

# Groundwater and Surface Water Interactions in Hayk and Ardibo Lake, Sustainability Challenge, Northern Ethiopia

*Thesis Submitted to School of Earth Sciences*



*Presented In Partial Fulfillment for the Degree of Master of Science in Hydrogeology*



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**ADDIS ABABA UNIVERSITY**  
Addis Ababa, Ethiopia  
March, 2021

**Groundwater and Surface Water Interactions in Hayk and Ardibo Lake,  
Sustainability Challenge, Northern Ethiopia.**

**By:  
Ebrahim Asqual**

**A Thesis submitted to:  
School of Earth Sciences**

**Presented in Partial Fulfillment of the Requirements for the  
Degree of Masters of Science in Hydrogeology**



**ADDIS ABABA UNIVERSITY  
Addis Ababa, Ethiopia  
March, 2021**

**Addis Ababa University**

**School of Graduate Studies**

This is to certify that thesis prepared by **Ebrahim Asqual**, entitled: - Groundwater and surface water interactions in Hayk and Ardibo Lakes, sustainability challenge, Northern Ethiopia and submitted in partial fulfillment of the requirements for the degree of Masters of Science in Hydrogeology complies with the regulations of the University and meets the accepted standards with respect to the originality and quality.

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I declare and confirm with my signature below, that this thesis is my own work. I have followed all ethical and technical principles of research in the preparation, data collection, data analysis and compilation of this thesis. Any scholarly article that is included in the thesis has been given

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Signature: \_\_\_\_\_

February, 2021

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## Acronyms and Abbreviations

$\mu\text{s/cm}$	Micro Siemens per centimeter
BH	Borehole
AET	Actual Evapotranspiration
DEM	Digital Elevation Model
EC	Electrical Conductivity
ENMA	Ethiopia National Meteorological Agency
ET	Evapotranspiration
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GPS	Global positioning system
GSE	Geological Survey of Ethiopia
GW	Groundwater
ITCZ	Inter Tropical Convergence Zone
Km	kilometer
Km <sup>2</sup>	kilometer square
LA	Lake Ardibo
LH	Lake Hayk
L/T	Litter per time
LU/LC	Land use land cover
m.a.s.l	Meter above Sea Level
m/s	Meter per second
MARF	Mean annual rainfall
Mg/l	Milligram per litter
mm	Millimeter
SP	Spring
ST	Stream
TDS	Total Dissolved solids
UTM	Universal Transverse Mercator
WetSpass	Water and Energy Transfer between Soils, Plants and Atmosphere under quasi-Steady State
WHO	World Health Organization

## Abstract

The Hayk and Ardibo lakes are characterized by continuous reduction level of water. This thesis work aimed to investigate the groundwater and surface water interactions using hydrochemical parameters and recharge estimation using WetSpas model to evaluate sustainability of water consumption in the Hayk and Ardbibo area located in northeastern Ethiopia. Eight (8) water samples were collected from lakes, bore holes, springs and stream and analyzed in laboratory and the results are plotted in different diagrams. Long term mean hydrometeorological data and land use/land cover, soil type, topography, groundwater depth and slope are used as an input to the WetSpas model. From the simulated results of WetSpas model, the mean annual groundwater recharge, surface runoff, and evapotranspiration were found to be 257.3 mm, 438.5 mm and 525.6 mm respectively. From these components the recharge accounts 19% of the mean annual rainfall and the remaining 81% are towards surface runoff and evapotranspiration. The water balance in the study area calculated using the simulated result of WetSpas model is -53.31mm. The imbalance of the inflow and out flow components in the study area is the challenge for the sustainability of water resources. Based on the Aquachem software hydrochemistry analysis of water samples, the results are plotted in Piper diagram and showed that six (6) out of eight (8) water samples are similar (Ca-HCO<sub>3</sub>) types. The two another water samples are Ca-Na-HCO<sub>3</sub> and Na-HCO<sub>3</sub> types. The groundwater samples and one stream water sample are similar (Ca-HCO<sub>3</sub>) types. Generally, all water samples are carbonate type. The samples were also plotted in Scholler diagram and showed that a similar trend in the composition of ions. The interaction of groundwater and surface water in the study area was also supported by groundwater contour map and the result showed that the groundwater flow direction is predominantly from Lake Ardibo towards Lake Hayk. From the chemical analysis of water samples almost all parameters are within the recommended limits of WHO for drinking and irrigation purpose. Generally, based on hydrochemical analysis and groundwater contour map, there is an interaction of surface and groundwater in the catchment and the outflow is greater than the inflow. For Future sustainability water resources in the study area, further identification of the surface and groundwater interaction using more hydrochemical sampling and accurate evaluations of groundwater recharge is essential.

**Key words:** Surface-water Groundwater interactions, WetsPass, Groundwater recharge, Runoff, Evapotranspiration, Hayk-Ardibo area

# CHAPTER ONE

## 1. INTRODUCTION

### 1.1 Background

Groundwater and surface water are not isolated components of the hydrologic system, but instead interact in a variety of physiographic and climatic landscapes. The movement of water between these two different regions is an essential event that comes from infiltration, spring outcrop, connections between rivers and geological strata, thermal flow, lakes and seawater intrusion. The interactions often involve not only the movement of water masses between the surface, rock and the soil but also the modification of the physical, chemical, biological, and energetic properties of the waters. The form of interaction depends on the characteristics of the water bodies occurred, and the prevailing ground characteristics and environment conditions.

It is widely recognized that groundwater and surface water interact at a variety of spatial and temporal scales, there is highly dependent on meteorological, fluvial, anthropogenic and geological processes (Winter et al., 1998). Such interactions play a significant role in determining the quantity and hydrochemical composition of water bodies at both local and regional scales.

Groundwater is one of the essential resources to life, which located beneath the earth's surface in soil and percolated due to pore space and fracture of the rock formation. Surface water bodies help for the recharge of groundwater and vice versa. Both surface and groundwater are primary requirement for the well-being of society in every country.

Ethiopia is a country of many lakes and rivers that are comprised of diverse aquatic ecosystems of great scientific interest and economic importance. The total area of inland waters in Ethiopia is 8,800km<sup>2</sup>, representing 0.72% of the total surface area of the country [2; 3]. According to these authors, the total surface area of open waters, including wetlands, is 7,444 km<sup>2</sup>. The Ethiopian Rift Valley is particularly endowed, containing a chain of permanent lakes lying in what is known as the lakes district, located within the main Ethiopian Rift.

Most of the inland water bodies are occurred within the Ethiopian Rift Valley, forming the spectacular lakes region, with the exception of the largest lake, lake Tana, in the highlands. There are also quite a number of crater lakes in the highlands and the rift escarpments. One such lake system is Hayk and Ardibo which is my study area situated in an elongated intermountain graben near the edge of the western escarpment of the Afar Rift in north-

eastern Ethiopia. The lakes are an outstanding and fascinating feature surrounded by elongated chains of mountains. The lakes sustains human livelihoods, supports economic activities, provides habitat for biodiversity and affords buffering capacities against hydrologic and climate fluctuations. The low salinity (freshness of the lakes), the beautiful scenery that the lakes are endowed, and the good productivity of fish and their protein content (Zenebe Tadess, 1998) are some of typical features that make these lakes suitable for development. Despite the freshness of these lakes, their beautiful disposition in an area attacked by different factors, their suitability for fish production (farming) and other related activities, attempts were not done so far in studying systematically hydrology and hydrogeology of these lakes and catchment they are draining.

## **1.2 Previous work**

Some researchers have worked in the study area both at regional and local levels in the past. Researchers in the area back to the Italian occupation during the 1930s a number of limnologists have visited lake Haiq (Baxter & Golobistch, 1970), some to mention were Vatova (1940), Zane (1941), Cannicce and Almagia (1947). Later Baxter & Golobistch (1970) have studied the limnology of Haiq based on their visit in 1969. Recently, Elizabeth et al. (1992) and Kebede Alemu (1995) reported on some aspect of the hydrobiology of lake Haiq. Baxter and Golobitsh (1970) observed that the water level of lake Hayq was appreciably lower at the time of their visit in January 1969 than in May 1938. The island near the west shore of the lake Hayk, on which a monastery is occurred, was attached to the shore by a low isthmus, covered with vegetation. A chemical data on the lake Haiq based on the works of Baxter & Golobistch (1970) is reported by wood & Talling (1988). Isotopic composition of the same lake is also published by schoell & Faber (1976).

The regional geology of the western escarpment and the Hayk-Ardibo surrounding area were described by many scholars among these Gass (1975) outline the magmatic and tectonic activities in the development of Afro-Arabian Dome; Kronberg et al., (1975) have reported, using Earth Resources Technology Satellite (ERTS) data, on the geology and tectonics of the Afar and adjacent regions; Zanettin et al., (1978) have presented the volcanics successions and tectonics of central Ethiopia and suggested the trend and age of the western Afar escarpment and correlated the volcanic and tectonic events of East Africa Rift System. Zanettin et al.,(1974) reported the migration of the Oligo-Miocene Ignimbrite volcanic in the central Ethiopia plateau from north to south and southwest following the rift escarpment; Justin Visentin and Zanettin, (1974) distinguished and reported the stratigraphy of the

Kombolcha and Eloa area and described the volcanotectonics phenomena; Gregnanin et al., (1973) have studied the volcanites of the Dessie and Kombolcha area and suggested a modified stratigraphy of the volcanics presented by Abate et al., (1968). Zanettin and Justin Visentin (1975) have identified three volcanic cycles in Afar margin and surrounding area, i.e., pre-Oligocene, and Oligocene, and plio-pleistocene in age; each being characterized by definite volcanic formation. More recently, Chorowicz et al., (1999) reported about the marginal basins of western Afar and attributed their formation to be initiated by north-trending left lateral motion. Ketema Tadesse (1978) has investigated groundwater for the town of Dessie. The same author, has studied in 1980 the hydrogeology of the borkena river basin which is situated immediately southwest of the study area apart from the aforementioned few limnologic and hydrobiology, and bathymetry of the Ardibo which is found a few kilo meter away from lake Haiq.

The hydrology, hydrogeology and hydrochemistry of the lakes were studied by Molla Demele (2000). In this study he has described the water balance of the area and detailed geological works, recharge values were dealt in detail by using conventional water balance method to study the water balance of Hayk-Ardibo catchment, Geological map and hydrogeological map were prepared and also he has reported the lake level of the lake Hayk decreased as compared to the lake level reported in previous bathymetric study by different researcher. G. Asmare, (2005) has studied groundwater flow modeling of the Hayq- Ardibo lakes catchment.

### **1.3 Statement of problem**

Hayk and Ardibo lakes are a remarkable feature in northeast Ethiopia highlands with rich endowment of resources which are useful for the surrounding areas as a domestic and irrigation water supply and fish ecosystem.

One of the local elders, Ato Ali Seid, indicated that around 30 years before the isthmus that connect the Istifanos Monastery to main land was covered with lake water due to high water level of lake Hayq (Zuriash Seid, 2016). This indicated that the previous lake Hayk water level situation was very high when we compare it with the current situation and lake Ardibo, which is situated southeast from and 231m higher than lake Hayk, was once used for overflow to lake Hayk sometime before the last few decades, through Ankerkah stream. From this date onwards, the lakes have been hydrologically disconnected, surface water and the watershed divided into two independent closed drainage basins. This shows the reducing nature of surface and subsurface inflows into the lakes.

Bathymetric studies of lake Hayq indicated the lake has experienced depth and surface area changes. Baxter and Golobitsch (1970) have observed that the water level of lake Hayq was appreciably lower at the same time of their visit in January 1969 than in May 1938. A maximum depth of 88.20 and 81.44 m, and surface area of 2302.02 and 2245.65 ha were recorded in 1941 and 2013, respectively (Baxter & Golobitsch 1970; Yesuf et al., 2013). Other studies (Dagnachew Melaku and Abate Shiferaw, 2014) also have indicated gradual decrement of water level in lake Hayq. This may cause total drying of the lake sometime in the future.

The people have been using water from these lakes in the study area without knowing the groundwater and surface water properties and the consequence of over using.

## **1.4 Objectives of the research**

### **1.4.1 General objective**

The general objective of this research is evaluating the groundwater and surface water interactions to evaluate sustainability of water consumption in lake Hayk and Ardiabo area.

### **1.4.2 Specific objectives**

- ✚ Evaluate annual recharge, evapotranspiration, runoff and water balance using WetSpa model.
- ✚ Provide general overview of the water quality for irrigation and drinking based on limited physico-chemical tests.
- ✚ Evaluate the lakes and surrounding groundwater interaction from hydrochemical and water level data
- ✚ On the basis of the outcome of the research suggest proper strategies that foster sustainable water resource management in the area.

## CHAPTER TWO

### 2. OVERVIEW OF THE STUDY AREA

#### 2.1 Location and accessibility

The studied area is located in the western margin of the Afar rift on the escarpment zone of the northwestern Ethiopia plateau, in Amhara Regional State. The catchment is found within the northwestern watershed of the Awash river basin and is situated some 435 km, northeast of Addis Ababa, 35 km northeast of Dessie town and it is bounded between  $11^{\circ}11'0'' - 11^{\circ}23'N$  latitude, and  $39^{\circ}45' - 39^{\circ}49'E$  longitude and at an average altitude of 2100 m above mean sea level (m.a.s.l). It is covering with a total area of 777.7 km<sup>2</sup>.

The access to lake Hayk is relatively good when it compared with lake Ardibo, the gravel road leads to the Monastery of Hayk Istifanos and the lake is not far from the Hayk town which is located on the main road that leads to South Wollo (Woldia). Whereas, the dry weather road that leads to lake Ardibo is very difficult especially in the rainy season.

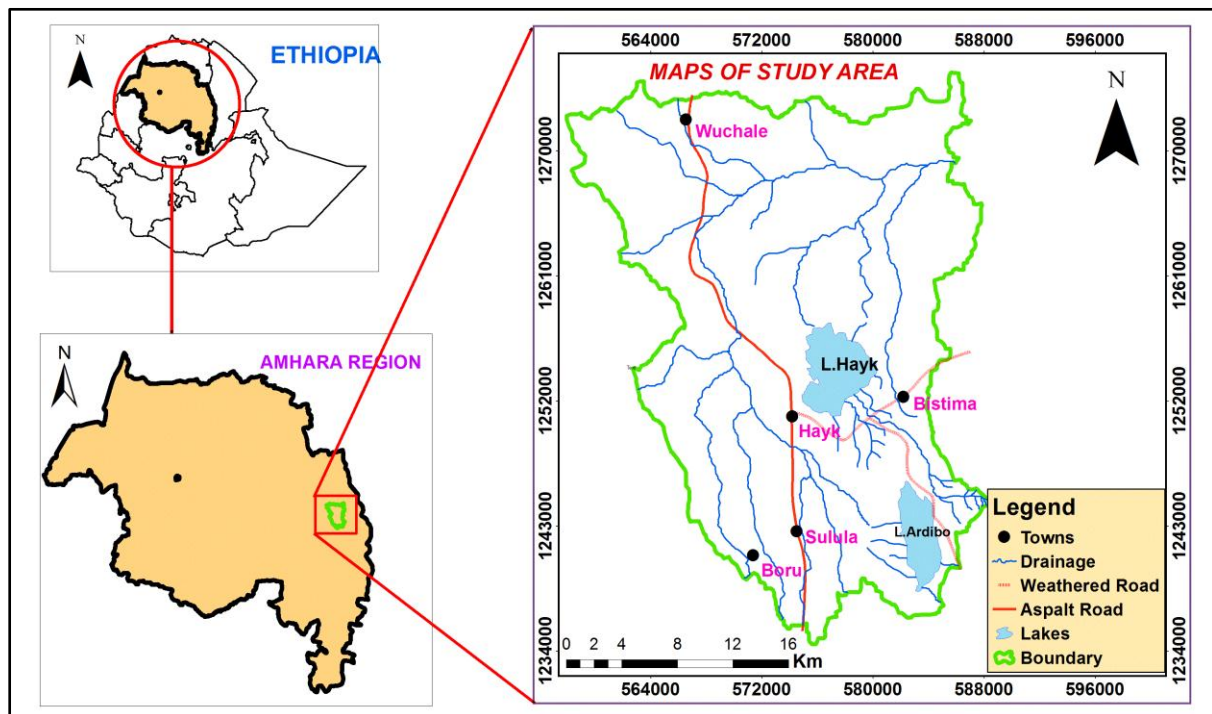


Figure 2.1 Location map of the study area

#### 2.2 Climate

Temperature and rainfall patterns vary according to location, altitude and the time of year. Hayk and Ardibo catchment has a semi/arid subtropical climate traditionally classified as “Weina Dega”. The rainfall in the area is bimodal. That is there are two maximal in the rainfall hydrograph of the area, which are traditionally named as “Belg” lasting from March

to May, which is small in amount, and “Kermit” lasting from July to September which is big in amount.

The amount of rainfall at any in Ethiopia is influenced by the location of the point relative to the source of moisture, the direction of winds and topographical relief. In summer a strong movement of air prevails from the southwestern the northeast direction, i.e. from the high pressure system over the Gulf of Guinea towards the low pressure of the center of Arabia, bringing the summer rain, during the summer months (June and July) the low pressure Intertropical convergences Zone (ITCZ) is located north of the country and the area will be under the influence of the Atlantic Equatorial waterlines which ascend over the highlands from southwest and produce the big summer rain, the amount of this rainfall decreases from southwestern Ethiopia towards the study area due to topographic and altitudinal effects, since in the course of the long journey from the Atlantic to the east African highlands, the moisture of the winds decreases. The area gets moisture from the easterly and southerly moist air currents in springs (Belg) when the ITCZ is located south of the country. Therefore, the area gets moisture from two sources at two distinct time of the year. From the Atlantic equatorial westerlies during summer and the southerly and easterly Indian Ocean air currents in springs. The long term mean annual rainfall for the study area is 1167.9 mm. The long- term mean monthly minimum and maximum temperature is 10.5 and 26.0 °C respectively, which gives a long term mean of 18.3 °C for the area. Based on the mean monthly temperature distribution, June is the warmest and December the coldest months.

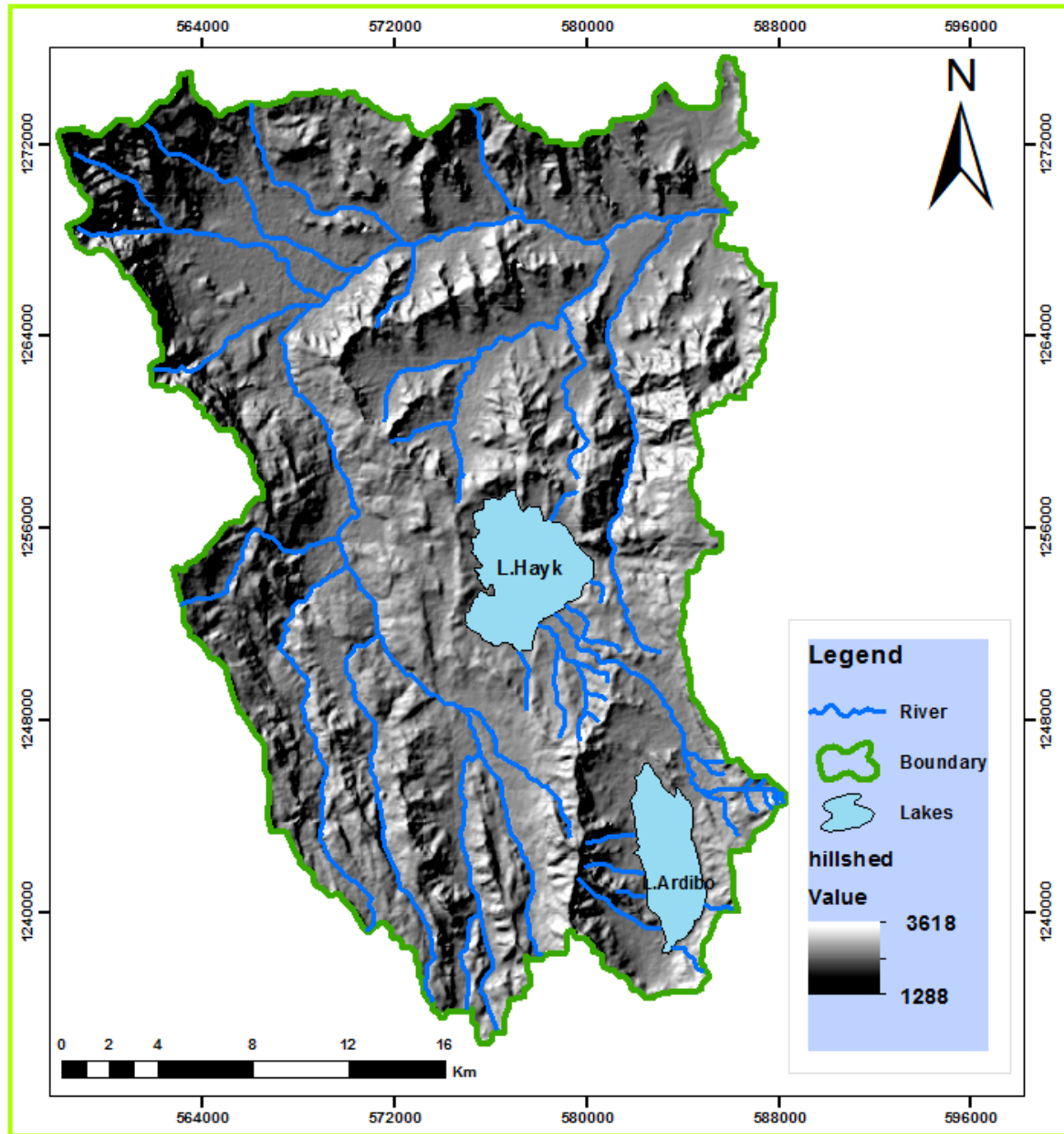
### **2.3 Physiography and drainage**

The present day physiography of the region is the result of Cenozoic volcano-tectonic and erosional processes. Lakes Hayk and Ardibo are occurred in two separate craters within a small graben bounded to the east and west by distinct NNW–SSE trending major fault system. Unlike the typical circular shape of a crater lake, later modification by faulting gave an elongated shape to lake Ardibo. There are many springs emanating along these faults. High discharge springs are evident west of lake Hayk out of the catchment not far from the water divide. This is likely to be outflow from lake Hayk through east–west trending faults. From geomorphologic point of view, lake Hayk looks like a subsided caldera bounded in the west, north and east by very steep crater walls; while in the southeast, south and southwest, the topography gets gentler and rim becomes falter. On the other hand, lake Ardibo which is aligned in the NW-SE directions following the general trend of the major structures in the

area, look like a fault bounded graben. It seems like and follows the trend of the major grabens of Borkena in the south and Corbetta in the north.

The Hayk and Ardibo catchment is contained in the western escarpment of the Afar rift escarpment there is 231 m topographic difference between the two lakes. The highest elevation is found at the southeastern and western boarder of the study area of lake Ardibo, which is around 2800 m a.m.s.l, whereas the lowest elevation is the level of lake Hayk, which is 1900 m a.m.s.l. Land elevation varies throughout the study area from 1900-2800m a.m.s.l. The vegetation cover in the highlands consists of shrubland, with a scattered occurrence of more valuable eucalyptus.

The main drainage pattern is radial, i.e., streams drain towards the nearby lakes locally. The only river that flow within a well-defined channel in the catchment is Ankerka, which is a stream that drains starting from northeast of lake Ardibo and then enter lake Hayk at the southeastern shore. However, now a day the stream is permanently dry due to Ardibo lake level reduction and upper irrigation scheme and it is known, there is no drainage out of it. According to Tadesse et al., 2011, lake Hayq is grouped as a small highland lake with fresh water.



**Figure 2.2 Physiographic and Drainage pattern of the study area**

## 2.4 Land use land cover

The lakes are totally surrounded by agricultural land. Due to the high population pressure that increases rapidly, the major land use is cultivation including very steep marginal areas. The changes with steepness of the slope and erodibility of the soil aggravated erosion, sediment yield and siltation in the watershed area. The population pressure has changed the land use land cover patterns. Area that was left for forest and for grazing is now deforested and cultivated.

Based on various studies (Hurni 1993; Tekle & Hedlund 2000; Demlie M, unpubl, data, 2000; Zeleke & Hurni 2001; Bewket 2003; Derbyshire et al. 2003; Demlie et al. 2007)

previously conducted in the highlands of the country in general, the increments in population density had an effect on land uses and land cover, resulting in shrinking forests and grassland, expansion of cultivated areas and intensified use attributed to the reduction and almost complete abandonment of fallow systems.

Land cover units are incorporated the soil-water balance by the way of rooting depth. The important land cover units are farmland, forest, lakes (permanent open water bodies), shrubland, grass lands and settlements. Most of the highlands, hills and plain area are cultivated. Irrigation is practiced in the area. The main crops are maize, teff, barley, wheat, beans, peas and lentils.

## **2.5 Socio economy**

As per the national population and housing census of 2007, the total population in the study area is about 184,892 out of this around 91% are living in rural while the rest are urban dwellers. The livelihood of the communities in the study catchment is mainly based on mixed farming by growing different crops and livestock production. Agriculture including rainfed and irrigated activities is the primary socio economic activity of the communities of the study area. Maize, teff, barley, wheat, beans, peas, lentils and chat are the major crops cultivated in the area.

The distribution of water demand is based on the location of irrigable lands and Population concentrations. There are irrigable lands in the lake Ardibo and Hayk. The concentration of agriculture in the area has created a growing demand for services and labor, leading to higher population densities and consequent additional demand for water resources.

The major socioeconomic factors that revealed the water level fluctuations of lakes are the significant over pumping surface water of lakes to irrigated fields without proper irrigation scheduling and a detailed scientific study and the establishment of irrigation schemes.

In general, the economic activity of the communities is mainly based on a mixed type of farming. Population pressure is much higher in the study area because of the presence of thick fertile soil and favorable climate condition for crops to grow. As a result, the land in this area is intensively cultivated with major cereal crops mentioned above.

## CHAPTER THREE

### 3. GEOLOGY AND HYDROGEOLOGY

#### 3.1 Regional Geology

The regional geological setting is going back to the Cenozoic geologic history of Eastern Africa and Southern Arabian is remarkable in that a major uplift with a concomitant volcanic episode took place in this region in the upper Mesozoic and early Tertiary times. The causes of this swell and volcanism has been a hot issue among earth scientist all over the world for the last forty years. According to Danielli and Azzoroli quoted in Mohr (1975), the first major uplift of the Ethio-Yemen swell occurred in the upper Eocene when the Western limit of the Mesozoic marine sedimentation retreated abruptly. The formation of Red Sea, Gulf of Aden, and the East Africa Rift which are joined at the Ethiopia Afar (a triple junction of these three rifts) is attributed in the subsequent tectonic coupes of the upper parts of the mentioned elongated dome and the north east drift of the Arabian plate in the Miocene. In this regard the Red Sea and East Africa rift system were the major features recognized as having been produced by extension of the earth's crust (meckenzie et.al. (1970). Normal of awaiting along the sides of the rift valleys during earthquakes shows that this phenomenon still continues.

The development of the Afar margin is summarized by Zanettin and Justin-Visentin (1975), and this margin was found in two phases: in the Miocene, the drift of the Arabian plate brought about the formation of a shallow basin owing to the effects of crystal thinning, accompanied by “tilted blocks” structure of the Western Afar margin. In the Pliocene and Pleistocene, the united action of tensional movement and the injection of large magnetic mass along the foot of the escarpment and in the rift caused intense fracturing of the escarpment itself with consequent large vertical throws, in this way the afar margin is formed.

Fracturing of the Afro-Arabian swell in the Early Tertiary in the Ethiopia side had produced the Ashanghi volcanism of the western Ethiopia plateau. The tectonic uplift of Ethiopia has a major role in the geology of the country.

The volcanic stratigraphy of the Central eastern Ethiopia plateau and western Margin of Afar, and its tectonic evolution has been studied thoroughly by many geologists. Zanettin, Justin and Visentin, (1975) have recognized three volcanic cycles in this area, namely a first cycle; a pre-Oligocene volcanic activity giving rise to the out pouring of the Ashanghi basalts that covered the upper sandstone unit. After a long time of quiescence, the second volcanic cycle began to erupt in the lower middle Oligocene and cover the ashanghi peneplain. This cycle started first with flood basalts (Aiba basalts) and later by large quantities of ignimbrites

(Alkaline rhyolites and Trachytes) with variable quantities of inters bedded basalts and these units too are tilted towards the Afar. This cycle is concluded with the emission of large quantities of basalts termed the Termaber basalts that cover most parts of the preceding Alaji rhyolites. The third cycle confined more to the rift and its periphery and is termed as “Fursa basalt”, “Balchi rhyolites”, and “Bishoftu Basalts” of plio-pleistocene age. The first two cycles clearly represent the “trap series” of Blanford which are divided into a lower Ashanghi and an overlying Magdala groups (Gregnaninet,al., 1973; Justin-Vistentin and Zanettin, 1974). The third cycle is grouped to a more recent volcanic unit termed the rift series, (Zanettin et.al., 1978).

The above two stratigraphy and age of the rocks outcropping in the central Eastern Ethiopia plateau and Western Afar are basically the same and therefore, the stratigraphy proposed by Zanettin et.al., (1978) is adopted in this work. The Oligo-Miocene volcanic rocks in the Western Afar between 10<sup>0</sup>30' and 12<sup>0</sup>00' N divided into stratigraphic units of the Alaji rhyolites and basalts, and Termaber basalts. In fact, these units have a different time of eruption between the North and Southwestern Afar Margin. The series of consisting of Ashanghi, Aiba, Alaji and Termaber formations make up the regional rock units from bottom to top respectively in the studied area. The Ashanghi formation is tholeiitic and /or basalts Alkaline (Zanettin et.al.,1978), low in Al<sub>2</sub>O<sub>3</sub> and high in TiO<sub>2</sub>. The Aiba basalts, which overlay uncomfortably the lower Ashanghi basalts, are transitional between tholeiitic and alkaline basalts (zanettin et.al., 1974).

The Alaji rhyolites and basalts, which are a product of fissural volcanism, are dominantly silicic and are made up of the alkaline rhyolites and sodic ignimbrites interclated with variable quantities of transitional basalts. Termaber basalts are products of central eruption and are alkaline in composition high in Al<sub>2</sub>O<sub>3</sub> and low in TiO<sub>2</sub>.

The predominant trends of the fractures and fault tracers in the western Afar are following the structural trend of the Red Sea Rift System, which is NNW-SSE, and some follow the orientation of the East Africa rift system (SSW-NNE) to SW-NE (Lronberg et.al., 1975). Less frequent WNW-ESE and WSW-ENE striking fault sets are also present. The area of study which marks the outer tectonic boundary of the Afar is basically characterized by NNW-SSE structures and rare E-W ones.

### **3.2 Geology of the study area**

The study area has a complex geologic history during which morph tectonic processes of faulting and volcanism controlled lake formation. The geology of the study area comprises

major groups of the Cenozoic volcanic rocks: i. Eocene-Oligocene, ii. Oligocene-Miocene, iii. Late Miocene and Quaternary volcanic rocks and associated lacustrine and superficial sediments. The details of each stratigraphic sequence is indicated and described as follows.

### **3.2.1 Eocene-Oligocene volcanic rocks**

This volcanic sequence comprises the Ashangie and Alajaie formation which are grouped in this age.

#### **3.2.1.1 Ashangie formation (Tab)**

The Ashangie formation represents the earliest fissural volcanism in the area (e.g. Tefera et al., 1996). The major part of the study area is covered by this formation. They are characterized by deeply weathered, greenish gray, dominated by columnarly jointed aphanatic basalt, intercalated with different layers of vesicular basalt, volcanoclastic sediment and agglomerates. The unit is unconformably overlain by the Dessie basalt formation.

Generally, the rock is black, dark gray and greenish gray in color. Texturally it varies from the aphanatic, medium to coarse grained. It has greenish alteration zones seen along the fracture zones, in the pyroclasts and along its contact with the overlying rhyolite.

This formation is exposed in the lake Ardibo and Hayk sub catchment and includes different types of rocks according to Molla Demile (2000). He has tried to correlate the stratigraphy and age of the rocks to the regional stratigraphy and age of the rocks outcropping in the central eastern Ethiopia plateau based on the works of Zantettin and Justin Visentin (1973, 1974; Zanettin et al., (1974) and Zanettin et al, (1978) based on the stratigraphy successions described by Zanettine et. Al., (1978). Rocks outcropping in the Hayk-Ardibo catchment belong to the ashangie and inter-bedded basalts of Oligocene age. The oldest rocks in Hayk-Ardibo catchment outcrop in the south and southeast of lake Hayk and consists rhyolite and ignimrite.

##### **3.2.1.1.1 The rhyolite and ignimbrite units**

This is the oldest unit outcrop at different parts of the catchment in different stratigraphy positions. It outcrops south and southeast of lake Hayk and at this position it is the lowest and probably the oldest unit in the catchment. When present above the degraded basaltic unit, the rhyolite becomes rare and ignimbrite dominates and the unit gets thick. It is finer grained and sometimes glassy in texture, reddish to gray in color. Feldspar phenocryst is observed in coarse-grained varieties of some exposures. Justin Visentin and Zanettin (1974) reported that the same rock unit localized in the Kombolcha-Eloa road is found to be highly glassy with a porphyritic texture, and composed of variable amounts of phenocrysts of plagioclase and

anorthoclase and with rare quartz. On the other hand, the ignimbrite unit is smaller at the bottom of the succession when associated the rhyolite and in the middle it occurs distinctly individually as a thin bed extending horizontally with almost the same thickness. There are rare trachytes in association with this rhyolitic and ignimbritic unit, probably with similar composition. The ignimbrite unit is smaller at the bottom of the succession when associated the rhyolite and in the middle. It occurs distinctly individually as a thin bed extending horizontally with almost same thickness. There are rare trachytes in association with this rhyolite and ignimbrite unit, probably with similar composition.

#### **3.2.1.1.2 Unwelded Acid (pyroclastic) unit**

The unwelded acidic unit is composed by various ash and fragmental acidic volcanite, which are loose and are highly weathered and dislocated by faults. This unit is likely a product of explosively erupted acidic magma. No welding and flow structures were observed. In most instances, it overlies the acidic rhyolitic ignimbritic rocks and undertaken by the basic degraded rock unit. Rare basic pebbles and gravel-sized materials were observed. Due to its loss and incoherent nature, high infiltration capacity is expected.

#### **3.2.1.1.3 Degraded basaltic unit**

This unit is composed of thick degraded deeply weathered; typical spheroidal weathered is characteristic of basaltic boulders. These boulders have a porphyritic texture where lithic fragments are present as phynocrysts within the ground mass. The weathered pebbles and boulders show alterations probably of the olivine into a green mineral matter. This basic degraded unit in all areas is immediately overlain by a thin fine-grained basaltic flow characterized by a columnar jointing and fracturing. The columnar joints end at the contact line of the underlying units.

#### **3.2.1.1.4 Upper basaltic unit**

This is the youngest unit in the Hayk-Ardibo catchment. It is a fine-grained dark colored basaltic unit characterized by columnar joining. Like other units, this unit is affected by high degree of fracturing. In some outcrops, this unit is associated with rare tuffaceous and volcanic ash units.

#### **3.2.1.2. Alajaie Formation**

The name Alajaie formation is adopted from Hofmann et al., (1997) and Ayalew et al., (2002) with an age of 30 Ma. It is exposed on north western part of the study area. The rock is pink, white, light gray and fine to coarse grained. The unit is layered or bedded. The

individual layers show variation in texture, they are dominantly porphyritic with microlitic or glassy matrix. Densely welded ignimbrites have a glassy appearance and exhibit a well-developed columnar jointing. The rock is composed of alkaline feldspar, quartz plagioclase and opaque.

### **3.2.2 Oligo-Miocene sequences**

#### **3.2.2.1 Dessie basalt formation**

The name Dessie basalt formation is adopted from Wolfenden (2003). It is exposed in the western plateau area forming chain of ridges. The contact with the underlying Ashangie basalt field relations show this unit is a package represented by association of different types of aphanatic and porphyritic, massive and vesicular basalts, with subordinates of pyroclasts and ash layers. The basalts within the package were dated ~ 25 Ma using  $^{40}\text{Ar}/^{39}\text{Ar}$  method (Ukstins et al. 2002). It is dark gray to greenish grey, fine to medium grained, and comprising alternate layers of vesicular olivine-plagioclase phyric basalts, agglomerates, pyroclastic rocks and aphanatic basalts. The aphanatic basalts dominated by fine microcrystalline matrix consisting fine plagioclase microlites. They also contain traces of augite, olivine, plagioclase and opaque minerals with scarce vesicles. The vesicles are partially filled by secondary calcite. The porphyritic basalts vary in composition as augite-plagioclase phyric, plagioclase-olivine-augite phyric and plagioclase phyric basalts.

### **3.2.3 Late Miocene and Quaternary volcanics**

#### **3.2.3.1 Undifferentiated alluvial, elluvial and lacustrine sediments**

These are exposed in low land plain and in the central part. Quaternary sediment overly basement of volcanic rocks and they are confined to interior valleys, river floodplains, and lakes bottom and margins. They are represented by black cotton and reddish brown silty to sandy soil with few outcrops of diatomite. Reddish brown sandy soil is mainly seen on the plain on the top of the western plateau and on the eastern low land. The lacustrine sediment is weathered gray, horizontally thinly laminated to thickly laminate.

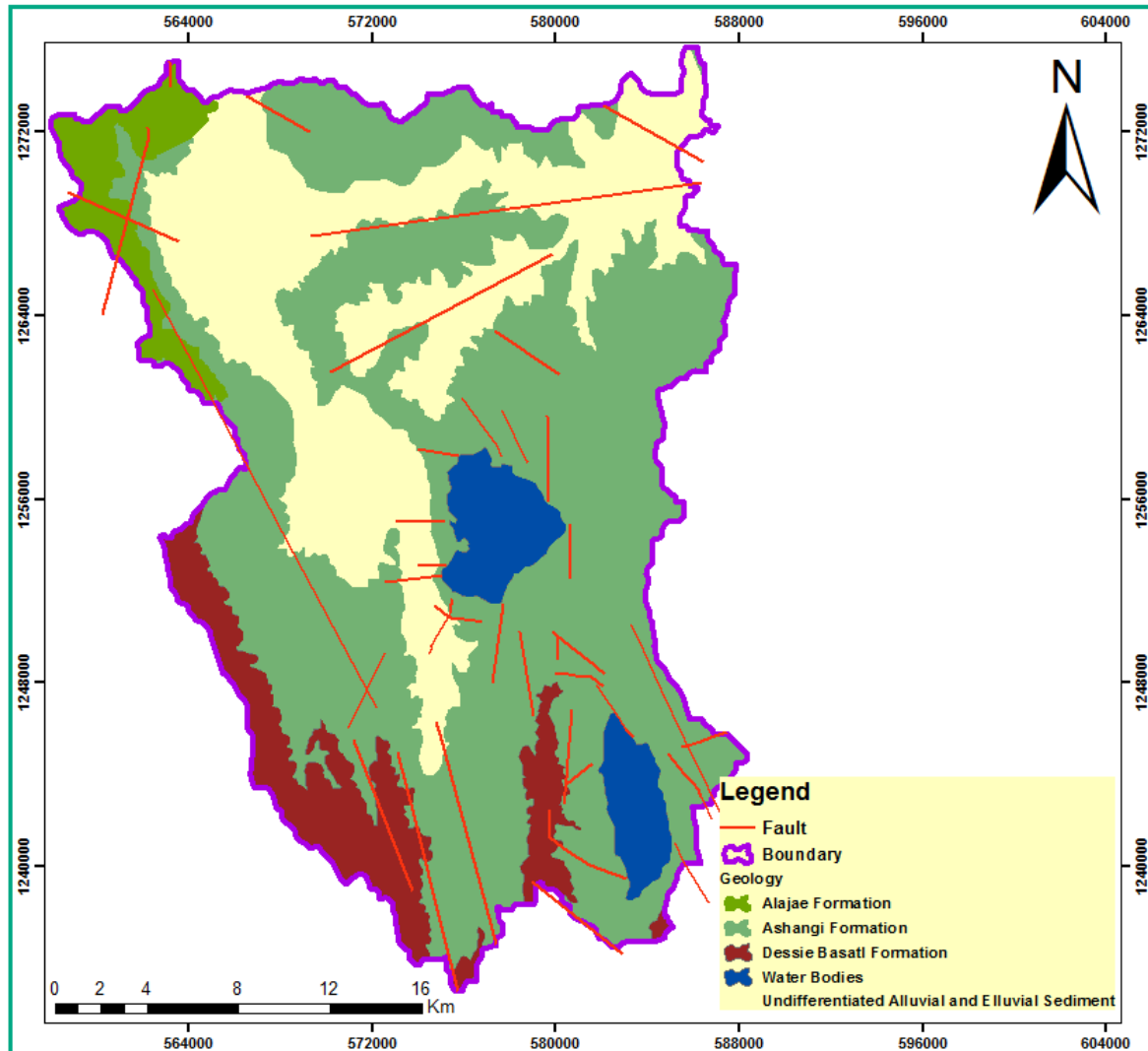


Figure 3.1 Simplified geological map of the study area (Modified from GSE, 2010)

### 3.3 Structure

#### 3.3.1 Fault

The central western margin of the Afar rift is a tectonically affected area, where one can observe without difficulty major structures that run NNW or nearly N-S. In this area, the N-S elongated ridges, which are related probably to the regional extensional rift tectonics.

Since the mid-Miocene, Hayk-Ardibo area has been affected by Trans current deformation related to sinistral shear on the north rift boundary, and the formation of a restraining bends through the eastern side of the study area. This has impacted the geometry of faults trends on the study area. Three main sets of fault define the morphological and tectonic features of Hayk-Ardibo area having a trend of N300W, having a trend nearly E-W found to cut the NNW trending ones and is probably younger from the course cutting relationship. The E-W trending ones are probably associated with the rift of the Gulf of Aden. According to the

interpretation by Zanettin et.al., (1978), these transverse faults are mainly situated between 1100 N and 12000N, parallel to the “pre-Oligocene rift of Ashangi” and are a rejuvenation of an old major tectonic lineament extending from the Gulf of Aden and having a trend of NNE, the dominant ones, which have affected all the rock units and cross in some cases entire study area. The major NNW sets are trending parallel to the trend of the Red Sea Rift (Korberge et.al., 1975), whereas those trending NNE are due to the influence of Ethiopia rift system or interaction of the Afar and main Ethiopia rifts. The structure of lake Hayk-Ardibo area is characterized by numerous faults that have undergone displacement since deposition of the Mid-Tertiary Volcanic. There are two major strikes; the dominant set is about  $155^{\circ}$ , while the subordinate set is oriented about  $95^{\circ}$ . Few faults strike in a NW-SW direction. Faults and joints control the orientation drainage patten in the Hayk-Ardibo area. Faults dissecting the Hayk-Ardibo Catchment are also oriented NNW-SSW and E-W.

There are also two dominant joints sets mapped in the study area trending on average N250W, and N-W. The spacing and aperture of these joints vary from outcrop to outcrop and are important from the perspective of water circulation with in these jointed rocks.

### **3.4 Hydrogeology**

#### **3.4.1 Hydrogeological characterization**

The hydrogeology and hydrochemistry of Dessie area including the study area (Hayk and Ardibo) has studied by Ministry of Mines, Geological Survey of Ethiopia Groundwater Resources Assessment Directorate (2013). The study was based on the geological description, qualitative and the very limited quantitative (the yield of springs and hydraulic properties of boreholes) of the various geological units together with their geomorphological position, drainage density and soil type within the map sheet, the elements of the hydrogeological system (Aquifer and Aquitards). Accordingly, in the Hayk and Ardibo area the hydrogeological characterization is classified in three major Categories. These are high productive fissured aquifer, moderate productive porous and low productive aquifer. The volcanic rocks occupy large portions of the study area. Geomorphology and the presence of springs were used to derive the thickness of hydrogeologic unit used to define the top layer and bottom layer of the unconfined aquifer. The presence of quaternary sediments with in the catchment increased the heterogeneity of aquifer hydraulic conductivity.

### **3.4.1.1 High productive fissured aquifer**

This is a hydrogeological unit which is exposed on major parts of the study area and it distributing to the north, central, western, southern and eastern parts of the area.

#### **3.4.1.1.1 Dessie basalt**

In the study area this unit exposed in the south western part of the area and this unit is affected by fault escarpment and fault lineament are enhanced by irregular sets of fractures which can facilitate the groundwater flow. The potential yield of this unit varies throughout its outcrop. This is due to the variation in frequency, intensity and distribution of the fracture system and topographic setup. Despite the presence of primary porosity such as vesicles and cracking joints their permeability is very low and have very little role in groundwater occurrence and movement. This is due to the poor interconnection of vesicles which do not permit the free groundwater movement and occurrence. Therefore, the primary porosity of Desse basalt has very little input in productivity of the aquifer. However, in some places the cooling joints are enhanced by mechanical weathering and fracturing which further increased the vertical permeability, which leads to the availability of springs at escarpment and hillsides. The relatively deeper groundwater level became shallow at the down through of the fault and permits the artesian groundwater and the availability of more than two springs in the area. The potential water bearing horizon of this unit is concentrated to the fractured and weathered surfaces.

#### **3.4.1.1.2 Ashangie Formation**

The Ashangie is thick, deeply weathered and fractured which is mostly covered the study area. Like other volcanic rocks in the area the main water bearing zone is the fracturing. The occurrence of mechanically weathered zones increases the porosity and sometimes the permeability of the rock and hence the groundwater circulation and occurrence. The out crop of this unit in the rift escarpment and rift floor is affected by major rift escarp faults, resulted in intense fractures and hence deep groundwater circulation. As observed in the map, different sets of faults have dissected the area which has contributed to the secondary porosity and permeability of the formation. Faults in this formation, played the major role in the infiltration and subsequent groundwater circulation in the volcanics which could be evidenced by the emergence of widespread fault controlled springs.

In this formation there are many springs emanating along the high angle normal fault and the lineament. However, in some areas the groundwater flow through those fractures tend to reduce the size of the open spaces due to the deposition of secondary infillings on the faces of

interstices and fractures, as a result the process often cause the formation of impervious layers. The presence of paleosols between the successive flows of this unit blocks the vertical groundwater flow and responsible for the formation of confined aquifer and hence leads to the emergence of springs. The occurrence of regional main fractures with linear alignments is important features for groundwater movement from high to low concentration areas.

### **3.4.1.2 Medium productive porous aquifer**

#### **3.4.1.2.1 Undifferentiated lacustrine and alluvial sediment**

This hydrostratigraphic unit is located in central and northeastern part of the study area along the main path of the drainage. It occurs by forming of the flat topography, it is quaternary lacustrine and transported and reworked alluvial depositional sediment overlying the Ashangie formation. The permeability of the lacustrine sediment is very variable depending on the grain size, sorting in a uniform recharge conditions. Those with grain size of silt and sand have better permeability and productivity. Whereas those with very fine ash and massive tuff interbreeding layer have low permeability. However, this aquifer consists both sand and clay materials so that the clay materials reduced the permeability of the unit in some places. The aquifer is recharged mainly from the some perennial rivers like Jarie and Mile. It is also recharge from direct precipitation.

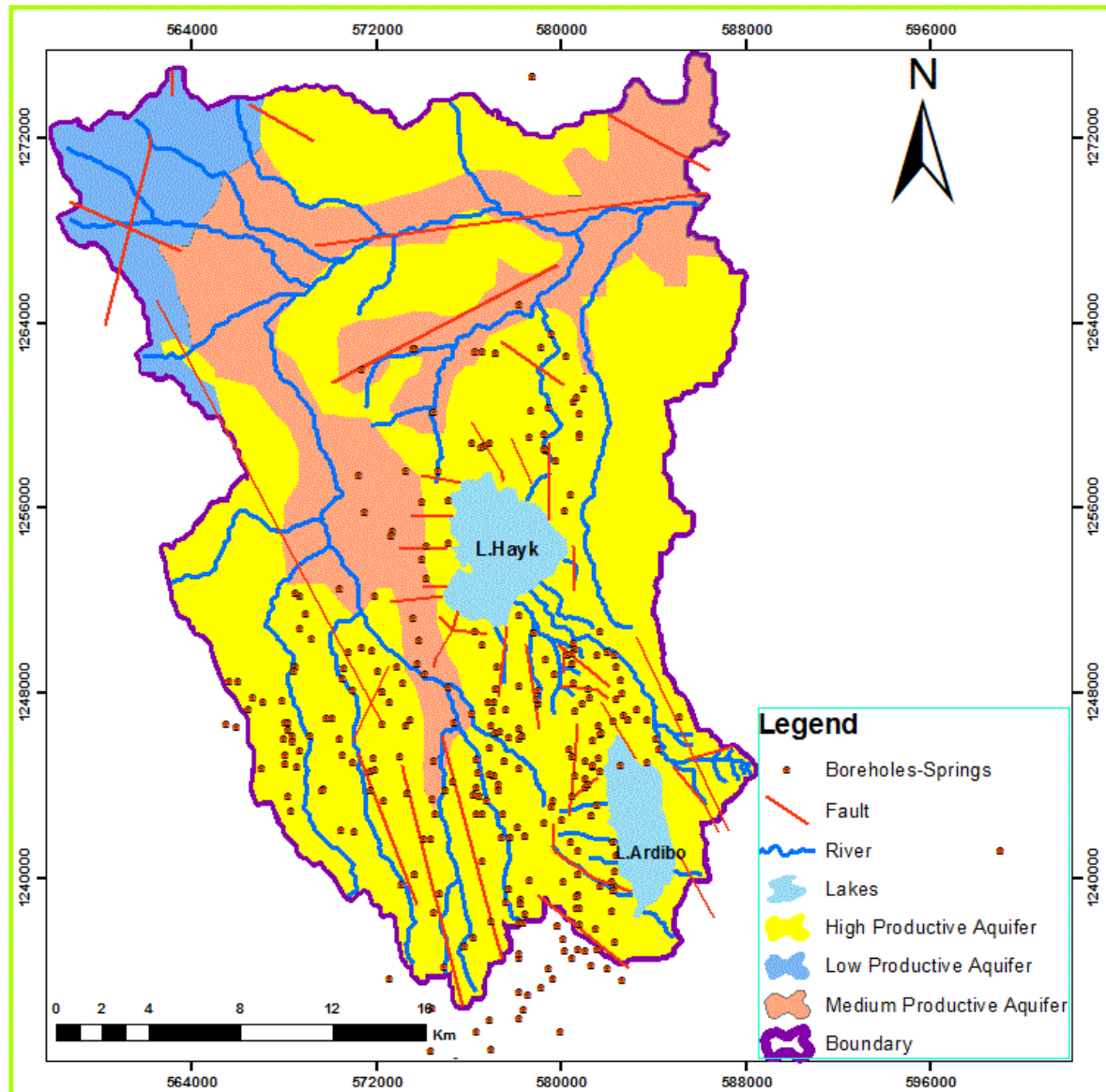
#### **3.4.1.3 Low productive aquifer**

This hydrostratigraphical unit is exposed in the study area especially to northwestern by forming elevated mountains and ridges. The main lithological units categorized under this hydrostratigraphy include Alajaie Formation.

##### **3.4.1.3.1 Alajaie Formation**

This unit is exposed on northwestern part of the study area. It is massive and fresh with less fracturing and weathering surfaces. Most of the water that precipitates on this unit is lost as runoff instead of vertical infiltration. This is due to the steeper slope of the rhyolite domes and massive and slightly weathered surfaces. In addition the absence of thick soil development facilitates runoff to be higher rather than infiltration and percolation. This unit is slightly to moderately weathered and interested by fractures and do not go deep so that the availability of groundwater is restricted to the shallower parts.

There are some springs in this, they are localized, small yield and do not have regional sources. This is highly dependent on the favorable climatic condition of the study area especially on the precipitation.



**Figure 3.2 Simplified hydrogeological map (modified from GSE, 2010)**

### 3.4.2. Groundwater recharge and discharge condition

Groundwater recharge and discharge are important aspects of the global hydrological cycle. Groundwater recharge can be defined as the entry into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table within the saturated zone. On the other hand, groundwater discharge is the removal of water from the saturated zone across the water table surface, together with the associated flow toward the water table within the saturated zone (Freezes and Cherry, 1997). In the recharge areas, there is often a rather deep unsaturated zone between the water table and the land surface, whereas, the water level is found either close to or at the land surface in discharge areas. Sometimes Surface water bodies can also recharge ground water i.e. this

conditions takes place to the greatest extent in arid areas. During heavy rainfall times lakes and dry creek beds may become full up with water, when the water table is low in underlying aquifers, water may leak from the sides of these water bodies and spread through pores into the ground water.

To describe and determine whether an area is recharge and discharge areas on the basis of field observation one has to give attention to the basic indicators such as topography, piezometric pattern, hydrochemical trends, environmental isotopes, and soil and land surface features such as seeps and springs. From topographic indicators, discharge areas are topographically low, whereas, recharge areas are topographically high. Even though, geochemical interpretation requires a large number of chemical analysis carried out on water samples, systematic samples representing the area along surface and groundwater flow path tells recharge and discharge area, since it is a well understood fact that moving groundwater through a flow system undergoes a geochemical evolution. In general, salinity either in terms of electrical conductivity or total dissolved solid increases along the flow path, therefore, recharge area are usually with fresh water, while water in discharge areas is often relatively saline.

In lake Ardibo catchment area the only source to get recharge is from direct precipitation. The volcanic ridge, fault escarpments that surround lake Ardibo area and the surrounding lowlying are recharge areas. While the lake surrounding foot hill area are discharge areas. The groundwater discharge is revealed in springs and seepage zones. This catchment is surficially a closed drainage system, there is no a perennial stream with a well-defined channel that enters the lake Ardibo.

In lake Hayk sub catchment area gets recharge from precipitation, summer season Ankerka river, and seepage from irrigation canals and groundwater inflow from lake Ardibo sub catchment. The ridges that surround south of lake Hayk and surrounding low-lying flat areas recharge the lake hayk sub catchment. The discharge areas in this catchment are lake Hayk and the surrounding springs, which are located southwest of lake Hayk in the adjacent catchment.

### **3.4.3 Groundwater flow**

The groundwater flow is significantly influenced by geomorphology, geological structures such as nature and orientation of faults, fractures, joints and lineament, availability of impermeable layers and hydraulic property and continuity of the aquifers.

Joints, fractures, and solution openings provide avenues through which groundwater flow is channeled (Kiersch and Hughes, 1952). Minor fault and major fracture traces are favorable sites for groundwater flow in the Hayk-Ardibo catchment. It might be possible to deduce from field observation of geological, hydrogeological and geomorphologic evidences that the two lakes are hydraulically connected. The two lakes are surficially connected by Ankerka river and moreover large faults trending NNE, NNW and E-W create favorable condition for groundwater movement from Ardibo catchment towards lake Hayk. There is a 231 m elevation difference between the two lakes, this is also an evidence that groundwater moves towards lake Hayk. Most of springs emerge at the down side i.e north of Lake Ardibo and joins Ankerka river. In the Hayk and Ardibo sub catchment two groundwater flow system were described. These are the local and intermediate flow system. The local flow system is developed following the surface water divide of the two sub catchment, that is lakes. The two local systems are developed as a result of the local topographical relief that gave rise to the two lakes and the surrounding geology. In these system, groundwater flow is towards the respective lakes and the flow is shallow. According to Fetter (1994), if the surface topography has a well defined local relief, local groundwater flow system can form. This is because of the undulation of the water table influenced by the topographic relief. In the intermediate flow condition, groundwater flow is from Ardibo sub catchment to the Hayk sub catchment that is recharging lake Hayk. The development of relatively large discharge and perennial springs in between the two lakes.

The interaction between surface and groundwater in the study area is evident in that both lakes and groundwater recharge interact one another. In relatively elevated areas where lake Ardibo is situated, due to the influence of hydrogeological (both structure and permeable rock units) groundwater is recharging through the lake in its north eastern shore probably for the contribution of the intermediate flow system. There is also shallow groundwater input to this lake but the amount of groundwater that enters the lakes is influenced by irrigation activities in the catchment. In topographically low area like lake Hayk, the lake groundwater interaction is such that the groundwater contributes to these lakes with and the groundwater table is not below the lake.

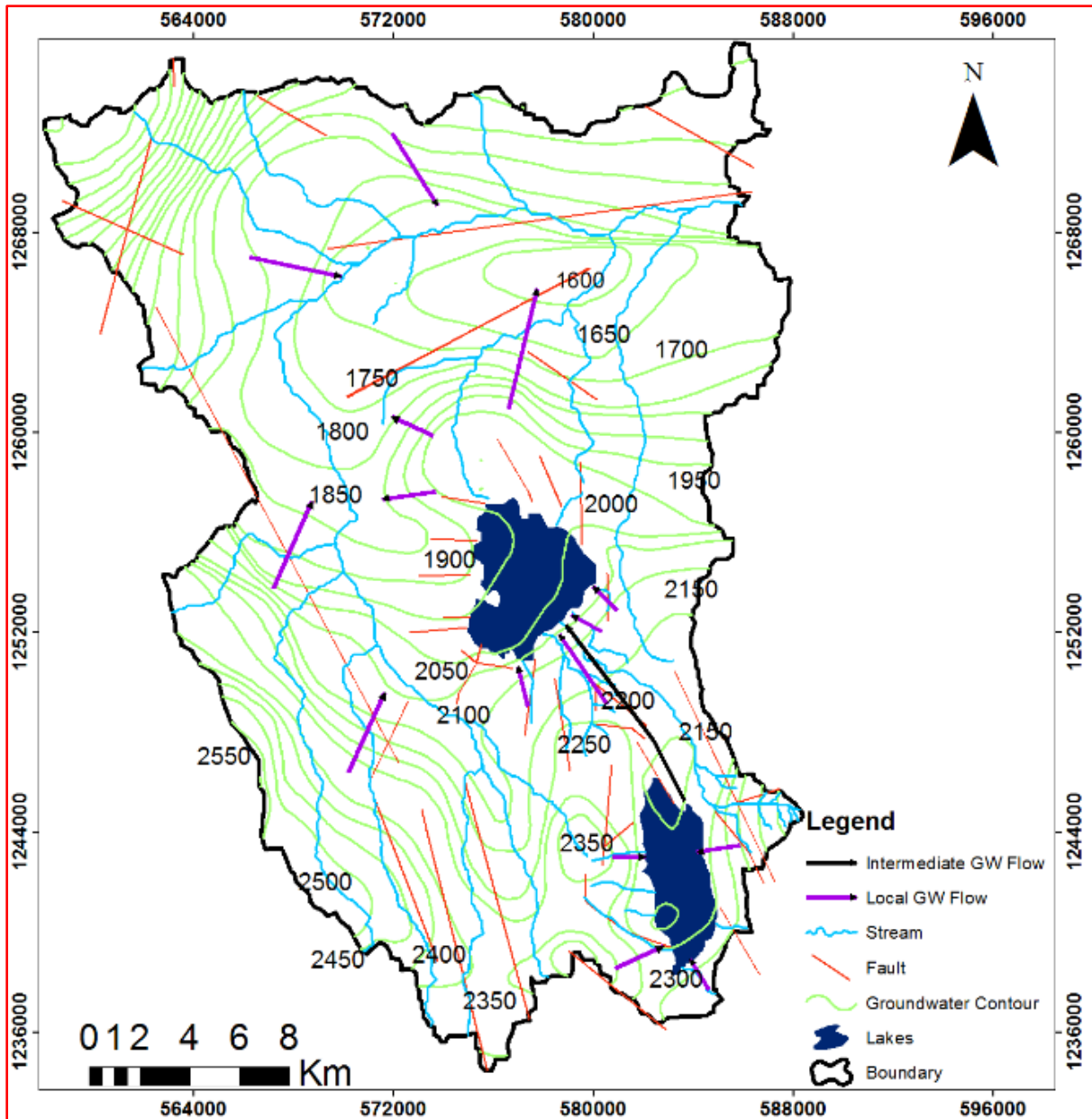


Figure 3.3 Groundwater flow

## CHAPTER FOUR

### 4. METHODS AND MATERIALS

#### 4.1 Methods

To achieve the given general and specific objectives of the research study the following methods were used. Those methods were generally categorized in to three types; pre-study, fieldwork, and post field.

##### 4.1.1 Pre-field study

This method is including literature search and review of previous works in the study area. Prior to field work data acquisition, including literature review, justifying of physical distinctive attribute from different maps, geological explanations, surface water and groundwater conditions, view in particular outlook; the geomorphologic and environmental features were collected. The sources of data used in this stage comprise published and unpublished reports, both national and international. Problems and data gaps were identified. This study also includes collection of meteorological data from National meteorological Agency like rainfall, temperature, sunshine hour, wind speed and relative humidity data. All other existing data like topo sheets/topographic map and geological and hydrogeological map have been collected from appropriate offices from Ethiopia mapping Agency and Geological Survey of Ethiopia respectively. Land use/land cover and soil information has been extracted and modified from FAO Land use land cover and soil maps of Ethiopia (FAO, 1997).

##### 4.1.2 Field study

The main purpose of this phase was to conduct the major activities which include measuring the in-situ parameters of water (i.e. electric conductivity (EC), PH, temperature), observation of geological, surface hydrogeological and drainage pattern and general geomorphological set up of the area. A different water samples was measured with its respective instrument. The field work was also supported by oral interview of the local inhabitants for gathering and generating essential information includes information on the nature of current water use condition, major constraints of management practices, levels of the lakes compared to previous level. Different water samples from different water bodies were collected for laboratory analysis to determine the general water quality for drinking, irrigation and to determine the interaction of surface water and groundwater. Soil samples were also collected for laboratory analysis its texture. The sampling methods of these samples were collected as follow:

#### 4.1.2.1 Water samples

Water samples were collected in the study area randomly from different water bodies. Three springs, two lakes, one river and two deep wells water a total of eight water samples were collected from the study area. And also the in-situ parameters of these samples were measured.

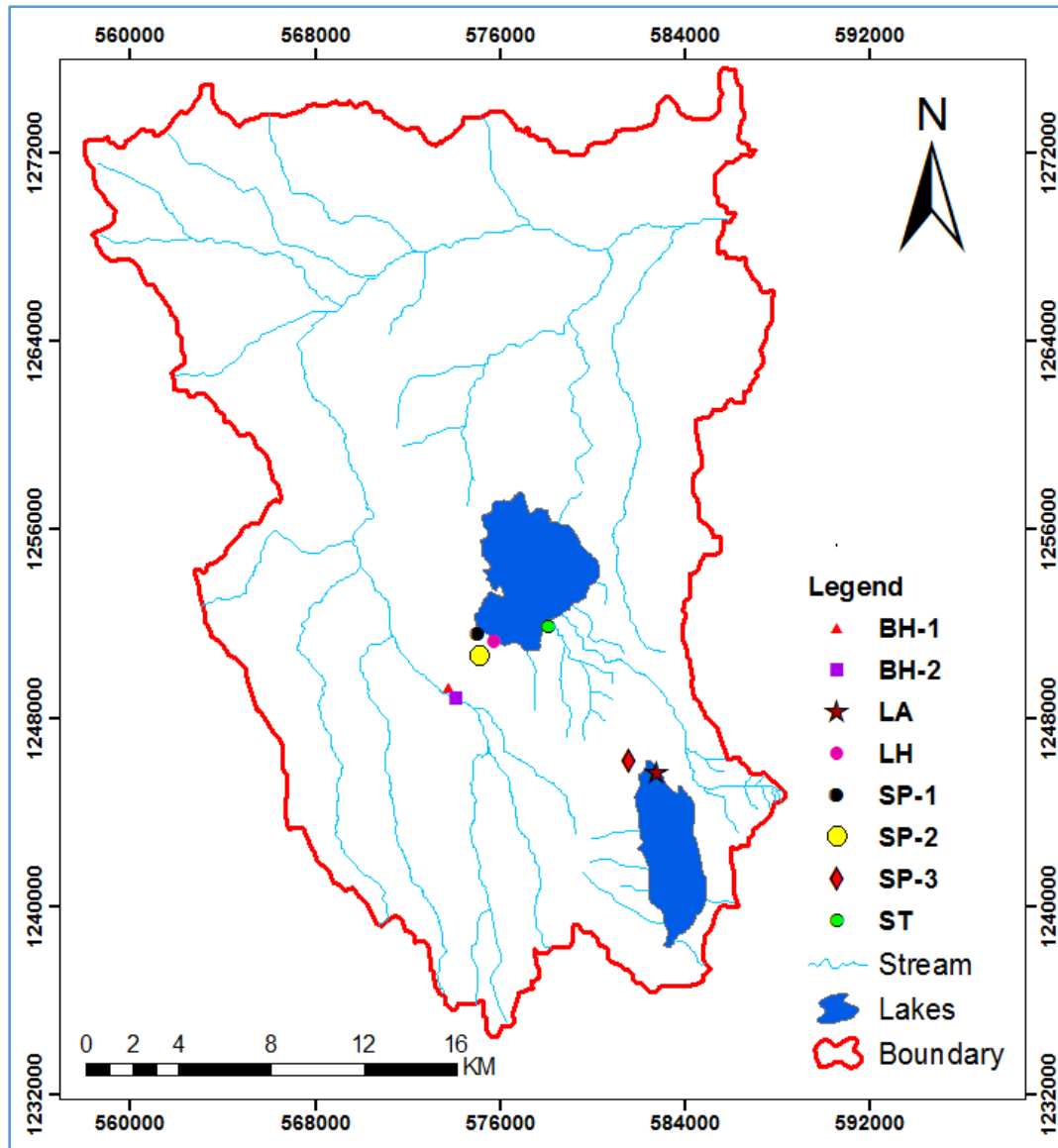


Figure 4.1 The distribution of water samples collected in the study area

#### 4.1.2.2 Soil samples

Six soil samples were also collected from the agricultural lands. Each sample consists of 15 to 20 sub samples taken from different locations within the proposed sampling area. These sub samples taken from 15-20 locations were placed at a single sampling area in a clean container and mix thoroughly, then after divide it in quarter on be spreading clean magazine papers. The quartering method was done repeatedly until the sample remains 1 kilogram

which is good enough for soil laboratory analysis. So the six samples were taken after mixing thoroughly the 15-20 sub samples and using quartering method.

#### **4.1.3 Analysis and interpretation (post Field)**

The hydrochemical of water and the texture of soil samples were analyzed in the laboratory of Addis University department of Chemistry and of Ethiopian Construction Design and Supervision Works Corporation Research, Laboratory and Training Center respectively. Therefore, data organization, and result analysis, different maps and graphs preparation and interpretation were prepared. To estimate the partially distributed and long-term average recharge of the area landuse/ landcover data, ground water depth, precipitation, potential evapotranspiration, wind-speed, temperature, soil type and slope data were processed with aid of Arc GIS software for an input of WetSpass model. The analysis and interpretations were also supported by the application of different software and helping tools including GIS (ArcMap10.5), global mapper, aquachem4, Microsoft excel, Microsoft word and power point were used.

#### **4.1.4 Evaluation groundwater recharges and discharge using WetSpass model**

Groundwater Recharge is the vertical downward movement and then joining of water in to the saturated zone (aquifers) bellow the water table. It is one of the most significant components of water balance. Understanding and enumerating recharge amounts and its processes until water reaches into the aquifer are the prerequisites for any examination and analysis of the water resource sustainability. Quantification of groundwater recharge is helpful for the policy makers to do a better and informed decisions regarding to water resource managements, land use activities and protections of natural recharge areas from different man made influences (Kresic, 2009). Several techniques are used to assess the groundwater recharge quantities, including experimental methods like water balance, Hydrograph separation (Conventional Method and Isotope), Chloride mass balance and Water level fluctuation. However, commonly groundwater recharge is determined to a large extent as an imbalance at the land surface between precipitation and evaporative demand (Gebreryfael, 2008) and it helpful method to determine the long-term average spatially distributed recharge as a spatial variable dependent on the soil texture, land-use, slope, topography and meteorological conditions, taking into account the influence of the spatial variability of the land surface on the groundwater system (Batelaan and De Smedt, 2004) is WetSpass model. In WetSpass, groundwater recharge is calculated as a residual term of the water balance (Equation 1).

$$R_v = P - S_v - E T_v - I \quad (1)$$

Where,  $P$  is the average seasonal precipitation,  $E T_v$  is the evapotranspiration [ $L/T$ ], given as the sum of transpiration and evaporation,  $S_v$  is the surface runoff over the land surface between the vegetation,  $I$  is the interception by vegetation, i.e. the part of the precipitation that evaporates from the wet surface of the vegetation, and  $R_v$  is the groundwater recharge, all variables have the unit of  $L/T$ . The methodology described above can be employed for the estimation of the spatially distributed groundwater recharge as a function of vegetation, soil texture, slope, precipitation, groundwater depth, and other climatic variables (Batelaan et al., 2003).

#### 4.1.4.1 Description of WetSpa model

WetSpa stands for *Water and Energy Transfer between Soil, Plants and Atmosphere* under quasi-Steady State (Batelaan and De Smedt, 2001). WetSpa was built on the foundations of the time dependent spatially distributed water balance model called "WetSpa" (Batelaan et al., 1996; Wang et al., 1996). It is a physically based model for the estimation of long-term average spatial patterns of groundwater recharge, surface runoff and evapotranspiration employing physical and empirical relationships.

WetSpa is especially suited for studying long-term effects of land use changes on the water regime in a watershed. It is handy in that it allows easy new definition of climatic as well as land use types. The spatially distributed recharge output of WetSpa model can improve the prediction of simulated groundwater level and the locations of discharge and recharge areas for a steady-state groundwater model.

To process WetSpa model it needs its own new folder directory as inputs and outputs of its requirements. It also needs input and output folders under the directory folder as well as the input folder include both maps and tables folder names. The input data under maps folder including groundwater depth, rain, potential evapotranspiration, temperature, wind, elevation or topography, slope, land use and soil were processed and prepared with the aid of Arc GIS 10.5 map and saved as ASCII grid format in their own folder if any. For example groundwater depth, rainfall, PET, temperature and wind should have their own folder to store the two seasons and annual average data in the form of map but the other remaining four parameters are set separately without folder under maps file.

While preparing those maps Arc GIS version 10.5 was used thus, WetSpa is totally assimilated with GIS Arc View as a raster model, coded in Avenue. Land use and soil were prepared both in the form of maps and tables and the later were connected to the model as

attribute tables of the land use and soil raster maps (Batelaan and De Smedt, 2001). This allows for informal definitions of new land-use or soil types and changes to the parameter values. To run successfully this model the cell size of all maps and their columns and rows should have been similar, so that the cell sizes were resampled in 30 by 30 resolutions and columns and rows were 1014 and 1371 respectively.

#### **4.1.4.2. Inputs of WetSpas model**

The WetSpas–M model requires a set of basic input data, including meteorological data (precipitation, air temperature, wind speed, and potential evapotranspiration), area configuration (land use types, topography (DEM and slope) and distributed groundwater depth), soil properties (hydraulic properties and empirical coefficients for modeling evapotranspiration and surface runoff) and boundary conditions (extension of the area to be modeled).

Such inputs data were prepared as maps using Geographic Information Systems (Arc GIS) collected for the period from 1988 to 2018 from National meteorological Agency. The cell size of the raster for the ASCII input files of the area to these model contain 1014 columns and 1371 rows of cells and each cell with dimensions 30 m × 30 m for more accurate representation of land cover changes and simulation.

The recharge process is determined by the interactions of climate, vegetation, geology and structural setup, geomorphological configuration of the area and soil condition (De Vriers and Simmers 2002). To obtain the output from WetSpas model, the input data were prepared in the form of maps of designated hydrological, meteorological and geographical components in the basin. The climate data of different stations found in and near around the area was obtained from the national meteorological agency of Ethiopia (NMAE) a total of thirty years data were collected and those data were prepared in the form of maps for the appropriateness of WetSpas model. There are 6 climatological stations in and around Hayk and Ardibo. Climatological data such as temperature, relative humidity, evaporation, sunshine hours, wind speed and direction, and rainfall are available for the period 1988 -2018.

To sum up the inputs of WetSpas model: as ArcGIS Grid files/maps are soil, land use, Dem/topographic map, slope map, groundwater depth, potential evapotranspiration, temperature, rainfall and wind as tables soil parameter, runoff coefficient and land use parameters.

#### **4.1.4.3. Hydrometrological Data**

Meteorological data plays a great role for hydrological analysis; they give information about seasonal and annual amount of climatic variability to know the hydrological conditions of an area. To evaluate the amount of recharge in a basin, one should have information about meteorological elements such as precipitation, temperature, actual and potential evapotranspiration, evaporation and sunshine duration of an area.

A total of thirty years meteorological data were collected from National Meteorological Agency of Ethiopia. Six meteorological stations are selected in this study. The Hayk and Wuchale stations are located in the study area. Hayk station is found at the center of the area whereas the Wuchale station is located north western age of the area. The other four stations (Dessie, Kombolcha, Boru Media and Bati) are located adjust to the area at different directions.

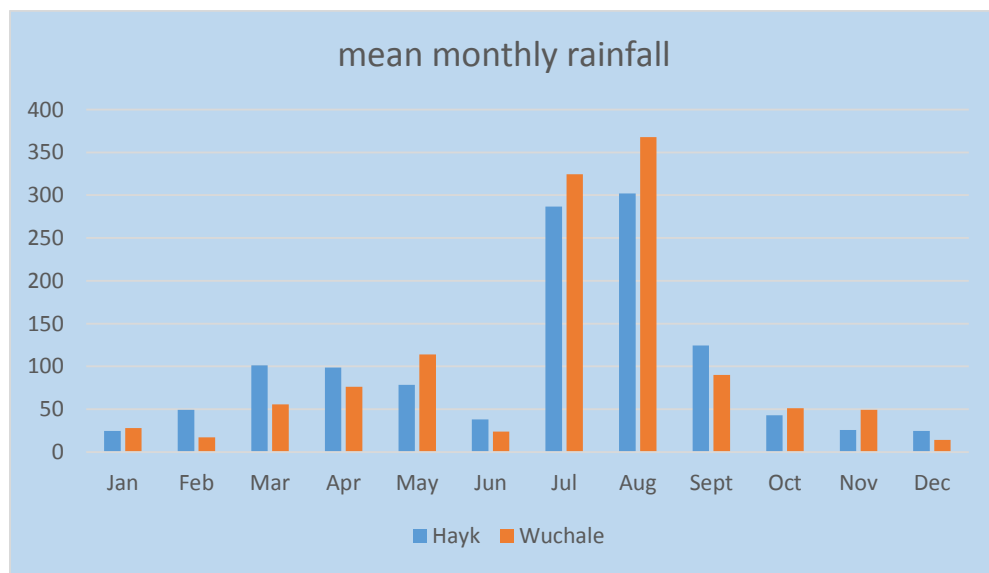
##### **4.1.4.3.1. Precipitation**

The amount of rain fall at in Ethiopia is influenced by the location of the point relative to the source of moisture, the direction of winds and topographical relief. In summer a strong movement of air prevails from the southwest the north east direction, i.e. from the high pressure system over the Gulf of Guinea towards the low pressure of the center of Arabia, bringing the summer rain, during the summer months (June and July) the low pressure Intertropical convergences Zone (ITCZ) is located north of the country and the area will be under the influence of the Atlantic Equatorial waterlines which ascend over the highlands from south west and produce the big summer rain, the amount of this rainfall decreases from southwestern Ethiopia towards the study area due to topographic and altitudinal effects, since in the course of the long journey from the Atlantic to the east African highlands, the moisture of the winds decreases. The area gets moisture from the easterly and southerly moist air currents in springs (Belg) when the ITCZ is located south of the country. Therefore, the area gets moisture from two sources at two distinct time of the year. From the Atlantic equatorial westerlies during summer and the southerly and easterly Indian Ocean air currents in springs. The study area catchment has a semi/arid subtropical climate traditionally classified as “Weina Dega”. The rainfall in the area is bimodal. That is there are two maximal in the rainfall hydrograph of the area, which are traditionally named as “Belg” lasting from March to May, which is small in amount, and “Kermit” lasting from July to September which is big in amount.

The most maximum annual recorded rainfall is 1210.9 mm at Wuchale station and the least minimum is 949.5 mm at Bati station. For the suitability of WetSpas model, the meteorological data were divided into two seasons such as summer (includes months from June-September) and winter (includes from October – May) and those data were interpolated separately to prepare maps as inputs.

**Table 4.1 Mean monthly rainfall (mm) of the study area.**

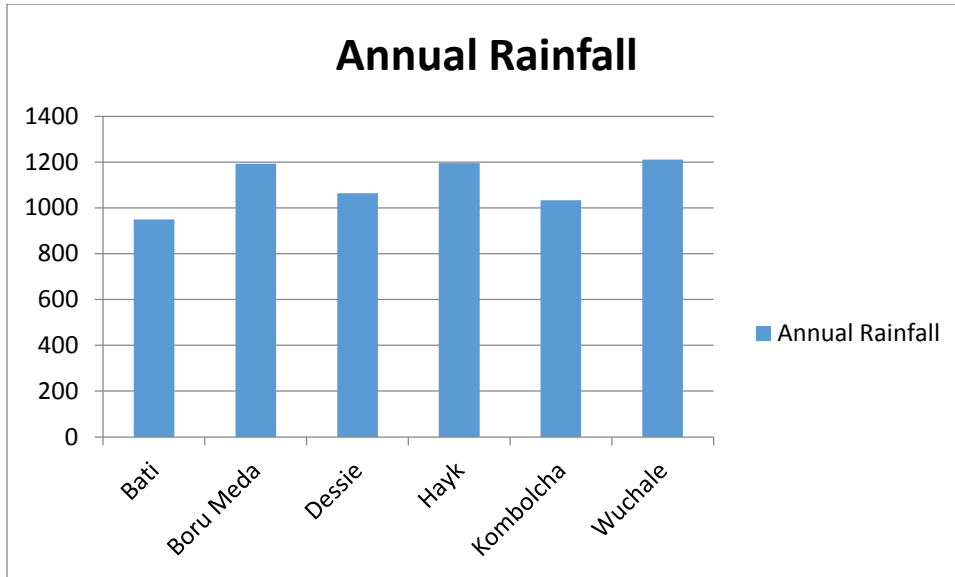
Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Hayk	24.6	49.1	101.1	98.5	78.2	37.9	286.8	301.9	124.4	43.0	25.8	24.5	1195.7
Wuchale	27.8	17.5	55.6	76.2	76.2	1140	23.7	367.7	89.8	51.2	49.1	13.9	1210.9
Mean	26.2	33.3	78.4	87.3	96.1	30.8	305.5	334.8	107.1	47.1	37.4	19.2	1203.3



**Figure 4.2 Mean monthly rainfall of the study area (mm) (EMNA)**

**Table 4.2 Mean Annual Rainfall of the study area and surrounding stations selected meteorological stations**

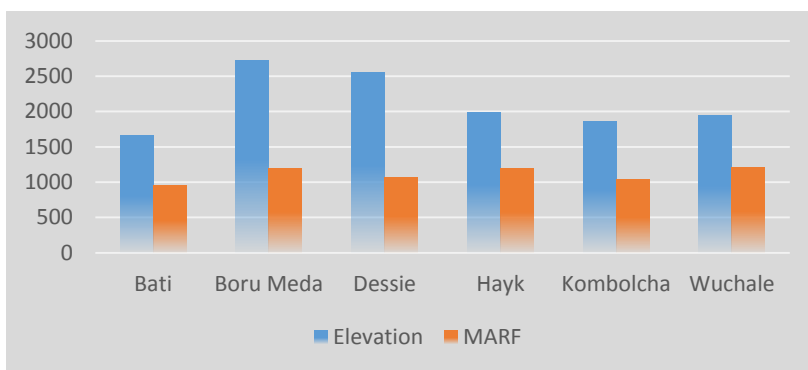
Stations	UTM Easting (X)	UTM Northing (Y)	Elevation (m)	MARF (mm)
Bati	574233.8	1249712	1660	949.5
Boru meda	550918	1256450	2720	1192.3
Dessie	569324.2	1228935	2553	1064
Hayk	574233.8	1249712	1985	1195.7
Kombolcha	578378.2	1225240	1857	1033.1
Wuchale	566058.9	1273167	1948	1210.9



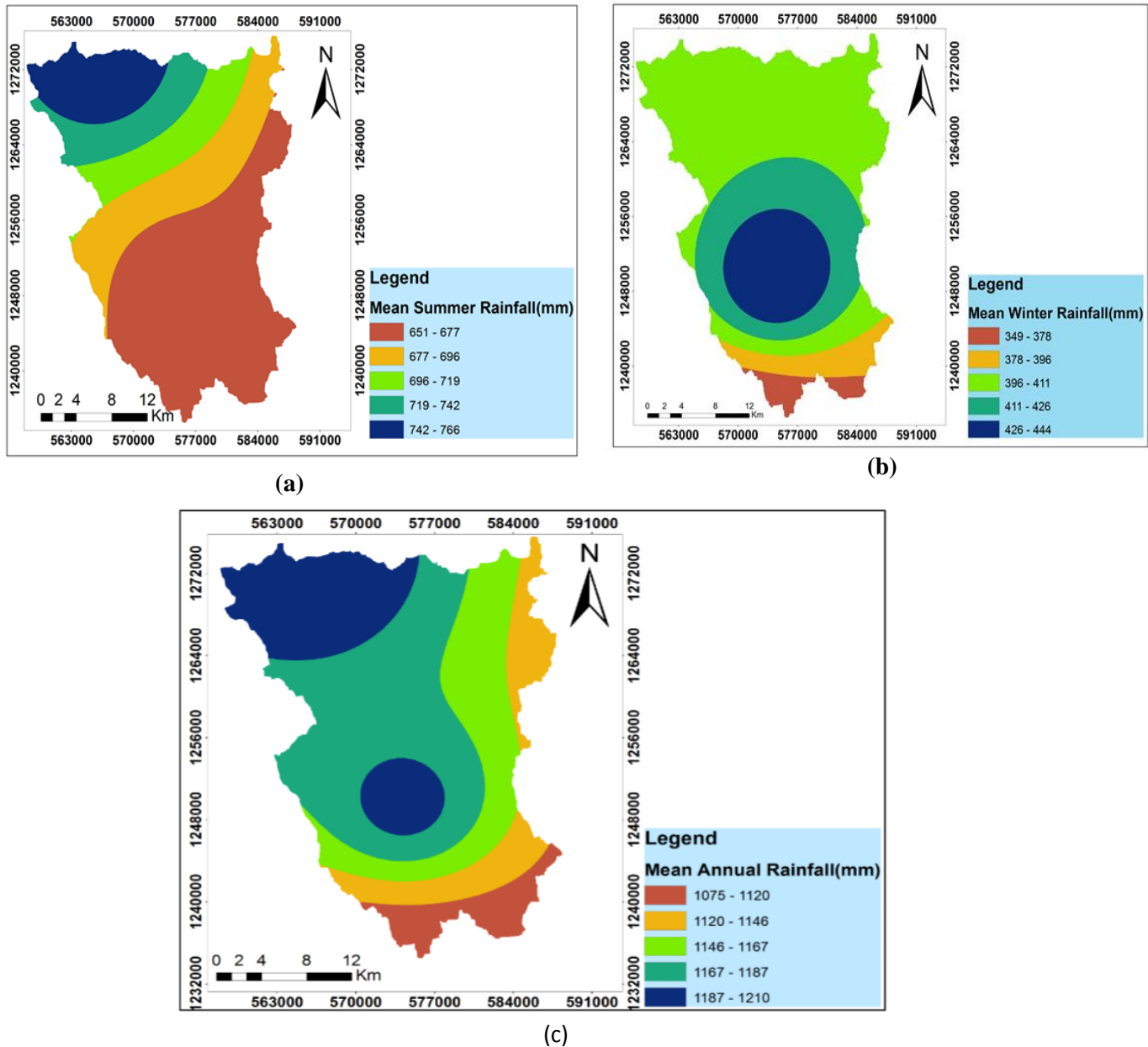
**Figure 4.3 Mean annual rainfalls of the selected meteorological stations (ENMA)**

One of the major factors determining climatic conditions in the region is altitude (UN, 1965). It affects rainfall, temperature and evaporation. In most area of the world, mean annual precipitation increases uniformly with altitude (Dune & Leopold, 1978; Dingman, 1994). Around and probably in the studied catchment, the relation between altitude and rainfall is evident in the four stations (Hayk, Wuchale, Kombolcha, and Bati) in which rainfall and elevation correlate linearly quantitative. However, local conditions such as gauge exposure, and probably wind direction has reduced the precipitation and Dessie and Boru Meda located an elevation of 2553 and 2720m respectively.

In addition to the variation observed with elevation, rainfall in the area found to vary also seasonally and spatially. The rainfall is found to be decreasing in a Southwest to northeast or east direction from an observation of a limited data it is also found to increase locally.



**Figure 4.4 Relations between mean annual precipitation and altitude (NMA)**



**Figures 4.5** Long term Rainfall distribution map of the study area (a), (b) and (c) represent summer, winter and annual rainfall in mm respectively as input data for WetSpss model.

As shown in figure (c) or in mean annual rainfall area has 1075 and 1210 mm minimum and maximum annual rainfall respectively, with mean of 1167.9 mm. And also the mean rainfall values of summer and winter seasons are 693.08 and 410.34 mm respectively, hence these values are useful for water balance calculation with simulation WetSpss results.

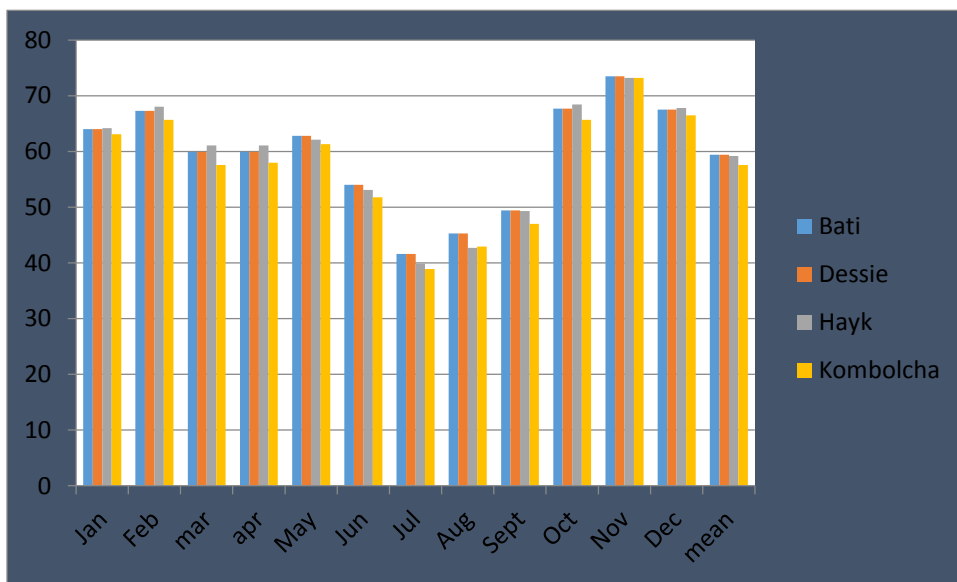
#### 4.1.4.3.2. Solar radiation, sunshine hours and temperature

Solar radiation is the source of energy that can change large quantities of liquid water into water vapor. Data of sunshine hours have been used in estimating evapotranspiration rates for determining of recharge. Sunshine hour's durations is not available in Boru and Wuchale

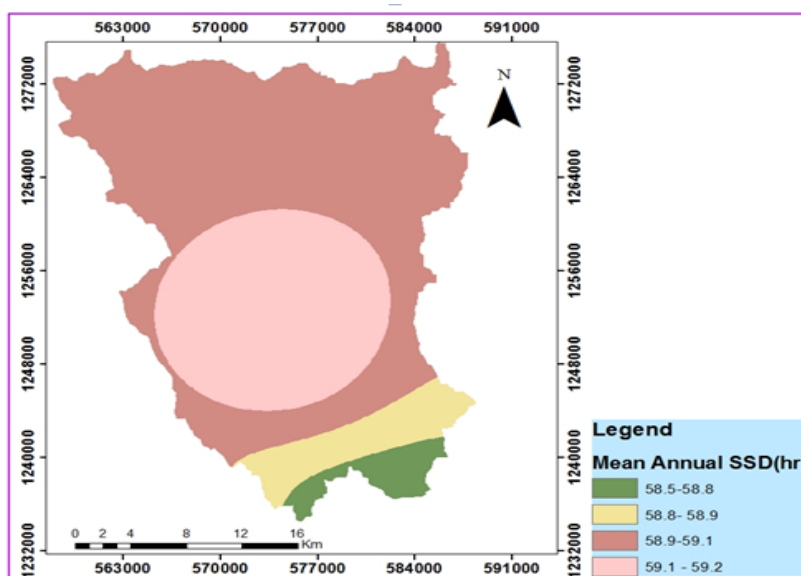
station. Sunshine Hour's duration is maximum in November and May and minimum in July, August, and September at both sunshine hour stations.

**Table 4.3 Mean monthly sunshine (hr/d)**

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Mean
Bati	64	67.3	59.9	62.2	54	41.6	45.3	49.4	67.7	67.7	73.5	67.5	59.4
Dessie	64	67.3	59.9	59.9	62.8	54	41.6	45.3	49.4	67.7	73.5	67.5	59.4
Hayk	64.2	68	61.1	61.1	62.1	53.1	39.9	42.7	49.3	68.4	73.2	67.8	59.2
Komb...	63.1	65.7	57.6	58	61.3	51.8	38.9	42.9	47	65.7	73.2	66.5	57.6
Mean	63.8	67.1	59.6	60.3	60.1	50.1	41.4	45.1	53.4	67.4	73.4	67.3	59



**Figure 4.6 Mean monthly sunshine hour's distribution (ENMA)**



**Figure 4.7 Map showing long terms mean annual sunshine day (hr)**

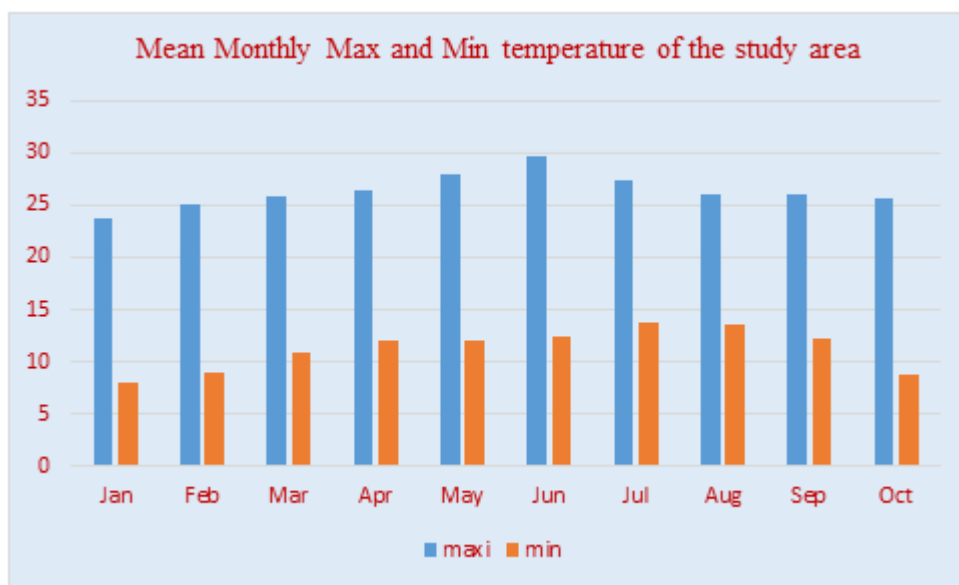
Water temperature and air has straightforward effect on evaporation by developing the environment hot and allows the passage of liquid state of water to vapor condition. According to Shaw, 1988 the higher the air temperature, the greater extent of water vapor it can carry, and in the same appearance if the temperature of evaporating water is high, it can more readily vaporized.

High daily temperature associated with longer sunshine hours duration and clear sky increases evapotranspiration. Temperature data are the major factor in computing potential evapotranspiration of an area. Temperature in the tropics is constantly high; the annual range, year to year variability, is low. Altitude is the major factor in reducing temperature in the tropics as compared to the high in coming solar radiation.

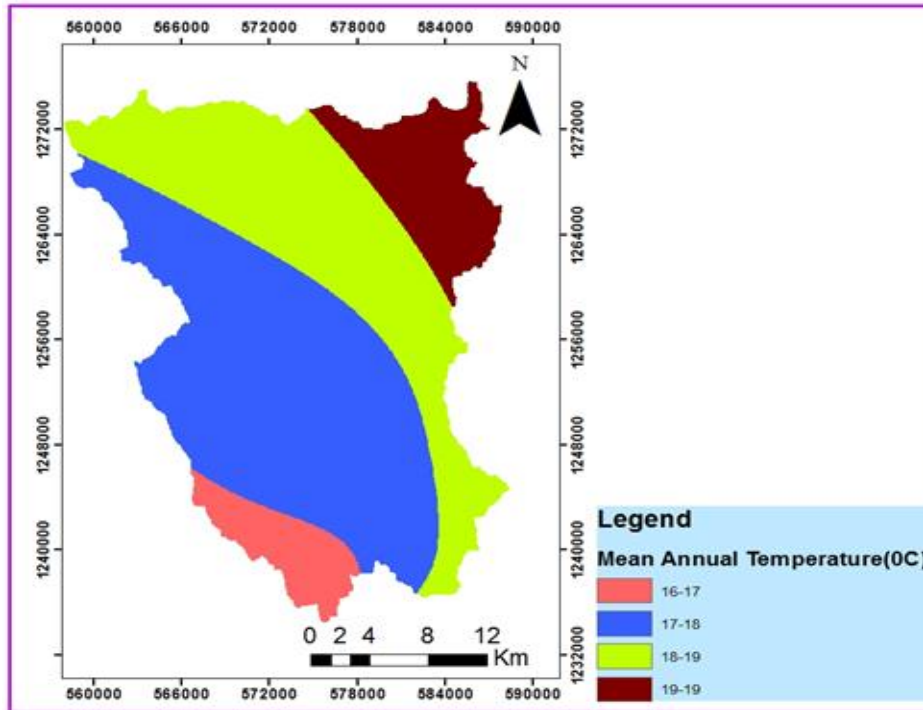
The mean monthly temperatures of years were brought in one from selected stations in the study and adjust area referring from National Meteorological Services Agency. From the six meteorological stations temperature is not recorded in Boru Meda and Wuchale stations. Accordingly the maximum average monthly temperatures in the study area /Hayk station/ are occurs in May and June (28 & 29.7 °C and minimum in November & January (7 & 8 °C).

**Table 4.4 Mean monthly temperatures**

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Av
Bati	17.7	17.8	20.6	21.7	23.3	24.8	23.8	22	22	20	18.4	17.5	20.9
Dessie	18.8	14.7	15.9	16.9	17.5	18.5	18.1	17.5	16.9	15.3	14.3	13.3	16.1
Hayk	15.8	16.9	18.4	19.2	20	21.1	20.5	19.9	19.2	17.2	16	15.3	18.3
Kombo	17.7	18.5	20	20.4	21.3	22.6	22.1	21	20.2	18.4	17.3	16.6	19.7



**Figure 4.8 Mean monthly maximum and minimum temperature of the study area (ENMA)**



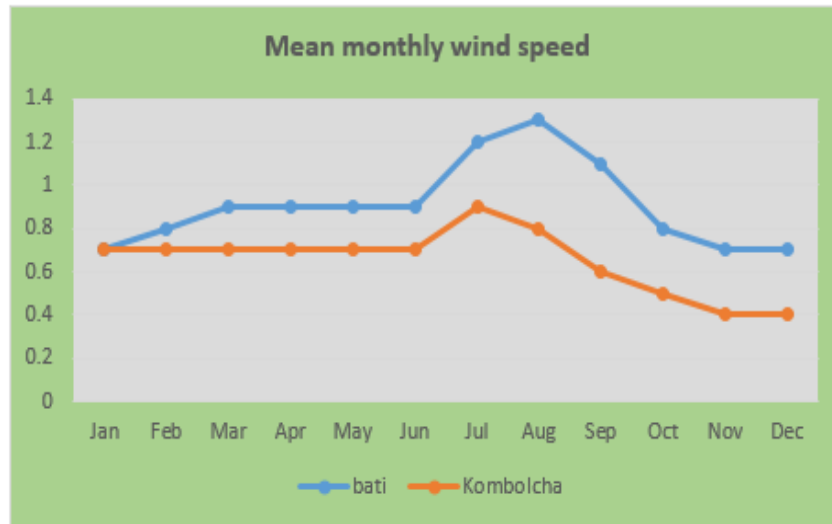
**Figure 4.9 Mean annual temperature**

#### 4.1.4.3.3. Wind Speed, relative humidity and Potential evapotranspiration (PET)

One of the major factors of evaporation is wind speed, the action of decreasing of wind speed resulting in non-removal of saturated vapor that make a difference to evaporation rate. Wind speed data in the study area is not available but it analyzed from the nearby stations of Kombolcha and Bati. Like rainfall and temperature, wind speed is not only the fundamental atmospheric parameter but also important as major input for WetSpss model to estimation groundwater recharge.

**Table 4.5 Mean Monthly Wind Speed**

Stations	Elevation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Bati	1660	0.81	0.90	0.96	0.96	0.95	1.15	1.27	1.1	0.80	0.70	0.70	0.80	0.93
Kombolcha	1857	0.66	0.72	0.70	0.67	0.73	0.85	0.78	0.63	0.46	0.41	0.44	0.55	0.63
<b>Average</b>		0.74	0.81	0.83	0.82	0.84	1.00	1.03	0.87	0.63	0.56	0.57	0.68	0.80



**Figure 4.10 Mean monthly wind speed**

Relative humidity is the relative amount of water vapor in the ambient air articulated as a percentage of the highest amount that the air could grasp at the specified temperature (Shaw, 1995). It is expressed a dimension less parameter and usually expressed by percentage. The relative humidity of the air is mostly dependent on temperature and rain fall. According to (Shaw, 1985) relative humidity is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature ed/ea represents as a percentage.

$$RH = \left(\frac{ed}{ea}\right)100$$

Where: - **RH** is relative humidity,

-**ed** is actual vapor pressure at the dew point, Td

-**ea** is saturated vapor pressure at air temperature, Ta.

As air humidity is in an instance of increasing, its capacity to absorb water vapor decreases and evaporation rate slows down. For evaporation to undergo there must be a difference in humidity (Tenalem Ayenew and Tamiru Alemayehu, 2001; Fetter C.W, 1994).

**Table 4.6 Relative humidity (%) stations in the nearby study area**

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Mean
Hayk	73.3	69.6	67.4	64.9	56.2	49.4	62.2	70.1	67.3	61.6	63	67.3	64.3
Kombolcha	64.4	61	60.1	58.5	50.7	43	60	66.8	65.1	60.6	59.7	61.5	59.3
Mean	68.9	65.3	63.4	61.7	58.5	46.2	61.1	68.5	66.2	61.1	61.3	64.4	62.2

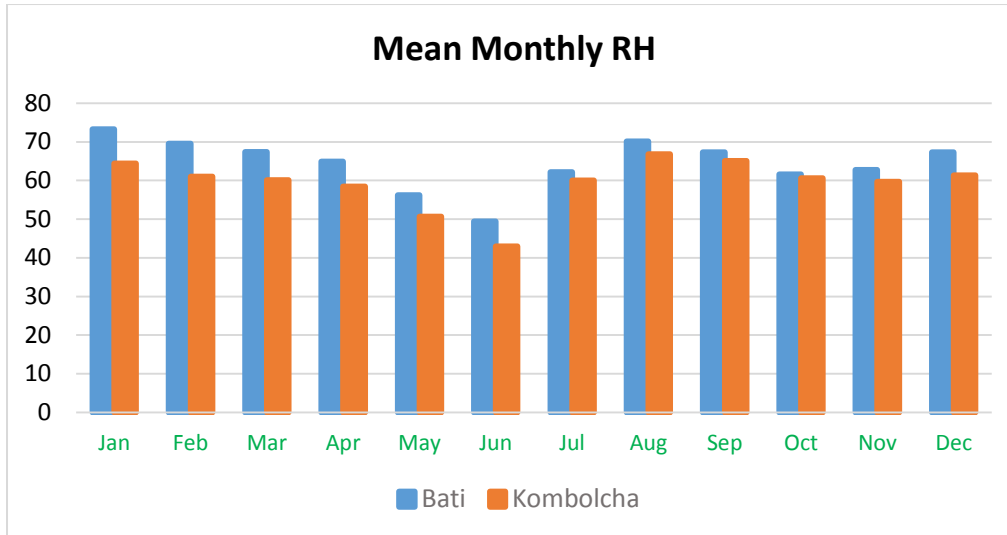


Figure 4.11 Mean monthly Relative Humidity

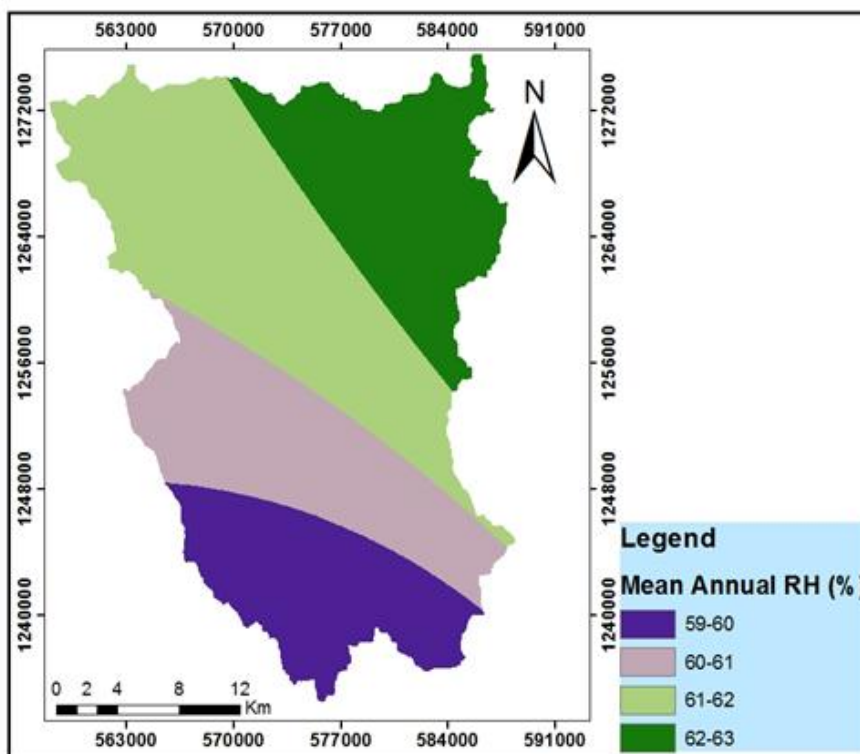


Figure 4.12 Map show long term mean annual relative humidity

Potential evapotranspiration can be defined as the total evaporation and transpiration from a vegetated surface with unlimited water supply (Shaw, 1994). It constitutes the maximum possible loss rate under the prevailing meteorological conditions. As stated by Brutsaert, (1982) PET is the quantity of water that was evaporated under an optimal set of circumstances, among unlimited supply of water. In other words, it would be the water needed for evaporation and transpiration given the local environmental significant influence. One of the greatest significant factors that establish water requirement is solar radiation as

energy supplied increases the pressing requirement for water. Different methods have been developed to calculate the PET. In this work, Thornthwaite methods are used to compute PET.

The potential evapotranspiration is estimated for the studied area by the Thornthwaite formula (Thornthwaite 1948; Federer 1979; Subramanya 2008) from meteorological data collected from selected meteorological stations. The main parameter in the equation of this formula is the temperature values in the different stations. Thornthwaite method relates PET to temperature with an adjustment being made for the number of daylight hour and gives figures for the consumptive use of short closed vegetation with adequate water supply. Thornthwaite take into consideration the average monthly temperature and thermal index. Potential evapotranspiration (PET) calculated on a monthly basis is given by:

$$\text{PET} = 16b (10Ta/I)^a$$

**Where**, PET is Potential evapotranspiration in mm, Ta is Mean monthly air temperature in ( $^{\circ}\text{C}$ ) I is annual heat index, b is latitude correction (is the monthly adjustment factor related to hours of daylight),

$$I = \sum_{i=1}^{12} \left[ \frac{Ta_i}{5} \right]^{1.514}$$

And  $a = 0.49 + 0.0179I - 0.0000771I^2 + 0.00000067$

**Table 4.7 Potential evapotranspiration compute by using Thornthwaite methods**

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Bati	52.2	60.7	75.8	90.1	106.5	123.8	110.4	94.3	90.6	70.9	57.2	47.7	979.9
Dessie	46.4	51.9	59.8	67	73.1	80.5	77.2	71.5	65.6	57.8	49.1	43.4	743.3
Hayk	49.7	57	67.7	76.1	83.4	92.9	87.7	80.9	74.7	59.4	50.3	43.4	823.2
Kombolch	56.8	62.8	75.5	80.9	90.3	102.5	97.6	86.6	78.4	62.8	54.2	49.4	897.8
Mean	51.3	58.1	69.7	78.5	88.3	99.9	93.2	83.3	77.3	62.7	52.7	46	861.1

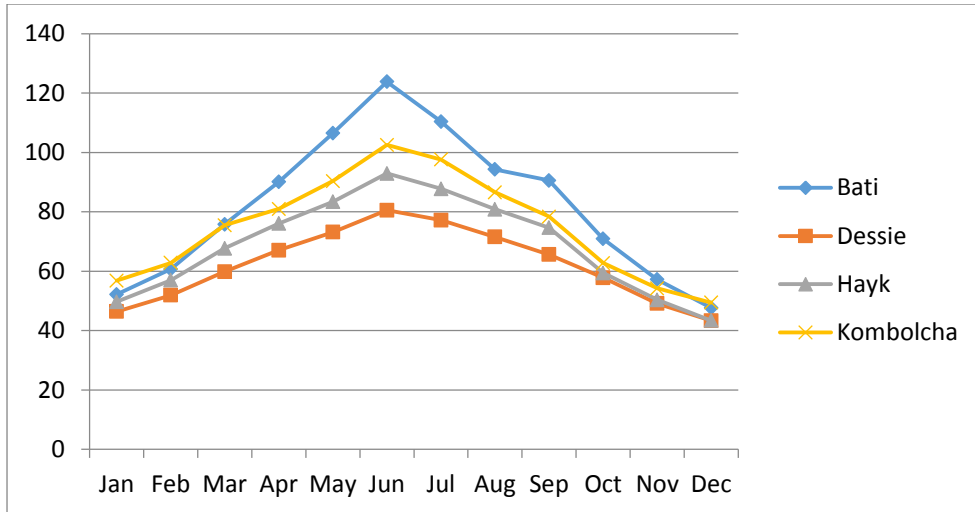


Figure 4.13 Potential evapotranspiration

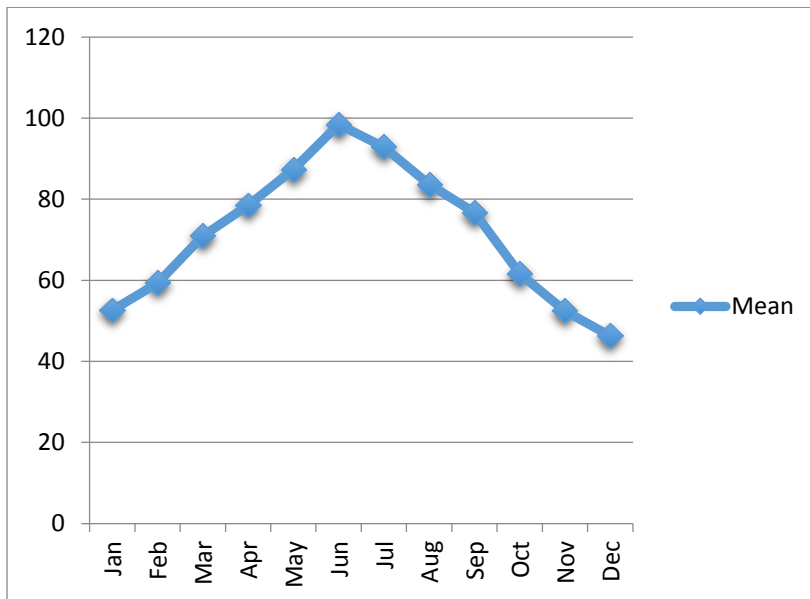


Figure 4.14 Mean monthly distribution of potential evapotranspiration

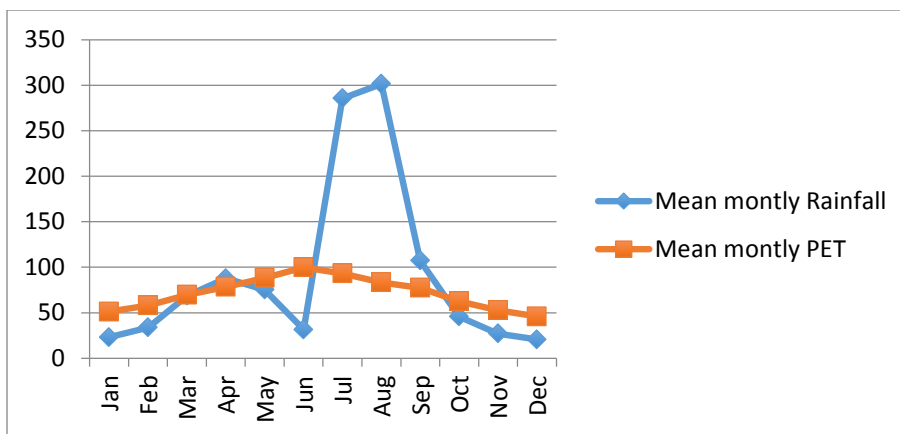
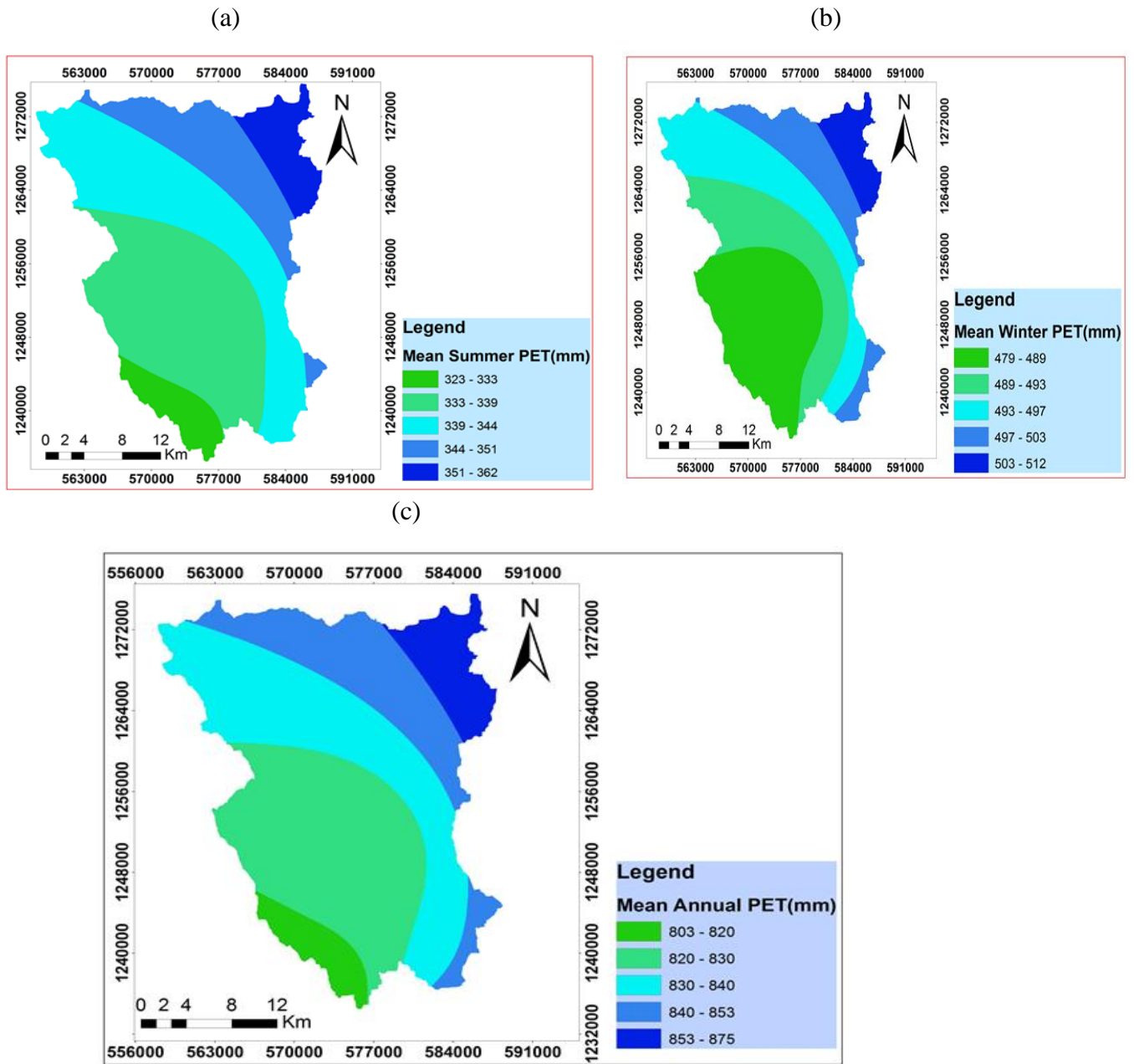


Figure 4.15 Comparison mean monthly rainfall and potential evapotranspiration



Figures 4.16 Long term distribution of (a) summer, (b) winter and (c) annual potential evapotranspiration

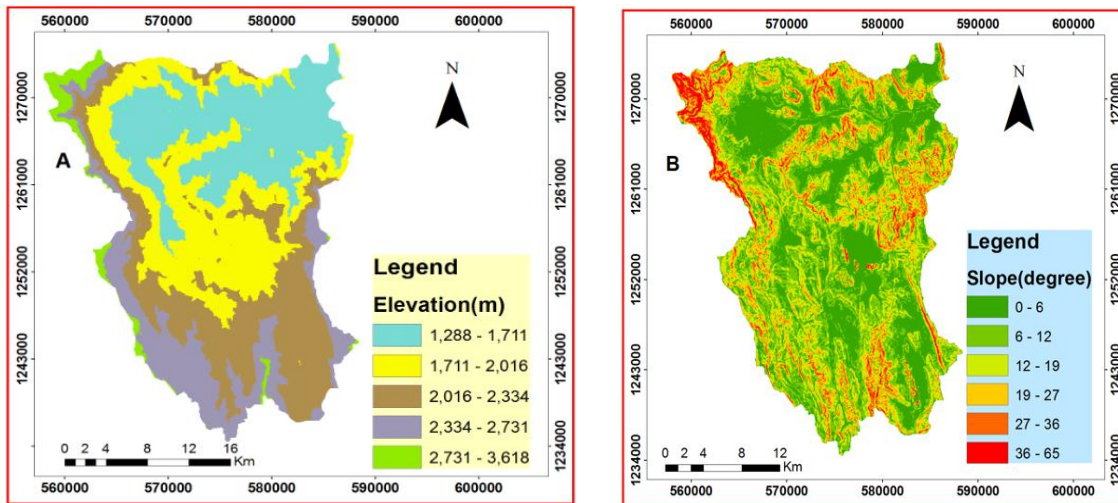
**Table 4.8 Summary of the average monthly meteorological data for the main meteorological parameters (ENMA) and PET by Thornthwaite methods**

Month	Mean precipitation(mm)	Mean PET(mm)	Mean temperature(0C)	Mean wind speed(m/s)
January	23.1	51.3	16.2	0.74
February	33.8	58.1	17.2	0.81
March	68.6	69.7	18.7	0.83
April	87.7	78.5	19.6	0.82
May	75.3	88.5	20.5	0.84
June	31.6	88.3	21.7	1.00
July	285.5	99.9	21.1	1.03
August	303.1	93.2	20.1	0.87
September	107.3	83.3	19.5	0.63
October	45.8	77.3	17.7	0.56
November	27.1	62.7	16.5	0.56
December	20.5	52.7	15.7	0.68

**4.1.4.3.4. Topography and slope**

Digital Elevation Model (DEM) of the study area which was prepared from ASTER DEM in Global Mapper is used with a cell size of 30m resolution. The DEM is processed to prepare topographic, slope and stream network of the study area. The lowest point in the basin is 1288 m in the valley and the highest is 3618 m at the escarpment part.

The slope map of the basin is directly derived from the topography map using the “derive slope” module in ArcView GIS 10.5. Accordingly, the slope ranges from 00 to 65. Slope and elevation are the most important factors that can determine both the recharge and runoff activities. Keeping constant the other factors, recharge and runoff decreases and increases respectively with increasing slope. Slope and elevation usually have direct relationship even though there are some areas relatively lowland and steep slope that facilitates runoff and also some are very highland with gentle slopes which is suitable for recharge.

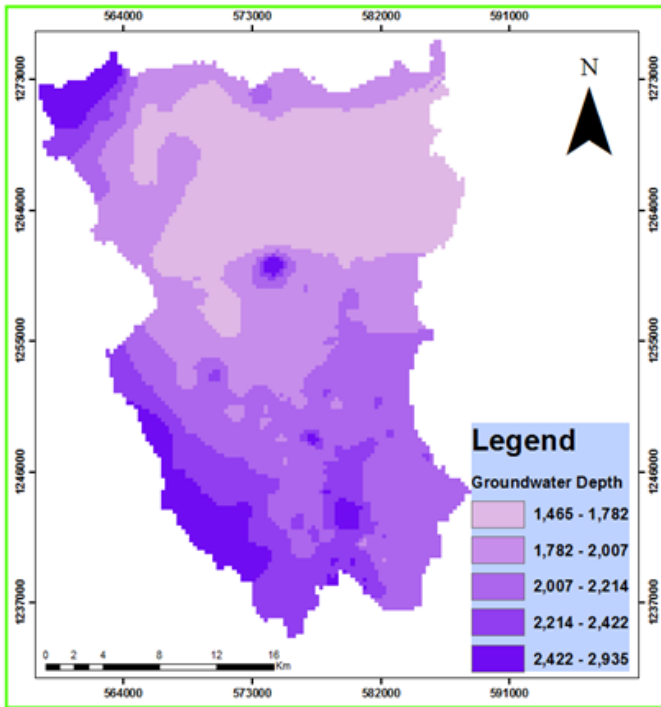


**Figures 4.17 Elevation map (a) and (b) slope map of the study area**

#### 4.1.4.3.5. Groundwater depth

Groundwater depth is an important component of WetSpass model to estimate both evapotranspiration and recharge within a catchment. It can inform the water table conditions of an aquifer whether it is shallow, nearby surface or deep far into the subsurface. The shallowest water table supports the soil to be wet which in turn facilitates the amount of evaporation and runoff in the case of fine grain soils like clay. Whereas the deepest water table may not reach near to the surface soil even its recharge is high because of high probability to seal by impermeable layers.

Groundwater depth is obtained by subtracting the static water level (measured using deep meter in the subsurface) from GPS recorded elevation on surface at which well is found. The static water level in the area is between 10m – 30m. The static water level of the spring is at the surface.

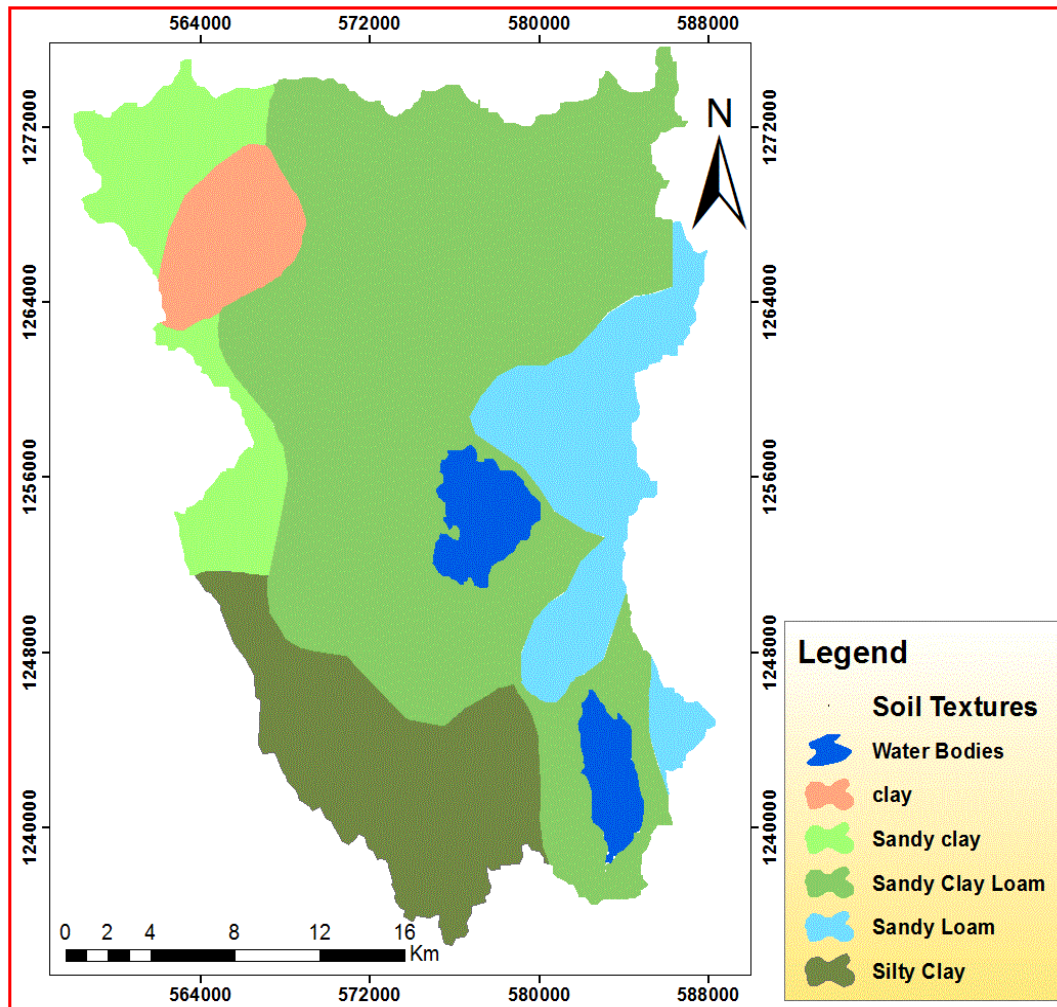


**Figure 4.18** Groundwater depth map

#### 4.1.4.3.6. Soil

Soil is one of the major inputs of WetSpas model. Its texture type is the main factor for the percolation of water into the saturated zone. Based on the laboratory results the texture of soils in the area is classified in to five major categories, such as clay, sandy clay loam, silty clay, sandy clay loam and sandy loam. The central and most part of the area are characterized by sandy clay loam texture as shown in the following figure.

The degree of weathering varies spatially, in the escarpment and in the area surrounding the two lakes; the soil material had been eroded and deposited to the central lower area. The thickness, type and distribution of soil vary with in the catchment.



**Figure 4.19 Soil texture map**

#### 4.1.4.3.7 Land use and land cover

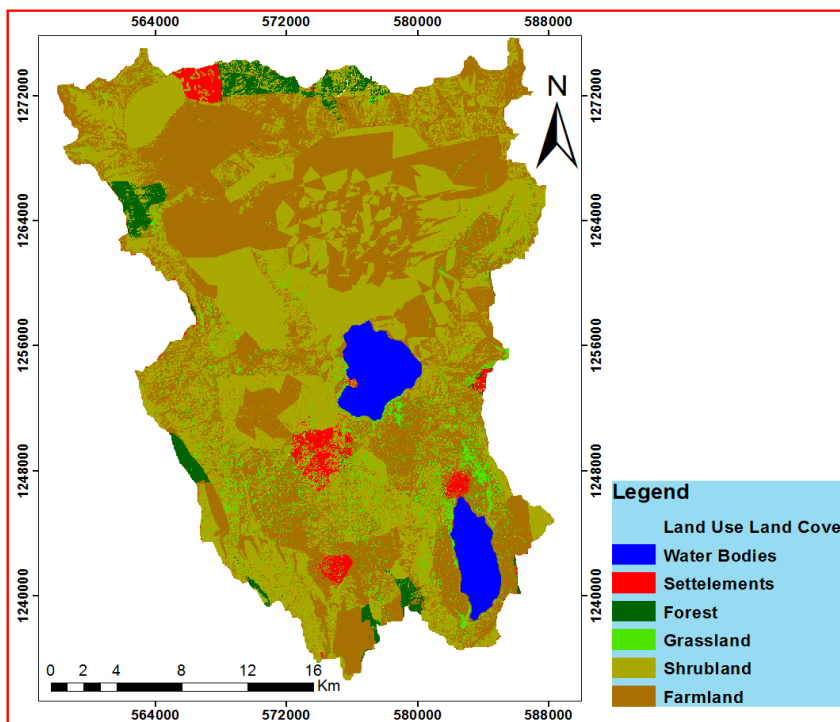
Land use and land cover is a major controlling factor of watershed hydrology (Fetter, 2001). The land use and land cover of the area provides important indications of the extent of groundwater requirements and utilization. From the point of view of land use, dense vegetation is an excellent site for groundwater exploration. Every division of land on the Earth's surface is unusual in the cover it possesses (Meyer, 1999). They are distinct yet closely linked characteristics of the Earth's surface. It is the manner in which human beings employ the land and its resources. Examples of land use include urban development, agriculture, logging, grazing, and mining use. In contrast, land cover describes the physical condition of the land surface cover. For example land cover categories include cropland, forests, wetlands, pasture, roads, and urban areas. The term land cover originally referred to the type and condition of vegetation, example forest or grass cover, but it has broadened in subsequent usage to include human structures such as buildings or pavement and other aspect

of natural environment, such as soil type, biodiversity, and surface and groundwater (Meyer, 1995). Land use is important in the hydrological and groundwater studies, because it is a prominent factor affecting the recharge (Getaneh, 2010). The land use and land cover map is produced using Landsat TM8 satellite image taken in 2018 and field delineation by using GPS.

The land use and land cover of the study area are grouped as farmland, forest, settlement, grassland, shrubland and water bodies from these the area is covered dominated by farmlands/ cultivated land.

**Table 4.9 Land use and land cover units and their area coverage**

S.No	LULC Unit Name	Area Coverage (km)	Coverage in %
1	Farmland	381.9	49.1
2	Forest	14.3	1.8
3	Grassland	5.6	0.7
4	Settlement	28.7	3.7
5	water bodies	36.5	4.7
6	Shrubland	310.7	39.9
<b>Total</b>		<b>777.7</b>	<b>100</b>



**Figure 4.20 Land use land cover map**

#### **4.2. Materials and equipment used**

The most important materials used conduct this research in the field were: Water quality kit for measurements of in-situ hydrochemical parameters (PH, EC, temperature, TDS) PH and temperature, sample bags for soil sample collection, water sample bottles, water and soil laboratory materials for physicochemical analysis, and topographic map of the area (Scale 1:25, 0000 and 1:50,000) and Garmin GPS, for locating water soil samples. The analysis and interpretations also were supported by the application of different software like Arc GIS 10.5 and Global mapper, surfer, aquachem4, and WetSpass model.

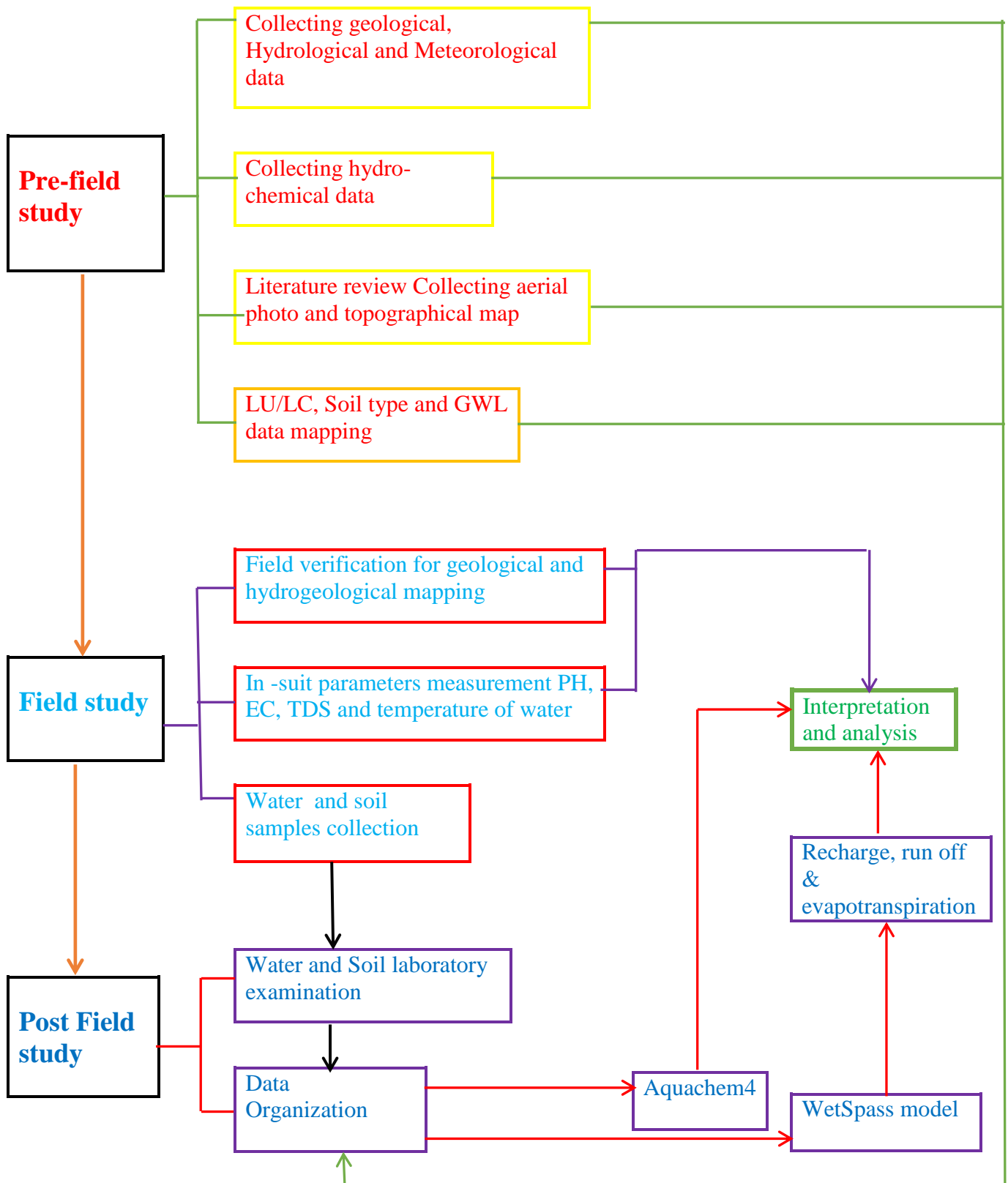


Figure 4.21 Summary of Methodology Flow Chart

## CHAPTER FIVE

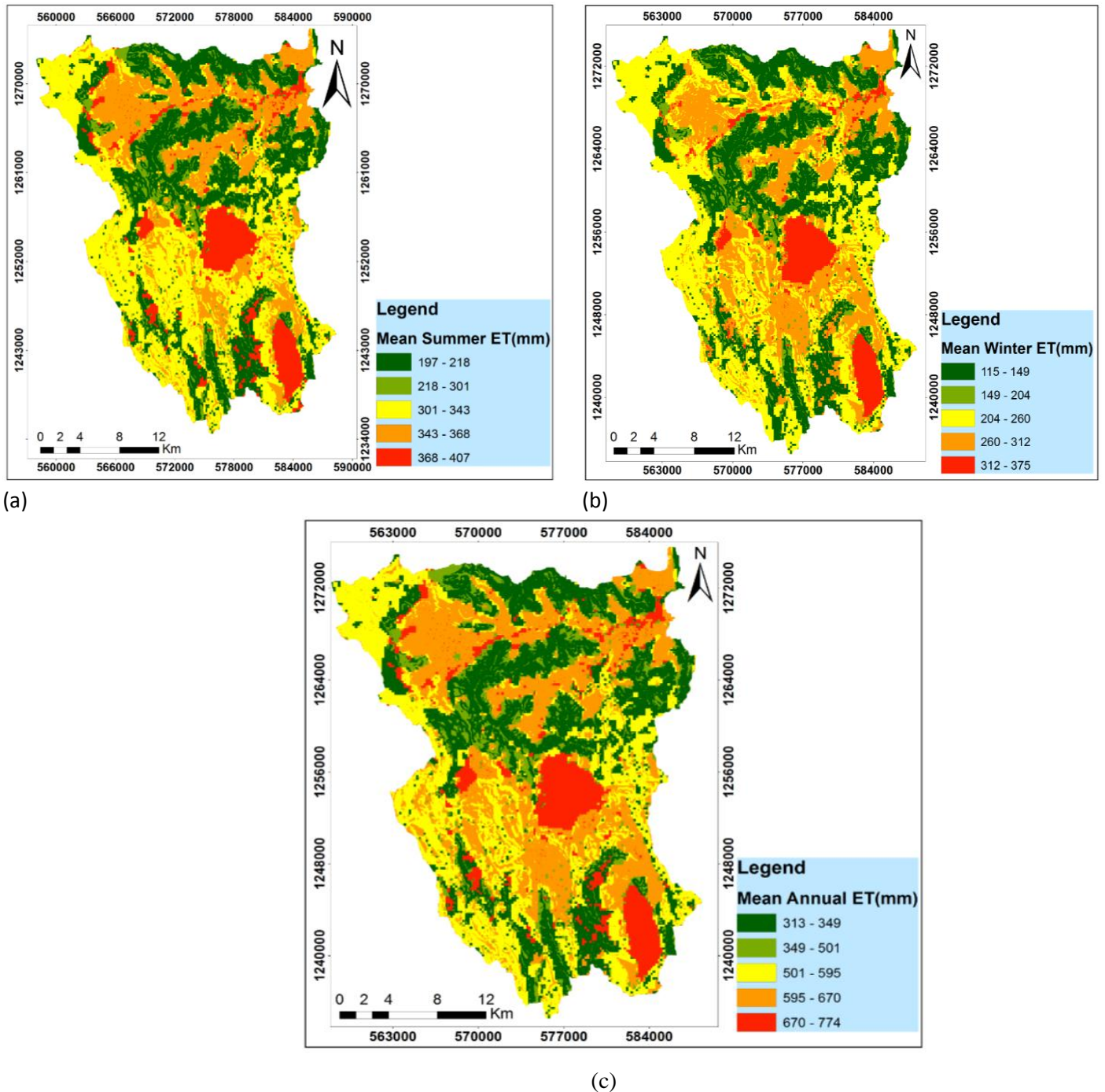
### 5. RESULTS and DISSUCION

The WetSpass model results consists several monthly, seasonally and annually out puts or results. For this study case the major results of the model are the digital maps of seasonally and annually surface runoff, evapotranspiration and groundwater recharge. These maps are raster-shaped, in which every pixel represents the magnitude of the respective component of water balance, expressed as layer thickness (in mm). A brief description those results are as follows:

#### 5.1 Evapotranspiration

The evapotranspiration per pixel is calculated by WetSpass model as a sum of evaporation from bare soil, open water and impervious surface area, summation of transpiration and interception of vegetated area (Batelaan and De Smedt, 2003; Abdollahi *et al*, 2016). WetSpass model simulates the annual of evapotranspiration of the study area varies from 313 mm/year to 774 mm/year as the minimum and maximum values. The mean annual and standard deviation of this distribution is 525.66 and 131.21 mm/year respectively. The annual evapotranspiration account 45% of total rainfall in the study area. Therefore, the result shows that evapotranspiration is the major process by which water is lost in the study area.

WetSpass model also simulates evapotranspiration of the study area to be 197 and 407 mm/year in summer and 115 and 375 in winter mm/year as minimum and maximum values with their average mean values of 303.25 and 222.4 mm/year, respectively. About 80% of the total annual evapotranspiration is lost during summer season and the remaining 20% is released in the winter season. The highest evapotranspiration distribution is in both lakes of the two seasons. The evapotranspiration distribution in other area is also varies. This variation arises due to differences in rainfall within the two seasons i.e. high rainfall depicts high evapotranspiration. The following figures 5.1 shows the highest evapotranspiration is occur in both lakes of summer and winter of the two seasons.



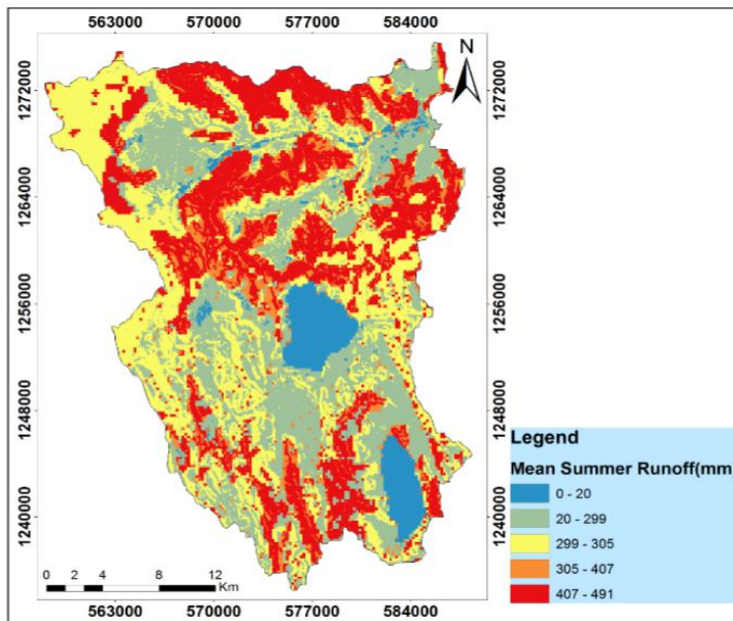
Figures 5.1 Spatial distribution of simulated WetSpass model output (a) mean summer, (b) mean winter (c) mean annual ET (mm)

## 5.2 Surface Runoff

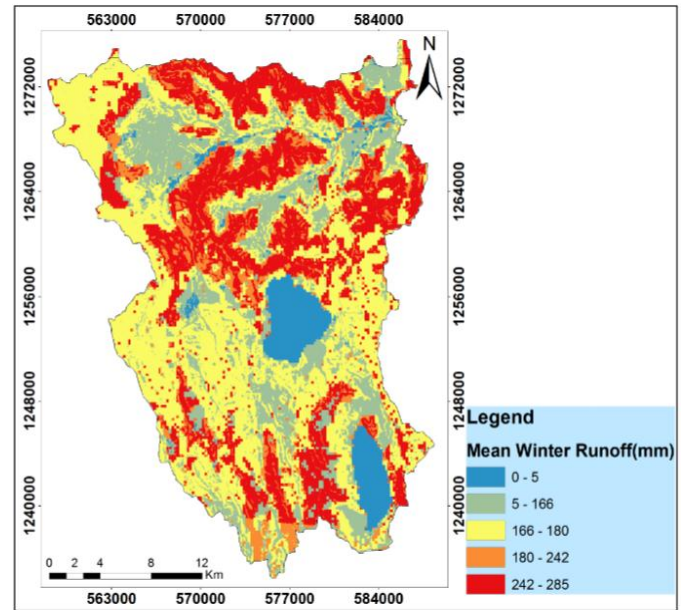
The used model calculates surface runoff in using a rational approach through an actual surface runoff and soil moisture coefficient. The surface runoff coefficient is a function of soil texture, land-use, slope, precipitation intensity and its relation to capacity of the soil infiltration. WetSpass model calculate the annual of surface runoff ranges from 0 mm/year to 750 mm/year as the minimum and maximum values. The mean annual and standard deviation

of surface runoff distribution in the area is 438.5 and 204.02 mm/year respectively. The mean surface runoff of the study area in summer season is 276.25, while in winter is about 162 mm. The average annual surface runoff account 36% of total rainfall in the study area. About 63% of surface runoff from rainfall is occurs during the summer seasons, while the remaining 37% is related to in winter season. This distribution is also variation comes from precipitation difference in the two seasons. The rainfall surpasses the infiltration capacity of soil during the rainy season which leads to high surface runoff.

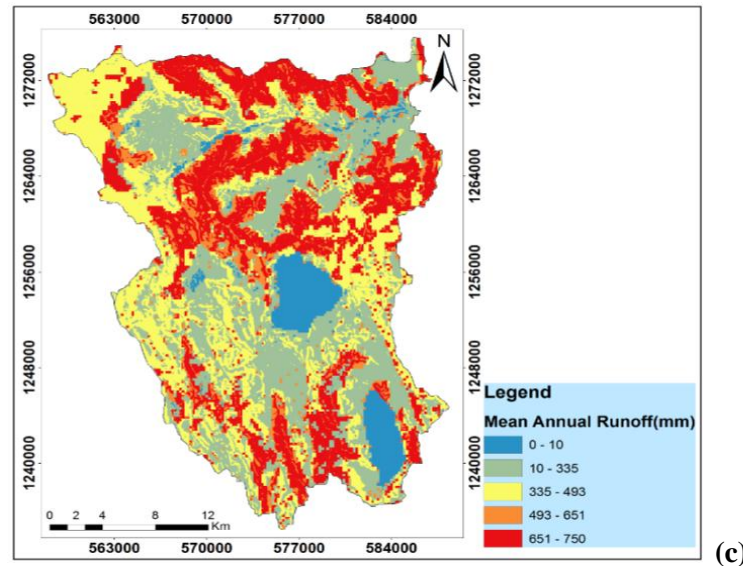
From the annually simulated surface runoff as presented in (Figure 5.2), the northern, central and some in southern hill have a high seasonal and annual surface runoff rate attributed to steep slope. The highest mean seasonal and annual surface runoff observed in northern western part attributed to presence of clay those have low permeability, which increases the surface runoff. On the other hand, the lowest runoff occurs in area due to the presence of sand and sandy loam soils and gentle slope. This clearly reveals that the soil map is strongly affected on the spatial distribution of surface runoff.



(a)



(b)

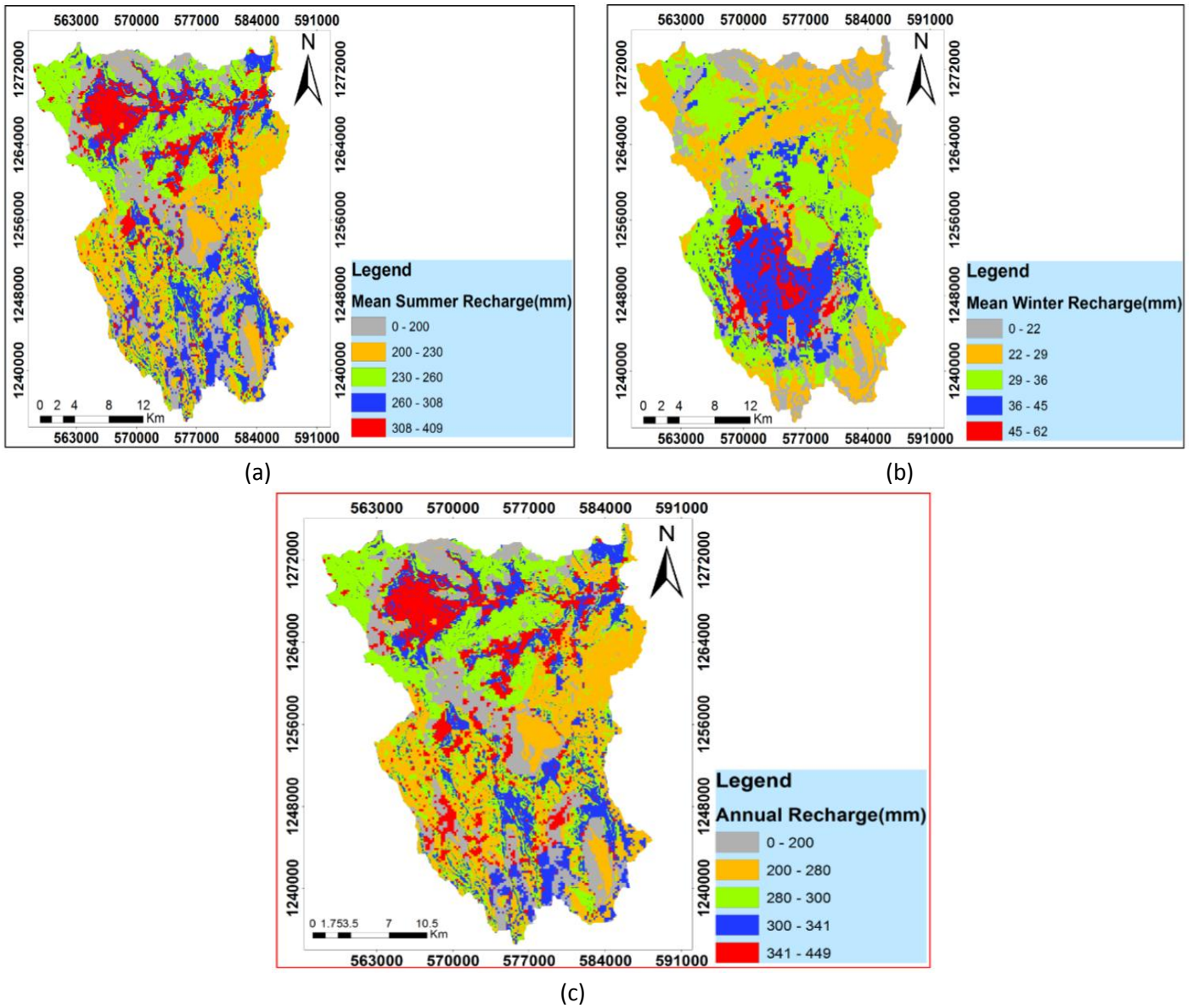


Figures 5.2 Showing the simulated (a) mean summer, (b) mean winter and (c) mean annual runoff

### 5.3 Groundwater Recharge

The amount of infiltrated water obtained from the fallen rain into groundwater (an aquifer) depends on factors such as vegetation cover, soil texture and degree of steepness and flatness of the area, depth to water table, and the presence or absence of impermeable beds over water table. Recharge is increased by vegetation cover, gentle sloped topography, permeable soils, a deep water table and the non-appearance of confining beds.

The WetSpss model estimates seasonal and annual long term spatial distribution amounts of groundwater recharge of the area by subtracting the seasonal and annual surface runoff and evapotranspiration from the seasonal and annual precipitation respectively. The resulting annual groundwater recharge from WetSpss for the present land use ranges from zero to 449 mm/year, with the mean value of 257.3 mm/year and a standard deviation of 74.62 mm/year. Like other components of water balance discussed above, the mean groundwater recharge of the area in summer and winter season is different which accounts 227.02 mm and 30.3 mm respectively. The highest groundwater recharge occurs in summer seasons it accounts 88.2% and the remaining 11.8% recharge occur in the winter seasons. From the simulated WetSpss model result the annual groundwater recharge accounts 19% of the total rainfall. In the study area the highest groundwater recharge is mostly occur in the northern parts and some central and southern parts. Generally the highest groundwater recharges occur in the study area also in gentle or flat, cultivated and vegetated (forest and shrubland) area and sandy loam soils and low recharge clay and steeply slope area.



Figures 5.3 Simulated groundwater recharge (a), (b) and (c) shows the summer, winter and annual groundwater recharge

**Table 5.1 Summary of long-term annual and seasonal WetSpas simulated components of the study area**

Periods	Values	Evapotranspiration	Runoff	Groundwater recharge
Summer	Minimum	197	0	0
	Maximum	407	750	400
	Mean	303.25	276.3	227.02
Winter	Minimum	115	0	0
	Maximum	375	491	62
	Mean	222.4	162	30.3
Annual	Minimum	313	0	0
	Maximum	774	750	449
	Mean	525.66	438.5	257.3

### 3.4 Water Balance calculation using raster cell

Water balance is a quantitative evaluation of the total water gained or lost from a given hydrological system during a specific period of time (Tamiru Alemayehu and Tenalem Ayenew, 2001). It considers all surface and groundwater that are entering, leaving or stored within the system. The study of water balance of a given basin forms a basis for the hydrological confirmation of projects for the rational use, control and redistribution of water resources in time and space. It is also used to make a quantitative evaluation of water resources and their change under the influence of man's activities. Knowledge of the water balance assists the prediction of the consequences of artificial changes in the regime of the given basin. Thus, for sustainable groundwater management, the water balance should be established for a given unit system over a given period of time. The water balance equation for any natural area such as a river basin or water body indicates the relative values of inflow, outflow and change in water storage for the area.

Water balance is a representation of the net result of the inflow and outflow of system. WetSpas model used to compute the water balance components. The total water balance for a raster cell (Figure 5.4) is split into self-determined water balances for the vegetated, bare-soil, impervious and open -water parts of each cell. This allows one to account for the non-homogeneous of the land-use per cell, which is reliant on the resolution of the raster cell. The processes in each cell are set in its order. Defining such an order is a requirement for the periodic time scale with which the procedures will be counted. A mixture of physical and empirical relationships is used to describe the processes.

WetSpas model is very accurate to compute the water balance since it can evaluate each pixel sizes of an area using raster cell due to its distributed in nature. The equations used to

calculate the WetSpass model are described by Batelaan and De Smedt (2001, 2007) and Batelaan and Woldeamlak (2007) and user guide of the WetSpass model. Batelaan and De Smedt (2007) described that the total water balance in WetSpass, as per raster cell and hydrological season. The total components of water balance of the vegetated, bare soil, open-water, and impervious fraction per raster cell are calculated using the following equations:

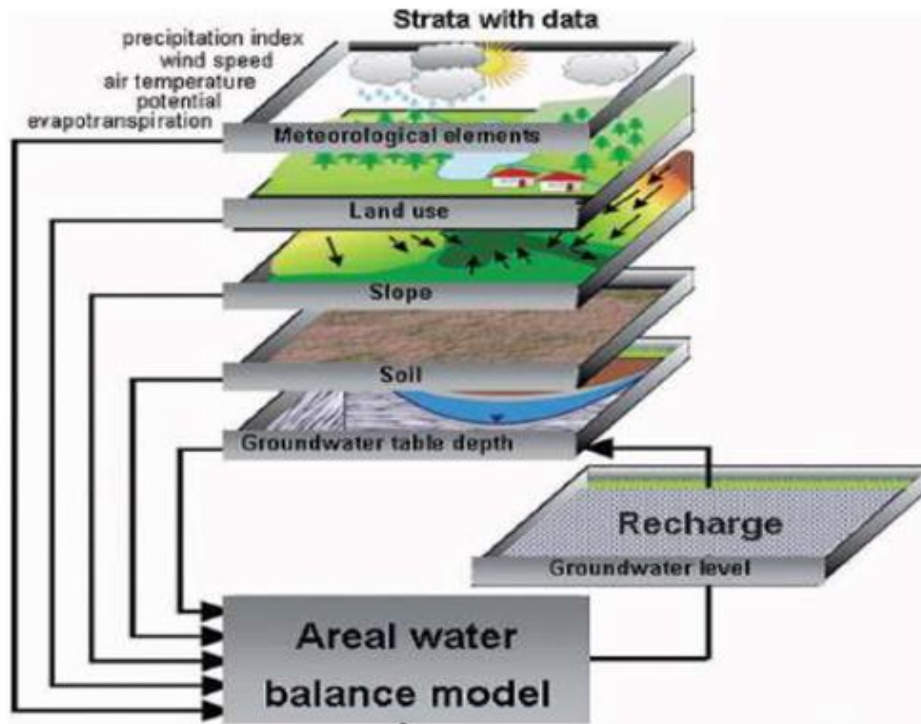
$$ET_{\text{raster}} = a_v ET_v + a_s E_s + a_o E_o + a_i E_i \quad (1)$$

$$S_{\text{raster}} = a_v S_v + a_s S_s + a_o S_o + a_i S_i \quad (2)$$

$$R_{\text{raster}} = a_v R_v + a_s R_s + a_i R_i \quad (3)$$

Where,  $ET_{\text{raster}}$ ,  $S_{\text{raster}}$  and  $R_{\text{raster}}$  are the total evapotranspiration, surface run-off, and groundwater recharge of a raster cell, respectively, each having a vegetated, bare-soil, open water and impervious area component denoted by  $a_v$ ,  $a_s$ ,  $a_o$  and  $a_i$ , respectively.  $s$ ,  $o$  and  $i$  indices are stand for the bare area, open water area and impervious surfaces respectively.  $S_s$ ,  $S_o$  and  $S_i$  are the surface runoffs in bare area, open water area and impervious surface, respectively.  $E_s$ ,  $E_o$  and  $E_i$  are the evaporations in bare area, open water area and impervious surface respectively.  $R_v$ ,  $R_s$ ,  $R_o$  and  $R_i$  are the groundwater recharges in vegetation area, bare area, open water area and impervious surface respectively.

The model by itself calculates the results of the components given by the equation 1, 2 and 3. Accordingly, the mean annual values of recharge, evapotranspiration and runoff are 251.3, 525.9 mm and 438.5 respectively. Those all values are the corresponding mean annual values so their sum should have given the mean value of their source called precipitation. The sum of mean annual recharge, mean annual evapotranspiration and mean annual runoff is 1221.21.mm. However, the mean annual precipitation or rainfall in the study area is 1167.9 mm. This value indicates that the precipitation is less than the total sum of simulated groundwater recharge, evapotranspiration and runoff in the area. In general, the water balance component which is computed from the WetSpass model in annually is not equal or approximately equal to the source of mean value precipitation.



**Figure 5.4** Schematization and integration of data for a hypothetical cell in the WetSpa water balance model after Batelaan and De Smedt [12]

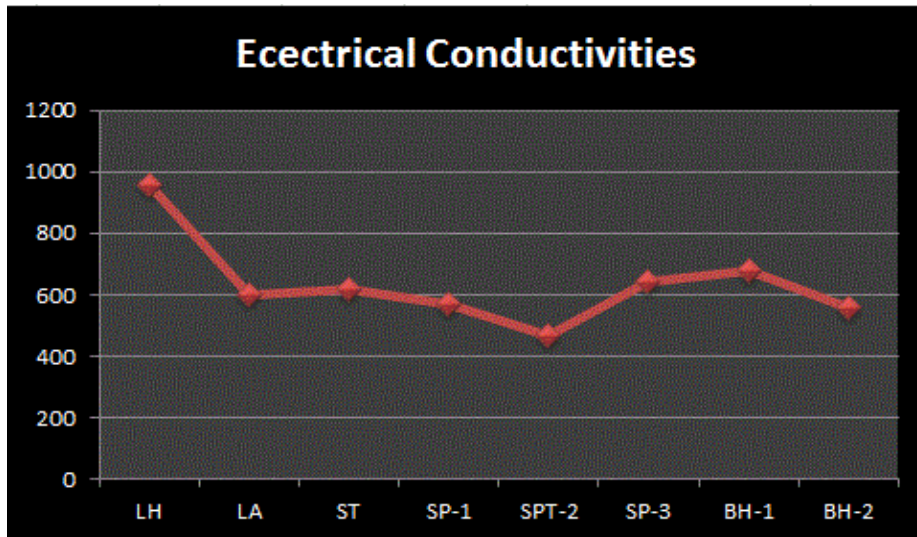
### 5.5 Hydrochemical analysis

The chemical composition of water is derived from many different sources of solutes, for example, gases and aerosols from the atmosphere, weathering and erosion of rocks and soil, precipitation reactions occurring below the land surface, and cultural effects rising from human activities. Solutes occur in natural water represent the net effect of a series of antecedent chemical reactions that have dissolved material from another phase, have altered previously dissolved components, or have eliminated them from solution by precipitation (Hem, 1985). The ways in which solutes are taken up or precipitated, and the amounts present in solution are influenced by environmental factors such as climate, structure and position of rock strata and biochemical effects associated with life cycle of plant and animals. The main objective of the hydrochemical study in this paper work is only to evaluate the surface water and surrounding groundwater interaction and to assess the quality of water for drinking and irrigation purposes based on limited physic- chemical tests. The chemical quality of water is an important as its quantity. Chemically constituents in both surface and groundwater determine its usefulness for domestic, agricultural, and industrial purposes. Only very important and relevant parameters are addressed.

### 5.5.1 P<sup>H</sup>, electrical conductivity (EC), total dissolved solids (TDS) and temperature

P<sup>H</sup> of water is an essential indication of its quality, which is controlled by the amount of dissolved carbon dioxide, carbonates and bicarbonates. Addition of salts to water may cause rapid rise in P<sup>H</sup>. The calcium carbonate (CaCO<sub>3</sub>) increases the P<sup>H</sup> of water making it alkaline. P<sup>H</sup> represents the concentration of hydrogen ion [H<sup>+</sup>] as the result of the dissociation of water. The P<sup>H</sup> of pure water at 25°C is 7.0 (neutral). When the water has more than 7, it will be alkaline and if it is less than 7 it becomes acidic. The water samples of the area are varies for different water bodies. The P<sup>H</sup> values of surface water (Hayk and Ardibo lakes and stream are 9.2, 8.8 and 7.3 respectively), and other water samples of the P<sup>H</sup> values of is ranges from 6.6 to 7.2. The P<sup>H</sup> of the lakes and groundwater differs markedly. The P<sup>H</sup> of both lakes are alkaline and having P<sup>H</sup> average of 9. Whereas, the groundwater having P<sup>H</sup> on average of 6.8. Electrical conductivity (Ec) is the ability of water to conduct electrical current. It is a function of temperature, type of ions occur and concentration of different ions. The calcium bicarbonate and calcium sulfate water types have the lowest conductance; on the contrary, sodium chloride water type has the highest conductance for a given total concentration of dissolved solids (Davis & De Wiest, 1966). And also high amount of salt content in water increases the electric conductivity (EC) of water; this is because of the addition of ion in the water.

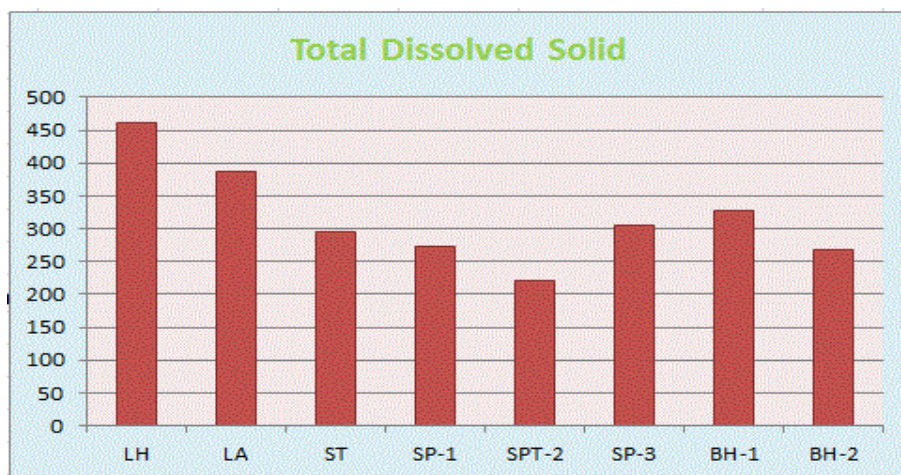
The EC values analyzed different waters from different water bodies of the study area are varies. For instance, the EC values surface water ranges from 599µs/cm to 95 µs/cm the groundwater ranges from 465µs/cm and 680µs/cm. Generally, the highest EC value recorded in lake Hayk which was reached to 956µs/cm and the lowest EC values is one sample spring which is occur near to lake Hayk. The EC values of the two Lakes were also recorded markedly different EC values.



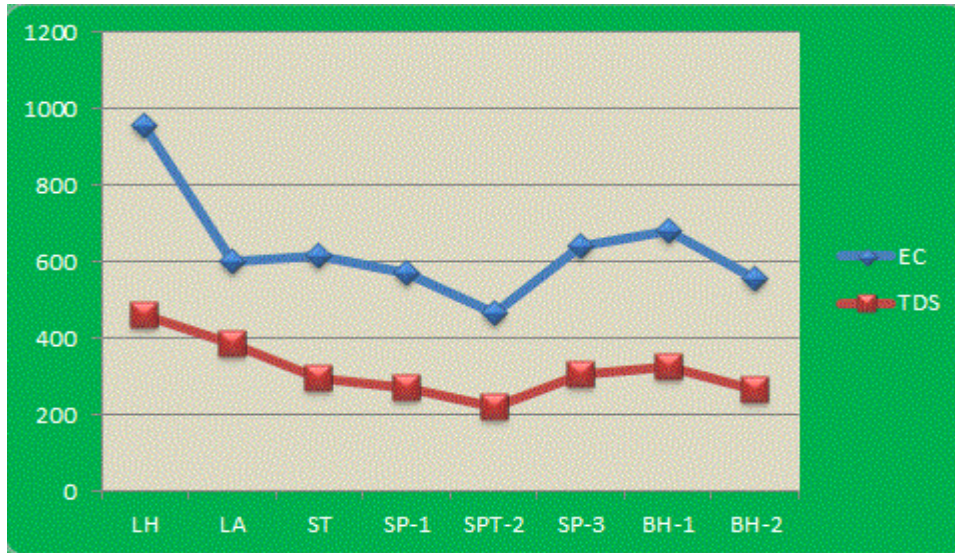
**Figure 5.5 Electrical conductivities values of the selected water samples**

The total dissolved solids (TDS) in a water sample include all solid material in solution, whether ionized or not. Total dissolved solid (TDS) is a measure of the joint content of all inorganic substances (like calcium, magnesium, sodium, potassium, chlorides, sulfates and bicarbonates) and organic materials which can dissolve in water. The naturally occurring TDS arise from the weathering and dissolution of rocks, minerals and soils. Based on specific site condition TDS in water could also have anthropogenic source.

The TDS values of waters in the study area have different values. The lakes of TDS values are higher than other water samples. Their TDS values are 462 mg/l to 388 mg/l for Hayk and Ardibo lake respectively. The TDS value of groundwater sample is ranging 222 mg/l to 328 mg/l. The minimum groundwater TDS value is occur in in the southern part of lake hayk which has TDS values 222 mg/l and maximum value of its occur in Hayk town borehole water sample.



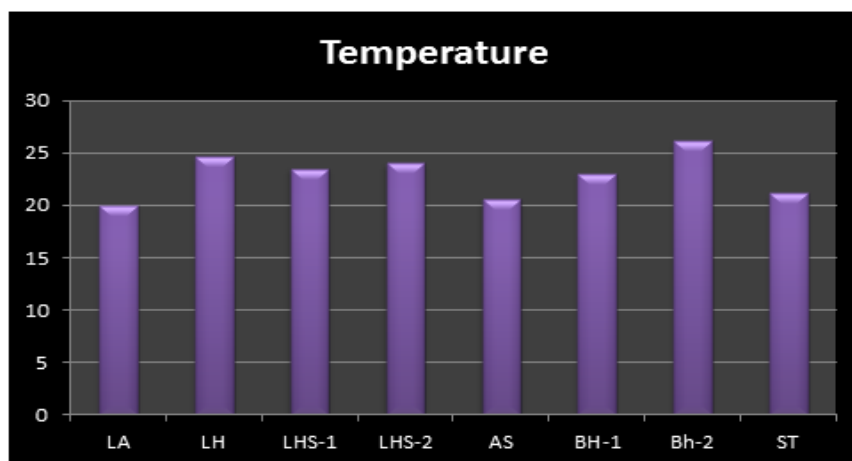
**Figure 5.6 Showing the TDS Values of different waters samples**



**Figure 5.7 Relationships of totals dissolved solid and electrical conductivity**

The total dissolved solids and electrical conductivity is directly related that demonstrates relatively high electrical conductivity at high amount of TDS concentration. This means the more the TDS concentration the more the ability of water to conduct electricity. This is because of the uniformly increasing and decreasing of electrically conductance of cations and anions from weathered rocks and soils throughout the samples area.

Water temperature is a physical property expressing how hot or cold water is. It is the main factor to consider when assessing quality of natural water. In addition to its own effects, temperature influences other several parameters and can change the physical and chemical characteristics of water. Temperature is measured insitu at the time of field work, immediately at the moment of sample collection. Because of its sensitivity, temperature is measured three or four times in a sample and takes average of these different measurements to be more accurate. The temperature of water in the study area ranges from 22<sup>0</sup>C to 26<sup>0</sup>C.



**Figure 5.8 Temperatures values of water samples**

### 5.5.2 Major cations analysis

Cations are the general name of positively charged ions which includes most metallic elements and some positively charged non-metallic elements like hydrogen. The major cations significantly found within most water are calcium, magnesium, sodium and potassium. However, the concentrations of these major cations are different from water to water depending on their source, host rock, temperature and other several factors.

The chemical analysis of water samples of the study area show that calcium is the most dominant cation of water samples, it ranges from 8.8 to 1037.2. The second dominant cation in the analyzed water samples is sodium. The maximum cation concentration recorded in this area is the sample taken from the stream which has 1037.2 of calcium cation and the minimum cation concentration is also the stream which has 2.6 in potassium cationic concentration.

**Table 5.2 Major cation concentration of different water samples (ppm)**

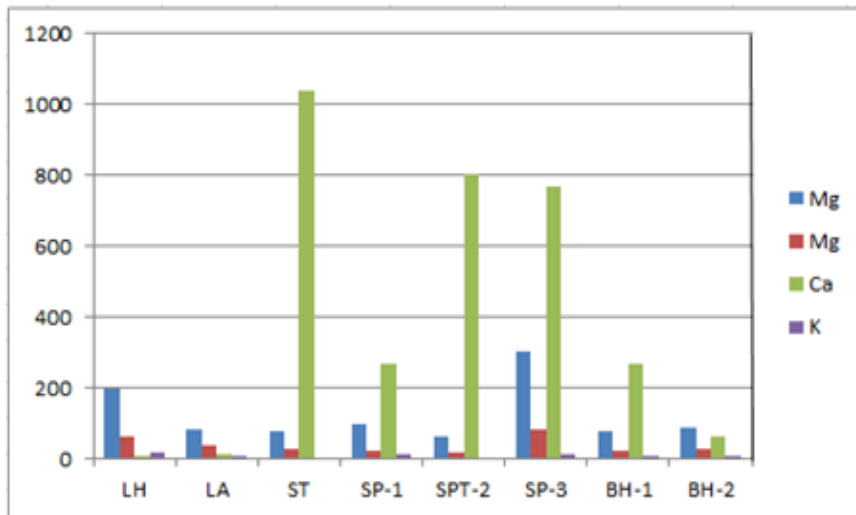
Sample ID	Na	Mg	Ca	K
LH	199.2	63	8.8	19.8
LA	85.1	38.5	11.5	8.2
ST	76.1	30.3	1037.2	2.6
SP-1	96.9	24	266.8	13.5
SP-2	64.5	16.2	803.2	2.8
SP-3	305.5	85	767.4	14.4
BH-1	79.1	24	270.2	5.7
BH-2	85.6	26	63.8	8

The order of major cation dominance concentration of different water samples are:

Lakes samples: **Na>Mg>K>Ca**, sodium is the dominant one with average concentration of 142.2 ppm.

Groundwater samples (springs and boreholes samples): **Ca>Na>Mg>k**, in this sample calcium is the dominant one has an average 434.3 ppm.

In stream sample, the cation concentration of calcium is the dominant one followed by Na, Mg, and K of. Major cation concentration of potassium is minimum in all water samples.



**Figure 5.9 Concentration of major Cations values**

### 5.5.3 Major anions analysis

Anions are species having negative charges. The chemical species may be a single atoms or a group of atoms. The major anions in water samples of the study area are bicarbonate, chloride and sulfate in their decreasing order of concentration. In the area bicarbonate ( $\text{HCO}_3^-$ ) is the most dominant ion among analyzed anions water samples. Its concentration varies from 366 mg/l to 180.5 mg/l with an average value of 250.1 mg/l total water samples. The maximum concentration of  $\text{HCO}_3^-$  is occurring in lake Hayk sample which has 366. The origin of  $\text{HCO}_3^-$  ions in groundwater are from the carbon dioxide in the atmosphere, carbon dioxide in soil, and solution of carbonate rocks (Davis and De Wiest, 1966).

Chloride ( $\text{Cl}^-$ ) is the next dominant anion in the groundwater next to bicarbonate. Its values range from 7.1 mg/l to 28.4 mg/l. The chloride concentration of the water samples all are similar have 7.1 mg/l except the two lakes water samples, the average chloride concentration of the lakes is 21.4 mg/l.

The maximum concentration of sulfate in spring samples is with average concentration of 8.3 mg/l. Lake Hayk has minimum concentration of sulfates which has 0.8 mg/l.

The carbonate concentration is only recorded in the two lakes, i.e., carbonate concentration is not recorded or analyzed in water samples of springs, streams and boreholes samples. The other water chemical parameter analysis was also determined in this work like salinity, alkalinity and hardness their concentration is presenting in the following table.

**Table 5.3 Summary of hydrochemical results of samples collected from different water bodies**

Sampl es ID	PH	EC	TDS	Cl <sup>-</sup>	CO <sub>3</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	Na	Mg	Ca	K	Salinity	Alkalinity	Hardness
LH	9.1	956	462	28.4	24	366	0.8	199.2	63	8.8	19.8	0.5	340	320
LA	8.8	599	388	14.2	12	244	2	85.1	38.5	11.5	8.2	0.3	220	280
ST	7.3	617	296	7.1	-	268.4	1.4	76.1	30.3	1037.2	2.6	0.3	220	260
SP-1	6.6	569	272	7.1	-	214.7	9	96.9	24	266.8	13.5	0.3	176	240
SP-2	6.7	465	222	7.1	-	180.5	10	64.5	16.2	803.2	2.8	0.2	148	220
SP-3	6.8	643	306	7.1	-	219.6	6	305.5	85	767.4	14.4	0.3	180	280
BH-1	6.8	680	328	7.1	-	263.5	5	79.1	24	270.2	5.7	0.3	216	300
BH-2	7.2	558	267	7.1	-	244	3	85.6	26	63.8	8	0.3	200	240

The unit of TDS, Cl<sup>-</sup>, CO<sub>3</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, alkalinity and hardness is mg/l, EC is  $\mu\text{s}/\text{cm}$  and the Cation is ppm

- ✚ Total alkalinity, hardness measurements have been undertaken by titration method
- ✚ EC, TDS, Salinity measurements have been undertaken by conductivity meter Model 145
- ✚ Cl<sup>-</sup>: Titration (Mohr's method)

#### 5.5.4 Water type classification

An essential requirement in geochemical investigation is the compilation and presentation of chemical data in a convenient manner for visual inspection. Different commonly graphical methods are available. Among the different methods, piper diagram have been used for water type classification. It is the most common and widely used method which classifies water based on the percentage of miliequivalent per liter of major cations and anions.

The classification of surface water and groundwater in the study area is made on the basis of laboratory results of major cations and anions by using Aquachem version 4.0 software. Based on the Aquachem software hydrochemistry analysis water samples, the results show that the water resources in the study area are Ca-HCO<sub>3</sub>, Ca-Na-HCO<sub>3</sub> and Na-HCO<sub>3</sub>. The dominant cations are calcium and sodium whereas the leading an ions are bicarbonates. The type of lakes water in the study area is Na-HCO<sub>3</sub> and Ca-Na-HCO<sub>3</sub>. Ca-Na-HCO<sub>3</sub> water type is the water with calcium followed by sodium as the dominant cation and bicarbonate as the dominant anion. And also based on the analysis the dominant groundwater types in the area are Ca-HCO<sub>3</sub>. One surface stream water sample is similar to the groundwater types.

The formation of different water type found beneath underground is controlled by several internal and external factors. The main determinant factors are the chemistry of source water to be recharged (the source of recharge may be rain water, stagnant water, river water or



The quality of water is determined by the concentration of solutes present in the natural water. This quality of water is determined by analyzing a sample of its in laboratory.

The chemical water quality parameters include Total dissolved solids (TDS), electrical conductance (EC), hydrogen ion activity (PH), hardness, sodium adsorption ratio (SAR), and major, minor and trace ion constituents. The primary objective of water quality analysis is to determine the suitability or fitness of water for the intended use mainly for drinking and irrigation purposes.

#### **5.5.5.1 Drinking water quality**

Groundwater and surface water used for domestic purposes, such as drinking and cooking, should be free from toxic chemicals and pathogens. The selected different water samples and the analyzed results are important to compare with the WHO (2008) water quality standards for drinking. From these results they are different parameters to assess the quality of water whether it is fit for drinking or not.

##### **5.5.5.1.1 Total dissolved solid and PH of water**

Water has the ability to dissolve a wide range of inorganic and some organic minerals or salts such as potassium, calcium, sodium, bicarbonates, chlorides, magnesium, sulfates etc. These minerals produced unwanted taste and diluted color in appearance of water. WHO is recommended water quality for drinking purpose the concentration of total dissolved solid is up to 1000mg/l and the TDS concentration of the selected water sample in this work is between 222 mg/l to 462 mg/l. Therefore, all are acceptable for drinking hence they agree with WHO standards.

According to WHO standards pH of water should be in between 6.5 to 8.5 for drinking water. In study area, the PH values of lakes water sample ranges from 8.8 to 9.2 and it slightly above WHO standards and the remaining water samples are agree with this standards because there values are in between 6.5 to 8.5.

##### **5.5.5.1.2 Chloride and sulfate**

Chloride is mainly derived from the dissolution of salts of hydrochloric acid (HCl) as table salt (NaCl), NaCO<sub>2</sub> and added through industrial waste, sewage, sea water etc. According to WHO standards chloride concentration should not exceed 250 mg/l. In study areas the chloride concentration is very low it ranges from 7.1 to 28 mg/l and all values are under WHO standards.

Sulfate mainly obtained from the dissolution of salts of sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) and abundantly found in almost all water bodies. The WHO has established 400 mg/l as the highest desirable

limit of sulfate in drinking water. All the water samples of sulfate concentration of the study area are not beyond the standard and are safe for drinking purpose.

#### **5.5.5.1.3 Magnesium, calcium and sodium**

According to WHO standards the permissible range of magnesium in water should be 150 mg/l and collected and analyzed samples are agree with this standards.

Calcium is most abundant element on the earth crust and is very crucial for human cell physiology and bones. About 95% calcium in human body stored in bones and teeth. The high deficiency of calcium in humans may cause rickets, poor blood clotting, bones fracture etc. and the exceeding limit of calcium produced cardiovascular diseases, certain nervous system defects, prenatal mortality and various types of cancer. According to WHO (1996) standards its permissible range in drinking water is 200 mg/l. High Ca concentrations (hardness) in water may lead to formation of solid scales in pipes, encrustation of kitchen utensils and increased soap consumption.

In the study area the calcium concentration of lakes is from 8.8 and 11.5mg/l and one borehole sample shows 63.8 and the remaining samples are above the standards. For examples the Ca concentration of stream and average groundwater is 1037.2 and 526.9 mg/l respectively.

According to WHO standards, sodium concentration in drinking water is 200 mg/l. In study areas, finding shows that sodium concentration except one spring sample ranges from 64.5 to 199.2 and these values were under the permissible limit of WHO standards. One spring sample is exceeds the standard which is from the southern part of lake Hayk which has the sodium concentration of 305.5 mg/l.

#### **5.5.5.1.4 Hardness**

Hard water is characterized with high mineral contents that are usually not harmful for humans. It is often measured as calcium carbonate ( $\text{CaCO}_3$ ) because it consist mainly calcium and carbonates the most dissolved ions in hard water. According to WHO hardness of water should be 500 mg/l. In study areas, hardness ranges from 220 to 320 mg/l. These results clear that hardness of water is in according to the WHO standards and it is acceptable.

#### **5.5.5.2 Irrigation water quality**

The sustainability of irrigation based agriculture is dependent on both quantitative and qualitative aspects of water. That means adequate quantity of water supply with suitable quality is needed. Good quality water allows maximum yields consistent with proper soil and water management. There are several factors that have to appraise to determine the water

quality criteria for the irrigation utility. Among the most vital are the climate of the area, the kinds of crops grown, the methods of irrigation, the composition of water and soil and the topography of the land (Hoffman et. al., 2010). The study is made to evaluate the sustainability of the water for irrigated agricultural practice regarding to water quality aspect particularly in this section. The irrigation water qualities of the study area have been evaluated with respect to salinity hazard, sodium hazard and specific ion toxicity.

#### **5.5.5.2.1 Salinity hazard**

Natural water used for irrigation purpose can vary greatly in quality depending upon the type and quantity of dissolved salts. These salts are occurred with the water to wherever it is used. They originate from dissolution or weathering of the rocks and soil, dissolution of lime, gypsum and other slowly dissolved clay soil minerals. Salts can harm plants growth physically by limiting the uptake of water through modification of osmotic process. Its effects on soils can also cause changes in soil structure, permeability and aeration which indirectly affect plant growth. The salinity hazard of any water commonly expressed in terms of its TDS or EC values. According to FAO (1985) irrigation water quality guide line, water with TDS value less than 450 mg/l is non-salinity hazard, waters in range of 450 – 2000 mg/l are slight to moderate salinity hazard while waters greater than 2000 mg/l are considered as sever salinity hazard.

Water samples from different water sources (borehole, springs and lakes) have been collected and analyzed. Out of the analyzed eight water samples, all samples have TDS values below 450 mg/l except one lake sample.

Generally, the TDS values indicate that only types of water are identified in the catchment from all sources and this type of water is not hazardous and needs no restriction on use. Therefore, the water can be used for irrigation for almost all crops and for almost all kinds of soils. No soil or cropping problems will rise in using of water for these purposes.

#### **5.5.5.2.2 Sodium hazard**

Irrigation water containing large amounts of sodium is of special concern due to sodium effects on the soil and poses a sodium hazard. Sodium hazard is sometimes called Sodicity in some scholars like Ayenew (2013) to express the amount of sodium in soil and water with respect to calcium and magnesium ions. Sodium hazard is usually determined in terms of Sodium adsorption ratio (SAR). Sodium adsorption ratio (SAR) is calculated from the ratio of sodium to calcium and magnesium. It is an important parameter for determination of suitability of irrigation water quality. The allowable value of sodium adsorption ratio of the

soil water depends upon soil salinity, irrigation type practiced in the farmland, soil texture and clay minerals.

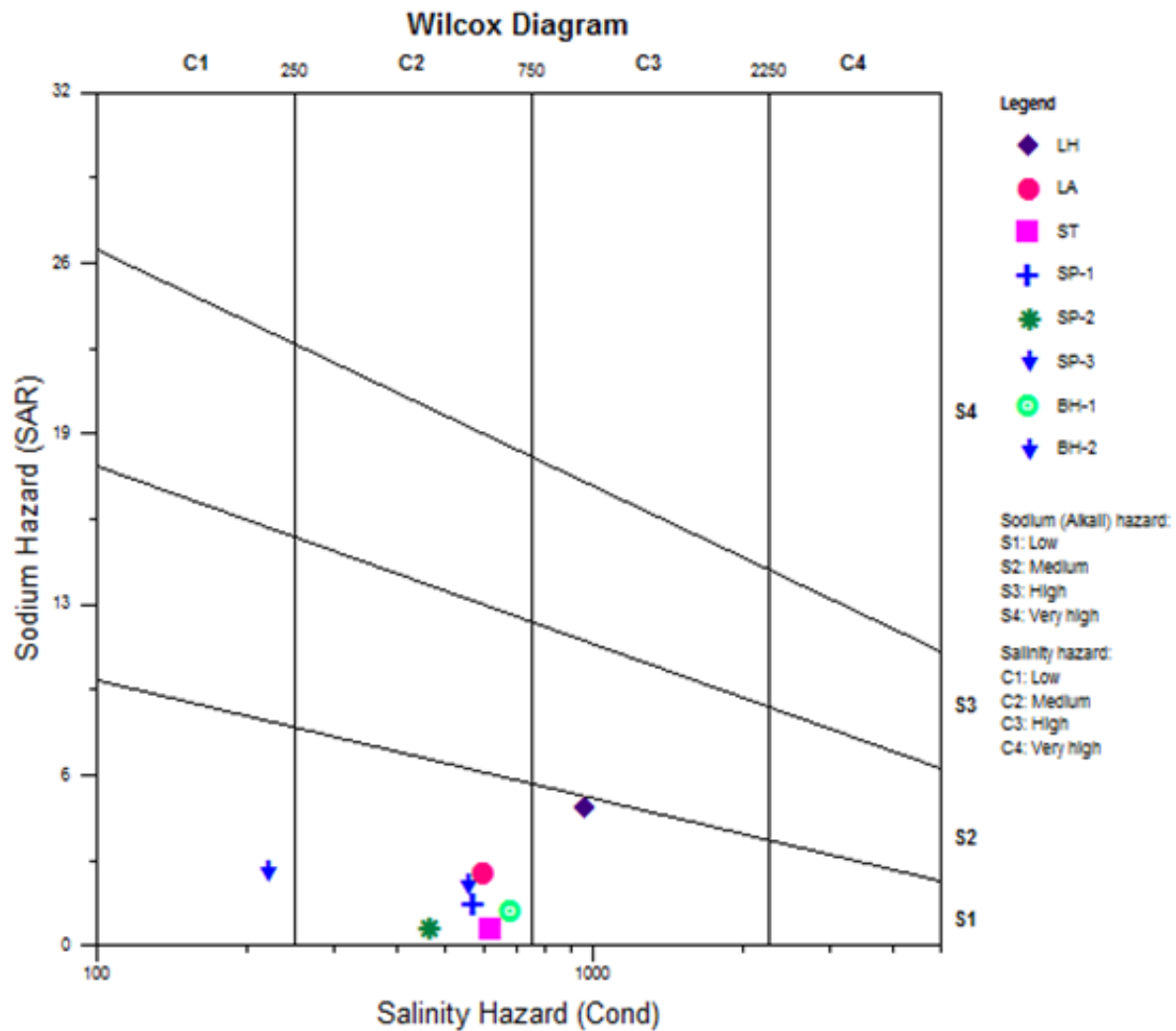
Continued use of water having a high SAR leads to a breakdown in the physical structure of the soil. Sodium in the irrigation water is absorbed and becomes attached to the soil particles as result pores and spaces between soil particles is clogged. The soil then converts in to hard and becomes compact when dry and increasingly impermeable to water penetration. Certain correction may be required to maintain soils under high SARs.

The sodium level in water used in irrigation is controlled by the absolute and relative concentrations of sodium (Na), calcium (Ca) and magnesium (Mg) (Hoffman *et al.*, 2010). The sodium absorption ratio (SAR) is calculated as the ratio of sodium ion concentration in meq/L to the under square root of the combined concentration of calcium and magnesium ions in meq/L per their valance number.

$$SAR = \frac{Na^+}{\sqrt{(Ca^{++} + Mg^{++})/2}}$$

Where, all ionic concentration is given in milliequivalents per liter (meq/L). SAR expressed in terms of low, medium and high for irrigation water quality analysis.

Wilcox plot using aquachem software is important for determination of sodium hazard in irrigation water quality classification graph using sodium hazard values indicating in the vertical axis and salinity hazard values indicating in the horizontal axis. Based on this plot the water samples collected analyzed in the study area are classified in low sodium absorption ratio and is suitable for irrigation.



**Figure 5.11 Irrigation water quality classification graph using sodium hazard and salinity hazard**

### 5.5.5.2.3 Toxicity

These problems occur if certain constituents in the soil or water are taken up by the plant, and accumulate to concentrations high enough to cause crop damage or reduced yields. It can also complicate salinity or water infiltration problem. The degree of damage depends upon the concentration by the toxic ion, crop sensitivity and the volume of water transpired by the crop. The constituents (ions) of primary concern are sodium and chloride damage results when the potentially toxic ions are absorbed in significant amounts with the water by the roots.

Chloride is the most common toxic ion that damages the irrigation of water. From the of FAO (1985) irrigation water quality guide line, water with chloride values less than 142 mg/l is non-toxic, waters in range of 142–343.5 mg/l are slight to moderate salinity toxic while waters greater than 343.5 mg/l are considered as sever toxic and causing soil and crop

problem. However, the concentration of the chloride values in collected water samples ranges from 7.1 to 28.4 mg/l and it categorized the first class and the water is can be used for irrigation. No soil or cropping problems will occur in using it.

### **5.5.6 Groundwater and Surface Water Interaction**

It is widely recognized that groundwater and surface water interact at a variety of spatial and temporal scales, there is highly dependent on meteorological, fluvial, anthropogenic and geological processes (Winter et al., 1998). Such interactions play a significant role in determining the quantity and hydrochemical composition of water bodies at both local and regional scales. Therefore, identifying locations and understanding mechanisms of groundwater and surface water interaction is vital for effective environmental management (Dahm et al., 1998).

Groundwater and surface water are highly interconnected in many landscapes streams, wetlands, and lakes can gain water from groundwater, lose water to groundwater; do either at different locations or at different times of the year. The relationship between groundwater and surface water largely depends upon the elevation of the water table relative to the elevation of the stream surface. Groundwater fed by rain and surface waters. Groundwaters ultimately discharge to surface waters or the sea. Surface water is fed by groundwaters. Surface and groundwaters form parts of one interlinked system.

Groundwater and surface water are not isolated components of the hydrological cycle; they interact in a range of topographic, geologic and climatic landscapes (Sophocleous, 2002; Winter *et al.*, 1998).

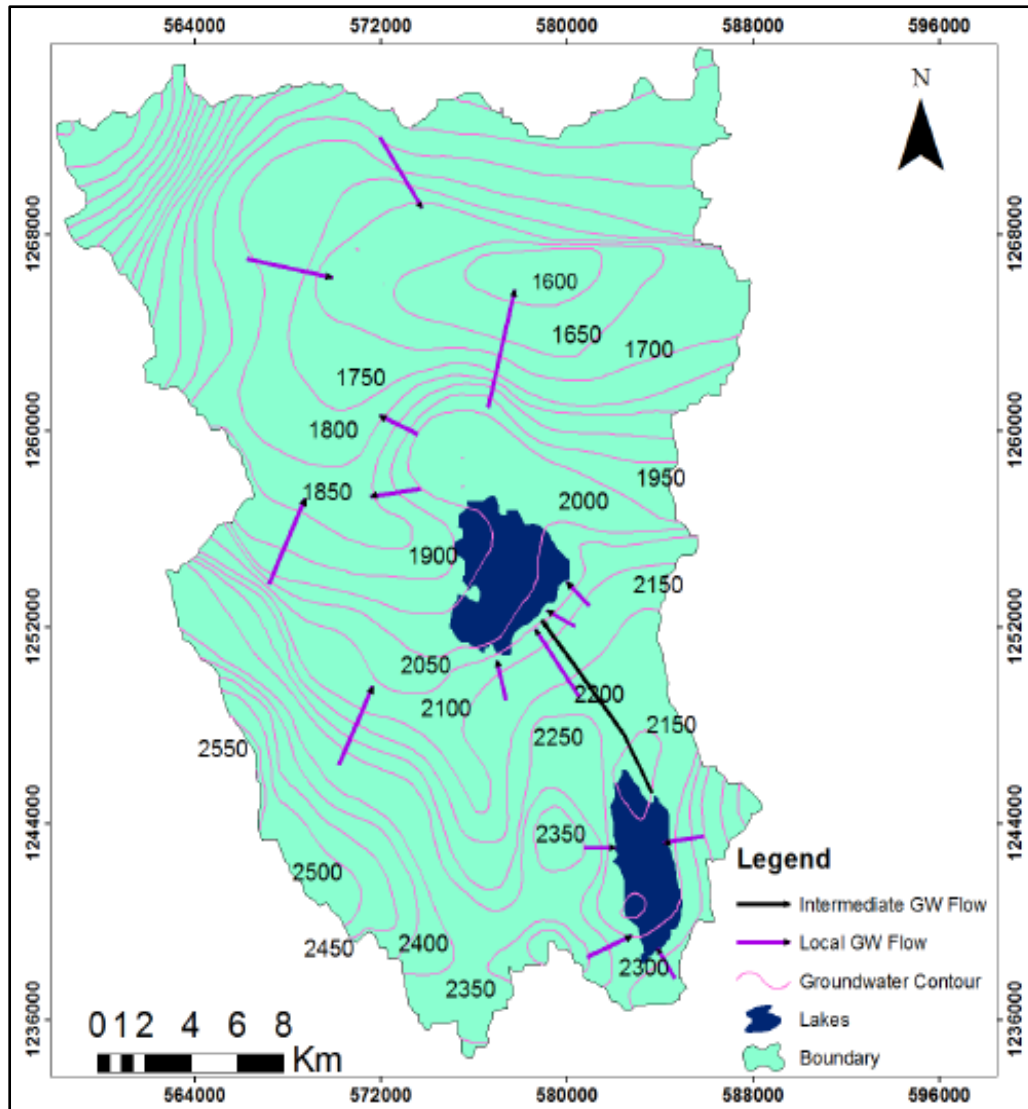
Joints, fractures, and solutions openings provide avenues through which groundwater flow is channeled (Kiersch and Hughes, 1952). Minor fault and major fracture traces are favorable sites for groundwater flow in the Hayk-Ardibo catchment.

It might be possible to deduce from field observation of geological, hydrogeological and geomorphologic evidences that the two lakes are hydraulically connected. The two lakes are surficially connected by Ankerka river and moreover large faults trending NNE, NNW and E-W create favorable condition for groundwater movement from Ardibo catchment towards lake Hayk. It is evident that lake Ardibo gets substantial groundwater from the west through E–W running faults and from the south. This can be easily observed from the appearance of fault-controlled springs. It loses groundwater to the north towards lake Hayk. The presence of large N–S running faults parallel to the axis of the graben favours the seepage of groundwater out of lake Ardibo.

The interaction between surface and groundwater in the study area is evident in that both lakes and groundwater recharge interact one another. In relatively elevated areas where lake ardibo is situated, there is a 231 m elevation difference between the two lakes, due to the influence of hydrogeological (both structure and permeable rock units) groundwater is recharging through the lake in its north eastern shore probably for the contribution of the intermediate flow system towards lake Hayk. There is also shallow groundwater input to this lake but the amount of groundwater that enters the lakes is influenced by irrigation activities in the catchment. In topographically low area like lake Hayk, the lake groundwater interaction is such that the groundwater contributes to these lakes with.

Groundwater contour map is generated from field measurements of static water level of spings, hand dug wells and deep wells in order to understand the flow direction. In most parts of the area the groundwater level distribution is similar to the topography, which follows the elevation variations. The general trend of groundwater flow is towards the depressed flat topography from the surrounding hilly landscapes. The groundwater flow is almost in the same direction with that of surface flow. The local groundwater of the study area is the movement and flow direction is dependent on the inclination of the topography of the area. Intermediate groundwater flows from Ardibo sub catchment to the Hayk sub catchment that is recharging lake hayk.

The water table elevation in the catchment of Hayk and Ardibo lake is defined by around 2000 and 2300 m a.m.s.l respectively. The lowest water table elevation is in lake Hayk catchment. According to Julius and Merrious (2010, cited in Buddemerier and Schloss, 2000) groundwater flows from the highest contour elevation to the lowest in the direction perpendicular to the contour line. The contour map revealed that groundwater flows downward from the north eastern in a higher hydraulic head towards to north located within the location lower hydraulic head close to lake Hayk. The groundwater generally flows from the Ardibo lake catchment to lake Hayk catchment and as it indicates from the groundwater contour map and this show that the two lakes are hydraulically connected.



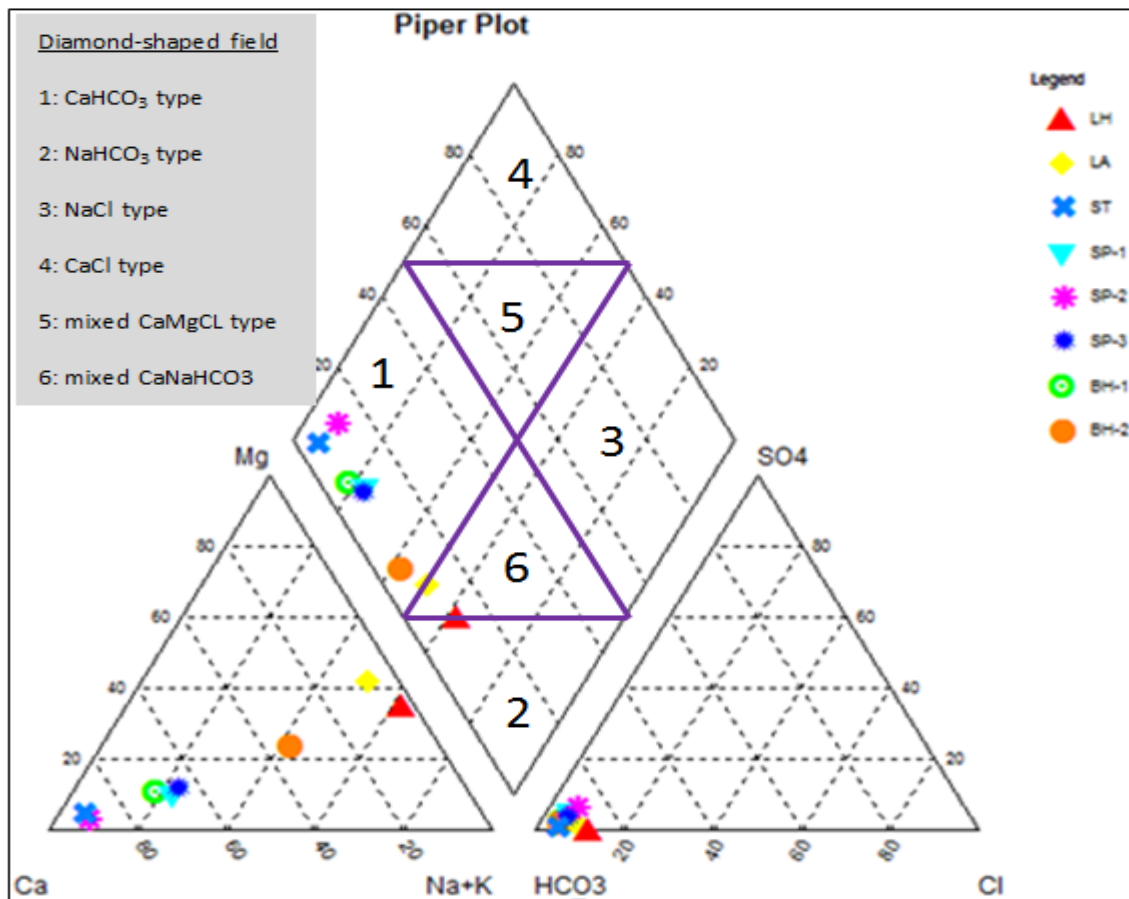
**Figure 5.12 Groundwater water flow directions**

Numerous studies suggest that similarities in water composition between neighbouring groundwater and surface water bodies, such as ion ratios or the concentration of total dissolved solids, can be used to qualitatively or statistically show potential groundwater and surface water interaction (e.g. Burden, 1982; Kumar et al., 2009; Taylor et al., 1989). From the chemical analysis of the collected water samples the TDS and EC value of the lake Ardibo is 599  $\mu\text{s}/\text{c}$  and 388  $\text{mg}/\text{l}$  and lake Hayk is 462 and 956 respectively. The average TDS and EC value of the analyzed spring's water is 559  $\text{mg}/\text{l}$  and 267  $\mu\text{s}/\text{c}$ . To infer whether the groundwater or the surface water interact to each other.

The dominance of the major ions is as  $\text{Ca} > \text{Na} > \text{Mg} > \text{K}$  for cations and  $\text{HCO}_3^- > \text{Cl}^- > \text{CO}_3^{2-} > \text{SO}_4^{2-}$  for anions. The orders of ions are the same for groundwater as well as surface water. The piper diagram clearly shows that the waters are plotted in two distinct zones: (1) Surface water (lakes and the river stream) and (2) groundwater (the springs and borehole). The

diamond diagram shows that six out of eight different water samples fall into field one (1) and the types of water in this field is  $\text{Ca-HCO}_3$ . The Ardibo lake water type is closed to field six (field 6) the type of water is  $\text{Ca-Na-HCO}_3$ , whereas the Hayk lake is more closed to field two (2) and the water type is  $\text{Na-HCO}_3$ .

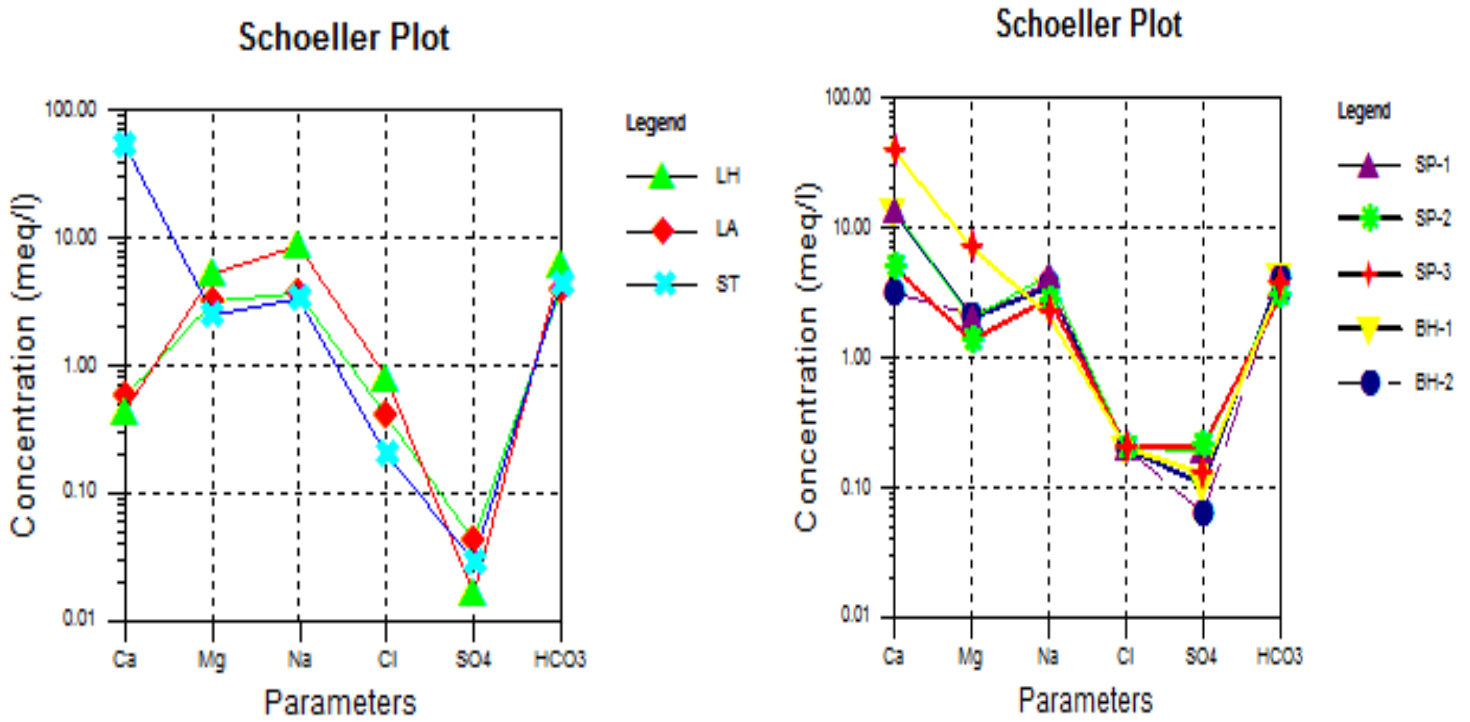
The river water sample which is flowing towards lake Hayk has similar water type with the groundwater and this indicates that the surface water and groundwater is interact to each other. Piper plots of surface water and groundwater indicate that samples can be classified as a bicarbonate type.



**Figure 5.13 Piper diagram**

Scholler diagram also plotted using aquachem software is important between nearby surface water and groundwater samples. This diagram represents concentration of major ions in  $\text{meq/l}$ . Surface water and groundwater concentration of major ions plotted show that wherever there is rise in ion concentration in surface water, there is also rise in concentration of that particular ion in groundwater and wherever there is fall in ion concentration in surface water there is also fall in concentration of that particular ion in groundwater. The groundwater and surface water characteristics in the area are similar as they show same type of variation in major ion concentration. This implies that the surface water and groundwater

quality is almost similar. The similarity in the percentage of major ions and cations between the surface water and groundwater indicate that they are interrelated.



Figures 5.14 Schoeller diagram

## CHAPTER SIX

### 6. CNCLUSION AND RECOMMENDATION

#### 6.1 Conclusion

Most of the inland water bodies are confined within the Ethiopian Rift Valley, forming the spectacular lakes region, with the exception of the largest lake, lake Tana, in the highlands. There are also quite a number of crater lakes in the highlands and the rift escarpments. One such lake system is Hayk and Ardibo which is the study area situated in an elongated intermountain graben near the edge of the western escarpment of the Afar Rift in north-eastern Ethiopia. The general objective of this research is evaluating the groundwater and surface water dynamics to evaluate sustainability of water consumption in lake Hayk and Ardiabo basin.

The groundwater contour map indicates that the groundwater generally flows from the Ardiabo lake catchment to lake Hayk catchment and this show that the two lakes are hydraulically connected. Surface water and groundwater concentration of major ions plotted in Scholler diagram show that wherever there is rise in ion concentration in surface water, there is also rise in concentration of that particular ion in groundwater and wherever there is fall in ion concentration in surface water there is also fall in concentration of that particular ion in groundwater.

Mean annual amount of recharge, evapotranspiration and surface runoff were estimated by WetSpass model and their values are 257.5 mm, 525mm and 438.5 mm respectively. Evapotranspiration is the principal cause of water loss from precipitation and is very high in the Lakes. The highest groundwater recharges occur in the study area is in gentle or flat, cultivated and vegetated (forest and shrubland) area and sandy loam soils and low recharge clay and steeply slope area. The sum of mean annual recharge, mean annual evapotranspiration and mean annual runoff is 1221.21.mm and the mean annual precipitation or rainfall in the study area is 1167.9 mm. This value indicates that the precipitation is less than the total sum of simulated groundwater recharge, evapotranspiration and runoff in the area. The water balance component which is computed from the WetSpass model in annually is not equal or approximately equal to the source of mean value precipitation.

Based on the Aquachem software hydrochemistry analysis water samples, the results show that the water resources in the study area are Ca-Na-HCO<sub>3</sub>, Na-HCO<sub>3</sub> and Ca-HCO<sub>3</sub>. From

the chemical analysis of water samples almost all parameters are within the recommended limits for drinking and irrigation purpose.

The groundwater contour map indicates that the groundwater generally flows from the Ardibo lake catchment to lake Hayk catchment and this show that the two lakes are hydraulically connected. Piper plot shows that both groundwater and surface water have the same chemical ratios indicating the interaction between the groundwater and surface water. Surface water and groundwater concentration of major ions plotted in Scholler diagram show that wherever there is rise in ion concentration in surface water, there is also rise in concentration of that particular ion in groundwater and wherever there is fall in ion concentration in surface water there is also fall in concentration of that particular ion in groundwater.

## 6.2 Recommendations

Accurate evaluation of the groundwater recharge and identifying the groundwater and surface water interaction is essential for sustainable planning of the water resource. The accuracy of the groundwater and surface water interaction in the study area could become better through further research. On the other hand, the results acquired in this work will need to be complemented by further detailed investigations at a local scale to allow a proper water management. Soil and water conservation has to be implemented to reduce runoff and enhance the recharge capacity of the catchment. To prevent land degradation, erosion and siltation of the existing lake, the yearly expansion rate of agricultural farm land has to be decreased and rational land use in the catchment should be promoted. The awareness of the communities has to be increased through providing effective land and lake management trainings and preparation workshops dealing on water utilization. Commitment to involve community members and local institutions in the management and conservation of natural resources must be implemented. Community participation is very essential for resource management as many natural resources have been degraded due to exclusion of the resource users in decision making and management systems.

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**Appendix Springs and Bore Holes Data**

Site Name	X	Y	Elevation(Z)	Actual user	Standards	Discharges
Geta Ager	573135	1239742	2562	161	170	0.07
Mofa	573684	1240194	2583	153	170	0.23
Ababofa	574954	1236163	2432	132	170	0.28
Ager Chora1	576986	1232609	2079	130	170	0.31
Ajo	577730	1239526	2311	165	170	0.3
Ketro ager	577320	1244057	2122	138	170	0.35
Meslo1	576195	1247091	2024	100	170	0.25
Meslo2	575124	1248248	1983	170	170	0.68
Mesal	570523	1242099	2592	155	170	0.06
Tengego1	571058	1242031	2527	160	170	0.06
Tengego2	569751	1243844	2448	155	170	0.5
Tengego3	569686	1243793	2447	200	170	0.26
Sheshegut	567076	1244769	2743	181	170	0.8
Godiguadet1	568326	1242928	2570	160	170	0.24
Korie	575355	1244168	2132	135	170	0.14
G.Gebisa	575417	1246706	2009	125	170	0.11
Berity	582933	1246892	2139	170	170	0.06
Sholaw1	581684	1250677	2265	190	170	0.12
Eilaw	582035	1249809	2201	188	170	0.07
Chikaw	582631	1244905	2133	133	170	0.1
Ehudit	582403	1247770	2236	130	170	0.123
Kedida	582598	1248556	2260	170	170	0.35
Semebo	582340	1249665	2232	169	170	0.6
Terateseso	583724	1244998	2145	135	170	0.32
Hawrit	584230	1245596	2143	190	170	0.22
Alayu1	582747	1247028	2134	183	170	0.99
Alayu2	552645	1246122	2099	180	170	0.65
Dergit	552244	1247190	2143	130	170	0.15
Zawyiu	585146	1247001	2100	190	170	0.5
Eyileyou	581599	1243155	2164	168	170	0.58
Aselele	581569	1236921	2031	181	170	0.01
Ardibo S/ool	581394	1244848	2157	600	170	0.88
Feyane Kelbie	578854	1250613	1938	120	170	0.3
Hitaw	580510	1249282	2189	131	170	0.01
Godiguadet2	574011	1256312	1946	180	170	0.3
Mercha2	575158	1254523	1922	170	170	0.3
Nolie	575177	1256387	1913	190	170	0.3
Burka2	573708	1262940	1592	181	170	0.083
Burka3	573676	1262936	1595	175	170	0.026
Burka4	573654	1262895	1598	160	170	0.3
Burka5	573630	1262902	1593	181	170	0.5
Burka6	573604	1262930	1596	185	170	0.06
Kistanie1	576236	1225650	1563	220	170	0.4

Segelen S/ool	576600	1262804	1590	180	170	0.1
Kistanie2	577156	1262722	1624	180	170	0.08
Alhasto	582285	1239478	2166	179	170	0.06
Kelfaw	582435	1240995	2142	165	170	0.2
Borso	582349	1240320	2140	200	170	0.32
Delmo S/ool	582239	1238599	2153	180	170	0.12
ehudite	583321	1247333	2135	165	250	0.83
Chama	581175	1244081	2130	289	250	0.4
Chore	576346	1243949	2122	190	250	0.1
Telekecha	577216	1248183	2089	186	250	0.076
Miregiso	576251	1243615	1995	356	250	0.43
ehude gebya	58270	1249598	1174	187	250	0.04
harewa	609459	1193404	1471	200	250	1.1
Balchi	604707	1115410	1149	219	250	0.54
balchi2	605272	1112890	1173	209	250	0.4
jarota	576794	1294486	1537	175	250	0.21
kichicho	613895	1172141	1543	230	250	0.065
mersa	576148	1288640	1491	344	250	0.45
shewa robit	595028	1103365	1254	161	250	0.1
ababoru	518466	1226808	3052	189	250	0.03
genete	502096	1194229	2467	321	250	0.76
Ketie	573825	1249284	1961	2530	250	4.6
Bishanako	574157	1248850	2012	1976	250	3
Bededo	574482	1238527	2345	555	250	0.36
Biraro	576262	1237451	2290	184	250	0.12
Abarabo	574741	1239348	2333	188	250	0.26
Biraro Lay						
Genda	576978	1238166	2407	191	250	0.17
Ararsa	573684	1240194	2583	140	250	0.08
Debo	574447	1234375	2146	202	250	0.81
Duchi	575445	1232077	2120	200	250	0.11
Ager Chora2	574364	1232507	2051	240	250	0.31
Ageda Meder	575871	1237041	2292	205	250	0.089
Korkia	576947	1233889	2231	180	250	0.12
Emehina	578378	1234333	2132	265	250	0.08
Korneguse	578564	1234972	2163	248	250	0.087
Ayelo	578182	1233912	2120	219	250	0.15
Chise Weha	576361	1233371	2303	204	250	0.12
Tachi Wolde	575646	1231337	2053	183	250	0.56
Aje	577620	1238942	2346	190	250	0.67
Lewecho	577536	1242805	2162	194	250	0.87
Mekerecho	578169	1242207	2264	197	250	0.045
Galisa	578177	1236558	2262	190	250	0.14
Gole Weha1	579466	1236115	2311	180	250	0.121
Ahmed Ager	580517	1236558	2260	187	250	0.15
Esimano	576582	1242801	2166	189	250	0.13

Keryou	548389	1235856	2204	200	250	0.162
Chatu Meda	578642	1239905	2442	192	250	0.09
fuafoatie	578245	1238920	2437	180	250	0.089
Keberite	578272	1239114	2399	123	250	0.086
Jegaro	578218	1236711	2257	180	250	0.16
Tachi Kosro	578225	1235051	2394	176	250	0.18
Abadegma	579145	1235297	2198	173	250	0.56
Berye	577825	1241769	2145	180	250	0.84
Sheh Musa	578452	1241860	2001	210	250	0.45
Qosro	578225	1238051	2394	185	250	1
Tekersho	579692	1235622	2193	180	250	0.6
Deledalie	578442	1241850	2307	169	250	0.52
Ismano	576778	1243368	2113	180	250	0.99
Ademie Ager	578469	1238430	2450	600	250	0.125
Shegura	577581	1245051	2131	181	250	0.12
Werkie Weha	577328	1243795	2151	190	250	0.31
Borden	578806	1274734	2316	85	250	0.153
Golbo	599053	1241189	2671	170	250	0.2
Abawoldu	577115	1244431	2104	160	250	0.056
Deka	576587	1240751	2008	190	250	0.08
Ababuyit	599053	1241189	2671	180	250	0.3
Alemayehu	576918	1245659	2072	170	250	0.55
Tegugunbie	576651	1258691	2210	200	250	0.4
Hita	579270	1242390	2565	379	250	0.039
Abateklie	577581	1245051	2131	380	250	0.3
Jaleager	579630	1243133	2667	180	250	0.06
Bereden	578806	1274734	2316	172	250	0.1
Minchu	578221	1244740	2502	188	250	0.17
Mintewab	577115	1244431	2104	200	250	0.5
Gojam	577115	1244431	2104	320	250	0.52
Sholaw2	576910	1244501	2015	198	250	0.23
Kurkurie	576372	1245140	2052	197	250	0.1
Bosena Gedera	576451	1244591	2203	200	250	0.15
Chorie	576486	1243529	2158	184	250	0.039
Jal Ager	579659	1243341	2595	545	250	0.4
Keyi Afer	578208	1246009	2232	200	250	0.12
GederaBosena	580024	1242555	2634	100	250	0.2
Abanefsie	579025	1247575	2238	169	250	0.12
Welawela	579025	1247559	2237	145	250	0.51
Meregiso	577021	1246635	2075	231	250	0.6
Abafelka	577120	1247601	2101	200	250	0.12
Chachito	570453	1252514	2318	185	250	0.26
Kulkualo	577234	1249181	2059	176	250	0.16
Siba Ager	573612	1251241	2105	169	250	0.156
Zebedeso	576855	1247621	2046	179	250	0.14
Gumbie	576612	1250123	2056	110	250	0.05

Ababorsho	577790	1246070	2134	190	250	0.19
Teraraw	578969	1247729	2207	180	250	0.11
Samato	577089	1247276	2059	190	250	0.2
Merfo	578234	1246491	2231	188	250	0.31
Qeyi Afer	578310	1246153	2230	188	250	0.98
Fusa	577160	1246272	2077	328	250	0.89
Abatebie	578303	1246153	2228	170	250	0.05
Ketie Weha	577636	1247304	2212	170	250	0.78
Tenegego	568177	12433583	2574	389	250	0.065
Kulmbie	571764	1243836	2409	185	250	0.32
Shembekit	568177	1243583	2574	180	250	0.069
Eilawe	572315	1243351	2630	200	250	0.05
Sholaw	574604	1242810	2204	186	250	0.3
Golbw	573057	1245243	2296	200	250	0.098
Gundie Ager	577348	1246380	2141	184	250	0.122
Aba Eyasu	574066	1241733	2318	181	250	0.15
Kobochi	575002	1243835	2092	200	250	0.22
Geshen	573367	1243669	2359	139	250	0.032
Lekolie	574495	1245092	2299	158	250	0.05
Dubedabie	577429	1241744	2287	184	250	0.12
Metekatie	576329	1242810	2422	175	250	0.31
Abagezaw	573367	1243669	2359	174	250	0.23
Hitaw	572610	1235622	2193	187	250	0.3
Biderso	573179	1248429	2073	168	250	0.22
Abalima	573316	1246619	2162	200	250	0.09
Siba	572590	1247635	2207	140	250	0.5
Godiguadet	570546	1245307	2352	181	250	0.165
Dermariya	571786	1244634	2359	178	250	0.21
Arobert	571871	1245201	2314	170	250	0.4
Gumbiee	572259	1248072	2150	185	250	0.36
Fuafuatie	572302	1248083	2141	175	250	0.05
Weliso	573516	1246885	2125	180	250	0.69
Ebahoyigenda	572938	1249127	2062	155	250	0.12
Mida	572304	1246654	2234	166	250	0.11
Deremariya	571978	1244710	2366	170	250	0.11
Kedi da	583757	1246882	2125	178	250	0.3
Gorbira	582923	1246882	2127	450	250	0.22
Sholaw/Chama	581584	1249679	2179	170	250	0.11
Chama	581075	1245084	2164	160	250	0.33
Ababie Shrie	582384	1249183	2143	200	250	0.25
Wesha ameba	580975	1247564	2239	190	250	0.1
Zaweya1	584145	1246009	2123	120	250	0.13
Ehudite	581635	1246632	2169	200	250	0.06
Aleketu	581275	1247838	2235	180	250	0.15
Zaweya2	580604	1247255	2311	190	250	0.16
Sholaw	581177	1248205	2215	250	250	0.55

Alayu	582648	1248027	2130	159	250	0.05
Soka	580354	1245578	2288	180	250	0.35
Konekona	581075	1243945	2239	200	250	0.21
Ababisa	581094	1244331	2191	250	250	0.14
Dema	580642	1244421	2230	190	250	0.4
Yasin ager	581734	1246200	2125	180	250	0.083
Folkie	581633	1245237	2150	188	250	0.25
Gobden	581376	1244921	2163	190	250	0.02
Teru Weha	581331	1242724	2211	188	250	0.25
Konkona	581378	124367	2233	185	250	0.3
Hawasw	581765	1246316	2158	200	250	0.06
Gashu ager	581408	1245957	2180	185	250	0.07
Ababisa ager	581717	1244658	2146	190	250	0.05
Degelalit	581331	1242724	2111	189	250	0.41
Huneda	580448	1241588	2357	200	250	0.145
Aweliya	580499	1245249	2269	255	250	0.88
Abawasie	580516	1243575	2474	275	250	0.254
Esetena	576325	1250685	1937	190	250	0.3
GaredawWeha	579045	1248157	2144	200	250	0.22
Racha	579334	1249487	2015	190	250	0.52
Abadima	580626	1249955	2105	130	250	0.25
Godeguadet	580337	1249658	2043	180	250	0.26
Ababona	579752	1248809	2117	120	250	0.2
Bode	580552	1250187	2044	190	250	0.2
Ababisa	580510	1249282	2144	175	250	0.3
Abesha ager	580554	1248427	2189	200	250	0.05
Shelekow	580525	1249748	2088	130	250	0.07
Arabie	578216	1248321	1990	180	250	0.13
Dawecha	571970	1252200	1881	170	250	0.3
Qilaw	573274	1257644	1950	180	250	0.2
Burkite	571271	1257427	1574	185	250	0.05
Muna Weha	571537	1255849	1693	190	250	0.2
Molties	571016	1248157	2121	100	250	0.1
Abago	569240	1250378	2055	140	250	0.06
Medaw	568986	1251468	2033	180	250	0.12
Tegu	570785	1249804	2098	170	250	0.1
Mezoriyaw	568541	1249131	2210	160	250	0.25
Wersega	570975	1245040	2283	600	250	0.6
Tabore	570554	1248653	2083	190	250	0.12
Medawe	570086	1246945	2264	200	250	0.26
Zebetatie	569711	12505112	2019	180	250	0.16
Aferatege	572070	1248955	2046	200	250	0.17
Menchu	568740	1250796	2057	190	250	0.14
Gorehita	568720	1252195	1949	184	250	0.05
Werelega	570417	1246060	2251	130	250	0.18
Guadal	571408	1250006	1981	180	250	0.017

Guada2	571821	1249850	1948	145	250	0.31
Arekisa	569844	1246955	2310	130	250	0.03
Gurebiyaw	568499	1252336	1954	200	250	0.99
Jarietis	568448	1248969	2197	1500	250	1
Yejochigen	570631	1249091	2090	225	250	0.7
Kekte	573888	1250306	2002	180	250	0.1
Chefie	574210	1254378	1870	200	250	0.12
Lemite	576939	1258823	1900	200	250	0.09
Bishangarie	576149	1258832	1869	185	250	0.08
Lucie	5744849	1257808	1820	180	250	0.21
Biserese	574207	1252995	1885	162	250	0.11
Soba	574681	1257627	1889	302	250	0.33
Korekoro	573980	1253795	1866	200	250	0.21
Melkusite	576549	1258645	1921	430	250	0.04
Sekela	571395	1262039	1711	170	250	0.087
Tachberka	579150	1263016	1552	2335	250	0.1
Leyiman	579624	1263555	1543	182	250	0.069
Lechesema	577156	1262722	1625	175	250	0.097
Gishen	578702	1260263	1844	160	250	0.167
Kualo	578184	1264809	1464	188	250	0.2
Motie	578673	1259085	1904	179	250	0.154
Delemo	582325	1239673	2148	189	250	0.047
Amedeager	582218	1239841	1950	375	250	0.3
Alahseto	582285	1239478	2166	200	250	0.058
Ababuda ager	581099	1236855	2245	180	250	0.08
Mucha	582364	1237252	2150	190	250	0.13
Chacha	582654	1235565	2185	200	250	0.1
Legegema	582285	1241588	2232	187	250	0.11
Gedera	580719	1238741	2354	175	250	0.2
Entereto	580739	1239285	2344	195	250	0.054
Nermertu	580122	1239836	2446	200	250	0.82
Godo	579983	1233363	2463	80	250	0.5
Boresho	580777	1241166	1850	170	250	0.8
Haroye	580825	1238023	2443	184	250	0.2
Bele	579886	1237969	2456	178	250	0.083
Minchu	582050	1236115	2188	160	250	0.32
Mekejaw	581693	1239673	2197	170	250	0.51
Jemeduager	580746	1236911	2257	175	250	0.078
Gorecheretu	580739	1239285	2344	180	250	0.2
Kobaw1	581496	1237815	2377	160	250	0.13
Abakolo	581345	1236195	2190	172	250	0.5
Deriesa	580728	1240204	2266	122	250	0.41
Jerejero	579886	1237969	2456	180	250	0.53
Gorchirtu	580728	1240204	2266	172	250	0.056
Haroie	580844	1238689	2464	170	250	0.3
Qotu	580683	1239245	2457	100	250	0.414

Hameza weha	580212	1236879	2338	335	250	0.3
Weyine	580148	1237364	2352	304	250	0.4
Gita	565540	1246674	2625	175	250	0.11
Werkalu	568729	1245544	2424	127	250	0.23
Aregaya1	568187	1246722	2345	170	250	0.12
Lankiso	566684	1247849	2542	180	250	0.2
Imehina	569144	1246133	2312	150	250	0.2
Amaregenda1	568044	1245309	2498	120	250	0.5
Amaregenda2	568015	1246028	2478	385	250	0.68
Tega ameba	567093	1247654	2494	190	250	0.65
aba negashe	566625	1245651	2203	170	250	0.55
Nibo	568057	1244925	2522	160	250	0.31
Horjie	567926	1247716	2281	175	250	0.082
Gitadebru	565992	1246542	2655	169	250	0.2
Telaset	565684	1248524	2685	120	250	0.5
Aregaya2	568064	1246721	2381	180	250	0.36
Amaregenda3	568218	1246447	2358	150	250	0.88
Baguncher	568558	1244821	2476	115	250	0.04
Tafachi	568421	1245932	2384	120	250	0.55
Kobaw2	568390	1246138	2348	120	250	0.05
Abatashu	566498	1247320	2731	250	250	0.09
Welienso	566045	1248523	2572	200	250	1
Eilaw	580227	1262571	1551	150	250	0.05
Mutiebelge	579340	1258530	2015	155	250	0.04
Hudadie	580541	1260613	1812	120	250	0.21
Robelie	579485	1260359	1703	170	250	0.099
Eregoye	580802	1259204	1942	165	250	0.14
Welawla	580813	1259102	1991	156	250	0.31
Kundea	579788	1258066	2154	145	250	0.09
Werekeamba	580172	1255898	2039	130	250	0.12
Guadeguadie	580850	1260115	1896	165	250	0.078
Fesadie1	579300	1258611	1904	180	250	0.23
Temuga	580711	1260787	1696	155	250	0.05
Fesadie2	580995	1261184	1654	169	250	0.13
Gumejo	580423	1256591	1996	145	250	0.061
Abasheh	530010	1232114	2303	176	250	0.06
Fesadin	579307	1259205	1846	145	250	0.23
Posmilie1	572742	1255050	1836	150	250	1
Bededomemcha	574490	1260167	2810	180	250	0.6
Gadite	578245	1238920	2437	154	250	0.34
Mekercho	578005	124380	2216	231	250	0.5
Muma qosero	578417	1238083	2460	167	250	0.09
Hitacha	574445	1243420	2161	234	250	0.2
Ehudite	582303	1246770	2138	321	250	0.31
Bishankalu	576312	1262804	1590	176	250	0.08