to extensive evaporation prior to recharge and the relative depletion observed in the river water points were not exposed for evaporation and lain along the east west fault zone and the streams could be the gaining streams.

From the isotopic data collected from ground water in the study area is characterised by lighter isotopic signature (depleted). The δ18O and δD values range from -2.35 to –5.04 and –5.6 to –23.9, respectively. Almost all samples plot to the left of the GMWL and highly depleted compared to the summer rain of Addis Ababa IAEA station. Relatively, highly depleted groundwater located in Holota River Catchment along EW fault zone indicates deep circulation of groundwater, long residence time and long flow path length.

Generally, from the result of isotopic signature, the recharge for depleted groundwater could be through long sub surface path from the higher precipitation altitude.

Table 3: Stable isotope data

No.	**Sample ID**	**Data source**	**UTME**	**UTMN**	**D**	**O-18**	**Source**
1	HRW1	Primary data	446105	1003873	-2.5	-2.07	Holeta river, weekly
2	HRW2	Primary data	446105	1003873	-0.8	-2.46	Holeta river, weekly
3	HRW1R1	Primary data	446105	1003873	-1.2	-2.38	Holeta river, during raining
4	HRW1R2	Primary data	446105	1003873	12.4	-0.68	Holeta river, during raining
5	HRW2R1	Primary data	446105	1003873	10.9	-0.79	Holeta river, during raining
6	HRW2R2	Primary data	446105	1003873	8.6	-0.41	Holeta river, during raining
7	HRW3	Primary data	446105	1003873	10.1	-0.88	Holeta river, weekly
8	HRW4	Primary data	446105	1003873	-5	-2.15	Holeta river, weekly
9	HRW5	Primary data	446105	1003873	4.4	-1.39	Holeta river, weekly
10	HRW6	Primary data	446105	1003873	-22.6	-4.49	Holeta river, weekly
11	HRW7	Primary data	446105	1003873	5.9	-1	Holeta river, weekly
12	HWEM	Primary data	449724	1002930	-21.5	-4.16	borehole
13	HRW8	Primary data	446105	1003873	-5.9	-2.02	Holeta river, weekly
14	HW1	Primary data	448440	1001427	-23.9	-5.04	borehole
15	HRW9	Primary data	446105	1003873	-3.3	-2.12	Holeta river, weekly
16	HRW10	Primary data	446105	1003873	-3	-1.49	Holeta river, weekly
17	HR4	Primary data	445374	1004738	-2.8	-1.32	Holeta river
18	HR7	Primary data	446465	1001086	-3.1	-1.14	Holeta river
19	HR8	Primary data	445913	997622	0.2	-0.88	Holeta river
20	MR1	Primary data	458600	1028944	-9.1	-2.51	Muger river
21	MR2	Primary data	451485	1027273	-1.2	-0.73	Muger river
22	MR3	Primary data	456140	1021714	-14.4	-2.76	Muger river

No.	Sample ID	Data source	UTME	UTMN	D	O-18	Source
23	MR4	Primary data	455762	1020665	-14.9	-2.86	Muger river
24	MR5	Primary data	458689	1030535	-14.9	-2.86	Muger river
25	HS2	Primary data	454700	995350	-5.6	-2.51	Holeta, spring
26	HR9	Primary data	452911	1000512	-4.8	-1.89	Holeta river
27	HR10	Primary data	454221	999759	-11	-3.13	Holeta river
28	HR11	Primary data	443118	995089	-4.5	-1.72	Holeta river
29	HR12	Primary data	433043	995231	-1.9	-1.06	Holeta river
30	HR13	Primary data	435104	989707	4.3	-0.61	Holeta river
31	HR14	Primary data	434980	998207	4.8	-1.01	Holeta river
32	HR15	Primary data	446492	995599	-4.8	-2.2	Holeta river
33	HR16	Primary data	445890	987801	-8.2	-2.47	Holeta river
34	HR17	Primary data	445231	996952	-0.7	-1.22	Holeta river
35	HR18	Primary data	447638	1012559	3.7	-0.01	Holeta river
36	HR19	Primary data	443517	1014536	21.8	3.53	Holeta river
37	HR20	Primary data	446596	1013226	21.5	3.48	Holeta river
38	HR21	Primary data	440295	1013053	7	1.54	Holeta river
39	HR22	Primary data	439310	1010218	-3.9	-1.37	Holeta river
40	HS3	Primary data	446601	987634	-7.4	-2.08	Holeta spring
41	HW2	Primary data	446117	990929	-12.3	-2.35	borehole
42	MR8	Primary data	455718	1019251	-6.3	-2.56	Muger river
43	MR9	Primary data	463275	1038355	-9.2	-1.78	Muger river
44	MR10	Primary data	464619	1033828	-0.8	-0.62	Muger river
45	MR11	Primary data	456078	1047291	-4.8	-0.23	Muger river
46	MR12	Primary data	462392	1041185	0.5	-0.43	Muger river

No.	Sample ID	Data source	UTME	UTMN	D	O-18	Source
47	MW1	Secondary data	463209	1038637	-11.33	-3.28	borehole
48	MW2	Secondary data	464387	1034248	-7.2	-2.7	borehole
49	MW3	Secondary data	455702	1027244	-16.3	-3.5	borehole
50	MW4	Secondary data	453986	1025102	-14.15	-4.22	borehole
51	HW3	Secondary data	440379	1006281	-8.4	-2.9	borehole
52	HW4	Secondary data	449572	1002149	-20.65	-4.24	borehole
53	HW5	Secondary data	444475	998414	-13.82	-3.32	borehole
54	HW6	Secondary data	427491	992970	-29.2	-5.3	borehole
55	HW7	Secondary data	427131	996390	-2.71	-1.92	borehole
56	HW8	Secondary data	450472	981241	-14.3	-3.1	borehole
57	HW9	Secondary data	457710	1002800	-1	-2	borehole
58	HW10	Secondary data	460254	997269	-16.18	-3.92-	borehole
59	HW11	Secondary data	435083	1016838	-12.75	-3.17	borehole
60	MW5	Secondary data	471407	1027667	-21	-3	borehole
61	MW6	Secondary data	470338	1035426	-9.16	-3.14	borehole
62	MW7	Secondary data	473819	1031909	-21.2	-4.1	borehole
63	MW8	Secondary data	475578	1035082	-7.31	-2.75	borehole
64	MW9	Secondary data	432020	1025151	-6.8	-2.5	borehole
65	HW12	Secondary data	418798	988451	-2.13	-2.02	borehole
66	HW13	Secondary data	416179	995355	-10.42	-2.95	borehole
67	HW14	Secondary data	457026	981375	-23	5	borehole
68	HW15	Secondary data	464923	992809	3	-3	borehole
69	HW16	Secondary data	466083	993808	-9	-3	borehole
70	HW17	Secondary data	466425	994760	-10	-3	borehole

Radioactive isotope (^{222}Radon)

It is very crucial to define whether rivers recharge local ground water or are fed by groundwater via base flow, and to document of the flux between groundwater and surface water.

The different geochemical tracers of groundwater–surface water interaction have potential advantages and disadvantages. Major ion concentrations and stable isotope ratios are relatively easy to measure and are often measured as part of general water quality studies. However, in-river modification by evaporation, mineral precipitation, or biogeochemical processes may modify major ion chemistry. Additionally, if groundwater and surface water have overlapping δ^{18}O and δD values, these tracers may not be easy to use. Radon is an important tracer that has increased in usage over the past two decades as the ease of measurement has improved.

^{222}Rn is produced from ^{226}Ra as part of the decay series of ^{238}U to ^{206}Pb. With a half life of 3.8 days, the activity of ^{222}Rn reaches secular equilibrium with ^{226}Ra over a few weeks. 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; The concentration of Radium in minerals in the aquifer matrix is several orders of magnitude higher than the dissolved Radium concentrations in surface water; hence, groundwater ^{222}Rn activities are commonly two or three orders of magnitude higher than those of surface water. Due to its relatively short half-life and degassing to the atmosphere, ^{222}Rn activities decline downstream from zones of groundwater inflow. (Ian Cartwright.et.al., 2011).

Although, 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 (Tilahun Azagegn, 2015).

Radon data availability and analysis methods

Thirty nine measurement of ^{222}Rn activity have been taken at different reaches of river in the study area (Figure 15). A handy instrument that can form the basis of a comprehensive radon measurement system known as RAD7 portable radon detector (Durridge Company Inc.) and its accessory RADAQUA, which brings radon in the air and in water into equilibrium. Water from the source is continuously pumped in to RADAQUA instrument where the radon is degassed which further pass through a closed circuit entering the desiccant tube where the gas remains dry before entering RAD7. Finally the radon passes through another closed circuit in to the inlet of RAD7 detector where the radon is counted. The counting of radon using RAD7 has been done for three cycles with 15 minute s duration for each cycle. Thus the 222Rn pumped from source using RADAQUA passing through closed circuit and diorite desiccant entering the RAD7 will be counted for a total of 45 minutes continuous measurement.

Radon concentration measured in both Holota and Muger Rivers with their tributaries in the study area varies between 11.2 Bq/l in tributary streams of Muger River catchment up to 1000 Bq/l in Holota River catchment.

From spatial distribution map of radon (Figure 16), Radon concentration decreases downstream in both river catchments. However, the radon concentration become high in the main Holota river and low in the tributary of Holota River inversely in Muger main River, Radon concentration is low rather that its tributaries. Although. At Wochecha Mountain in Holota River catchment and in the upper Eastern part of tributary streams of Muger River catchment and around the center part of tributary streams of Muger River catchment the radon concentration also become high.

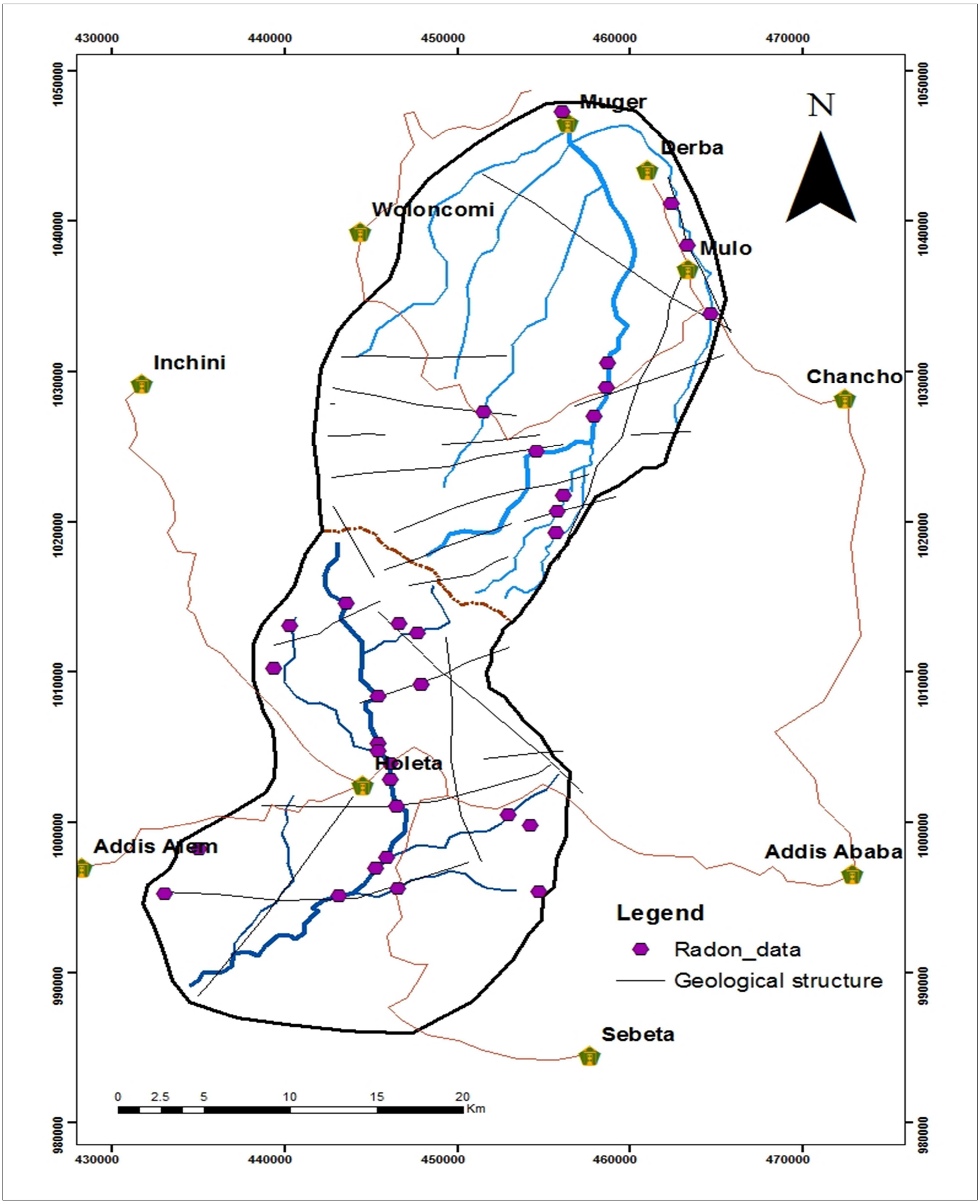

Figure 15: Radon data availability map

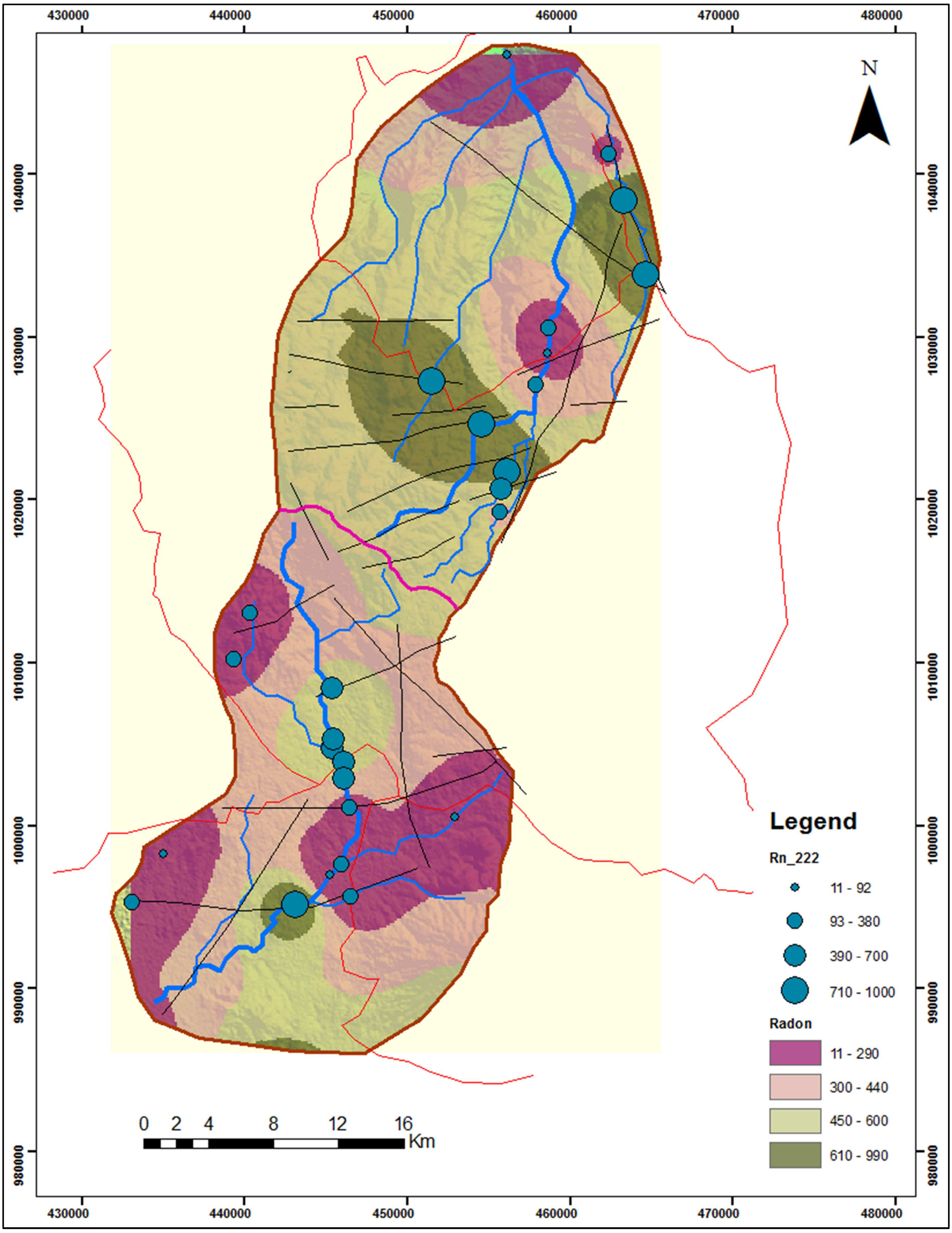

Figure 16: Radon distribution map

Radon concentration measured in the study area varies between 11.2 Bq/l up to 1000Bq/l. From spatial distribution map of radon concentration, very high radon concentration is observed along the geological structure zone in Holota river catchment, at the acidic rocks found in Wochecha Mountain and around the upper Eastern part of Muger river catchment.

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Generally, the results indicates that, groundwater is recharged the Holeta river and it is a gaining River, whereas the Muger river recharged the groundwater and it is a losing river.

Table 4: Radioactive isotope data

No	Sample ID	UTME	UTMN	^{222}Rn, Bq/l
1	HR-1	447894	1009131	1450
2	HR-2	445399	1008379	462
3	HR-3	445407	1005268	620
4	HR-4	445374	1004738	649
5	HR-5	446105	1003873	473
6	HR-6	446101	1002833	430
7	HR-7	446465	1001086	138
8	HR-8	445913	997622	162
9	HR-9	452911	1000512	46.1
10	HR-10	454221	999759	3590
11	HR-11	443118	995089	995
12	HR-12	433040	995231	173
13	HR-14	434984	998212	57.7
14	HR-15	446492	995599	173
15	HR-17	445231	996952	11
16	HR-18	447638	1012559	1450
17	HR-19	443517	1014536	1090
18	HR-20	446596	1013226	1560
19	HR-21	440295	1013053	163
20	HR-22	439322	1010213	209
21	HS-1	447864	1009140	1230
22	HS-2	454700	995350	2350
23	MR-1	458600	1028944	92.3
24	MR-2	451485	1027273	802
25	MR-3	456140	1021714	824
26	MR-4	455762	1020665	541
27	MR-5	458689	1030535	197
28	MR-6	457900	1027032	313
29	MR-7	454540	1024628	871
30	MR-8	455718	1019251	382
31	MR-9	463275	1038355	923
32	MR-10	464619	1033828	793
33	MR-11	456078	1047291	11.2
34	MR-12	462392	1041185	225

5.3 Groundwater flow

To understand the inter basin groundwater transfer between tributary streams of Muger river catchment and Holota River catchment, groundwater level elevation contour map was constructed from the data collected from the existing bore holes found in the study area and surrounding of it. The groundwater elevation contour map was generated applying Arc map 10.2 software with the contour interval 20m.

From groundwater elevation map, the groundwater divide and groundwater flow direction is identified. Surface water divide is not coinciding with groundwater divide which is fall in tributary streams of Muger river catchment. And it shows there is groundwater flow from tributary streams of Muger river catchment towards Holota River catchment. (Figure 17)

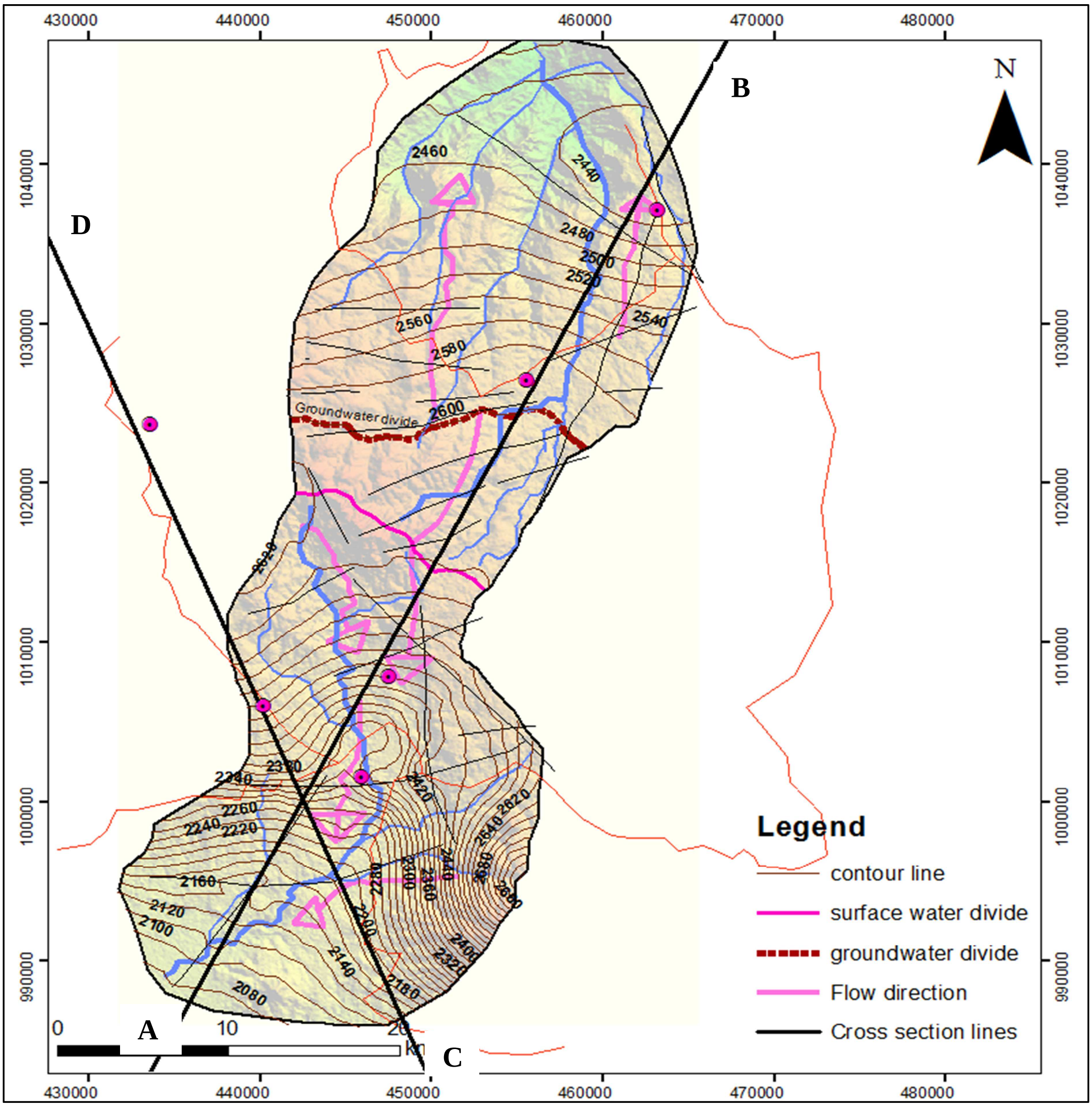

Figure 17: Groundwater contour map

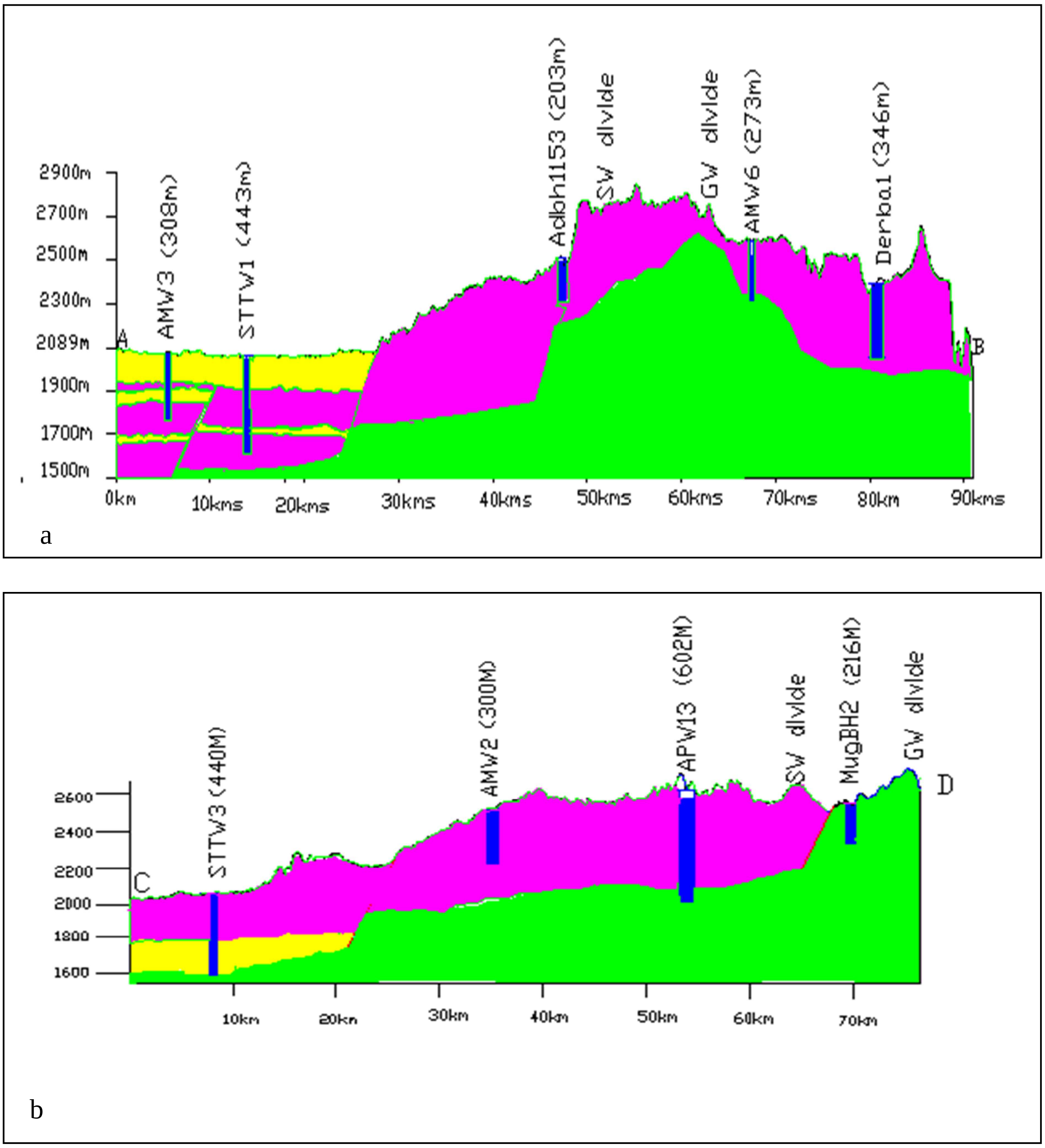

Figure 18: Cross section along AB (a) and CD (b)

Table 6: Existing boreholes data

NO.	ID	UTME	UTMN	Elevation, m	SWL, m	RWL, m	Depth, m
1	BHC1	400409	954207	2379	22	2357	48
2	BHC2	461930	970844	2193	144	2049	183
3	BHC3	427126	971361	2064	4	2060	308
4	BHC4	451420	971692	2050	58	1992	60
5	BHC5	473576	972821	2076	74	2002	150
6	BHC6	471027	973709	2034	25	2010	378
7	BHC7	461900	974300	2081	38	2043	
8	BHC8	460464	974637	2081	38	2043	61
9	BHC9	409122	975187	2107	14	2093	15
10	BHC10	438871	977181	2049	13	2036	443
11	BHC11	442842	977555	2052	14	2038	100
12	BHC12	442811	977625	2055	10	2045	179
13	BHC13	444000	977700	2058	17	2041	100
14	BHC14	441366	977899	2049	8	2041	10
15	BHC15	444624	978143	2048	10	2038	65
16	BHC16	448502	978502	2044	13	2031	440
17	BHC17	447224	978514	2051	13	2038	440
18	BHC18	473566	978610	2056	24	2033	122
19	BHC19	480900	978800	2120	86	2034	160
20	BHC20	473108	979851	2049	7	2042	103
21	BHC21	473069	979881	2048	6	2042	116
22	BHC22	481200	980000	2138	9	2129	173
23	BHC23	449082	980399	2059	11	2048	440
24	BHC24	447966	980422	2052	54	1998	80
25	BHC25	450359	981037	2075	11	2064	280
26	BHC26	441901	981393	2046	6	2041	7
27	BHC27	479400	981400	2114	3	2111	100
28	BHC28	460810	981473	2203	67	2136	102
29	BHC29	453538	982154	2068	8	2060	80
30	BHC30	455426	982736	2085	16	2069	150
32	BHC32	455450	983014	2091	15	2076	120
33	BHC33	420071	983317	2061	10	2051	350
34	BHC34	455550	983750	2122	47	2075	181

NO.	ID	UTME	UTMN	Elevation, m	SWL, m	RWL, m	Depth, m
35	BHC35	441831	983807	2041	6	2035	50
37	BHC37	455525	984000	2133	63	2070	124
38	BHC38	458646	984363	2161	44	2117	161
39	BHC39	457030	984617	2186	89	2097	140
40	BHC40	462260	984901	2273	83	2190	180
41	BHC41	459676	984947	2196	28	2168	96
42	BHC42	455000	985200	2204	51	2153	126
43	BHC43	463742	985378	2347	18	2329	125
44	BHC44	460121	985966	2240	40	2200	120
45	BHC45	461412	986324	2267	45	2222	145
46	BHC46	460500	986500	2256	27	2229	100
47	BHC47	460937	986565	2275	46	2229	114
48	BHC48	460295	986769	2287	31	2256	158
49	BHC49	462500	987000	2299	84	2216	137
50	BHC50	465419	987294	2249	15	2234	120
51	BHC51	463600	988200	2248	28	2221	64
52	BHC52	463700	988500	2249	19	2230	130
53	BHC53	465741	989188	2239	3	2236	134
54	BHC54	466308	989421	2235	4	2231	185
55	BHC55	465591	989872	2240	8	2232	257
56	BHC56	465295	990132	2234	10	2224	200
57	BHC57	429252	993949	2099	15	2084	45
58	BHC58	469050	994450	2297	27	2271	120
60	BHC60	427635	994816	2107	7	2100	125
61	BHC61	427193	994953	2113	2	2111	
62	BHC62	455475	994995	2829	61	2768	152
63	BHC63	487300	995300	2347	88	2259	120
65	BHC65	401157	996412	2299	25	2275	302
67	BHC67	401801	996640	2311	31	2280	246
69	BHC69	401587	997298	2295	22	2273	302
70	BHC70	446338	997431	2236	13	2223	125
71	BHC71	404656	997733	2230	22	2209	81
72	BHC72	459700	998075	2562	10	2552	67
73	BHC73	444677	998215	2274	6	2268	100
74	BHC74	444209	998733	2275	7	2268	98
75	BHC75	444677	998808	2293	21	2272	100

NO.	ID	UTME	UTMN	Elevation, m	SWL, m	RWL, m	Depth, m
77	BHC77	444168	998992	2278	7	2271	98
78	BHC78	443984	999625	2298	10	2288	70
79	BHC79	434015	1000129	2334	5	2329	147
80	BHC80	489927	1000153	2333	10	2323	500
81	BHC81	433779	1000228	2326	1	2325	193
82	BHC82	435382	1000251	2343	10	2333	206
83	BHC83	440595	1000333	2378	81	2297	170
84	BHC84	436160	1000453	2359	37	2322	153
85	BHC84	444997	1000718	2326	38	2289	91
86	BHC86	443132	1000869	2375	30	2345	116
87	BHC87	456856	1001081	2069	18	2051	20
88	BHC88	457162	1001115	2615	7	2608	115
89	BHC89	445773	1001323	2380	30	2350	75
91	BHC91	440110	1001337	2393	37	2356	153
92	BHC92	442635	1001366	2385	25	2360	220
93	BHC93	453522	1001474	2550	58	2492	115
94	BHC94	443050	1001649	2388	24	2364	130
95	BHC95	445180	1002459	2381	23	2358	101
96	BHC96	457823	1002833	2601	3	2599	104
97	BHC97	465900	1002875	2607	16	2591	110
98	BHC98	465410	1002944	2575	11	2564	124
99	BHC99	444642	1002960	2409	49	2360	66
100	BHC100	446155	1003073	2367	7	2360	90
101	BHC101	441584	1003445	2446	11	2435	50
102	BHC102	445099	1003816	2378	30	2348	130
103	BHC103	458783	1003841	2633	6	2627	9
104	BHC104	446266	1004147	2384	37	2347	148
105	BHC105	456212	1005371	2675	18	2657	20
106	BHC106	440274	1006055	2384	12	2372	300
108	BHC108	447549	1007893	2493	24	2469	203
109	BHC109	473038	1008484	2642	4	2638	460
110	BHC110	406722	1009647	2993	6	2987	150
111	BHC111	472975	1011144	2594	12	2582	114
112	BHC112	474421	1013070	2592	18	2574	304
113	BHC113	468100	1016250	2577	3	2574	193
114	BHC114	474463	1022973	2585	5	2580	50

NO.	ID	UTME	UTMN	Elevation, m	SWL, m	RWL, m	Depth, m
115	BHC115	433672	1023691	2560	46	2514	602
116	BHC116	473871	1024156	2565	6	2559	15
117	BHC117	432500	1024270	2585	2	2583	182
118	BHC118	432432	1024464	2591	11	2580	161
119	BHC119	420012	1030815	2609	78	2531	104
120	BHC120	398274	1030923	2801	7	2794	
121	BHC121	466233	1031004	2442	55	2387	117
122	BHC122	473911	1031930	2565	1	2564	324
123	BHC123	464387	1034248	2439	12	2427	300
124	BHC124	464070	1034816	2458	7	2452	300
125	BHC125	464387	1034248	2442	20	2422	180
126	BHC126	464612	1034331	2439	19	2420	150
127	BHC127	499461	1034506	2652	2	2650	68
128	BHC128	473020	1035389	2518	2	2516	
129	BHC129	463376	1036388	2400	7	2393	246
131	BHC131	421795	1040108	2442	20	2422	146
132	BHC132	418279	1048618	2515	38	2477	108
133	BHC133	417700	1051243	2519	5	2514	96
134	BHC134	493003	1051307	2647	25	2622	492
135	BHC135	493215	1051415	2634	6	2628	90
136	BHC136	501322	1068067	2553	70	2483	209
137	BHC137	474590	1068254	2642	6	2636	43
138	BHC138	462806	1072054	2783	10	2773	73
139	BHC139	499617	1077915	2525	80	2445	168
140	BHC140	459862	1086322	3006	33	2973	141
141	BHC141	431500	1090300	2572	2	2570	
142	BHC142	427000	1095000	2579	7	2572	100

CHAPTER 6- CONCLUSION AND RECOMMENDATION

6.1 Conclusion

An integrated hydro geochemistry and isotope hydrology approach together with water level measurements have been used to investigate the groundwater dynamics between Holeta River catchment from Upper Awash River basin and tributary streams of Muger River catchment from Abay River basin. From this study the following conclusions have been made:

- The groundwater type in the study area is characterized by four major water types (CaHCO3, Ca-Na-HCO3, Na-Ca-HCO3, Na-HCO3 and others). Water type of most river samples in the study area shows CaHCO3 water type with high TDS concentration which are characterized by recharge area waters as early stage geochemical evolution. Ca-Na-HCO3 and Na-Ca-HCO3 groundwater types are located along with the fault zone with rock-water interaction phase, in the upper part of the ground water divide and around the relatively high elevated areas which characterizes the recharge zone of the study area. Na-HCO3 groundwater type is located only in Holota River catchment along the fault zone and the eastern boundary of Holota River catchment of the study area this type of groundwater is highly evolved water types with rock-water interaction with long flow path length which characterizes the discharge zone of the study area.

- The stable isotopes signature of the deep groundwater found in the study area characterized by depleted isotopic signature. Deep aquifers of Holota River catchment shows highly depleted isotopic signature than aquifers found in tributary streams of Muger river catchment. This indicates that the aquifer found in Holota River catchment recharges through long sub surface path from the adjacent catchment.

- Radon concentration is decreases from groundwater divide towards the downstream of the rivers. High radon concentration is observed along Holota Main River and around NE and SE of the study area, which is characterized by acidic geology (Figure 2 and Figure 16). Low radon concentration is observed in the main River of Muger.

  From the above discussed integrated methods (hydrogeochemistry, isotope hydrology and groundwater level investigation), and generally reached, the groundwater divide is not coincide with the surface water divide, which is fallen in the Tributary streams of Muger River catchment and there is an interbasin ground water transfer between the tributary streams of Muger River catchment and Holota River catchment.

6.2 Recommendation

- Seasonal measurements of radon concentration along River flow path and tributary streams are recommended as it helps characterize surface water-groundwater interaction and ground water dynamics in detail.
- Detail studies like this work are recommended to in other adjacent catchments to characterize complex aquifers between Awash and Abay River basins.

CHAPTER VII- REFERENCE

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