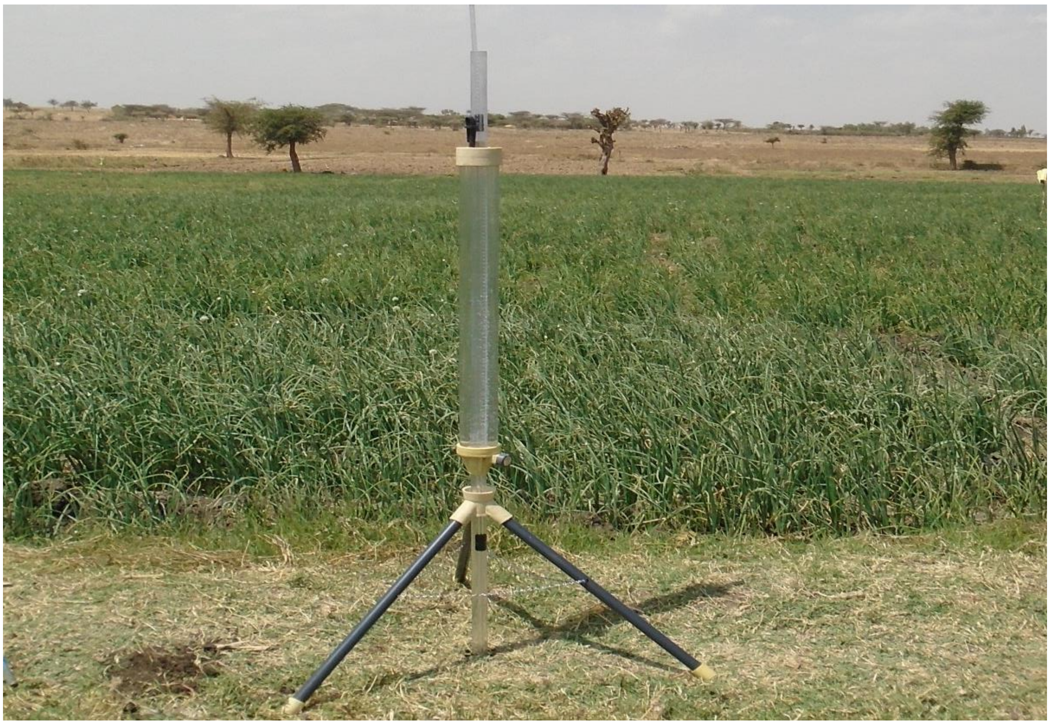
Groundwater dynamics and aquifer characterization of the shallow aquifers of Becho and Koka area

A Thesis submitted to School of Earth Sciences



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

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Signature page

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This is to certify that the thesis prepared by **Alemu Mesele**, entitled: *Groundwater dynamics and aquifer characterization of the shallow aquifers of Becho and Koka area* and submitted in partial fulfillment of the requirements for the Degree of Master of Science (Hydrogeology) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Acronyms and Abbreviations

AA	Addis Ababa
ATA	Agricultural Transformation Agency
BF	Base Flow
BFS	Base flow separation
DEM	Digital Elevation Model
EC	Electrical Conductivity
EVDSA	Ethiopian Valleys Development Studies Authority
GNIP	Global Network of Isotopes In Precipitation
GSE	Geological Survey of Ethiopia
HDW	Hand Dug Well
IAEA	International Atomic Energy Agency
ITCZ	Inter Tropical Convergence Zone
Kfs	Field Saturated Hydraulic Conductivity
m.a.s.l	Meter above Sea Level
MBF	Mean Base Flow
MRF	Mean River Flow
MSRO	Mean Surface Runoff
SAR	Sodium Adsorption Ratio
SWL	Static Water Level
T	Transmissivity
TDS	Total Dissolved solids
TF	Total Flow
USDA	U.S. Department of Agriculture
WHO	World Health Organization
WWDSE	Water Works Design and Supervision Enterprise

Abstract

The present study area is located in upper Awash river basin, in central part of the country, which covers a total area of about 2780 Km^2.The elevation ranges from 1519 to 2300 m.a.s.l. Becho and Koka areas were the focused areas for this specific research. The main objective of the present study was to provide detail information on the groundwater flow and characterize the shallow aquifers of Becho and Koka areas which will be vital information for future sustainable use of the groundwater resource.

From long term mean monthly rainfall data, Becho and Koka areas receive 1141.6 and 914.4 mm mean annual rainfall respectively. Flow records at, Teji and Modjo river; Awash river at Hombole and Bello were selected for estimating recharge by BFS. Results from BFS by using excel spreadsheet program showed that the mean annual recharge for Becho and Koka areas were found to be 79 mm and 104.1 mm respectively. Based on groundwater level and TDS contour map the local groundwater flow direction in Becho area is tends to be the main Awash river. Whereas local groundwater flow direction in Koka area is tends to be towards lake koka. The average estimated soil field saturated hydraulic conductivity in Becho and Koka areas are 0.000421 and 0.00107 cm/sec respectively. In Becho area medium field saturated hydraulic conductivity values are come from due to the presence of alluvial deposits during the wet season, which covers the most upper parts of the soils. While in koka area the soil has medium to high field saturated hydraulic conductivity, since the area has primary porosity due to dominated by the lacustrine deposits. Hydrochemical study indicated the presence of two major water types in the study area. These are Ca-HCO3 and Na-HCO3. The Ca-HCO3 is dominant in Becho area, while Na-HCO3 is dominant in Koka area. Using SAR values in USDA (1954) groundwater classification, in Becho and Koka areas the shallow groundwater has been classified as excellent and good for irrigation purpose respectively. In both areas, the stable isotopes signature of the Hand dug well water characterized by depleted isotopic signature. From the result of isotopic signature, the recharge for depleted hand dug well water is from the precipitation. In Becho and Koka areas are estimated transmissivity values range from 0.03 to 19.70 m^2/d and 0.97 to 57.27m^2/d respectively. Because of the lacustrine deposits, Koka area has relatively high transmissivity values compared to Becho area.

Key words: Aquifer characterization, Field saturated hydraulic conductivity (Kfs), Groundwater dynamics, Hand dug well, Upper Awash basin

CHAPTER 1 INTRODUCTION

1.1 Background

The Upper Awash river basin is located at the transient of the Main Ethiopian Rift (MER) and the central highlands of Ethiopia (Andarge Yitbarek et al., 2012). Becho and Koka areas are found in the upper part of Awash river basin situated in Oromia regional state, Central Ethiopia. Becho is one of the woreda in the Oromia region of Ethiopia ,and its major town is Tulu Bolo.The Koka reservoir is located in the upper reaches of the Awash basin approximately 75 km southeast of Addis Ababa, and has been in operation for the last 45 years.

Awash river basin is actively and potentially utilizing for various levels of irrigation developments. The potential of irrigable land inside the basin, geographical suitable for, accessible condition along the Awash river basin are some of the factors that make the basin more utilizable than others. These active irrigation developments are mainly occurring in the upper Awash river basin where population density is high and crop productivity is good. To utilize groundwater for, domestic and agricultural purpose; the occurrence, quantity, sustainability and quality are among the major factors.

Adaa and Becho groundwater resource evaluation project is one of the areas in the country designated for potential use of groundwater for irrigation. Three aquifer systems have been identified in the study area, namely alluvial and lacustrine deposits, the upper basaltic and lower basaltic aquifer (Semu Moges,2012 as cited in Engida Zemedagegnehu et al.,2008).

Shallow groundwater is significant sources of water for agricultural production especially during drought periods. Groundwater based irrigation is still extremely rises in different parts of the country particularly in the upper Awash river basin, which this particular study was focused on in Becho and Koka areas with shallow groundwater farmer-driven groundwater development is taking off rapidly.

The amount of land irrigated using shallow groundwater and the corresponding number of shallow groundwater wells used to irrigate is increasing with time in the upper Awash river basin. In view of increasing demand of water for various purposes like agricultural, domestic, etc, a greater emphasis is being laid for optimal utilization of water resources. It is obvious that for the full utilization of existing water resources, good understanding of groundwater flow and hydraulic parameter of an aquifer is essential.

1.2 Problem Statement

Because of the costs of performing a well designed aquifer test and the expertise required to collect and analyze the data, most water supply wells, especially shallow groundwater wells, have not had time drawdown tests performed on them. Therefore, to left the hydraulic parameter of the shallow aquifers especially for the hand dug wells (Robert,2001).

According to Andarge Yitbarek et al. (2013) explained that management and modeling of the groundwater resources require a good understanding of the hydrogeological properties of the rocks /soils that form the major aquifers.

In the study area, shallow groundwater (hand dug wells) are being used for irrigation and domestic purpose throughout the year. But detail investigation has not been conducted in terms of quality, groundwater level and hydraulic parameter of the soil. Therefore, great emphasis is given to aquifer characterization of the area. The present study aims to understand the basic hydraulic parameter of the soil and groundwater flow of the shallow aquifers that will have great benefit for the future management of groundwater, and inputs for developing numerical groundwater flow models to predict the future availability of the water resource.

1.3 Objectives

1.3.1 General objective

The principal objective of this study is to provide detail information on the groundwater flow and characterize the shallow aquifers of Becho and Koka areas which will be vital information for future sustainable use of the groundwater resource.

1.3.2 Specific objective

To accomplish the present research, the following specific objectives were designed:

- ✓ To characterize the aquifers by giving emphasis to hydraulic parameter such as soil field saturated hydraulic conductivity.
- ✓ Determine groundwater flow direction in the area.
- ✓ To estimate groundwater recharge by BFS.
- ✓ To characterize the hydrochemical parameters of the aquifers.

1.4 Methodology

Approaches and methodologies were applied in order to come up with the results. These are:

Desk study: Reviewing the available previous works which includes geological, hydrogeological studies in the study area. The Secondary data is collected from different organizations and woredas like information about shallow groundwater and related technical reports from Becho and Illu Woredas water resource development office and irrigation authorities, iDE Ethiopia (innovation for rural prosperity Tulu Bolo Project office) and Ethiopian ATA. Topographic maps are purchased from Ethiopia map agency (EMA). River discharge data and meteorological data were collected from Ministry of Water, Irrigation and Electricity and National Meteorological Service Agency, respectively, and used for estimating recharge and the analysis of hydrometeorology of the study area. GIS shapefiles maps of soil, geology, hydrogeology and land use land cover and technical reports were collected from WWDSE.

Field work: The water samples were collected from hand dug wells for chemical analysis and stable isotopic composition, and inventoried of hand dug wells were given emphasis of measurements of well depth and SWL with hydrochemical parameters including their GPS locations are conducted by using dip meter, Water quality kit and Garmin GPS respectively. Field photographs are captured for documentation and interpretation.

Representative in -situ field saturated hydraulic conductivity of the soil was measured from by using the Model 2800K1 Guelph Permeameter.

Figure 1.1 Explains measurements of soil field saturated hydraulic conductivity by using Guelph permeameter within the study area.

The Guelph Permeameter is an easy to use instrument to quickly and accurately measure in-situ hydraulic conductivity of the soil. The Guelph Permeameter has a complete Kit consisting of the permeameter, field tripod, borehole auger, borehole preparation, cleanup tools, collapsible water container, and vacuum test hand pump, all in a durable carrying case. Measurements can be made in the range of 15 to 75 cm below the soil surface, and. can be made in 1/2 to 2 hours, depending on soil type, and require only about 2.5 liters of water (Soil Moisture Equipment CORP, 1985).

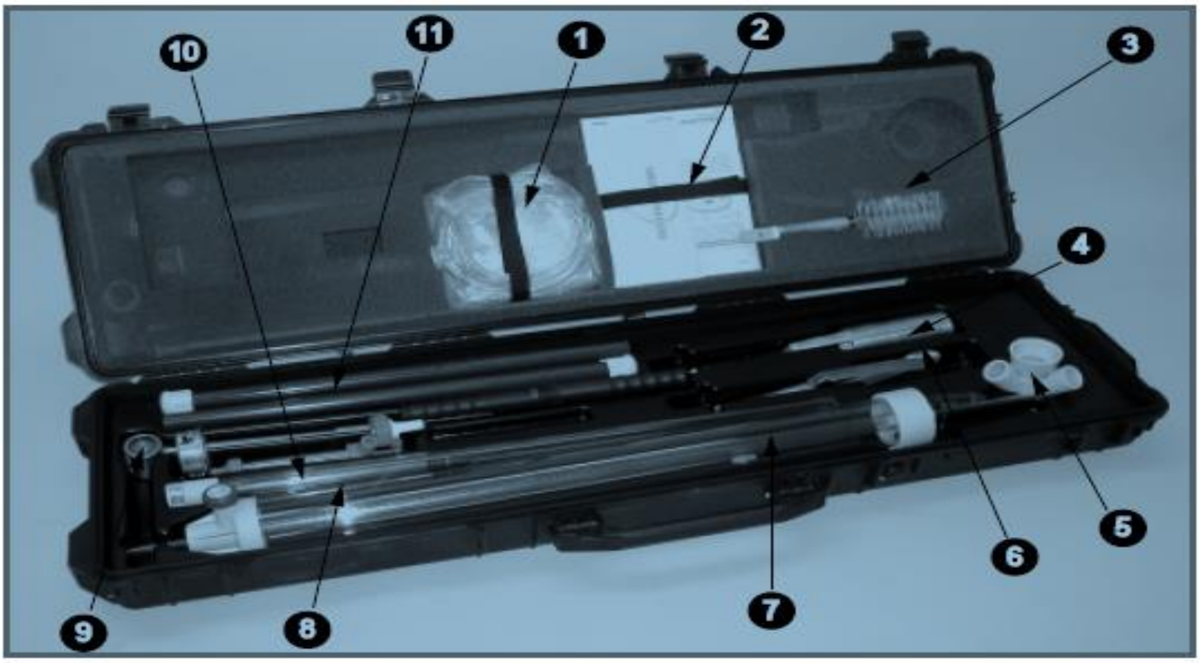


Figure 1.2 Guelph Permeameter Kit (2800K1) components in Carrying Case:(1) Water Container, (2) manual of Guelph permeameter, (3) Well Preparation Brush, (4) Sizing Auger, (5) Tripod Base, Tripod Bushing and Tripod Support Chain, (6) Soil Auger, (7) Reservoir Assembly, (8) On Top: Support Tube and Lower Air Tube; On Bottom: Well Head Scale and Upper Air Tube, (9) Auger Handle Assembly, (10) Vacuum Test Hand Pump, (11) Tripod Legs (source: Soil Moisture Equipment CORP, 1985).

In the study area measurements of soil field saturated hydraulic conductivity of representative soil was performed according to the standardized procedures and calculations of model 2800K1 Guelph permeameter operating instructions manual.

The Standardized procedures method of measurement using the Guelph permeameter:

I. Site Evaluation
II. Well hole preparation
III. Assemble permeameter
IV. Fill reservoirs
V. Place permeameter
VI. Select reservoir

Reservoir combination (fast bubbling):

Set H_1 = 5 cm determine $\bar{R}_1$

Set H_2 = 10 cm determine $\bar{R}_2$

Calculation

Kfs = ((0.0041) (X) ($\bar{R}_2$)) - ((0.0054) (X) ($\bar{R}_1$))

Matrix flux potential = ((0.0572) (X) ($\bar{R}1$)) – ((0.0237) (X) ($\bar{R}2$))

Inner reservoir (slow bubbling):

Set H_1 = 5 cm determine $\bar{R}_1$

Set H_2 = 10 cm determine $\bar{R}_2$

Calculate

Kfs = ((0.0041) (Y) ($\bar{R}_2$)) - ((0.0054) (Y) ($\bar{R}_1$))

Matrix flux potential = ((0.0572) (Y) ($\bar{R}1$)) – ((0.0237) (Y) ($\bar{R}2$))

H_1 = The first head of water established in the well hole measured in cm.

$\bar{R}_1$ = The steady state rate of fall of water in the reservoir when the first head H_1 of water is established, and expressed in cm/sec.

H_2 = The second head of water established in the well hole, measured in cm.

$\bar{R}_2$ = The steady state rate of fall of water in the reservoir when the second head H_2 of water is established, and expressed in cm/sec

X = Reservoir constant used when reservoir combination is selected, and corresponds to the cross-sectional area of the combined reservoir expressed in cm^2.

Y = Reservoir constant used when inner reservoir is selected, and corresponds to the cross-sectional area of the inner reservoir expressed in cm2.

Kfs = Field saturated hydraulic conductivity expressed in cm/sec

The standardized data sheet format and calculations of Guelph permeameter used to determined field saturated hydraulic conductivity of the soil as specified by Guelph permeameter operating instructions manual included in appendix 5.

Post field work: The hydrochemical and stable isotopic composition of water samples were analyzed in the laboratory of Ethiopian construction design and supervision works corporation research, laboratory and training center water quality section and Addis Ababa University water isotope laboratory respectively. Based on the detailed field observation, chemical and stable isotopic composition results of the water samples and the data collected analysis was made. The analysis and interpretation of data were carried out by using different softwares. The softwares used in this research are: ArcGIS 10.2.2, Global mapper 15, surfer 10, Aquachem version 4.0, River Analysis Package Version 3.0.3 (RAP), excel spreadsheet program and Microsoft excel 2016.

1.5 Materials used

To achieve the objectives of this research work, the following materials were used.

- ✓ Garmin GPS, for locating water points.
- ✓ Topographic Maps (Scale 1:250000 and 1:50000)
- ✓ Digital camera for photograph captured.
- ✓ Stop watch.
- ✓ Water quality kit for measurements of in-situ hydrochemical parameters (P^H, Ec, temperature, TDS).
- ✓ Dip meter for measurements of groundwater depth and SWL.
- ✓ Model 2800K1 Guelph permeameter for measurements of in-situ field saturated hydraulic conductivity of the soil.

1.6 Literature review of previous studies

Some of related journal articles, academic researches and technical report that have been conducted in the upper Awash river basin are described below.

Andarge Yitbarek et al. (2013) conducted a study on the title of estimating transmissivity using empirical and geostatistical methods in the volcanic aquifers of upper Awash river basin, explained that transmissivity and specific capacity values are spread over several orders of magnitude, revealing the strong heterogeneity of the volcanic aquifer.

Andarge Yitbarek et al. (2012) conducted a study on the title of Hydrogeological and hydrochemical frame work of upper Awash river basin: with special emphasis on inter basins groundwater transfer between Blue Nile and Awash river. According to their study the different aquifers in the area at different places have different water levels. In the upper basaltic aquifer and lower aquifer, the static water level varies from place to place from artesian condition to 120 to150 m and 67.5 m below ground surface respectively.

Geological Survey of Ethiopia (GSE), (2011) worked on Hydrogeology and hydrochemistry of the Akaki-Beseka Sheet (NC 37-14), unpublished report. According to their study the groundwater of the area is dominantly bicarbonate (Na-HCO3 and Ca-HCO3). The Ca-HCO3 is mainly available on the plateau, whereas the Na-HCO3 is dominant on the rift floor. The groundwater flow is from the south-eastern part to the rift and to the western and southwestern parts of the area. Moreover, there are local groundwater flows from northern part of Entoto and Wechacha volcanic ridges to Becho plain and Akaki well field.

Ethiopian Agricultural Transformation Agency (ATA), (2014) conducted a study on national shallow groundwater mapping Exercise. Pilot Phase: Central Ethiopia, Including Woredas in Oromia and Southern Regions. unpublished Report.

In a study by **Behailu Berehanu et al. (2017)** focused on inter-basin groundwater transfer and multiple approach recharge estimation of the upper Awash aquifer system, Journal of Geoscience and Environment Protection. They were found that recharge estimated for the upper Awash river basin ranges from 51.5 mm/year to 157 mm/year, and estimated mean annual recharge from base flow separation over the upper Awash river basin is 91.25 mm.

Andarge Yitbarek (2009) focused on Hydrogeological and hydrochemical framework of complex volcanic system in the upper Awash river basin, Central Ethiopia: with special emphasis on inter-basins groundwater transfer between Blue Nile and Awash rivers. Published PhD Thesis. According to his investigation the shallow systems (springs, rivers and shallow wells) in the plateau regions of the study area is represented by Ca–Mg-HCO3 water type. Besides this he was also recognized that waters from rivers, springs, and wells tapping the upper unconfined shallow aquifers are the majority of the isotopic compositions concentrate around the rain isotopic composition of the area (Addis Ababa), which signifies that the aquifers they represent are getting their recharge from the modern precipitation.

Berhau Melaku(1982) investigating the general hydrogeology of the Upper Awash Valley Which includes, the Akaki river Catchment.

Wakgari et al. (2011) Conducted fluoride enrichment mechanism and geospatial distribution in the volcanic aquifers of the middle Awash basin, northern main Ethiopian Rift.

Tilahun Azagegn et al. (2015) Conducted litho-structural control on inter basin groundwater transfer in central Ethiopia.

Tenalem Ayenew et al. (2008) Conducted hydrogeological framework and occurrence of groundwater in the Ethiopian aquifers.

Water works design and supervision enterprise (WWDSE), (2008) worked on evaluation of water resources of the Adaa and Becho plains groundwater basin for irrigation development project.

Mekdes Nigatie (2012) Conducted a study on the title of characterization of aquifers and hydrochemistry in volcanic terrain of central Ethiopia, unpublished MSc Thesis, Addis Ababa University. She has investigated that hydrogeological classification on the basis of hydrogeological characteristics of lithologic units high productive porous aquifers and aquiclud or minor aquifers with limited groundwater resources.

Reys Asfaw (2016) worked on ground water potential evaluation and use trends in upper Awash basin, unpublished MSc Thesis, Addis Ababa University. According to his investigation the amount of land irrigated using shallow groundwater and the corresponding number of shallow groundwater wells used to irrigate is increasing with time.

Daniel Nuramo (2016) Carried out temporal changes in groundwater recharge in the upper Awash Basin, unpublished MSc Thesis, Addis Ababa University. He has investigated that mean annual recharge of Becho and Koka areas using the water balance method was found to be 319.5 mm and 49.5 mm, and baseflow separation by using excel spread sheet program it was found to be 81.4 mm and 104.3 mm respectively.

1.7 Significance of the study

The study may contribute to referenced in groundwater exploration, helpful to planners in the development and management of aquifer characterization and aquifer related works, and also it will be used as input for advanced scientific research works of the study area.

1.8 Structure of the Thesis

This Thesis is organized in to five chapters. Chapter one deals with the general introduction, objective, methodology and previous studies. Chapter two gives the general overview of the study area that includes the climate, physiography, drainage, land use and land cover and also includes meteorological elements. Chapter three gives an overview on the geological units and hydrogeological units of the study area. Chapter four presents the hydrogeological characterization, which includes groundwater recharge estimation and flow, hydraulic parameter of the soils, hydrochemistry and isotope. Chapter five presents conclusions and recommendations.

CHAPTER 2 DESCRIPTION OF THE STUDY AREA

2.1 Location

The study areas (Becho and koka) that are found in the upper Awash river basin, which is situated in Oromia regional state in central Ethiopia. Approximately, geographically bounded by 407172mE - 457246mE; 951409mN- 991578mN and 471828mE – 509245mE; 923071mN- 967092mN respectively, which covers a total area of about 2780 Km^2, and the elevation ranges from 1519 to 2300 m.a.s.l. Becho area is found along 30 to 65 km from Addis Ababa along Addis Ababa - Jima road. It occupies a total area of about 1502 km². Koka area is found along 75 km from Addis Ababa along Addis Ababa-Djibouti high way. It occupies a total area of about 1278 km².

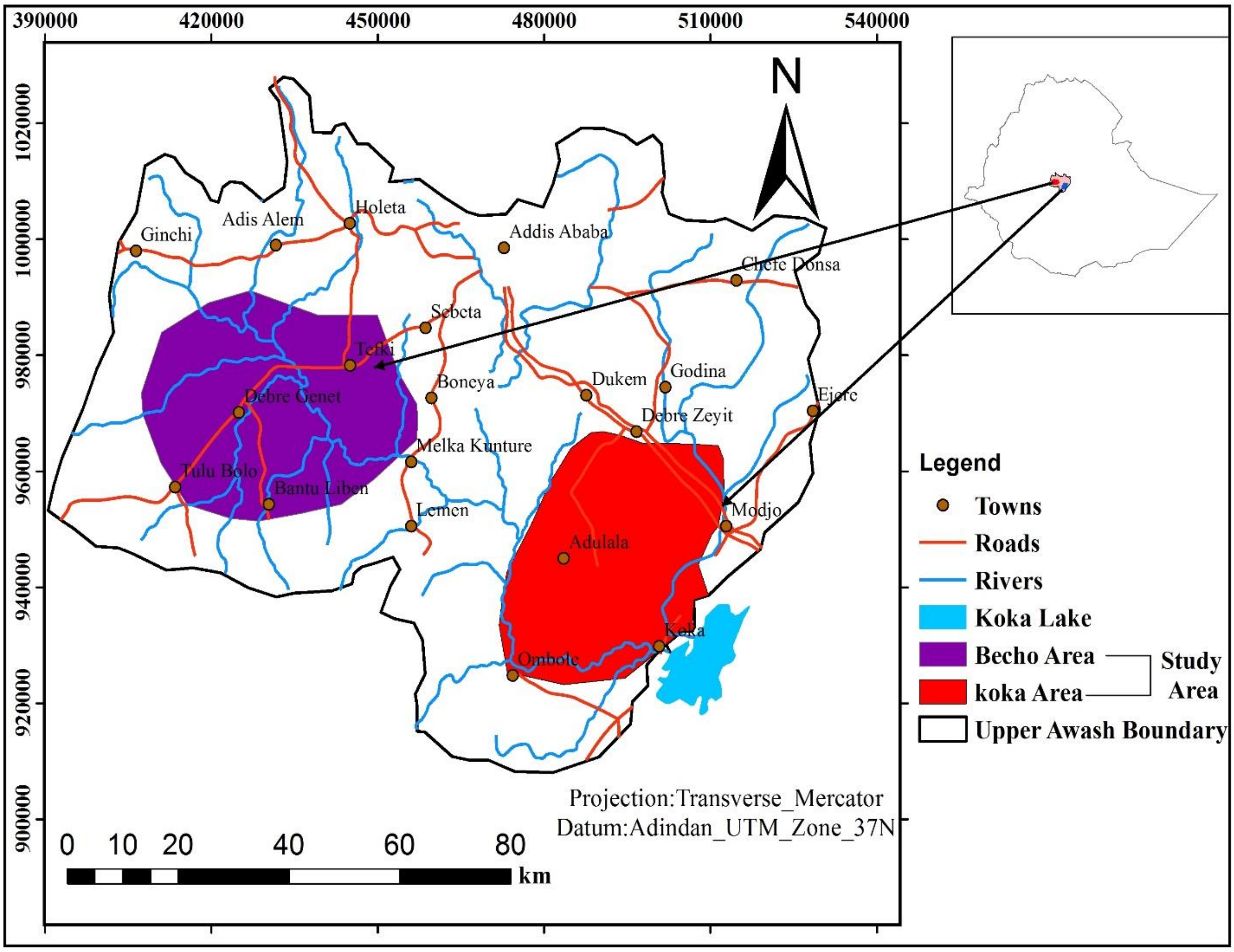


Figure 2.1 Location map of the study area.

2.2 Physiography and relief

The formation and development of the Main Ethiopian Rift Valley system during miocene caused the formation of the north-western and south-eastern Ethiopian plateaus to the west and east respectively, and separated by the rift valley itself. The north-western plateau is drained due west by the Abay drainage system and due north-east by the Awash drainage system. The study area is located at the western margin of the Main Rift Valley system and has three distinct geomorphologies: The plateau marginal area, where the Awash river and its tributaries emerge, supposed to be the main recharge area for the groundwater. The plateau is the western limit of the study area. The steep to gentle slope area extending from the plateau to the southeast of the area. The rift valley depression area, including the vicinity of the towns Modjo, and koka is extending to the northwest and southeast of the area. This area of the rift valley depression lies at a relatively lower elevation 1519 to1700 m.a.s.l. (WWDSE,2008).

The Becho area is bordered in the north by the east-west trending rift escarpment (Ambo fault), in the east Wechecha Mountain which has an elevation of about 3400 m.a.s.l, while in the south it is bordered by Guraghe highlands and in the west by Weliso highlands. It is a flat seasonally flooded plain with small scrubs and trees, and the main groundwater is recharged from Abay plateau. The koka area has an extensive lacustrine deposit of flat area with isolated hills and mountain like mountain Ziquala.

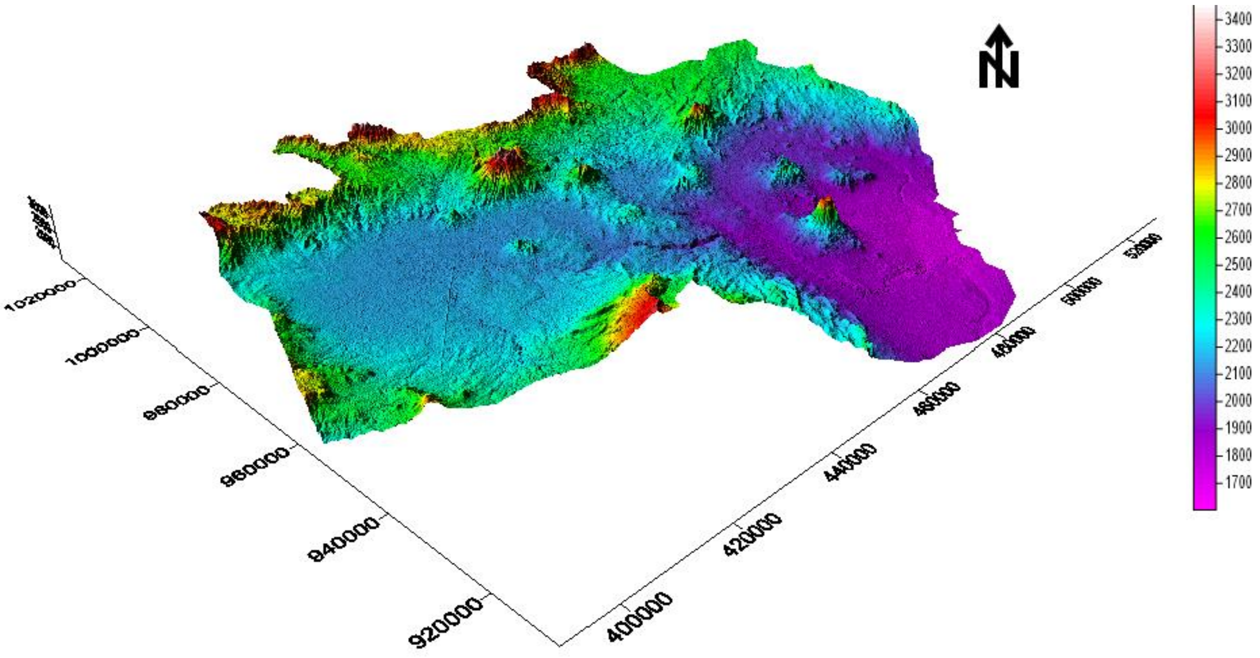


Figure 2.2 DEM of the study area and the surrounding area.

2.3 Drainage

According to EVDSA (1989) the upper Awash river basin has an area of around 11,500 km^2, and is located between 8^0 and 9^0N latitude and 38^0 and 39^0 E longitude. The drainage pattern of upper Awash river basin and its tributaries form dendritic drainage pattern, and it flows in a NW to SE general direction (Andarge Yitbarek, 2009). Modjo and Teji river are the major tributaries of the Upper Awash river basin in the study area. The Becho area has an average elevation of 2060 m and is surrounded by Wechecha Mountain in the east, the Guraghe highlands in the south and the Weliso highlands in the west (WWDSE, 2008). The Awash river and several tributaries rise in these Mountains that reach over 3300 m.a.s.l. The Berga, Holeta, Kelina, Dilolo Dilu, Teji and Watira tributaries join the Awash river in Becho area that flows towards Lake Koka in southeastern direction. Downstream of Mulka Kunture , Akaki, Guracha and Dukem, Lemen and other smaller tributaries join the Awash river before it enters the plain surrounding Lake Koka. The Modjo river also flows into Lake Koka. This low lying plain at the west shore of Lake Koka that is also surrounded by volcanic hills has a mean elevation of 1590 m.

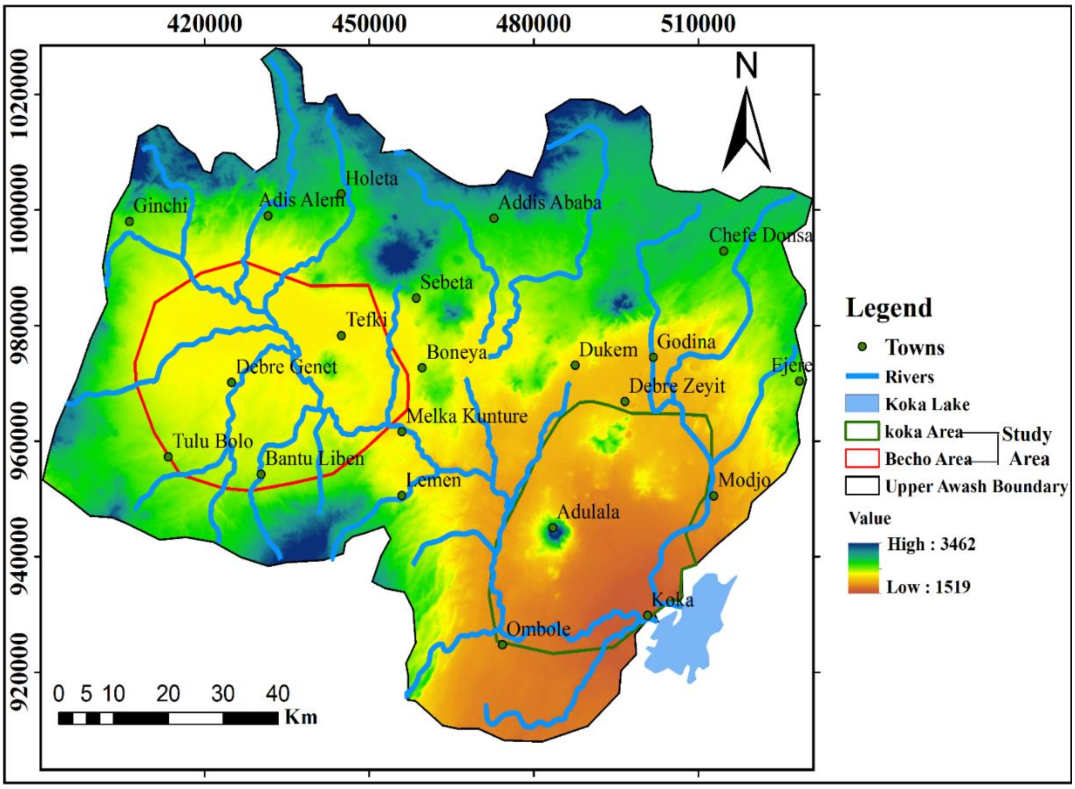
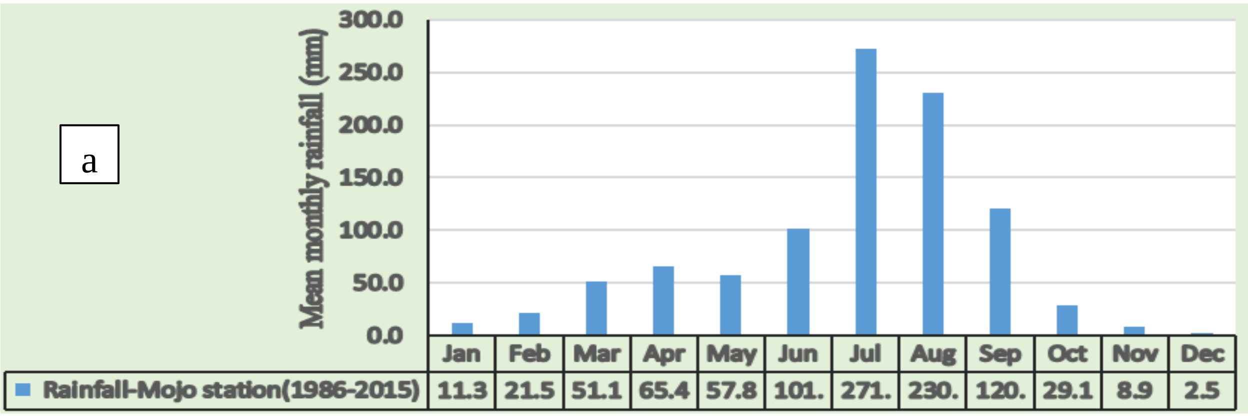
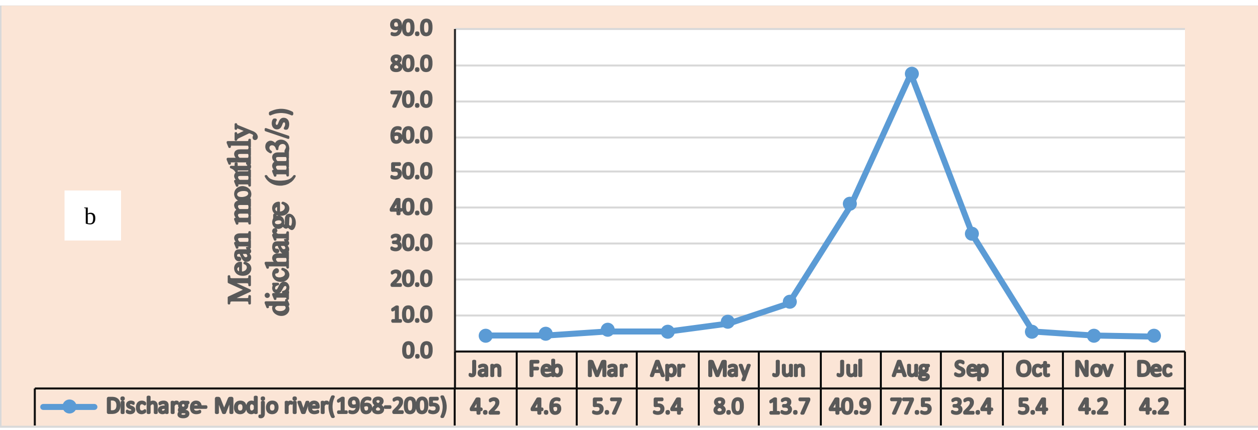


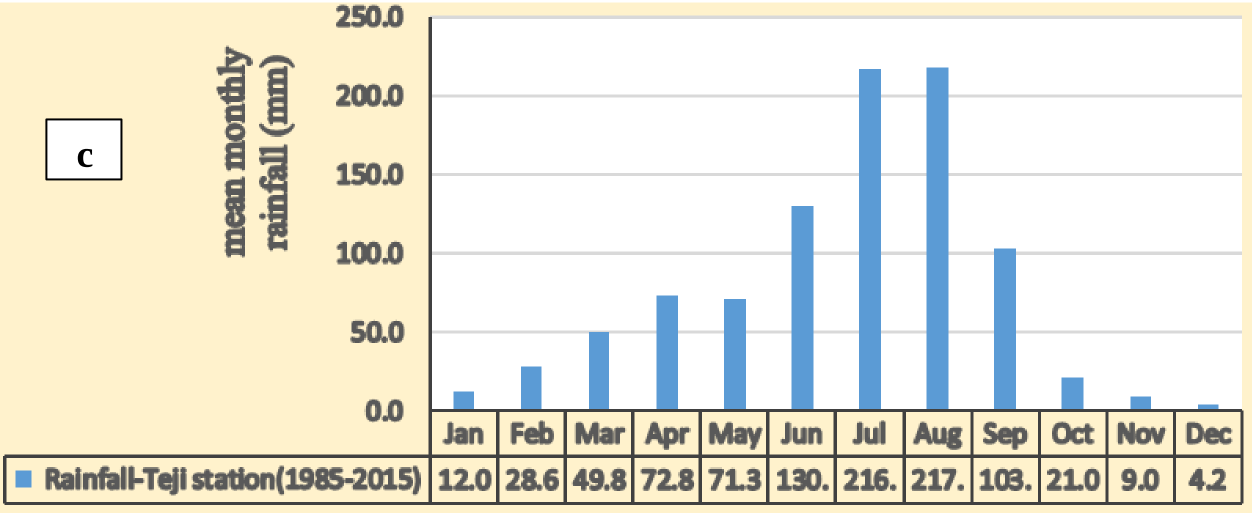
Figure 2.3 Map showing the drainage and the DEM of the study area.

2.4 Hydrograph analysis

According to Charles (2002) explained that river hydrograph is the plot of river discharge versus time at specific location. The main Awash river and most of its major tributaries are gauged at different locations. Major tributaries: Modjo and Teji are gauged at their outlets before joining Awash river, and the main Awash river is gauged at, Hombole and at Bello in Koka and Becho areas respectively. The discharge records exhibit similar trends, the highest flow corresponding with the wettest months of July, August and September (figure 2.4). The data from the gauging station near Koka, before the river enters the Lake, best represents the whole river discharge from the Upper Awash river basin, but, as it is explained a bit earlier, due to back flow effect of the Lake to the staff gauges of this station the data is not found to be reliable for interpretation (Andarge Yitbarek, 2009), hence flow records at Modjo river, Awash river at Hombole, Teji river and Awash river at Bello were used in Koka and Becho areas for this study respectively, and their area coverage and UTM location presented in table 2.1.







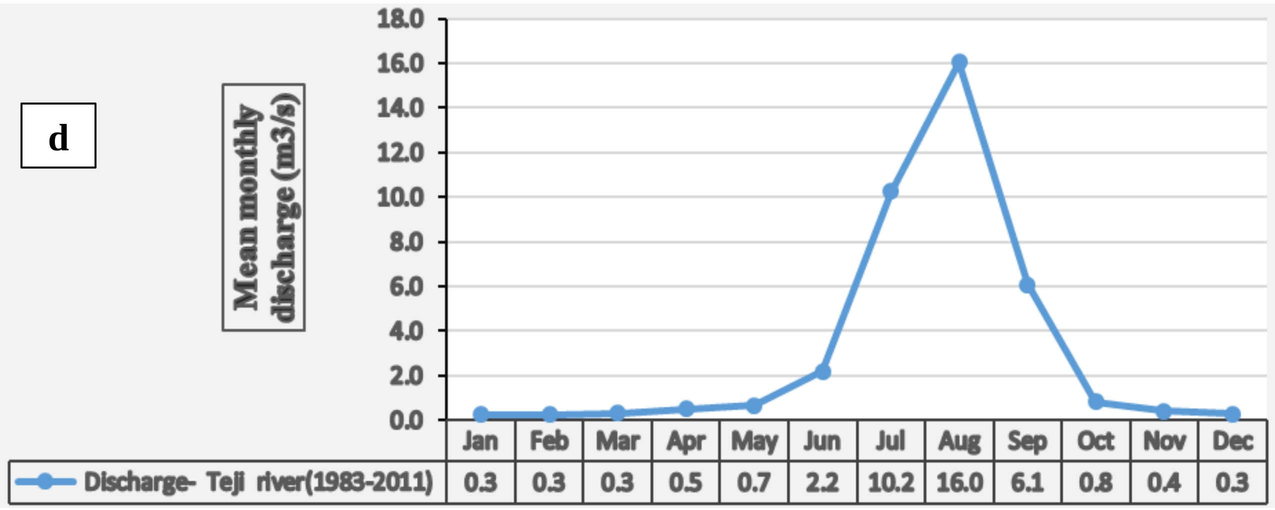
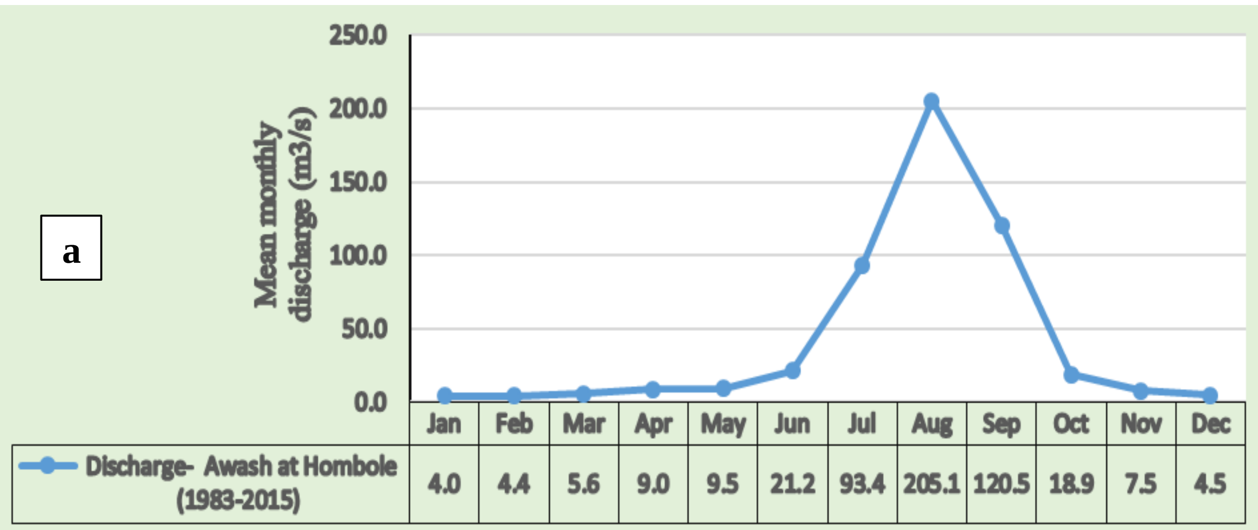


Figure 2.4 Explain mean monthly rainfall (mm) and river discharge (m^3/s) at selected stations. (a), rainfall at Modjo station, (b), discharge at Modjo river, (c), rainfall at Teji station and (d) discharge at Teji river respectively.



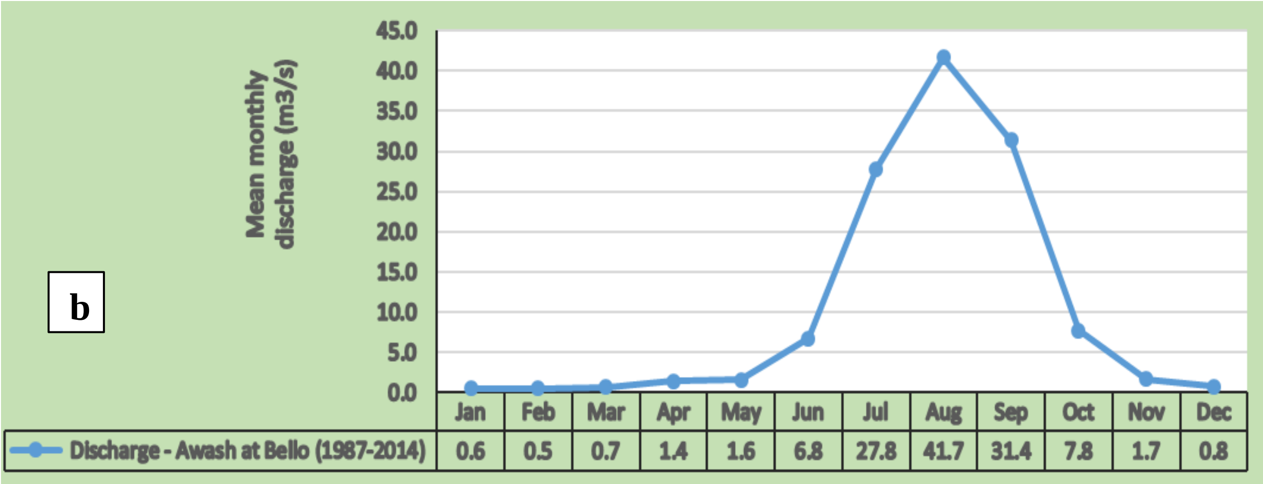


Figure 2.5 Mean monthly discharge flow of the selected gauging stations in the main Awash river. (a), discharge at Awash river at Hombole and (b) discharge at Awash river at Bello.

Table 2.1 The hydrological stations in the study area.

Sl. No	River gauging Stations	UTM coordinates			Drainage area (km^2)	Recorded Year
		Easting	Northing	Altitude(m)		
1	Awash river at Bello	435855	978231	2091	2568.8	1987-2014
2	Teji river	426678	970876	2415	662.5	1983-2011
3	Awash river at Hombole	475632	925539	1699	7656	1983-2015
4	Modjo river	509170	950545	1763	1264.4	1968-2005

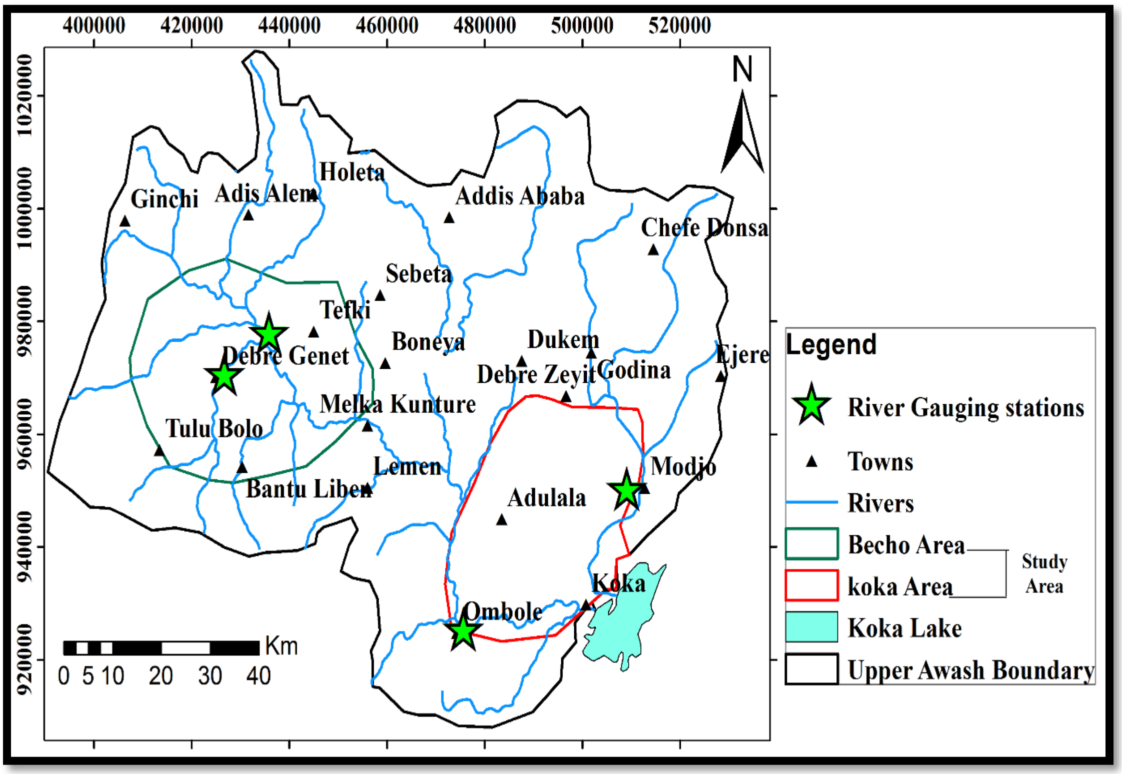


Figure 2.6 The selected hydrological stations within the study area.

2.5 Climate

The movement of the Inter Tropical Convergence Zone (ITCZ) that allows dry easterlies or moist westerlies dominates the climate of this part of Ethiopia. In March the ITCZ advances across the Awash river basin bringing spring rains in the ‘Belg’ season. The ITCZ reaches its most northern position when heavy summer rains come from the west. This season is the main rainy season called ‘Kiremt’ and lasts until September,and the dry season called ‘Bega’extend from October to February (EVDSA, 1989).

Thus, in the study area two rainy seasons has been experienced. The main rainy season often extends from end of June through end of September and the small rainy season from end of February to middle of May, the rest of the months are generally dry. The amount of rainfall is influenced by orographic effects and shows a strong correlation with altitude (WWDSE, 2008). Mean annual rainfall varies from over 1200 mm per year in the high-elevated uplands to below 700 mm per year in the lower areas surrounding Lake Koka. 70 to 75% of the total rainfall occurs in the main wet season (WWDSE, 2008).

The mean annual rainfall of Becho area groundwater basin is about 1141.6 mm, and mean monthly temperature is about 17. 9°C.The mean annual rainfall of Koka area groundwater basin is about 914.4 mm, and mean monthly temperature is about 21. 3°C.The mean annual rainfall and the mean annual temperature are included in appendix 3.

Table 2.2 Meteorological stations within and the surrounding of the study area and data recorded years.

		UTM coordinates			
No.	Metrological stations	Long.(E)	La.(N)	Altitude (m)	Recorded Year
1	Addis Ababa	38.75	9.033333	2354	1986-2015 1*
2	Bantuliben	38.357	8.6185	2167	1985-2014 4*
3	Debrezeit	38.95	8.733333	1900	1986-2012 1*
4	Modjo	39.10817	8.60533	1763	1986-2015 2*
5	Koka	39.1542	8.46933	1618	1986-2014 3*
6	Sebeta	38.63	8.93	2240	1986-2014 3*
7	Tulu bolo	38.2065	8.6545	2190	1986-2015 3*
8	Teji	38.36667	8.8333	2091	1985-2014 4*
9	Tefki	38.489	8.84	2063	2010-2015 3*

1* Records of rainfall, temperature, relative humidity, wind speed and sunshine hours.

2* Records of rainfall, wind speed and temperature.

3* Records of rainfall and temperature.

4* Records of rainfall only.

Table 2.3 Mean monthly rainfall of the study area

Study Area	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
koka	Debrezeit (1986-2012)	10.0	19.2	52.4	55.3	42.3	91.3	203.0	208.4	107.5	31.1	5.2	5.0	830.6
	Mojo (1986-2015)	11.3	21.5	51.1	65.4	57.8	101.9	272	230.2	121	29.1	8.9	2.5	972
	Koka (1986-2015)	11.8	25.4	58.1	66.4	60.0	76.1	231.7	259.1	114.0	23.0	9.8	5.2	940.6
	Average	11.0	22.0	53.9	62.4	53.4	89.8	235.6	232.6	114.2	27.7	8.0	4.2	914.4
Becho	Sebeta (1986-2014)	12.4	61.6	78.8	119.8	118.5	177.8	323.7	389.9	155.9	32.7	12.6	6.9	1490.6
	Bantuliben (1985-2014)	13.1	18.0	59.3	83.2	77.6	169.9	321.5	305.9	155.6	39.6	10.1	4.0	1257.9
	Teji (1985-2015)	12.0	28.6	49.8	72.8	71.3	130.5	216.9	217.6	103.1	21.0	9.0	4.2	936.8
	Tefki(2010-2015)	4.3	36.2	26.2	55.1	64.9	120.2	186.2	224.3	119.9	16.2	18.3	5.2	876.8
	Tulu bolo(1986-2015)	10.5	15.9	47.9	65.9	102.3	214.9	282.0	268.6	113.1	15.4	3.5	5.8	1145.8
	Average	10.5	32.1	52.4	79.4	86.9	162.7	266.1	281.3	129.5	25.0	10.7	5.2	1141.6

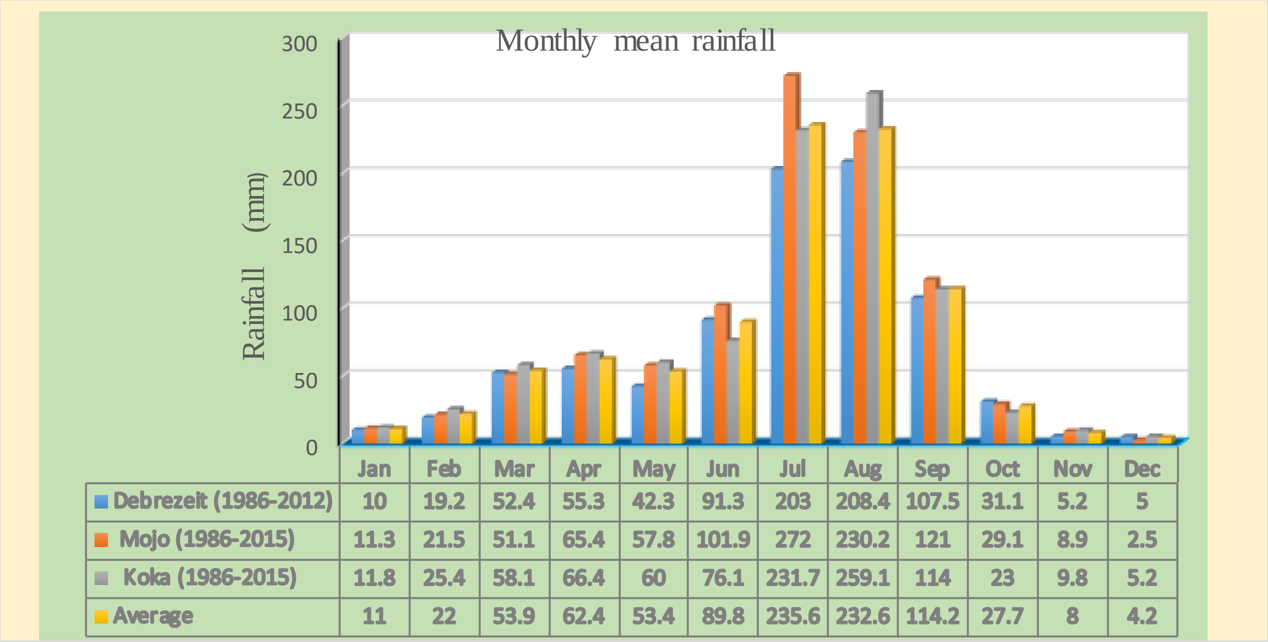


Figure 2.7 Mean monthly rainfall distributions of Koka area and surrounding area.

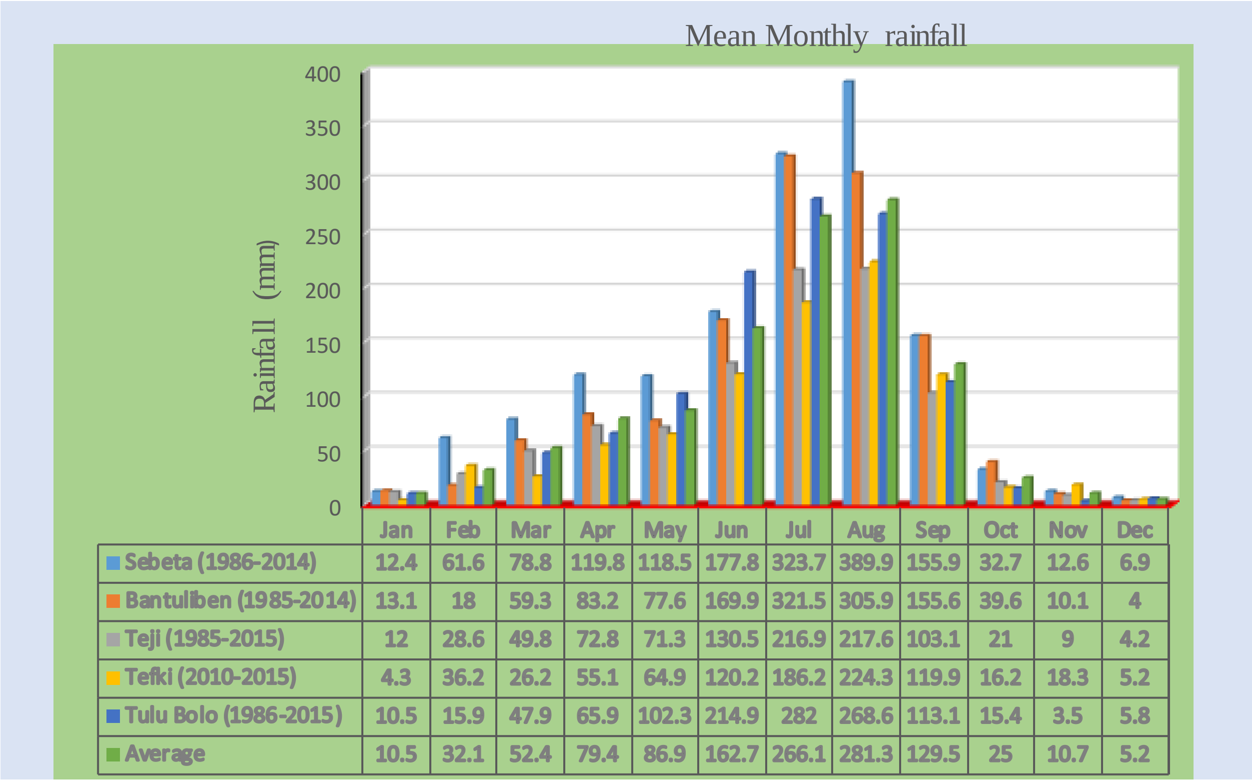


Figure 2.8 Mean monthly rainfall distributions of Becho area and surrounding area.

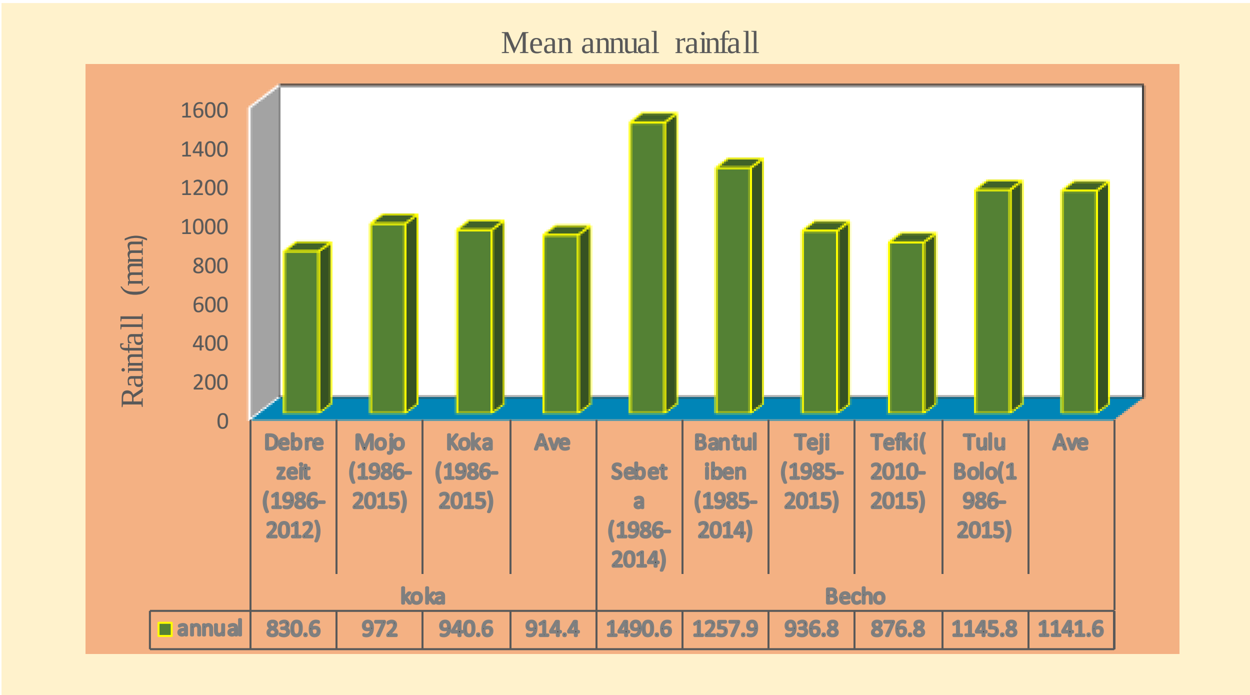


Figure 2.9 Mean annual rainfall distributions of Koka and Becho areas and surrounding area.

Table 2.4 Monthly maximum mean and minimum mean temperature variability of the four stations in the study area.

Study Area	Stations		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Koka	Koka	Min	12.6	13.8	14.9	15.5	15.7	15.3	14.8	14.7	14.9	13.6	12.9	11.6
		Max	29.3	30.3	31.6	31.6	32.2	31.5	29.5	29.2	29.9	29.4	29.0	28.8
		Ave	20.95	22.05	23.25	23.55	23.95	23.4	22.15	21.95	22.4	21.5	20.95	20.2
	Mojo	Min	9.3	11.0	12.9	13.5	13.8	13.4	13.2	12.8	12.3	10.6	9.2	8.2
		Max	28.8	29.8	30.6	30.6	31.0	29.7	26.1	25.9	27.3	28.7	28.4	28.1
		Ave	19.1	20.4	21.8	22.1	22.4	21.6	19.7	19.4	19.8	19.7	18.8	18.2
Becho	Tulu Bolo	Min	8.7	9.0	9.9	10.2	10.1	10.1	10.1	10.2	9.7	8.9	8.2	7.8
		Max	25.0	25.6	26.2	26.2	26.3	25.0	23.5	23.5	23.8	24.2	24.3	24.1
		Ave	16.9	17.3	18.1	18.2	18.2	17.6	16.8	16.9	16.8	16.6	16.3	16.0
	Tefki	Min	7.5	9.1	11.3	12.1	12.3	12.1	12.7	12.7	11.4	7.7	7.4	6.3
		Max	27.5	28.5	28.8	29.1	28.4	26.9	24.7	24.2	25.3	26.8	27.2	26.9
		Ave	17.5	18.8	20.05	20.6	20.35	19.5	18.7	18.45	18.35	17.25	17.3	16.6

Table 2.5 Monthly mean temperature(°c) of the study area.

Study Area	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
Koka	Koka (1986-2015)	20.95	22.05	23.25	23.55	23.95	23.4	22.15	21.95	22.4	21.5	20.95	20.2	22.2
	Mojo (1986-2015)	19.1	20.4	21.8	22.1	22.4	21.6	19.7	19.4	19.8	19.7	18.8	18.2	20.3
	Average	20.0	21.2	22.5	22.8	23.2	22.5	20.9	20.7	21.1	20.6	19.9	19.2	21.3
Becho	Tulu Bolo (1988-2015)	16.9	17.3	18.1	18.2	18.2	17.6	16.8	16.9	16.8	16.6	16.3	16.0	17.1
	Tefki (2010-2015)	17.5	18.8	20.05	20.6	20.35	19.5	18.7	18.45	18.35	17.25	17.3	16.6	18.6
	Average	17.2	18.1	19.1	19.4	19.3	18.6	17.8	17.7	17.6	16.9	16.8	16.3	17.9

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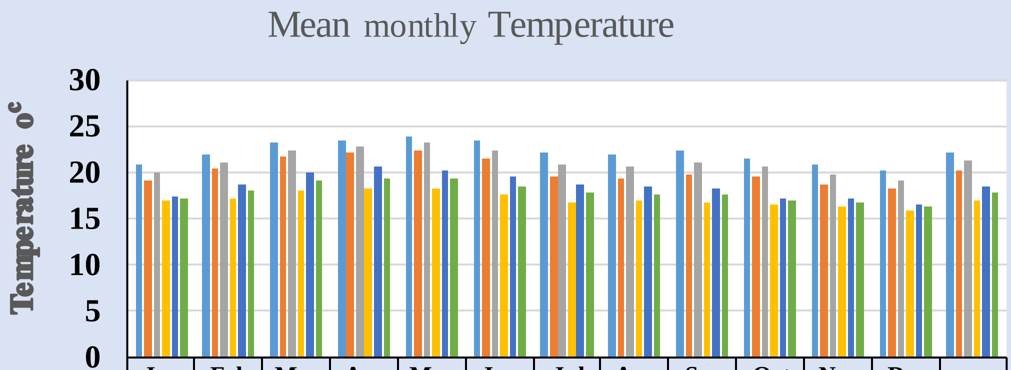

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
Koka (1986-2015)	20.95	22.05	23.25	23.55	23.95	23.4	22.15	21.95	22.4	21.5	20.95	20.2	22.2
Mojo (1986-2015)	19.1	20.4	21.8	22.1	22.4	21.6	19.7	19.4	19.8	19.7	18.8	18.2	20.3
average	20	21.2	22.5	22.8	23.2	22.5	20.9	20.7	21.1	20.6	19.9	19.2	21.3
Tulu Bolo (1988-2015	16.9	17.3	18.1	18.2	18.2	17.6	16.8	16.9	16.8	16.6	16.3	16	17.1
Tefki (2010-2015)	17.5	18.8	20.05	20.6	20.35	19.5	18.7	18.45	18.35	17.25	17.3	16.6	18.6
Average	17.2	18.1	19.1	19.4	19.3	18.6	17.8	17.7	17.6	16.9	16.8	16.3	17.9

Figure 2.10 Monthly mean temperature (°c) distributions for four stations of the study area.

Table 2.6 Monthly mean relative humidity of the area in %.

Study Area	Stations		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Becho	AA(1998-2012)	At 600	73.5	67.9	69.3	73.5	70.5	82.8	89.0	89.0	84.8	69.2	69.1	71.8	75.9
		At1200	50.5	45.0	47.2	50.0	47.2	58.7	70.6	72.7	65.1	48.9	47.0	47.9	54.2
		At 1800	52.6	43.9	48.1	54.8	49.8	62.7	74.4	76.9	69.6	52.5	50.2	50.4	57.2
		Ave	58.9	52.3	54.9	59.4	55.8	68.1	78.0	79.5	73.2	56.9	55.4	56.7	62.4
Koka	Debrezeit(2001-2012)	At 600	78.2	73.3	76.2	77.6	78.8	84.3	88.8	90.4	90.7	80.5	78.7	78.7	81.4
		At 2100	46.3	41.1	42.9	46.8	46.3	56.3	68.5	72.5	63.1	43.0	41.1	44.5	51.0
		At 1800	41.9	35.3	38.5	43.8	43.5	53.6	66.0	70.4	64.7	43.4	39.7	42.0	48.6
		Ave	55.5	49.9	52.5	56.1	56.2	64.7	74.4	77.8	72.8	55.6	53.2	55.1	60.3

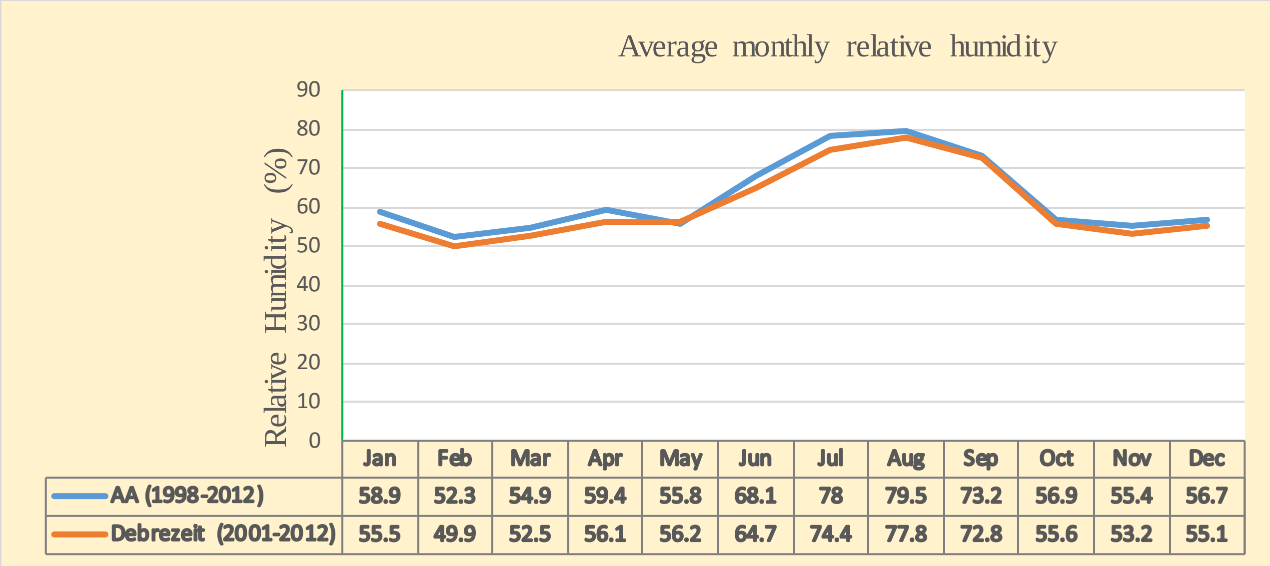

Figure 2.11 Monthly Mean relative humidity of the study area

Table 2.7 Mean monthly sunshine hours of the selected meteorological station of the surrounding area

Study Area	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Becho	AA (2006-2015)	9.4	9.0	8.3	7.1	7.3	5.8	3.9	4.0	5.6	8.6	9.2	9.0	7.3
Koka	Debrezeit (1994-2012	9.0	9.6	8.7	8.1	8.4	6.8	5.2	5.4	7.0	9.0	9.6	9.4	8.0

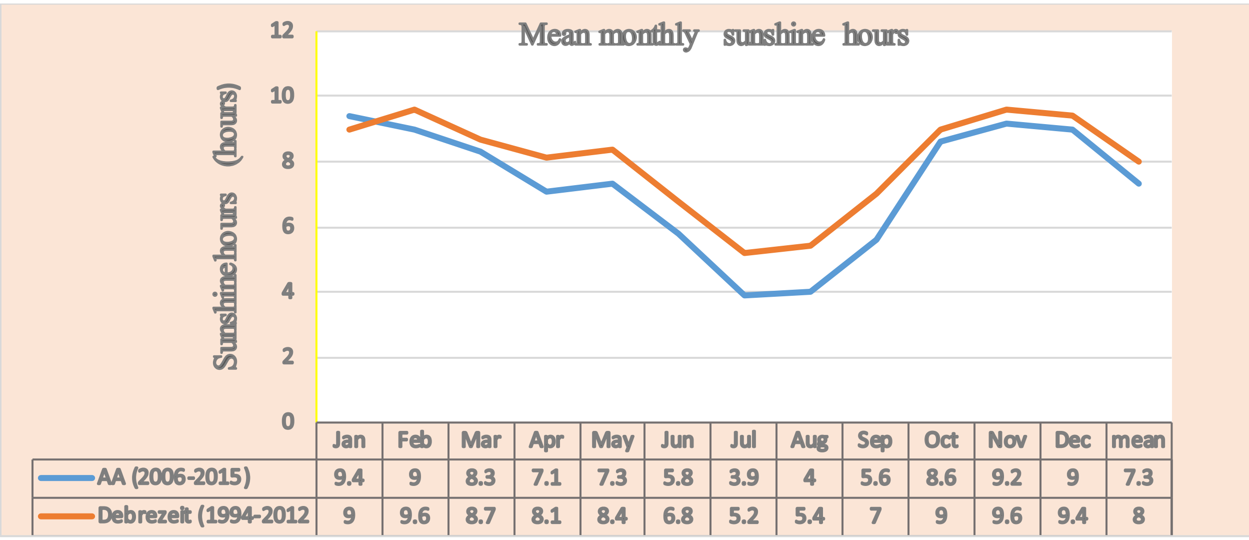

Figure 2.12 Monthly mean sunshine hours of surrounding stations in the study area

Table 2.8 Mean monthly wind speed (m/s) of the surrounding stations of the area

Study Area	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Becho	AA (1982-2004)	0.7	0.7	0.8	0.8	0.8	0.5	0.4	0.3	0.5	0.8	0.8	0.7	0.7
Koka	Debrezeit (1994-2005)	1.3	1.6	1.6	1.6	1.6	1.3	1.2	1.0	1.0	1.4	1.6	1.5	1.4

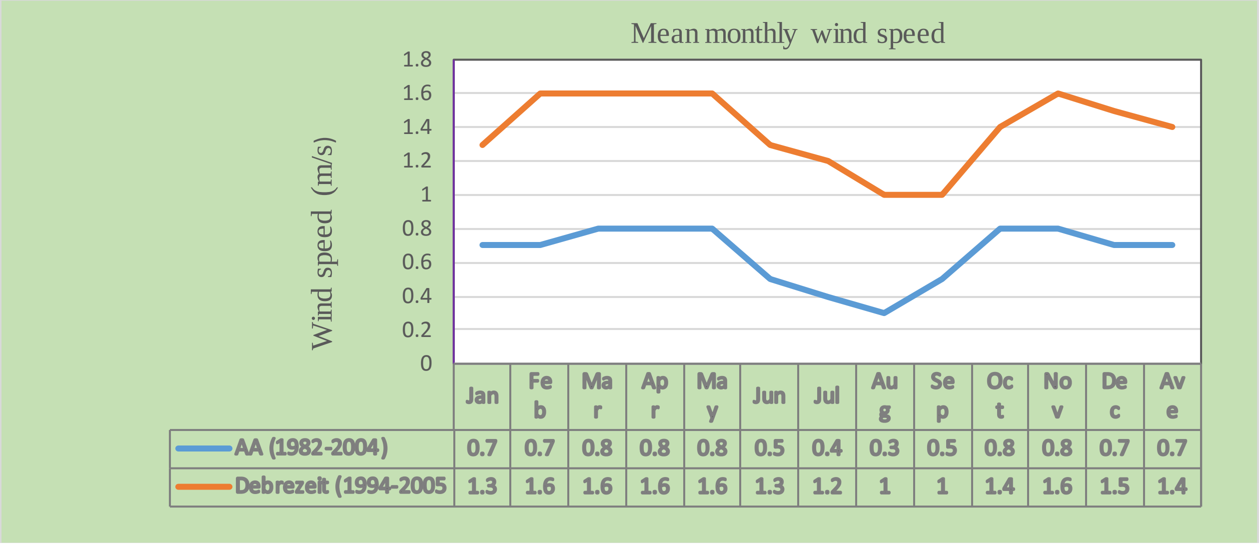

Figure 2.13 Monthly mean wind speeds of the surrounding area.

2.6 Soil

According to WWDSE (2008) the soil map of the identified soil units of the study area described as follows: The dominant soil type in Becho area is Pellic vertisols (figure 2.15). In small scale there are also consists orthic solonchakes, leptosols and chrombic cambisols. The pellic vertisols in the Becho area is black clays that are dominated by the montomorillonite clay mineral. This mineral expands when wet and contracts when dry, causing cracks at the surface in the dry season (figure 2.14.) Major soil type in Koka area is Vertic cambisols ,Chromic luvisols ,Chromic vertisols and Pellic vertisols (figure2.15).

Figure 2.14 Characteristics of black cotton soil in Becho area.

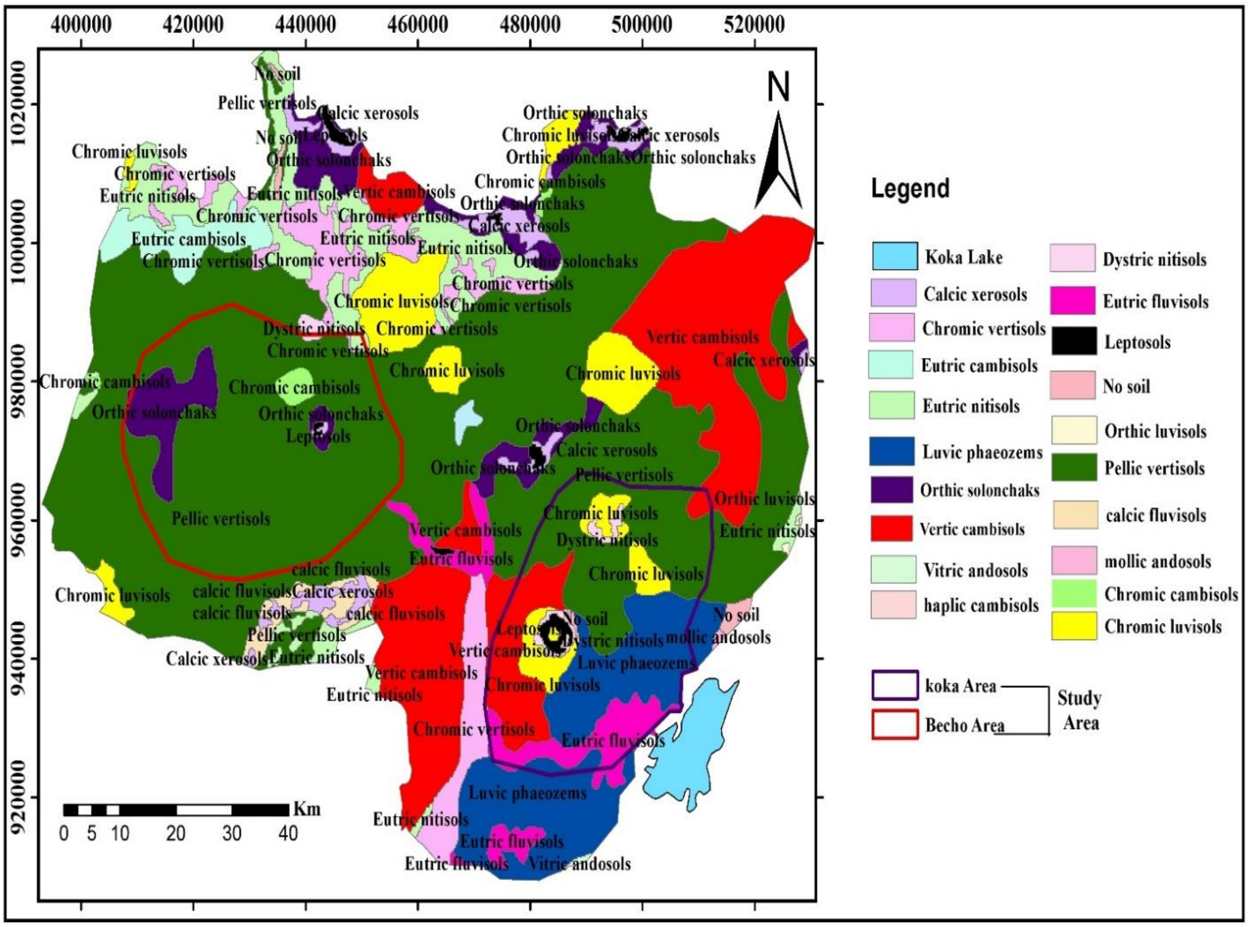

Figure 2.15 Soil types of the study area (after WWDSE,2008).

2.7 Land use and land cover

Most of the land uses of the study area is agricultural land. More than 70% of the population in the study area is involved in agriculture (Nippon Koei, 1996). In the Becho area 78.4% of the land is agricultural land, 11.9% is used for grazing land and is seasonally swamped and 9.7% of the land consists of villages, roads and woodlots (Nippon Koei, 1996). Major crops grown in the area is Teff, wheat, barely, beans, oil seeds and peas and some vegetation like Onion, Cabbage, Tomato and Potato is cultivated by irrigation. Most of the Mountains in the area is covered by Forest. In terms of areal coverage, the important land cover units are cultivated land, shrubland, wetland and grassland the cultivated land consists about largest portion of the total area.

CHAPTER 3 GEOLOGY

3.1 Regional Geological Setting

According to Andarge Yitbarek et al. (2013) Upper Awash river basin is exclusively confined within the north central plateau and the adjacent escarpment and rift.

The outline of the regional geological setting as described by WWDSE (2008, as cited in Pierre Gouin ,1979) summarized as: The Ethiopian plateau is underlain at depth by Precambrian rocks of the Afro Arabian Shield. The Precambrian basement is covered for the most part by glacial and marine sediments of Permian to Paleogene period and Tertiary volcanic rocks with related sediments. The Precambrian rocks of Ethiopia is consisting of high grade gneiss, metamorphosed volcano sedimentary rocks and associated ultramafic bodies and intrusive ranging from mafic to granitic composition. At the end of Precambrian era, 600 million years ago, the crystalline basement complex of the present Afro Arabian swell had been above sea level for a long time and remained for another 370 million until the end of Paleozoic era. Such a long period of erosion and denudation left the earth's surface almost completely peneplained. Crustal motion started in the beginning of Mesozoic era, about 225 million years ago. During the late Triassic and early Jurassic periods, a regional epirogenic sinking of the crust commenced causing a progressive transgression of the ocean from the south east that is, from the Indian Ocean coast of present day Somalia in the general direction of Lake Tana in the North-West Ethiopia. This downward crystal movement, connected with a sedimentation process, started a cycle of marine transgression and recession of Mesozoic sea. Within this large epicontinental sea,extensive layers of sediments were deposited to form hundreds of meters of rocks consisting of sandstone, shale, gypsum, limestone and other varieties of sedimentary rocks. The crustal movement was reversed into the upward motion during the late Jurassic period, which brought the crust's surface up to sea level by marine regression in late Cretaceous period.

The youngest sediments are quaternary age. These include conglomerate, sand clay and reef limestone which accumulated in the Afar Depression and the northern end of the main rift Valley. Sediments which accumulated in the former Lakes occur in the south end of the Afar, in the Main Rift Valley, and in the Omo valley (Andarge Yitbarek ,2009, as cited in Kazmin,1972).

3.1.1 Geology of the study area

The Black cotton soil, Alluvial deposits, Entoto Becho rhyolite, Addis Ababa ignimbrite and centeral volcanics of wechecha outcrops are mainly dominated the Becho area (figure 3.2) respectively. **Black cotton soil** is recent soil of regolith and alluvial deposits.It is characterized by rare silt and gravel, interlayered with reworked and weathered pyroclastics. Recent sediments grouped as alluvium are made up of a succession of black cotton soil, fluvial silt, sand and gravel, as well as reddish clay and silty soil, or white, silty clay containing reworked pyroclastic clasts (ATA,2014).

Addis Ababa Ignimbrite is grayish to white color and when welded it exhibits elongated rock fragments of various color. It is composed of welded tuff (ignimbrite) and non-welded pyroclastic fall (ash and tuff). In the Becho area it is covered by a thin 5 to 7m thick residual soil developed from the same rock. The age of this unit is 5.11 to 3.26 Ma (WWDSE,2008, as cited in Morton et al., 1979). **Entoto Becho rhyolite,** the rhyolites form isolated cones. Obsidian up to 10 cm across is common at the picks of the cones. From the cross cutting relationship, they can be younger than the adjacent ignimbrite. The Entoto ridge forms watershed divide of Abay and Awash river basins. The ridge forms steep slope towards the Abay basin, and steep to gentle slope towards the Awash basin. In fresh hand specimen, it is grayish pink and reddish brown to yellowish grey color when weathered (WWDSE,2008). **Alluvial deposits** is consisting of regolith, reddish brown soils, talus and alluvium with maximum thickness of about 7 m (WWDSE ,2008, as cited in Becho area hand dug well data). **Centeral volcanics of wechecha** is porphyritic in texture with phenocrysts of feldspar up to 1cm across. Trachytes of Wecheca composed of alkaline pyroxene and rare olivine. The ages of the trachytes of Wecheca 4.6 to 3.7 Ma (WWDSE,2008, as cited in Kazmin, 1979; Abebe et al., 1999; Chernet et al.,1998).

Figure 3.1 pumice unit. (a) shows the pumice unit exposed along the Teji river with semi rounded to rounded gravel, (b) pumice unit exposed at Jato village in Becho area.

The Lacustrine deposits, Ziquala Trachyte, Bede Gebaba volcanic unit and Chefe donsa pyroclastics outcrops are mainly dominated the Koka area (figure 3.2) respectively. **Lacustrine deposit** is particularly distinguished in the Koka area of the Lake region. It is fine grained deposit generally brown-yellowish, thinly stratified and often contained volcanic matrix; whose thickness ranges from 5 to 8m (WWDSE,2008). **Zquala Trachyte** is isolated, well preserved cone standing about 1300m from the surrounding plane area, located in the southern part of the study area. It has a summit caldera 1.5 km wide and partially filled by water. It is grayish pink in color, coarse grained and composed of anorthoclase, minor clinopyroxene, phenocrysts and glassy alkalifeldspar groundmass. The age of the Ziquala trachyte is 1.28-0.85 Ma (WWDSE, 2008, as cited in Morton et al., 1979). **Bede Gebaba volcanic unit** is a circular volcanic complex outcropped north of the Ziquala Mountain with maximum elevation of 400m above the surrounding plane. Its morphology dominated by the occurrence of several coalescent caldera structures. The most recent products are represented by rhyolitic obsidians whose age is 0.36 Ma (Abebe et al 1999). Pumice and lavas show a composition ranging from rhyolites to minor trachytes. According to Gasperon et al (1993) the lava contains microphenocrysts and rare phenocrysts of sanadine and quartz as well as scattered plagioclase and clinopyroxene set in glassy to microcrystalline groundmass. **Chefe donsa pyroclastics** units are outcropped at the east, north east, south and west extreme parts of Debrezeyt. They are consisting of fall deposits (ash, tuff and pumice) and poorly welded ignimbrites of rhyolitic composition. At places in the Dukem and Mojo river valleys they are observed under the lacustrine deposits. The age of this unit ranges 2.24 to 1.71 Ma (WWDSE ,2008, as cited in Morton et al.,1979).

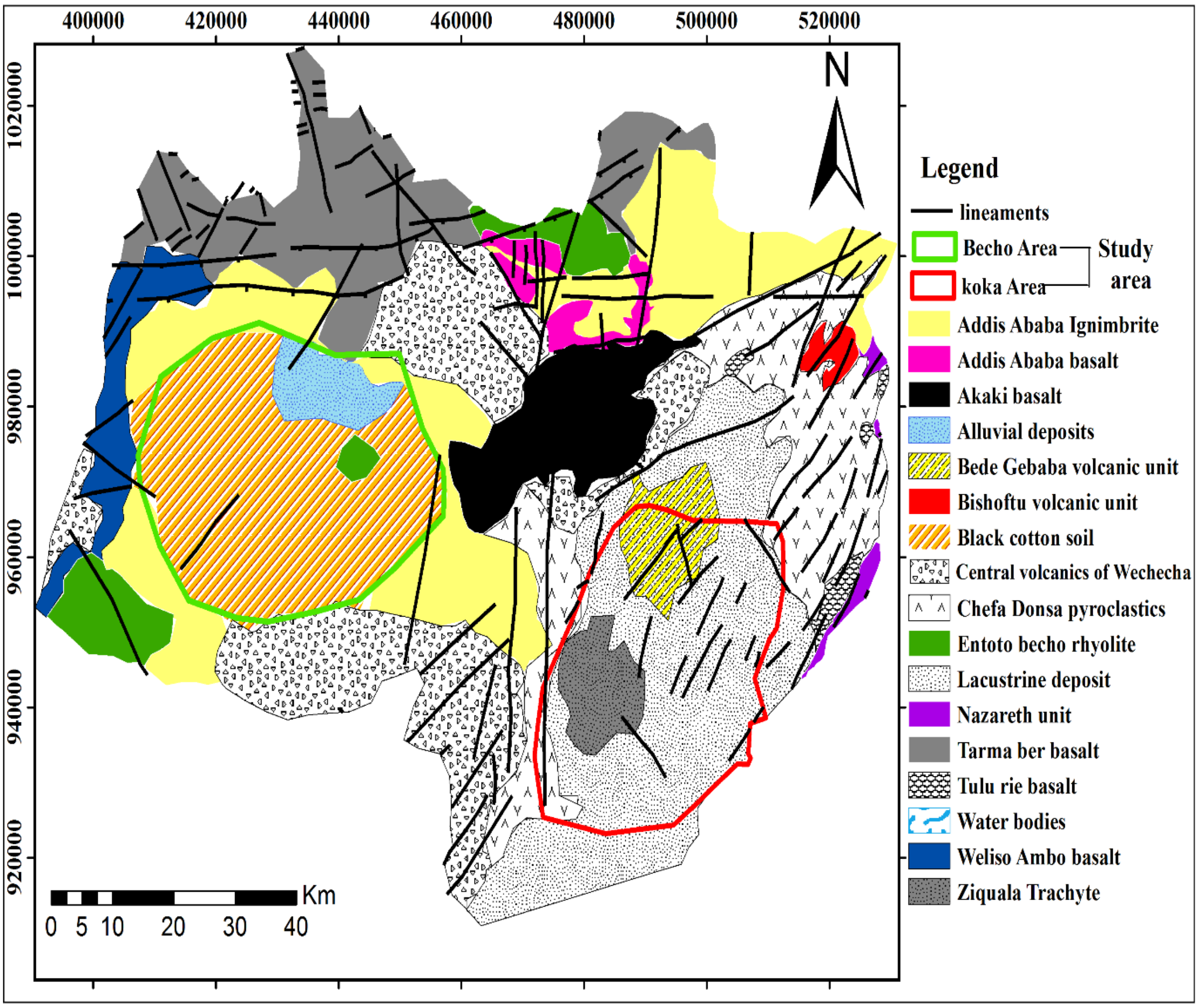

Figure 3.2 Simplified geological map of study area (modified from WWDSE, 2008 and ATA ,2014)

3.2 Hydrogeology

The hydrogeological set up of the Upper Awash river basin is governed by the lithological stratigraphy of the area and structures (WWDSE,2008). According to Andarge Yitbarek (2009) explained as the complex nature of the lava flow, the volcanic rocks have highly variable primary porosity. Later on through time, these volcanic rocks have been subjected to weathering and fracturing related to tectonics giving rise to secondary porosities. These volcanic aquifers can be considered as a double porosity medium due to the fact that both the matrix and the fracture porosity contribute to the circulation and storage of groundwater.

The hydrogeological units of the Becho area mainly moderate to highly productive aquifer, Primary porosity aquifer and local aquiclude. Moderate to highly productive aquifer is characterized by with high storage and yield (> 0.5 l/s); aquifer thickness around 60m; yield increases towards rivers; seasonal water level flactuation is 1 to 2m (ATA,2014).

The major auifer in Koka area is primary porosity aquifer (figure 3.3). Primary porosity aquifer comprises aquifers related to quaternary alluvial and lacustrine deposits. The alluvial and lacustrine aquifers are found dominantly in the southeast around Debrezeit,Modjo and koka towns, and locally in the northwestern part of the Becho area and along the main perennial river courses. The alluvial and lacustrine deposits around Debrezeit and Modjo have thickness up to 80 meters and composed of coarse sediments with static water level varies from 7 to 39 meters (Andarge Yitbarek, 2009, as cited in WWDSE, 2008). The water quality is generally fresh and the electrical conductivity varies from 444 to 841 µS/cm and total dissolved solids from 220 to 750 mg/l (WWDSE,2008).

Upper Basaltic Aquifer: Is composed of quaternary of Weliso-Ambo basalts, Akaki basalts: scoria and spatter cones, and Tertiary-Neogene's basalt of Addis Ababa basalts. It is distributed in Upper Awash, where it outcrops at central Addis Ababa, Weliso and Akaki and it also overlain by ignimbrites and tuffs at Becho area, Legedadi area, in general where the ignimbrites and tuff outcrops. This aquifer has wide distribution and forms confined and unconfined aquifer system. The formation is intruded by trachytic and ryholitic volcanic ridges and centers. Most of the groundwater of this aquifer forms the base flow of the rivers in upper Awash and part of it is discharged in to Debre Zeit lakes, where most of the outflow from these Lakes is by evaporation and also recharges the lower aquifer. The Electrical conductivity of the aquifer varies from less than250 µS/cm to900 µS/cm. The groundwater level depth increases from north-south direction. At the northern part the groundwater of the aquifer is shallow (less than 5 meters) and at the central part it varies from 5 to 20 meters deep and to the south depth increases progressively to more than 50 meters deep (WWDSE,2008).

Lower Basaltic Aquifer:This unit is composed of lower Tertiary Tarmaber and Amba Aiba basalts, dominantly scoraceous. The recent exploratory wells drilled in Becho, Holeta,Melkakunture, and Legedadi areas penetrated this aquifer under thick impermeable ignimbrites (up to 225m). The water level significantly rises from its first striking depth (220m rise at Asgori well) and the yield of the wells were progressively increasing when the depth of penetration increase in this aquifer. So far none of the deep wells fully penetrate this aquifer. Static water level varies from artesian condition to a depth of 67.5 meters below ground surface. The thickness of the aquifer is considered to be 100 meters and the storage coefficient of the aquifer to be about 0.15 (Andarge Yitbarek ,2009, as cited in WWDSE, 2008).

Local aquiclude: These are localized acidic volcanic units of quaternary Bede Gebaba volcanic unit. They are composed of rhyolitic to minor trachytic lavas, pumice, Ziquala trachytes,Tertriary Entoto-Becho rhyolites, Central Volcanics of Wechecha and prophyritic trachytic lavas. They have low permeability, except along weathered and fractured zones, and less fractured and faulted (WWDSE,2008).

regional aquicludes: These units are grouped in two to upper aquicludes and lower auicludes. Upper aquicludes which includes Chefe Donsa Pyroclastics, Nazaret unit (Welded ignimbrites) and Addis Ababa ignimbrites of low productive along the weathered and fractured zone. Acts as a regional aquiclude which separates the upper and lower volcanic aquifer in Becho area and Legedadi area, whereas lower Aquicludes which includes Assange basalt and Blue Nile basalt of old basalt and columnar massive basalt practically impervious except at local area due to secondary fracturing. Due to the massive and hard condition, it was difficult to drill in Blue Nile basalt. These formation acts as an aquiclude between the Mesozoic sedimentary formation and lower basalt aquifer (WWDSE,2008).

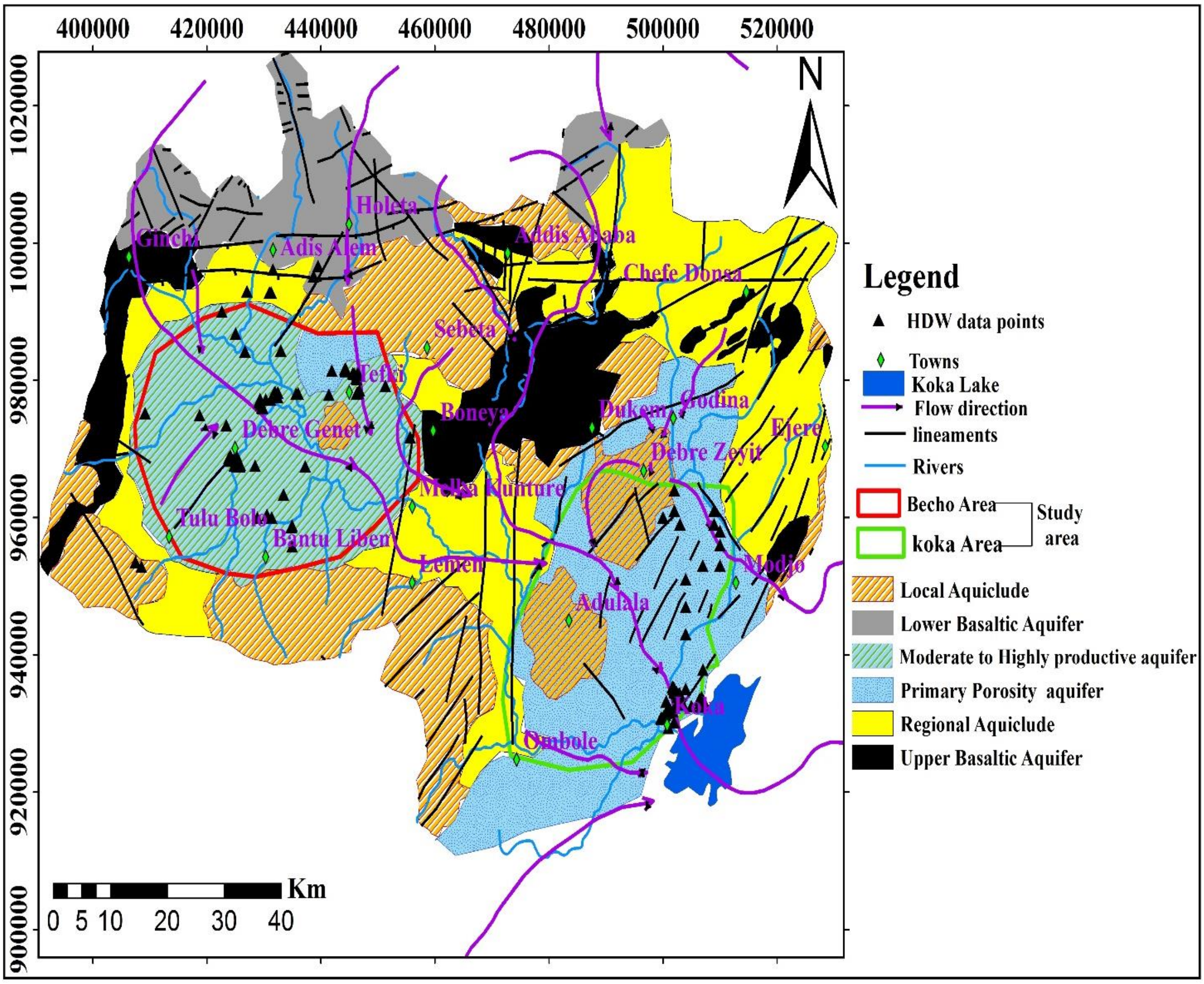

Figure 3.3 Hydrogeological map of the study area (modified from WWDSE, 2008 and ATA,2014)

CHAPTER 4 HYDROGEOLOGICAL CHARACTERIZATION

4.1 Recharge estimation

4.1.1 General

According to Andarge Yitbarek (2009, as cited in Balek, 1988) recharge is defined as the process of downward movement of water through the saturated zone under the force of gravity or in the direction determined by hydraulic conditions. Recharge is essential for hydrogeological characterization of aquifer systems, a key component in any model of groundwater flow, and water resource management for sustainable use and benefit of the different water users (Behailu Berehanu et al.,2017; Andarge Yitbarek, 2009). For this study, Base Flow Separation (BFS) method by using both River Analysis Package Software Version 3.0.3 and Excel spreadsheet program used as an indirect recharge estimation method.

4.1.2 Base flow

All water flowing in a stream originates as precipitation, but the water takes various routes to get there. Thus, the runoff of a river consists of three major components: i) direct runoff which flows over land and makes up the main river channel, ii) interflow which only flows part of the way into the ground but does not join the main runoff, and iii) baseflow which is thought of as the natural groundwater discharge (Soteriou ,2016 as cited in Meyboom, 1961; Charles ,2002). The major assumption in using base flow for estimating recharge is that base flow equals groundwater discharge from the aquifer storage and that groundwater discharge is approximately equal to recharge, assuming that loses from gauged watersheds caused by underflow, groundwater evapotranspiration and abstraction are minimal (Andarge Yitbarek,2009; Charles ,2002). However, for some rivers the assumption that baseflow consists entirely of groundwater discharge is false by anthropogenic influences such as reservoirs or dams, and irrigation return flow can often control much of a rivers hydrograph during periods of low flow (Soteriou ,2016 as cited in Capesius and Arnold, 2012; Nathan and McMahon, 1990).

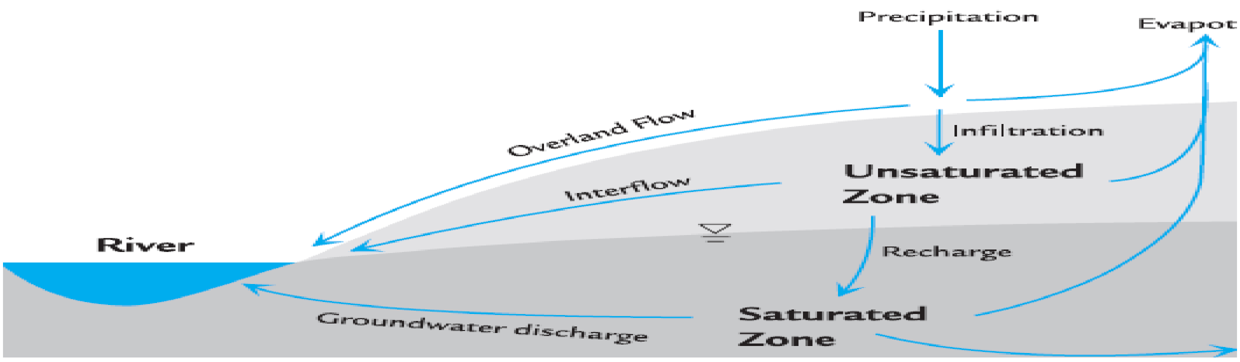

Figure 4.1 The incoming and outgoing fluxes associated with the water balance of a river system (source: Charles ,2002).

4.1.3 Estimating base flow

The chosen techniques for this study were the Sliding Interval, Fixed Interval, Local Minimum and IH low flow approach by using excel spreadsheet program. The Fixed Interval, Sliding Interval and Local Minimum separation techniques were established from a study measuring the water quality in Ohio (Pettyjohn and Henning, 1979) and using the formula in equation 1. Where, N represented the number of days after surface runoff ended and A, was the catchment area.

$$N = (A/2.59)^{0.2} \quad (1)$$

Each of these three separation techniques used slightly different algorithms which can be seen in Appendix 1. The 4th baseflow estimation was the Institute of Hydrology (IH) low flow separation technique, which was established to estimate baseflow for rivers in the UK (Gustard et al.,1992). Out of the four methods used, this technique uses the most complex algorithm to calculate the baseflow component; this can also be seen in Appendix 1.

Along with entering daily discharge data, the catchment area for each river gauging station had to be specified. It was then possible to calculate the four baseflow components for each day. As a result, the mean total flow, mean base flow, mean baseflow index values were calculated in m^3/s.

The most suitable periods of data were chosen to be analyzed for both Koka and Becho areas are the daily river flow records for Awash river at Hombole 33 years (1983-2015), Modjo river 38 years (1968-2005), Teji river 29 years (1983-2011) and Awash river at

Bello 28 years (1987-2014) respectively. Although, the most suitable periods of data were chosen to be analyzed, there were still some days of missing data. In order to account for any missing daily discharge values linear interpolation gap filling method were applying by using RAP software version 3.0.3.

The mean annual flow summary in m^3/s of each gauging stations presented in appendix 2, and mean annual base flow, surface runoff, recharge and precipitation Awash river at Hombole, Modjo, Teji and Awash river at Bello gauging stations presented in table 4.2.

Based on the base flow obtained by excel spreadsheet program, the average annual groundwater recharge of Koka and Becho areas Awash river at Hombole is estimated to be 111mm, which is amounts to only 12.1 % of the mean annual areal precipitation of the study area, Modjo river is estimated to be about 97.2 mm , which is only 10.4% of the mean annual areal precipitation, Teji river is estimated to be 58.7 mm ,which is only 5.64 % of the mean annual areal precipitation and Awash river at Bello is estimated to be about 99.2 mm , which is only 10.6% of the mean annual areal precipitation of the study area respectively.

Table 4.1 Mean monthly river flow, base flow, surface runoff and base flow index in the study area in m^3/s.

Study area	River gauging stations		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
Koka	Awash river at Hombole (1983-2015)	MRF	4.0	4.4	5.6	9.0	9.5	21.2	93.4	205.1	120.5	18.9	7.5	4.5	42.0
		MBF	3.5	3.4	3.4	4.7	5.4	10.7	54.4	138.0	78.5	13.7	6.5	4.1	27.2
		MSRO	0.5	1.0	2.2	4.3	4.1	10.5	39.0	67.1	41.9	5.2	1.0	0.4	14.8
		BF/TF%	0.9	0.8	0.6	0.5	0.6	0.5	0.6	0.7	0.7	0.7	0.9	0.9	0.7
	Modjo river (1968-2005)	MRF	4.2	4.6	5.7	5.4	8.0	13.7	40.9	77.5	32.4	5.4	4.2	4.2	17.2
		MBF	4.1	4.3	4.2	3.4	5.0	7.3	10.0	31.7	13.2	3.2	4.1	4.1	7.9
		MSRO	0.1	0.3	1.4	2.0	3.0	6.4	30.9	45.8	19.1	2.2	0.1	0.1	9.3
		BF/TF%	1.0	0.9	0.7	0.6	0.6	0.5	0.2	0.4	0.4	0.6	1.0	1.0	0.7
Becho	Teji river (1983-2011)	MRF	0.3	0.3	0.3	0.5	0.7	2.2	10.2	16.0	6.1	0.8	0.4	0.3	3.2
		MBF	0.2	0.2	0.2	0.3	0.3	0.8	3.3	5.3	2.7	0.6	0.4	0.3	1.2
		MSRO	0.0	0.0	0.1	0.2	0.3	1.4	6.9	10.7	3.4	0.2	0.0	0.0	2.0
		BF/TF%	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.3	0.4	0.7	0.9	0.9	0.6
	Awash river at Bello (1987-2014)	MRF	0.6	0.5	0.7	1.4	1.6	6.8	27.8	41.7	31.4	7.8	1.7	0.8	10.2
		MBF	0.5	0.4	0.4	0.8	0.8	4.3	21.9	38.2	26.4	5.5	1.4	0.7	8.4
		MSRO	0.1	0.1	0.3	0.7	0.8	2.4	5.9	3.5	5.0	2.3	0.2	0.1	1.8
		BF/TF%	0.9	0.7	0.6	0.5	0.5	0.6	0.8	0.9	0.8	0.7	0.9	0.9	0.7

Table 4.2 Mean annual base flow, surface runoff, recharge and precipitation Awash river at Hombole, Modjo, Teji and Awash river at Bello gauging stations using baseflow excel spread sheet program.

Study Area	Gauging stations	Area (km^2)	BF(mm/y)	SRO(mm/y)	Recharge(mm/y)	Rainfall(mm/y)
Koka	Awash river at Hombole (1983-2015)	7656.0	111.0	61.3	111.0	914.4
	Modjo river (1968-2005)	1264.4	97.2	187.5	97.2	940.6
Becho	Teji river (1983-2011)	662.5	58.7	94.2	58.7	1041.3
	Awash river at Bello (1987-2014)	2568.8	99.2	21.9	99.2	936.8

Accordingly, the estimated mean annual recharge from base flow separation over the Koka and Becho areas are 104.1 mm and 79 mm respectively. The low permeability clayey soils in Becho area specifically the gauging station at Teji river limit infiltration, recharge, and baseflow to a small amount of precipitation, and most of the river discharge comes from overland flow. On the other hand, in the koka area specifically the gauging station Awash river at Hombole has significantly thick alluvial/lacustrine deposits, since direct recharge is possible due to primary porosity and permeability of this unit and most of the river discharge there is baseflow.

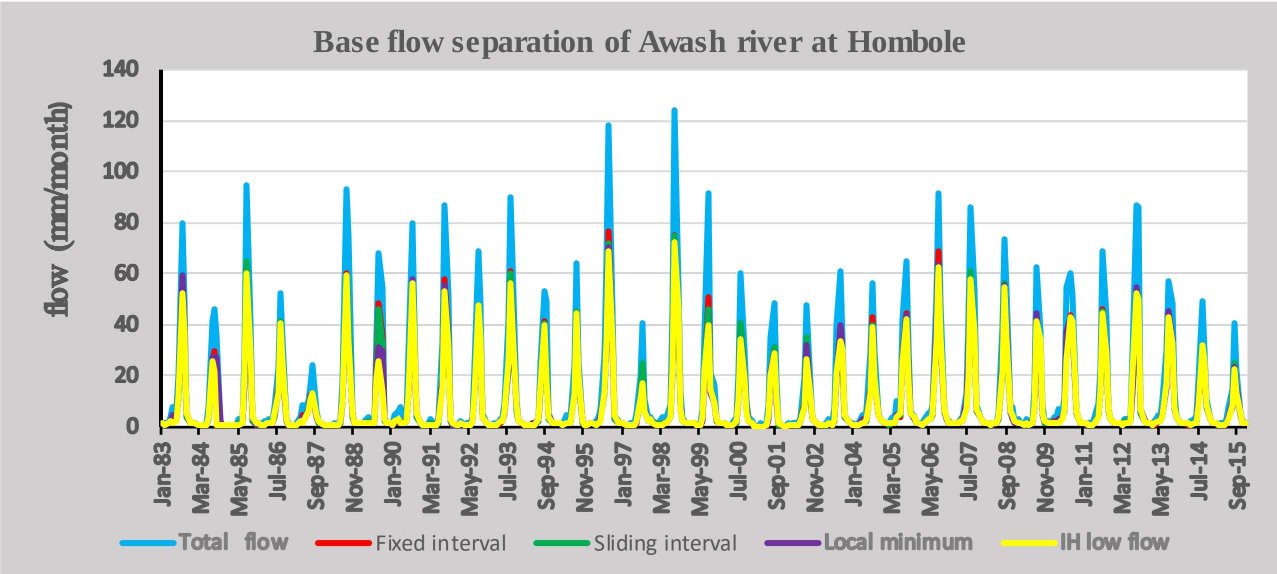

Figure 4.2 Total flow and four base flow separation methods for river gauge: Awash river at Hombole (1983-2015). The blue line is the total flow, red line is the fixed interval, green line is the sliding interval method, purple is the local minimum method and yellow is the IH low flow method.

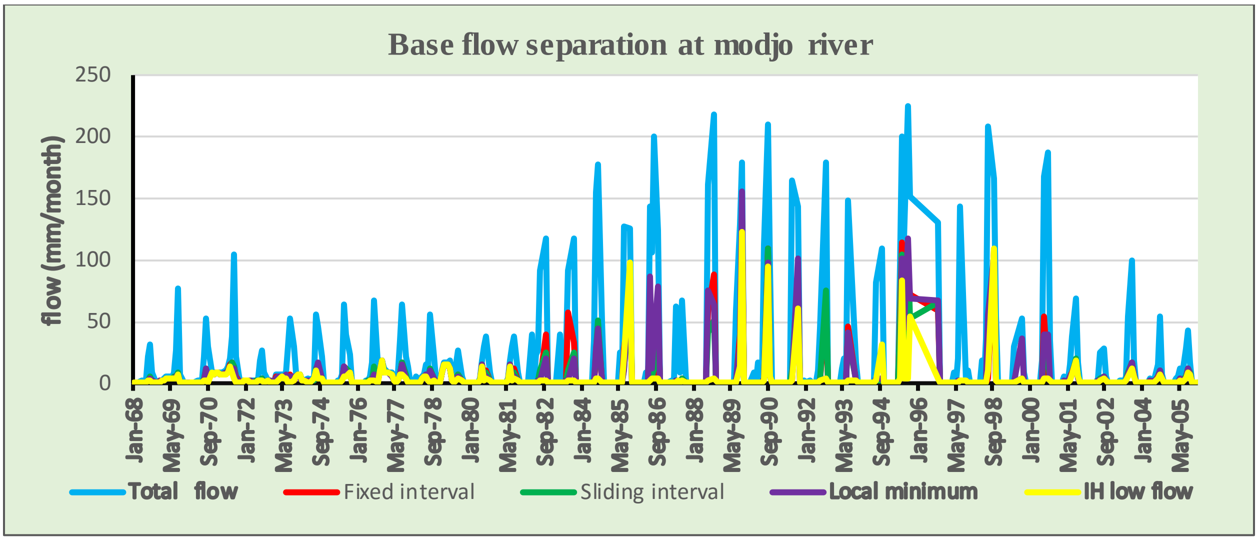

Figure 4.3 Total flow and four base flow separation methods for river gauge: Modjo river (1968-2005). The blue line is the total flow, red line is the fixed interval, green line is the sliding interval method, purple is the local minimum method and yellow is the IH low flow method.

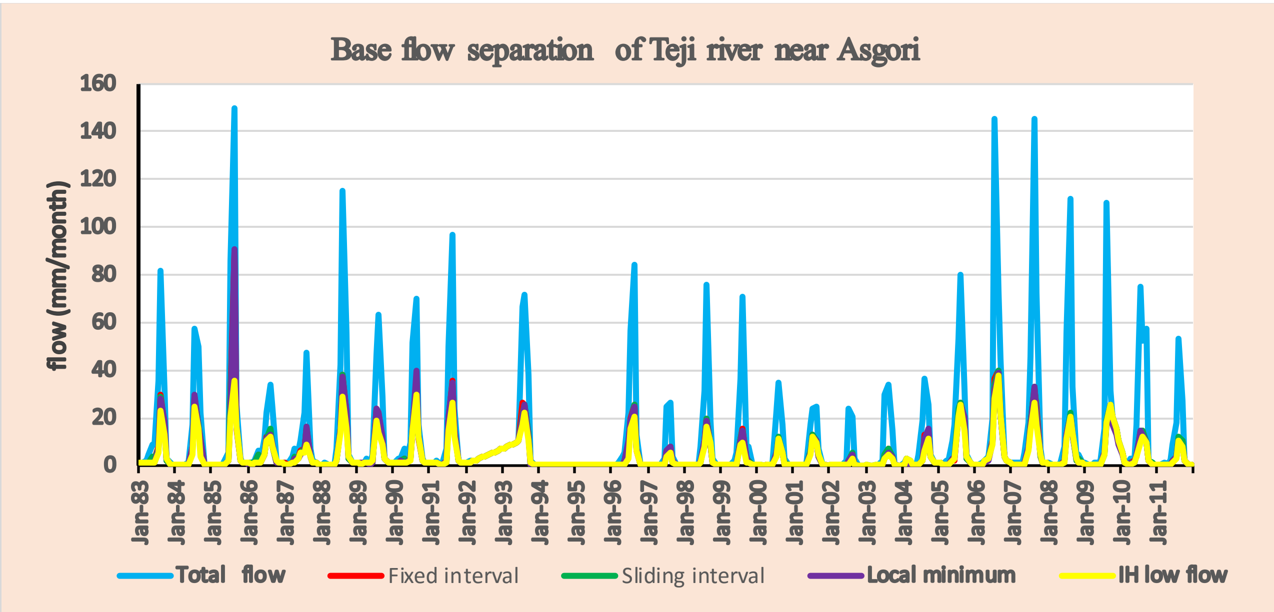

Figure 4.4 Total flow and four base flow separation methods for river gauge: Teji river (1983-2011). The blue line is the total flow, red line is the fixed interval, green line is the sliding interval method, purple is the local minimum method and yellow is the IH low flow method.

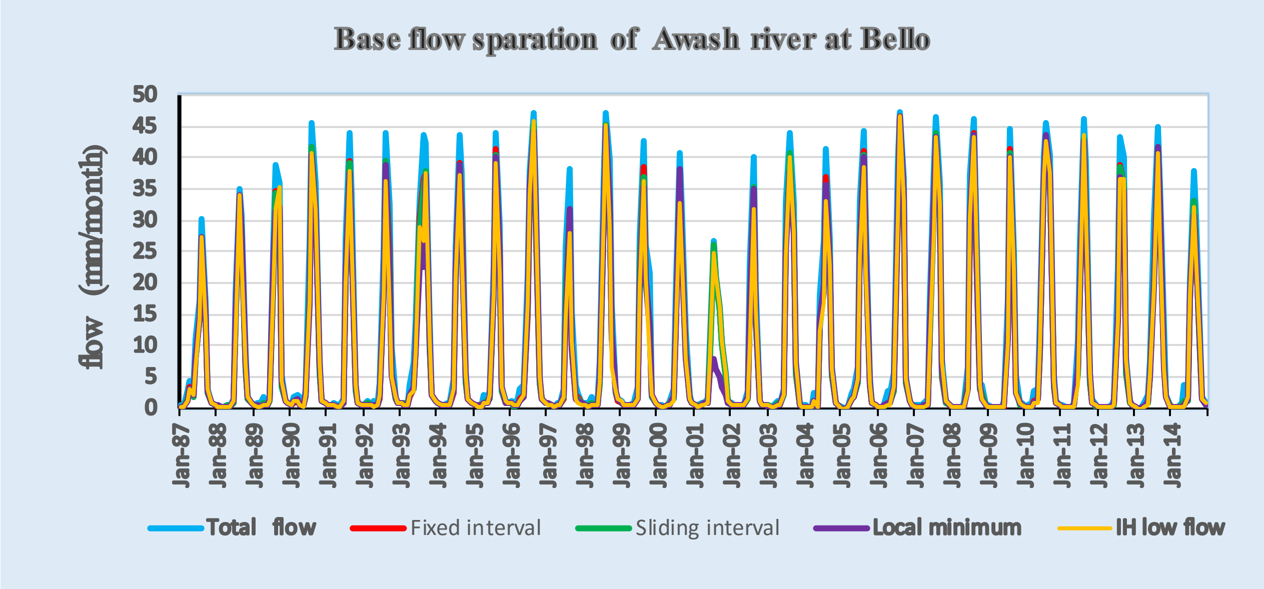

Figure 4.5 Total flow and four base flow separation methods for river gauge: Awash river at Bello (1987-2014). The blue line is the total flow, red line is the fixed interval, green line is the sliding interval method, purple is the local minimum method and yellow is the IH low flow method.

4.2 Water points of hand dug wells.

In Becho and Koka areas exploitation of groundwater through the construction of hand dug wells are major source for irrigation and domestic purpose. Most of the hand dug wells are on flat and gently sloping terrain on the recent deposits, alluvial deposits, Lacustrine deposits, and most of them have a depth ranging from 4 to 35 meters below ground surface. A total of 96 hand dug wells water points were inventoried from during field study and the inventoried 46 hand dug wells water points were taken as secondary data from ATA (2014) and WWDSE (2008) as described below in figure 4.7. Inventorying is done by field parameter measurements such as geographic locations using GPS, depth of well, static water level and the different water chemistry parameters (P^H, EC, TDS and temperature), which are included in appendix 4.

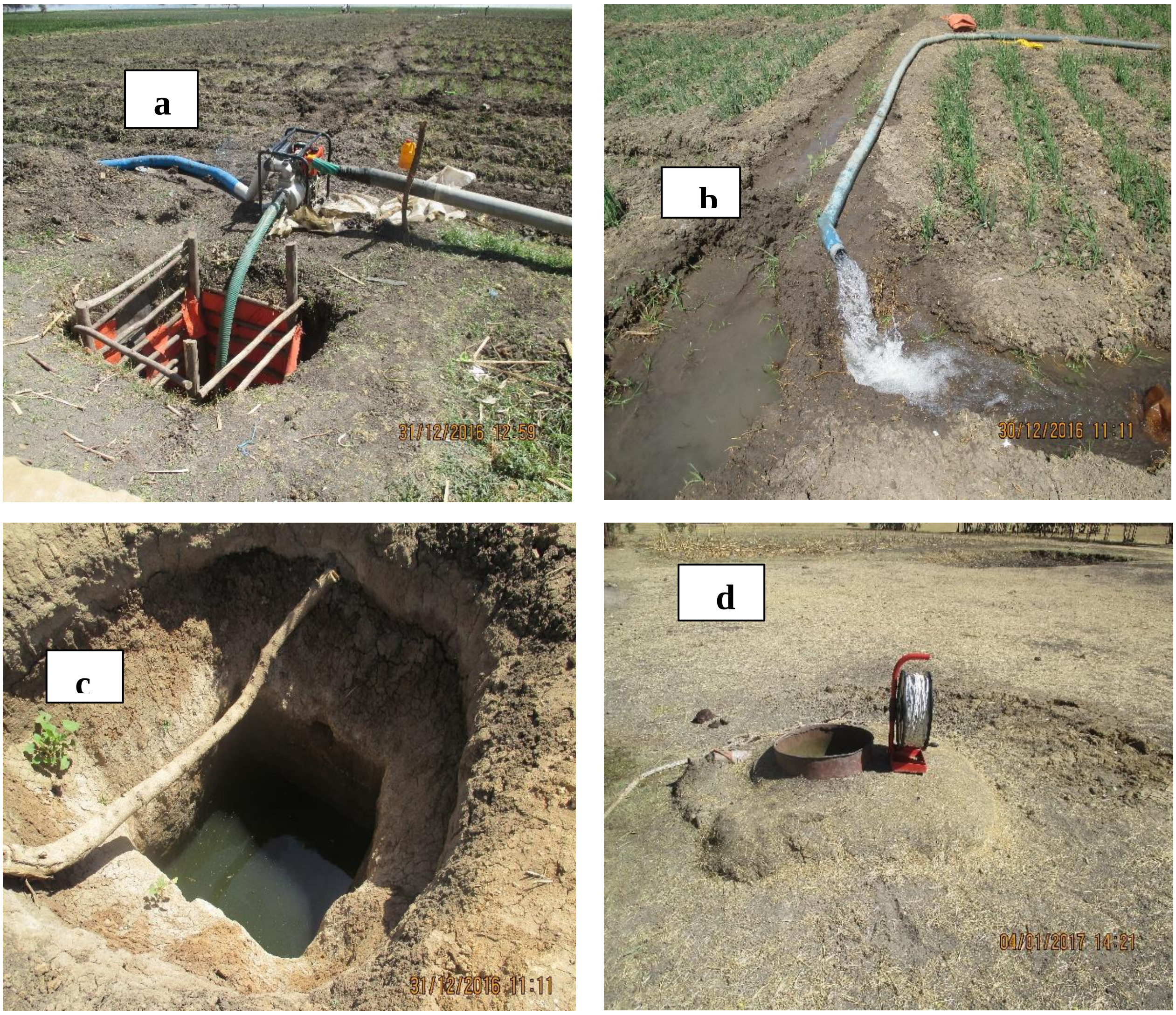

Figure 4.6 Hand dug wells. (a) HDW pumped by motor powered, (b), HDW used for irrigation purpose, (c), Very shallow HDW in Koka area near to Lake koka and (d) HDW in Becho area.

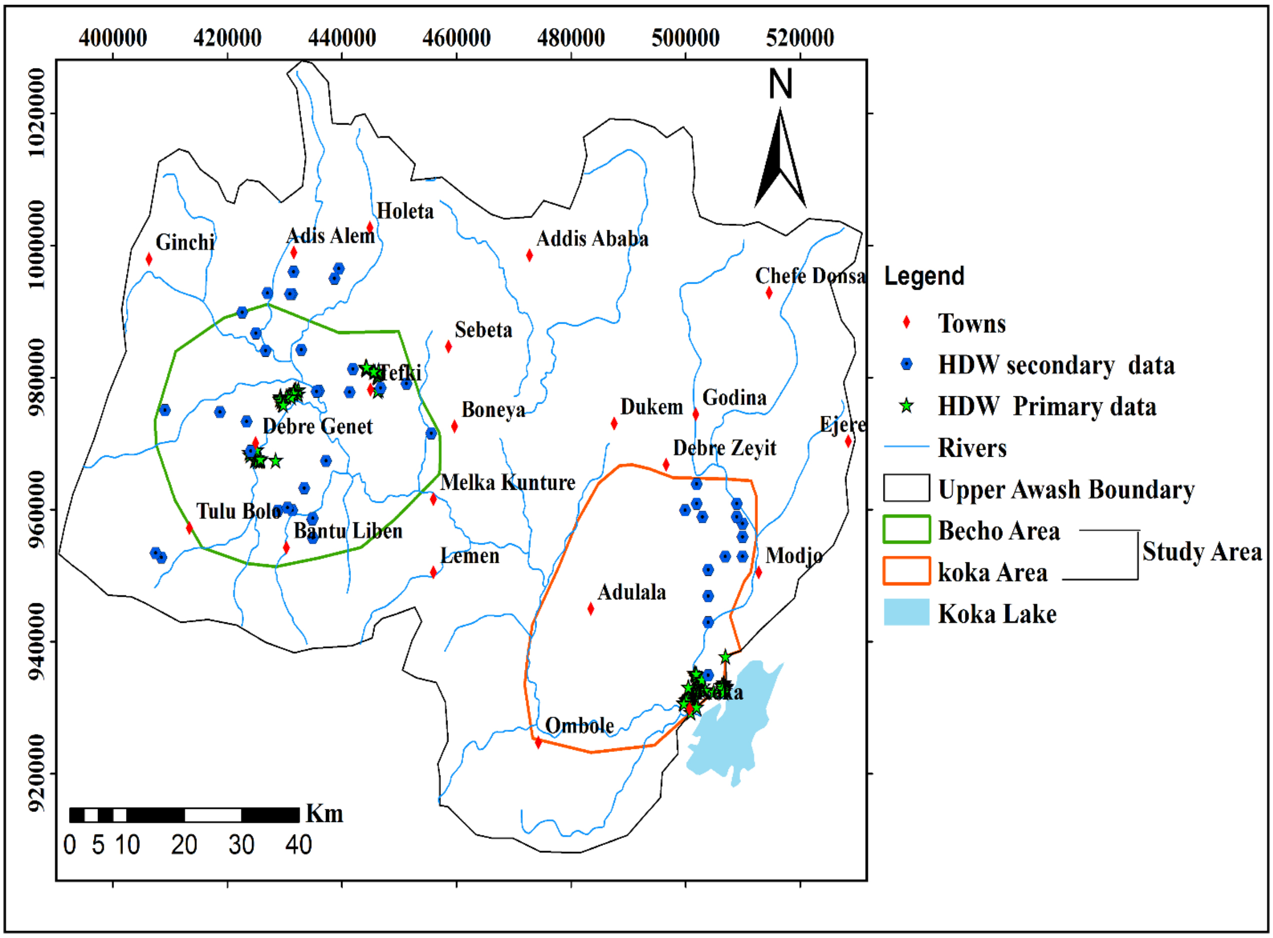

Figure 4.7 Distribution of inventoried water points within the study area and the surrounding area.

4.2.1 Groundwater flow

The groundwater flow in the study area is influenced by geomorphology, which is the primary controlling factor on the flow system of the groundwater. Groundwater contour map is generated from field measurements of static water level of hand dug wells in order to understand the flow direction. In most parts of the area is the groundwater level distribution is similar to the topography, which follows the elevation variations. The groundwater level is generally flat to gentle slope except at some ridges. Accordingly, the shallow groundwater of the study area is the movement and flow direction is dependent on the inclination of the topography of the area. Regionally the groundwater flows from high plateau west of Addis Ababa and flows along the rift valley (WWDSE,2008).

The local groundwater flow direction in Becho area is tends to be towards the main Awash river. The local groundwater flow direction in Koka area is tends to be towards lake koka (figure 4.8).

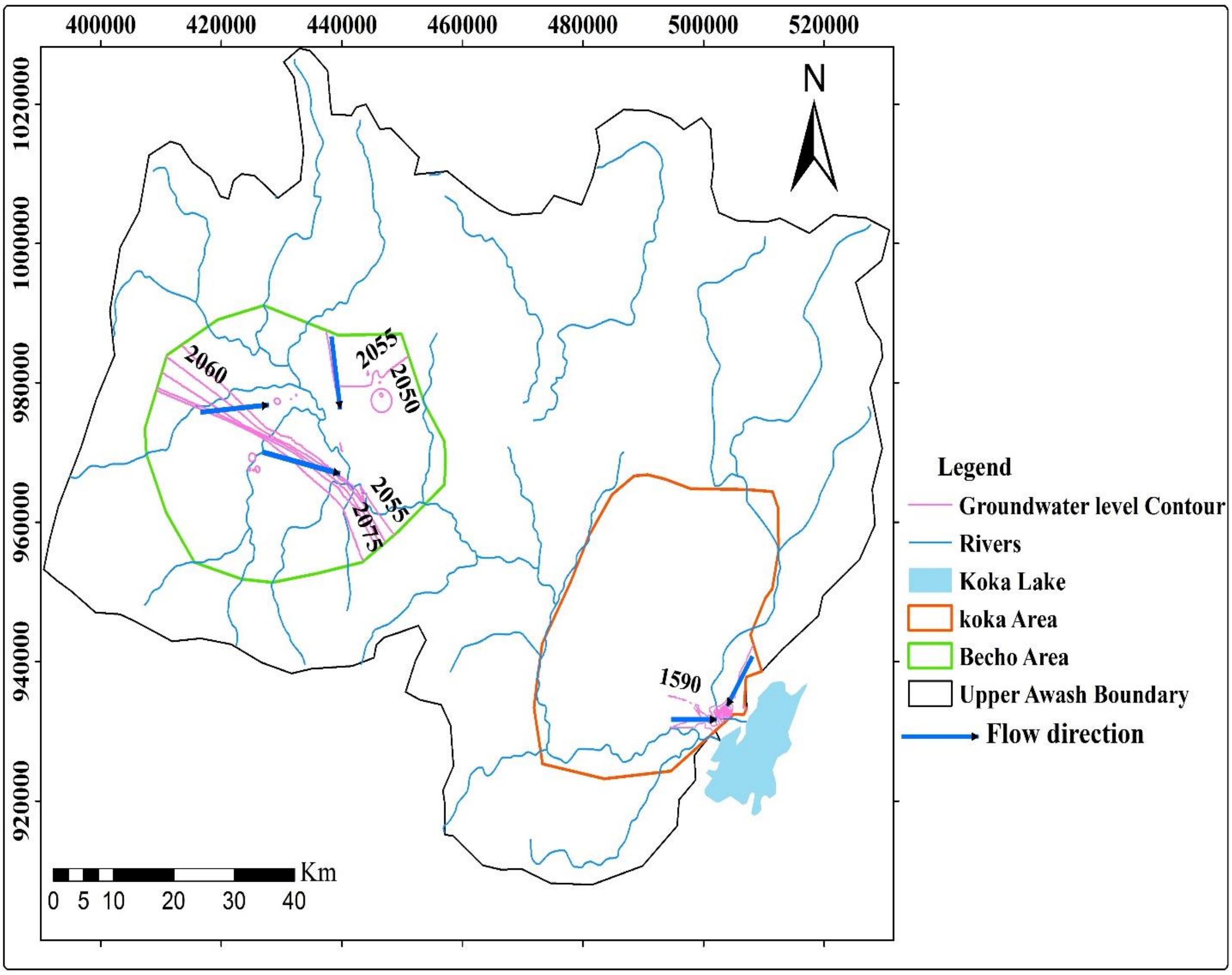

Figure 4.8 Groundwater level contour lines and the general groundwater flow.

Identification of the groundwater flow as well as recharge and discharge condition is also supported by the hydrochemical parameter data especially the distributions of TDS.The high elevated areas have low TDS values than relatively low laying lands, hence they are considered as the recharge areas and vice versa. In both areas, the distribution and contour map of TDS can confirm the groundwater flow almost similar with that of the groundwater level contour map (figure 4.9). Generally, it is possible to say the topographical highlands are recharge where as lowlands are discharge areas.

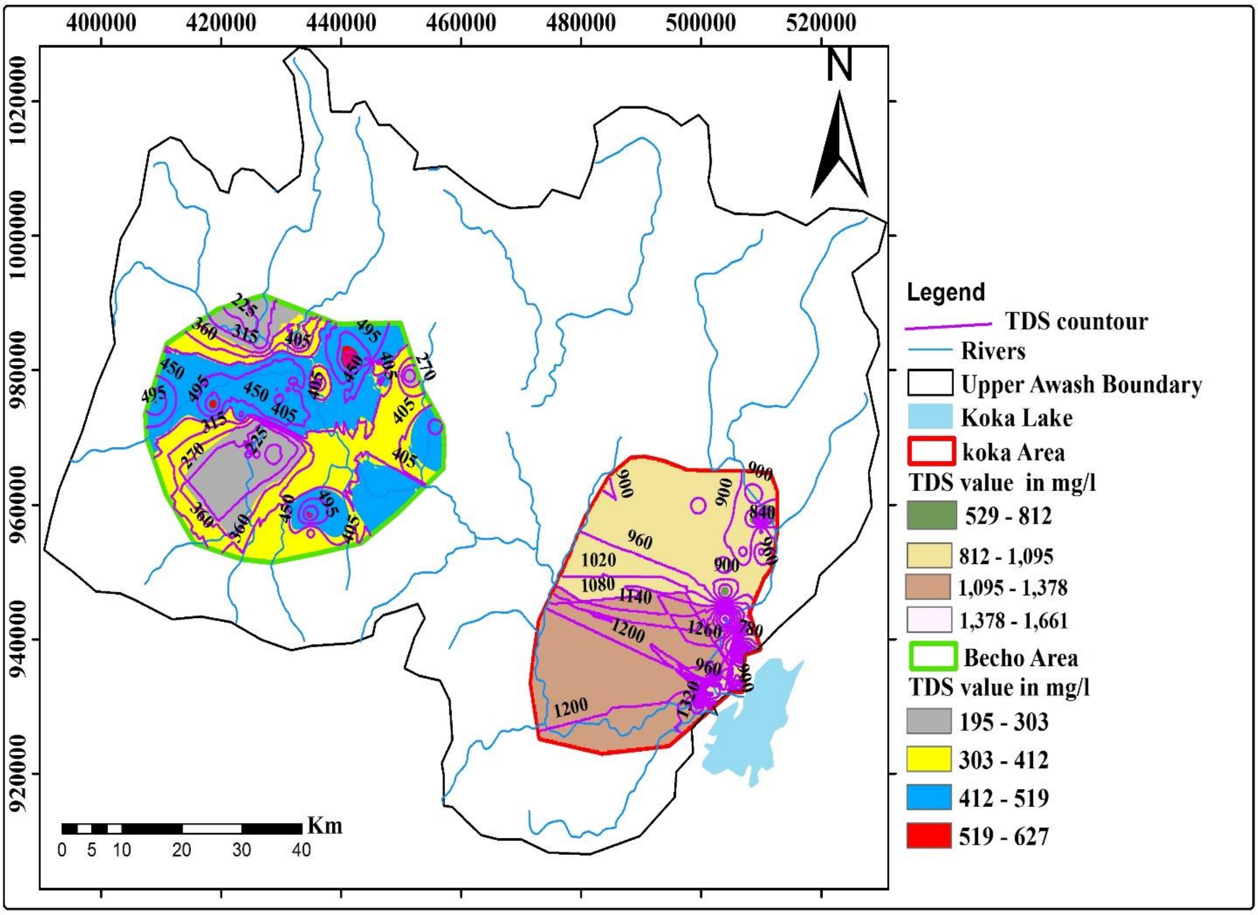

Figure 4.9 TDS distribution and contour map of the study area

4.3 Hydraulic property of the soil

4.3.1. Theory of operation

Hydraulic conductivity is the measure of the ability of a soil to conduct water under a unit hydraulic potential gradient. Among the most important factors governing liquid transmission in unsaturated soils are field saturated hydraulic conductivity (Kfs). According to Soil moisture equipment CORP (1985) field saturated hydraulic conductivity refers to the saturated hydraulic conductivity of soil containing entrapped air.

The Guelph Permeameter is an in hole constant head Permeameter, employing the Mariotte Principle. When the Permeameter is operating, an equilibrium is established. The reduced pressure (vacuum) in the air above the water in the reservoir (p_1) together with the pressure of the water column extending from the surface of the well to the surface of the water in the reservoir (p_2) always equals the atmospheric pressure (p_0) Known as Mariotte Principle (Soil moisture equipment CORP,1985) as stated in figure 4.10.The method involves measuring the steady state rate of water recharge into unsaturated soil from a cylindrical well hole, in which a constant depth (head) of water is maintained.

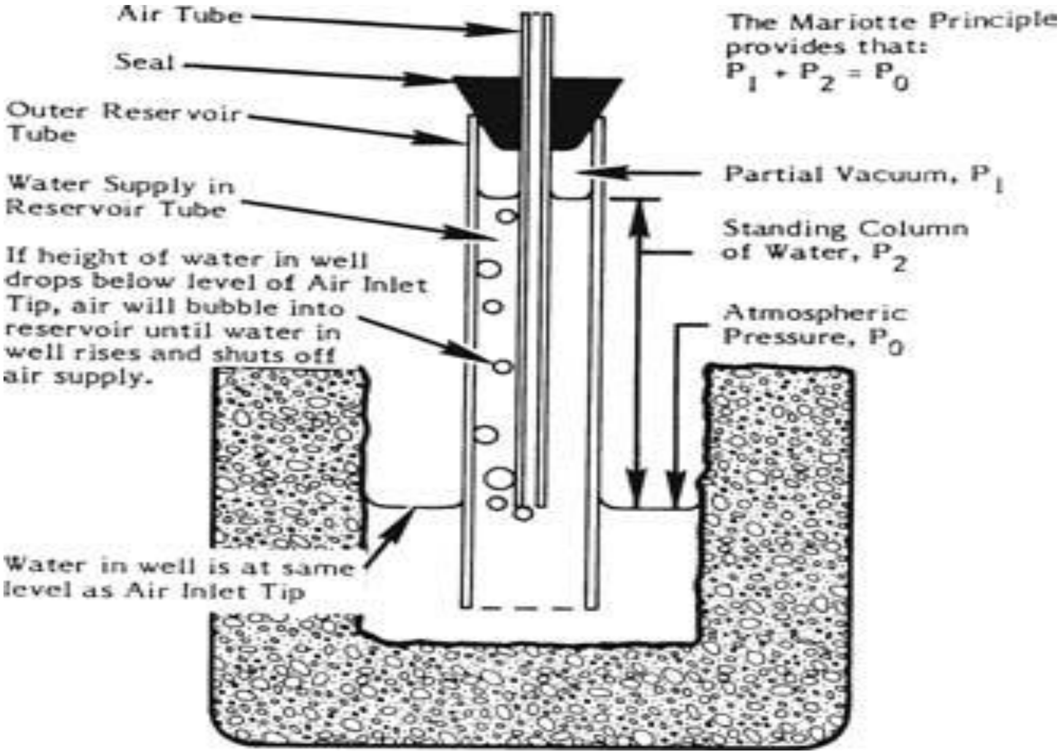

Figure 4.10 In hole constant head permeameter setup (Source: Soil moisture equipment CORP,1985)

A constant head level in the well hole is established and maintained at the level of the bottom of the air tube by regulating the position of the bottom of the air tube, which is located in the center of the Permeameter. As the water level in the reservoir falls, a vacuum is created in the air space above the water. The vacuum can only be relieved when air of ambient atmosphere pressure, which enters at the top of the air tube, bubbles out of the air inlet tip and rises to the top of the reservoir. Whenever the water level in the well begins to drop below the air inlet tip, air bubbles emerge from the tip and rise into the reservoir air space. The vacuum is then partially relieved and water from the reservoir replenishes water in the well. The size of opening and geometry of the air inlet tip is designed to control the size of air bubbles in order to prevent the well water level from fluctuating. When a constant well height of water is established in hole in the soil, a "bulb" of saturated soil with specific dimensions is rather quickly established (figure 4.11). This "bulb" is very stable and its shape depends on the type of soil, the radius of the well and head of water in the well (Soil moisture equipment CORP,1985).

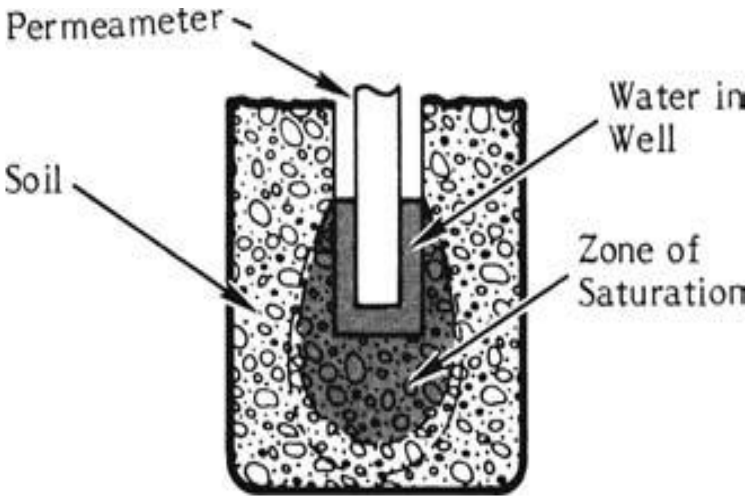

Figure 4.11 saturated zone around well (saturation bulb) (source: Soil moisture equipment CORP,1985)

Once the unique "bulb" shape is established, the outflow of water from the well reaches a steady state flow rate, which can be measured. The rate of this constant outflow of water, together with the diameter of the well, and height of water in the well can be used to accurately determine the field saturated conductivity (Soil moisture equipment CORP,1985).

According to the Soil moisture equipment CORP (1985) some of the specification unit ranges for field saturated hydraulic conductivity, well height range, well depth and well diameter are 0.000006 to 0.02cm/sec, 2.5 cm to 25 cm, 15 to 75 cm and 6 cm respectively. The reservoir combination is used in soil of moderate to high permeability. Soils that fit into this category typically have some degree of structure, medium to coarse texture, and little to no cementation or compaction, whereas the inner reservoir used for soils that have low permeability. Soils that fit into this category are typically fine textured, structureless, or significantly cemented or compacted (Soil moisture equipment CORP ,1985).

4.3.1.1 Field saturated hydraulic conductivity of the soil

Soil field saturated hydraulic conductivity measurements were taken from the total of Twenty (20) selected sites based upon topography, general soil appearance and intensive application of the soils (figure 4.14). Out of 20 are 10 sites for Becho area and also 10 sites are for Koka area had been taking measurements of soil field saturated hydraulic conductivity as stated in table 4.3. Measuring is done by according to Guelph permeameter field data sheet, which is provided site information and standardized procedure for permeameter readings and calculations. and each measurement has three (3) consecutive sheets. For as an example in situ soil field saturated hydraulic conductivity test results of MB4 and MK7 are presented in appendix 6.

During measurements of soil field saturated hydraulic conductivity in Becho area the reservoir used almost combined reservoirs except two selected sites, and the well depth ranges from 28 to 32 cm. The average estimated soil field saturated hydraulic conductivity is to be 0.000421 cm/sec, and estimates range from 0.00000230 to 0.00197 cm/sec, which reveals the minimum and maximum soil field saturated hydraulic conductivity (figure 4.15 a). The test results of soil field saturated hydraulic conductivity in this area except some parts manifests that the soil has medium field saturated hydraulic conductivity particularly western parts of Tefki as described in figure 4.15a, figure 4.16 and figure 4.17.

It is believed that medium field saturated hydraulic conductivity values are come from due to the presence of alluvial deposits during the wet season ,which covers the most upper parts of the soils .

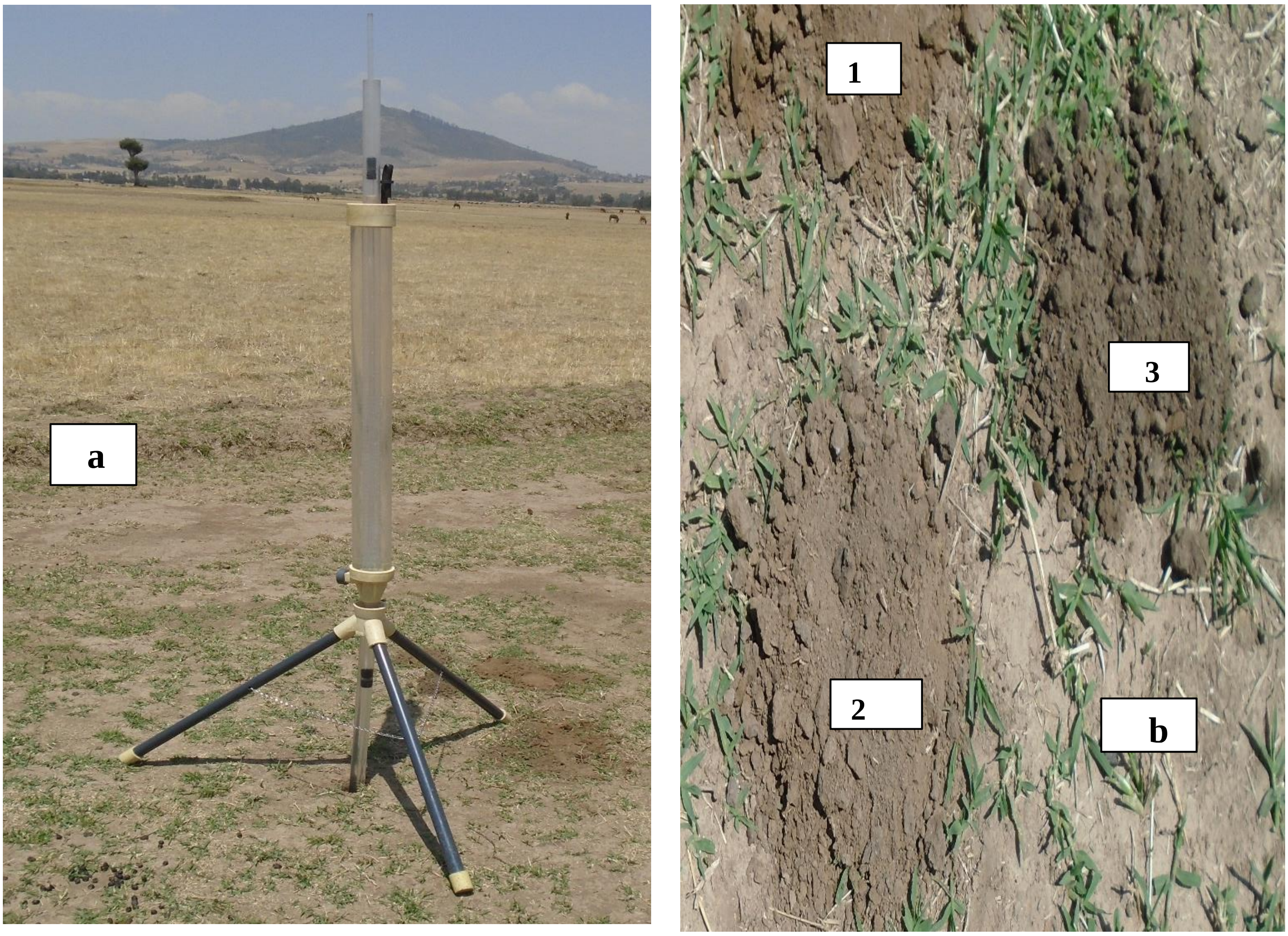

Figure 4.12 Measurements of Kfs by Guelph permeameter in Becho area. (a) placement of the Guelph permeameter in to the prepared well in the village of Nano kersa, (b) logs of soil was taken from during the preparation of the well: (1) and (2) represents depth range of well from 0 to 17 cm has medium grain and (3) represents well depth range from 17 to 31cm, and its color is gray to black with fine grained to medium grain.

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During measurements of soil field saturated hydraulic conductivity in Koka area the reservoir used was combined reservoirs, and the well depth ranges from 26 to 28 cm. The average estimated soil field saturated hydraulic conductivity is to be 0.00107 cm/sec, and estimates range from 0.0000704 to 0.00947 cm/sec, which reveals the minimum and maximum soil field saturated hydraulic conductivity (figure 4.15 b). The test results of soil field saturated hydraulic conductivity in this area manifests that the soil has medium to high field saturated hydraulic conductivity particularly Adulala nearby mountain Ziquala as described in figure 4.15b, figure 4.16 and figure 4.17, since the area has primary porosity due to dominated by the lacustrine deposits.

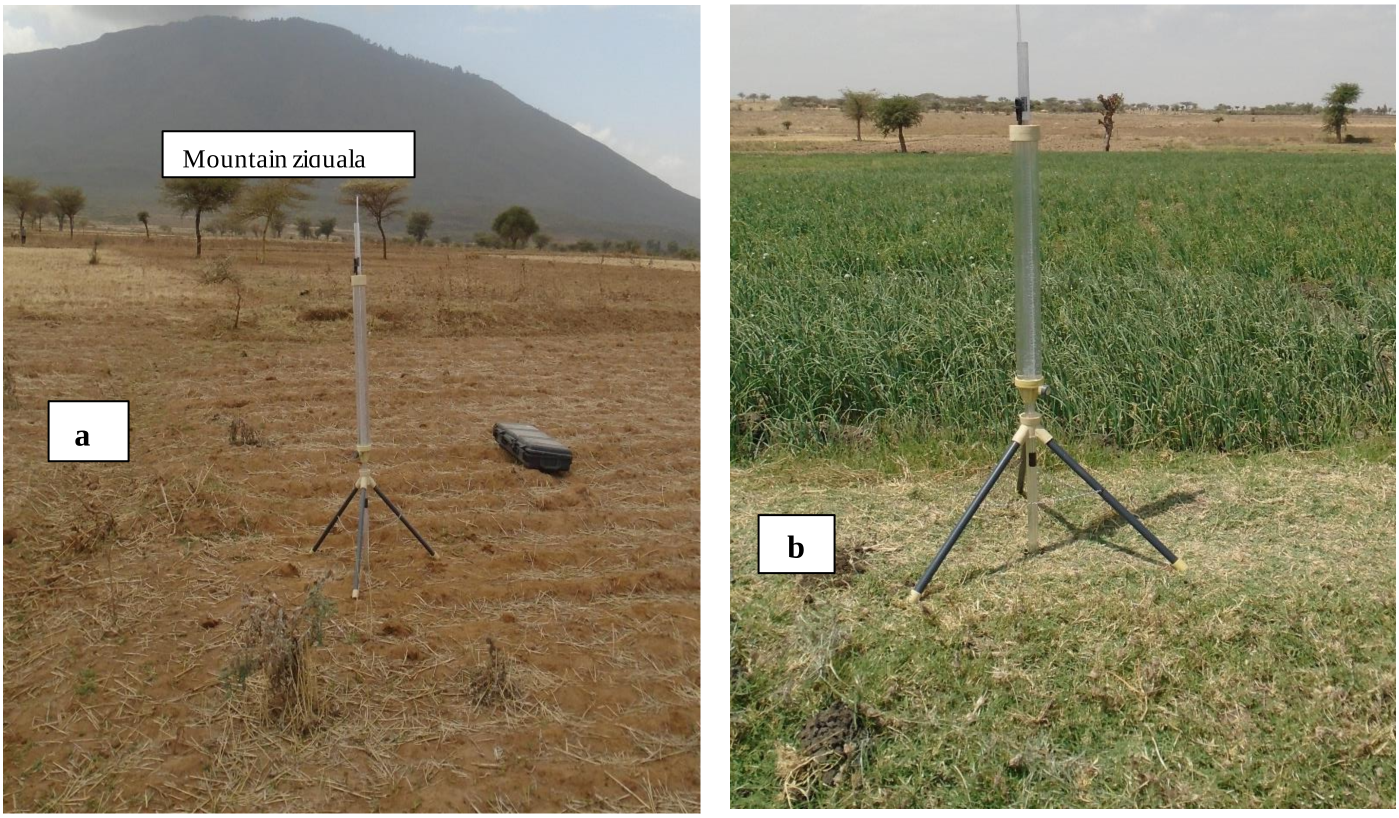

Figure 4.13 Measurements of Kfs by Guelph permeameter in Koka area. (a) placement of the Guelph permeameter in to the prepared well nearby Adulala, (b) placement of the Guelph permeameter in to the prepared well nearby koka Lake, which is intensive irrigation has been performing.

Table 4.3 Soil field saturated hydraulic conductivity test results

Locality Name	ID	Reservoir(s) Used	UTM location X	Y	Elv (meter)	Soil type	Kfs (cm/sec)	Well depth(cm)	Study Area)
Engugi Bekele	MK1	Combined	505694	933839	1599	Silty clay	0.000603	26	koka
Engugi bekele	MK2	Combined	505691	933288	1598	Silty clay	0.00098	27	koka
Engugi Bekele	MK3	Combined	505696	934142	1603	Silty clay	0.000415	27	koka
Gogeti goro	MK4	Combined	498602	933791	1594	clay loam	0.000169	28	koka
Liben Gadulla	MK5	Combined	494487	933734	1603	silty clay	0.00098	27	koka
Adelemeacha	MK6	Combined	489569	940584	1707	clay loam	0.00947	26	koka
Engugi Bekele	MK7	Combined	506513	933168	1596	clay loam	0.00197	26	koka
Sheradibandiba	MK8	Combined	510412	951946	1804	Silty clay	0.0000944	26	koka
Hude kebele	MK9	Combined	505378	958085	1870	silty clay	0.0000704	28	koka
keta	MK10	Combined	501032	963744	1887	clay loam	0.00053	28	koka
Keta Asgori	MB1	Combined	423666	968186	2097	Clay	0.000153	31	Becho
Keta Asgori	MB2	Inner reservoir	424155	968145	2091	Clay	0.0000023	31	Becho
Wesarbi basi	MB3	Combined	427706	968833	2102	clay	0.0000171	31	Becho
Koritu	MB4	Combined	432355	977702	2063	clay loam	0.00114	28	Becho
Jigdumida	MB5	Inner reservoir	432523	978807	2065	clay	0.00000576	31	Becho
Jigdumida	MB6	Combined	432611	979508	2069	clay loam	0.000339	32	Becho
Roge	MB7	Combined	429738	979830	2064	Clay	0.0000165	31	Becho
Tefki	MB8	Combined	446310	978170	2065	Clay loam	0.000528	31	Becho
Nano Kersa	MB9	Combined	444792	961440	2069	clay loam	0.00197	31	Becho
Nano kersa	MB10	Combined	445883	983529	2093	clay loam	0.0000352	31	Becho

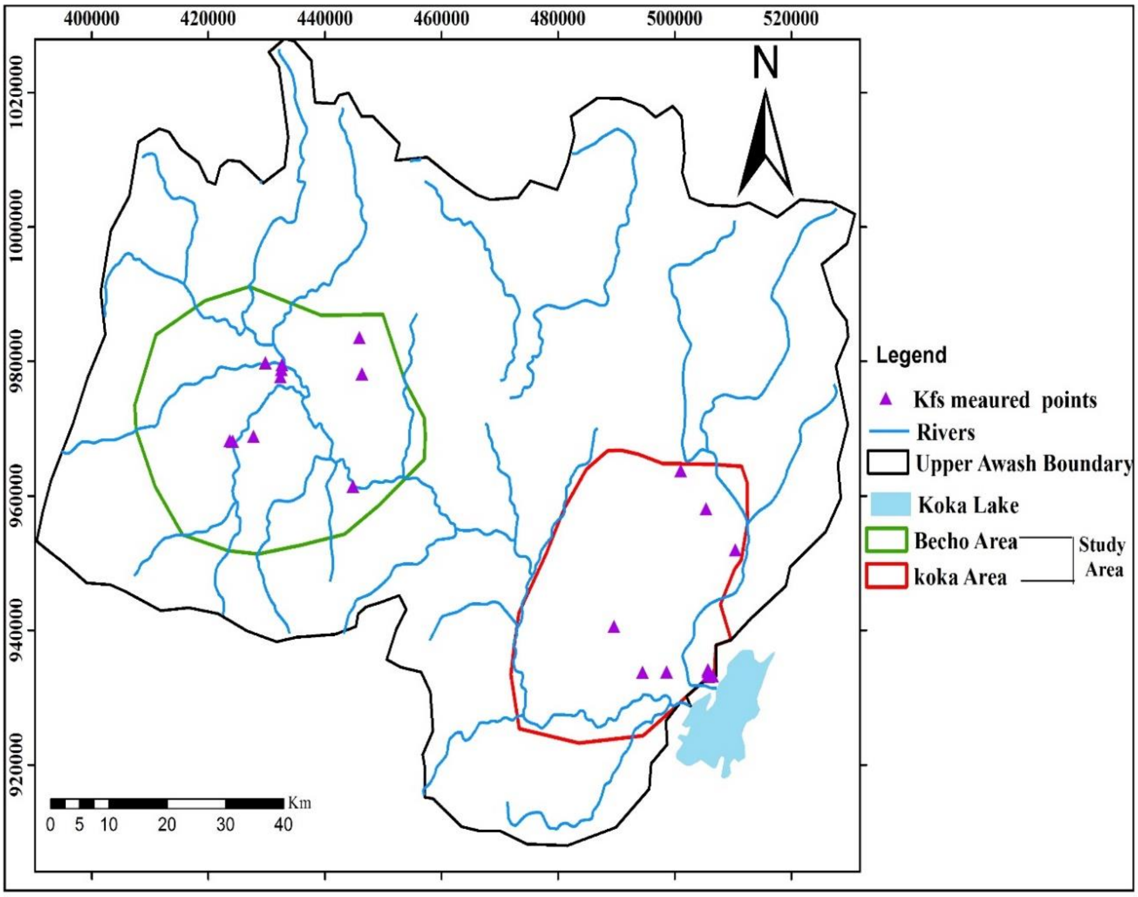

Figure 4.14 Distribution of field saturated hydraulic conductivity (Kfs) of soil data points within the study area

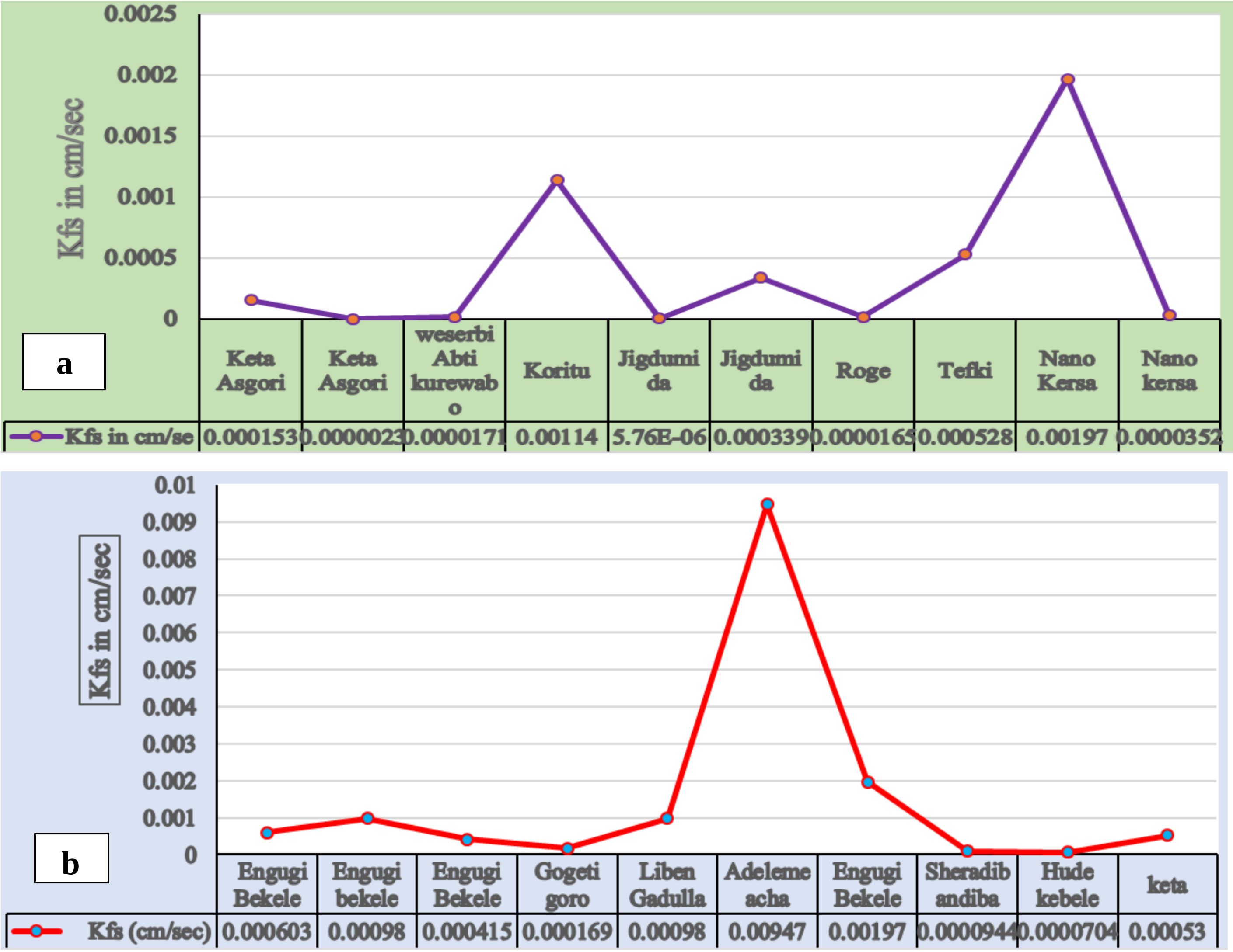

Figure 4.15 Distribution of field saturated hydraulic conductivity of the soil. (a), in Becho area, (b), in koka area.

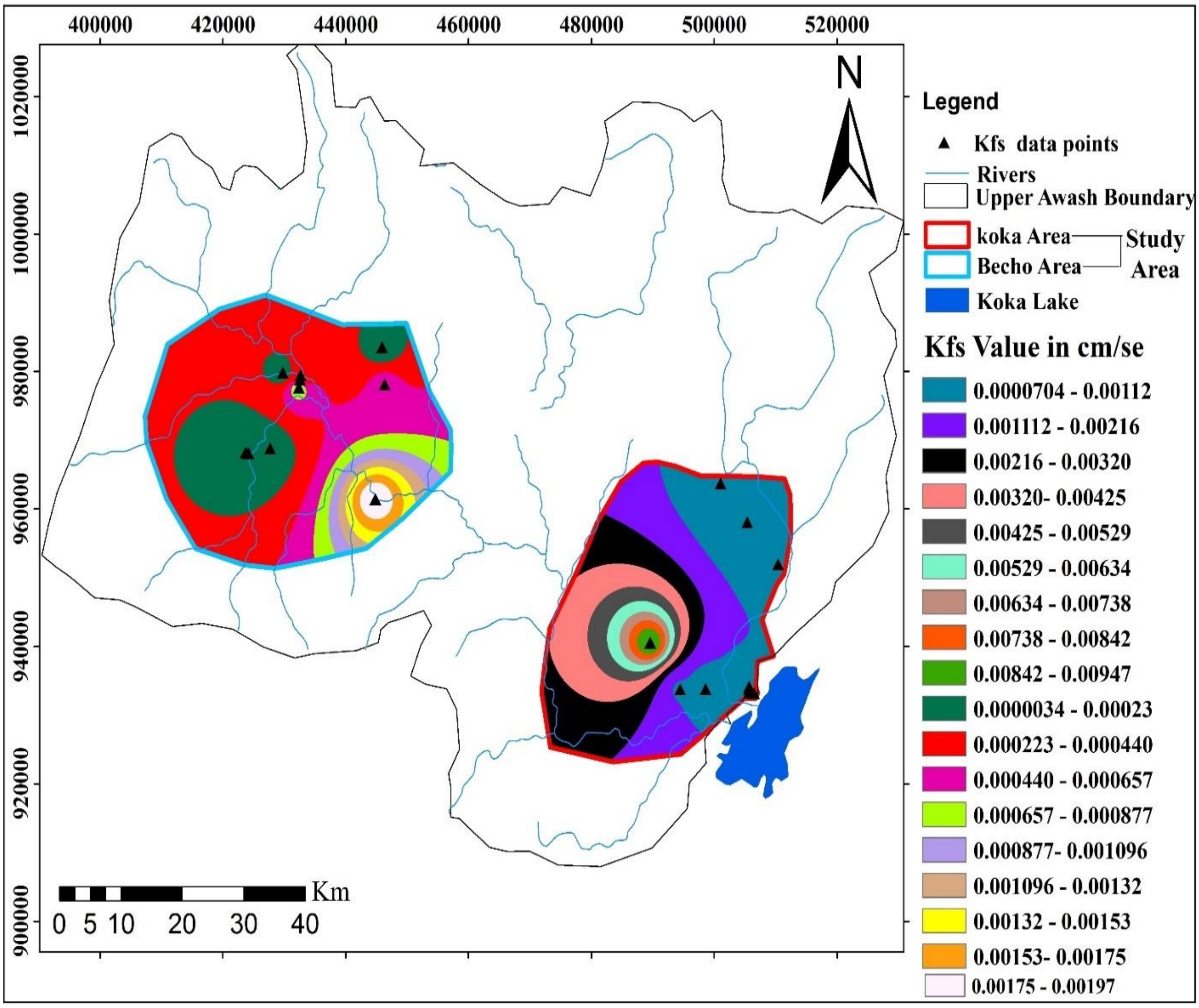

Figure 4.16 The map showing that distribution of soil field saturated hydraulic conductivity in the study area.

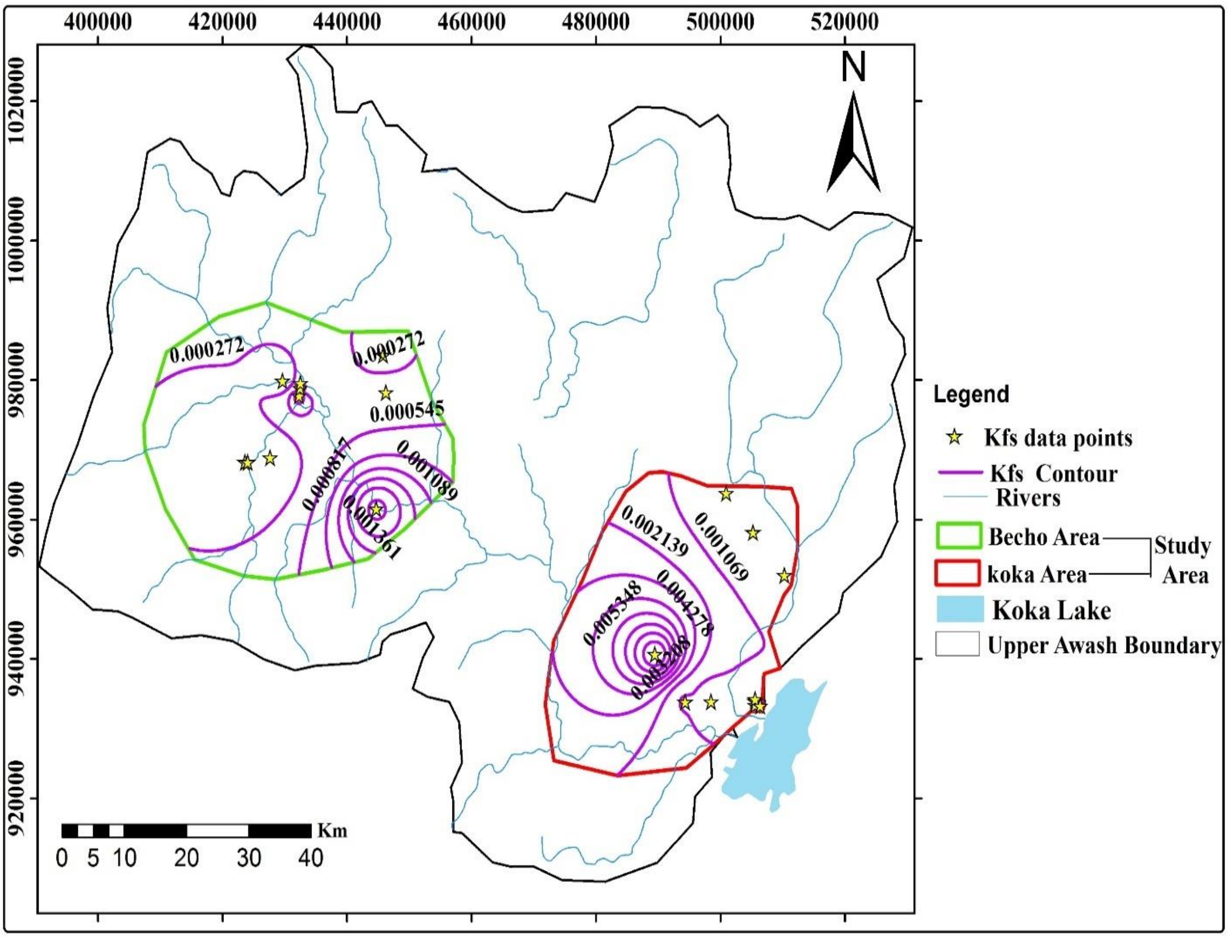

Figure 4.17 Contour map of soil field saturated hydraulic conductivity (Kfs) within the study area.

4.3.2 Transmissivity of the soil.

Transmissivity of an aquifer measures how much water can be transmitted horizontally. It is the product of the hydraulic conductivity times the thickness of the aquifer (Driscoll, 1986).

For this study, an attempt to estimate transmissivity of the soils by assuming the estimated soil field saturated hydraulic conductivity to represent the related the hand dug well depth, which is taken as thickness of the representative soils. Transmissivity of the soils of the study area have been examined using 19 data points of transmissivity, estimated from the empirical relations of T= Kfsb (figure 4.18 and table 4.4).

Table 4.4 Estimated transmissivity of the soils

Study area	ID	Locality	X	Y	Elv(m)	Well depth(m)	K (m/d)	T(m^2/d)
Koka	MK1	Engugi Bekele	505694	933839	1599	7	0.521	3.65
	MK2	Engugi bekele	505691	933288	1598	7.5	0.847	6.35
	MK3	Engugi Bekele	505696	934142	1603	7	0.359	2.51
	MK4	Gogeti goro	498602	933791	1594	18	0.146	2.63
	MK5	Liben Gadulla	494487	933734	1603	7	0.847	5.93
	MK6	Adelemeacha	489569	940584	1707	7	8.182	57.27
	MK8	Sheradibandiba	510412	951946	1804	20	0.082	1.63
	MK9	Hude kebele	505378	958085	1870	16	0.061	0.97
Becho	MK10	keta	501032	963744	1887	19	0.458	8.70
	MB1	Keta Asgori	423666	968186	2097	13.5	0.132	1.78
	MB2	Keta Asgori	424155	968145	2091	17	0.002	0.03
	MB3	weserbi Abti kurewabo	427706	968833	2102	10	0.015	0.15
	MB4	Koritu	432355	977702	2063	20	0.985	19.70
	MB5	Jigdumida	432523	978807	2065	21	0.005	0.10
	MB6	Jigdumida	432611	979508	2069	18	0.293	5.27
	MB7	Roge	429738	979830	2064	23	0.014	0.33
	MB8	Tefki	446310	978170	2065	8	0.456	3.65
	MB9	Nano Kersa	444792	961440	2069	11	1.702	18.72
	MB10	Nano kersa	445883	983529	2093	13.5	0.030	0.41

In Becho area the transmissivity estimates range from 0.03 to 19.70 m^2/d (table 4.4). The variations of transmissivity values may arise from the heterogeneity of the soils in the study area. In Koka area the transmissivity estimates range from 0.97 to 57.27m^2/d (table 4.4). The variations of transmissivity values likewise may arise from the heterogeneity of the soils in the study area. Because of the lacustrine deposits, Koka area has relatively high transmissivity values compared to Becho area.

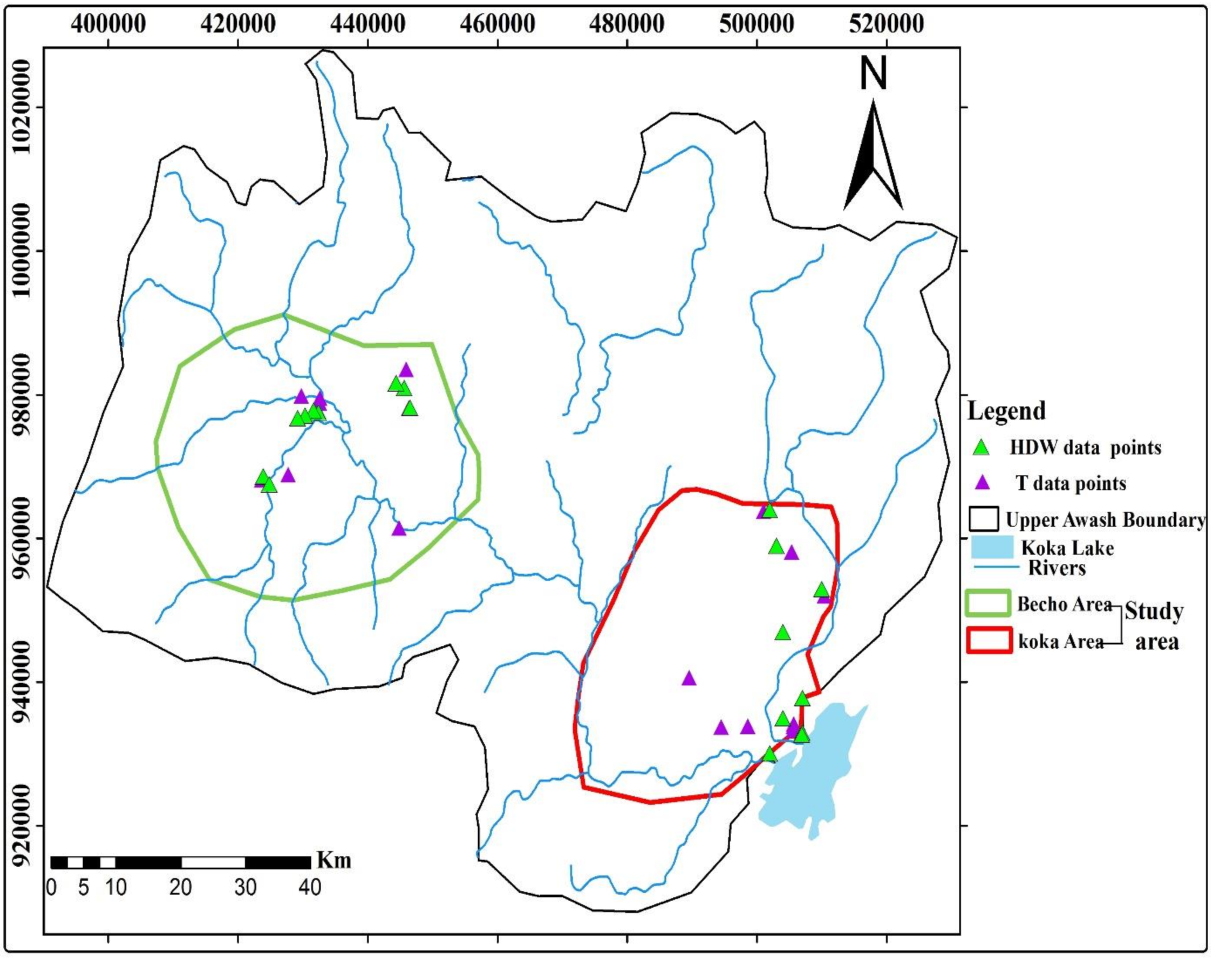

Figure 4.18 Data points of transmissivity of soils and the related HDW within the study area.

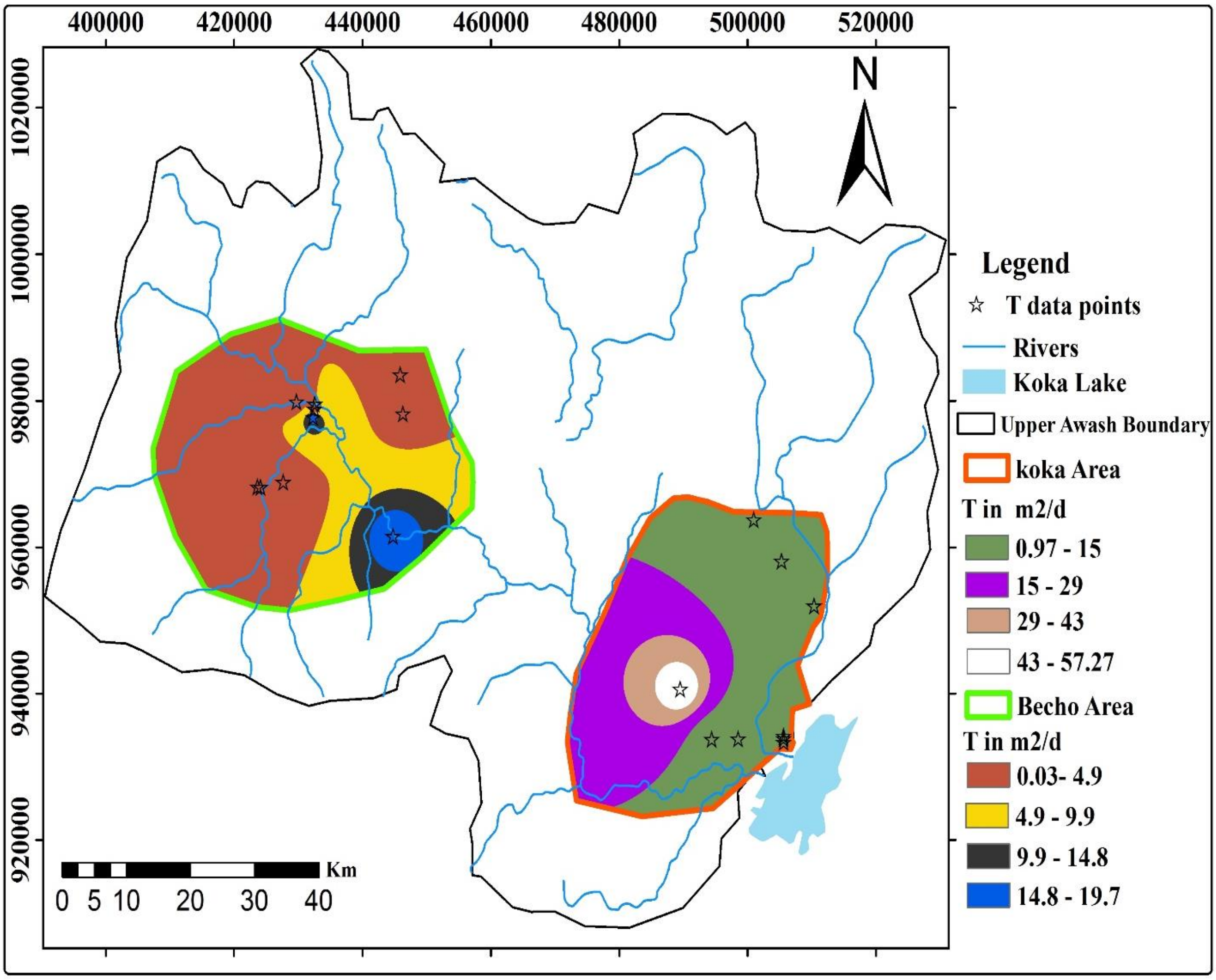

Figure 4. 19 Distribution of estimated transmissivity map of the study area

4.4 Hydrochemistry and Isotope

4.4.1 Hydrochemistry

4.4.1.1 General

According to Hem (1985) explained that the main factors that control the groundwater chemistry are lithology, structure of the rock strata, climate, topography, chemistry of rainwater, biochemical effects and subsurface resident time of water. In the study area the water quality is mainly controlled by the occurrence of basic and acidic volcanic rocks, soil type and topographic setup. In addition to the classification for drinking and irrigation the analysis of the chemistry of groundwater is useful for understanding of movement and direction of groundwater flow as well as recharge and discharge area. The usefulness of groundwater for various purpose can be established based on the type and concentration of the dissolved solutes. That is way the determination of groundwater quality is essential.

4.4.1.2 Sampling and Analysis

A total of Ten (10) water samples from hand dug wells were collected based on intensive application, soil and geology variations of the study area (figure 4.20). After the in situ measurement of P^H, TDS, Temperature(T) and Electrical Conductivity (EC) of the water samples were submitted to the laboratory of Ethiopian construction design and supervision works corporation research, laboratory and training center water quality section. The chemical analysis was conducted for major cations constituents (, Ca^{2+}, Na^+, Mg^{2+} $K^{+,}$), anions constituents (HCO_3^-, $SO^{2-}{}_4$, $NO^-{}_3$, $Cl^{-,}$ CO_3^{2-} $F^{-)}$ and total hardness and alkalinity (table 4.5). Existing complementary data of hand dug wells in the study area from previous studies and organizations were collected, and this data was used for only Physical Parameters in this concern.

Table 4.5 Results of chemical analysis of water samples

Units of cations and anions in (mg/l).

ID	UTME	UTMN	Na+	K+	Ca^{2+}	Mg^{2+}	$CO3^{2-}$	$HCO3^{-}$	Cl^{-}	$SO^{2-}{}_4$	NO^{-} 3	F^{-}	Total Hard (Ca CO3)	Total Alka (Ca CO3)
AB1	432357	977585	136.00	8.50	48.00	12.00	35.64	393.74	7.50	10.59	0.08	1.29	170	382.14
AB14	429423	976516	42.00	12.60	112.00	21.60	23.76	429.98	36.55	16.09	0.04	0.72	370	392.04
AB18	446257	978115	70.00	8.40	65.60	25.92	28.51	388.91	15.00	29.18	0.08	1.29	272	366.30
AB28	444173	981654	41.50	6.30	116.00	14.40	21.38	454.13	26.24	17.16	0.02	0.75	350	407.88
AB42	425123	969144	18.00	5.70	49.60	8.64	19.01	178.75	8.43	6.10	0.24	0.29	160	178.20
AK18	500978	929324	440.00	84.00	11.20	2.88	95.04	845.46	66.54	48.27	1.99	1.36	40	851.40
AK20	502627	932763	325.00	138.00	24.00	2.88	49.90	744.00	57.17	39.27	3.94	0.13	72	693.00
AK33	501651	938266	405.00	54.00	20.00	9.60	59.40	748.84	80.60	11.46	9.56	0.68	90	712.80
AK37	506752	933787	350.00	66.00	48.00	10.56	33.26	705.36	127.46	80.76	9.34	0.21	164	633.60
AK53	504982	932449	405.00	50.00	8.80	14.88	76.03	763.33	43.11	22.85	2.64	0.85	84	752.40

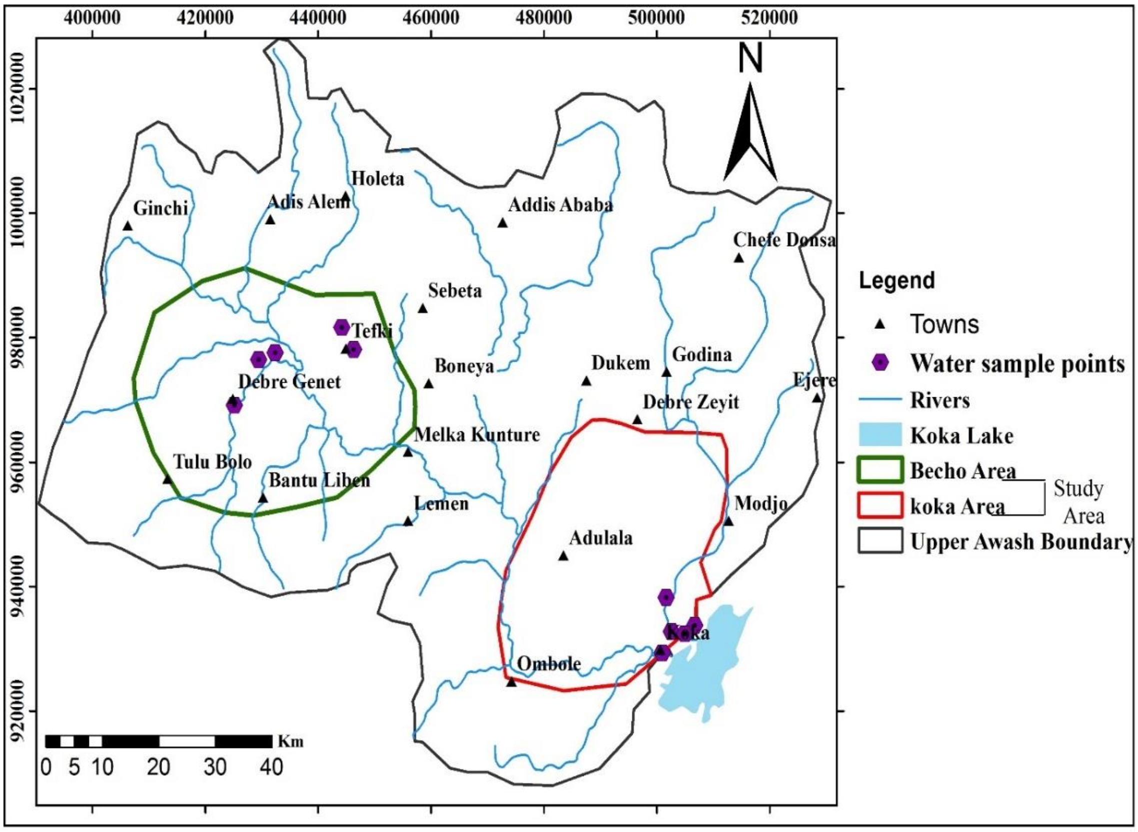

Figure 4. 20 Distributions of water sampling points Within the study area.

4.4.1.3 Evaluation of Hydrochemical parameters

4.4.1 3.1 Physical Parameters

I. **pH**

In WHO standard, less than 6.5 is acidic, 6.5-8.5 is normal and greater than 8.5 is basic water. In Becho area the minimum and the maximum pH values are 6.7and 7.7 respectively. The result reveals that the hand dug wells water of the area is almost nearest to pure water in terms of pH values. The field measured pH values in Koka area is ranges from 7.6 to 8.8. Except in some inventoried hand dug wells to behave basic water almost in Koka area the water has within the permissible range of pH values. The water has a good quality in terms of pH as specified the standard of WHO.

II. **Temperature**

The temperature ranges from 20 to 26 ^{o}c for Becho area, and 21 to 35 ^{o}c for Koka area .

Electrical conductivity (EC)

According to Tenalem Ayenew, and Tamiru Alemayehu (2001) described most groundwater the specific conductance multiplied by a factor of 0.55 to 0.75 gives reasonable estimate of the dissolved solids.

In Becho area high electrical conductivity (EC) and TDS value observed in the designated AB30 well has 1036 µS/cm and 622 mg/l respectively, which is observed in Nano kersa Kebele.The relationship of electrical conductivity versus total dissolved solids for the inventoried water points gave the equation expressed by TDS = 0.599EC (figure 4.21a), and there is a straight line regression (R^2=0.9991). Thus, the relationship between TDS and electrical conductivity values of the inventoried water points with a little deviation (figure 4.21a). The result indicates that EC is directly proportional to TDS.

In Koka area high electrical conductivity (EC) and TDS value observed in the designated AK41 well has 4080 µS/cm and 2460 mg/l respectively, which is observed in the village of Haruma near to the Lake koka. The relationship of electrical conductivity versus total dissolved solids for the inventoried water points gave the equation expressed by TDS = 0.602EC (figure 4.21b), and there is a straight line regression (R^2=0.9702).Thus, the relationship between TDS and electrical conductivity values of the inventoried water points with a very low deviation (figure 4.21b).The result indicates that EC is directly proportional to TDS.

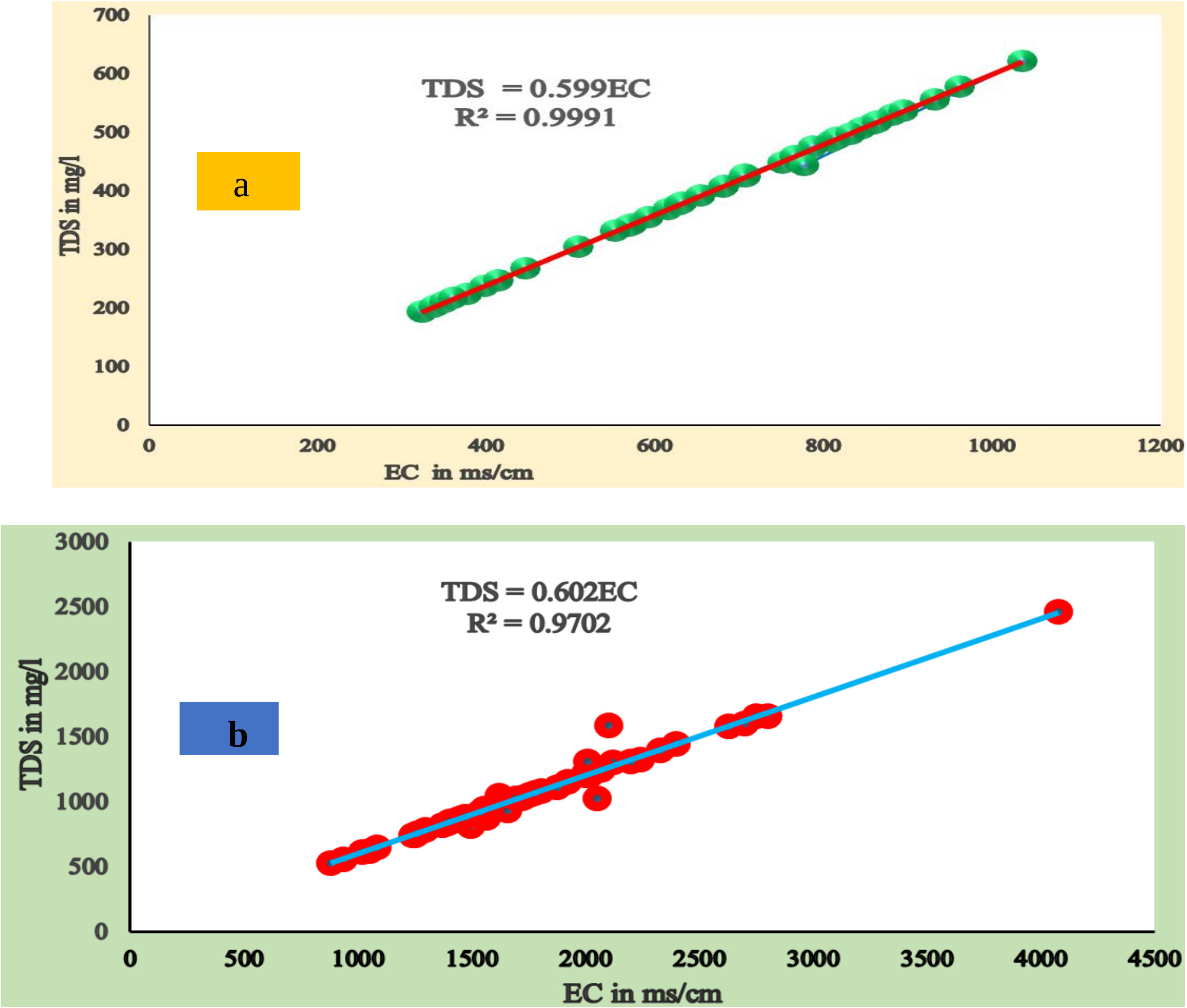

Figure 4.21 Relation between TDS and EC of the inventoried water points in the study area. (a) in Becho area, (b) in Koka area.

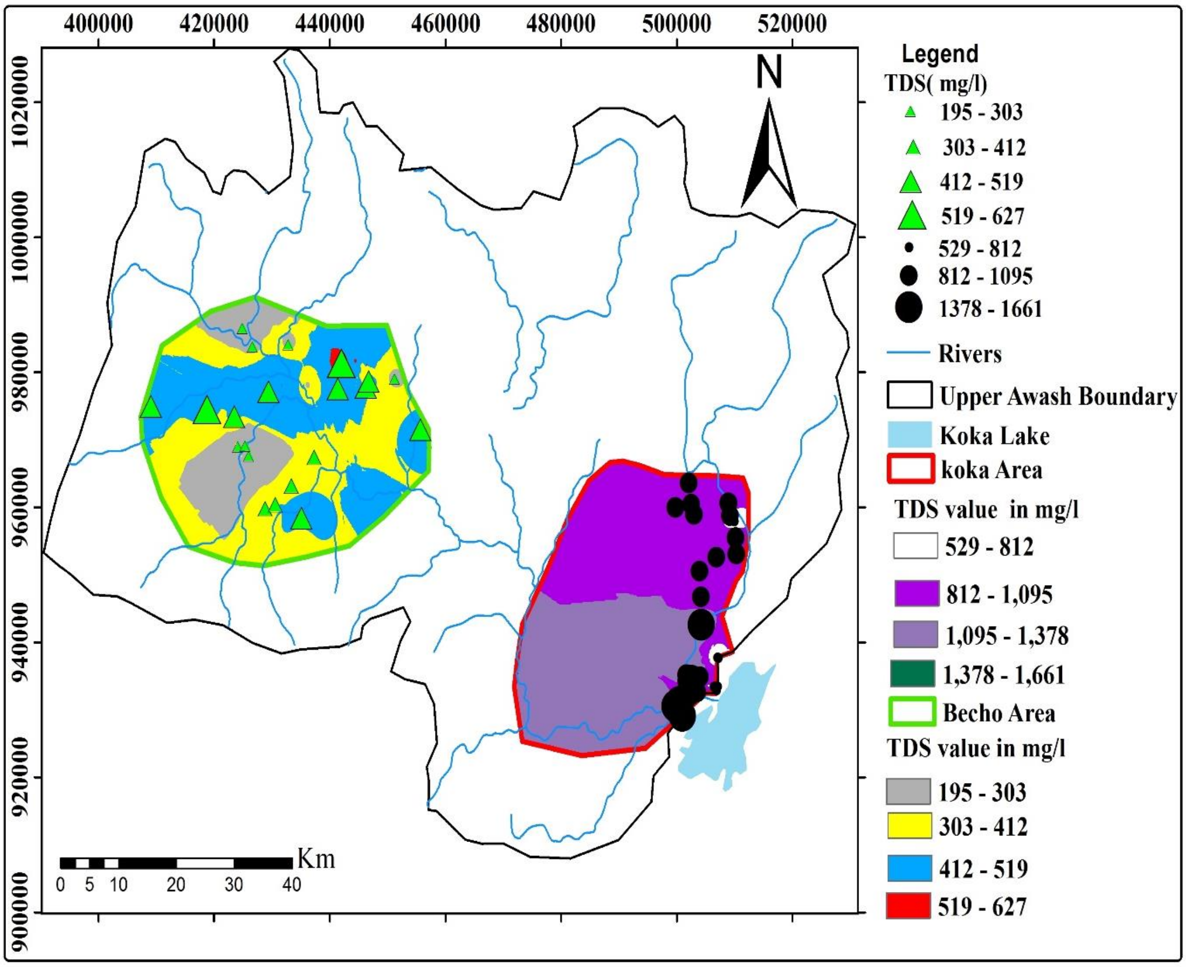

Figure 4.22 TDS distribution map of the study area

III. Hardness

A generally accepted classification for hardness as mg/l of CaCO3 according to Dufer and Becker (1964, as cited in Tenalem Ayenew and Tamiru Alemayehu ,2001) hardness range in milligram per liter (mg/l) is given by:

0 to 60 = Soft

61 to 120 = moderately hard.

121 to 180 = Hard

>181 = Very Hard.

Table 4.6 Classification of the water samples of the study area based on hardness

Study area	Sample ID	Total hardness (as Ca CO3 mg/l)	Water class
Becho	AB1	170	hard
	AB14	370	Very hard
	AB18	272	Very hard
	AB28	350	Very hard
	AB42	160	hard
Koka	AK18	40	soft
	AK20	72	moderately hard
	AK33	90	moderately hard
	AK37	164	hard
	AK53	84	moderately hard

4.4.1 3.2 Major Cations

The major cations that have been considered are sodium, calcium, magnesium and potassium. In Becho area calcium is the dominant cation followed by sodium, magnesium, and potassium. Calcium shows significant variation whose values range between 48 to 116 mg/L. The Ca^{+} concentration ranges from minimum value in the koritu kebele, which is relatively the eastern part of Becho area to maximum value in the Nano kersa kebele, and this area has high elevation compared to the other sampling of water points and represents the western parts of the Becho area. The dominance of calcium in Becho area is likely to be attributed from short time of water-aquifer interactions. The result reveals the water is high hardness, since the concentrations of calcium is high compared to the other major cations.

In koka area Sodium is the dominant cation followed by potassium, calcium and magnesium. Sodium shows significant variation whose values range between 325 to 440 mg/L. The Na^{+} concentration ranges from minimum value in the lafto kebele, which is the western parts of koka area to maximum values in Gorbta kebele nearby the Lake koka, represents the southern part of koka area. The dominance of Sodium in Koka area is likely to be recognized to the dominance of the acidic volcanic rocks, mainly lacustrine deposits.

The result tells that the water is moderately hard, since the concentrations of calcium and magnesium are low compared to the other major cations.

4.4.1 3.3 Major anions

The major anions that have been considered are bicarbonate, carbonate, sulfate, and chloride in this concern.

In Becho area bicarbonate is the dominant anion, and its proportion to carbonate was being controlled by the pH values of respective hand dug well samples.The minimum and maximum bicarbonate concentration is 178.75 and 454.13 mg/l in eastern part of Asgori and western part of Tefki respectively. Chloride is another anion known by its conservative nature in the chemical evolution process and good indicator of the relative age of ground water compare to other major anions. The chloride value of Becho area ranges from 7.5mg /l in koritu kebele to 36.55mg/l in Alengo Tulu kebele. Sulfate concentrations is found to be in low amounts compared to the given major anions.

In Koka area bicarbonate is the dominant anion followed by chloride, carbonate and sulfate. The minimum and maximum bicarbonate ion concentration is 705.36 and 845.46 mg/l in Haruma village near by the Tannery factory in eastern part of koka area and in Gurbta kebele nearby Awash river respectively. The chloride value of Koka area ranges from 43.11mg /l in kelna village to 127.46mg/l in Haruma village nearby the Tannery factory. Relatively high chloride concentrations in Haruma village believed to be from waste disposals from the Tannery factory. Sulfate concentrations is found to be in low amounts compared to the given major anions.

4.4.1 3.4 Minor anions

The minor anions that have been considered are fluoride and nitrate.The fluoride concentration of the hand dug wells in the study areas are shows almost uniform with little variations. The fluoride guideline values for World Health Organization and Ethiopian drinking water quality guidelines are 1.5 and 3.0 mg/l respectively. In both areas, the fluoride concentration for all samples taken from the hand dug wells are under the range of the limit of the standard fluoride guideline values of World Health Organization and Ethiopian drinking water quality guidelines.

In Becho area, the relative maximum concentration of fluoride ion is 1.29 mg/l around Tefki (AB18), and Koritu village (AB1). In Koka area, the relative maximum concentration of fluoride ion is 1.36 mg/l in Gurubta village nearby Awash river south of Koka area (Ak18).

The Nitrate guideline values for World Health Organization (2008) and Ethiopian drinking water quality guidelines (2002) are 45 and 50 mg/l respectively.

In both areas are the nitrate concentration for all samples taken from the hand dug wells are under the range of the limit of the standard nitrate guideline values of World Health Organization and Ethiopian drinking water quality guidelines. The Nitrate concentrations in Becho area has trace amount from 0.02 to 0.24 mg/l in the western parts of Teji and eastern parts of Asgori respectively.

In Koka area, the relative maximum concentration of nitrate is 9.56 mg/l in lafto village western part of Koka area (Ak33), and 9.34 mg/l in haruma village nearby the Tannery factory east of koka area (AK37). Relatively high nitrate concentrations in lafto village may be the intensive irrigated land as well as the consumption of fertilizer increase results in the concentrations of nitrate is high. On the other hand, relatively high nitrate concentrations in Haruma village near to the Tannery factory believed to be the waste disposals from the Tannery factory.

4.4.1. 3.5 Water Types

The classification of Hand dug well water in the study area is made on the basis of laboratory results of major cations and anions by using Aquachem version 4.0 sotware.

In Becho area based on Aquachem software results, the dominant water type of the study area is calcium bicarbonate (Ca-HCO3) followed by Na-Ca-HCO3 and Ca-Na-Mg-HCO3 (table 4.7 and figure 4.23a). Ca-HCO3 water type is water with calcium as the dominant cation and bicarbonate as the dominant anion. Based on the groundwater chemical evolution models, Ca-HCO3 group of water represent groundwater that are recently recharged and/or contain water at the early stages of geochemical evolution which have not undergone significant water-aquifer interactions (Bartolino and Cole, 2003). Of course, further evidenced by the association of this water type to the hand dug wells in Becho area. This kind of water is often regarded as recharge area water which is at their early stage of geochemical evolution, shallow depths of rapid circulation, relatively low residence time in sub surface and without significant water–aquifer interactions.

In Koka area based on Aquachem software results, the water type is sodium bicarbonate (Na-HCO3) (table 4.7 and figure 4.23b). Na-HCO3 water type is water with sodium as the dominant cation and bicarbonate as the dominant anion. This type of water indicating relatively long duration of water-aquifer interactions, mixing effect of local recharge with regional flow and longer residence time which leads to further hydrolysis of silicate minerals in the Ca-Mg-HCO3 type water, likely with intensive ion exchange that replaces the whole calcium in the water whereby the concentration of Na, K and HCO3 increase (Seifu et al., 2005).

Table 4.7 Hydrochemical types of individual anions and cations and water classification of the study area

Study area	Anion	Water type	Cation	Sample ID	Number of case
Becho	Bicarbonate (HCO_3^-)	Ca-HCO3	Ca	AB42,AB28 and AB14	3
		Ca-Na-Mg-HCO3	Ca-Na-Mg	AB18	1
		Na-Ca-HCO3	Na-Ca	AB1	1
Koka	Bicarbonate (HCO_3-)	Na-HCO3	Na	All samples	5

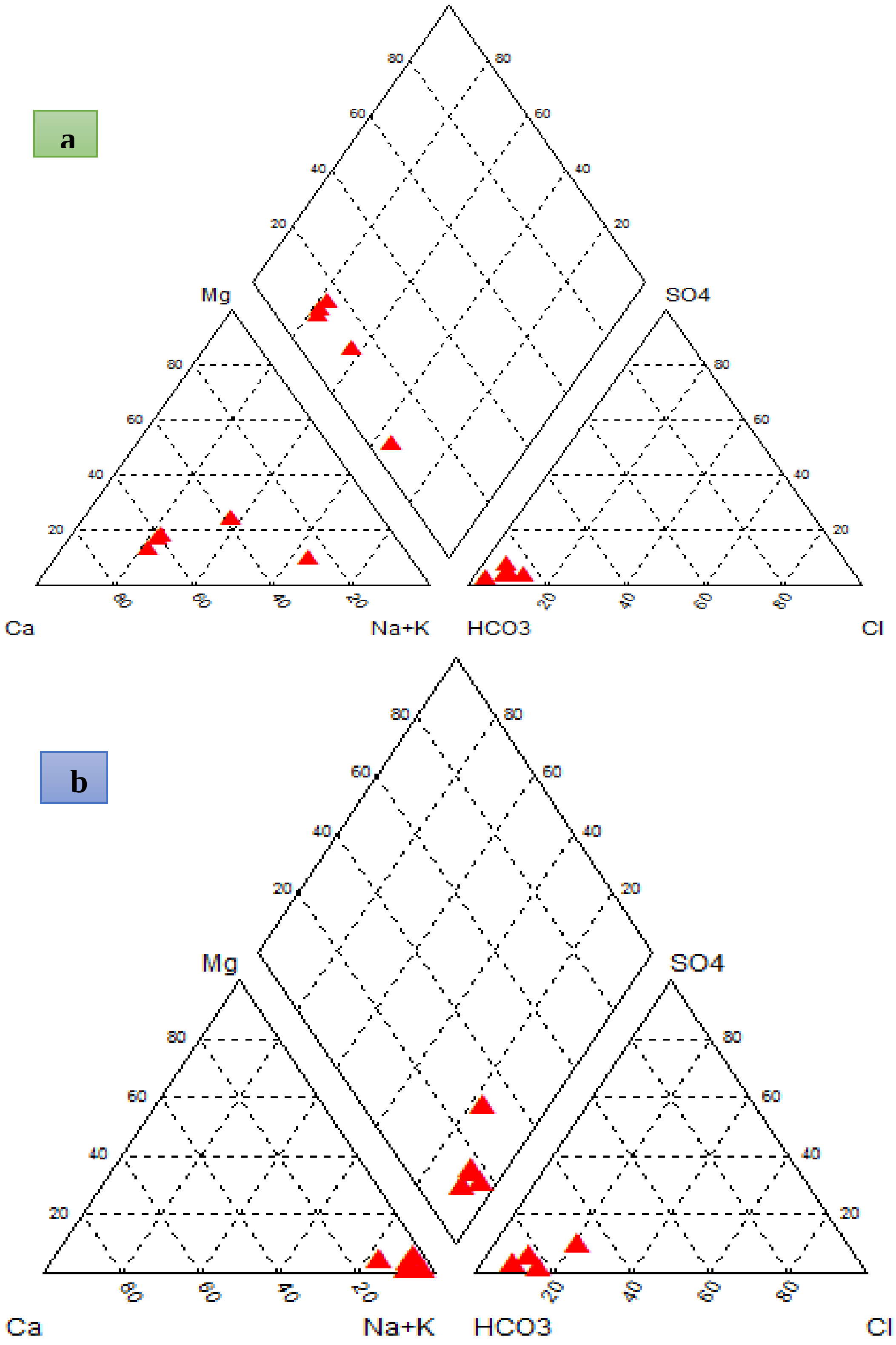

Figure 4.23 Piper Plot diagram representation of water types of the study area. (a) represents piper plot diagram of Becho area, (b) represents piper plot diagram of Koka area.

4.4.1 3.6 Standards of water for irrigation purpose

Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. High sodium concentrations can be toxic for crops. Moreover, irrigation process with high sodium concentration water makes the physical properties of the soils to be unsuitable for agriculture; in fact sodium can replace calcium and magnesium in clay, damaging the soil structure (Sabrina et al.,2005).

To study the suitability of groundwater for irrigation purposes the use of sodium Adsorption ratio (SAR) is used. According to USDA (1954) SAR defined as SAR = Na/√ [(Ca + Mg)/2], Where all the concentrations of the constituents are expressed in milli equivalent per liter.

Table 4. 8 Groundwater classification using SAR values Sabrina et al (2005, as cited in USDA, 1954).

SAR	Groundwater quality	Irrigation type
<10 (Low)	Excellent	All soil types can be irrigated
10 - 18 (medium)	Good	Low cation exchange soils can be irrigated
18 - 26 (high)	Fair (tolerable)	For irrigation, soils need a good drainage and organic compounds addition
> 26 (Very high)	poor (unsuitable)	Irrigation is possible only with low salinity waters

Table 4.9 SAR (Sodium Adsorption Ratio) values for hand dug well of the water samples

Study area	well	SAR
Becho	AB1	4.5
	AB14	0.9
	AB18	1.8
	AB28	1.0
	AB42	0.6
Koka	AK18	30.2
	AK20	16.7
	AK33	18.6
	AK37	11.9
	AK53	19.2

Table 4.10 Number of case of the water samples referenced with SAR values

Study area	Value of SAR	Water class	Number of case
Becho	<10 (Low)	Excellent	All selected samples
	10 - 18 (medium)	Good	none
	18 - 26 (high)	Fair(tolerable)	none
	> 26 (Very high)	poor (unsuitable)	none
Koka	<10 (Low)	Excellent	none
	10 - 18 (medium)	Good	2
	18 - 26 (high)	Fair(tolerable)	2
	> 26 (Very high)	poor (unsuitable)	1

In Becho area all of water samples are found to be suitable for irrigation, since all the water samples of hand dug wells show the SAR value below 4.6, which is within the excellent range of water quality from the point view of their SAR value for irrigation purpose.

In koka area only two samples (AK20 and AK37 hand dug wells) show a medium SAR (good water class); low cation exchange soils can be irrigated using these hands dug wells. High SAR is present in AK53 and AK33 samples in Kelna and Lafto village respectively; groundwater quality is tolerable but, if used for irrigation, soils need a good drainage and organic compounds addition. In one hand dug well sample, SAR value is 30.2 (AK18) in Gurbta village south of Koka area, and this water can be used for irrigation only if salinity is low. Accordingly, most of the SAR values in Koka area lie in the range between 11.9 and 19.2 with an average of 16.6; they are classified from good for irrigation purpose, and low cation exchange soils can be irrigated using these hands dug wells.

4.4.2 Stable isotopes

4.4.2.1 General

Isotopes are forms of a given chemical element that have different atomic masses and number of neutrons, but have the same number of protons and atomic number. Stable isotopes are those isotopes that do not undergo radioactive decay. In terms of the water molecule itself, oxygen has three stable isotopes, ^{16}O, ^{17}O, and ^{18}O; and hydrogen has two stable isotopes, ^{1}H and ^{2}H (deuterium). Application of environmental isotopes in hydrological investigations provide important information, including origin of waters, recharge conditions, water-aquifer interactions, water flow paths and groundwater and surface water interactions (Andarge Yitbarek and Tewodros Rango ,2009,as cited in Clark and Fritz, 1997; Cook and Herczeg, 2000; Coplen ,1993; Mazor ,1997; Fontes and Edmunds 1989).

According to Tewodros Rango (2009) the basis for the interpretation of variations in stable isotope in the hydrologic system is based on the vapour pressure of $H_2{}^{16}O$ which is higher than that of $H_2{}^{18}O$. Because of the variability in isotopic vapour pressures, evaporation produces residual water enriched in the heavier isotopes relative to the initial isotopic composition. Water that has undergone evaporation lies to the right of the local meteoric water line due to the enrichment of heavier isotopes (Coplen, 1993).

The isotopic composition of water is commonly expressed in per mill deviation from the standard mean ocean water (Craig 1961); the standard solution is later modified as Vienna Standard Mean Ocean Water, commonly abbreviated as VSMOW. These deviations are denoted by $\delta^{2}H$ for deuterium and $\delta^{18}O$ for ^{18}O, and expressed as:

$\delta^{2}H$ (‰) = (Rsample/Rstandard - 1) x 1000

$\delta^{18}O$ (‰) = (Rsample/Rstandard - 1) x 1000

Rsample = heavier isotope /lighter isotope in the sample

Rstandard = heavier isotope /lighter isotope in the standard

If $\delta^{18}O$ and $\delta^{2}H$ samples contain more of the heavier isotopes (^{18}O or ^{2}H) than the standard, the samples have positive per mil values and vice versa.

From the long term $\delta^{18}O$ and δ^2H measurements of precipitation at Addis Ababa GNIP station of IAEA (Data from 1961 to 2005) the $\delta^{18}O$ ‰ against δ^2H‰ are plotted and resulted with a linear trend represented by the equation $\delta^2H(‰) = 7.12\delta^{18}O+11.9$ is known as the local meteoric water line (LMWL).Craig (1961) and Dansgaard (1964) found a relation between the $\delta^{18}O$ and δ^2H values of precipitation from various parts of the world ,which were formulated the equation $\delta^2H(‰) = 8\ \delta^{18}O + 10$,known as Global meteoric water line (GMWL).The LMWL and GMWL are the reference lines to study the groundwater recharge sources of the study area. The 'd-excess' is another useful parameter to interpret the effect of evaporation in modifying the isotopic character of rainwater prior to groundwater recharge. The deuterium excess (d) defined as $d = \delta^2H - 8* \delta^{18}O$ (Dansgaard,1964). For atmospheric moisture not influenced by secondary evaporative processes, the d-excess approximates the y-intercept of the GMWL of 10 ‰ (Dansgaard 1964), and by analogy to y-intercept of the LMWL for groundwater recharged from that precipitation is 11.9 ‰ in the study area. Increased deuterium excess in groundwater can arise from the evaporation of the rainwater before it percolates to the subsurface (Andarge Yitbarek,2009).

4.4.2.2 $\delta^{18}O$ and δ^2H Stable isotopes of hand dug well water in the study area.

Twenty (20) water samples were collected from current activity, and has been conducted between 29/12/2016 and 06/01/2017 is presented in figure 4.24. The collected water samples were analyzed in Addis Ababa University water isotope laboratory, and the $\delta^{18}O$ and δD results are reported in per mil (‰) notation calibrated against VSMOW (table 4.11).

Table 4.11 Stable isotopes of Hydrogen and oxygen data

Study area	ID	Locality	utmE	utmN	Elv(m)	δ^2H‰	δ^{18}O‰	d=δD -8*δ^{18}O	Source
Becho	AB1	koritu	432357	977585	2063	-9.07	-2.74	12.85	HDW
	AB9	Alengo Tullu	430310	977177	2069	-18.02	-3.4	9.18	HDW
	AB14	Alengo Tullu	429423	976516	2070	-11.09	-3.54	17.23	HDW
	AB18	Tefki	446257	978115	2055	-2.11	-2.69	19.41	HDW
	AB23	Nano kersa	446423	981088	2067	-8.38	-3.09	16.34	HDW
	AB28	Nano kersa	444173	981654	2071	-3.68	-1.73	10.16	HDW
	AB31	Keta Asgori	423850	968718	2098	-14.37	-3.31	12.11	HDW
	AB32	Keta Asgori	423961	968288	2093	-10.42	-2.39	8.7	HDW
	AB34	Jato	424863	967598	2094	-11.32	-3.01	12.76	HDW
	AB42	Keta Asgori	425123	969144	2085	-13.71	-2.92	9.65	HDW
Koka	AK3	Gorbta	501285	931767	1594	-22.13	-4.57	14.43	HDW
	AK7	Gorbta	500883	931725	1594	-19.56	-4.72	18.2	HDW
	AK18	Gorbta	500978	929324	1595	-18.01	-3.76	12.07	HDW
	AK20	Bereket	502627	932763	1599	-15.14	-3.14	9.98	HDW
	AK33	Lafto	501651	938266	1598	-8.48	-2.16	8.8	HDW
	AK36	Lafto	502927	934350	1603	-7.09	-1.72	6.67	HDW
	AK37	Haruma	506752	933787	1595	-3.38	-1.53	8.86	HDW
	AK52	Kelna	506725	932427	1594	-6.72	-1.98	9.12	HDW
	AK53	Kelna	504982	932449	1595	-15.55	-3.36	11.33	HDW
	AK54	koka	503523	932760	1524	-13.7	-1.46	-2.02	HDW

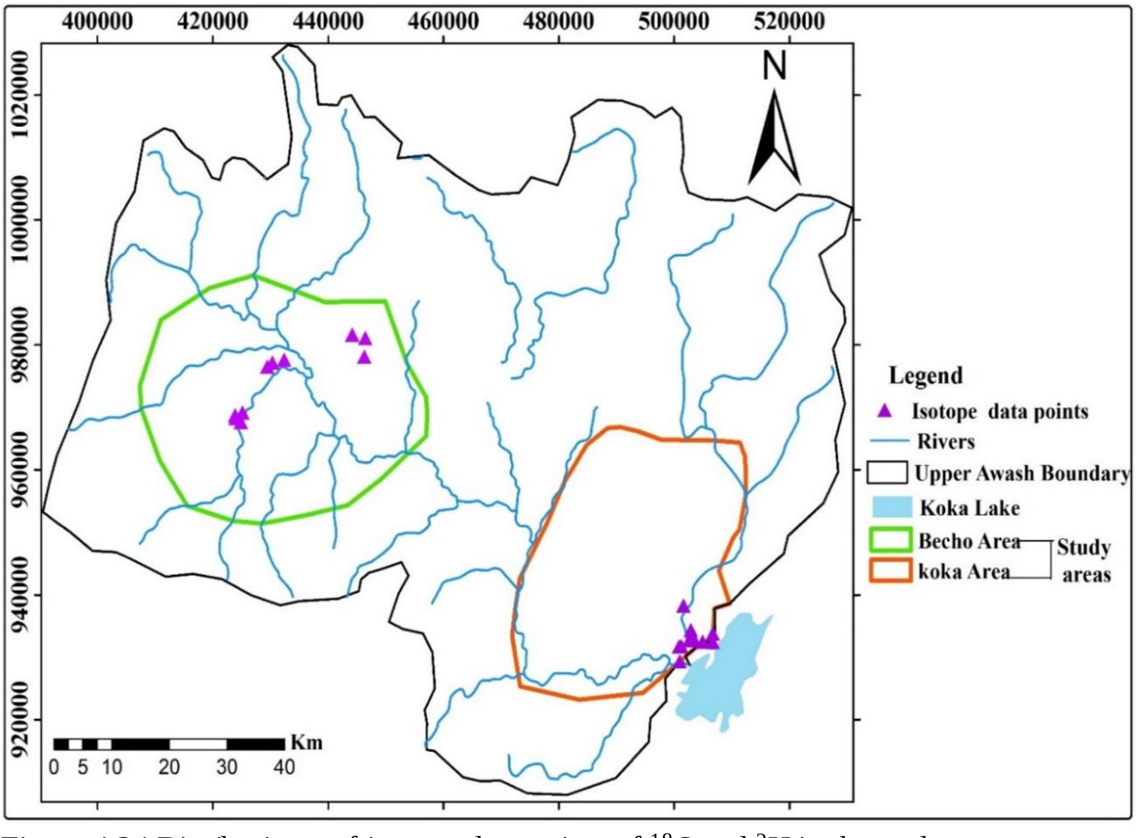

Figure 4.24 Distributions of isotope data points of ^{18}O and ^{2}H in the study area

The stable isotopic values of the HDW water of the study area is drown together with LMWL and GMWL (figure 4.25). Based on the isotopic data of the HDW water in Becho area is revealed the isotopic composition is depleted. The $\delta^{18}O$ and $\delta^{2}H$ values range from -3.54 to -1.73‰ and -18.02 to -2.11‰ respectively. The majority of the water samples lie below the LMWL suggesting of rain water is influenced by evaporation before ground water recharge (figure 4.25). From the result of isotopic signature, the hand dug well water is getting recharge from rainfall. Based on the isotopic data of the HDW water in Koka area is revealed the isotopic composition is depleted. The $\delta^{18}O$ and $\delta^{2}H$ values range from -4.72 to -1.46 3‰ and -22.13 to -3.38 ‰ respectively. Almost all water samples except AK7 water sample lie below the LMWL suggesting of rain water is influenced by evaporation before groundwater recharge (figure 4.25). From the result of isotopic signature, the hand dug well water is getting recharge from rainfall.

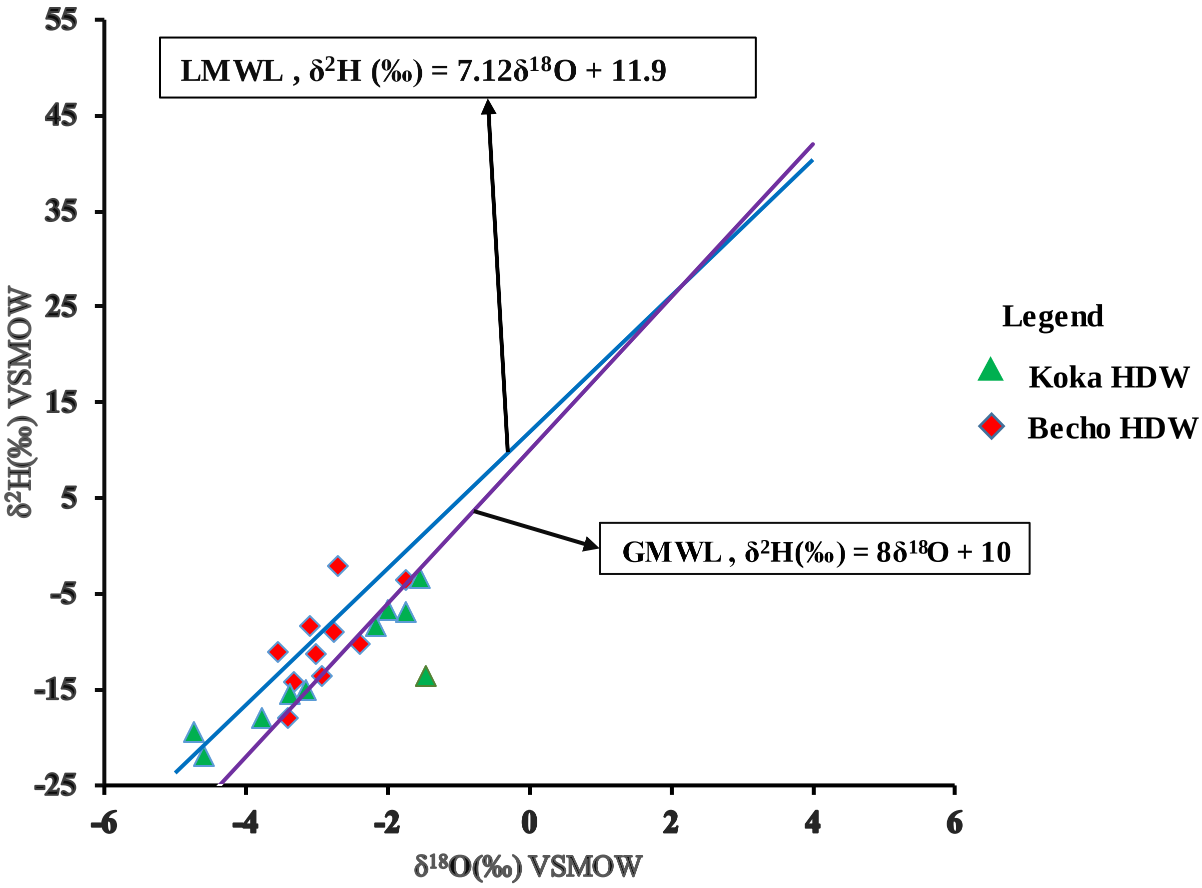

Figure 4.25 Plot of $\delta^{2}H$ ‰ versus $\delta^{18}O$‰ of HDW water in the study area along with the LMWL and GMWL

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The present study area is located in upper Awash river basin, in central part of the country, which covers a total area of about 2780 Km^2.The elevation ranges from 1519 to 2300 m.a.s.l. Becho and Koka areas were the focused areas for this specific research. Becho area occupies a total area of about 1502 km^2, whereas Koka area is occupies a total area of about 1278 km^2. The main objective of the present study was to provide detail information on the groundwater flow and characterize the shallow aquifers of Becho and Koka areas which will be vital information for future sustainable use of the groundwater resource.

In Becho area gets 1141.6 mm of annual mean rainfall and 17. 9°c mean monthly temperature. In Koka area gets 914.4 mm of annual mean rainfall and 21. 3°c mean monthly temperature. Rainfall amount vary with altitude and physiographical setting of the area. The area has two rainfall regime (bimodal rainfall characteristics) that is small rain ("Bulg" season) in the month of March, April and June and heavy rain ("Kiremt" season) in the month of July, August and September.

The Black cotton soil, Alluvial deposits, Entoto Becho rhyolite are mainly dominated the Becho area. Black cotton soil is characterized by rare silt and gravel, interlayered with reworked and weathered pyroclastics (ATA,2014). The Entoto ridge forms watershed divide of Abay and Awash river basins. The ridge forms steep slope towards the Abay basin, and steep to gentle slope towards the Awash basin. Alluvial deposit is consisting of regolith, reddish brown soils, talus and alluvium with maximum thickness of about 7 m (WWDSE ,2008). The lithological units exposed in Koka area mainly include the lacustrine deposits, Ziquala Trachyte and Bede Gebaba volcanic unit. Lacustrine deposits are particularly distinguished in the Koka area of the Lake region. It is often contained volcanic matrix; whose thickness ranges from 5 to 8m (WWDSE,2008).

The main aquifer types in the study areas are moderate to highly productive and primary porosity aquifer. Moderate to highly productive aquifer is characterized by with high storage and yield (> 0.5 l/s); aquifer thickness around 60m; yield increases towards rivers; seasonal water level flactuation is 1 to 2m (ATA,2014). Primary porosity aquifer comprises aquifers related to quaternary alluvial and lacustrine deposits. The alluvial and lacustrine aquifers are found dominantly in the southeast around koka area, and locally in the northwestern part of Becho area and along the main perennial river courses. The alluvial and lacustrine deposits around Debrezeit and Koka have thickness up to 80 meters and composed of coarse sediments with static water level varies from 7 to 39 meters (Andarge Yitbarek, 2009, as cited in WWDSE, 2008).

Flow records at Modjo river, Awash river at Hombole, Teji river and Awash river at Bello were selected in Koka and Becho areas for estimating recharge by BFS respectively. The discharge records exhibit similar trends with corresponding the wettest months of July, August and September. Results from BFS by using excel spreadsheet program shows that the mean annual recharge for Becho and Koka areas are 79 mm and 104.1 mm respectively.

The shallow groundwater of the study area is the movement and flow direction is dependent on the inclination of the topography of the area. Both the groundwater level and TDS contour map show that the local groundwater flow direction in Becho area is tends to be the main Awash river ,whereas in Koka area is tends to be towards Lake koka.

According to Soil moisture equipment CORP (1985) suggested that reservoir combination is used in soil of moderate to high permeability, and Soils that fit into this category typically have some degree of structure, medium to coarse texture, and little to no cementation or compaction, while the inner reservoir used for soils that have low permeability, and Soils that fit into this category are typically fine textured, structureless, or significantly cemented or compacted. in Becho area the reservoir used almost combined reservoirs except two selected sites, but in Koka area the reservoir used was combined reservoirs. The average estimated soil field saturated hydraulic conductivity in Becho and Koka areas are 0.000421 and 0.00107 cm/sec respectively. In Becho area medium field saturated hydraulic conductivity values are come from due to the presence of alluvial deposits during the wet season, which covers the most upper parts of the soils. In koka area the soil has medium to high field saturated hydraulic conductivity, since the area has primary porosity due to dominated by the lacustrine deposits.

In the study areas, the dominant water types are Ca-HCO3 and Na-HCO3. The Ca-HCO3 water type is dominant in Becho area, while the Na-HCO3 type is dominant in Koka area. Using SAR values in USDA (1954) groundwater classification, in Becho and Koka areas the shallow groundwater has been classified as excellent and good for irrigation purpose respectively.

The study areas (Becho and Koka) have compositions of $\delta^{18}O$ -3.54 to -1.73 ‰ and -4.72 to -1.46 ‰, and $\delta^{2}H$ is -18.02 to -2.11 ‰ and -22.13 to -3.38 ‰ (VSMOW) respectively. In both areas, the stable isotopes signature of the Hand dug well water characterized by depleted isotopic signature. Generally, from the result of isotopic signature, the recharge for depleted hand dug well water is from the precipitation.

In Becho and Koka areas are estimated transmissivity values range from 0.03 to 19.70 m^2/d and 0.97 to 57.27m^2/d respectively. Because of the lacustrine deposits, Koka area has relatively high transmissivity values compared to Becho area.

5.2 Recommendations

- In this study, it was also planned to try monitoring of shallow groundwater, however due to time constraints it becomes impossible. For the future, it is highly recommended to perform regular monitoring of hand dug wells based on the results of this study, which is important to recognize groundwater fluctuation and easily to estimate the recharge.

- Communal well should be adopted by the community to minimize evaporation of groundwater from the open hand dug wells.

- As there is groundwater pollution potential of shallow aquifers especially in the hand dug wells, hence precautions must be made so as not to further pollute the resource.

- Most of the inventoried water points from the responsible organizations are not well organized. Therefore, great emphasis should be given during the inventory of water points.

- It is better to perform pumping test for the shallow groundwater in the focused areas that will be enables detail characterization of the aquifers.

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Appendices

Appendix 1: Baseflow separation methods used in the Excel spreadsheet

1. Fixed interval method
2. Sliding interval method
3. Local minimum method
4. Institute of Hydrology low flow method

References

Methods 1 to 3

Pettyjohn, W.A. and Henning, R. (1979). A report on Preliminary estimate of ground water recharge rates, related to streamflow and water quality in Ohio. Ohio State University Water Resources Centre Project Completion Report Number 552.

Method 4

Gustard, A. Bullock, A. and Dixon, J.M. (1992). A report on Low flow estimation in the United Kingdom. Institute of Hydrology Report No. 108.

Algorithms for methods 1 to 3

The period of surface runoff is calculated from the empirical equation,

$$N = (A/2.59)^{0.2}$$

where,

N is the number of days after which surface runoff ends,
A is the drainage area in square kilometers.
The interval, I, used in the baseflow separation method is the odd integer between 3 and 11 nearest to 2N.

Fixed interval method

In this method, the minimum flow in the interval, I, is taken to be the baseflow for all of the days in the interval. The interval is repeatedly moved by I days along the period of record.

Sliding interval method

In this method, the minimum flow is found over the period of one-half of the interval, I, minus one day [0.5(I-1)] either side of the day under consideration. This minimum flow is then assigned as the baseflow to that day, i.e. the median day in the interval. The interval is then repeatedly moved by one day along the period of the record.

Local minimum method

In this method, the flow on the central day of the period one-half of the interval, I, minus one day [0.5(I-1)] either side of the day under consideration is checked to determine if it is the lowest flow in the interval. If it is then it is specified as a local minimum (and the baseflow on the median day) and connected by straight lines to the to the previous and next local minima. The baseflow on the days between the local minima is calculated by linear interpolation and constrained to equal the total flow on any day when the baseflow exceeds the total flow.

Algorithm for method 4

Institute of Hydrology (IH) low flow method

The following description of the method is taken from the reference cited above.

The algorithm calculates the minima of five-day non-overlapping consecutive periods and subsequently searches for the turning points in this sequence of minima. The turning points are then connected to obtain the baseflow hydrograph, which is constrained to equal the observed hydrograph ordinate on any day when the separated hydrograph exceeds the observed. The procedure for calculating the baseflow is as follows:

I. Divide the mean daily flow data into non-overlapping blocks of five days and calculate the minima for each of these blocks, and let them be called Q_1, Q_2, Q_3,…Qn

II. Consider in turn (Q_1, Q_2, Q_3), (Q_2, Q_3, Q_4), (Q_{i-1}, Q_i, Q_{i+1}) etc., if $Q_{i-1} > 0.9Q_i < Q_{i+1}$), then the central value is an ordinate for the baseflow line. Continue this procedure until all the data have been analyzed to provide a derived set of baseflow ordinates QB_1, QB_2, QB_3...QBn, which will have different time periods between them.

III. By linear interpolation between each QBi value, estimate each daily value of QB_i ... QBn

IV. If then $QB_i > Q$, then set $QB = Q$

Appendix 2: Annual flow summary of study area (m^3/s).

year	Study area: Koka						Study area: Becho					
	Awash river at Hombole			Modjo river			Teji river			Awash river at Bello		
	MF	MBF	BF/TF%	MF	MBF	BF/TF%	MF	MBF	BF/TF%	MF	MBF	BF/TF%
1968				2.9	0.6	0.2						
1969				5.9	1.4	0.2						
1970				5.6	1.8	0.3						
1971				9.6	3.9	0.4						
1972				3.0	0.9	0.3						
1973				7.0	2.3	0.3						
1974				5.9	1.7	0.3						
1975				5.9	1.7	0.3						
1976				6.3	2.4	0.4						
1977				7.4	2.4	0.3						
1978				5.2	1.5	0.3						
1979				4.8	2.7	0.6						
1980				4.2	1.6	0.4						
1981				4.2	1.6	0.4						
1982				25.8	7.5	0.3						
1983	45.4	29.9	0.7	25.8	9.5	0.4	3.9	1.5	0.4			
1984	35.0	21.9	0.6	17.3	2.9	0.2	3.2	1.4	0.4			
1985	45.1	29.8	0.7	27.3	14.1	0.5	5.9	3.1	0.5			
1986	33.4	23.2	0.7	24.0	5.0	0.2	2.3	1.1	0.5			
1987	20.6	12.5	0.6	7.1	0.5	0.1	2.4	1.0	0.4	7.6	6.2	0.8
1988	50.4	30.6	0.6	27.8	12.2	0.4	5.0	1.8	0.4	8.3	7.2	0.9
1989	44.3	31.0	0.7	15.2	7.4	0.5	3.4	1.5	0.4	9.7	8.2	0.8
1990	45.2	29.5	0.7	18.3	5.1	0.3	3.6	1.6	0.5	10.7	8.9	0.8
1991	46.8	30.7	0.7	25.3	7.3	0.3	4.1	1.7	0.4	9.6	7.8	0.8
1992	39.8	26.2	0.7	19.2	7.1	0.4	1.0	1.0	1.0	10.2	7.9	0.8
1993	57.5	37.3	0.6				5.0	2.5	0.5			
1994	36.0	23.2	0.6	18.0	4.8	0.3	0.1	0.1	1.0	10.3	8.6	0.8
1995	33.2	22.2	0.7				0.1	0.1	1.0	9.1	7.9	0.9
1996							4.1	1.4	0.3			
1997	22.9	14.1	0.6	17.3	2.8	0.2	1.3	0.4	0.3	7.7	5.6	0.7
1998	66.1	40.2	0.6				3.0	0.9	0.3			
1999	46.0	26.7	0.6	28.1	10.4	0.4	2.8	0.7	0.2	10.7	8.5	0.8
2000	34.7	22.0	0.6	17.0	2.8	0.2	1.7	0.5	0.3	9.4	7.6	0.8
2001	29.1	17.0	0.6	6.2	1.8	0.3	1.6	0.7	0.4	8.0	7.5	0.9
2002	25.3	16.4	0.6	2.9	0.7	0.3	1.1	0.2	0.1	7.6	5.9	0.8
2003	40.0	24.7	0.6	7.8	1.7	0.2	1.7	0.3	0.2	10.4	8.9	0.9
2004	35.5	23.6	0.7	3.7	1.1	0.3	2.1	0.8	0.4	10.4	8.4	0.8
2005	44.6	29.7	0.7	4.8	1.5	0.3	4.4	1.7	0.4	10.5	8.8	0.8
2006		41.4	0.7				6.4	2.6	0.4	11.8	9.9	0.8
2007	55.3	38.4	0.7				6.5	2.0	0.3	12.6	10.7	0.8
2008	48.5	33.3	0.7				4.7	1.3	0.3	11.1	9.1	0.8
2009	35.3	23.7	0.7				4.6	2.1	0.5	8.1	6.7	0.8
2010	53.1	35.6	0.7				4.7	1.2	0.2			
2011	41.2	27.5	0.7				2.5	0.7	0.3	11.0	8.8	0.8
2012	56.2	32.5	0.6							9.9	8.1	0.8
2013	44.4	29.6	0.7							11.5	9.3	0.8
2014	31.8	21.1	0.7							9.3	7.5	0.8
2015	25.5	16.3	0.6									

Appendix 3: Meteorological Data

Appendix 3.1: Mean annual rainfall of the study area

year	Study area : Koka				Study area : Becho				
	Debrezeit	modjo	Koka	mean	Bantu liben	Tulu Bolo	Teji	Tefki	mean
1985					1105.0		844.1		974.6
1986	465.8	571.8	169.3	402.3	1274.2	1008.5	998.6		1093.8
1987	792.9	865.0	500.1	719.3	1123.1	939.2	727.1		929.8
1988	704.1	1061.5	818.9	861.5	1523.1	1128.8	1152.8		1268.2
1989	709.6	1033.6	833.0	858.7	1442.1	1169.4	898.2		1169.9
1990	727.2	906.5	1208.4	947.4	998.9	838.3	990.8		942.7
1991		879.5	576.9	728.2	1261.6	775.2	961.0		999.3
1992		798.0	2244.4	1521.2	1092.7	1668.8	962.0		1241.2
1993		839.1	1943.8	1391.5	1870.9	2258.2	1093.6		1740.9
1994	699.2	731.4	767.0	732.5	1381.6	1378.1	866.1		1208.6
1995	630.6	658.0	815.9	701.5	986.5	696.7	786.8		823.3
1996	1077.4	1059.6	590.4	909.1	2467.2	1217.4	946.1		1543.6
1997	854.4	760.3	885.5	833.4	998.3	1144.4	794.7		979.1
1998	984.7	1050.8	1193.7	1076.4	1595.4	1448.2	1135.7		1393.1
1999	926.5	1057.9	814.6	933.0	889.9	1372.4	833.8		1032.0
2000	1009.0	852.1	1164.7	1008.6		1223.4	866.1		1044.8
2001	864.5	788.1	1612.0	1088.2	1007.7	856.3	872.5		912.2
2002	648.3	564.3	615.6	609.4	984.2	1021.5	811.1		938.9
2003	1089.3	1060.1	1007.5	1052.3	1363.8	979.4	1082.0		1141.7
2004	862.5	1192.9	776.4	943.9	1329.1	1158.6	941.9		1143.2
2005	915.3	1560.3	537.6	1004.4	1843.1	1267.9	1112.6		1407.9
2006	999.2	1088.9	833.0	973.7	1569.2	1039.0	1170.2		1259.5
2007	863.5	989.4	774.8	875.9	1165.7	1026.0	969.3		1053.7
2008	821.0	1441.4	1134.6	1132.3	1091.0	1139.1	806.5		1012.2
2009	662.6	989.4		826.0		844.8	891.5		868.2
2010	919.1	1110.4	1120.1	1049.9	378.0	1402.8	1247.6	916.8	986.3
2011	939.2	869.1	1031.7	946.7		853.7	902.5	928.0	894.7
2012	768.6	1543.9	1174.6	1162.4	785.5	934.2	720.6	867.8	827.0
2013		1096.4	756.6	926.5	1152.2	1683.6	965.4	1006.5	1201.9
2014		875.1	791.1	833.1	1282.7	1028.7	844.8	747.7	976.0
2015		877.3	586.0	731.7		872.0	845.4	794.2	837.2

Appendix 3.1.1: Mean annual temperature of the study area (ºc).

Year	Study area: Koka			Study area: Becho		
	Koka	modjo	mean	Tulu Bolo	Tefki	mean
1986	21.3	18.9	20.1			
1987	21.6	20.6	21.1			
1988	21.8	20.3	21.1	15.6		15.6
1989	22.1	20.4	21.3	15.0		16.6
1990	23.0	20.0	21.5	14.4		17.6
1991	22.6	20.5	21.6	16.0		18.6
1992	22.8	20.4	21.6	18.0		19.6
1993	22.7	20.2	21.5	18.5		20.6
1994	22.0	20.2	21.1	18.6		21.6
1995	22.6	20.5	21.6	18.1		22.6
1996	21.4	20.0	20.7	16.6		23.6
1997	21.3	20.5	20.9	16.8		24.6
1998	20.9	20.5	20.7	16.0		25.6
1999	22.9	20.8	21.9	15.4		26.6
2000	23.2	20.2	21.7	14.9		27.6
2001	23.3	20.2	21.8	17.8		28.6
2002	21.8	20.3	21.1	18.0		29.6
2003	22.9	19.6	21.3	17.5		30.6
2004	22.2	19.5	20.9	17.4		31.6
2005	21.0	19.0	20.0	17.8		32.6
2006	22.6	19.8	21.2	17.4		33.6
2007	21.8	20.7	21.3	17.9		34.6
2008	21.8	20.0	20.9	17.5		35.6
2009	22.0	20.4	21.2	17.7		36.6
2010	22.0	20.4	21.2	18.1	18.2	18.2
2011	21.7	20.6	21.2	17.7	18.3	18.0
2012	22.1	20.2	21.2	17.4	18.2	17.8
2013	22.4	20.3	21.4	17.6	18.6	18.1
2014	22.9	20.6	21.8	17.8	19.0	18.4
2015	23.0	20.9	22.0	17.9	19.4	18.7

Appendix 4: Hand dug wells data

4.1: HDW Primary data in Becho area

Date	ID	Locality name	Gw elev (amsl)	UTM			SWL(m)	Well. depth (m)	Physical parameters			
				E	N	Elv (m)			PH	T(°c)	EC µS	TDS Mg/l
04/01/2017	AB1	Koritu	2050.2	432357	977585	2063	12.8	23	7.7	25	681	407
04/01/2017	AB2	Koritu	2052.5	432334	977574	2065	12.5	32	7.8	25	682	409
04/01/2017	AB3	Chora	2049.7	432434	978248	2061	11.3	22.8	7.52	25	863	518
04/01/2017	AB4	jigidumida	2052	431957	978288	2064	12	28	7.56	21	860	515
04/01/2017	AB5	jigidumida	2051.3	431712	978050	2064	12.7	26	7.54	25	883	531
04/01/2017	AB6	jigidumida	2052	431599	977831	2065	13	27	7.6	20	816	490
04/01/2017	AB7	jigidumida	2049.3	431536	977721	2062	12.7	29	7.5	25	809	485
04/01/2017	AB8	jigidumida	2053.1	431153	977152	2066	12.9	30	7.6	25	708	426
04/01/2017	AB9	Alengo Tullu	2054.8	430310	977177	2069	14.2	31	7.3	25	788	476
04/01/2017	AB10	Alengo Tullu	2056.5	429320	977231	2072	15.5	30	7.3	25	845	507
04/01/2017	AB11	Alengo Tullu	2057	429248	977143	2073	16	20	7.5	25	707	428
04/01/2017	AB12	Alengo Tullu	2055	429242	976959	2071	16	32	7.1	25	752	449
04/01/2017	AB13	Alengo Tullu	2051.6	429142	976806	2067	15.4	28	7.2	25	816	491
04/01/2017	AB14	Alengo Tullu	2053.4	429423	976516	2070	16.6	30	7.6	25	767	459
04/01/2017	AB15	Alengo Tullu	2052.5	429630	976072	2068	15.5	24	7.3	25	933	556
04/01/2017	AB16	Alengo Tullu	2052.3	429768	975985	2068	15.7	23	7.5	25	833	498
05/01/2017	AB17	Tefki	2043	446467	978252	2050	7	8	7.8	25	574	343
05/01/2017	AB18	Tefki	2047	446257	978115	2055	8	11.5	7.6	25	706	425
05/01/2017	AB19	Nano kersa	2047.8	446269	980159	2055	7.2	8.5	7.7	25	593	356
05/01/2017	AB20	Nano kersa	2056	446163	980312	2064	8	9.5	7.6	25	616	370
05/01/2017	AB21	Nano kersa	2051.5	446361	980748	2059	7.5	8.5	7.6	25	629	378
05/01/2017	AB22	Nano kersa	2056.5	446447	980846	2065	8.5	10	7.6	25	568	341
05/01/2017	AB23	Nano kersa	2058.5	446423	981088	2067	8.5	10.5	7.5	25	962	578
05/01/2017	AB24	Nano kersa	2053.3	445770	980981	2061	7.7	9.5	7.5	25	633	380
05/01/2017	AB25	Nano kersa	2053	445584	981024	2061	8	11	7.3	25	654	393
05/01/2017	AB26	Nano kersa	2064	444319	981353	2074	10	12	7.5	25	865	518
05/01/2017	AB27	Nano kersa	2057.4	444261	981473	2069	11.6	14	7.5	25	895	538
05/01/2017	AB28	Nano kersa	2059.1	444173	981654	2071	11.9	14.5	7.5	25	766	459
05/01/2017	AB29	Nano kersa	2054	444258	981620	2066	12	15	7.7	25	777	444
05/01/2017	AB30	Nano kersa	2054.7	444311	981671	2067	12.3	13.5	7.4	25	1036	622

06/01/2017	AB31	Keta Asgori	2077.5	423850	968718	2098	20.5	25	7.1	25	398	238
06/01/2017	AB32	Keta Asgori	2076.8	423961	968288	2093	16.2	23	6.9	25	415	248
06/01/2017	AB33	Jato	2068	424781	967604	2076	8	10	6.9	25	553	333
06/01/2017	AB34	Jato	2082.4	424863	967598	2094	11.6	13	6.7	25	509	305
06/01/2017	AB35	Jato	2076.3	424946	967729	2088	11.7	12.5	6.8	25	446	268
06/01/2017	AB36	Jato	2077	425216	967984	2085	8	12	7	25	325	194
06/01/2017	AB37	Jato	2081	425317	967498	2094	13	14.5	6.8	25	342	205
06/01/2017	AB38	Jato	2077.8	428442	967554	2091	13.2	15	7	25	323	195
06/01/2017	AB39	Jato	2077.4	425681	967497	2093	15.6	20	7.1	25	337	202
06/01/2017	AB40	Jato	2084.5	425781	967558	2099	14.5	18	7.3	25	351	211
06/01/2017	AB41	Jato	2081	425813	967767	2096	15	23	7.1	25	377	225
06/01/2017	AB42	Keta Asgori	2071	425123	969144	2085	14	18	6.9	25	361	217

4.1.1: HDW secondary data in Becho area from Agricultural Transformation Agency (ATA ,2014).

Date	Locality name	Gw elev (amsl	UTM			SWL(m)	Well depth (m)	Physical parameters			
			E	N	Elv(m)			PH	T(°C)	EC(μS)	TDS Mg/l
9/4/2014	Golole Kiltu	2074	426663	984210	2079	5	18	6.9	23.5	319	239
9/4/2014	Tulu Kore	2180	431552	996120	2182	2	6	7.18	24	676	247
9/4/2014	Endode	2087	431266	992786	2095	8	10	7.53	26	356	334
9/4/2014	Hora	2087	430929	992786	2095	8	12	7.5	21	501	306
9/4/2014	Hide	2066	432924	984328	2070	4	10	7.1	23	405	263
9/4/2014	Kimoyo	2104	426994	992931	2106	2	8	7.3	22	622	195
9/4/2014	Arabsa	2080	425009	986821	2084	4	10	6.9	26	240	206
9/4/2014	Rare Sequ	2073	422574	990009	2083	10	22	7.45	23	708	198
10/4/2014	Kusaye	2253	439484	996628	2259	6	10	7.4	22.5	565	204
9/4/2014	Golin	2209	438712	995145	2217	8	10	6.8	21.5	257	213
11/4/2014	Gora Arkiso	2065	451274	979178	2069	4	8	6.7	24	309	227
11/4/2014	Awash Belo	2051	435967	978086	2066	15	25	6.8	25	720	216
11/4/2014	Awash Belo	2061	435605	978021	2067	6	9	7.2	26	949	448
11/4/2014	Awash Belo	2060	446751	978534	2065	5	8	6.9	27	320	495
12/4/2014	Atebela Gudisa	2050.5	455617	971686	2053	2.5	5	6.8	23	190	457
5/4/2014	Abebe	2123	434813	958627	2126	3	10	7.2	22	396	559
5/4/2014	Kamisa Sadafa	2117	434931	958819	2122	5	9	6.7	23	300	494
5/4/2014	Kamisa Sadafa	2117	434929	955825	2122	5	18	6.8	24	204	348
5/4/2014	Banja	2113	431318	959999	2126	13	14	7.2	23.5	459	429
5/4/2014	Godina	2119	428814	959981	2145	26	28	7.3	24	354	357
7/4/2014	Awash	2002	437226	967469	2022	20	22	6.9	22	307	372
7/4/2014	Arada Tokofa	2096	433413	963354	2105	9	10	7.2	26	186	375
7/4/2014	Arada Gudo	2126	430503	960393	2140	14	15	7.6	25	575	343
7/4/2014	Mendi Toffisa#1	2263	408475	952876	2273	10	50	7.4	23	140	579
9/4/2014	Mendi Toffisa#2	2269	407460	953526	2278	9	36	7.5	22	944	385
9/4/2014	Keta	2077	424094	968971	2099	22	24	6.9	21	908	398
9/4/2014	Wajitu	2089	409122	975187	2103	14	15	7.4	23	1068	519
9/4/2014	Jiduka	2069	418707	974898	2079	10	12	7.5	24.5	149	531
9/4/2014	Jiduka	2070.5	423375	973439	2089	18.5	19.5	7.4	26	209	456
9/4/2014	Tefki	2057	441366	977899	2065	8	10	6.9	23	150	443
9/14/2014	Holota-Gole Lima	2060.5	441901	981393	2066	5.5	7	7.3	**21.5**	204	627

4.2: HDW Primary data in Koka area

Date	ID	Locality name	Gw elev (amsl	UTM			SWL(m)	Well. Depth (m)	Physical parameters			
				E	N	Elv(m)			PH	T(°C)	EC (µS)	TDS
29/12/2016	AK1	Gorbta	1591	501725	931782	1597	6	11	8.04	25	1426	854
29/12/2016	AK2	Gorbta	1591	501416	931857	1595	4	6	7.73	31.4	1496	812
29/12/2016	AK3	Gorbta	1589.5	501285	931767	1594	4.5	7	8.01	35.6	2020	1206
29/12/2016	AK4	Gorbta	1591	501211	931807	1595	4	6	8	25	1554	947
29/12/2016	AK5	Gorbta	1588	501101	931768	1593	5	7.5	8.4	25	1601	957
29/12/2016	AK6	Gorbta	1585.25	500978	931761	1589	3.75	5.5	8.02	25	1468	884
29/12/2016	AK7	Gorbta	1590.1	500883	931725	1594	3.9	5.5	7.7	31	1591	958
29/12/2016	AK8	Gorbta	1590.3	500827	931672	1594	3.7	6	7.82	25	1556	930
29/12/2016	AK9	Gorbta	1596.4	500827	931617	1600	3.6	5.6	8.13	25	1620	1046
29/12/2016	AK10	Gorbta	1591.8	500699	931596	1595	3.2	7.9	7.61	25	1563	878
29/12/2016	AK11	Gorbta	1589.8	500628	931612	1593	3.2	6.1	7.61	25	2050	1025
29/12/2016	AK12	Gorbta	1588.5	500596	931478	1592	3.5	8.5	7.9	25	1576	947
29/12/2016	AK13	Gorbta	1587	500410	931326	1590	3	5	7.97	25	2120	1301
29/12/2016	AK14	Gorbta	1586.6	500417	931253	1590	3.4	4	8.4	25	2240	1323
29/12/2016	AK15	Gorbta	1591.5	500183	931114	1595	3.5	5.5	8.1	25	2330	1394
29/12/2016	AK16	Gorbta	1590	499690	930768	1595	5	7	7.7	25	2800	1661
29/12/2016	AK17	Gorbta	1591	499803	930662	1596	5	8	8.01	25	2750	1663
29/12/2016	AK18	Gorbta	1592.5	500978	929324	1595	2.5	4	8.02	30	2200	1312
29/12/2016	AK19	shulki	1589	501984	930139	1594	5	7.1	7.96	25	1920	1156
30/12/2016	AK20	Bereket	1511.3	502627	932763	1519	7.7	15.5	8.02	25	1539	920
30/12/2016	AK21	Bereket	1593.7	502626	933098	1600	6.3	7.8	7.83	26.5	1447	870
30/12/2016	AK22	lafto	1592	502542	933881	1599	7	10.7	7.8	25	1754	1053
30/12/2016	AK23	lafto	1592.8	502761	934156	1598	5.2	9	7.62	23.1	1395	837
30/12/2016	AK24	lafto	1600.5	502604	934067	1606	5.5	8.8	7.71	23.3	1660	997
30/12/2016	AK25	lafto	1593	502343	934370	1598	5	7.5	7.81	25	2000	1203
30/12/2016	AK26	lafto	1594.7	502398	934405	1602	7.3	9.2	8.24	25	2700	1600
30/12/2016	AK27	lafto	1592.3	502462	934485	1599	6.7	19	8.08	25	2630	1580
30/12/2016	AK28	lafto	1596	502105	934540	1601	5	12	8	25	2100	1590
30/12/2016	AK29	lafto	1596.5	501992	934619	1602	5.5	8	7.9	25	2070	1244
30/12/2016	AK30	lafto	1592	502097	934722	1598	6	9	8	25	2000	1222

30/12/2016	AK31	lafto	1594	502008	934804	1600	6	8	7.8	25	2010	1314
30/12/2016	AK32	lafto	1599.8	501817	935014	1606	6.20	16	7.72	25	1249	746
30/12/2016	AK33	lafto	1591	501651	935266	1598	7	14	8.04	25	1728	1037
30/12/2016	AK34	lafto	1597.5	501753	935316	1605	7.5	10.5	8.13	25	1807	1086
30/12/2016	AK35	lafto	1595	501932	935187	1603	8	11	8.14	25	2400	1448
30/12/2016	AK36	lafto	1596	502927	934350	1603	7	16	7.56	23.4	1297	783
31/12/2016	AK37	Haruma	1588.5	506752	933787	1595	6.5	9	7.82	25	1648	989
31/12/2016	AK38	Haruma	1592	506663	933554	1595	3	9.5	7.94	23	1372	823
31/12/2016	AK39	Haruma	1591.5	506574	933385	1594	2.5	10	7.62	22.9	1719	1030
31/12/2016	AK40	Haruma	1588	506768	933359	1591	3	10.5	7.52	25	1239	744
31/12/2016	AK41	Haruma	1590	507116	933302	1592	2	8.5	7.80	25	4080	2460
31/12/2016	AK42	Haruma	1594	507071	933162	1596	2	3.5	7.81	18.4	937	560
31/12/2016	AK43	Haruma	1589	506974	933014	1591	2	7	8.30	22.9	1405	847
31/12/2016	AK44	Haruma	1589.1	507024	937821	1591	1.9	7.5	8.72	25	878	527
31/12/2016	AK45	Haruma	1587.7	506912	932702	1590	2.3	7	7.97	25	1780	1070
31/12/2016	AK46	Haruma	1585	506811	932832	1587	2	7	8.24	25	1050	620
31/12/2016	AK47	Haruma	1589.5	506699	933082	1592	2.5	8	8.49	25	1259	757
31/12/2016	AK48	Haruma	1591.5	500563	933165	1594	2.5	8.5	7.65	25	1258	754
31/12/2016	AK49	Haruma	1590	506401	933419	1594	4	9	7.42	25	1020	615
31/12/2016	AK50	Haruma	1587	506395	933364	1590	3	7	7.71	25	1082	648
31/12/2016	AK51	kelna	1585	506523	932958	1587	2	11	8.2	25	1471	883
31/12/2016	AK52	kelna	1591.5	506725	932427	1594	2.5	7	7.8	25	1657	938
31/12/2016	AK53	kelna	1590	504982	932479	1595	5	7	8.04	27	1873	1115
01/01/2017	AK54	koka	1496	503523	932760	1524	28	30	8.76	32	1693	1026

4.2.1: HDW secondary data in Koka area from Water Works Design and Supervision Enterprise (WWDSE,2008).

Date	Woreda	Gw elev (amsl	UTM			SWL(m)	Well depth (m)	Physical parameters			
			E	N	Elv(m)			PH	T(°C)	EC(μS)	TDS Mg/l
14/2/2008	Adaa	1609	504000	935000	1627	18	18	8.01	23.4	878	1086
9/2/2008	Adaa	1635	504000	943000	1692	57	58	8.02	25	1780	1448
9/2/2008	Adaa	1704	504000	947000	1732	28	28	7.96	23	1050	783
9/2/2008	Adaa	1940	504000	951000	1961	21	21	8.02	22.9	1259	989
9/2/2008	Adaa	1812	507000	953000	1835	23	23	7.83	25	1258	823
9/2/2008	Adaa	1773	510000	953000	1808	35	36	7.8	25	1020	1030
9/2/2008	Adaa	1662	500000	888000	1687	25	26	7.62	18.4	1082	744
9/2/2008	Adaa	1816	510000	956000	1839	23	23	7.71	22.9	1471	965
10/2/2008	Adaa	1823	510000	958000	1847	24	25	7.81	25	1657	560
9/2/2008	Adaa	1819	509000	959000	1844	25	26	8.24	31.4	1873	847
11/2/2008	Adaa	1835	509000	961000	1845	10	11	8.08	35.6	1693	947
11/2/2008	Adaa	1878	503000	959000	1890	12	16	8.13	25	1426	957
11/2/2008	Adaa	1877	500000	960000	1911	34	34	8.14	25	1496	884
11/2/2008	Adaa	1872	502000	961000	1898	26	26	7.56	25	2020	958
12/2/2008	Adaa	1844	502000	964000	1873	29	30	7.82	31	1554	930

Appendix 5: The standardized data sheet format and calculations of Guelph permeameter

Study Area ____________ Section 1: site information

Date__________

ID __________

GPS Reading: E________, N__________, Elevation(m)____________

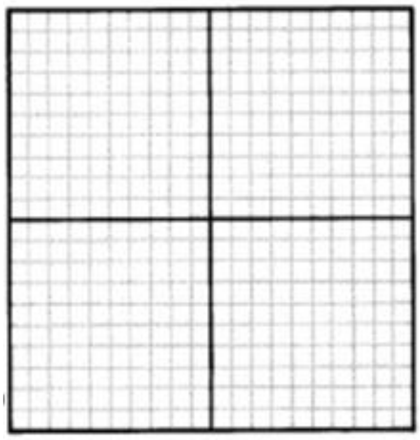
Site location ___________

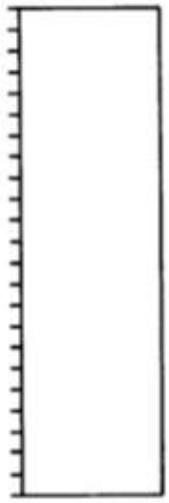
Investigator_____________

Dominant soil type(s)_________________________

Soil profile description (horizon depth. Texture, structure, color,etc.)

Site map Depth (cm) Description





Comments and notes (topography, slope, vegetation, etc.):

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____

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____

____

____________________________.

Date ___________, Investigator___________

Section 2: standardized procedure for permeameter readings and calculations

Reservoir constants:(see label on permeameter)

Combined reservoirs	X	35.22	cm^2	
Inner reservoir	Y	2.15	cm^2	

Depth of well hole _______

Check reservoir used

Note: In standardized procedure, the radius of the well hole is always 3.0cm

2nd set of readings with height of water in well (H_2) set at 10 cm.

1st set of readings with height of water in well (H_1) set at 5 cm

Reading Number	Time(mn)	Time interval(mn)	Water level in reservoir (cm)	Water level change(cm)	rate of water level change R_1(cm/mn)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					

Reading Number	Time (mn)	Time interval(mn)	Water level in reservoir (cm)	Water level change(cm)	rate of water level change R_2(cm/mn)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					

calculations

$\overline{R}$ the steady state of flow, is achieved when R is the same in the three consecutive time intervals.

For the first set of readings $\overline{R}_1$ = (_______)/60 = ___________cm/se

For the 2nd set of readings $\overline{R}_2$ = (________)/60 = ___________cm/se

K_{fs} = ((0.0041) (_________) (__________)) ├ ((0.0054) (__________) (___________)) =__________cm/se

Field saturated hydraulic conductivity — Reservoir Constant — $\overline{R}_2$ — reservoir constant — $\overline{R}_1$

ϕ_m = ((0.0572) (_________) (__________)) – ((0.0237) (_________) (___________)) = _________cm²/se

matrix flux potential — reservoir constant — $\overline{R}1$ — reservoir constant — $\overline{R}_2$ steady state rate of flow

Alpha parameter = (__________) / (_________) =___________ cm⁻¹

K_{fs} — ϕ_m

Delta Theta = field saturated water content of soil in cm/cm - Ambient water content of soil in cm/cm =_________cm^3/cm^3

= (______________________________) - (________________________) = __________ **cm^3/cm^3**

Estimated

Measured

S = square root of 2(_____________) (______________) =___________ cm $sec^{-1/2}$

sorptivity — Delta Theta — matrix flux potential

Appendix 6: In situ soil field, saturated hydraulic conductivity test results of MB4 and MK7

Study Area :Becho

Section 1: site information

Date28/02/2017

ID:**MB4**

GPS Reading : E,432355 ,N,977702,Elevation(m) 2063

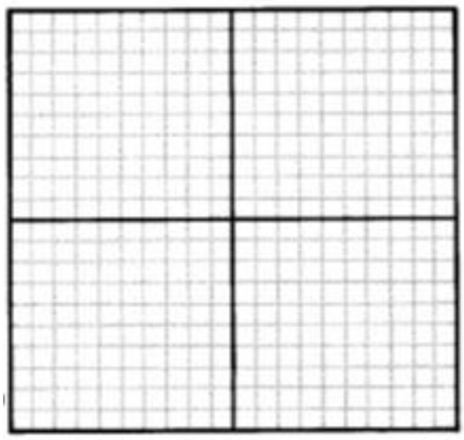
Site location locality/kebele/village :Koritu

Investigator:Alemu Mesele

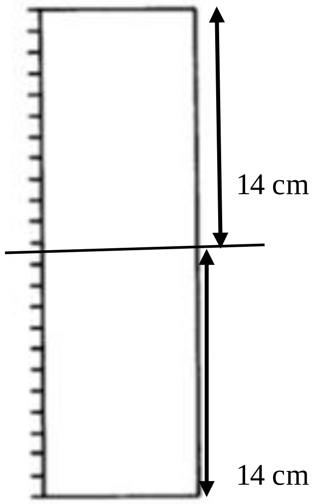
Dominant soil type(s): clay loam

Soil profile description (horizon depth. Texture, structure, color,etc.)

Site map



Depth (cm)



Description

Brown to gray

Moist soil

Fine grain soil

Brown to Gray soil

Medium to fine grained

Slightly dry soil

Comments and notes (topography, slope, vegetation, etc.):

Extremely flat area

For irrigation purpose

Date 28/02/2017, Investigator:Alemu Mesele

Section 2: standardized procedure for permeameter readings and calculations

Reservoir constants:(see label on permeameter)

Depth of well hole 28 cm

Combined Reservoirs X	35.22	cm^2	✓
Inner Reservoir Y	2.15	cm^2	

Check reservoir used

Note: In standardized procedure, the radius of the well hole is always 3.0cm

2nd set of reading with height of water in well (H_2) set at 10 cm.

1st set of readings with height of water in well (H_1) set at 5 cm

Reading Number	Time(sec)	Time interval(sec)	Water level in reservoir (cm)	Water level change(cm)	rate of water level change R_1(cm/sec)
1	0	---	6.1	---	---
2	30	30	6.5	0.4	0.013
3	60	30	6.9	0.4	0.013
4	90	30	7.3	0.4	0.013
5	120	30	7.7	0.4	0.013
6	150	30	7.9	0.2	0.0067
7	180	30	8.1	0.2	0.0067
8	210	30	8.3	0.2	0.0067
9	240	30	8.5	0.2	0.0067
10	270	30	8.8	0.3	0.01
11	300	30	9	0.2	0.0067
12	330	30	9.2	0.2	0.0067
13	360	30	9.3	0.1	0.0033
14	390	30	9.5	0.2	0.0067
15	4120	30	9.7	0.2	0.0067
16	450	30	9.9	0.2	0.0067
17	480	30	10	0.1	0.0033
18	510	30	10.1	0.1	0.0033
19	540	30	10.3	0.2	0.0067
20	570	30	10.4	0.1	0.0033
21	600	30	10.5	0.1	0.0033
22	630	30	10.6	0.1	0.0033
23	660	30	10.7	0.1	0.0033
24	690	30	10.9	0.2	0.0067
25	720	30	11	0.1	0.0033
26	750	30	11.1	0.1	0.0033
27	780	30	11.3	0.2	0.00067
28	810	30	11.4	0.1	0.0033
29	840	30	11.5	0.1	0.0033
30	870	30	11.6	0.1	0.0033
31	900	30	11.7	0.1	0.0033
32	930	30	11.8	0.1	0.0033
33	960	30	11.9	0.1	0.0033
34	990	30	12	0.1	0.0033
35	1020	30	12.1	0.1	0.0033
36					

Reading Number	Time (sec)	Time interval(sec)	Water level in reservoir (cm)	Water level change(cm)	rate of water level change R_2(cm/sec)
1	0	---	16	---	---
2	20	20	16.5	0.5	0.025
3	40	20	17	0.5	0.025
4	60	20	17.5	0.5	0.025
5	80	20	17.9	0.4	0.02
6	100	20	18	0.1	0.005
7	120	20	18.4	0.4	0.02
8	140	20	18.6	0.2	0.01
9	160	20	19	0.4	0.02
10	180	20	19.4	0.4	0.02
11	200	20	19.8	0.4	0.02
12	220	20	20.4	0.6	0.03
13	240	20	20.8	0.4	0.02
14	260	20	21.3	0.5	0.025
15	280	20	21.6	0.3	0.015
16	300	20	22	0.4	0.02
17	320	20	22.5	0.5	0.025
18	340	20	22.8	0.3	0.015
19	360	20	23.2	0.4	0.02
20	380	20	23.7	0.5	0.025
21	400	20	24.2	0.5	0.025
22	420	20	24.6	0.4	0.02
23	440	20	25	0.4	0.02
24	460	20	25.5	0.5	0.025
25	480	20	25.7	0.2	0.01
26	500	20	26.2	0.3	0.015
27	520	20	26.7	0.5	0.025
28	540	20	27	0.3	0.015
29	560	20	27.5	0.5	0.025
30	580	20	27.9	0.4	0.02
31	600	20	28.2	0.3	0.015
32	620	20	28.5	0.3	0.015
33	640	20	28.8	0.3	0.015
34	660	20	29.1	0.3	0.015
35	680	20	29.4	0.3	0.015
36					
37					
38					
39					

calculations

$\bar{R}$ the steady state of flow, is achieved when R is the same in the three consecutive time intervals.

For the first set of readings $\bar{R}_1$ = (----)/60 = 0.013 cm/se

For the 2nd set of readings $\bar{R}_2$ = (-----)/60 = 0.025cm/se

K_{fs} = ((0.0041) (35.22) (0.025)) - ((0.0054) (35.22) (0.013)) = 0.00114 cm/se

Field saturated hydraulic conductivity — Reservoir Constant — $\bar{R}_2$ — reservoir constant — R_1

ϕ_m = ((0.0572) (35.22) (0.013)) – ((0.0237) (35.22) (35.22) = 0.00532 cm^2/se

matrix flux potential — reservoir constant — $\bar{R}1$ — reservoir constant — R_2 steady state rate of flow

Alpha parameter = (0.00114) / (0.00532) = 0.21 cm^{-1}

K_{fs} — ϕ_m

Delta Theta = field saturated water content of soil in cm/cm - Ambient water content of soil in cm/cm = 0.002 cm^3/cm^3

= (0.015) - (0.013) = 0.002cm3/cm3 Estimated

S = square root of 2(0.002) (0.00532) = 0.0046 cm $sec^{-1/2}$

sorptivity — Delta Theta — matrix flux potential

Study Area :Koka

Section 1: site information

Date:25/02/2017

ID :**MK7**

GPS Reading :E, 506513,N,933168 ,Elevation(m) :1596

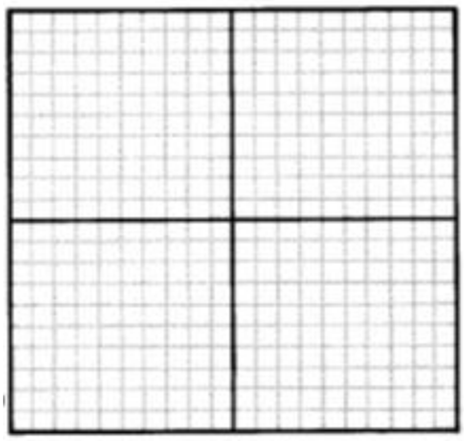
Site location locality/kebele/village :Engugi Bekele

Investigator: Alemu Mesele

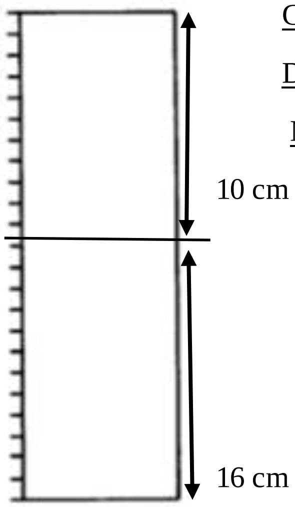
Dominant soil type(s):clay loam soil

Soil profile description (horizon depth. Texture, structure, color,etc.)

Site map



Depth (cm)



Description

Gray to black soil

Dry soil

Medium to fine grained soil

Moist soil

edium to fine grained soil

Gray to black soil

Comments and notes (topography, slope, vegetation, etc.):

Flat Area

For Irrigation purpose

Date 25/02/2017, Investigator : Alemu Mesele

Section 2: standardized procedure for permeameter readings and calculations

Reservoir constants:(see label on permeameter)

Depth of well hole:26 cm

Combined Reservoirs X	35.22	cm^2	✓
Inner Reservoir Y	2.15	cm^2	

Check reservoir used

Note: In standardized procedure, the radius of the well hole is always 3.0cm

1st set of readings with height of water in well (H_1) set at 5 cm

Reading Number	Time(sec)	Time interval(sec)	Water level in reservoir (cm)	Water level change(cm)	rate of water level change R_1(cm/sec)
1	0	--	13	---	----
2	5	5	13.1	0.1	0.02
3	10	5	13.2	0.1	0.02
4	15	5	13.3	0.1	0.02
5	20	5	13.6	0.3	0.06
6	25	5	13.9	0.3	0.06
7	30	5	14	0.1	0.02
8	35	5	14.1	0.1	0.02
9	40	5	14.3	0.2	0.04
10	45	5	14.6	0.3	0.06
11	50	5	14.9	0.3	0.06
12	55	5	15	0.1	0.02
13	60	5	15.1	0.1	0.02
14	65	5	15.3	0.2	0.04
15	70	5	15.5	0.2	0.04
16	75	5	15.9	0.4	0.08
17	80	5	16	0.1	0.02
18	85	5	16.1	0.1	0.02
19	90	5	16.2	0.1	0.02
20	95	5	16.3	0.1	0.02
21	100	5	16.5	0.2	0.04
22	105	5	16.9	0.4	0.08
23	110	5	17	0.1	0.02
24	115	5	17.1	0.1	0.02
25	120	5	17.2	0.1	0.02
26	125	5	17.5	0.3	0.06
27	130	5	17.6	0.1	0.02
28	135	5	17.9	0.3	0.06
29	140	5	18.2	0.3	0.06
30	145	5	18.5	0.3	0.06
31	150	5	18.6	0.1	0.02
32	155	5	18.7	0.1	0.02
33	160	5	18.8	0.1	0.02
34					
35					
36					
37					
38					
39					

2nd set of reading with height of water in well (H_2) set at 10 cm.

Reading Number	Time (sec)	Time interval(sec)	Water level in reservoir (cm)	Water level change(cm)	rate of water level change R_2(cm/sec)
1	0	---	22	---	----
2	5	5	22.1	0.1	0.02
3	10	5	22.3	0.2	0.04
4	15	5	22.5	0.2	0.04
5	20	5	22.7	0.2	0.04
6	25	5	22.9	0.2	0.04
7	30	5	23	0.1	0.02
8	35	5	23.1	0.1	0.02
9	40	5	23.2	0.1	0.02
10	45	5	23.5	0.3	0.06
11	50	5	23.6	0.1	0.02
12	55	5	23.7	0.1	0.02
13	60	5	23.9	0.2	0.04
14	65	5	24	0.1	0.02
15	70	5	24.1	0.1	0.02
16	75	5	24.2	0.1	0.02
17	80	5	24.5	0.3	0.06
18	85	5	24.6	0.1	0.02
19	90	5	24.8	0.2	0.04
20	95	5	25	0.2	0.04
21	100	5	25.1	0.1	0.02
22	105	5	25.2	0.1	0.02
23	110	5	25.4	0.2	0.04
24	115	5	25.5	0.1	0.02
25	120	5	25.8	0.3	0.06
26	125	5	26	0.2	0.04
27	130	5	26.1	0.1	0.02
28	135	5	26.2	0.1	0.02
29	140	5	26.3	0.1	0.02
30	145	5	26.5	0.2	0.04
31	150	5	26.7	0.2	0.04
32	155	5	26.9	0.2	0.04
33	160	5	27	0.1	0.02
34	165	5	27.1	0.1	0.02
35	170	5	27.4	0.2	0.04
36	175	5	27.6	0.2	0.04
37	180	5	27.8	0.2	0.04
38					
39					

calculations

$\bar{R}$ the steady state of flow, is achieved when R is the same in the three consecutive time intervals.

For the first set of readings $\bar{R}_1$ = (-----)/60 = 0.02 cm/se

For the 2nd set of readings $\bar{R}_2$ = (------)/60 = 0.04 cm/se

K_{fs} = ((0.0041) (35.22) (0.04)) - ((0.0054) (35.22) (0.02)) = 0.00197cm/se

Field saturated hydraulic conductivity; Reservoir Constant; $\bar{R}_2$; reservoir constant; R_1

ϕ_m = ((0.0572) (35.22) (0.02)) – ((0.0237) (35.22) (0.04) = 0.006903cm^2/se

matrix flux potential; reservoir constant; $\bar{R}1$; reservoir constant; R_2 steady state rate of flow

Alpha parameter = (0.00197) / (0.006903) = 0.29 cm^{-1}

K_{fs} ... ϕ_m

Delta Theta = field saturated water content of soil in cm/cm - Ambient water content of soil in cm/cm = 0.02 cm^3/cm^3

= (0.04) - (0.02) = 0.02 cm3/cm3 Estimated

S = square root of 2(0.02) (_0.006903) = 0.016 cm sec$^{-1/2}$

sorptivity; Delta Theta; matrix flux potential