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Collage of natural and computational sciences

School of Earth Sciences

**Implication of Spring Spatial Discharge Variation on Groundwater Hydrology
in Kulfo River Catchment, Arba Minch, Southern Ethiopia**



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Submitted to School of Earth sciences in partial fulfillment of the requirements for the
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This is to certify that the thesis prepared by Tekle Bangu, entitled: Implication of the spring's spatial discharge variation on the groundwater hydrology in kulfo river catchment, Arba Minch, Southern Ethiopia submitted in partial fulfillment of the requirements for the Degree of Master of Science in Hydrogeology complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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By I signature below, declare that this thesis is my original work and has not been presented previously for a degree on any other university. I have followed all ethical and technical principles of research in the preparation, data collection, data analysis and compilation of this thesis. All sources of materials used for the thesis have properly acknowledged.

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Abstract

Mostly water supply for utilize purposes is from underground storage systems which would be conceptualized by geology, structures, topographic set up, land cover and surface drainage. In this study, the assessment of groundwater occurrence, flow and distribution with respect to perennial springs discharge has been made. Thus, the main objective of current study is to characterize and assess implication of springs spatial discharge variation on groundwater hydrology in kulfo river basin by using combined approaches of field study, DEM and satellite imageries, geologic cross-section, springs discharge evaluation and hydrochemical analysis. Hence, Perennial springs located on the surface geologic environment are good indicators of water placed underground. For this reason, the controlling factors that have role in spring's emergence and made variant discharge in the Kulfo River basin are identified. Springs in the area are connected dynamically with the groundwater directly through fractures and tectonic fault line. Consequently, the fault systems are very important on the occurrence and circulation of groundwater. It produces water natural over flow on the surface by help of artesian pressure. Distribution of springs along fault line indicates major faults are strong factors that control occurrence, distribution and flow of groundwater. Faults can act as conduit and storage medium or they can act as barrier. Nature of geological formation is a factor that can be considered next to fault structures to control groundwater dynamics. Thus, amount of springs discharge can be increase from older to younger lithology while its distribution is reversely associated older to younger. Topographic variation is also responsible for the variation of spring discharge. Integration of the factors mentioned above is responsible for spatial spring discharge variation and groundwater occurrence in the River basin. Hydrochemical characteristics such TDS, EC, PH, temperature, major cation and anion analysis could be measured at field and tested in laboratory. Their dominance is increasing from upper to lower rift floor. Combining this evidence, springs discharge chemistry is one of the best indications of groundwater flow direction, aquifer geology, residence time from recharge area to discharge one in the catchment.

Key words: Spring, Groundwater, Upper and Lower Zone, Kulfo River basin, fault and Arba Minch

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ACRONYMS

AAS – Atomic Absorption Spectroscopy

a.s.l. - Above sea level

AM - Arba Minch

BH – Q – Borehole yield

Conc. – Concentration

EC – Electrical conductivity

E.D – Egzer dildy

Fig. – Figure

L/S – Litters per second

L/min – litter per minute

LGWD – Local Groundwater Divide

Mg/l – Milligram per litters

MER – Main Ethiopia Rift

mmMaxRf – mean monthly maximum rain fall

mmMinRf – mean monthly minimum rain fall

NNE - North-North East

NNW - North-North West

RVLB – Rift valley lake basin

SSW - South-South West

SNNPRWRD – South nation nationality and peoples region water resource development

SQ – Spring discharge.

TDS – Total dissolved solute

μS – Microsiemens

UV – Ultra visible

CHAPTER ONE

1. Introduction

1.1 Background

Water is one of highly essential natural resources for survival of all living thing on the planet Earth. It exists in the atmosphere, on the Earth's surface (the hydrosphere), and under the Earth's surface (the lithosphere). The water exists under earth surface is called as ground water. Ground-water hydrology is subdivision of science of hydrology that deals with the occurrence, movement and quality of water in a complex subsurface environment (Ralph C. heath, 1983). Hydrology has been defined as the study of the occurrence and movement of water on and over the Earth's surface independent of the seepage of groundwater and springs which sustain river flows during seasonal dry periods (Kevin M. Hiscock, 2005).

The ground-water environment is hidden from view except in caves and mines (Ralph C. heath, 1983), hence the subsurface openings large enough to yield water in a usable quantity to wells and springs. And this make ground water is one of the most widely available natural resources. Groundwater is removed from aquifer by withdrawal through well, springs discharge, sub surface outflow and base flow in river. However, the principal ways of using groundwater are through spring and well developments.

A spring is a natural outflow of water from an underground supply to the ground surface. Ground or spring water represent an important source of drinking water and its source determined by chemical analysis of water chemistry that arise during interaction with geology through flow path and temperature through which water is circulated below surface of earth. From the spatial distribution of springs water overflow from groundwater types in the area, system of hydrogeological characterization has been made and dominant hydrochemical processes were also defined. The spring distribution in study area defined based on topographic setting, geologic structure and drainage pattern.

Groundwater natural discharge is the term used to describe the movement of groundwater from the subsurface to the surface and result spring flow on the land surface. The spring flow on the surface has direct linkage with groundwater storage and movement. However, the all springs that have no discharge in dry season, may not represents potential groundwater storage below surface of earth. It discharge variation is also based on geology, geological

structure and physiographic variation. The springs spatial discharge variation defined as the variation of springs yield with source, location, elevation, geology and geological structure in given catchment. The essential factors in the production of springs are the source of the water and the rock structure which brings it to the surface.

The Arba Minch and its surrounding area is an area characterized by various surface as well as subsurface water bodies. The surface water bodies include the lakes (Abaya and Chamo), the rivers (Kulfo and Hare) and groundwater (springs and wells). The Arba Minch or forty springs are the only springs in lower catchment which exist in dry seasons. But in the high land part of study area, the large numbers of the springs are available in dry season.

This research will give detail understanding on the previous researches which were done on and around the kulfo river catchment by using hydrochemistry, recharge estimation, modeling and apparent resistivity method evidences. And, this study will provide detail information on the spring water characteristics and factors that control groundwater come up to form out crop on the surface of earth. The approaches proposed to achieve this work are field observation, field measurement and hydrochemical analysis.

1.2. Statement of the Problem

For the most part, water supply for domestic purposes in the study area is from underground storage systems (springs), due to its abundance and portability without excessive treatment. Due to central increase of population and industrialized use, only looking forward to springs water may not be enough for further life. Hence, evaluating groundwater productive zone in relation to spring distribution is essential to preserve water resource for future generation. There are a number springs are found in the kulfo river catchment including Arba Minch spring. However, using this spring directly for water supply is a big problem due to topographic difficulty and accessibility especially in upper zone of catchment. Therefore, one of the options for such condition is develop study on springs spatial discharge variation in relation to groundwater environment, water underground circulation and controlling factors behind. The availability of spring that has flow through year may give information on availability of water bearing materials below ground surface.

Previously some of researches have been carried out by different researchers in the issue relate to groundwater investigation, water quality assessment and water supply for domestic and irrigation use. But still the study shows that their focus straights to ward Arba Minch

spring and surrounding geology in the kulfo river basin. They did not consider the upper zone of catchment.

1.3. Research objectives

1.3.1. General objectives

Characterize and find out implication of springs spatial discharge variation on Groundwater Hydrology in kulfo river catchment by using different techniques is the main objective of this research.

1.3.2. Specific objective

- ✓ Quantify spring discharge at measurable site and identify its spatial variation in the catchment
- ✓ Characterize springs by using chemical parameters, physical parameters, and topographic location. And estimate the depth of circulation of spring water selected for measurement by considering natural dissolved solute.
- ✓ Characterize lithologic units and structures in terms of spring location. And indentify their effect on spring spatial discharge variation.
- ✓ Characterize aquifer properties, determine ground water flow direction and identify groundwater discharge and recharge zones based on susceptibility of water-rock interaction.

1.4. Methodology and materials

In order to achieve the research objectives, different methods are selected from first to last in whole work that has been done. The methods decided to perform the research work are mentioned as follows.

1.4.1. Spring discharge Measurement

In order to measure and identify spring spatial variation in the catchment, previously recorded discharge data was collected. Depend on exist discharge data; nine springs are selected to check their discharge and field sample collection. Due to volume discharge and location, six springs at dry season is measured by using direct peach per time while two is quantified by plotting. But the Arba Minch spring discharge recorded from gauging is directly used for analysis due to their large volume discharge.

1.4.2. In situ water quality measurement and sample collecting for laboratory analysis

The analysis items of water quality in the site are: temperature, electrical conductivity, total dissolved solids and concentration of hydrogen ion (PH) which may varies with springs discharge from upper zone to lower zone of study area. This is intended to grasp information on water quality variation before laboratory analysis. By considering procedure, the nine spring's water sample is collected for laboratory analysis. When collecting sample, laboratory test water chemistry such as Ca, Mg, Na, K, HCO₃, SO₄, Cl, NO₃, and alkalinity spatial variation in the basin is was considered. Identify these parameters is very important so as groundwater discharge zone of catchment since it has dominant chemical content and recharge zone since water is less susceptible to rock water interaction. During sample collection, the geology, geologic structure at and surrounding of springs location is noted and described. In relation to these factors, the minimum yields of springs are recorded.

1.4.3. Field description and identification

In terms occurrence and circumstance of springs, detail field observation and description has taken. At the same time, identification of structure that may govern emergence of springs in different location is also main issue. These parameters of field study carried out by using materials of geological hammer, button compass, GPS, digital camera and topo map. By using these materials, field description associated with springs opening and location has been characterized. Using secondary data with field study, DEM and satellite imageries, geology and geologic structures were identified.

Considering groundwater flow direction in the catchment, water point inventory, and water level measurement in dug and drilled wells as well as use of secondary data was performed. By using data collected, contour map could be constructed to point flow direction in the catchment.

1.4.4. Data analysis

Based on data available and primarily collected, perennial springs distribution and its discharge variation analyzed by producing geologic map contain structures, and cross-section. Depending on above evidence, hydrogeology of catchment is characterized. This processed by using Arc GIS 10.3 and Auto cad 2007. To emphasize hydrochemical variation springs in the river basin, water sample tested and analyzed. Hydrochemistry of springs characterized by using software such as of Aquachem 4.0 and Diagrammes. Generally, data analyzed performed by using field result, laboratory test, and designed software.

1.5. The previous works

In the southern Ethiopia Arbaminch area, some of systematic investigators and organizations have been directed their research and projects on groundwater investigation to evaluate groundwater resources. The followings are study area related works that have been conducted previously.

Samuel Dagalo (2009), studied on title of Groundwater Condition Assessment in the Arba Minch Area, Aquifer types in the lower kulfo river basin are dominantly confined, unconfined and partly semi confined. The high values of transmissivity in the area indicate that aquifer can carry a good yield from the formation.

(Tamiru Alemayehu, 2006). Generalized as, one of the most famous cold springs in Ethiopia with maximum yield of 250l/s is Arbaminch spring (meaning forty springs) which associated with the rift escarpment. This may be because the normal faults that form the scarp act as a barrier.

Amanial Haile Rada (2015), conducted on Assessment of Physicochemical Quality of Spring Water in Arbaminch. Spring water is a major source of water for drinking, agricultural, and industrial desires. The availability of water determines the location and activities of humans in an area and our growing population is placing great demands upon natural fresh water resources.

South Nation Nationality and People's Region Water Resources Development Bureau, (2009) is carried out the final feasibility study of water supply in Arbaminch town. According to this study fractured Aquifer of Quaternary Basalt on the down thrown side of the escarpment in Arbaminch area is the potential very high productive aquifer as observed from the big spring originating from the quaternary basalt. It is highly fractured and weathered scoriaceous rock with gas vesicles. The tertiary basalt aquifer is the lowest productive rock group in the area. The weathering in these rock formation results in clayey material which reduce the aquifer transmissivity whereas the fractures facilitate the groundwater flow (Report).

Paulos Masresha (1996), conducted his research on Hydrological and hydrogeological study on kulfo river basin. The springs develop when ground water reaches the earth surface. So, chemical composition of springs is related to the soluble product of host rock, weathering, decomposition and changes with respect to time and space. This study not included other springs in the kulfo river catchment except Arba Minch.

Ministry of water and electricity (2012), worked on master plan study in rift valley lake basin. In this study, the hydrogeology, geology, groundwater occurrence and water resources evaluation has been done, unpublished report.

Geological survey of Ethiopia (2017), groundwater resource assessment directorate worked on integrated hydrogeological and hydrochemical mapping of dime map (NB37-5), report.

The above all studies are appreciated and acknowledged by their different study title that conducted in RBLB include study area around Arba Minch. They have been focused their investigation on the lower zone of kulfo river basin around Arba Minch springs. But their study show the gap in the groundwater–springs, springs-geological structure relation, springs spatial discharge variation–groundwater occurrence and flow relation, and factors that that bring variation of springs discharge in kulfo catchment. Therefore, this study on title of implication of the spring’s spatial discharge variability on groundwater hydrology in kulfo river catchment may fill some of above missed previous study and cover all kulfo river catchment. It may contribute to map perennial spring’s distribution and their discharge variation that imply productive aquifers in the catchment.

1.7. Significance of the study

The study significantly develops understanding on spring–groundwater integration that makes possible hydrogeological investigation to indicate groundwater occurrence. Furthermore, the finding of this research will also serve as a basic information and reference for those who want to conduct further research on the area.

In addition, this research work is significant to conceive controlling factors that made groundwater exposed on the ground surface in the form of spring. Groundwater flow direction in catchment and source of springs for surface flow provide good information for us about aquifer system.

CHAPTER TWO

2. Description of Study Area

2.1. Location and size of study area

Study area is lies within southern sector drainage system of the Main Ethiopian Rift Valley and located in rift valley Lake Abaya – Chamo basin. Geographically it is placed in between UTM Coordinate of 313000-346000 m E Longitude and 6535000 – 691000 m N Latitude. The altitude varies from 1100m - 3456m. The investigation carried out on this area is covering an area of 453 square kilo meters large as shown below in figure 1.

The accessibility straightens for study is order into three Asphalt, gravel and foot trial roads. The site of study is found in 510km south of Addis Ababa within Southern Nations, Nationalities and Peoples Region and accessible by asphalt road from Addis Ababa-Butajira-Sodo for 395 km and Sodo-Arba Minch for 115 km as shown in Figure 1 of the study area.

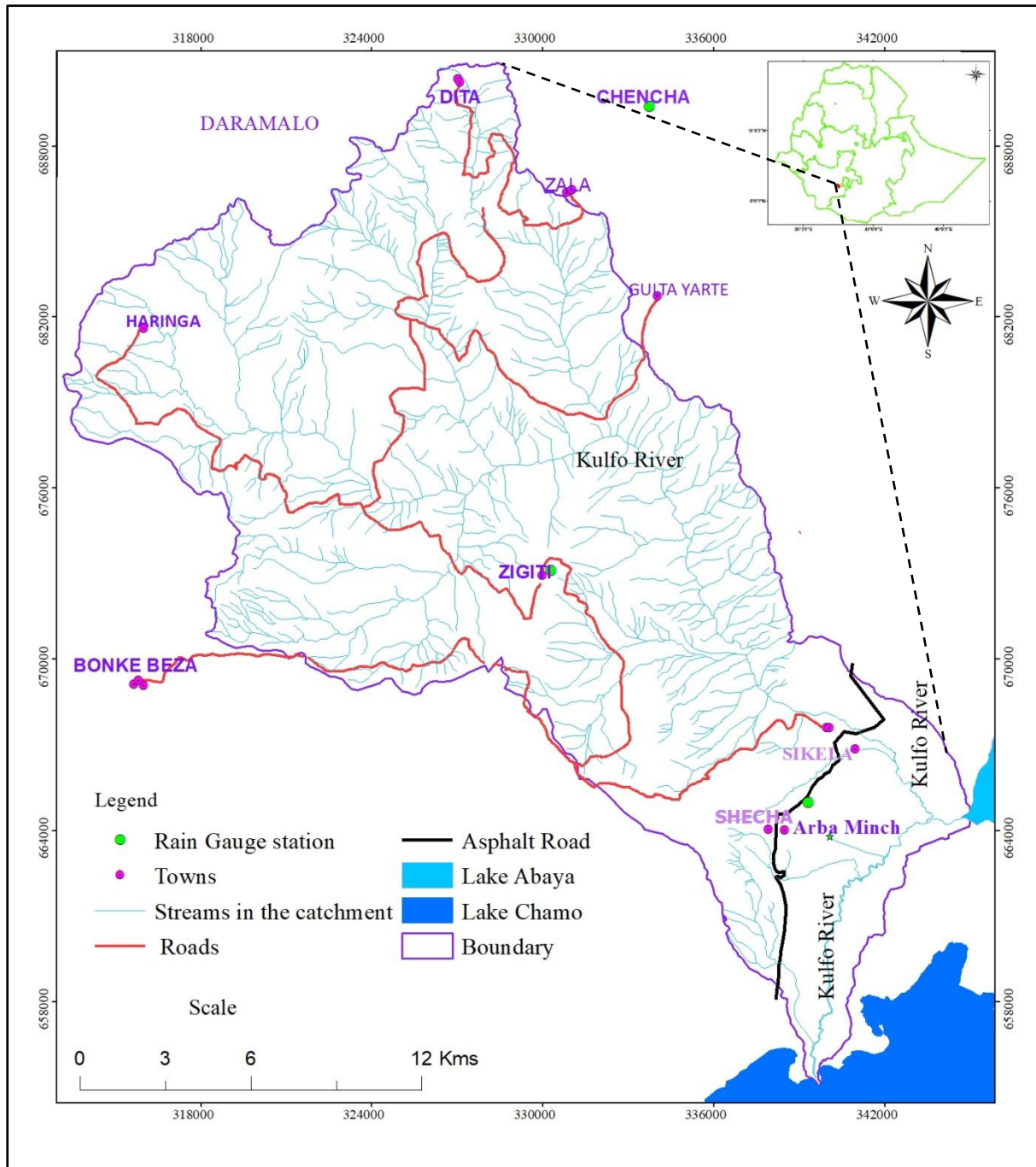


Figure 1. Location map of study area

2.2. Physiographic setting and drainage system

The physiography of kulfo river basin located in southern part of rift valley lake basin along Chenchu escarpment and bordered by water divide of Omo River basin in the north, Hare River in the eastern, Sile River in western part of study area. It dominated by volcanic bridged mountain range that chain together by river cut. This type of physiography largely observed in the upper part of the catchment shown in (fig.2). Tectonic processes such as fracturing and faulting of the rocks and external processes including weathering and erosion

are the reason for the present landscape. Major NNE-SSW faults of the extension the Wonji Fault Belt have down thrown in the lower part of the forming plain land later filled by alluvial deposit (SNNPWRD, 2009). The faulting is controlling physiographic feature due to tectonic system in the catchment that result present surface.

In general the tectonic processes can divided the landscape of study area in to three; the Trap of Ridges and plateau areas, the escarpment which is mainly the sloppy part from the foot of the mountain up to the top one, and the river valley and the alluvial – lucustrine depsits plain. The geomorphologic classification of the area is presented in (Fig. 2).

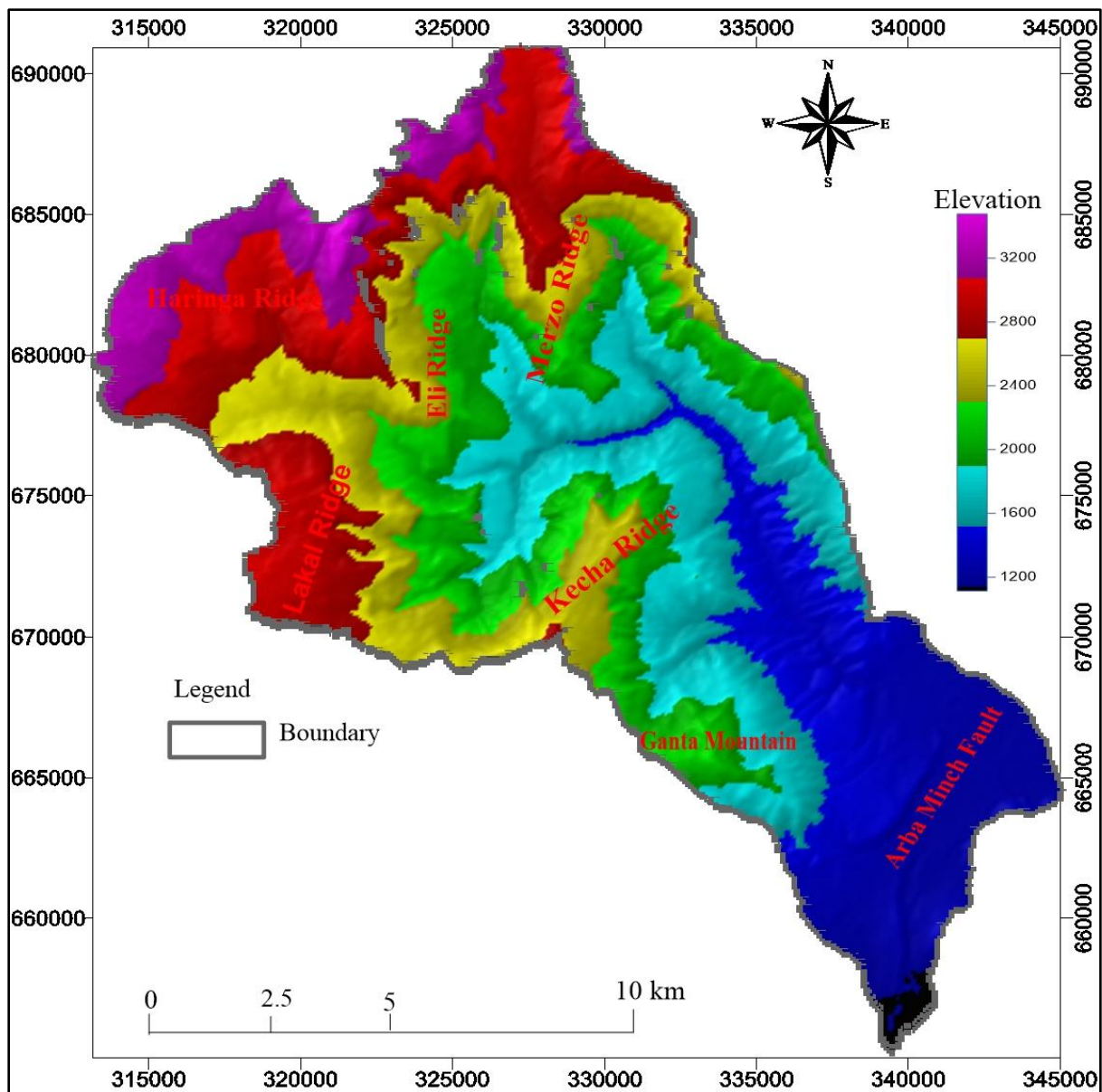


Figure 2. Physiographic map of study area

The kulfo river catchment is incorporated with gravity flow dominated springs which results streams and sub rivers in the upper part and Main River (kulfo) in intermediated to lower basin zone.

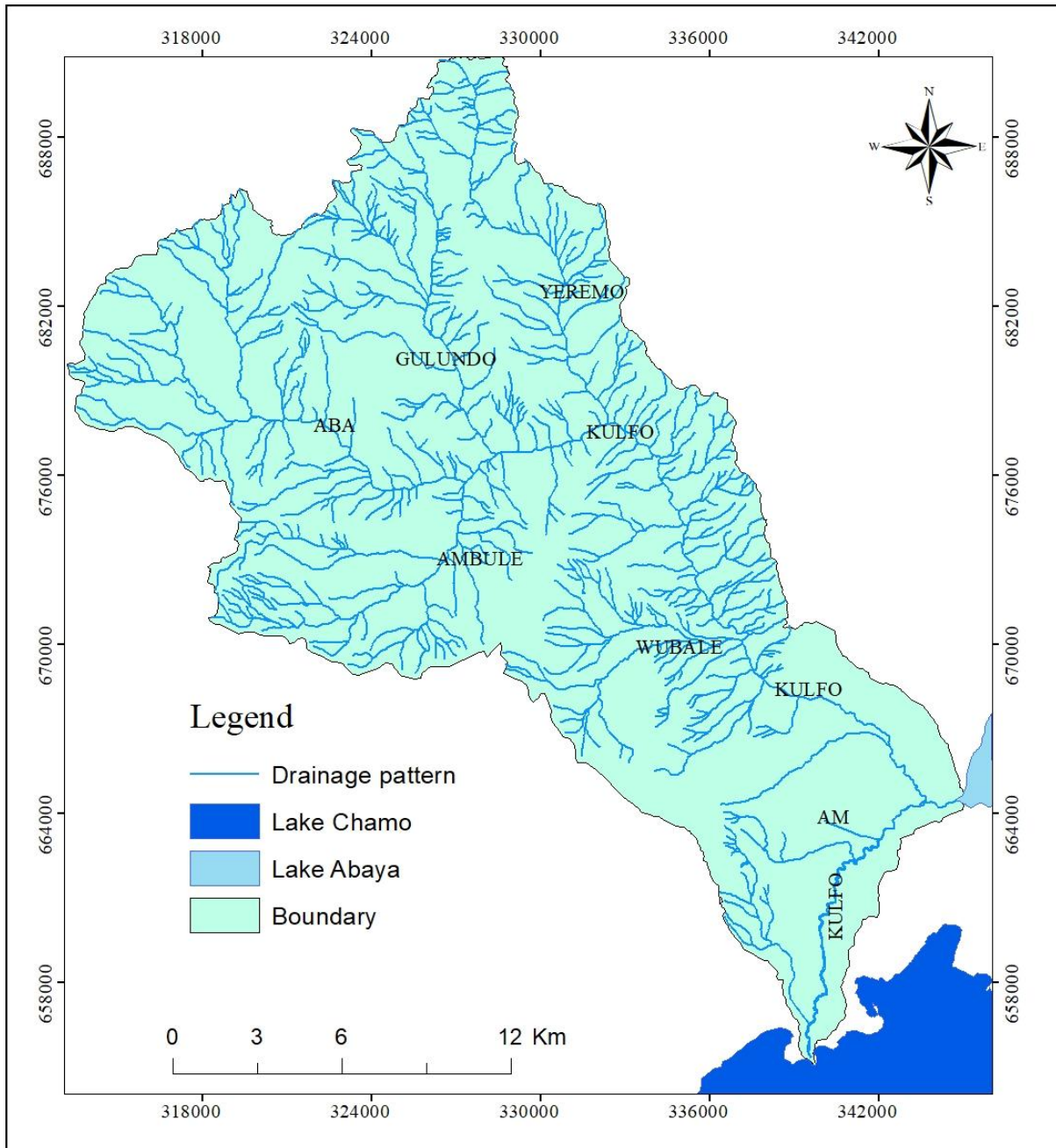


Figure 3. Drainage map kulfo river basin

In the catchment the upper part controlled by numerous springs that form streams which cause four Sub river of Baba, Ambule, Gulundo, Wobale River and Yeremo. Including this entire sub river, forty springs and Abaya Lake over flow feeding Kulfo River in slight quantity are form out let in to Chamo Lake.

The discharge volume of Kulfo River varies with climate condition. Hence at dry seasons, it gets low in volume at lower catchment and medium at upper part. Based on drainage pattern and topographic setting, the catchment divide into three; upper zone, intermediate and lower zone. The springs that have been selected for this study are situated in topographic settings representing the three classes of river basin. The distribution of spring in all three parts is expected to be different in quantity, quality, and discharge amount.

The local name of the springs, their geographic coordinate (UTM) and geographic position in which they lie are describe in (table 1), and the location map of the springs with their respective delineated physiographic zone of catchment is given in (fig. 4).

Table 1. Geographic position of the studied springs

No	Springs name	x	y	Z (m asl)	Topographic position
1	Arba Minch	340032	663604	1220	Lower zone
2	Ganta spring	332495	665984	2211	Intermediate zone
3	Eshato spring	329380	670071	2390	
4	Lakal spring	318304	675874	2874	
5	Shanke spring	323281	669897	2560	Upper zone
6	Gum'ee spring	328227	688642	2974	
7	Bosha spring	328055	687570	2920	
8	Merzo spring	327766	683002	2732	
9	Shale spring	322670	676872	2237	

The most of springs in the intermediate zone are gets dry mean that not available in dry season. But the spring's Ganta, eshato, and others are available in western part of intermediate zone. In the upper zone more than 80 springs have continuous discharge in the dry season. Among them, the springs mentioned in table 1 are selected to represent others. In the lower zone springs are emerges in the location with enough discharge and form springs group or Arba Minch (forty springs).

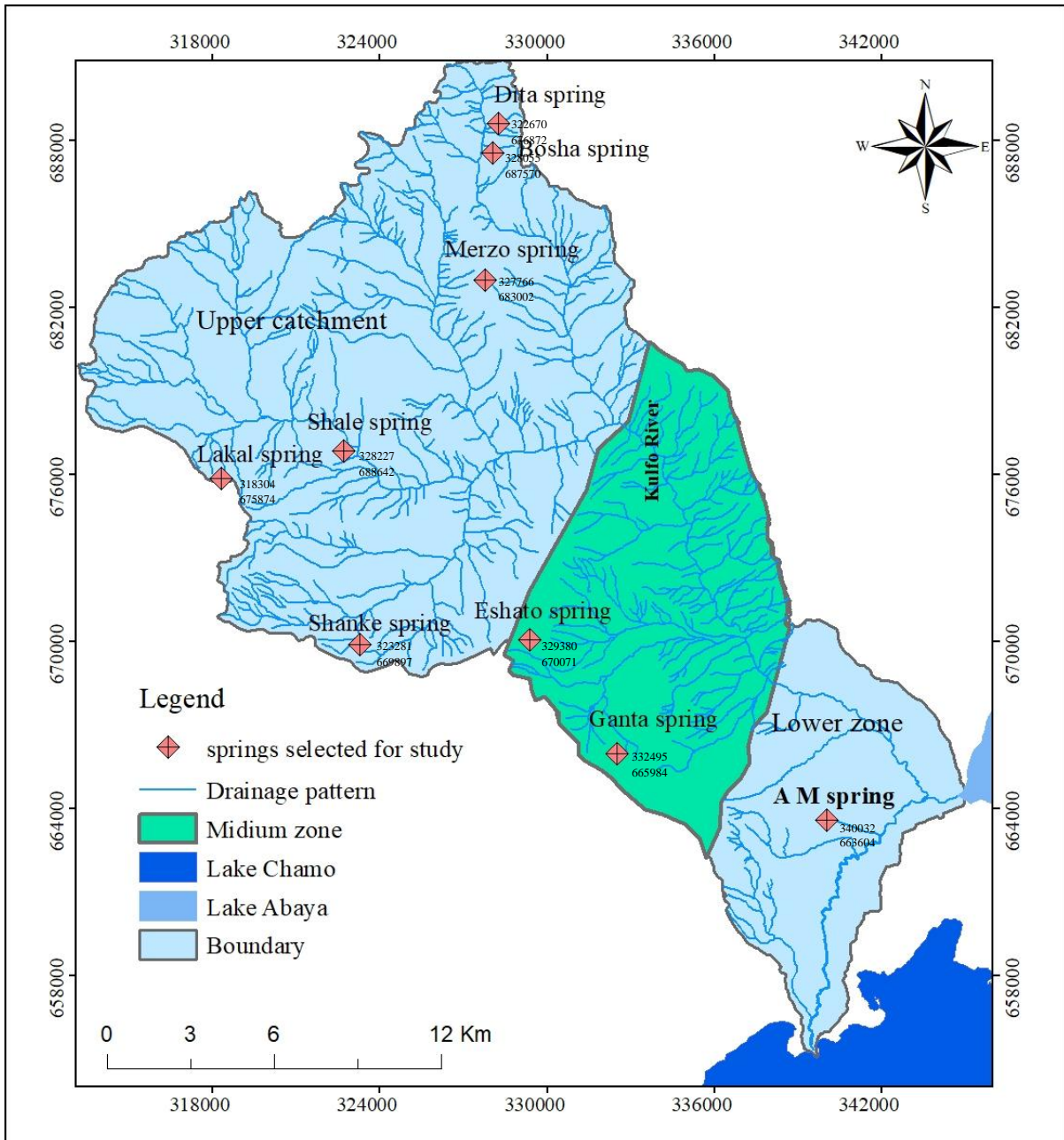


Figure 4. Springs water location map in the catchment.

2.3 Climate

Climate is the factor that in a natural way determines the schedule of recharging groundwater resource. It causes direct influence on infiltration, groundwater storage and over flow that brings to the springs on the surface of earth. The metrological data include rainfall and temperature in the Arba Minch, zigit and Chenchu that represent upper zone of catchment are used to identify the climatic schedules of study area. The climate condition of study area that has been described to select dry season for minimum discharge of spring are rainfall and temperature.

Rainfall

Gissila T. et al, 2004) stated that the three rainy seasons which affect Ethiopia are February/March to May, June/July to September and October to November. However, these seasons are not common in all local part of Ethiopia. Based on meteorological data, the rainfall pattern of the study area is analyzed by using three station; Arbaminch, Zigiti and Chenchu which belongs to lower, intermediate and upper zone of river basin respectively. The rainfall schedules in these three zones are almost bimodal seen in figure 5. But in upper zone, there is some variation in wet season that first rain time from March to May with mmMaxRf reaches 191.1mm and second rainy time from July to October with mmMaxRf reaches 162.2 mm. similar to wet season, dry season in these region is also bimodal mean that other all months in the same station have taken as dry seasons.

In the lower and intermediate part, wet and dry season schedule is approximately the same; first rainy time from April to May with mmMaxRf reaches 157.67mm, 182.3 mm and second from September–October with mmMaxRf reaches 98mm, 110.85 mm respectively. But the other all months has been taken as dry months. Similar to wet season, dry months in the intermediate and lower zones is bimodal; the first dry season from months of December to March and second dry time exist from June to August. There the common dry months in the study area is November, December, January, February and June observed in figure 2-5. Most of springs in the study area going dry at these season but some them are still flow through the year.

Selectively, the dry months in the lower zone or Arba Minch station noted from (fig.5) are November to March as first dry season and the second from June to August. In these seasons all except forty springs are gets dry.

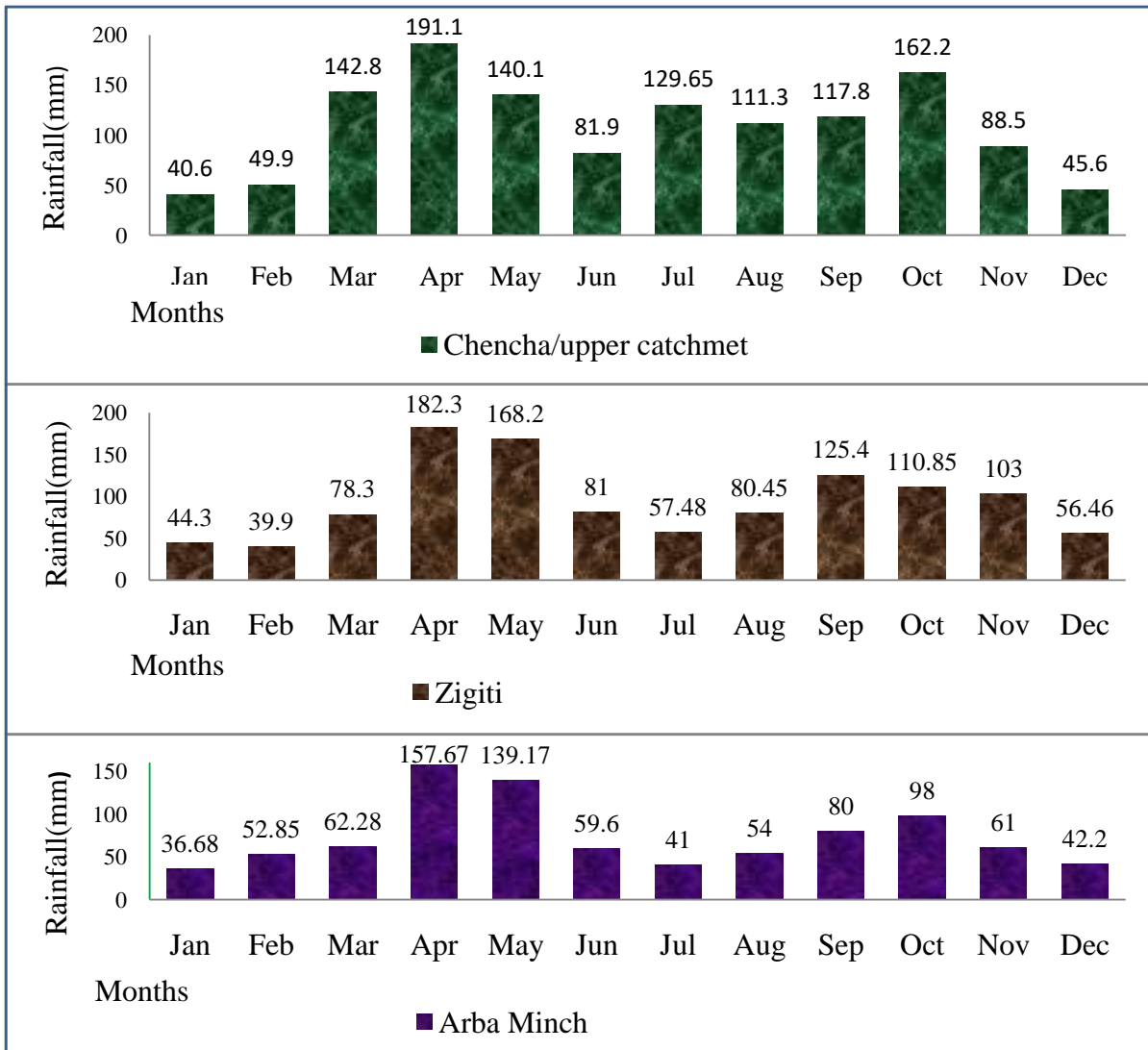


Figure 5. Mean monthly rainfall of study area.

Temperature

According to meteorological data, the mean monthly maximum and mean monthly minimum temperature of study area are observed in (fig. 6). The highest mean monthly maximum temperature of Arba Minch is 33.4 °c in February and lowest is 27.17 °c in June. The highest and lowest mean monthly minimum temperature of AM is 18.6 °c in March and 15.5 °c in December respectively. The highest and lowest mean monthly maximum temperature zigiti in intermediate zone is 21.8 °c in February and 16 °c in August. According to relation of spring water discharge temperature with mean monthly temperature in lower and intermediate zone, the upper catchment of study area has lowest temperature.



Figure 6. Mean monthly maximum and minimum temperature of Study area

CHAPTER THREE

3. Geology and hydrogeology

3.1. General

Main Ethiopia rift valley is a sunken block which divides Ethiopia into two parts to western and eastern plateaus. Based on surface morphology, Main Ethiopia rift can be divided in to three sections Northern, Central and Southern sector (Giacomo C. et al, 2013). The volcanically and seismically active MER system transects the uplifted for a distance of 1000 km, extending from afar depression to south ward a broad zone of basin and ranges near the Ethiopia border with Kenya (Ebinger et al, 1996).

In the Southern MER, extensional basins are bounded by faulted escarpments and characterized by large-offset, major boundary faults (Hayward Et al., 1996). The MER begins to broaden south of lake abaya (Ganjul basin) where the topographic expression of the rifts valley broaden in to two basin separated by the 20 km wide Amaro Horst, the 40 km wide chamo basin and the 30 km wide Galana basin (Ebinger et al., 1993). According to Zanettin et al., 1978), the southern part of the MER which includes the Ganjul graben (lake abaya) and the western side of lake abaya including plateaus and chenchas escarpment which has been affected by volcanism since the Oligocene (about 37 My ago).

The chenchas plateaus in the west and Bale plateaus in the east where the two uplifted regions separated by wide and quite shallow proto rift. The proposed age and width of the rift seem to be confirmed by the fact that the Amaro flood basalts, which also flooded the present amaro horst which were emitted into the rift during the lower Miocene. The lifting up of the Amaro horst was beginning at the same time as emission of basalts, and quickened after their emission (Levitte et al., 1974) causing the appearance of two parallel rifts, the Ganjuli and Galana graben inside the proto rift.

Other important eruptive episodes occurred in the upper Miocene (13 to 11 my ago) is plateaus basalt with the emplacement of rhyolites. The eruption of the rhyolites was followed by a lifting up which narrowed the rift and whose floor was later covered Plio- Pleistocene rhyolite (Zanettin et al 1974). The youngest formation, during the quaternary, was the emission of alkali basalts and the accumulation of fluvial and lacustrine deposits. Finally the axis of Ganjuli graben which runs NNE - SSW was fractured by the Wonji fault belt (Levitte et al., 1972), and alkali basalts, rhyolite, pumice and obsidian were erupted.

The Oligocene Volcanism and the subsequent volcanic episodes which occurred in the rift were fed by fissures parallel to axis of the Ganjuli Graben. The main faults of the escarpment run in the same direction. It seems that the territory has been affected, from the upper most Oligocene until the Quaternary, by single crustal stress system (Zanettin et al., 1978).

The origin, flow and chemical constitution of groundwater is controlled by the type of lithology, distribution, thickness and structure of hydro geological units through which it moves (UNESCO, 1972). Moreover, the stresses due to tectonism and weathering conditions govern the hydrogeochemical characteristics of earth materials (Solomons Waltenigus, 2007). Therefore; acquiring knowledge about the existing aquifer materials, their spatial distribution and hydraulic properties is a necessity.

The aquifer properties in the rift basin are controlled by the lithostratigraphy of the volcanic rocks and the structures (fractures) that affect them. However, in the rift shoulder, the aquifers is mainly governed by geologic structures include fault, joints and dike. The volcanic rocks have highly variable primary porosity because of the nature and conditions of the lava flow. Later on through time, these volcanic rocks have been subjected to weathering and fracturing related to tectonic activities giving rise to secondary porosities. These volcanic aquifers can be considered as a double porosity medium due to the fact that both the matrix and the fracture porosity contribute to the circulation and storage of groundwater.

3.2. Local Geology

Geologically kulfo river basin is mostly volcanic which emitted in Oligocene - Plio-Pleistocene period (Zanettin, 1978) and belongs to plateaus, rift margin and rift floor formed due to volcanic activities in the southern section of MER system. The rift valley plateaus and margin geology includes basalt, rhyolite and ignimbrite, exposed in high land and half graven around lower margin of study area and called as trap rocks group. The rift floor part is made up of alluvial - lacustrine deposits and rift floor basalt. Based on field observation, high land or upper zone of catchment is the part of fractured basalt that fresh out cropped along river channel and highly weathered on the surface water divide along trap ridges. It is characterized by high degree of fracturing along fault scarp.

Generally, there are five type of lithology have been identified and mapped in to four group using field observation and previous study (MoWE, 2012., EGS, 2017., SNNPRWRD, 2005

and Paulos Masresha 1996). This includes trap series (basalt and rhyolite & ignimbrite), rift floor basalt, and alluvial - lacustrine deposits (Fig. 7).

Plateau and rift margin volcanic units (trap series basalt and rhyolite - ignimbrite)

This group of rock is found in upper and intermediate river catchment by forming the escarpment and mountain ranges. Under this group, trap series basalt is predominant observed over study area.

Trap series basalt

This unit is older basalt in the rift valley (Zanettin et al 1974) which emplaced in plateaus topographic section. It is the numerous units in the upper zone border line kulfo observed in (fig.7) and makes continuous extension to ward rift floor in between rhyolite – ignimbrite unit. It has boundary with rift floor basalt, alluvial sediments and rhyolite-ignimbrite observed in figure 7. This unit is fresh along river channel and highly weathered on the trap ridges. In the area selected for investigation, it is characterized as large distribution of springs which are discharging through years. The occurrence of large number of springs in selected part of this unit indicates, the unit is highly controlled by fault and fractures that interlinked by volcanic joints below earth surface.

Rhyolite and Ignimbrite units

As (Zanettin et al 1974), the formation of the rhyolites and ignimbrite in study area was occurred followed by a lifting up which narrowed the rift and whose floor was later covered Plio- Pleistocene rhyolite. This rock unit is out cropped in the central – lower plateaus along western and eastern part of catchment divide (fig.7). It bounded with highly weathered trap basalt which is finely crushed in central part of study area. Again they are characterized by weathered and crushed face. That is may be occurred due to the thick serious normal faults lifted volcanic succession to west of rift valley causing the repetition of basalt – rhyolite – ignimbrite succession. As result of this, the weathering is severe the rock turns to more of clay soil and this may fill fracture and reduce the hydraulic conductivity. According to this, geology observed in the central part of catchment is finely weathered and highly fractured with no perennial spring's water and utter vegetation.

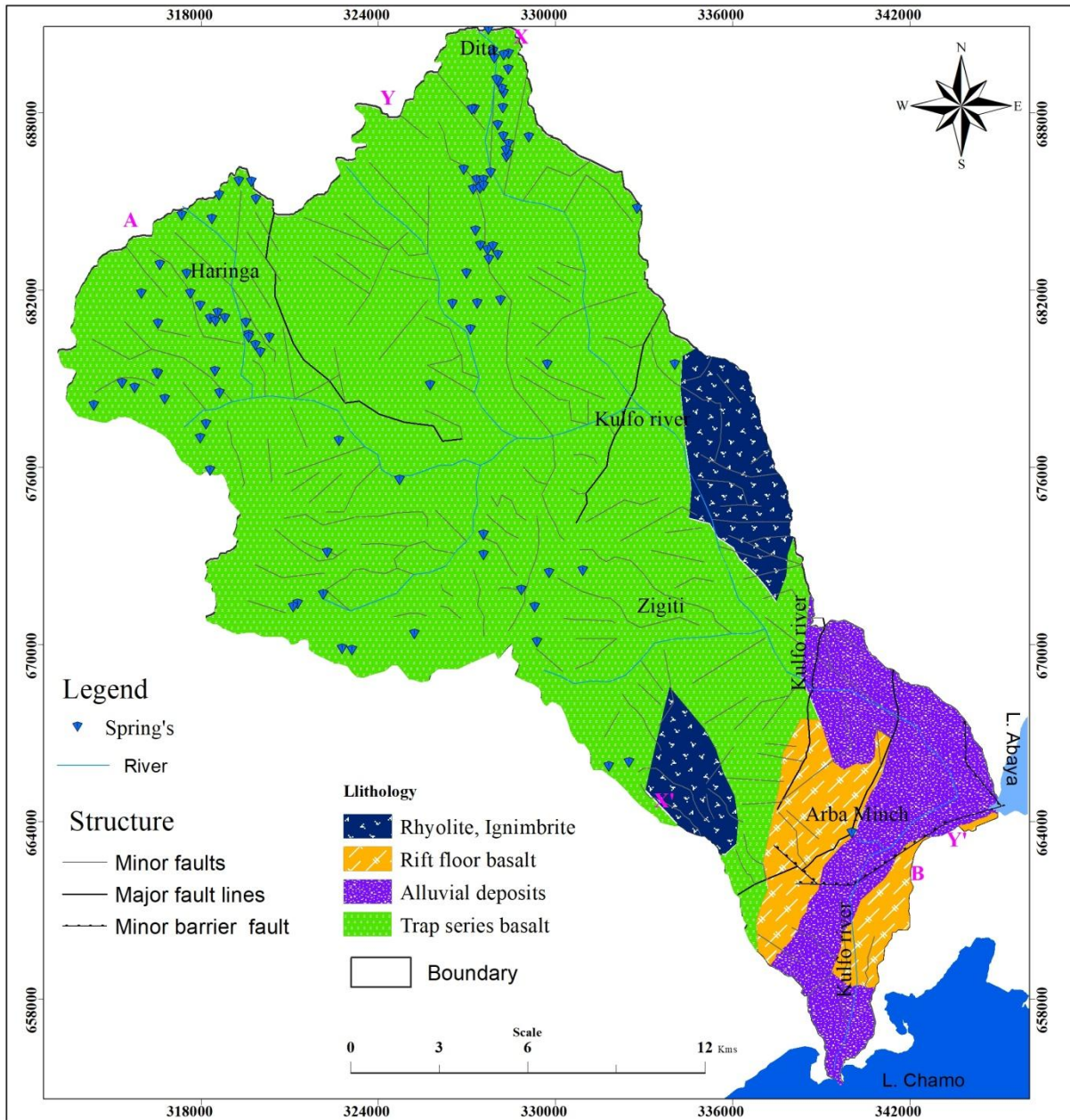


Figure 7. Geologic map of kulfo river basin (modified from MoWE, 2012)

Rift floor basalt

This unit is younger formation formed during the quaternary period and was characterized by the emission of alkali basalts and the accumulation of fluvial and lacustrine deposits (Zanettin, 1974). Mean that it is a group of volcanic deposit formed during the rift formation recently. It manifested in the rift floor part of the study area forming the high ground between the two lake Abaya and chamo called Egzabher dildy local name and steep fault escarpment named as forty spring formed fault and others around Arba Minch town. The Arba Minch town is totally founded on this rock. The Quaternary rift floor basalt in the area is scoraceous

basalt with gas vesicles and fresh joints have seen in the field. They are also highly fractured and faulted.

Alluvial - lacustrine deposits

As field observation, alluvial deposits largely extended on the flat plain of study area following the river courses, farmland as well as the utter plantation on the rift floor around Arbaminch, lakes Abaya and Chamo shown in figure 7. It is constituted of the various sizes of alluvial which range from clay to boulder as observed along the river banks. According to the field observation along river channel, they are reconstructed from basalt fragments. Based on Borehole logs around Arba Minch, the thickness of the alluvial deposit is range from 42 – 110 m. As observed from the logs, the grain size increases with depth becoming more of coarse sand and gravel at the contact with underlying basalt formation.

3.2.1. Geological structure

The geological structure in the study area consists of NNW - SSE and NNE – SSW trending blocks of fault lineaments (fig. 8) and volcanic rock joints that interconnect local fault. The presence of dominant fractures and normal faults in the study area are due to extensional tectonics related to evolution of MER.

Faults and joints

Fault dominantly observed and identified in the study area are fall under minor and major fault which characterized as groundwater conduit and barrier fault line. There are two major faults in the upper class of study area with strike of $N305^{\circ}W$ in the north western part and $N46^{\circ}E$ in the north eastern part. And two major again identified with the same strike of $N35^{\circ}E$, $N31^{\circ}E$ in the lower class of study area called as upper AM fault and AM formed fault respectively (fig.9). These faults are crossed by local fault lineament in the south western part. According to satellite image observation in relation study area and Giacomo C. et al, 2013, in the Lakes Abaya and Chamo area, the rift splits into two basins separated by the N-S trending Amaro Horst. The rift in this region is delimited by few, widely spaced, and large normal faults that strike $\sim N0^{\circ}-25^{\circ}E$.

AM fault is located in this area as large long extended to ward south and north along MER valley in and out of study area. Based on field identification, it is crossed by another NNW-SSE oriented fault with strike of 315° in the lower western corner of study area observed in (fig. 9). Including this fault, abaya fault dam and Egzer dildy fault in the rift floor are form

common fence like common escarpments and utter rift valley forest on the full graven rift floor (fig. 7 and 8). These fault conceptualized as groundwater barrier as well as surface water dam in the rift floor. Dominant fault lineaments mapped in the study area are minor or local (conduit or barrier) faults in the upper- medium trap series basalt, rhyolite- ignimbrite and rift floor basalt. Upper trap basalt unit in the study area is highly governed by faults that form network in down escarpment of trap ridges. Along these networked laterally and vertical penetrated fault, there are numerous perennial springs are available with different discharge amount. But in the most intermediate zone include rift valley shoulder is characterized by dry springs at dry seasons may indicates high rock deformation due to a thick serious normal faults lifted volcanic succession at moderate depth result impermeability of rack fracture by closing open in the fractures.

Based on topographic face integrate with up and down thrown block of fault along escarpments, fault penetration is estimated by producing geologic crass section along line 1,2 and 3 (fig.9). The up and down thrown of faults observed on the surface steep hill side show underground fault penetration. The deep penetrated fault has long lineaments and large steep to gentle sloped escarpment identified as Kecha fault, Haringa fault, Ganta fault, Lakal fault, Merzo faults, and AM fault. These fault areas fault is largely observed in cross-section map along line A-B and X-X' has shown (fig. 9). The complex up – down faced cross section is due to topography result from tectonic movement. The other section is along Y-Y' (fig. 9) comprises shows shallow fault penetration in eastern margin medium zone and deep penetration in the whole lower and some of upper zone (fig. 9).

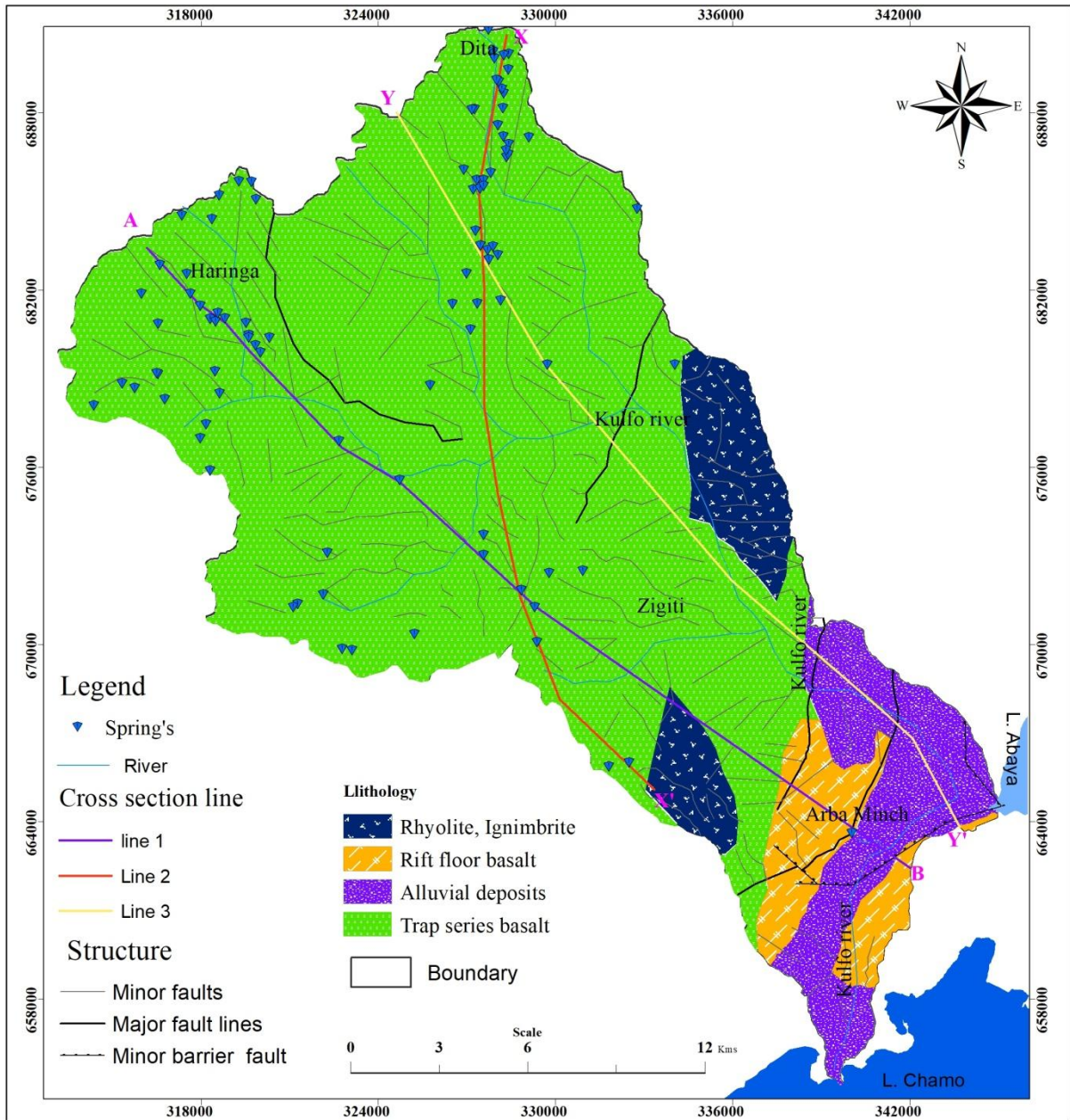


Figure 8. Geological map consist of cross section line.

The line 2 and 3 sections unify upper, intermediate and lower class of study area fault line pattern with geology and springs location. The section along line3 (fig. 9) shows shallow of fault penetration especially in margin of rift valley may point out geology is highly deformed to form disturbed land escape.

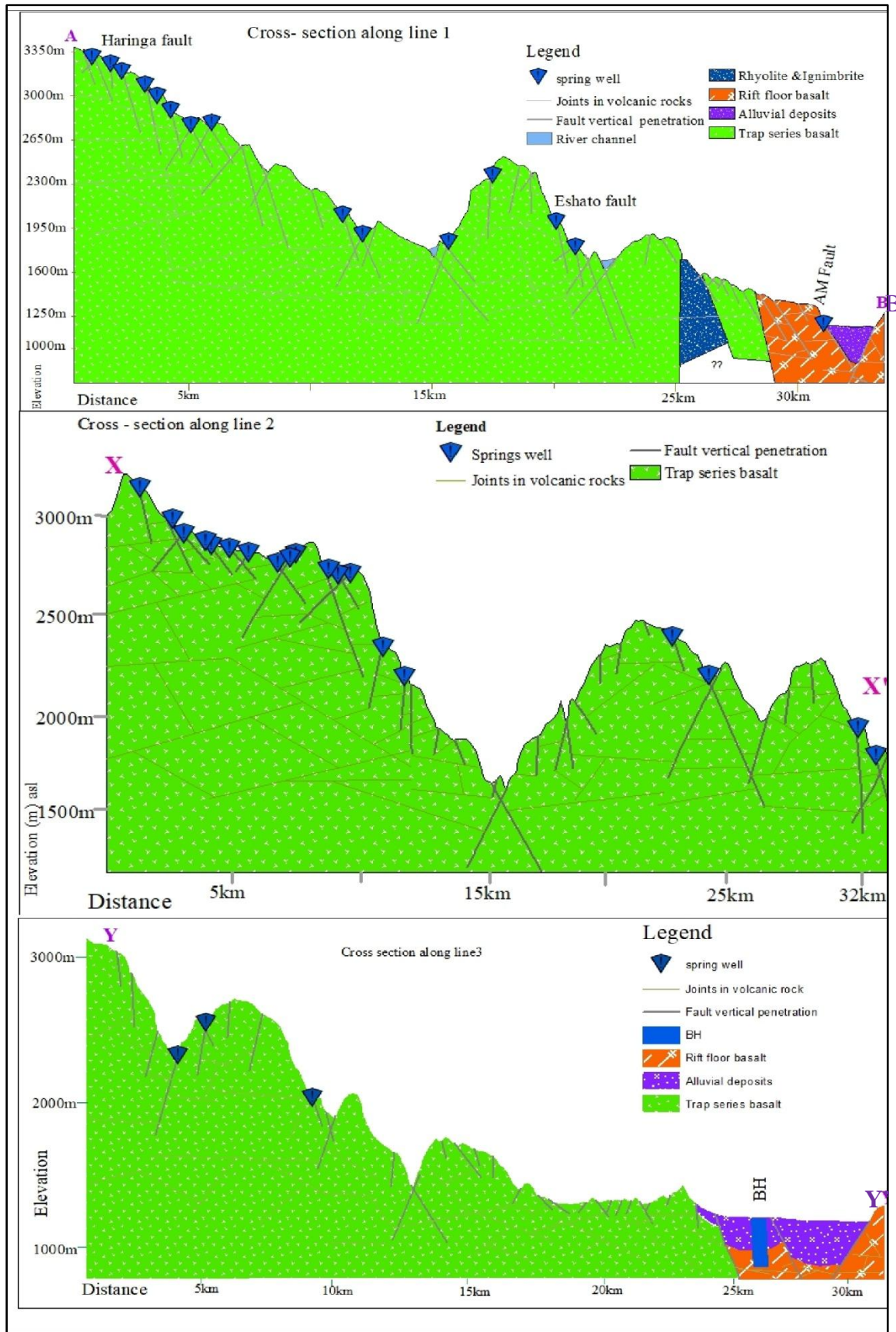


Figure 9. Geologic cross- section expressing hydrogeological significance

The areas with highly weathered geology on the mountain, surface water divide and intermediate zone have shallow fractures penetration. But at and along river channels in upper class and rift floor in lower zone consists of deep penetrated fault. In order to detect fault role in groundwater movement, springs are pointed on the cross section face by keeping exact geographic position. As observe on line section, the most springs are located at foot of mountain range or escarpment. However, their distribution is not same along three line section. In line section 1 and 2, springs largely allocated with respect fault through topographic set up and wet land in the upper part. Basically this two section shows role of fault in the emergence of spring at dry seasons. From point view of location, in the section line 2 of upper part the most spring are associated with wet land. But in line section 3, only three springs are observed in higher elevated zone. This is because of geology and structures that characterized as disturbed set up with highly fractured and weathered face.

Joint is a fracture group that has no measurable amount of displacement in the rock body. It lineament is not merge by keeping line originated and originated. Joints in water bearing volcanic rock play role by receiving and transmitting water freely to natural spring chamber. Some of springs on margin of mountain in basaltic rock has small discharge are produced by joints by help of barrier local fault and joints.

3.3. Hydrogeology

The nature of groundwater system; occurrence, movement and distribution of water in aquifer below surface of earth is very complex. However, by using different parameters and approaches as well as considering subsurface opening, the hidden water resource in underground environment represented by different hydrogeologists (Niven Kresic, 2010). The rift valley lake basin which located in MER has two portion, northern (Lake Ziway to Hawassa) and southern (Lake Abaya to Lake Chew Bahir). The aquifer in the RVLB are identified into three; (1) alluvium and lacustrine aquifer, (2) Pleistocene tuff, tuff breccia and basaltic rock units aquifer (3) plio – Pleistocene tuff and basalts aquifer based on the study of existing well inventory (MoWE, 2012).

However, the nature of aquifer system in the northern to southern portion RVLB is variable in hydraulic properties from regional to local area. Kulfo river basin is one of sub river basin in Lake Chamo and its hydrogeology varies from upper to lower portion. The aquifer system of this basin is highly governed by tectonic fractures and normal faults. Due to this area is known by number of springs which has perennial discharge through the year. Based on detail

geological map, geologic structures, existing well information, spring distribution, springs position and its yield at dry season, topography set up and field observation, the hydrogeology of study area is characterized shown in (fig. 10). To characterize the hydrogeology and classify aquifer, groundwater supply to the surface in the form of spring form used for upper zone and existing well inventory used for alluvium plain rift floor.

3.3.1. Hydrogeological classification

The hydrogeological classification of different lithological units in the study area is based on parameters of hydrogeological and hydraulic properties of the aquifers that supply groundwater through natural and well pumpage. Based on parameters, the hydrogeologic units in the study area are characterized as aquifer of fractured rift floor basalt, fractured trap series basalt, highly weathered and fractured trap series basalt, ignimbrite and rhyolite) aquifer and alluvium aquifer.

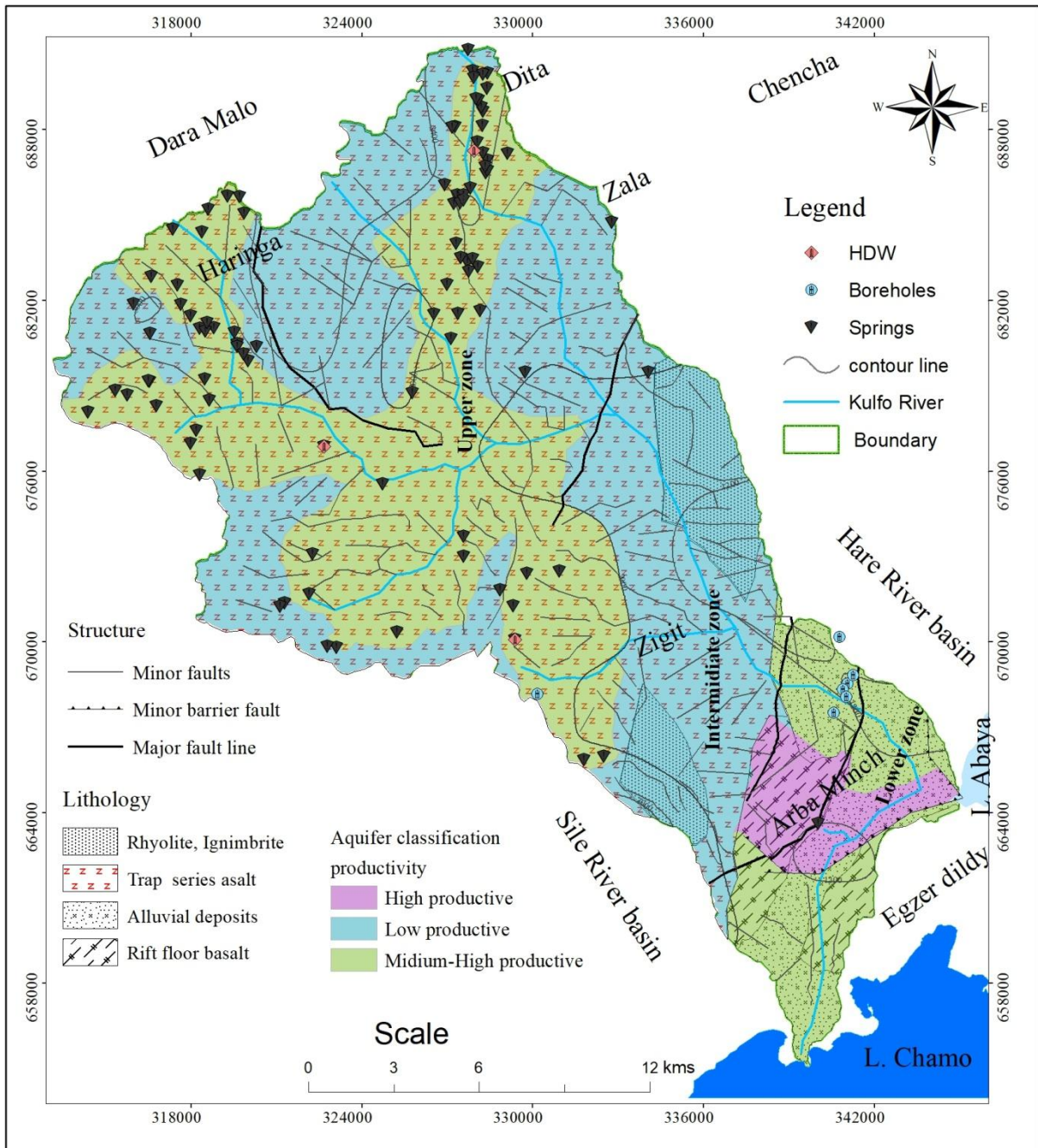


Figure 10. Hydrogeology map of kulfo river basin

Fractured aquifer rift floor basalt

This unit is younger quaternary formation in the area which characterized as scoraceous basalt with gas vesicles and fresh joints. It is identified by major or regional fault across Arba Minch (forty springs) which has minimum yield of 130 l/s and maximum yield 250 l/s. This indicates, rift floor basalt is highly fractured and faulted unit. As result, it demonstrated as the potentially very high productive aquifer in the Arba Minch town area and medium – high productive aquifer in between Lake Abaya and chamo.

Fractured aquifer of trap series basaltic unit:

This unit is large mapped units that recognized by more than 92 perennial spring's distribution that has continuous flow through the year. And it is associated with numerous local (minor) faults and two major faults with of N305⁰W and N46⁰E. These faults facilitate groundwater flow and produce springs on the earth surface. On the hydrogeological point of view, this unit has different nature along surface water divides, river channel, spring catchment and foot line of escarpment. As field observation, alongside of river channel and lower fault scarp, it shows fresh fracture face with large trees. This is not common in all study area. But on the top of mountain and most part of intermediate zone, it has highly weathered surface with dried spring point at dry season. From point view of this, the fractures associated with area are in filled with weathering product at moderate depth. Accordingly, this unit characterized as fractured aquifer or medium – high water productive and mixed aquifer or low productive respectively.

Highly fractured and weathered of aquifer trap series basalt, rhyolite and ignimbrite:

This is common on top part of mountain and most part of intermediate zone. Like others, they are fractured, weathered and jointed and they have good porosity. But due to high degree of weathering and in filled crystal materials (clayey), it has low permeability and seasonal spring discharge. Therefore, they are recognized as the intercalated units act as low productive aquifer (fig.10).

Aquifer of alluvial - lacustrine deposits:

This aquifer unit extended from the foot of the mountains (Egzer dildy) to Lake Abaya toward north, Lake Chamo to south, and to forty springs formed at foot of fault escarpment. It is laterally extensive unit in the rift floor (see fig.7). It is constituted of the various sizes of alluvial deposit which range from clay to boulder as observed along the river banks of Kulfo River, well logs and lacustrine deposits near of Lake Environment. They are reworked from basalt as observe and described from boreholes geologic formation. The boreholes penetrated the alluvial deposit are AMT# BH1at at depth of 112m, AMU-BH6 at depth of 68 m, AMU-BH7 at depth of 86m, AMU-BH8 at depth of 42 m, and AMU-BH9 at 60 m. The thickness of the alluvial deposit varies from 42 – 112 m as observed from lithological logs of boreholes drilled in the study area lower catchment. The hydrolithologic units which form this aquifer are found by overlying the basalt unit observed from AM Town borehole litho-logs with depth of 183m (table 2). According to yield of BH which is 3-52l/s, transmissivity and water

bearing formation, this unit is mapped as medium to high productive. The main reasons that raise yield of AM town BH#1 is identified as fresh fractured rift floor basalt which under landed by alluvial deposits and penetrated by this BH at depth of 112 m (seen in table 3). This hydrogeologic unit is big spring producing unit exposed in the AM town, along forty springs and egzer dily.

Table 2. Summarized geologic description of alluvial deposits in the lower zone

Depth	Corresponding Lithology
0 – 2	Top soil
Feb-38	Boulder with cobble and pebble
38 - 44	coarse sand
44 – 50	Gravel
50 - 54	Sand
54 - 56	Clay
56 – 66	Gravel with sand
66 - 68	Clay
68 – 90	Pebble and cobble
90 – 94	Gravel
94 – 104	Sand medium to coarse size
104 – 108	Coarse sand with gravel
108 – 110	Clay
110 – 134	Slightly fractured basalt
134 – 146	Moderately to highly fractured basalt
146 – 154	Massive basalt
154 – 1704	Highly fractured and weathered basalt
170 – 178	Moderately fractured and weathered basalt
178 – 183	Moderately to highly fractured basalt
183 – 184	Fresh basalt

Transmissivity

As Samuel Dagalo (2009), Aquifer types in the lower kulfo river area are dominantly confined, unconfined and partly semi confined. The high values of transmissivity in the area indicate that aquifer can carry a good yield from the formation in the area. The flow of Groundwater from the area of AMU towards Lake Abaya indicates that the Groundwater

gradient also follows the surface gradient in the area. Transmissivity of geology in the lower catchment analyzed by using borehole drilled and tested previously. It can range from 30 – 525 m²/day. As observe from previous borehole report, transmissivity of BH varies with depth. Deep penetrated BH has high trasmissivity than shallow well. Consequently, the increase of ability of aquifer to transmit groundwater through entire volume of saturated zone is due to overly young volcanic units. However, transmissivity of hard volcanic rocks through the catchment is not known. From point view of spring's minimum discharge at driest seasons, the hydrogeological condition in the study is characterized. Perennial spring with large volume discharge and dense distribution has good information about aquifer condition. As Davis, SN and et al, (1966) springs are largely located in hard fractured and varies with age of trap series to young rift valley basalt. Therefore, the springs in them reflect the discharge of younger volcanics yield large volume than older plateaus basalt.

Table 3. Summary of Hydrogeology characterization and aquifer classification

Hydrogeological classification	Borehole yield (l/s)	Minimum springs yield (l/s)	Transmissivity (m ² /day)	Distribution of perennial springs (No)	Aquifer classification
Fractured rift floor basaltic unit	-	130	unknown	40	High productive
Fractured trap series basaltic unit	-	0.1 – 4.4	unknown	72 - 90	Medium - high productive
Mixed trap series (basalt and rhyolite, ignimbrite) units	-	< 0.08	unknown	4 - 12	Low productive
Quaternary alluvial - lacustrine deposits unit	3 to 52	No spring	30 - 525	-	Medium - high productive

3.3.2. Groundwater flow

Groundwater flow is not follows single lateral or vertical line below earth surface toward lower catchment. This is due tectonism that result crustal break produces faults and joints in the body of geology (seen in fig. 16). The important parameters used for constructing contour map for groundwater flow direction are static water level of existing boreholes, dag well and perennial spring well position (elevation). Just as surface water tends to flow downhill, groundwater tends to move down gradient from water table areas from higher elevation to lower elevation (Niven Kresic, 2010). In this case, groundwater flow in the river basin is common and depends on water head decreases in the flow direction seen in (fig. 11). In this figure groundwater flow pattern oriented downstream in to forty springs and alluvial aquifer. This is mostly observed in the north to south west and to south east indicates the catchment in this part of river basin is highly fractured and dynamically connected at depth. This regions of study area is also characterized as potential spring that controlled by faults line. Fault is hydraulic connection that facilitates ground water flow with help of hydraulic pressure and difference in water head.

As observed on (fig. 11), subsurface water flow around Dita in the upper class of area is diverted to ward spring catchment suggests presence of LSWD. In all higher class of area, flow direction points toward river link in locally. The groundwater flow varies by influence of sub surface water divide and local fractures in hard rock's of river basin seen in figure 11. Association of Perennial springs and flow direction suggests the productivity of supplying aquifer. As observed in the same map, groundwater flow direction is parallel and perpendicular to fault lineaments may indicate fault line that transmit and limit flow progress below surface. Local groundwater flow direction Parallel with fault lineament noticed as flow in the conduit fault line. And flow direction perpendicular with fault lineament may imply fault line act as barrier that obstacle flow steps forward. Therefore, the major factors govern groundwater flow variation in locally and commonly (regionally) in the study area are tectonism that resulted geology, geological structure and topography setting.

Geologically groundwater in hard rock's is flow through fracture, fault and joints. But in unconsolidated units (alluvial deposits), the flow groundwater is through porous media. Geology with fresh fracture diverts and transmits ground water flow to ward surface by help of artesian pressure. As a result, a subsurface water supply or flow path is rise good understanding of the distribution of porosity and permeability, which is a function of the geologic materials (Charles R. Fitts, 2002).

Topographically, water flow from highest elevation (plateaus) to lowest elevation (gorges). In shallow groundwater, the movement and flow direction is dependent on the inclination of the topography. In the upper part of river basin, most flow direction is directed along the spring's water catchment produce common groundwater reservoirs and distributes springs. The topography and geology along this environment is observed as highly faulted and fractured. Accordingly, water flow below ground of hard rock's depending on geologic structures that facilitate groundwater flow.

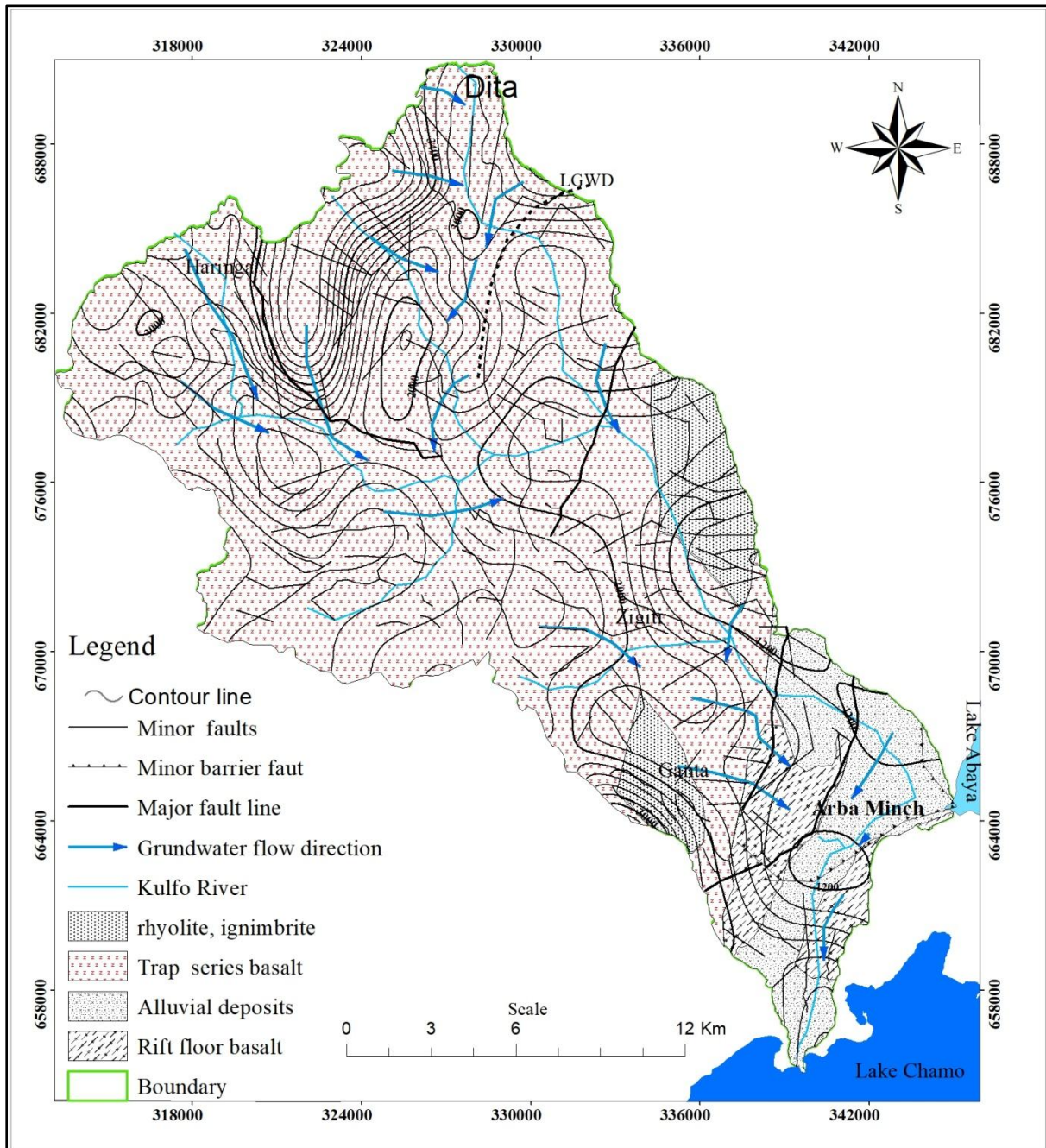


Figure 11. Groundwater flow direction map belongs to kulfo river basin.

In the lower class, the regional fault line in the rift floor (figure 11) is observed in the point view of water flow that unifies flow of groundwater and produce large groundwater over flow at foot of AM fault escarpment. In the kulfo river basin wise, this fault is identified as collection chamber of groundwater in the catchment. The emergence of groundwater out flow in the large volume at this area is governed by surrounding barrier fault that divert flow to ward surface.

And structurally, water flow in hard volcanic rocks following the fault line orientation and joints. In the (fig. 11), local water flow direction is parallel and perpendicular fault lineaments indicate that fault is passage tube of groundwater by collecting water from conduit fractures. A lineament of major and minor fault has cross relatively contour line which shows subsurface water flow in the fault line. Therefore, faults facilitate the flow of deep and shallow seated water to surface of earth by help of artesian pressure.

3.4. The spring's water and its spatial discharge variation

3.4.1. Springs water

A spring is a location at the land surface where the natural discharges of groundwater from the aquifer supply to the ground surface. It is also natural over flow of groundwater reservoir because of gravity and hydraulic pressure beyond movement. It is formed since groundwater once outside of its natural environment (aquifer).

Spring discharge is not only caused by difference in the elevation of the hydraulic head in the aquifer and the elevation of the land surface where the discharge takes place. But also it come up by lateral impermeable barrier in fractured rock, caused by faulting which may force groundwater from greater depth to ascend through the overlying sediments and release at the surface (Neven K., 2010). Consequently, it represents a transition or link connecting the ground and the surface water in circulation system.

As discussed by Amanial Haile Rada (2015), spring water is a major source of water for drinking, agricultural, and industrial desires. The availability of water determines the location and activities of humans in an area and our growing population is placing great demands upon natural fresh water resources. In view of that, spring is a direct use of groundwater. The main interested objective of research is to conduct investigation on perennial or permanent springs flow throughout the years and their discharge variation with respect to location on geographic section that imply groundwater hydrology. There are more than 90 potential

springs are available in the kulfo river basin of dry season. These springs are not getting waterless at quiet dry months and taken as direct indicator of groundwater occurrence. To implement their spatial discharge variability on groundwater hydrology, nine springs are selected for deep study by field description ad collecting representative sample. Some of these are discussed as follows.

Forty springs (Arba Minch):

As Tamiru Alemayehu, 2006, one of the most famous cold springs in Ethiopia is Arbaminch spring (meaning forty springs) located about 500km south of Addis Ababa. It is one of various numerous springs that located in the rift valley which associated with escarpment at elevation of 1220 m (figure 12). This spring’s are located along regional fault that exist deep penetrated which is act as conduit for groundwater flow. Most of springs in the study area are found in faults zone may represent large collective displacement because it afford good water passage.



Figure 12. Arba Minch springs point location (field photograph)

Forty springs related with deep penetrated (large) fault that allow deep seated water escape into the surface in large quantities. Consequently, it is fault springs which exist associated with wide planar opening in bed rock that act as a passage for water flow.

Eshato spring: this spring is located at border line of upper-lower class of study area at elevation of 2390 m a.s.l. It is also characterized as deep seated fault spring according to TDS and minimum dry season discharge. It has discharge of 4.4 l/s and TDS of 100mg/l (chapter 4) at dry season. It located at foot graven of mountain ranges that overlying by sediments observed in (fig. 13). This spring is first big spring in the upper class of the study area.



Figure 13. Eshato spring and it location environment

Shale and lakal springs: these springs are located in upper zone in the north western part at elevation of 2237m and 2874m a.s.l. Lakal spring is raised at surface water divide at mountain range but shale spring occurred at lower elevated upper region. Their point location is different that shale located with vegetation cover and lakal has grass land that keeps wet in surrounding (fig. 10).



Figure 14. Point observation of lakal and shale springs

3.4.2. Discharge and classification of springs

The main control for the springs could be lithology, structure and topography. Based on these, the type of springs in the study area could be fault springs dominantly. Fault springs are formed when groundwater over flow occurs through faults affecting different lithological formations. In the case of Arba Minch, Ganta eshato, merzo, shale, gum'ee and other springs are located along series of fault separate the geology up and down which form unconsolidated sediments in plain land. This is seriously observed on Arba Minch, eshato, ganta, merzo, gum'ee and shale springs. As groundwater reaches the fault system, it tends to flow through faults line (Paulos Masresha, 1996). The shallow water table at the alluvium side verifies water pass across the faults.

Several authors have proposed different types of classification of springs. The spring in the study area may be classified in the following manner. This classification is based on dry season discharge data for the year 2008 and 2010 during field studies. During field study eight springs discharge are measured but Arba Minch springs discharge data is according to gauging from Arba Minch town water resource services. This discharge data are taken as minimum discharge that is available at dry months. An interview with local residents implies that there is very little variation in the spring discharge from upper to lower catchments that placed along fault line. But except Arbaminch spring, other springs maximum discharge is not formally recorded to test variation.

The springs which has minimum and maximum discharge measurement in the study intended for classification by using the meinzer index R expressed in %

$$R = 100 * \left(\frac{a-b}{c} \right)$$

Where a: maximum discharge per unit time

b: the minimum discharge per unit time

c: Mean discharge per unit time

By means of this method it is possible to classify Arba Minch spring as follows

- Constanta spring when R is less than 25%
- Sub variable when R is greater than 25% and less than 100 %
- Variable when R is greater than 100%

As far as, Arbaminch spring is concerned, the maximum discharge is 250 l/s and the minimum discharge is 130 and the mean discharge is 190 l/s

$$R = 100 * \left(\frac{a-b}{c} \right)$$

$$R = 100 * \left(\frac{250-130 \text{ l/s}}{190 \text{ l/s}} \right)$$

$$R = 63.15 \%$$

Therefore, Arba Minch spring is classified as sub variable springs. The sub variability is may be detected due to water table fall down at dry seasons in the upper class of basin.

The spring classified based on mean discharge

The following table (4) shows meinzer's classification of springs based on the mean discharge. Similarly, all springs except Arba Minch have no mean discharge. So, this classification used for Arba Minch springs only.

Table 4.Meinzer's springs classification based on discharge

Magnitude (order)	discharge
1 st	>10 m ³ /l
2 nd	1-10m ³ /l
3 rd	0.1-10 m ³ /l
4 th	10-100 l/s
5 th	1-100 l/s
6 th	0.1-1 l/s
7 th	10-100 ml/s
8 th	< 10 ml/s

Since the mean discharge of Arba Minch springs is 190 l/s, the springs are classified as 3rd order springs.

Including Arba Minch spring, minimum discharge of 98 springs (annex- 4) is used in this study to assess groundwater hydrology in the kulfo river basin. As observed in (fig. 15), the yield varies from 0.01 – 130 l/s. From all this spring's 9 spring are selected to characterize minimum discharge and chemical constituent. Most of these springs are assess as potential for community services. Potentiality of spring is checked by dry season discharge which is mostly cap for community service. Consequently, the potentiality of spring mostly used for forecasting characterization of aquifer.

3.4.3. The spring's spatial discharge variation

Springs that have discharge in the dry season are recharged by groundwater stored in deep or shallow reservoir which has flow linkage through fractures. As observed on (fig.16), discharge value identified as 130 l/s, 1.5 -4.4 l/s, 1.5 - 1 l/s, 1 – 0.1 and 0.1 – 0.01 l/s. Labeled discharge range defines position and associated structures of springs. Therefore, in the entire catchment, the discharge and distribution of springs varies with nature of geology, structure and topography.

Spring discharge variation with respect geographic position

The study area is divided in to three upper, intermediate and lower zones. In this entire zone, discharge of springs is different (figure 15). In the upper zone, the springs largely distribute but the perennial discharge measured as 0.01 – 2.7 l/s (observed in figure 15 and table 5). In the medium zone, the minimum discharge at dry season reaches zero in the most part and 0.1 – 4.4 l/s.

Table 5. Selected and measured springs discharge and its geographic location

S.No	Springs name	X	Y	Elevation	Yield(l/s)	Yield (l/min)	Sample code
1	Arba Minch	340032	663604	1220	130	7800	S1
2	Ganta	332495	665984	2211	1.5	90	S3
3	Lakal	318304	675874	2874	0.08	4.8	S4
4	Shanke	323281	669897	2560	0.3	18	S5
5	Gum'ee	328227	688642	2974	0.2	12	S6
6	Bosha kashe	328055	687570	2920	0.6	36	S7
7	Merzo	327766	683002	2732	0.4	24	S8
8	Shale	322670	676872	2237	0.2	12	S10
9	Eshato	329380	670071	2390	4.4	264	S11

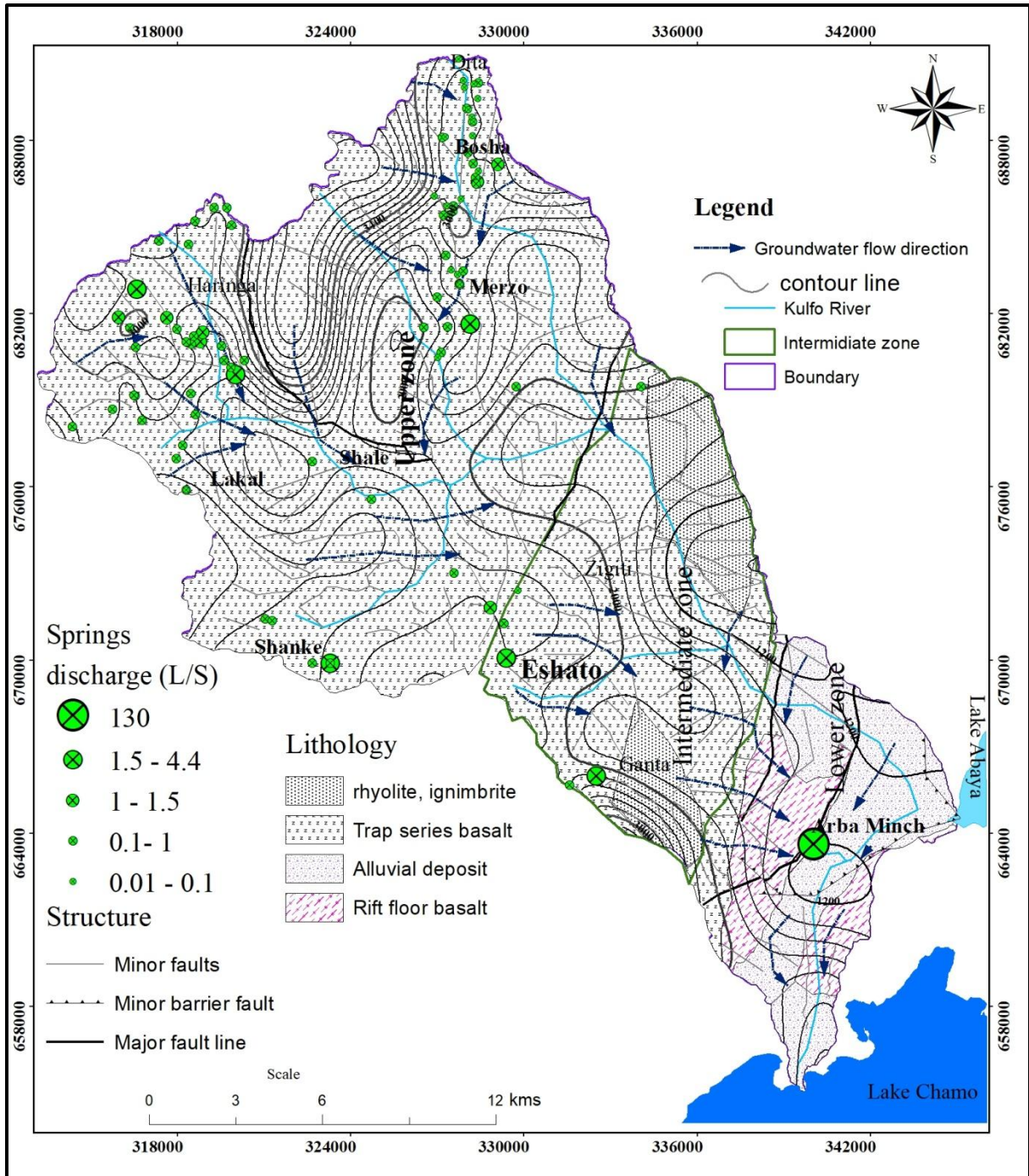


Figure 15. Springs distribution and spatial discharge variation map

Perennial flow of springs in the study area reflects the flow lines rising up from the deeper aquifer portions toward springs. Under similar physiographic condition in the upper part, the volume of springs discharge is variable (fig. 15). In the north western part two big and small springs situated near to each other. Similarly, in the upper – lower part the same two springs are occurred at identical elevation with different opening point. The factor made variant spring on same physiographic condition may be conceptualized as size of fracture opening that linked with water saturated body of rock. From evidence of field observation, height of

mountain ranges above spring point and degree of weathered lithologic unit has role in discharge variation. Discharge in range between 1.5 – 4.4 l/s reflect spring opening associated with large faults. Having yield of 130 l/s at dry season dedicate location of spring associated with regional fault. While discharge range in 0.01 – 0.1 l/s and 0.1 – 1 l/s is dominantly distributed may inform presence of shallow penetrated litho-structural assemblage that contribute groundwater flow on the surface. According to field observation, location of large springs associated with large fault, at foot of mountain ranges. High distribution of springs in the upper class of study area indicates upper sub basin is characterized spring losing recharge zone.

Spring discharge variation with respect geology

An aquifer draining toward a spring is a geologic body, characterized by its internal structure, hydrogeologic properties, and hydraulic boundary conditions (Burkhard et al., 1998). Consequently, the degree of fracturing and weathering of geology on the water divide and the spring's catchments of study area is described. Beside these, spring distribution in relation to geology and structures imply characteristics of aquifers. Geological environment of the springs covered by fertile soils and large trees points' groundwater flow pass through it. As observed (fig. 15), flow pattern of water below surface oriented with distribution of springs. These fertile soil and large trees on the fault graven keeps moisture of the spring's environment by impounding groundwater to surface and indicate groundwater over flow below earth surface through fracture tube. In the highest elevated area, springs has small discharge amount and this is may be due to weathering of basalt and existence of local fractures. However, in the lower zone of catchment, rift floor basalt is characterized by big the springs group that collected in the same location. This confirmed by (Kirk Brayn, 1919), the subsurface geology control on springs considered that the irregularities of rocks produced due to tectonic activity under an alluvial plain that forces water in to surface and these may be project or outcrop at floor of basin. The forty springs subsurface geology is controlled by fresh deep penetrated fault and may be irregular in the water passage surface that can project forty springs in the same area due to fault dam, partly consolidated older alluvium, or volcanic plugs especially around forty springs. Therefore, geology is one the factor for spatial discharge variability of springs.

Therefore, the potential spring's distribution in north western part of upper class, western part of intermediate zone and lower part at dry months indicates most groundwater system is dynamically connected. The trend of the spring's distribution again implies the groundwater

flow direction of river basin is occupied by passing potential spring's environment at depth. In addition to this, large green colored trees along fault scarp and around spring position suggest groundwater movement still passing subsurface at dry season. The big springs with maximum yield of 250 l/s and minimum yield of 130 l/s in lower zone and plenty distribution of spring in upper zone of study area indicate existence of common very permeable water bearing fractured zone at depth below earth surface. Therefore, the potential springs discharge variation along catchment at dry seasons help to predict groundwater potential zone and groundwater movement in aquifers.

3.4.4. Faults and its control on spring discharge variation and groundwater flow

As result of geotectonic (Davis SN., and et al, 19660), morphologic system in the in the study area is separated up and down with sharp fault escarpments (fig.16). As result of step down thrown of fault block, young deep penetrated fault is associated with lowest elevated rift floor and some of upper zone. Fault is the major geologic and geomorphologic structure that controls the discharge of spring water in the form of conduit and barrier below surface of earth. As discussed by MEINZER 1923; Neven K. et al 2010), faults play a major role in the emergence of springs, especially in hard fractured rock aquifers. They are also uncommon in unconsolidated and semi consolidated sediments. In any case, faults themselves may play one of the following three roles: conduit for groundwater flow, storage of groundwater due to increased porosity within the fault (fault zone), and barrier to groundwater flow due to a decrease in porosity within the fault. Large fault brings groundwater on to ground in the form of springs that have perennial discharge. In this case fault is groundwater passage for perennial springs which occur at dry time. When groundwater flow can get passage to surface or in the depth along fault line, it called as conduit fault. And fault that blocks or bars groundwater flow and cause spring discharge on the surface. So it is barrier fault in case of flow direction. Arba Minch spring at lower part along regional fault dedicates that there is many local faults assemblage connected with regional faults which receive water from upper catchment. The forty springs is the largest spring in the rift valley lake basin that formed along regional fault line shown (fig. 17B).

In the south east low land, there are three dam faults: Arba Minch dam fault, Abaya Lake and chamo lake dam fault. The contribution of this fault on the spring's emergence is that hinder groundwater flow. The Arba Minch fault is act as conduit regional fault that collect water from kulfo river basin as well as away from other river basin. But Arba Minch dam fault in

the south west of forty spring point is act as barrier minor fault that interrupt the regional flow of groundwater trough large long regional fault shown in (fig.8).

The Arba Minch spring is the largest spring in the rift valley lake basin with minimum discharge amount of 130 l/s and called as largest fault spring. This forty spring's former fault in the rift floor is identified as deep penetrated fault below earth surface. This is according to elevation variation in whole catchment and step up fault. This fault line may hold potential groundwater reservoirs due to number of local faults which are acts as conduits for groundwater flow in the upper part. On the other hand, impermeable fault barrier (AM dam fault) in fractured rock, caused by tectonism also force groundwater from greater depth to ascend and discharge forty springs at the same surface through the overlying alluvial sediments.

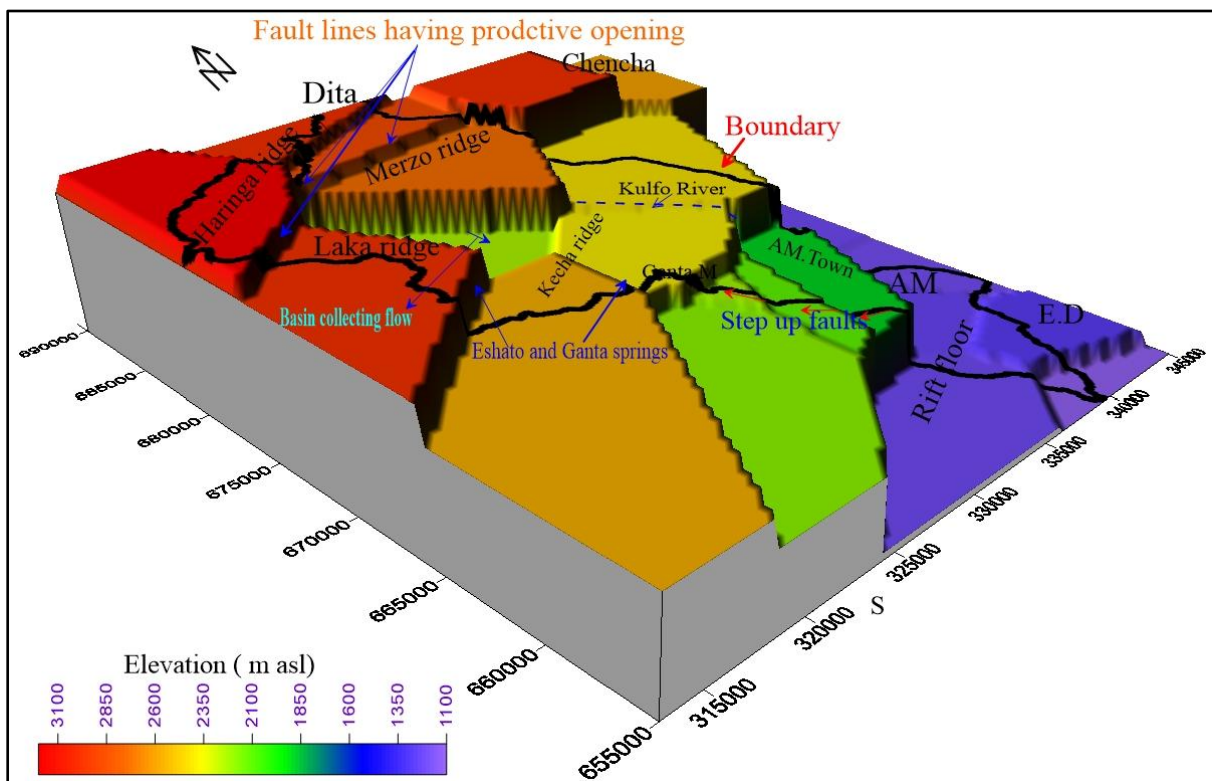


Figure 16. Physiographical faults system having hydrogeological significance

Based distribution and location, the most of springs in the study area are classified as fault spring which has gravity flow. This is due to their location associated with fault line. Under similar physiographic condition in the catchment, the discharge of springs is variable. This is due to difference of size of opening that transmits and force resulting groundwater discharge on the surface.

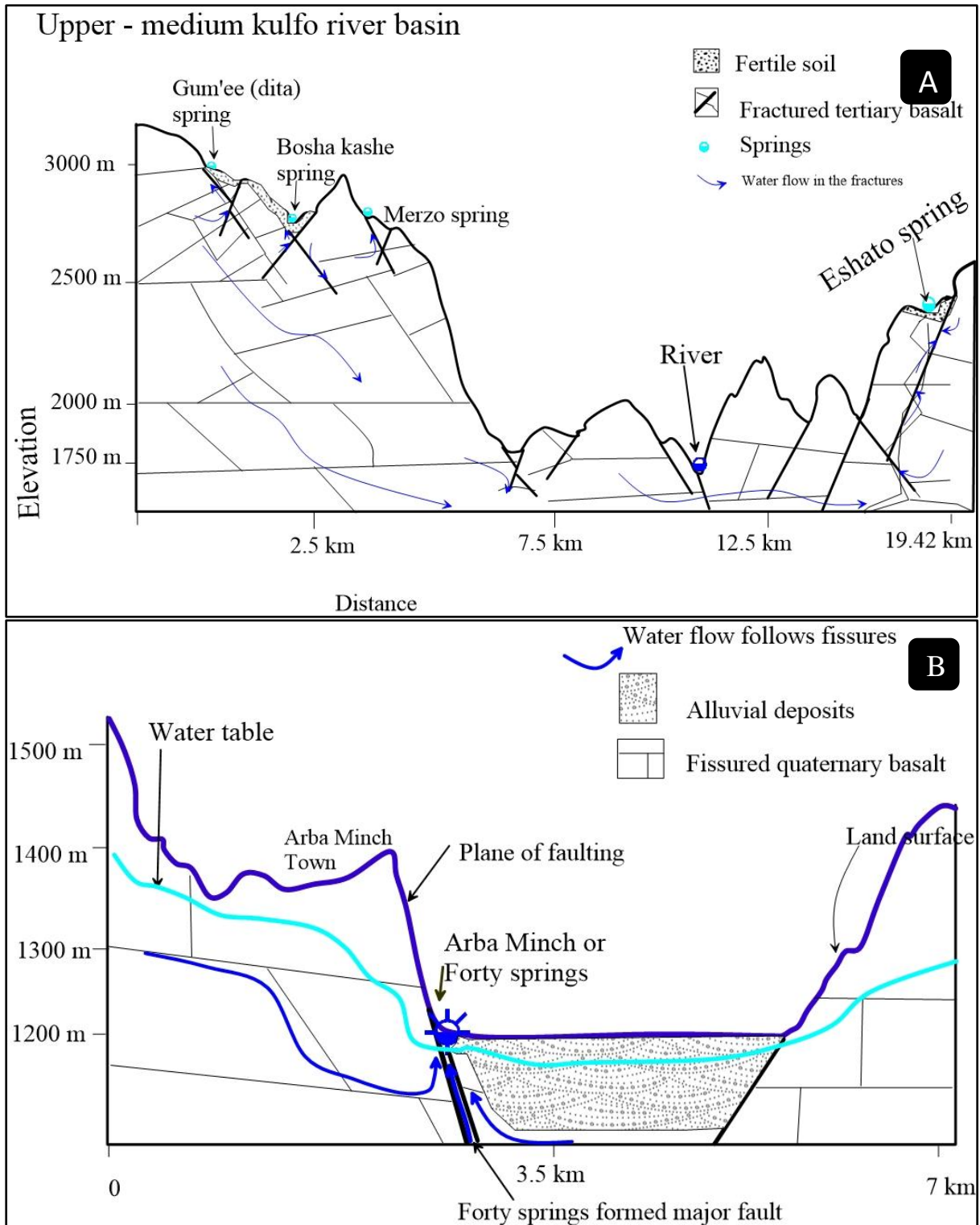


Figure 17. Idealized overview of fault control on groundwater flow

Therefore, for emergence of springs on the earth surface is due to both of barrier and conduit faults.

3.5. Groundwater occurrence

The presence of perennial springs of study area with large discharge is best evidence groundwater movement. Thus, groundwater in aquifer is may not occurs as immobile form. Since, its flow is continuous through the saturated zone due to force beyond movement. Mean that it always takes place in movement toward water bearing layers and comes out surface by forming springs. Spring is natural pumpage or overflow of groundwater reservoir due to fractures and fault that connected vertically and laterally open line. So structure network system raise hidden water may indicate groundwater occurrence underneath land surface or aquifer. An aquifer is a geologic formation or group of hydraulically connected geologic formations storing and transmitting significant quantities of potable groundwater (Neven K. and Zoran S., 2010). In the study area, groundwater occurrence is governed by geology, geologic structure (fault), physiographic condition, and distribution of springs. The numerous permanent springs in relation to fractured lithology and interconnected geologic structure in upper zone (figure 11) and big spring in relation to regional fault in lower basin are main focus to see subsurface water in the River basin. Based on this approaches, groundwater potential zone is mapped into low productive, medium – high productive and high productive (fig. 10). In the figure 11, the distribution perennial spring and presence of large trees along down thrown normal fault line shows occurrence of potential groundwater reservoir in the hidden environment. The quaternary basalt in rift floor contain big forty springs, alluvial deposits with borehole in the rift floor and perennial springs catchment in upper – intermediate zone of trap basalt is evaluated as groundwater potential zone. These hidden water saturated zone in upper and lower river basin are linked by faulting line at deep distance below earth surface (fig. 16). This map shows structural evidence with topographic set up in groundwater occurrence and flow. Therefore, Emergence of spring's with significant discharge from trap basalt and rift floor basalt sequence implies the occurrences and productivity of the Aquifer systems in the study area.

CHAPTER FOUR

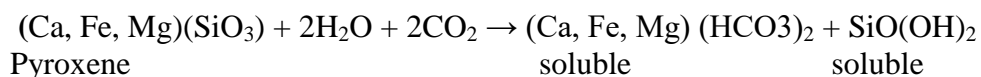
4. Hydrochemistry

4.1. General

An igneous rock terrain contains significant amounts of quartz, aluminosilicate and silicate minerals such as calcic plagioclase, alkali feldspar, olivine, pyroxene and micas. Quartz and feldspar minerals are originally formed at temperatures and pressures occurring at or near the earth's surface (Solomon Waltenigus, 2007). The silicate minerals are formed at high temperatures and pressures far below earth surface. However, these mineral are occurring at shallow geologic depth due to existence of silicate host rock like trap series basalt, rhyolite, ignimbrite and granite.

The chemical constitute of springs directly supply from subsurface water is governed by minerals of aquifer host rocks that dissolve during groundwater circulation. The chemical composition of springs varies from recharge zone toward discharge area. This is due to the susceptibility of water - rocks interaction increase with downstream line. Due to the evidence of groundwater flow path at depth, groundwater or springs in the discharge zone is high in chemical composition than in the recharge zone.

Water containing high concentration of HCO₃ indicates CO₂ induced interaction with rocks. Due to process of dissolution, CO₂ induces during interaction of water with lime stone and silicate rocks. However, in volcanic terrain, CO₂ induces interaction of water with rocks which is rich in alkali feldspars, calcic plagioclase and pyroxene as confirmed by (Emanuel, M., 2004):



As result of CO₂ induced silicate rocks, HCO₃ is highly concentrated in the groundwater hosted volcanic rocks. Similarly, springs with predominant bicarbonate reflect that the aquifer supply water is silicate rocks. The additional source of the extra CO₂ is biogenic: respiration of plant roots and bacterial decomposition of buried plant remains (Emanuel, M., 2004).

4.2 Physico – chemical characteristics of spring's water

The physico – chemical parameters of the spring water determined in the study area were PH, total dissolved solid, temperature and electrical conductivity. These parameters measuring

have been taken in situ location of springs by using instrument of digital PH meter, TDS meter, Multimeter and digital thermometer.

Hydrogen ion (PH):

PH of springs shows neutral solution of alkalinity and acidity in the river basin. The spring water of PH measured at field is ranging in 5.6 – 7.9. The variation observed due to geochemical reaction in variant discharge of spring (groundwater) of different location. Arba Minch, Shale and Gum'ee spring have PH greater than seven are locate plain land. This may indicate water spends more time in the subsurface of silicate rock. As result, these springs are characterized as basic or OH ion dominated and others are acidic or H ion dominated. The low PH value of Shanke spring may indicate shallowest depth water source rapid transmit time. This spring is found away from other eight spring group as seen in (fig. 21). Therefore, PH springs in the study area suggest their alkalinity is produced by the dissolved bicarbonate dominantly.

4.2.1. TDS and EC

These parameters showed parallel variation from upper class to lower one. The high TDS value of spring has high value EC but it not recorded in the same value. This indicates presence of dissolved minerals in water. The value of these parameters is increase from recharge area to discharge area, high elevation to low elevation and relatively low discharge spring to high spring discharge. Therefore, EC and TDS are increasing parallel along stream line.

The ascending trend of electrical conductivity in downstream of river basin (in table. 6) forecasts as ions produced by dissolution of solids in water is going predominant across groundwater environment. Along upper to lower spring's catchment, displacement of ions is not mostly observed. In this case, groundwater reservoir in the catchment is relatively hosted by same geology.

The TDS of fresh surface waters and groundwater's is typically in the range 10–500 mg/L, much higher than the levels found in precipitation (Charles R. Fitts, 2002). The TDS of springs water in the study area range from 35 -209 mg/l. Therefore, the springs in the study area are classified as fresh water recharging from subsurface reservoir.

The EC map kulfo river basin has interpolated by using measured electrical conductivity of nine springs and two boreholes in (fig.18). As observed on map, EC is linearly increasing

from upper zone to lower one. At and around Arba Minch spring EC value reaches peak. This suggests this spring's dynamically connected with recharge higher zone at depth.

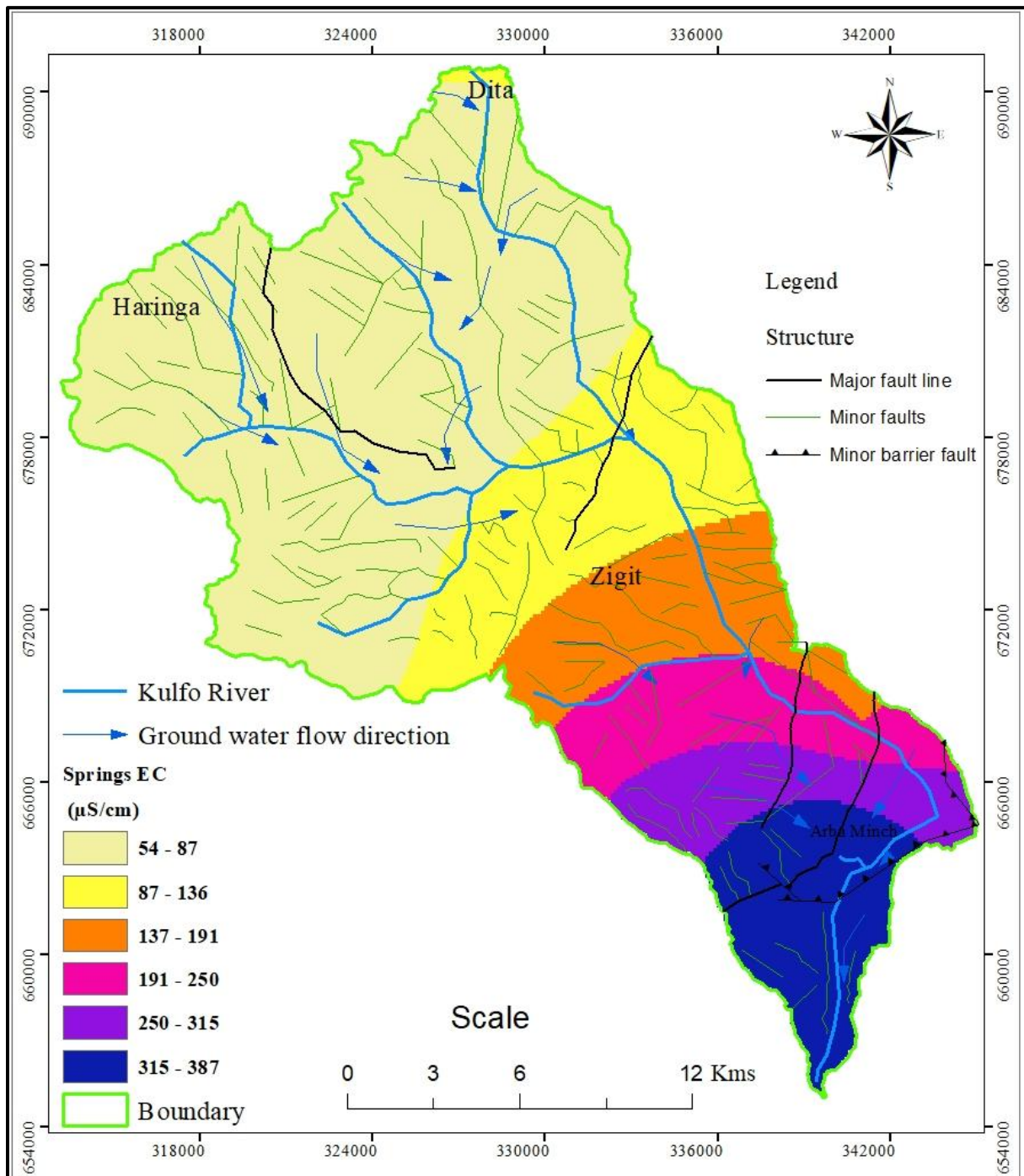


Figure 18. EC spatial variation map of study area

The low value related upper class of catchment points out groundwater supply associated with shallow depth at recharge zone. Based groundwater flow path oriented with ascending EC toward rift floor. In the alluvial aquifer flow direction trends toward barrier fault separate Lake Chamo from Arba Minch. All flow pattern direct to big spring suggests there is

enormous groundwater reservoir. From this evidence, AM fault is acts as groundwater collection chamber in the ground. Also linearly increasing of EC implies concentration of cation and anion in the catchment shows ever-increasing trend in from zone of recharge to discharge. Therefore, EC and TDS are increase approximately in a linearly way with anions and cation content seen figure 18 and 22.

Temperature: the springs involved in study area are cold springs having temperature below normal air temperature at dry seasons. This indicates presences of vegetation at and around spring's eye. According to Brayn, Kirk, 1919, most non-thermal springs have temperatures that are approximately the same as the mean annual temperature of the air in which they are found. The springs water temperature measurements collected during field study is varies an interval of 16⁰C - 25⁰C. The variation is due to discharge and location of springs. The springs pumping at in lower catchment have highest temperature with highest discharge than the intermediate and upper catchment observed in table 6. Therefore, the springs discharge temperature of study area depend on size of discharge and it location. The fresh groundwater that rises from water table due to hydraulic pressure and tectonic fracture takes up surface air temperature below normal.

Table 6. Physico-chemical characteristics of nine springs in study area

springs name	TDS (mg/l)	PH	EC (μ S/cm)	Alkalinity (mg/l)	Hardness	T (⁰ C)	Elevation	Sample code
Forty spring	209	7.41	388	420.8	181	25	1220	S1
Ganta spring	160	6.6	248	315.67	144	20.5	2211	S3
Lakal spring	35	7	54.4	112	14	18	2990	S4
Shanke spring	39	5.6	55	53.28	13	19	2560	S5
Gum'ee spring	68	7.9	77	176	53	17	3000	S6
Bosha spring	56	6.6	72	112	48	17	2875	S7
Merzo spring	59	6.6	61	106.7	27	19	2743	S8
Shale spring	65	7.4	67	144	49	19	2237	S10
Eshato spring	100	6.9	155	165.28	85	22	2390	S11

Hardness of springs

Water is considered “soft” if the hardness is less than 75 mg/L, and considered “hard” if hardness is above 150 mg/L (Benefield and Morgan, 1990). As noted in table 6, the hardness of springs in the study area varies in range between 13 – 181 mg/l. Its variation relatively increases with bicarbonate (fig.19). The dominance of Ca²⁺ and Mg²⁺ associated with silicate hydrolysis that result HCO₃ is predominant in all springs. The increasing concentrations of

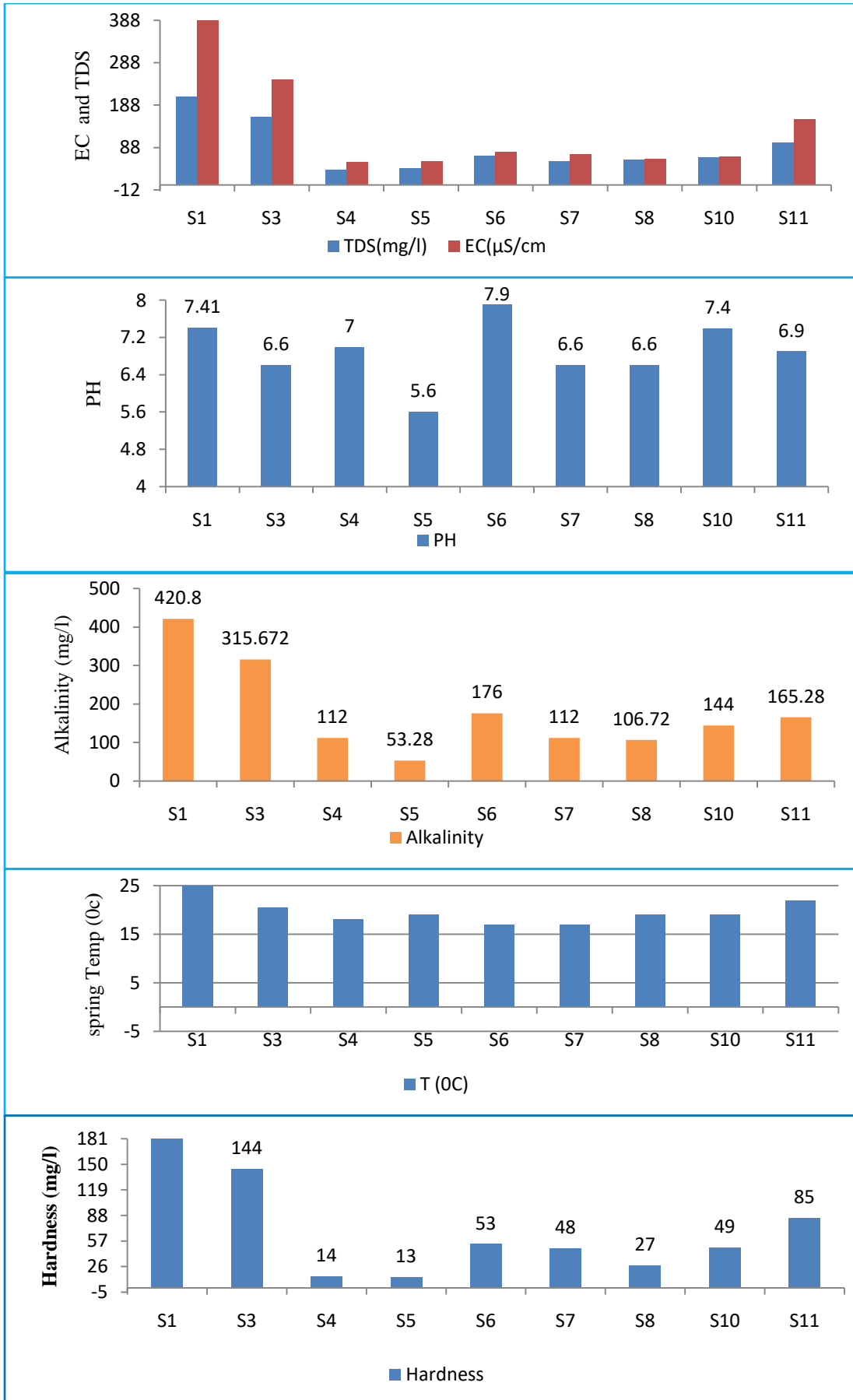


Figure 19. the relationship between physico- chemical parameters and alkalinity

HCO₃⁻ correlate with a corresponding increase in hardness - ($R^2 = 0.941$). Therefore, the hardness of spring in the study area is associated with Ca²⁺ and Mg²⁺ bicarbonate. It also increase with temperature and elevation observed on (fig. 20). The increasing concentrations of hardness relatively correlate with a corresponding increase in temperature - ($R^2 = 0.62$).

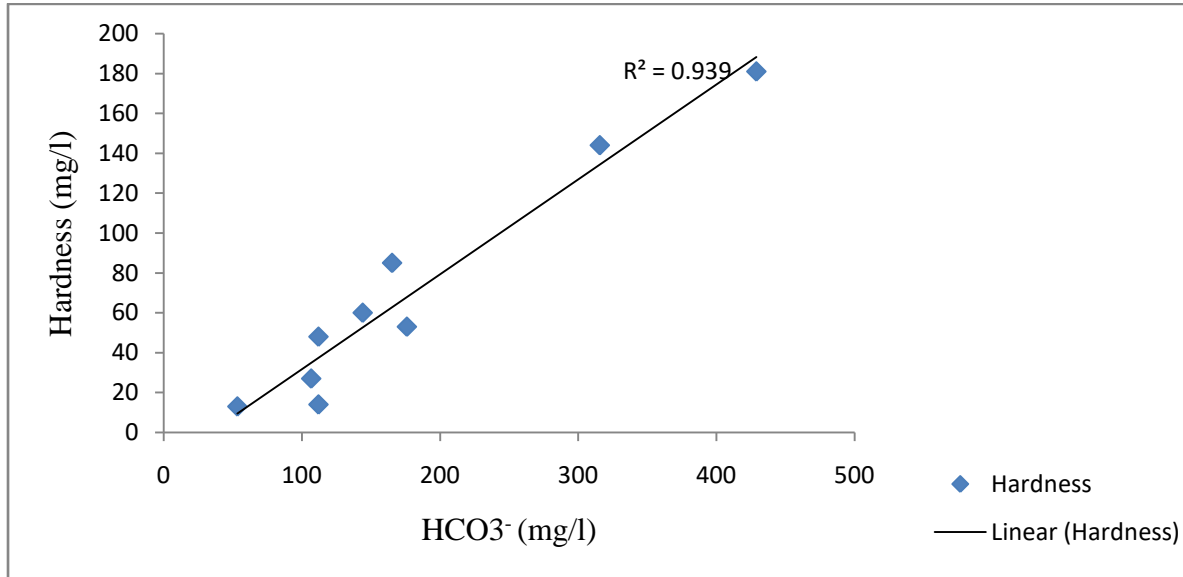


Figure 20. HCO₃⁻ – vs. hardness

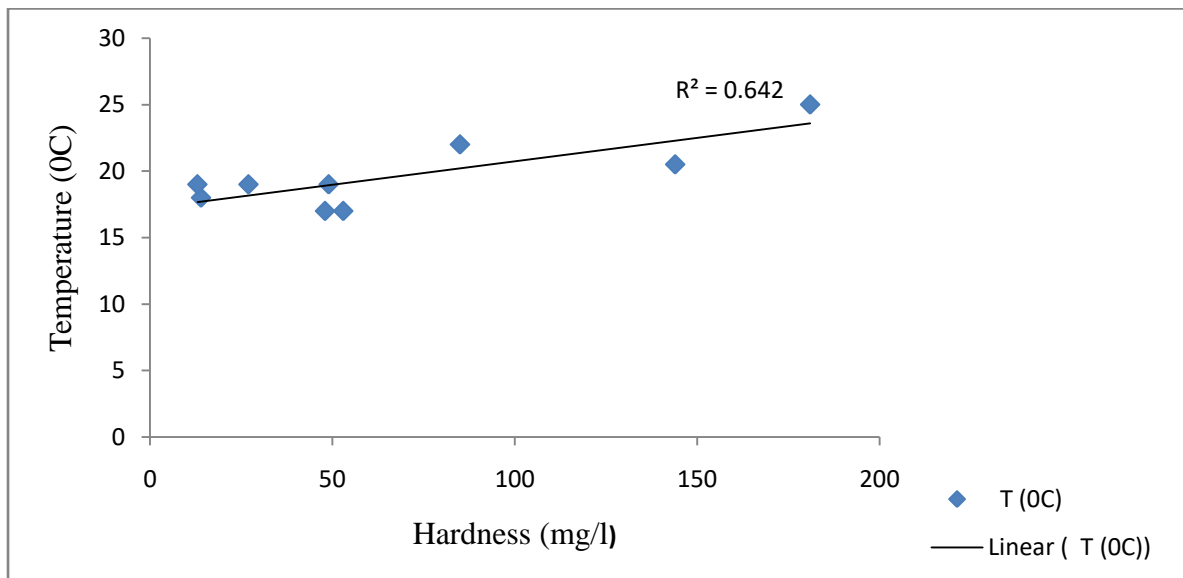


Figure 21. Hardness vs. Temperature

4.3 Major ions characteristics of spring’s water

The major ions laboratorial tested are calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), bicarbonate (HCO₃), chloride (CL), sulphate (SO₄) and nitrate (NO₃). These parameters are tested by laboratory analysis by using methods of AAS for Na and K, UV-Visible spectrophotometer for SO₄ and NO₃, titration for Ca, Mg, Cl and HCO₃. The values

of ions of spring water in upper, intermediate and lower river basin are different with respect to spring discharge and location. Its concentration value is decrease with increasing elevation and small discharge quantity of springs. In the anions bicarbonate reflects the highest value (figure 22) may indicates CO₂ induces interaction of water with rocks rich in alkali feldspars, calcic plagioclase and pyroxene. The major ions chemical concentrations of the spring's water imply the sources of spring water geology below earth surface. The variation of these ions in different springs in the study area may reflect consistence of fracture opening size and group of fractures that form spring water as one group. The groundwater followed single crust break to move and rise up to form spring water may have less chemical concentration than that of springs formed due to plenty fractures which transmit and store groundwater. The alkali ion in all springs from upper catchment to lower of part or forty springs is not observed in large variation shown (fig. 21). From view point of alkali ion variation, the springs water in the catchment has genesis linkage from recharge upper zone where less susceptible to water – rock interaction to ward discharge zone where water is highly susceptible to water – rock interaction. Not only this, bicarbonate dominance trend from upper catchment to lower zone in the river basin is the best indication that there are common spring's supply aquifer rocks. Low concentration of calcium in spring sample (S5) and S4 observed in (fig. 21) is point outs quit small the water–rock interaction relation form chemical constituent in water. Therefore, this type of springs is shallow seated water.

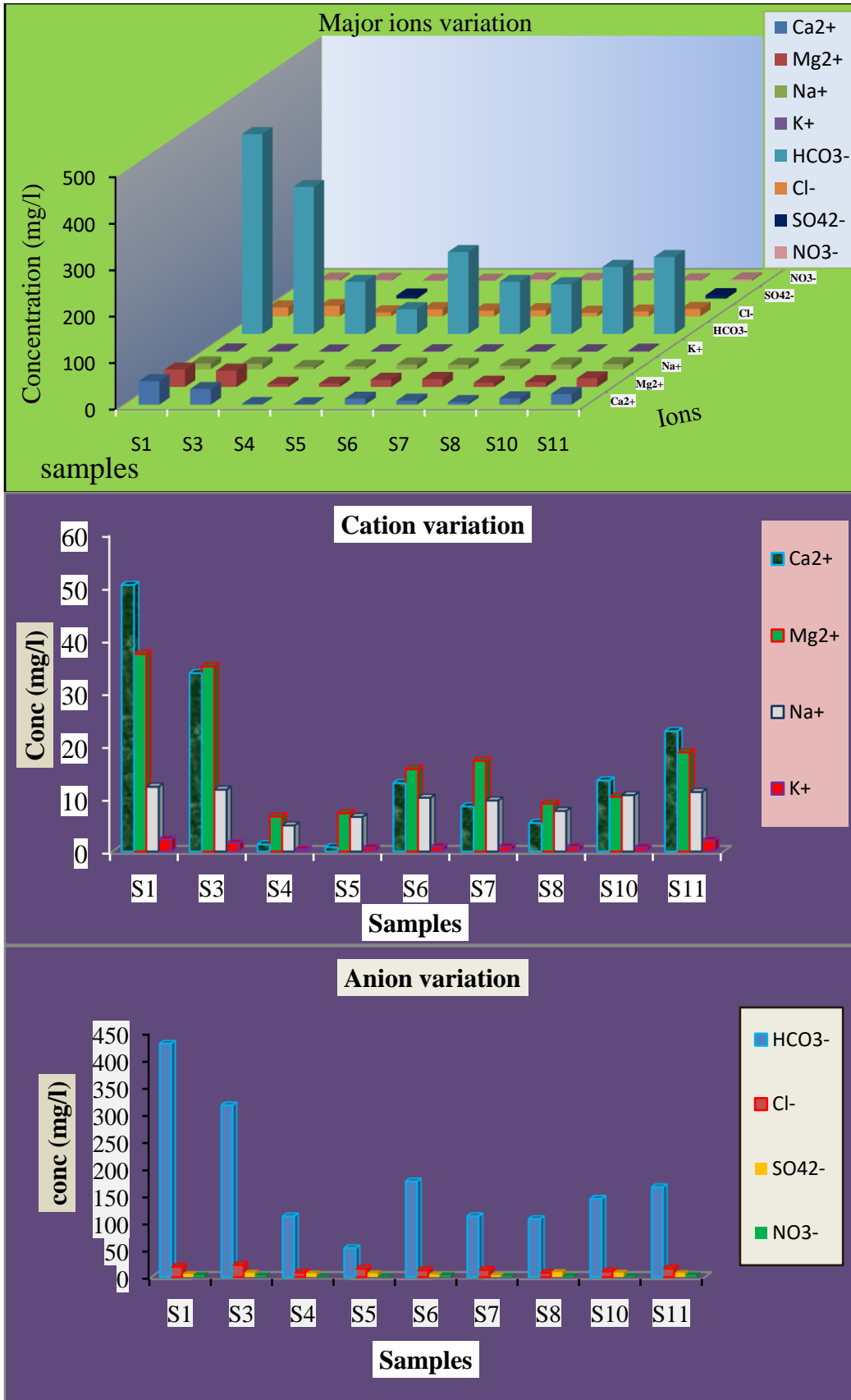


Figure 23. Major ion characteristics of representative springs water

Table 7. Laboratory tested major ions of nine spring's water sample (mg/l)

Sample code	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
S1	50.3	37.3	12.2	2.3	429	19	5.6	3.2
S3	33.66	34.9	11.66	1.6	315.672	22.25	8	2.7
S4	1.34	6.6	4.9	0.4	112	8.52	6.8	0.7
S5	0.8	7.2	6.5	0.73	53.28	15.33	7	0.8
S6	12.9	15.5	10.12	0.9	176	12.3	4.5	3.3
S7	8.49	17.1	9.6	0.88	112	13	3.3	2.1
S8	5.37	9	7.63	0.84	106.72	7.5	9.2	1.8
S10	13.39	10.3	10.6	0.77	144	10.36	8	1.6
S11	22.69	18.7	11.2	2.12	165.28	15.62	7.5	3.5

The six samples, S3, S4, S5, S6, S7 and S8 magnesium (Mg) exceed calcium (Ca) and three samples S1, S10 and S11 Calcium (Ca) exceed magnesium (Mg). And in all springs, sodium (Na) exceeds potassium (K) The bicarbonate (HCO₃⁻) is the major chemical constituent in all water samples which exceed all other major ions (fig. 22).

4.4 Other chemical constituents

Alkalinity

There are a number of source of naturally occurring chemicals in spring water that drive from rock and soil during groundwater circulation. Springs water at dry season usually contain naturally occurring chemicals as result of slowly happening natural filtration processes. These naturally occurring chemicals concentration varies in water according to the nature of chemicals and sources.

Alkalinity is related to the sum of the carbon-containing species dissolved in the water: CO₂, HCO₃, and CO₃. Bicarbonate is commonly the dominant ion (Emanuel, M., 2004) in the water. The most natural waters contain significant amounts of dissolved carbon dioxide species, which are the principal source of alkalinity.

4.5 The spring water types

Based on hydrochemical properties and piper plot (fig. 23), spring water selected for chemical analysis to represent spring in the study area are grouped in to Mg-Ca- HCO₃, Mg-HCO₃ and Mg-Na-HCO₃-Cl (observed in appendix 3). The spatial distribution of springs water hydrochemical characterization has been made in piper plot is based on dominant cation and anion processes applied in the aquifer rocks.

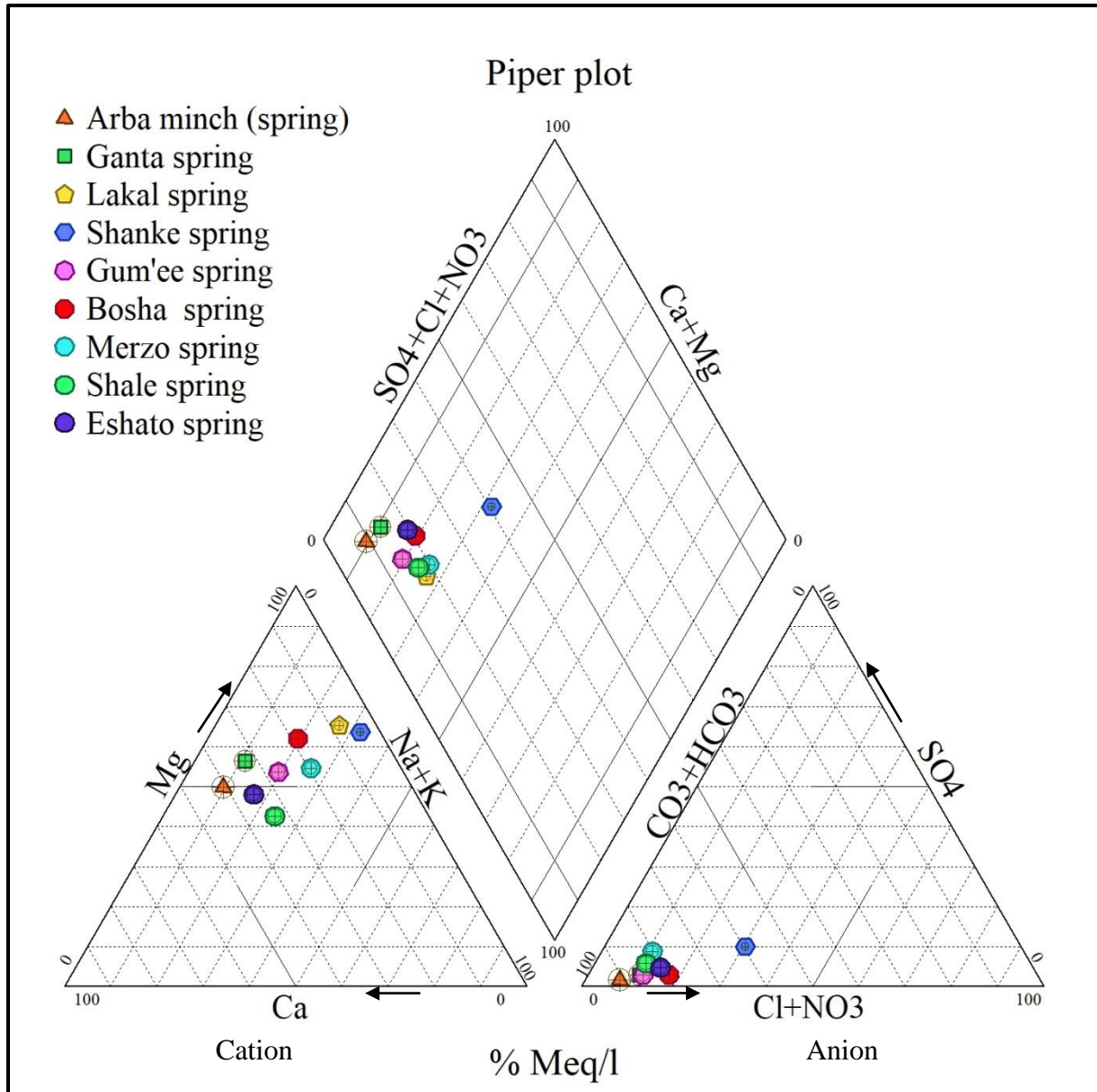


Figure 24. Piper plot applied to all the selected springs' water

The common cations in spring's water are Ca²⁺, Mg²⁺, Na⁺ and K⁺; while the common anions are HCO₃⁻, SO₄²⁻ and Cl⁻. Together, these ions form the basis for the classification of spring water. As Neven K. et al, 2010, the three main groups of water which are bicarbonate waters where Ca and Mg tend to be the dominant cations, sulfate waters where Mg may be greater than Ca and alkali ions are also present; and chloride waters where alkali ions tend to be dominant. Ca and Mg are dominantly observed in piper plot suggest the most spring's water type in the Kulfo River is bicarbonate water (fig. 23).

The dominant chemistry usually depends on the host rock of the aquifer from which the spring emerges. The water type identified in the catchment again belongs to CaHCO₃

includes MgCaHCO_3 and MgHCO_3 includes MgHCO_3 and $\text{MgNaHCO}_3\text{Cl}$. Accordingly, the spring belongs bicarbonate water type in study area are grouped into CaHCO_3 and MgHCO_3 . Arba Minch, Ganta, Eshato, Gum'ee and Shanke springs are belongs to CaHCO_3 and other five springs in the upper zone are belongs to MgHCO_3 . All springs are emerges from basaltic aquifers which are different in degree of weathering, depth of fractures, density of lineaments. Consequently, common type of water classification suggests groundwater in recharge and discharge zones are dynamically linked and source aquifer rocks are genetically same. However, water type $\text{MgNaHCO}_3\text{Cl}$ of Shanke spring moved away from other spring group seen figure 22 due to evaporation in shallowest aquifer. In this spring concentration of Na and Cl is highest as compared with other upper catchment springs.

4.6. Spatial variation of spring water chemistry

The variability of water chemistry depends on geology, geologic structure, topographic setting, groundwater flow direction and drainage system seen in (fig.24). The groundwater moves from higher elevations to lower elevations and from locations of higher pressure to locations of lower pressure. As result of groundwater movement, water takes up soluble substances from the rocks through which it flows and store. The springs found on the water divide of catchment especially Shanke (S5) and Lakal (S4) has less chemical concentration as observed figure 4-5 and table 4-4. These springs and others are located in recharge zone of study area where less susceptibility of water – rocks interaction. As noted from table. 8, high average concentration of chemicals in water is observed in forty springs; then intermediate zone springs and lowest in the upper zone. As Tilahun Azagegn (2014), residual alkalinity (RA), the difference between concentration of HCO_3^- and the sum of concentration of Ca^{+2} and Mg^{+2} , is used for understanding the changes affecting the chemical composition of the groundwater along the flow path. Together with TDS, it helps to identify recharge area from discharge area. This is approved in figure 23, TDS is increasing toward low elevated region from recharge region to discharge region of kulfo river basin. The integrated evidence above imply chemical constituent of water increase along flow path groundwater.

Table 8. Average water chemistry representative in the three zone of study area

Parameters	Lower catchment	Intermediate catchment			Upper catchment		
	S1	Min	Max	Average	Min	max	Average
TDS(mg/l)	209	S11, 100	S3, 160	130	S4, 35	S6, 68	53.67
PH	7.41	S3, 6.6	S11, 6.9	6.67	S5, 5.6	S6, 7.9	6.85
EC(Sμ/cm	388	S11, 155	S3, 248	201.5	S5, 55	S6, 77	64.4
Hardness	181	S11, 85	S3, 144	114.5	S5, 13	S6, 53	34
HCO ₃ ⁻	429	S11, 165.28	S3, 315.67	240.47	S5, 53.3	S6, 176	117.33
Ca ⁺⁺	50.3	S11, 22.69	S3, 33.66	28.175	S5, 0.8	S10, 13.4	7
Mg ⁺⁺	37.3	S11, 18.7	S3, 34.9	26.8	S5, 7.2	S7, 17.1	10.95
Na ⁺	12.2	S11, 11.2	S3, 11.66	11.43	S4, 4.9	S10, 10.6	8.25
K ⁺	2.3	S3, 1.6	S11, 2.12	1.86	S4, 0.4	S4, 0.9	0.75
Cl ⁻	19	S11, 15.62	S3, 22.25	18.9	S8, 7.5	S5, 15.33	11.16
SO ₄ ⁼	5.6	S3, 7.5	S11, 8	7.75	S7, 3.3	S8, 9.8	6.46
NO ₃ ⁻	3.2	S3, 2.7	S11, 3.5	3.1	S4, 0.7	S6, 3.3	1.7
T (0C)	25	20.5	22	21.25	16	19	17.5
Q (l/s)	130	1.12	4.4	2.31	0.08	2.7	1.4
Elevation (m)	1220	2211	2390		2237	3000	

The over flow of groundwater or discharge of spring's water varies with respect to topographic setting and depth of fractures. Similarly, the chemistry of spring water differs with the quantity of spring discharge and topographic position (fig. 24).

According to field observation, most of springs in the intermediate zone are dried at dry seasons. This may indicates the springs in this selected parts are may be emerge at wet season due shallow groundwater circulation. But in the most spring catchment in the studied area, springs still flowing at driest months. As Seifu Kebede, (2013), faulting and fracturing in the aquifers still the porous flow type dominates the flow in the volcanic terrain. This dominantly conceptualized in upper and lower zone lithologic unit. The chemical analysis indicates chemical characteristics of spring's water discharge in dry season only.

Therefore, the springs water hydrochemical characteristics and it variation in river basin point out groundwater hydrology as one parameter. Chemical characteristics of groundwater define the groundwater flow direction and its quality. This is already discussed in chapter 4 and 3 with some reasonable evidences.

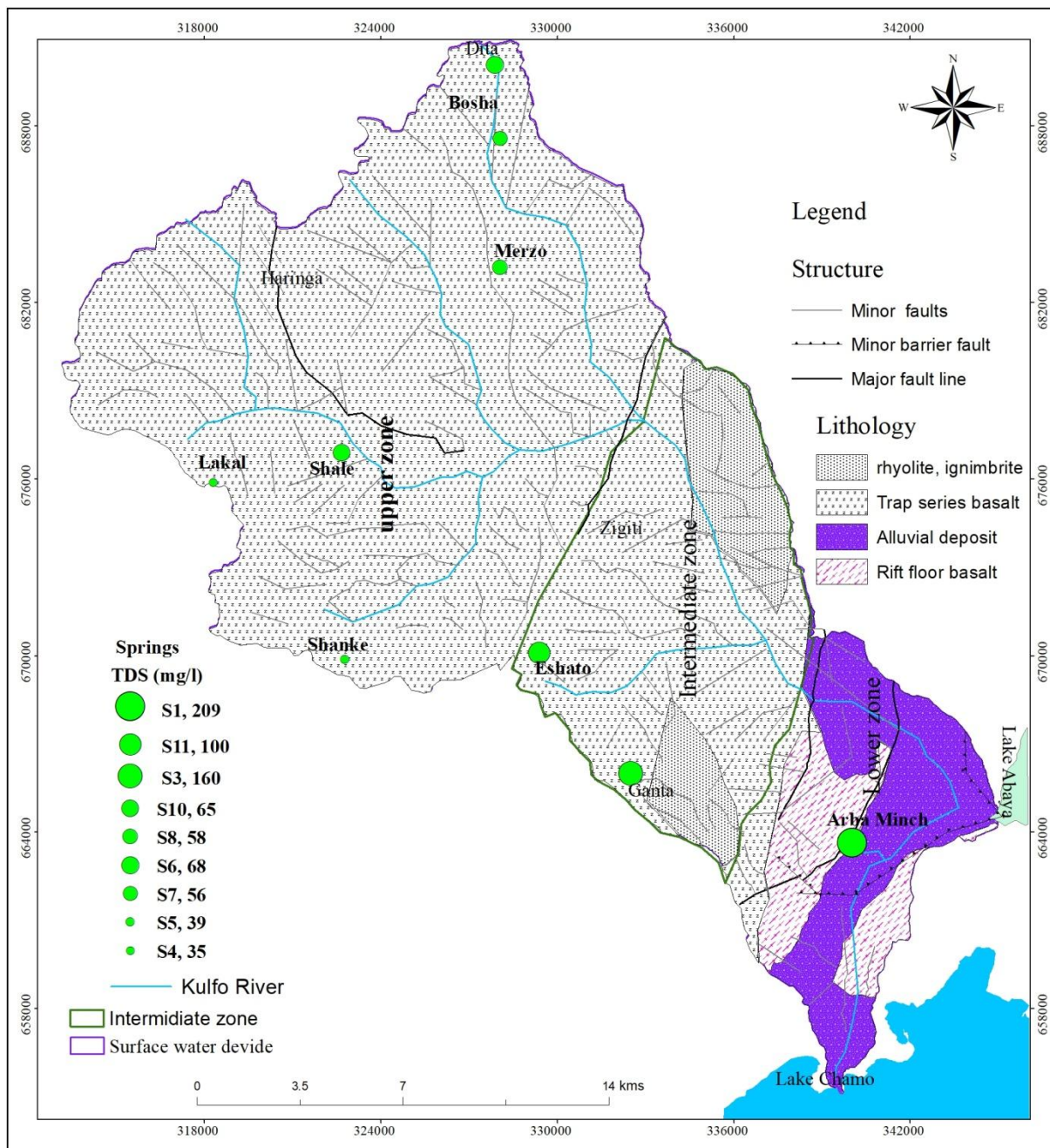


Figure 25. Springs spatial discharge chemistry variation map

The discharge of eshato spring (S11) in the lowest upper zone is higher than that of Ganta spring (S3) in the middle zone but TDS of S11 is less than S3. This is due to variation of elevation and groundwater flow direction. When comparing TDS of eshato spring (S11) with Ganta spring (S3), Ganta spring is found below elevation of eshato spring which has 4.4 l/s discharge with TDS of 100mg/l. But Ganta spring has 1.5 l/s discharge amount with TDS of 160 mg/l observed on figure 23. The discharge variation in between these two springs is due variation of presence and size of fracture opening that transmit and supply groundwater to surface naturally. TDS decrease with increasing elevation (fig. 25) indicates groundwater

flow direction below ground surface. In general the TDS of spring water varies with location and amount of discharge at dry season. TDS of groundwater increase with groundwater flow direction from recharge area to discharge area. $R^2 = 0.648$ points increasing of TDS correlate with corresponding decrease of elevation.

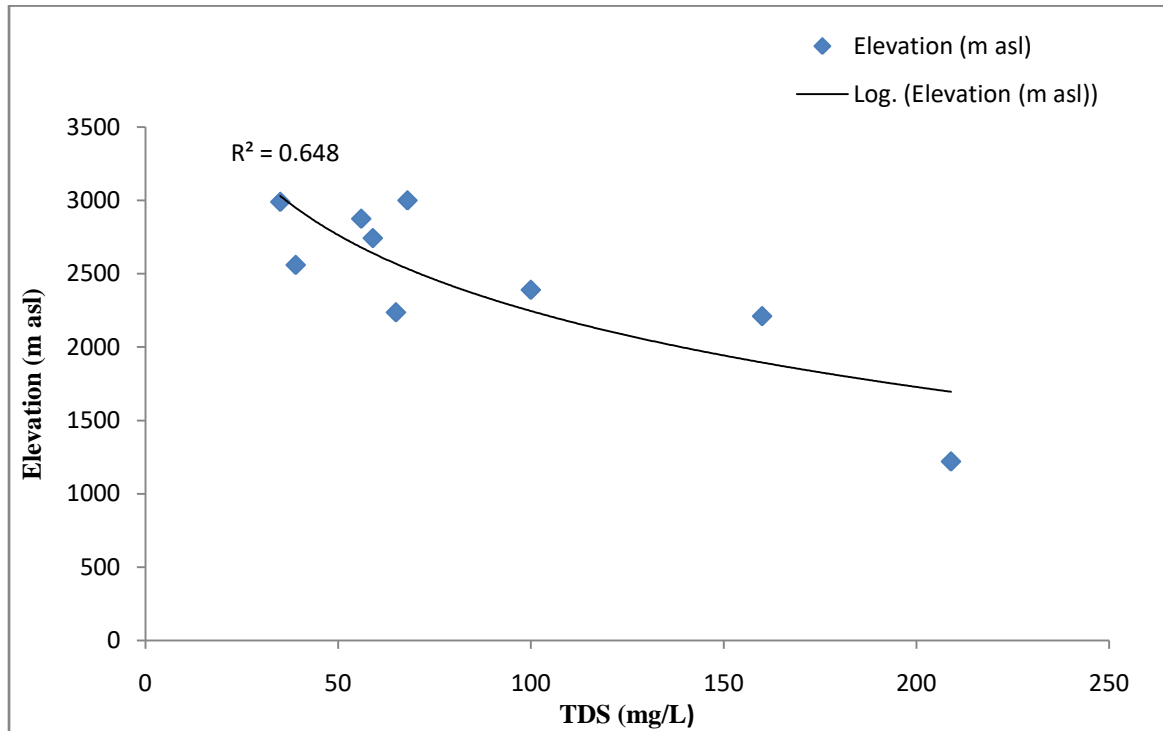


Figure 26. The variation of TDS vs. topographic positions

4.7. Water - rocks interaction in the river basin.

When ground water pass through subsurface geologic environment, water takes up soluble substances from the rocks through which it flows (Kevin, M. Hiscock, 2005). The geology of a groundwater flow pass through is a key factor in determining the concentration and composition of dissolved solids (Charles R. Fitts, 2002). As the water spends more time in the subsurface, inorganic solute concentrations is increase after long residence times. As result, chemical constituent in water increase from recharge area to discharge area. Dissolved solute constituent of spring water in the study area is increase from recharge area to discharge zone observed in (fig. 24). Long residence water below earth surface encounter large chemical consistence and reflect aquifer geology that water stored and passed. Based on this, low TDS and low average discharge in upper zone of river catchment indicates less susceptablity of water-rocks interaction. As observed in (fig. 24), TDS of spring in the upper zone is viries locally. This is because, variation of depth of flow lines rising up groundwater to surface. Also water - rock interaction varies from water devide to ward down streams.

The springs located in water divide has low TDS with low discharge evidence suggest this zone is quiet discharge zone that water have short residence time through aquifer. In the lower chatchment, ArbaMinch spring is characterized as dominant consistence of chemicals suggest water has long residence time by keeping aquifer geology. The predominant bicarbonte constituent in the arba minch spring (fig. 26) points groundwater is moved long residence time through silcate rocks. As Kirk Bryan, 1919, water temperature, dissolved salts, contained gases; rate and amount of flow, form and position of the spring opening are all characteristics of springs, which while in many cases related to genesis, vary among springs of the same origin.

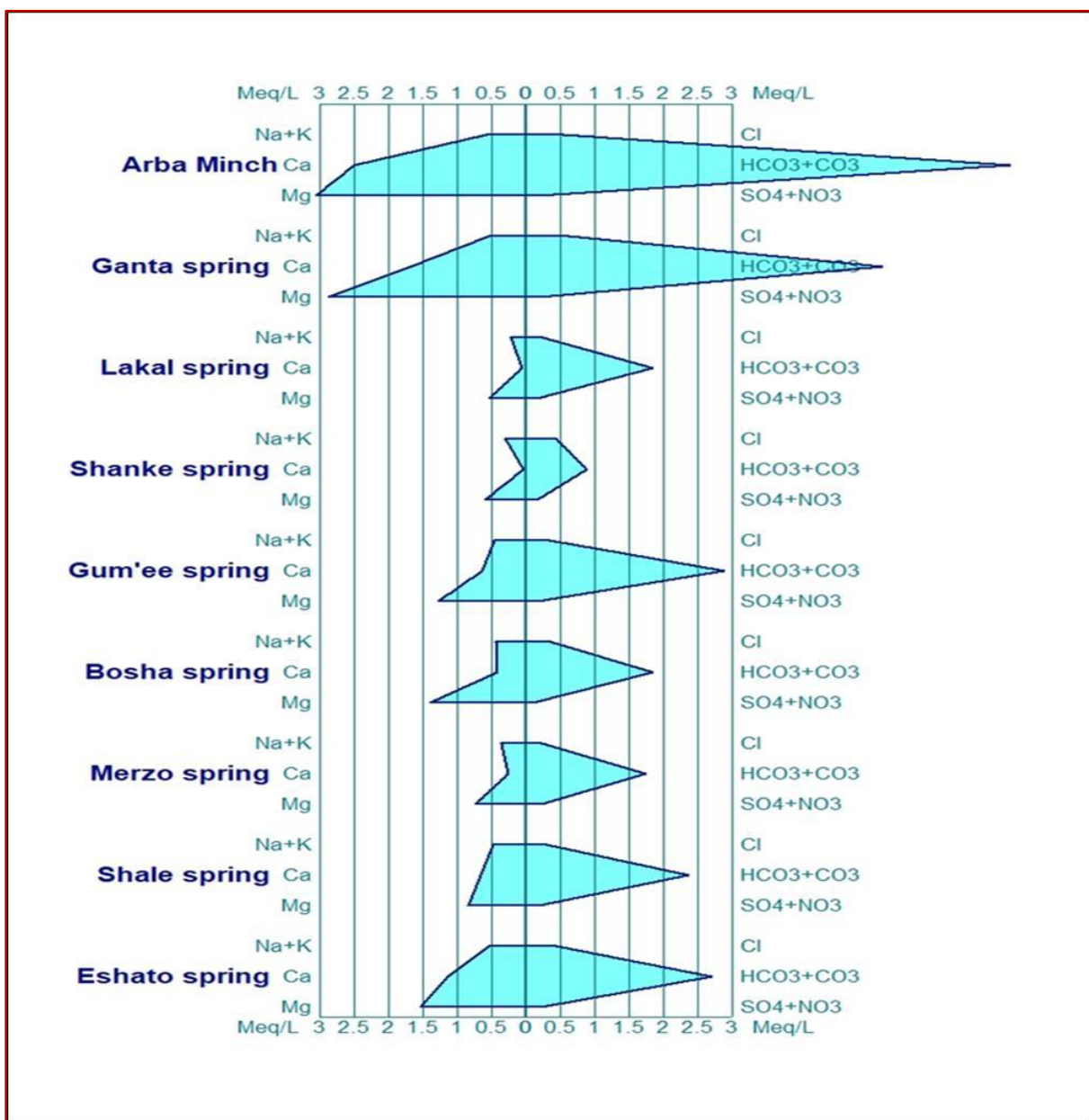


Figure 27. Stiff diagram point's predominant major ions concentration in the springs

In the figure 26, the predominated ion in the all spring's water suggests that the water – rocks interaction in the aquifers governed by silicate hydrolysis. Its concentration show increasing from upper zoned springs such as Gum'ee, shale, and others to ward eshato and Ganta (intermediate zoned) to Arba Minch points out groundwater flow occur slowly in the silicate dominant terrains example trap or plateaus and rift floor basalt. The spatial variation of hydrochemistry in the upper zoned spring water discharge may signify upstream flow of groundwater in the ground due to highly fracture geology that control aquifer.

The perennial spring's water in the study which circulates in the ground may be roughly divided into two: deep seated and shallow seated. This is according to discharge characteristics, location (structures) and dominance of chemical concentration at dry time. The springs due to deep seated is contain long residence time water with excess dissolved chemicals.

Springs due deep seated water

These springs may have regional or local origin from different groundwater reservoir which is connect each other by break of earth crust due to tectonic movement. The presence of important breaks in the earth's crust or of other structures along which water could rise provides positive evidence for existence of spring from deep seated water (Kirk Bryan, 1919). This type of springs are located and measured in intermediate zoned springs, and lower part of forty springs. Their TDS observed (figure 23) is raised from 100 – 209 mg/l. As compared with other springs in the study area, Ganta, eshato and Arba Minch springs are deep seated spring water. The fracture opening that produce this type's spring is estimated as large enough for water circulation. As compare their discharge TDS (fig. 24) lower elevated Arba Minch spring is highest in temperature, dissolved salt, rate of discharge, spring opening and suggest long residence time water – rock interaction below surface.

Shallow seated spring water

This spring's form due to locally intersected fault and other fracture that facilitate water passage and their origin may belong to local groundwater origin. This group of spring existing low TDS suggest short residence time in the aquifer rocks. The springs in the upper class of study area reflect structurally shallow seated water. The distance between recharge and discharge zone not teams apart. During laboratory titration, Lakal and Shanke, spring

sampled from upper class is change color immediately from pink to purple. This shows that very low concentration of minerals in water.

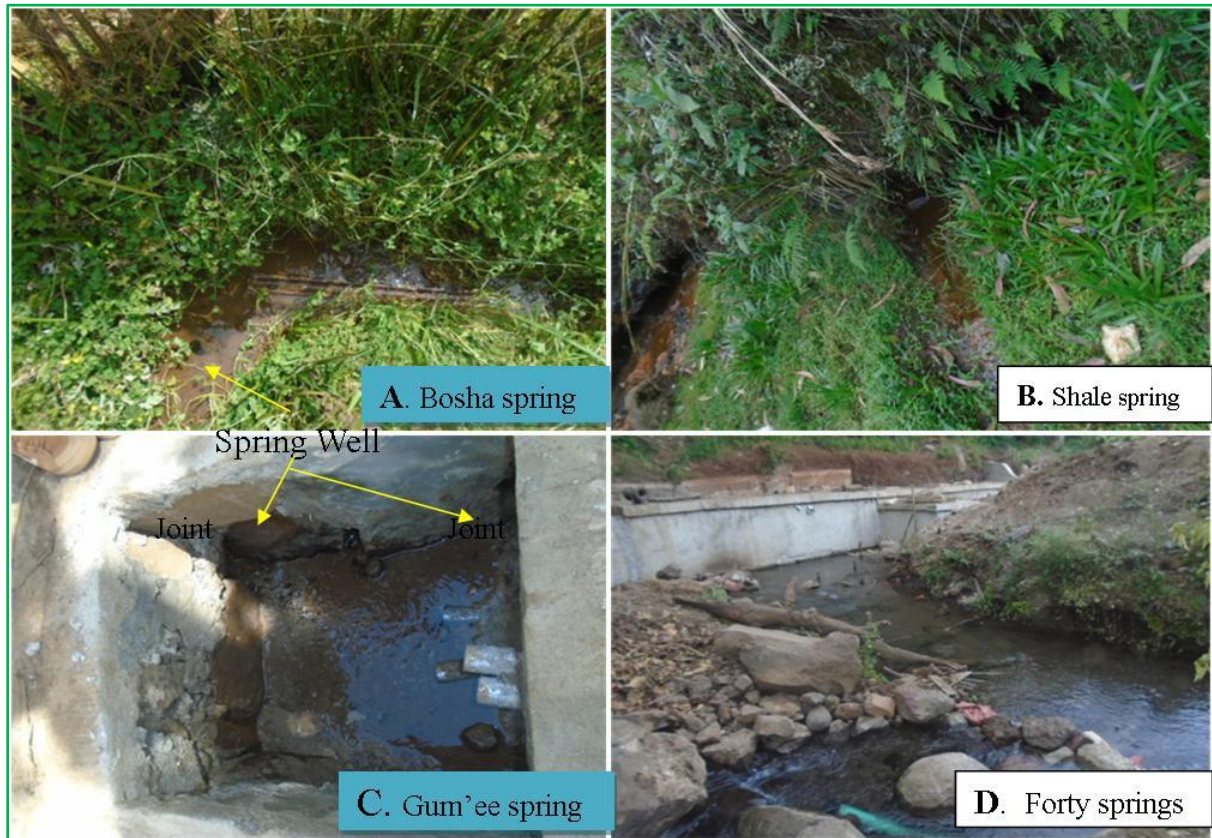


Figure 28. Physical over view of spring discharge at location point

As shown in figure 27, Shale, Gum'ee and Bosha springs are shallow seated and Arba Minch (forty springs) deep seated. The physical field observation with chemical constituent of spring helps to estimate its depth below surface. Bosha spring shown in (fig. 27A) suggests groundwater discharge exposed in artesian flow through single open on the surface while B, C and D are exposed in artesian flow through more than one fractures open. According to nature of spring discharge, constituent of dissolved minerals is variable.

CHAPTER FIVE

5. Conclusion and Recommendation

5.1. Conclusions

Geomorphologic set up of kulfo river basin in the southern section of rift valley lake basin is so complex and challenge due to geotectonic features. However, through these all challenge finding evidences from controlling factors that bring groundwater on the surface, field study, DEM and satellite imageries, geology, structures and hydrochemistry approaches have been used. To define geographic position and discharge opening of springs, field investigation have been taken as a series effort. Concerning the methods used, conclusion of the study as follows.

- ✓ The main factors that produce variant discharge and distribution of springs in the study area are faults, nature of geology and geographic setting. Among these factors, fault has greatest role in the groundwater over flow due to force beyond subsurface water movement.
 - The minimum discharge of Arbaminch spring =130 l/s indicate, spring opening associated with major regional fault.
 - SQ range between 1.5 – 4.4 l/s associated with major large fault
 - SQ between 0.1-1.5 associated with local large fault
 - SQ value between 0.01 – 0.1 l/s associated with shallow penetrated litho-structural that contributes groundwater flow on the surface.
- ✓ Fracturing and faulting is major factor for groundwater store as barrier and transmit as conduit in volcanic rocks. On the other hand, Rift valley margin of study area is highly weathered, crushed and fractured. Consequently, hydrogeology of this part as discussed low productive indicated fault opening which is filled with crashed clayed soil.
- ✓ The dense distributions of perennial springs with open discharge at dry seasons imply the productivity of aquifers host rocks that supply water toward surface. In this case, water from groundwater reservoir still flowing through productive fault line. As result, groundwater is still available with regularly unlimited flow below the earth surface.
- ✓ Groundwater flow pattern and perennial spring distribution from upper part to western intermediate zone and to lower zone of study area producing big spring indicates

groundwater reservoir in this layer is dynamically connected. Hence, all groundwater flow pattern direct to big spring suggests there is enormous groundwater reservoir. From this evidence, AM fault is acts as groundwater collection chamber in the ground by help of surround barrier fault.

- ✓ The hydrochemical characteristics of the springs in kulfo river basin point out all springs supplying subsurface reservoir are dynamically connected from recharge zone discharge zone. The variation involved is due to residence time of water-rocks interaction in the catchment.
- ✓ Low concentration chemical constituent in the upper zone of study area indicates upper zone is recharge class with low susceptibility of water rock interaction while lower zone discharge area of catchment with high concentration of dissolved mineral in spring water.
- ✓ The main concentration of Mg^{2+} , Ca^{2+} and bicarbonate in the volcanic terrain of spring water points suggests water supplying aquifer in the basin is controlled by silicate mineral dominant rock such as trap series basalt, rhyolite and most probability quaternary basalt. Therefore, chemical constituent in the spring linearly increase from upper class to lower one.
- ✓ High TDS Springs in the River basin indicates these water spent more residence time in the subsurface before emergence on the earth surface. These types of springs have deep seated circulation through geologic environment.
- ✓ Arba Minch spring at foot of river basin indicates, it has groundwater recharge from upper catchment through conduit fault line at depth. This is due the best evidence of linear corresponding increase of dissolved natural solutes from recharge to discharge zone.

Generally, emergence of spring's significant discharge from trap basalt and rift floor basalt sequence implies the productivity of the aquifer systems in the study area. Springs water discharge at dry season provides to enhance the opportunity in groundwater investigation and understandings on groundwater hydrology. Thus, under similar physiographic conditions, it is possible to differentiate aquifer subsystems in terms of perennial spring's distribution, minimum yield in relation to geology and geologic structure which facilitate groundwater circulation.

5.2 Recommendation

In main Ethiopia rift valley especially in rift valley basin including kulfo river catchment in chamo lake basin is characterized by spacious distribution of the springs at all seasons. But season based continuous the springs discharge measurement in this basin is not applied before. The method used in this study to characterize springs in relation to groundwater hydrology is point's way for further investigation on groundwater occurrence, movement and distribution. To apply additional methods for further study, recommendation as follows;

- ✓ Seasonal based the springs discharge measurement should be important which is better to represent the actual field conditions (the variability's) with more reasonable accuracy leading to a more realistic output.
- ✓ Seasonal based the springs discharge hydrochemical characteristics would be important in order to represent water chemistry variability with discharge change.

The methods used in this study may points the way for further investigation to identify additional factor that leads emergence of potential springs on the surface and their implication on groundwater hydrology.

- ✓ The potential spring in driest months is direct indication of groundwater reservoir. To understand hidden water resource, recharge and discharge estimation of springs producing river catchment will be better to estimate volume of aquifer storage in the river basin.
- ✓ Springs water producing groundwater reservoir investigation needs time and integrated methods to identify all spring's field condition.
- ✓ According to WHO (1973) international standard water quality, all springs except shanke in the study area are recommended for drinking.

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Annexure

Annex 1. Summarized mean monthly rain fall and temperature

Summarized mean monthly rain fall and temperature														
No	station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	ARBA MINCH	P	36.68	52.85	62.3	158	139.2	59.6	41	54	80	98	61	42.2
		mmMaxT	32	33.4	33.1	30	28.7	21.2	27.5	29	30.3	29.9	30.58	31.1
		mmMinT	16.2	17	18.6	18.2	18	17.9	17.8	18	17.8	17.4	15.88	15.5
2	ZIGITI	p	44.3	39.9	78.3	182	168.2	81	57.48	80	125	111	103	56.5
		mmMaxT	20.5	21.8	21.6	19.9	19.8	18	17.4	16	17.8	19.2	18.8	20.4
		mmMinT	12.56	11.8	12	11.3	11.3	10.4	9.9	10	10.7	11.4	10.9	10.7
3	CHENCHA	P	40.6	49.9	143	191	140.1	81.9	129.7	111	118	162	88.5	45.6

Annex 2. Spring's water type from piper plot

Springs name	Water type	Sample code	Lithology	Date of sample
Arba Minch	Mg-Ca-HCO ₃	S1	Rift floor basalt	5/5/2010
Ganta spring	Mg-Ca-HCO ₃	S3	Trap basalt	23/4/2010
Lakal spring	Mg-HCO ₃	S4	Trap basalt	23/4/2010
Shanke spring	Mg-Na-HCO ₃ -Cl	S5	Trap basalt	23/4/2010
Gum'ee spring	Mg-Ca-HCO ₃	S6	Trap basalt	10/5/2010
Bosha spring	Mg-HCO ₃	S7	Trap basalt	10/5/2010
Merzo spring	Mg-HCO ₃	S8	Trap basalt	11/5/2010
Shale spring	Mg-Ca-HCO ₃	S10	Trap basalt	23/4/2010
Eshato spring	Mg-Ca-HCO ₃	S11	Trap basalt	24/4/2010

Annex 3. Springs and its minimum discharge value kulfo river basin at dry months

Springs and its minimum discharge value kulfo river basin at dry months						
	Name of source	x	y	Z	Q (l/s)	Date of measured (dd/mm/yyyy)
1	Arba Minch	340032	663604	1220	130	20/5/2010
2	Ganta spring	332495	665984	2211	1.5	21/5/2010
3	Lakal spring	318304	675874	2874	0.08	23/5/2010
4	Shanke spring	323281	669897	2560	0.3	23/5/2010
5	Gum'ee spring	328227	688642	2974	0.2	23/5/2010
6	Bosha spring	328055	687570	2920	0.6	23/5/2010
7	Merzo spring	327766	683002	2732	0.4	23/5/2010
8	Shale spring	322670	676872	2237	0.2	25/5/2010
9	Eshato spring	329380	670071	2390	4.4	25/5/010
10	Mishallo	328346	686485	2925	0.2	28/6/2008
11	Batto	328418	686936	2897	0.091	28/6/2008
12	Zimbayne	329106	687165	3088	1	28/6/2008
13	Homea	328406	686575	2947	1	28/6/2008
14	Shochore	328328	686712	2930	0.33	28/6/2008
15	Buze	328055	687570	2920	0.12	28/6/2008
16	Galso	328242	687189	2978	0.2	28/6/2008
17	Homea	328227	688153	2974	0.05	28/6/2008
18	Pulte	328254	688642	2947	0.045	28/6/2008
19	Shasha	328193	688798	2959	0.06	28/6/2008
20	Gazaze	328398	689451	3033	0.035	28/6/2008
21	Buldkanche	328082	689050	2962	0.09	28/6/2008
22	Paranje	328016	689100	2950	0.14	28/6/2008
23	Elloynda	327704	683345	2768	0.0125	29/06/08
24	Ese	327464	683499	2729	0.011	29/06/08
25	Salile	327301	684003	2682	0.33	29/06/08
26	Mashachare	326991	682555	2455	0.33	29/06/08
27	Kasho	326520	681515	2006	0.214	29/06/08
28	Oirallo	327004	680479	1872	0.025	29/06/08
29	Kanna	327176	60744	1950	0.025	29/06/08
30	Zitta	327360	681538	2303	0.33	29/06/08
31	Makine	328143	681633	2590	1.5	29/06/08
32	Sisile	327766	683002	2732	0.025	29/06/08
33	Tsabale	327752	683019	2725	0.45	29/06/08
34	Kantse	327132	680651	2423	0.33	29/06/08
35	Mello	327889	683458	2764	0.12	29/06/08
36	Busha	327729	690812	3058	0.083	28/06/08
37	Pulte	327887	690063	2974	0.0625	26/06/08

38	Donthoynde	328417	689992	3038	0.2	26/06/08
39	Docha	328259	689948	3011	0.04	26/06/08
40	Garsa tilalo	327928	689833	2976	0.011	26/06/08
41	Chilash	327219	685402	2823	0.21	26/06/08
42	Hotse	327341	685713	2806	0.05	26/06/08
43	Tibabade	327269	688113	2943	0.045	30/06/08
44	Goze	327170	688095	2966	0.5	30/06/08
45	Bobile	326898	686071	2949	0.05	30/06/08
46	Adama	327453	685429	2990	0.085	30/06/08
47	Batane	327561	685713	2975	0.125	30/06/08
48	Dedina	327569	685517	2986	0.075	30/06/08
49	Mogosa	327809	685953	2928	0.05	30/06/08
50	Lisho	316346	681497	2950	0.33	30/06/08
51	Mula	320306	680378	3030	0.35	30/06/08
52	Margo	320004	679877	2665	2.5	24/06/08
53	Mashogawle	319863	685054	3240	0.48	24/06/08
54	Susulie	319521	680875	2741	0.28	23/06/08
55	Gubuna	319613	680369	2762	0.62	23/06/08
56	Margo	319844	680121	2725	0.5	23/06/08
57	Walla	316595	682842	3147	1.5	23/06/08
58	Chomie	316543	680841	3165	0.45	23/06/08
59	Zero kore	317641	681865	3054	1.2	23/06/08
60	Bine	315976	681869	3059	1.2	23/06/08
61	Arzo	315743	678673	2887	0.25	23/06/08
62	Xisse	314362	678074	3032	0.12	18/10/08
63	Pola	317346	684510	2874	0.75	18/10/08
64	Ganka	318173	677433	2599	0.12	19/10/08
65	Gamo	317964	676963	2671	0.2	19/10/08
66	Charo	318469	679231	2695	0.2	19/10/08
67	Buxa	318803	681033	2814	1.4	19/10/08
68	Lasho	318371	684393	3074	0.12	19/10/08
69	Mula	319704	685654	3254	0.5	19/10/08
70	Bola lasho	319271	685663	3220	0.2	19/10/08
71	Bara lasho	318603	685196	3213	0.25	19/10/08
72	Ala	317977	681458	3020	0.38	25/5/2008
73	Ala	318303	681015	2976	0.15	25/5/2008
74	Ala(otilo)	318487	680926	2945	0.25	25/5/2008
75	Buxa(dubusha	318875	681362	2796	1.2	25/5/2008
76	Mazha	319264	689954	2641	1	25/5/2008
77	Mayla shore	316537	679148	2799	0.5	30/7/2008
78	Mayla Gela	316489	679168	2760	0.2	30/7/2008
79	Galo	316763	678296	2191	0.45	30/7/2008
80	Kore	318627	678492	2344	0.1	30/7/2008
81	Gantamerche	331572	665672	2636	0.3	30/7/2008
82	Woretto	324707	668114	2705	0.5	30/7/2008

83	Shero	322667	669884	2770	0.43	30/7/2008
84	Gollo	324724	675554	2745	0.45	28/7/2008
85	Tsidesso	321029	671418	2743	0.63	28/7/2008
86	Shero	321275	671354	2012	0.6	28/7/2008
87	Morzo	318560	681212	2820	0.2	28/7/2008
89	Shoffa zigiti	329306	671253	2421	0.12	28/7/2008
90	Shalle	328851	671825	2403	1.21	28/7/2008
91	Ago	329785	672409	2459	0.01	28/7/2008
92	Golcho	327569	673015	2450	0.2	28/7/2008
93	Gobel	334050	679467	2018	0.25	29/7/2008
94	Balla	329727	679467	2078	0.1	29/7/2008
95	Zagale- bonke	329329	667269	2285	0.21	29/7/2008
96	Bano	318304	675874	2874	0.15	29/7/2008
97	Mitsa	323281	669897	2560	2.7	28/7/2008
98	Golle	322670	676872	2237	0.75	28/7/2008

Annex 4. Laboratory result of water chemistry

Parameters	S1	S3	S4	S5	S6	S7	S8	S10	S11	Date of Analysis (dd/mm/yy)
TDS(mg/l)	209	160	35	39	68	56	59	65	100	
PH	7.41	6.6	7	5.6	7.9	6.6	6.6	7.4	6.9	
EC(Sμ/cm	388	248	54.4	55	77	72	61	67	155	9-Feb-18
Alkalinity	420.8	316	112	53.3	176	112	107	144	165	10-Feb-18
Hardness	181	144	14	13	53	48	27	49	85	10-Feb-18
HCO3-	420.8	316	112	53.3	176	112	107	144	165	10-Feb-18
Ca++	49.16	33.7	1.34	0.8	12.9	8.49	5.37	13	22.7	10-Feb-18
Mg++	38	34.9	6.6	7.2	15.5	17.1	9	10	18.7	12-Feb-18
Na+	12.1	11.7	4.9	6.5	10.1	9.6	7.63	11	11.2	20-Feb-18
K+	2.27	1.6	0.4	0.73	0.9	0.88	0.84	0.8	2.12	20-Feb-18
Cl-	18.46	22.3	8.52	15.3	12.3	13	7.5	10	15.6	15-Feb-18
SO4=	5.8	8	6.8	7	4.5	3.3	9.2	8	7.5	25-Feb-18
NO3-	3.1	2.7	0.7	0.8	3.3	2.1	1.8	1.6	3.5	25-Feb-18
T (0C)	25	20.5	18	19	17	16	19	19	22	
Q(l/s))	130	1.5	0.08	0.3	0.2	0.6	0.4	0.2	4.4	
Date of sample (dd/mm/y)	20/5/2010	21/5/2010	23/5/2010	23/5/2010	23/5/2010	23/5/2010	23/5/2010	25/5/2010	25/5/010	

Annex 5. Borehole Data around Arba Minch

S.No	Name of BH	X	Y	Z	Depth	SWL (m)	Q(L/S)	GWL	T(M ² /d)
1	AMUBH4	340942	671002	1229	73	24	3	1205	492
2	AMU-BH5	341050	671208	1229	92	19	3	1210	4
3	AMU-BH6	340798	670209	1230	100	19	4	1211	17
4	AMU-BH7	340693	670331	1220	91	24	4	1196	
5	AMU-BH8	340777	670174	1227	69	18	8	1209	130
6	AMU-BH9	340618	339974	1235	75	27	10	1208	205
7	ATF-BH10	341044	668541	1209	70	19	4	1190	360
8	ATF-BH11	340880	668346	1225	61	18	4	1207	525
9	ATF-BH12	341252	668834	1222	61	22	2	1200	30
10	ATF-BH13	341010	668070	1225	70	19	4	1206	
11	ACF-BH14	345046	666302	1201	51	12		1189	
12	ACF-BH15	345057	666349	1191	74	7	3	1184	408
13	AMT BH#1	340693	670331	1248	183	16	52	1232	72.86