



**Temporal changes in Groundwater Recharge in the Upper Awash Basin**  
**with particular emphasis to Becho and Koka areas, Central Ethiopia**

***A Thesis Submitted to School of Earth Sciences***



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**Presented in partial fulfillment of the requirements for the Degree of  
Master of Science (Hydrogeology)**

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This is to certify that the thesis prepared by **Daniel Nuramo**, entitled: *Temporal changes in Groundwater Recharge in the upper Awash basin with particular emphasis to Becho and Koka areas, Central Ethiopia, 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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## **Abstract**

An estimate of groundwater recharge is important for water resources planning and management to determine the sustainability of groundwater resources. Estimates of groundwater recharge can be made using river discharge records. In this study baseflow separation excel spread sheet program and water balance method using long term meteorological data has been utilized. The study area Becho plain and Koka plain is located in upper Awash basin, in the central part Ethiopia. Awash River at Bello, and Hombole, Mojo and Teji River catchments of upper Awash River basin have been identified as focal areas for assessing the recharge process. The main objective of this study is to evaluate the temporal changes of groundwater recharges which will be vital information for future sustainable use of the groundwater resource. The mean annual recharge of the Becho and Koka areas using the water balance method was found to be 319.5 mm and 49.5 mm and using baseflow separation excel spread sheet program it was found to be 81.4 mm and 104.3mm respectively. A trend analysis of long term and recent hydrometeorological variables for the study area was conducted to detect possible effects of climate changes and human activities in the area. Long term river flow and baseflow in the Mojo and Teji Rivers have a slightly decreasing trend but the main Awash River at Bello and Hombole shows increasing trend. The recent trends of river flow and baseflow except the Awash River at Bello the other rivers in the study area shows decreasing trends. The possible reason for this is slightly decreasing trend of precipitation, increasing of evapotranspiration and excessive human activity in the study area.

**Key words:** Baseflow, Ethiopia, Excel Spread Sheet, River Flow, Upper Awash River Basin and Water Balance.

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## List of abbreviations and Symbols

WWDSE	water works design supervision enterprise
ITCZ	Inter-Tropical Convergence Zone
GSE	geological survey of Ethiopia
EMA	Ethiopian map agency
GIS	Geographic Information Systems
GPS	Global Positioning System
PET	Potential evapotranspiration
AET	actual evapotranspiration
ENMA	Ethiopian national meteorological agency
UTM	Universal Transvers Mercator
SRO	surface runoff
P	Precipitation
R	Recharge
MR	Mojo River
TR	Teji River
MRF	mean River flow
AR@H	Awash River at hombole
AR@B	Awash River at Bello
MBF	mean baseflow
MSRO	mean surface runoff
BF	baseflow
TF	total flow

# Chapter 1. Introduction

## 1.1 Background

Groundwater is an important natural source of water supply throughout the world. It is a precious and most distributed resource. The use of groundwater is increasing day by day in irrigation, domestic water supply, municipalities, and rural areas and in industries. It is the main source of water supply development in Ethiopia covering about 85% (Getachew, 2004).

Groundwater recharge is downward flow of water reaching the water table, forming an addition to the groundwater reservoir. It is the most important water budget component of groundwater system. Understanding and quantifying recharge processes are the prerequisites for any analysis of the resource sustainability (Foster, 1988). It also helps policymakers make better informed decisions regarding land use and water management since protection of natural recharge areas is paramount to the sustainability of the groundwater resource (Kresic, 2009).

The sources of recharge to a groundwater system include both natural and human induced phenomena. Natural sources include recharge from precipitation, lakes, ponds, and rivers including perennial, seasonal, and ephemeral flows, and from other aquifers. Human-induced sources of recharge include irrigation losses from both canals and fields, leaking water mains, sewers, septic tanks, and over-irrigation of parks, gardens, and other public amenities (Sophocleous, 2004).

Groundwater recharge is influenced by hydrologic processes and physical characteristics of the land surface and soil profile. Excessive withdrawal of groundwater and at the same time insufficient recharge is causing rapid depletion of groundwater level at many places in developing country. As a consequence, groundwater quantity and quality is also deteriorating day by day. Nowadays the need for ground water utilization is likely to increase due to expansion of irrigated agriculture and different development activities within the basin and surrounding areas. Therefore, the exploration and exploitation of these limited groundwater resources need to understand the source of recharge, spatial and temporal distribution of groundwater recharge rate for the intended uses.

Estimating groundwater recharge in arid- and semi-arid regions can be difficult, since in such areas the recharge is generally low compared to the average annual rainfall or evapotranspiration, and thus difficult to determine precisely. Recharge processes vary from one place to another, and there is no guarantee that a method developed and used for one locality will give reliable results when used in another. Therefore, it is necessary to identify the probable flow mechanisms and the important features influencing the recharge in a locality before deciding on the recharge method to use (Lerner et al., 1990). The recharge to a groundwater aquifer cannot be easily measured directly, and usually estimated by indirect means. A wide variety of methods exists for estimating groundwater recharge direct measurement, water balance, Darcian approach, tracer techniques and empirical relations, which have been designed to represent the actual physical processes of the recharge.

## **1.2 Statement of the problem**

The demand for groundwater resources is increasing day by day due to ever increasing population, mostly from developing countries. The study area has high potential groundwater resources but currently there are many challenges including high spatial and temporal variability in rainfall, global climate change, deforestation, land degradation, and high population growth rate. These challenges put immense pressure on the groundwater resources. This has resulted in abstracting more water from the ground water reservoir.

Therefore, quantification of the rate, spatial distribution and temporal changes of groundwater recharge is a pre-requisite for efficient ground water resource management. It is particularly important in regions with large demands for ground water supplies, where such resources are the key to economic development. Previously a lot of studies have been undergone in the study area by the ministry of water Resource, water works design and supervision enterprise and different bodies. The studies were carried out with respect to water balance, Hydrogeological and groundwater potential evaluation of the area on general and regional basis and have estimated groundwater recharge in different areas of upper awash basin. However, Most of the studies have identified the spatial distributions, therefore, present studies evaluates the temporal changes of groundwater

recharges which will be vital information for future sustainable use of the groundwater resource.

### **1.3 Objective of the study**

#### **1.3.1 General objective**

The general objective of this study is to evaluate the temporal changes of groundwater recharges which will be vital information for future sustainable use of the groundwater resource.

#### **1.3.2 Specific objective**

The Specific objectives of the study are:

- To evaluate basic components of hydrologic cycles
- To estimate total amount of ground water recharge.
- To estimate spatial distribution and temporal changes of ground water recharge.
- To identify the sources of groundwater recharge
- To identify factors that changes groundwater recharge

### **1.4. Significance of the research**

Depending on the groundwater potential result obtained in the upper awash basin, other than domestic water supply currently there is an increasing demand to start developing groundwater resource for irrigation. This could increase stresses on naturally limited groundwater resources in the upper awash basin. Therefore, the contributions of this study are to know the spatial distribution and temporal changes of ground water recharge and thus helps to exploit and effectively utilize this limited and precious resource. In such highly water demanding environments, the results of this study will play its own role to establish a trend for future groundwater resource management in the study area.

## Chapter 2. Literature Review

### 2.1 Groundwater recharge

Groundwater use is fundamental importance and often the key to economic and social development in many areas world-wide, particularly in arid and semiarid areas where surface water supplies are unreliable and poorly distributed. The evaluation of the groundwater resources involves several factors of which the groundwater recharge is a key.

The recharge to the groundwater system is also variable as the rainfall over Ethiopia is extremely variable in both space and time. The main source of recharge for the vast groundwater system is the rainfall on the highlands. The major recharge occurs in the northeastern and southwestern plateau where annual rainfall is high. Rapid infiltration occurs in areas covered by fractured volcanics and to a lesser extent in sedimentary rocks and thick permeable soils. The Ethiopian rift acts as a discharging zone, which contains numerous perennial rivers, fresh and salt lakes, cold and thermal springs (Tamiru Alemayehu, 2006).

Table 2.1 Recharge classification (Source: Tenalem Ayenew and Tamiru Alemayehu, 2001)

Annual recharge (mm)	Location
250-400	Highlands of Illu Ababora, Keffa and Wollega
150-250	Much of the Western and western and central Ethiopia and Arsi-Bale highlands
50-150	Much of Northern and northwestern highlands, central Main Ethiopian rift, southern and eastern regions between the Rift plain and the Arsi-Bale Highlands
less than 50	Southern Afar and the extreme northern end of the western Lowlands

### 2.2 Definition and concepts of groundwater recharge

Groundwater recharge can be defined as the entry of water in to the saturated zone of water made available at the water table surface together with the associated flow away from the water table with in the saturated zone (Freeze and cheery, 1979). The basic mechanisms of groundwater in arid and semi-arid areas are reasonably well known. However, estimation of the various processes of the hydrological cycle in order to quantify the recharge is a difficult task (Lerner et al, 1990). The two major flow

mechanisms in arid- and semi-arid- areas are piston or uniform flow, and preferential flow.

## **2.3 Recharge estimation methods**

Estimating groundwater recharge in arid and semi-arid regions can be difficult, since in such areas the recharge is generally low compared to average annual rainfall or evapotranspiration, and thus difficult to determine precisely (Scanlon et al.,2002). A number of methodologies are used to estimate recharge. These can be classified as: direct or indirect, isotopic, methods based on the analysis of inflow, outflow, or aquifer response, methods based on the unsaturated or saturated zones and methods based on numerical modeling of groundwater flow, soil-water flow, both soil and groundwater flows, or modeling of the hydrologic balance at plot, field, or watershed scales (Sophocleous, 2004).

### **2.3.1 Groundwater recharge evaluation using baseflow separation**

Baseflow is that part of stream flow usually attributed to groundwater discharge (U.S. Geological Survey, 1989). Although base flow is not recharge, it is sometimes used as an approximation of recharge when underflow, evapotranspiration from riparian vegetation, and other losses of ground water from the watershed are thought to be minimal. When used as a proxy for recharge, baseflow has sometimes been referred to as “effective recharge” (Daniel, 1996), “base recharge” (Szilagyi and others, 2003), or “observable recharge” (Holtschlag, 1997) to acknowledge that it probably represents some amount less than that which recharged the aquifer. The major assumptions in using baseflow for estimating recharge are that baseflow equals ground-water discharge, and that groundwater discharge is approximately equal to recharge. Implicit is the assumption that groundwater losses from the gaged watershed caused by underflow, groundwater evapotranspiration, and exports of ground water are minimal. If these conditions are met, base flow may provide a reasonable estimate of recharge for long time periods (1 year or more). There are different methods for separating base flow will provide different results and the user is left to determine which estimate (if any) is most representative of recharge.

## **2.4 Limitations and errors in estimating groundwater recharge**

Estimating the recharge to groundwater is often achieved using indirect methods, because it is difficult to measure directly. The use of indirect methods is associated with various limitations, which make the recharge rates prone to large uncertainties and errors. For instance, unsaturated zone methods are mostly founded on the principle of mass balance. An important underlying assumption of such recharge methods is that recharge occurs through a diffuse process or piston flow of water and, therefore, recharge flux through preferred pathways is often not accounted for. Meanwhile, in many arid and semi-arid areas, particularly in Sub-Saharan Africa, recharge flux via preferred pathways is the rule rather than the exception and, therefore, recharge estimates from unsaturated-zone methods can be questionable (Xu and Beekman, 2003; Tonder and Bean, 2003).

## **2.5 Previous works**

In the upper awash basin many academic researchers and organizations have conducted their Research on groundwater investigations to assess groundwater resources.

Hussen Endre (2006) conducted a study on the title of Water resource potential evaluation of Berga river catchment, west shewa zone, oromia regional state. In the study area the main source of recharge is from direct precipitation the annual recharge in the catchment is 82.71mm (25.1mcm), which is 7.4% of annual precipitation by using water balance and base flow separation

Ketema Wogari (2006) conducted a study on the title of Water resource potential evaluation of Holeta river catchment, west shewa zone, and central oromia. The amount of recharge in Holeta catchment is calculated as 310.6 mm (160 mcm) using water balance and base flow separation of this amount of recharge 79% leaves the basin in the form of base flow. The above result shows that recharge, AET and SRO are 24%, 60% and 16% respectively of the total rainfall which indicates that the topography of the basin is good for ground water percolation.

Mussa Kurkura (2006) conducted a study on the title of Water balance of upper awash basin based on satellite-derived data (remote sensing).he estimates of major/ water balance components of the Upper Awash Basin were obtained for year 2008. Satellite

rainfall data and SEBS model output were used to assess the temporal and spatial distribution of major water balance components on a pixel-by-pixel basis.

Behailu Berehanu (2007) conducted a study on the title of Impact of Industries and Urbanization on water Resource in Mojo River Catchment, Oromia regional state. The estimated recharges of the area are 282 million cubic meter using water balance method.

Andualem Eshetu (2008) conducted a study on the title of Water resource potential evaluation of Teji river catchment, south west shewa zone, oromia regional state. In the study area the main source of recharge is from direct precipitation. The annual recharge in the catchment is 325.39 mm, which is 29.5% of annual precipitation using water balance and base flow separation.

WWDSE (2008) studies Executive Summary Evaluation of the Ground Water Resources of Ada'a-Becho Plains Ground Water Basin for Irrigation Development Project. In this study The WATBAL model is used to estimate recharge estimated annual recharge into Ada'a-Becho plains groundwater system from awash up to Melka kunturi is 142 mm and Mojo-Wedecha is 153mm.

WWDSE (2008) studies geology, hydrology and geophysics Ada'a-Becho Plains Ground Water Basin for Irrigation Development Project. In this study The WATBAL model is used to estimate recharge estimated annual recharge into Ada'a-Becho plains groundwater system Estimated mean monthly recharge over the Upper Abay and Awash basin. Mojo watershed mean annual deep recharge is 85.9 mm where as Akak and Teji watersheds mean annual recharges are 25 mm and 32 mm respectively. Holeta mean annual recharge is high (88.7 mm) where its soil has little vertisoils. The model predicts that mean deep recharges over Upper Abay watersheds of Muger, Robi Gida, Robi Gumara and Aleltu more than 75 mm/year.

Andarge Yitbarek (2009) conducted a study on the title of Hydrogeological and hydro chemical 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. He estimates groundwater recharges by using baseflow separation is 18.4 and 22.6 mm of the main Awash River at Melkakunture and Hombole representing a catchment area.

## Chapter 3. Study Area Description

### 3.1 Location of Study area

The study areas are found in the upper part of the Awash River Basin situated in Central Ethiopia, in Oromia Regional State. The elevation ranges from 1599 to 2998 m.a.s.l. and approximately between coordinates 405000E-455000E and 950000N-985000N and 475000E - 515000E and 920000N -965000N respectively (figure 3.1). Becho area is found along 30-40 km from Addis Ababa along Addis Ababa - Jima road. It occupies a total area of about 1552 km<sup>2</sup>. Koka area is found along 70 km from Addis Ababa along Addis Ababa-Djibouti high way. It occupies a total area of about 1461 km<sup>2</sup>.

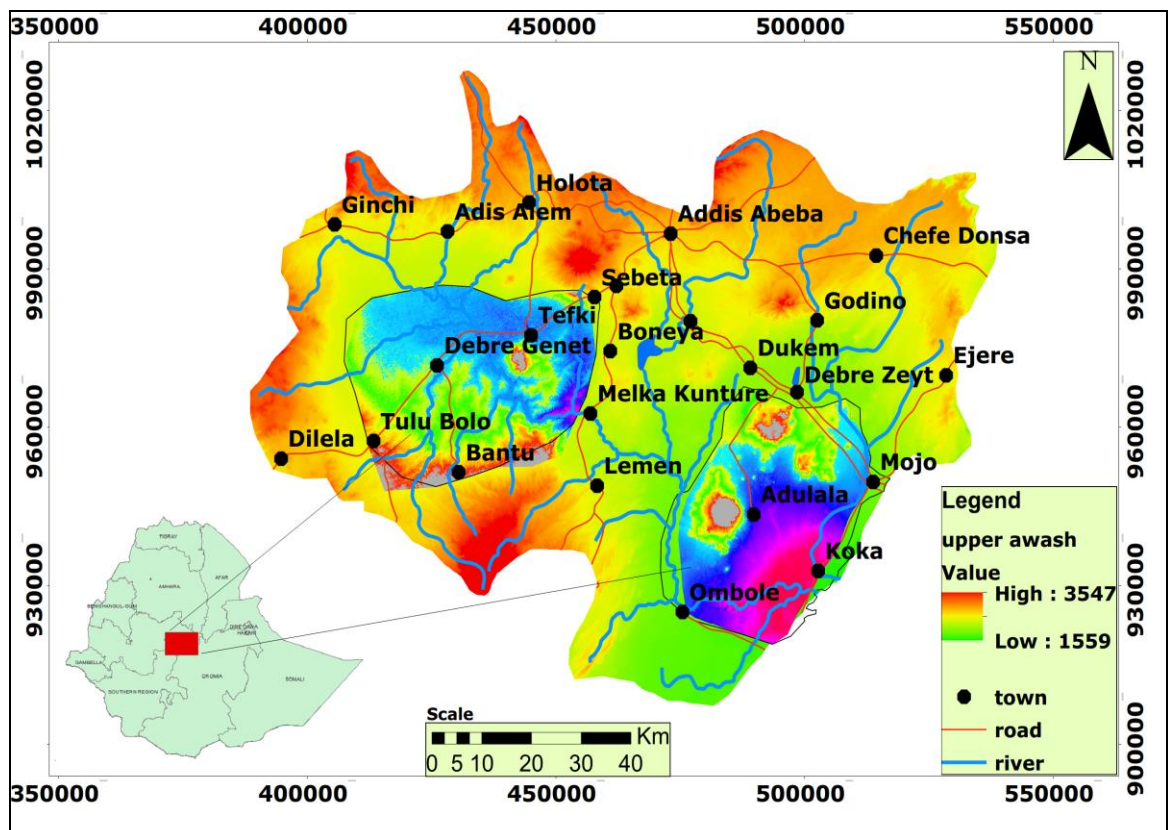


Figure 3.1 Location map of the study area.

### 3.2 Climate

The climate of the study area is diverse due to the large topographic differences. It is humid in the highlands and arid to semiarid in the escarpment and rift valley floor. The Inter-Tropical Convergence Zone (ITCZ) influences the rainfall formation over the study area. This zone of low pressure marks the convergence of dry tropical easterlies and the moist equatorial easterlies. The distribution of rainfall over the highland areas is modified by orographic effects and is significantly correlated with altitude. The seasonal rainfall distribution within the study area results from the annual migration of the ITCZ. 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 mean annual rainfall of the Becho area groundwater basin is about 1130.5mm, and mean monthly temperature is about 17.4°C. The mean annual rainfall of the Koka area groundwater basin is about 878.5 mm, and means monthly temperature is about 20.5°C.

Table 3.1 Location of Meteorological Stations and data recording years

No.	Metrological stations	Location UTM		Altitude	Record Year
		Easting	Northing		
1	Addis Ababa	38.75	9.033333	2354	1971-2014
2	Asigori	38.3342	8.79	2072	1981-2014
3	Bantuliben	38.357	8.6185	2167	1981-2014
4	Debrezeit	38.95	8.733333	1900	1971-2012
5	Mojo	39.10817	8.60533	1763	1971-2015
6	Koka	39.1542	8.46933	1618	1975-2005
7	Sebeta	39.0215	9.152167	2231.663	1981-2014
8	Tulu bolo	38.2065	8.6545	2190	1988-2014
9	Teji	38.36667	8.8333	2091	1974-2014

Table 3.2 Location of hydrological Stations and data recording years

No.	Hydrological stations	Location UTM		Altitude	Record Year
		Easting	Northing		
1	Awash River at Bello	38.25	8.51	2091	1987-2007
2	Awash River at Hombole	925539	475632	1699	1976-2009
3	Mojo	8.360	39.50	1763	1968-2013
4	Koka	9327744	502215	1590	1975-2010

### 3.3 Drainage and Physiography

The physiographic set up of the study area is the result of volcano- tectonic, rifting, erosion and deposition processes .The study area is bounded in the north by the east-west trending rift escarpment (Ambo fault belt) and the Intoto mountain range, in the west by Weliso and Guraghe highlands, in the east by Kesem river basin and in the south east by the Koka reservoir. In the basin the two area is characterized by gentle to flat topography. The major volcanic centers and ridges with in the basin are Bedegebaba and Ziquala Mountain. The area falls within the elevation range of 1559-2998 m.a.s.l (fig.3.1).Awash River and its tributaries form dendritic drainage pattern. It flows in a NW – SE general direction. Mojo and Teji are the major tributaries of Awash River in the study area (fig.3.2).

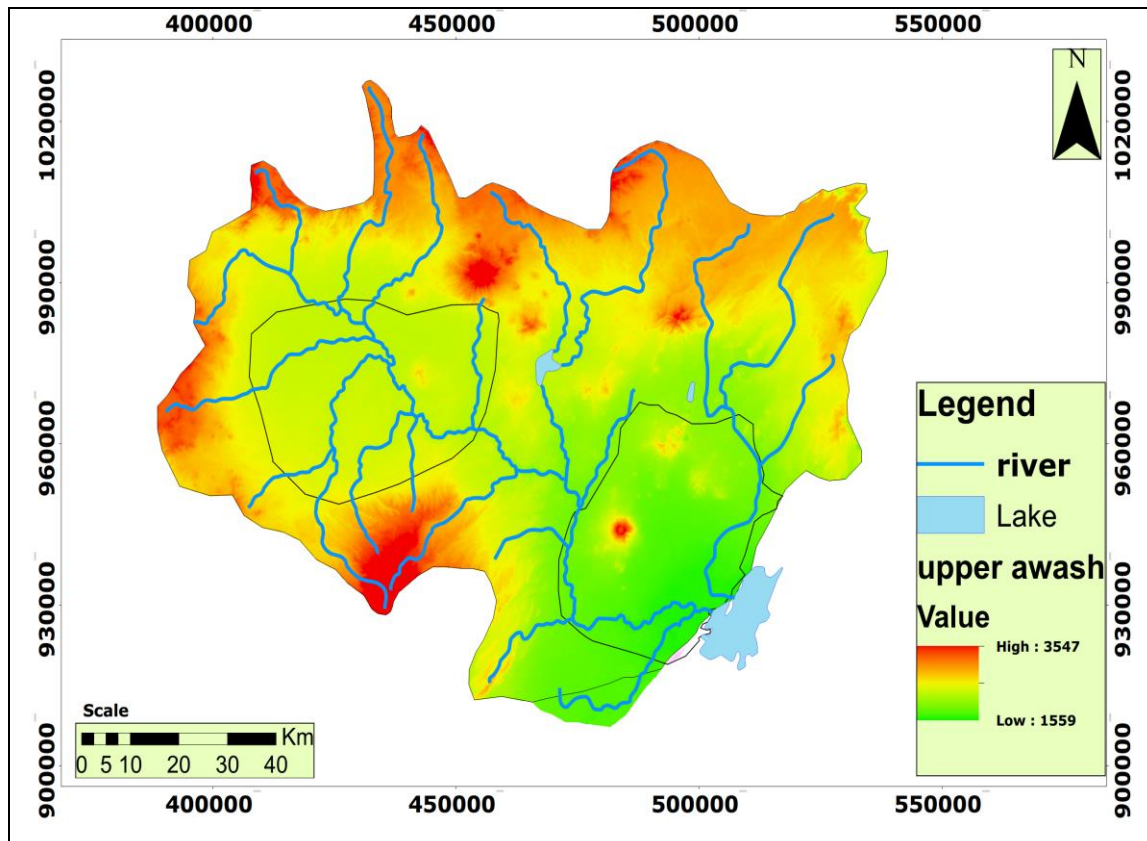


Fig.3.2 Drainage Map of the study area

### 3.4 Land use/ land cover

Land use is one of the most important factors that affects surface erosion, runoff, and evapotranspiration in a catchment. Poor land use practices, improper management systems and lack of appropriate soil conservation measures have played a major role in causing land degradation problems in the country. Because of the rugged terrain, the rates of soil erosion and land degradation in Ethiopia are high. In terms of areal coverage the important land cover units are intensively cultivated land, open shrub land, open grassland, moderately cultivated land, and swamp and water body (figure 3.3). The intensively cultivated land consists about largest portion of the total area. Major crops grown in the area are Teff, wheat, barely, beans and oil seeds.

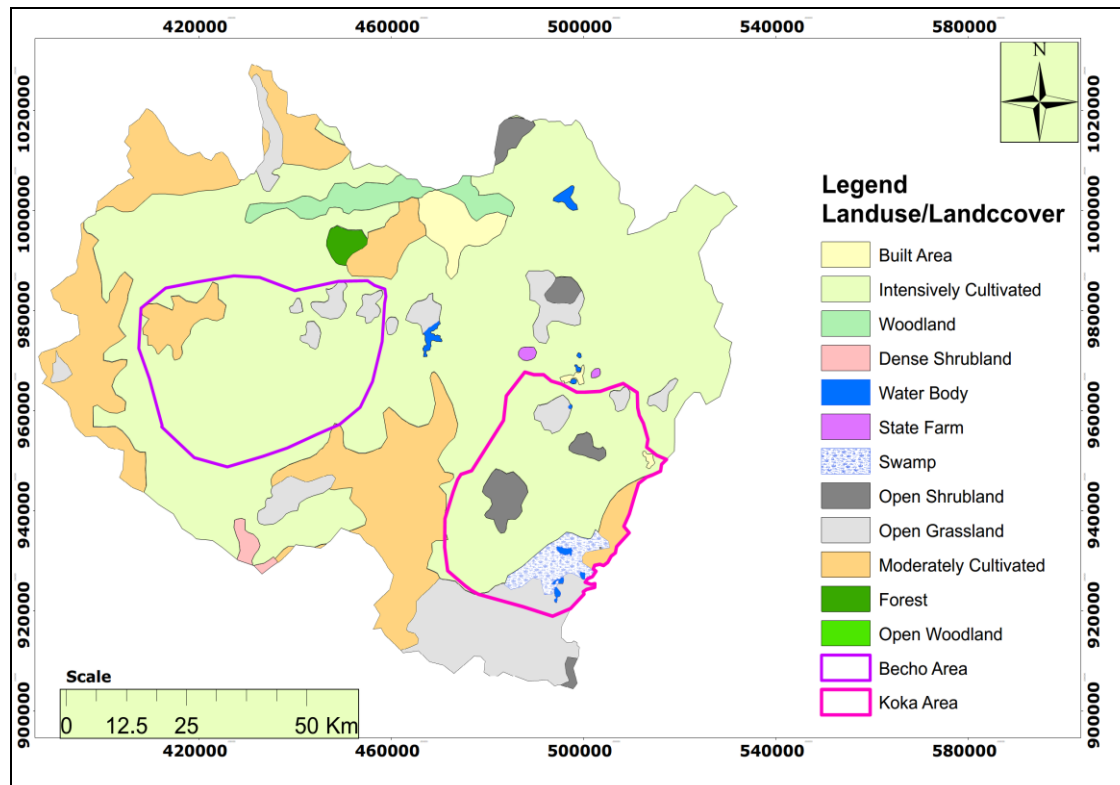


Figure 3.3 Land use and land cover map the study area.

### 3.5 Regional Geological set up

In Ethiopia, the present morphology, Physiography, and geological settings are a result of two major post-Paleozoic events which were followed by important phases of volcanic activity (Mhor, 1964). The first tectonic event which occurred in late Mesozoic-Early Tertiary period produced the Afro Arabian Dome. The associated fissure volcanic activity gave rise to the extrusion of the Trap Series succession (plateau volcanism) which is considered to be the up-doming (Mohr, 1967). The extrusion of the Trap Series fissure basalt during Eocene-Oligocene time was the major and the largest volcanic episode on both the South Eastern and the Western plateau of the pre-Miocene period (Kazmin, 1975). The second tectonic event resulted in rift development and related volcanic phenomenon during late Tertiary-Quaternary period. The extensional tectonics which produced the Ethiopian Rift is genetically related to the Great Rift Valley of East Africa.

### **3.5.1 Mesozoic sedimentary rocks**

The Mesozoic sedimentary rocks includes Adigrat Sandstone, Amba Aradam Sandstone, Antalo limestone and Mughher mudstone. These sediments are formed by the transgression and regression of the Indian Ocean during Triassic to Cretaceous. They unconformably overlie the crystalline basement rocks. The Succession from lowest to top lower most Triassic Adigrat sandstones, has a maximum exposed thickness of about 150 meters, it consists of reddish brown to medium-fine grained sandstones, has high strength, fine to medium grained, light gray to dark-grey color.

The uppermost unit, the Jurassic Antalo limestone, has high strength, yellowish grey in color with about 50 meters thick beds and maximum exposed thickness of 25 meters (Kazmin, 1975).

### **3.5.2 Tertiary Volcanics**

The Tertiary volcanics consists of basalts and silicics of Miocene to Pliocene age. They unconformably overlay the Mesozoic sediments. The Central Ethiopian plateau geology is dominated by Tertiary volcanic comprises of Aiba basalts, Alaji rhyolites and basalts, Tarmaber basalts and Balchi rhyolites (B.zanetine et al ,1974 and E.ustine-vlsentine et al, 1974).

#### **3.5.2.1 Aiba basalt**

It is a thick cover of flood basalts out poured on the Ashangi penne plain as a result of distensile crustal movement. This rock unit is exposed in small area of southern and northeastern part of the study area.

#### **3.5.2.2 Alaji series**

The Alaji series contain interbedded layers of rhyolites and basalt overlying the Aiba basalts. The Alaji rhyolites are the first silicic rocks omitted in the central eastern Ethiopian plateau making up large ignimbrite unit lying on the Aiba basalts or interlayered in varying quantities with the Alaji basalts (B.Zannettio et al, 1974).

### **3.5.2.3 Tarmaber- Megezez formation**

The Tarmaber basalts that cover the Oligocene Alaji is termed Tarmaber Guassa (Oligocene) basalts and those that cover Miocene Alaji are termed as Tarmaber-Megezez basalts (late Miocene) basalts. This rock unit is exposed mainly in western and northern part of the study area .Petrographically it is composed of plagioclase, pyroxene and opaque minerals.

### **3.5.2.4 Addis Ababa basalts**

Addis Ababa basalt is characterized by fine to coarse grained texture and in most cases it is relatively thin (20m) lava flow overlying the ignimbrite (Chernet et al., 1998; Morton et al., 1979).

### **3.5.2.5 Addis Ababa Ignimbrite**

The Addis Ababa Ignimbrite outcrops in most part of the plain area around Addis Ababa and in the western part (Becho plain). It is composed of welded tuff (ignimbrite) and non-welded pyroclastics fall (ash and tuff). Around the Legedadi plain and in Melkakunture area the thickness of this unit reaches up to 200m (WWDSE, 2008). In the Becho plain it is covered with 5-7m thick residual soil developed from the same rock. The age of this unit is 5.11-3.26 Ma (Morton et al., 1979).

### **3.5.2.6 Nazret Group**

This group comprises a thick succession of ignimbrite, unwedded tuffs, ash flows, Rhyolites and trachytes out cropping mainly on the rift floor attaining a thickness of more than 250m and to some extent in the rift escarpments and on the adjacent plateau margins. According to Kazmin and Seifmicheal, this group name was informally used for lower welded tuff( related to Werchecha trachyte volcanism) , Aphanitic Basalt( shows vertically curved columnar jointing together with sub horizontal sheet jointing) and upper welded tuff( related to Yerer volcanism). The wide distribution of rhyolitic domes is an evidence at hand to say silicic centers dominate at the latest stage of Nazret volcanism which was accompanied by the Arba Gugu shield volcano and Chilalo and Badda volcanoes which occurred during the early and later stages of Nazret volcanism respectively. The Nazret group rests uncomfomably on

the Addis Ababa Basalts and there is Bofa Basalt on the top of the Nazret volcanic succession. This group corresponds to the youngest age of Addis Ababa Basalt and to the oldest age of Bofa Basalt within a range in age of 6.4 to 2.8my.

### **3.5.2.7 Bofa Basalt**

This young olivine porphyritic basalt of age 2.8my (Morton et al., 1978), dated in the Awash Gorge near Kereyu Logde, is characterized by big vesicles that are filled by calcite. Bofa Basalts are not restricted to the central part of the rift as are younger units, but are rather evenly distributed over the rift floor. And they represent an episode of fissure eruption which immediately followed a major faulting. The Bofa Basalts may include much older flows, for example an age of 3.5myr, which was established by Mohr (1971) for Basalts in the Nazareth vicinity which possibly belong to the same unit. They outcrop southward from Akaki River in the form of boulders 10m thick and appear to terminate a few kilometers west of Mojo. Bofa Basalts contains labradorite, plagioclase, olivine and augite phenocrysts within crystalline andesine, clinopyroxene, and indigitized olivine ground mass and some calcite vein in place of plagioclase. Bofa Basalt comprises a number of flows of compact fiamme ignimbrites in places intercalated with aphanitic basalt and unwedded pyroclastics

### **3.5.2.8 Wonji group**

This groups are controlled by structures of the wonji fault belt and are restricted to the rift floor. Although some volcanic manifestations such as eruption of basalts and central volcanoes occur outside the belt, the bulk of the Pleistocene-Recent volcanism is undoubtedly controlled by this tectonic feature. According to Kazmin and Seifemichael, 1978 the name Wonji group has been used for Dino ignimbrites, Pentelleritic volcanic centers, and sub recent and recent fissure basalt and with some minor units such as hyeloclastites, explosion centers and rhyolite domes. This group is dated 1.6-1.8 million years and found aligned en-echelon along segment of the Wonji fault belt. It is overlain by porphyritic plagioclase basalt near Nazret and underlain by the aphanitic basalt of the Nazret group at the same place.

### **3.5.3 Quaternary Deposits**

This rock unit occupies the central and northern part of the study area and forming steep cliff topography. Specific rock units in this group are described below.

#### **3.5.3.1 Gash Megal rhyolites**

This unit is exposed in central part of the study area at the west of main Ethiopian Rift shoulder on top of Guraghe escarpment. It has medium strength, fine to medium grained, light gray color. This rock unit composed of feldspar, quartz, and muscovite minerals.

#### **3.5.3.2 ChefeDonsa pyroclastic deposits**

This rock unit is exposed in north east of the koka area. It has low strength, light to dark gray color, fine grained un welded to poorly welded, fine volcanic ash flow and fall deposits composed mainly of rhyolites and mainly exposed in the rift floor, Microscopically, it composed of Kefeldspar, quartz, plagioclase and hornblend having vitrophyric texture.

#### **3.5.3.3 Wechacha trachytes**

This unit is out crops in the northern and north east part of the mapped area and consists of western rift shoulder central silicic volcanoes such as Wechacha, Furi and Yerer. These central volcanoes preferentially aligned in the E-W direction. It has medium to coarse-grained, light gray to dark-grey and very high strength. Microscopically it is composed of K-feldspar.

#### **3.5.3.4 Ziquala trachytes**

Exposure of this unit is found around Ziquala Mountain. The unit has very high strength, dark gray color, and medium to coarse-grained. Microscopically, it comprises crystals of K- feldspar, pyroxene, quartz, and opaque having trachytic textures. Plagioclase, quartz and horn blend showing trachytic texture.

### **3.5.3.5 Pyroclastics and Pumice fall deposits**

This unit is exposed in northern part of the study area. It has high strength, light to dark material. Microscopically, it consists of crystals of K-feldspar (sanidine), quartz, plagioclase and hornblende having vitrophyric texture.

### **3.5.3.6 Bora-Bericha rhyolites**

This rock units is exposed in the north east around debrezeit area and eastern part of the study area. It comprises younger rift floor volcanoes such as Bedegebabe, Gedemsa, Bericha, Bora and Tullu-Moye. Products of these centers are mainly peralkaline trachytes. It has high strength, light gray to pink in color composed of alkali feldspar, quartz and mica.

## **3.5.4 Quaternary lacustrine and alluvial deposit**

### **3.5.4.1 Lacustrine Deposits**

The lacustrine deposit is particularly distinguished in the Adaa plain of the Lakes region. They are fine grained deposits generally brown-yellowish, thinly stratified and often contained volcanic matrix; whose thickness ranges from 5 to 8m. More thickness is reported in the groundwater well drilling reports. In these successions volcanic layers are frequent and become predominant and coarse grained near by the maars.

### **3.5.4.2 Alluvial Cover**

The alluvial cover mainly outcropped above the Tertiary volcanics on the plateaus and Becho Plain and consisting of regolith, redish brown soils, talus and alluvium with maximum thickness of about 7 m (Becho area hand dug well data).

## **3.5 .5 Tectonic Structures**

The geological structures in the area are normal faults, bedding and joints, block faulting, fissuring and tilting of the rocks affecting the various rock units in the area. The East African Rift System (EARS), formed as a result of the brittle African continental 'plate' responding to stretching forces that are driven by very slow creep of rocks hundreds of kilometers deep in the Earth, is a region of continental break-up that

accommodates the relative movement between the African and Somalian Plates. Within the EARS, the Main Ethiopian Rift (MER) represents a key area as it connects the Afar depression to the Kenya Rift. The MER is characterized by a fault pattern composed of a NE-SW border fault system and an N-S to N20°E-trending system, composed of en-echelon right-stepping faults obliquely affecting the rift floor (Wonji Fault Belt, WFB). The MER tectonic evolution is matched by an intense volcanic activity up to historical times, characterized by a typical bimodal composition. Correlation of pyroclastic deposits on the rift shoulders and within the rift depression suggests that these explosive deposits were associated with the main initial events of the MER opening, which took place around 6.5 Ma. This first phase of rifting was associated with a NW-SE extension direction and determined the development of the NE-SW trending boundary faults and related fractures. Due to a lateral, extension-parallel, migration of magma from below the rift depression, important off-axis volcanoes formed on the MER shoulders during this rift event. A change in the extension direction to E-W to ESE-WNW determined a later (Quaternary) stage of oblique rifting with a left-lateral component of motion along the rift axis. This oblique rifting determined the development of the WFB system. The dextral components of displacement along some WFB faults can be explained as related to a counter-clockwise block-rotation internal to the deformation zone, as also supported by analogue modeling. The Quaternary stress field re-orientation also caused the off-axis volcanic activity to be strongly reduced by inhibiting the lateral transfer of magma. Particularly, during the second oblique phase, the development of the newly-formed echelon oblique and strike-slip faults of the WFB localized the uprising of melts within the rift axis and favored the volcanic activity to be concentrated along the en-echelon WFB segments (Behailu Berehanu, 2007).

### **3.6 Local Geology**

#### **3.6.1 Lacustrine cover and alluvial deposits**

The lacustrine deposits are interbedded with Pliocene-Pleistocene ignimbrites in the rift areas in the closest vicinity of Lake Koka (Mohr, 1966). They are fine grained deposits generally brown-yellowish, thinly stratified, very friable, and less compacted and often contained volcanic matrix; whose thickness ranges from 5 to 8m (WWDSE, 2008). The alluvial cover mainly outcropped above the Tertiary volcanics on the plateaus and Becho

Plain and in the Mojo area and consisting of regolith, redish brown soils, talus and alluvium with maximum thickness of about 7 m (WWDSE, 2008).

### **3.6.2 Ignimbrite**

This unit covers most part of the study area in the Becho and Koka area (Figure 3.4). In the Becho area it occurs intercalating with the other; the relatively thick deposit of unwelded tuffs and volcanic ash are most of the time blanketed by ignimbrite sheets of up to about 30 m thick. It is grayish to white color, poorly welded. They are covered by thin residual soil made of the same rock units and alluvial deposit. In the koka area this units are grayish red in color, moderately to highly weathered rock units are medium to coarse grained with a kind of sheet flow structures and show eutaxitic texture with oblate glassy fragments (WWDSE, 2008). Rock fragments and crystals, generally broken, are abundant; alkali feldspars, quartz, aegirine and amphiboles are the most common crystals. They constitute the upper part of Nazret Group in the Koka area Kazmin and Seifemichael Berhe (1978) and Addis Ababa group in Becho area.

### **3.6.3 Quaternary Trachyte**

This units are located around Ziquala Mountain with minor around Bedegebeba of the study area. It is grayish pink in color, coarse grained and petrographically composed of anorthoclase, sanadine, minor clinopyroxene phenocrysts and glassy alkalifeldspar groundmass. Covers a small part of the study area and it is found in the central part koka area intercalated within the Bofa basalt. This unit is compact, porphyritic rhyolitic lava flow described as the remnant wall of the volcano tectonic sub-circular collapse of the Pleistocene age (Berehane et al, 1978).

### **3.6.4 Quaternary Rhyolite**

Covers a small part of the study area around bedegebeba intercalated within the Bofa basalt. This unit is compact, porphyritic rhyolitic lava flow described as the remnant wall of the volcano tectonic sub-circular collapse of the Pleistocene age.

### 3.6.5 Tarmaber basalts

Covers a small portion of the study area around Becho area. The rock consists of porphyritic and rarely aphyric olivine and pyroxene and sometimes plagioclase phenocrysts (WWDSE, 2008).

### 3.4.6 Tulu Rie Basalt

This unit is outcropped in the northern part of the Koka area and forms NE trending escarpments. It is lava flow coarse grained basalt with olivine and plagioclase phenocrysts with rare clinopyroxene. The Tulu Rie Basalt is considered, for its stratigraphic position and composition, as a part of Bofa Basalt of Kazmin and Seifemichael Berhe (1978). The TRB consists of sub horizontal or slightly tilted tabular lava flows. The maximum observed thickness is 20m at Tulu Rie Basaltic ridge (Behailu Berehanu, 2007).

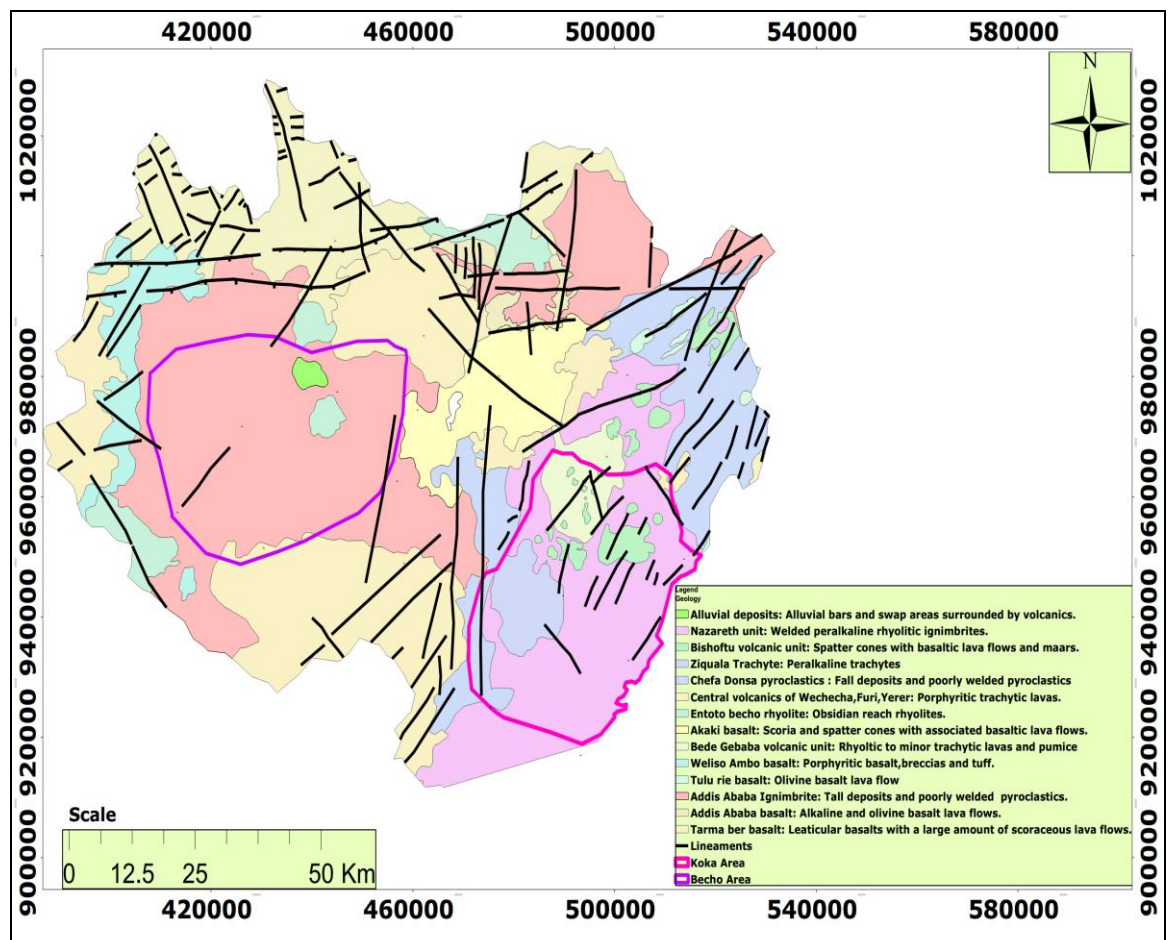


Figure 3.4 Geological map of the study area (modified from WWDSE, 2008)

### 3.7 Hydrogeological setting

The division of lithological units is based on hydrogeological characteristics of various rock types. These were divided into units with dominant porous and/or fissured permeability and impermeable rocks. The aquifer properties in the upper awash basin are controlled by the litho-stratigraphy of the volcanic rocks and the structures that affect them. Because of 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 (Andarge Yitbarek, 2009).

Table 3.3 dominant lithological units in the study area

Name of Geological formation	Area	Properties
Alluvial sediments and lacustrine sediments	Koka and becho area	moderately pervious
Trachyte and Rhyolite	Becho and koka	Impervious
Addis Ababa-Akak-Bishoftu basalts	Becho and koka	highly pervious
Addis Ababa ignimbrites and Nazaret group	Becho and koka	moderately pervious
Tarmaber and Aiba basalt	Becho area	highly pervious

The aquifers in Upper Awash basin can be divided broadly into two categories; primary porosity aquifers and double porosity aquifers. The first category comprises aquifers related to Quaternary alluvial and lacustrine deposits and the second broad categories belongs to the basaltic volcanics and again subdivided in to upper and lower basaltic aquifers separated by less permeable, along fractured and weathered zones and/or impermeable otherwise, of acidic volcanics.

In the study area the alluvial and lacustrine aquifers are found dominantly in the Koka area around Mojo towns and locally in the northwestern part of the Becho plain and along the main perennial river courses.in the Mojo area have thickness up to 80 meters and composed of coarse sediments (WWDSE, 2008).

The alluvial cover mainly outcrops above the products of the western Rift margin complex and consists of regolith and alluvium with maximum thickness of about 2m. It is

grouped under the Moderate permeable unit. These sediments are exposed in the study area around Mojo area with thin but extensive spatial distribution and consist of sands, silts, clays, tuffs, pumice, and ignimbrites. In most places are mixed compositionally with quaternary volcanic products and form a specific mixed volcano-sedimentary rock type (Behilu Berahanu, 2007). They are recharged locally from rainfall and runoff and partly outflow of the lakes. The alluvial aquifers do not form an independent aquifer but it is interconnected with the basaltic main aquifer in the area. Laterally where the lacustrine deposits are exposed at the surface of the study area they appeared to be a loosely cemented material texturally ranging from fine grained to coarse-grained. Based on the above visual observation one can group the lacustrine deposits by its superficial water conductive nature.

The volcanic units can be grouped into three major zones based on the degree of fracturing and their hydrostratigraphic position as follows:

**Upper Basaltic Aquifer:**-This unit in the study area is composed of Quaternary flows of Woliso-Ambo basalts, Akaki basalts, scoria and spatter cones, and Tertiary-Neogene basalts of Addis Ababa area. The upper basalt aquifer has wide distribution in the study area found overlain by ignimbrites and tuffs in Becho areas. It forms confined and unconfined aquifer system, locally obliterated by Trachytic and rhyolitic volcanic centers and ridges. The thickness of this formation is less than 50 meters in the Becho plain (WWDSE, 2008).

**Lower Basaltic Aquifer:** This unit is composed of lower Tertiary Tarmaber dominantly scoriaceous found around Becho plain. 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 (Andarge Yitbarek, 2009).

**Localized and regional aquicludes:** -this unit covers most part of the study area in the Becho area and some parts of Koka around in Bedegebaba and Ziquala mountain area composed of Quaternary Bedegebaba rhyolites, Ziquala trachytes and Tertiary Intoto-Becho rhyolites, low permeability, except along weathered and fractured zones and act as

local aquicludes by compartmentalizing the upper basaltic aquifer. Nazaret group Welded ignimbrites and Addis Ababa ignimbrites of low productivity along the weathered and fractured zones and/or impermeable otherwise, act as aquicludes by separating the upper and lower basaltic aquifers in most parts of Becho area (Andarge Yitbarek, 2009).

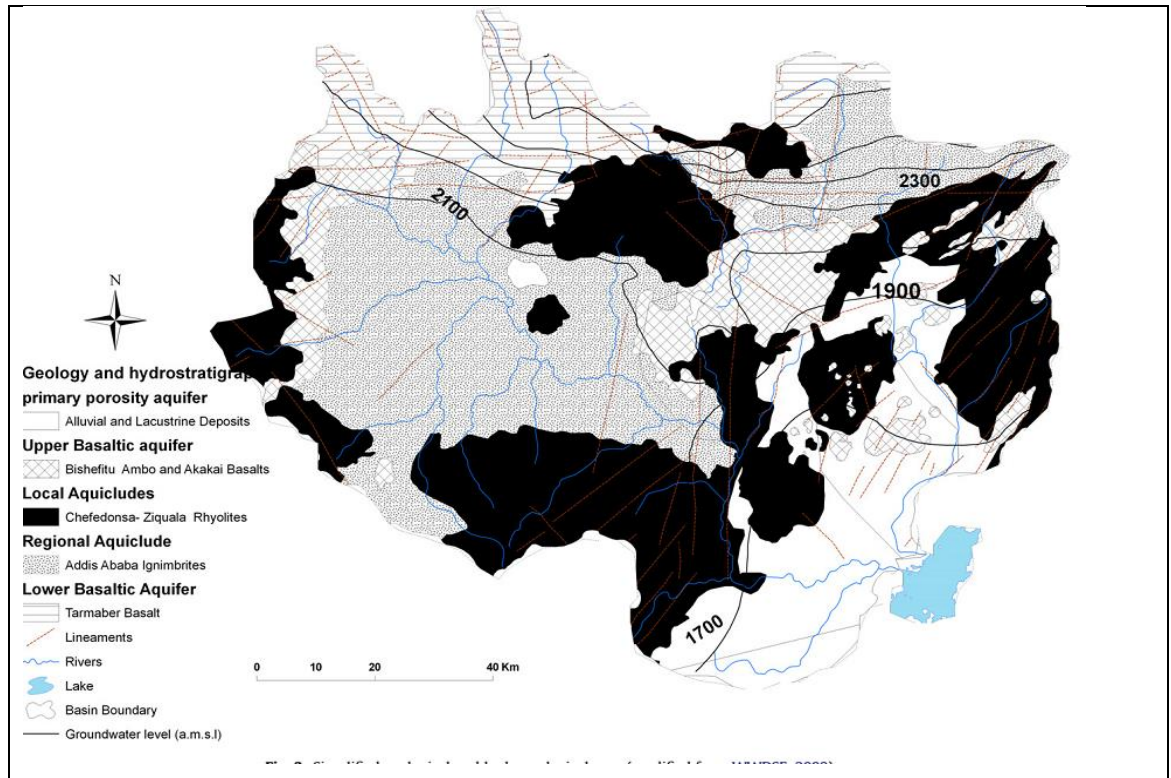


Figure 3.5 Hydrogeological map of upper awash basin (Andarge Yitbarek et al., 2012).

### 3.8 Groundwater Flow, Recharge and Discharge

#### 3.8.1 Groundwater Flow

Groundwater movement is controlled by several factors in the study area. These includes the recharge and discharge zones, the ground water table elevation the presence of faults and fractures, etc. Groundwater movement in the study area is topographically and lithologically controlled. It flows from high plateau west of Addis Ababa and flows along the rift valley.

### **3.7.2 Groundwater Recharge and Discharge**

Recharge is the process by which aquifers are replenished with water from the surface. This process occurs naturally as part of the hydrologic cycle as infiltration when rainfall infiltrates the land surface and as percolation of water into underlying aquifers. A number of factors influence the rate of recharge including physical characteristics of the soil, plant cover, slope, water content of surface materials, rainfall intensity, and the presence and depth of confining layers and aquifers. Surface water bodies may also recharge ground water. This occurs most often in arid areas. Lakes and dry creek beds may fill up with water during heavy rains. If the water table is low in underlying aquifers, water may seep from the sides of these water bodies and percolate into the ground water. Topographically high areas can generally be considered as recharge areas and topographically low areas can be considered as discharge areas. The study area is found in the low lying parts regional aquifers are mainly recharged over the extended plateau of the upper part of the Abay basin, above the gorges of Abay River and its tributary rivers (Muger, Jema, etc.) And the upper watershed of the Awash River above the Becho plain are assumed to contribute recharge into the upper aquifer of Becho and Koka area Groundwater basins. Direct recharge occurs from the rainfall while much of this rainfall is lost through evapotranspiration in the Koka area.

## **Chapter 4. Research Methodology and Materials**

This chapter includes methods of groundwater recharge estimation and data collection of the research as well as ways of their analysis.

### **4.1 Data collection and data analysis:**

Various available data were gathered from concerned deferent organizations, persons and different websites.

#### **4.1.1 Pre-field work**

Work prior to the field work relevant materials like

- Acquisition and reviewing of previous maps, reports and relevant data from different sources
- Geological reports was collected from geological survey of Ethiopia (GSE).
- Hydrogeological, hydrological and borehole data in the study area are also collected from minster of water, irrigation and electricity and water works design supervision enterprise.
- Topographic maps are purchased from Ethiopian map agency (EMA). Using the information collected and previous hydrogeological works preliminary interpretation of the data is made.

#### **4.1.2. Field works**

During field work the following major activities can be conducted:

- Measuring groundwater levels, taking readings of borehole locations and elevation.
- Observation of hydrogeological features and description of geology, Geomorphologic setting, surface water divide, land cover and land use practices, and location of recharge and discharge areas.

#### **4.1.3 Post field work**

This was the main phase of the research work and it includes:

- Characterization of the meteorological elements within and the surrounding of the Study area;
- Interpretation of the satellite imagery of the study area with appropriate resolution;
- Characterization of geological, hydrological, hydrogeological, and structural condition of the study area based on the existing data;
- The analytical data generated from the field study and desk study were organized and processed using various kinds of software. These include: Arc GIS, and Global Mapper, Surfer, and Microsoft office Excel 2003 and 2007. For geo Referencing of some places and borehole locations Garmin GPS was used.
- Finally, analyses and interpretations were conducted on the geological, Hydrogeological, hydrological, meteorological and borehole data gathered both as secondary and primary data by baseflow separation and water balance method.

## **4.2 Methods of recharge estimation**

In this study Groundwater recharge is estimated by two methods: baseflow separation and water balance method.

### **4.2.1 Baseflow separation methods using Excel spreadsheet**

#### **A. 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 (Pettyjohn et al., 1979).

#### **B. 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 (Pettyjohn et al., 1979).

### C. 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 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 (Pettyjohn et al., 1979).

### D. 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 (Gustard, 1992). The procedure for calculating the baseflow is as follows:

1. 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  $Q_1, Q_2, Q_3, \dots, Q_n$
2. 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  $QB_1, QB_2, QB_3, \dots, QB_n$ , which will have different time periods between them.
3. By linear interpolation between each  $QB_i$  value, estimate each daily value of  $QB_i \dots QB_n$
4. If then  $QB_i > Q$  then set  $QB = Q$

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

$$N = \left( \frac{A}{2.59} \right)^{0.2} \quad (4.1)$$

Where, the interval,  $I$ , used in the baseflow separation method is the odd integer between 3 and 11 nearest to  $2N$ .

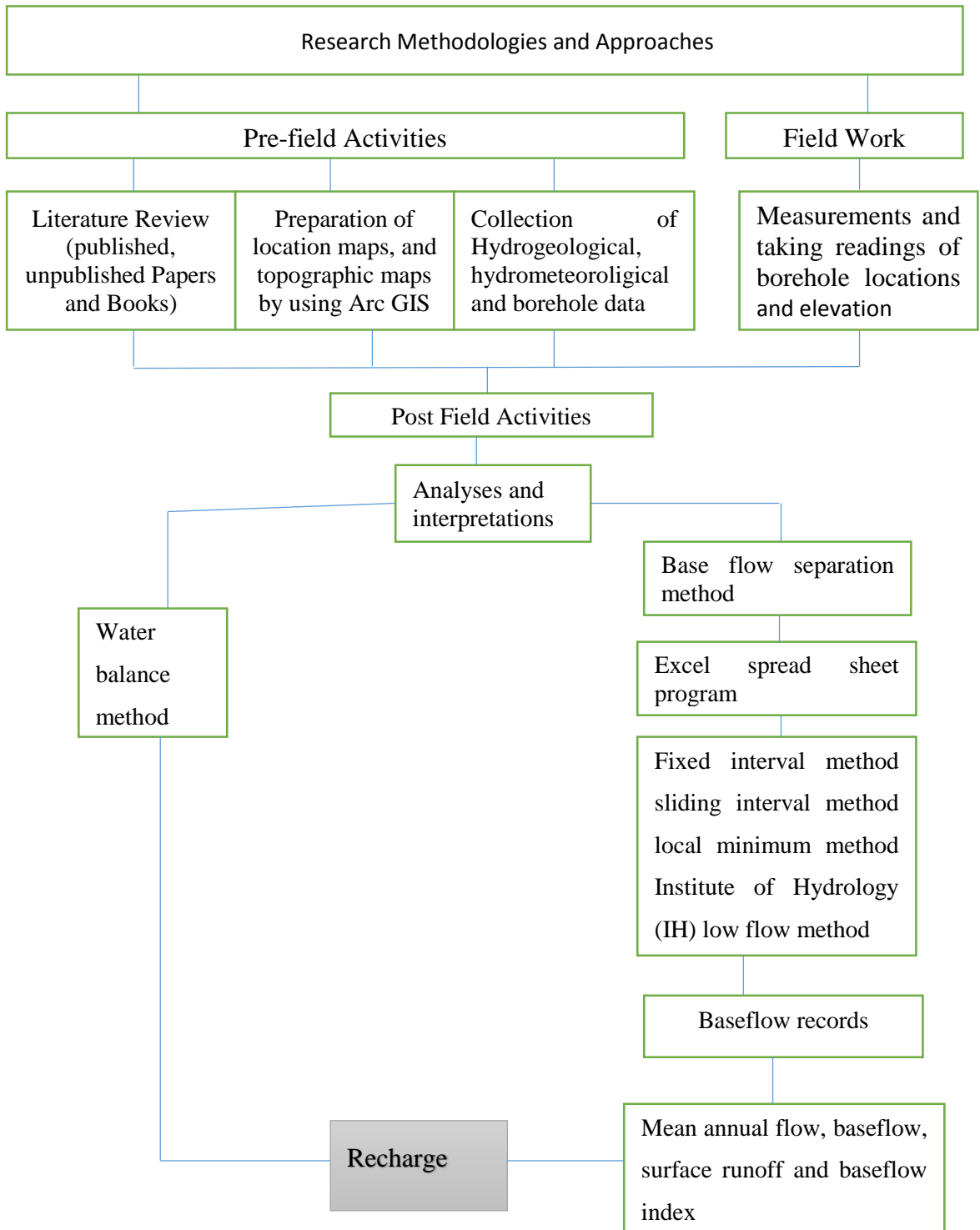


Figure 4.1 Flow chart of the methodology.

### **4.3 Materials and equipment**

To conduct the field work and fulfill the objective of the research different material has been used. The materials and equipment's used for the research study include:

- Topographic Maps (Scale 1:25000 and 1:5000) and geological maps (Scale 1:250000),
- Garmin GPS, Computer, Compass, digital camera,
- LandsatTM7 Satellite imagery (30 by 30 resolution), digital elevation model data (90 by 90 resolution),
- water level meter
- geological hammer, stationary materials

## **Chapter 5. Results and Discussions**

### **5.1 Hydro-meteorological data analysis**

The study of hydrometeorology has evolved as a specialist branch of hydrology linking the fundamental knowledge of the meteorologist with the needs of the hydrologist. The two fundamental phases in the hydrological cycle which involve processes in the atmosphere and at the Earth's surface/atmosphere interface (Shaw, 1994). Hydro-Meteorological data for the study area were daily collected from the Ethiopian national Meteorological Agency and minister of water, irrigation and electricity. The hydro-meteorological parameters collected are river discharge, precipitation, maximum and minimum temperatures, relative humidity at 06:00, 12:00 and 18:00 hours, sunshine hours, and wind speed.

#### **5.1.1 Precipitation data analysis**

Precipitation is the release of water from the atmosphere to reach the surface of the earth. The term 'precipitation' covers all forms of water being released by the atmosphere, including snow, hail, sleet and rainfall (Davie, 2001). It is the major input of water to a river catchment area and as such needs careful assessment in any hydrological study.

Precipitation is the main source of all fresh water in hydrologic cycle falls nearly everywhere, but its distribution is highly variable. From all the components of the hydrological cycle the elements of precipitation, are the most commonly measured. Atlantic equatorial westerlies, the southerly and easterly Indian Ocean air currents being the sources from which Ethiopia receives rainfall. The main rainfall is experienced between June to September when moist winds from the Atlantic and Indian Oceans converge over the Ethiopian highlands (Daniel Gemechu, 1977). Observation of the amount of rainfall at the nine meteorological stations considered in this study show that there is a strong correlation ( $r^2= 0.6177$ ) between altitude and the amount of rainfall. The mean annual rainfall increases with an increase in altitude (Figure 5.1).

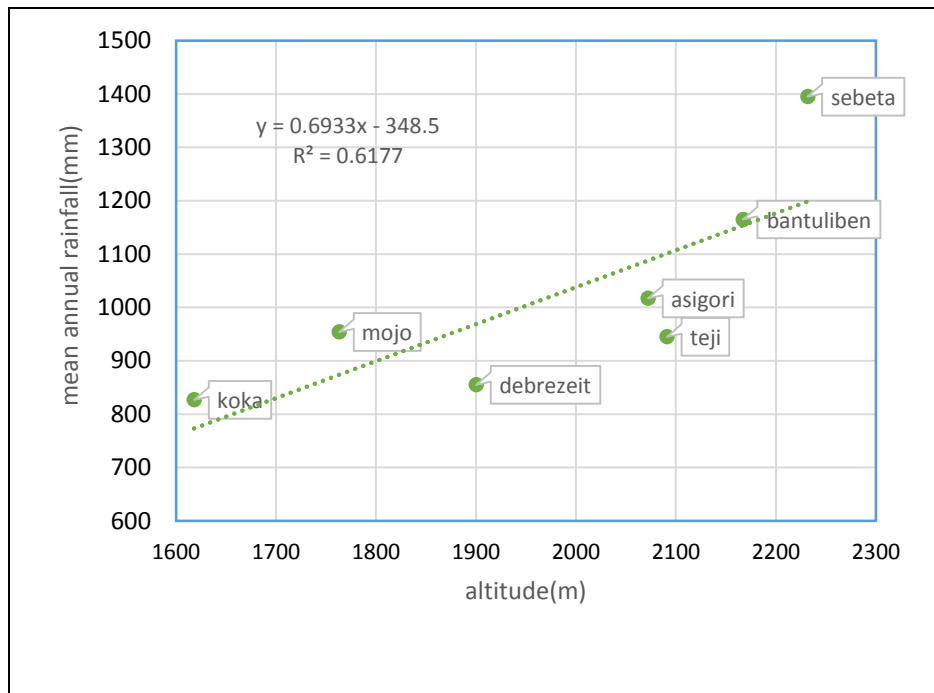


Figure 5.1 Relation between mean annual precipitation and altitude

Thus a year is characterized by a major rainy season for 4 months long, from June to September, during which about of the annual rain falls in the study area, followed by a relatively dry season for 4 months long until the end of January and the short rains season from February to the end of April. The rainfall distribution in the study area ranges from 826.6mm to 1395 mm.

Table 5.1 Long term mean monthly precipitation of the study area

	station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
Koka area	Debrezeit	10.1	18.3	50.4	57	58.2	101.7	214.7	210	102.3	23.5	5.2	3.7	855
	Koka	11	22.2	41.2	58.8	58.2	65.1	204.4	227	103.8	22.7	6.9	5.3	826.6
	Mojo	11.4	22.6	45.1	62.5	66.8	104.5	259.5	225.9	117.3	28.9	7.4	2.1	953.9
	Average	10.9	21	45.6	59.4	61.1	90.4	226.2	220.9	107.8	25	6.5	3.7	878.5
Becho area	Bantuliben	11.4	17.3	58.8	79.1	69.1	154.6	303.4	282.1	139.3	35.5	10.2	4.2	1164.9
	Sebeta	11	56.7	74.8	106.7	104.9	170.7	317.4	358	146.9	30.9	10.8	6.1	1395
	Teji	14.9	32.6	51.8	72	73.4	125.2	221.7	215.3	103.2	24	6.7	4.2	945
	Asigori	15.1	30.6	52.9	84.9	70.2	135.3	250.6	243.9	106.8	17	6.2	3.4	1017
	Average	13.1	34.3	59.6	85.7	79.4	146.5	273.3	274.8	124.1	26.9	8.5	4.5	1130.5

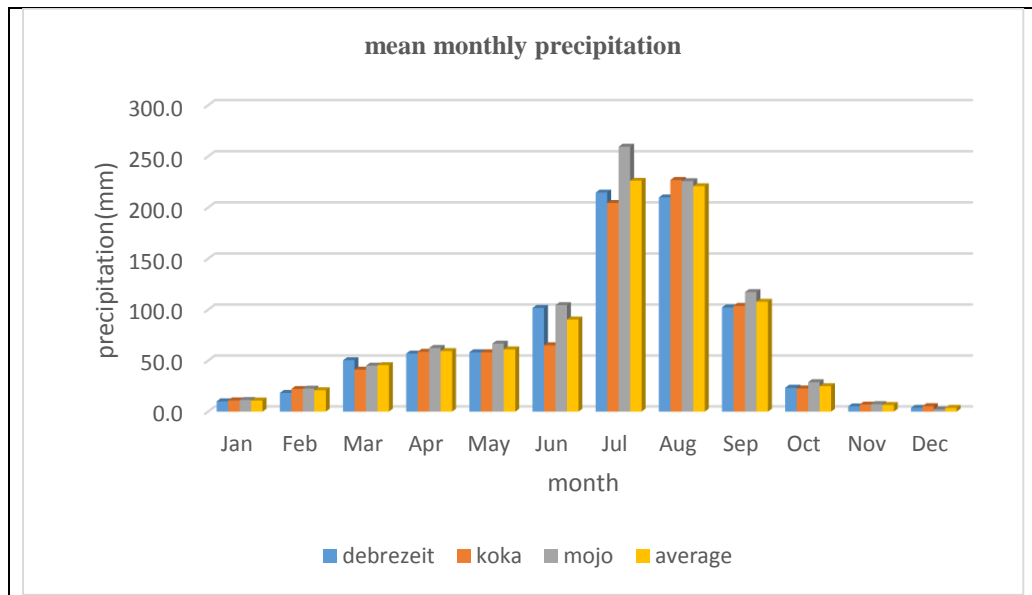


Figure 5.3 long term mean monthly precipitation of the Koka area

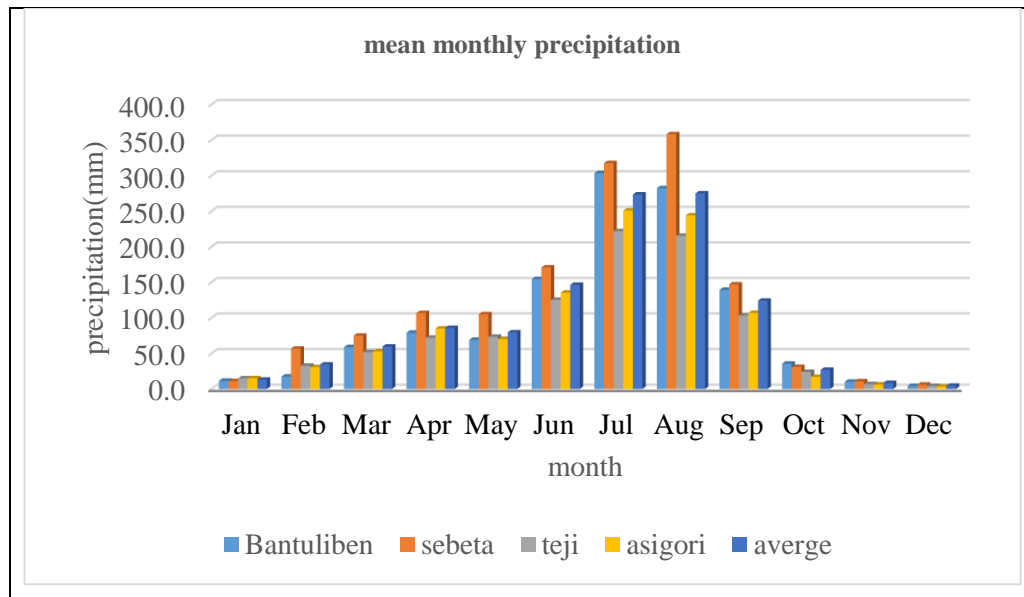


Figure 5.3 long term mean monthly precipitation of the Becho area

The highest rainfall is recorded in Becho area and the lowest rainfall is in Koka area as shown in (table 5.1). As it is shown in the precipitation bar graph, the maximum rainfall is recorded in the month of July in Becho and august in Koka area and the minimum in the month of December in the study area. The majority of rainfall in the study area is concentrated during wet season.

### 5.1.2 Determination of aerial depth of precipitation

A rainfall measurement is a point observation and may not be used as a representative value for the whole area under consideration. To obtain more reliable and representative result, the effective uniform depth of precipitation for the catchment has to be worked out. Therefore, the point measurement has to be averaged over the area (Tenalem Ayenew and Tamiru Alemayehu, 2001). There are three different methods to determine the average depth of rainfall over the study area, such as: Arithmetic mean, Thiessen polygon and Isohyetal methods.

#### A. The Arithmetic mean

This is the simplest objective method of calculating the average rainfall over an area. The simultaneous measurements for a selected duration at all gauges are summed and the total divided by the number of gauges. The rainfall stations used in the calculation are usually those inside the catchment area, but neighboring gauges outside the boundary may be included if it is considered that the measurements are representative of the nearby parts of the catchment (Shaw, 1994). Applicable if rain gauge stations are close and there is good distribution and rain fall is uniform or closer over the rain gauge stations which seldom is the case. It is used in flat area or uniform topography. This method in our case is used due to the fact that the stations are more or less distributed evenly and the topography is flat. Using this method the average rainfall over the Becho and Koka area is calculated to be 1130.5 and 878.5mm.

$$PA = \frac{\sum_{i=1}^n P_i}{n} \quad (5.1)$$

Where, PA = average rainfall the total area

P<sub>i</sub> = Measured precipitation at a given station and time

n = Number of rain gauges.

### 5.1.3 Temperature

Air and water temperature have direct influence on evaporation by making the environment hot and favors the passage of liquid state of water to vapor state. The higher the air temperature, the more water vapor it can hold, and similarly if the temperature of

evaporating water is high, it can more readily vaporized (Shaw, 1988). The mean monthly temperature years was taken from a number of stations in the study area Referring from National Meteorological Services Agency The mean annual temperature of the Becho and Koka area is 17.4°C and 20.5°C respectively.

Table 5.2 Monthly Mean annual Temperature (°C) of study area

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
Koka area	Debrezeit	17.9	19.2	20.3	20.7	20.7	19.9	18.8	18.6	18.7	18.1	17.4	17	18.9
	Koka	21.4	22.3	23.4	23.8	24.1	23.7	22.5	22.4	22.7	21.8	21.3	20.7	22.5
	Mojo	19	20.4	21.8	22.1	22.4	21.5	19.7	19.5	19.9	19.7	18.8	18.1	20.2
	Average	19.4	20.6	21.8	22.2	22.4	21.7	20.3	20	20.4	19.9	19.2	18.6	20.5
Becho area	Tulu bolo	17.2	17.1	17.1	16.8	16.7	16.9	17.1	17.3	17.2	17.7	17.2	17.1	17.1
	Asigori	17.3	18	19	19.3	19.2	18.7	17.8	17.8	17.7	15.9	15.6	15.9	17.7
	Average	17.2	17.5	18	18.1	18	17.8	17.4	17.6	17.5	16.8	16.4	16.5	17.4

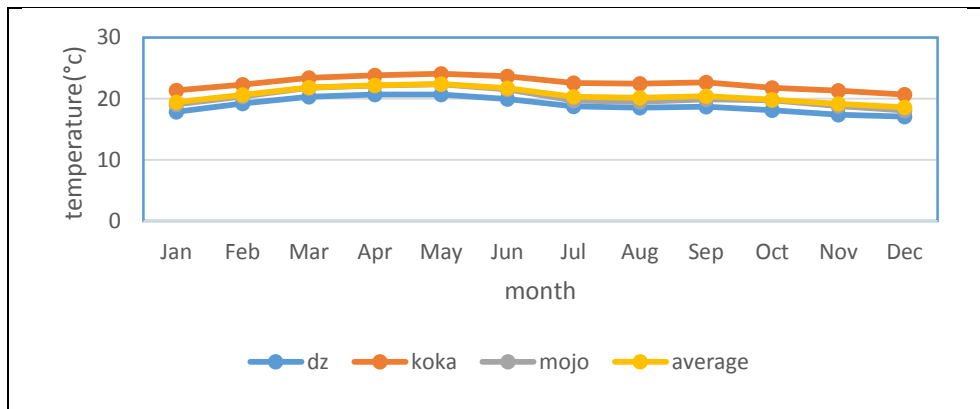


Figure 5.4 Monthly Mean annual Temperature (°C) of the Koka area

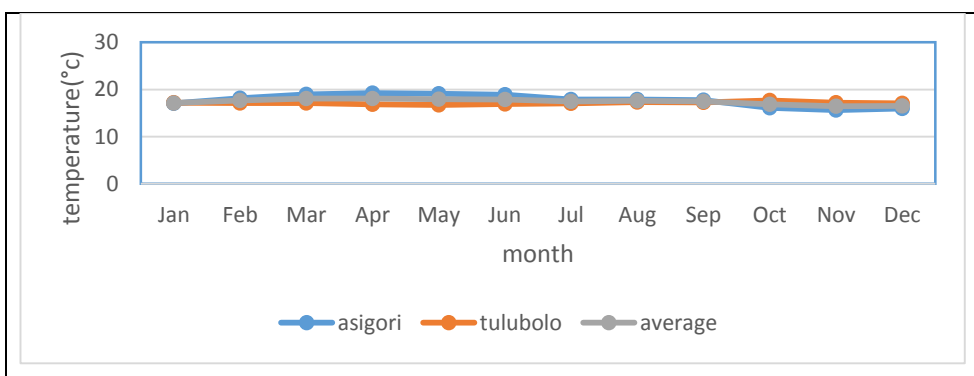


Figure 5.5 Monthly Mean annual Temperature (°C) of the Becho area

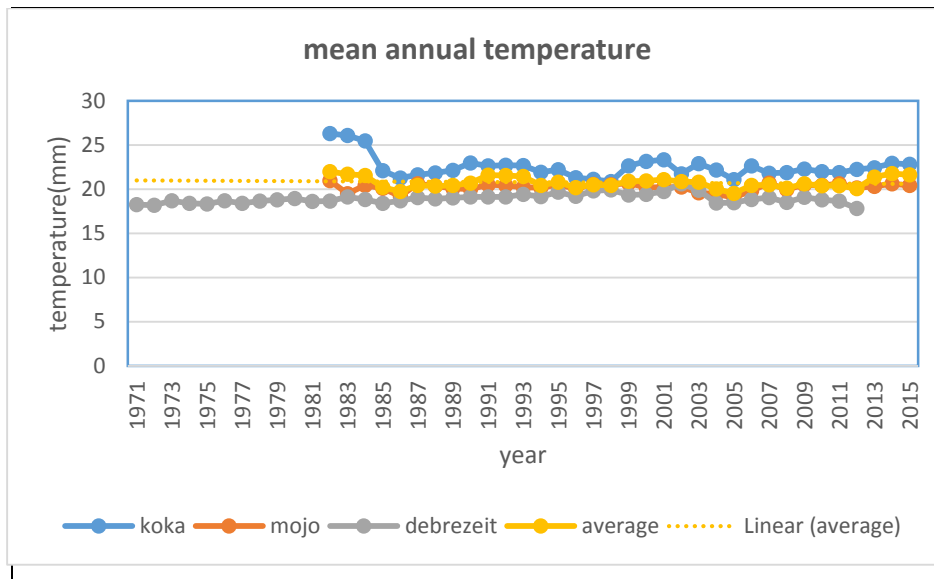


Figure 5.6 long term mean annual temperature (°c) of the Koka area.

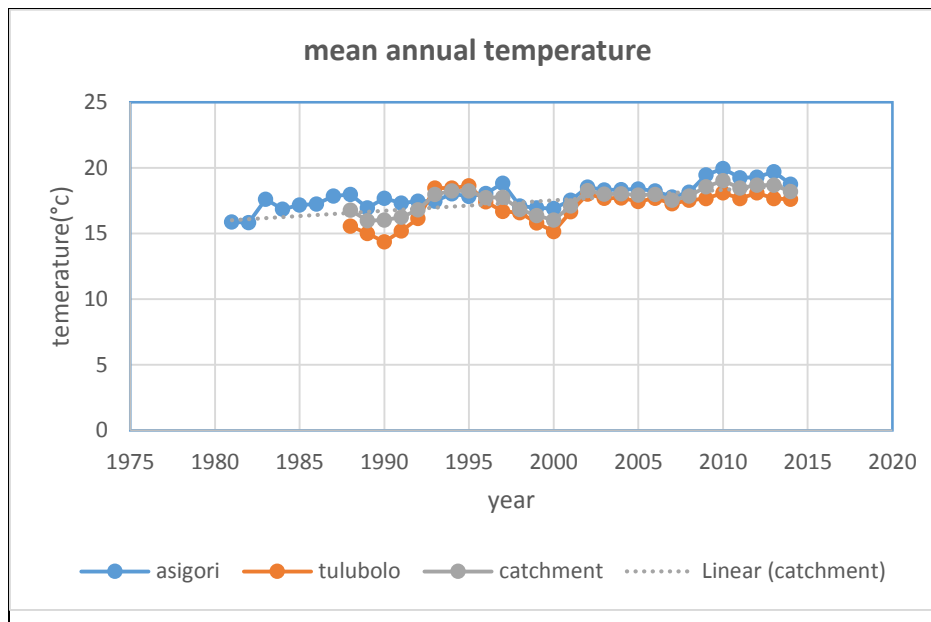


Figure 5.7 long term mean annual temperature (°c) of the Becho area.

### 5.1.4 Wind speed

One of the factors of evaporation is wind speed, the decrease of wind speed resulting in non-removal of saturated vapor that affects evaporation rate. Wind speed data in the study area for Koka area is analyzed from the Debrezeit station and for Becho area from Addis Ababa Meteorological Station. The mean monthly wind speed data is shown in Table 5.5. The magnitude varies from 1– 1.6 m/sec and 1.4– 2 m/sec. Wind speed is relatively low, especially in the rainy season.

### 5.1.5 Sunshine hour

Sunshine hour of the area is represented by data taken from Debrezeit station for Koka area and Addis Ababa station for Becho area. The maximum sunshine hour is observed in the months of October, November, December and February and minimum values in the months of July and August.

### 5.1.6 Relative humidity

Relative humidity is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature. The relative humidity of the air is largely dependent on temperature and rain fall. Koka area at Debrezeit station has a maximum mean humidity value of 78.7 in the month of August and a minimum humidity value of 55.73 in the month of February and Becho area at Addis Ababa station has a maximum mean humidity value of 75.9 in the month of August and a minimum humidity value of 52.43 in the month of February.

Table 5.3 Mean monthly wind speed, sunshine hour and relative humidity of the selected meteorological stations.

	station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
WS	DZ	1.4	1.6	1.6	1.6	1.6	1.3	1.2	1.0	1.0	1.4	1.6	1.5	1.4
	AA	1.6	1.7	1.8	1.8	2.0	1.8	1.5	1.5	1.5	1.5	1.4	1.6	1.6
SSH	DZ	8.9	9.0	8.8	8.1	8.2	6.9	5.2	5.5	7.0	9.1	9.7	9.4	8.0
	AA	8.6	8.4	7.6	6.5	7.0	5.2	3.2	3.5	5.1	8.1	9.2	8.8	6.8
RH	DZ	59.4	55.7	56.9	58.9	59.8	67.2	77.1	78.8	73.7	59.5	58.1	58.7	63.7
	AA	55.8	52.4	53.6	58.9	57.2	65.5	74.7	75.9	70.5	56.5	54.7	55.6	60.9

Where, WS, SSH, RH, DZ and AA stands wind speed, sunshine hour, relative humidity, Debrezeit and Addis Ababa respectively.

### 5.1.7 Evapotranspiration

Evapotranspiration is the combined processes of direct evaporation at the ground surface, direct evaporation on plant surfaces and transpiration (Fitts, 2002). Evapotranspiration rates are governed by several factors, the most important of which are the temperature and humidity of the air and the availability of water on the surface and in the shallow subsurface. Evapotranspiration is the process of water loss from a vegetated land surface by evaporation plus transpiration (Shaw, 1988). The evaporation from a vegetated surface

is a function of available energy, net radiation, the temperature of the surface and air, the saturation deficit, the wind speed, and the available soil moisture. Therefore, the assessment of transpiration loss takes in to account the water available to the plant in the rooting zone of the soil. In the study area, there is no direct measurement value of evaporation from open water body or pan evaporation. There for evapotranspiration has been computed using the recorded data of meteorological stations of the catchments employing the pen man, Thornthwaite and Turc empirical formula.

#### 5.1.7.1 Estimation of potential evapotranspiration (PET).

PET is defined as the evapotranspiration which would occur under unrestricted availability of water to a fully vegetated surface (Shaw, 1988) or it is the maximum possible evaporation under given meteorological conditions (Tenalem Ayenew and Tamiru Alemayehu, 2001). PET has a positive relation with temperature, sunshine, and wind speed but has a negative relationship with air humidity.

##### A. Thornthwaite method

The Thornthwaite method uses air temperature as an index of the energy available for evapotranspiration, assuming that air temperature is co-related with the integrated effect of net radiation and other controls of evapotranspiration, and that the available energy is shared in fixed proportion between heating the atmosphere and evapotranspiration. The resulting formula is based mainly on temperature with an adjustment being made for the number of daylight hours. An estimate of the potential evapotranspiration, PEm, calculated on a monthly basis, is given by:

$$PE_m = 16 N_m \left( \frac{10 \bar{T}_m}{I} \right)^a \text{ mm} \quad (5.2)$$

Where PEm is Potential evapotranspiration ,m is the months 1, 2, 3...12, Nm is the monthly adjustment factor related to hours of daylight, is the monthly mean temperature °C, I is the heat index for the year, given by:

$$I = \sum i_m = \sum \left( \frac{\bar{T}_m}{5} \right)^{1.5} \quad (5.3)$$

$$a = 0.49 + 0.0179 I - 0.0000771 I^2 + 0.000000675 I^3 \quad (5.4)$$

Table 5.4 potential evapotranspiration of Koka area calculated by Thornthwaite method

	Jan	Feb	May	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tm	19.4	20.6	21.4	22.2	22.4	21.7	20.3	20.2	20.4	19.9	19.2	18.6
N)	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
Nm	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0
i(m)	7.6	8.4	8.9	9.4	9.5	9.0	8.2	8.1	8.3	7.9	7.5	7.2
I	99.8											
a	2.2											
Em	68.7	78.4	84.9	92.1	93.8	87.7	76.0	74.6	76.7	72.2	66.7	62.4
PEm	66.4	77.1	84.9	94.4	98.5	92.8	79.8	77.1	77.3	71.0	64.5	59.8
PET of the year = 941.1 mm/year												

Table 5.5 potential evapotranspiration of Becho area calculated by Thornthwaite method

	Jan	Feb	May	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total
Tm	17.2	17.5	18.0	18.1	18.0	17.8	17.4	17.6	17.5	16.8	16.4	16.5	
N	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5	
Nm	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	
Im	6.4	6.6	6.9	6.9	6.8	6.7	6.5	6.6	6.5	6.2	5.9	6.0	
I	77.9												
a	1.7												
Em	63.7	65.7	69.0	69.2	68.5	67.4	65.0	65.9	65.1	60.8	58.2	58.9	777.4
PET	61.6	64.6	69.0	70.9	71.9	71.3	68.2	68.1	65.7	59.8	56.2	56.4	783.8

The potential evapotranspiration calculated by this method for the Koka and Becho area is 941.5 and 783.8mm/year respectively.

## B. Penman method

Penman combined the energy balance with the mass transfer methods of evaporation estimates; and derived an equation to compute the evaporation from an open water surface using standard climatological records of sunshine, temperature, humidity and wind speed. Later on the equation was modified (MAFF, 1967 as cited in Shaw, 1994) to allow for the condition under which evaporation plus transpiration takes place from a vegetated surface. The most general and widely used equation for calculating ET is the Penman equation. The Penman-Monteith variation is recommended by the Food and Agriculture Organization.

The basic equation of penman to calculate potential evapotranspiration, PET, is

$$PET = \frac{\frac{\Delta}{\gamma} Ht + Eat}{\frac{\Delta}{\gamma} + 1} \quad (5.5)$$

Where Ht is the available heat and is calculated as

$$Ht = 0.75RI - Ro \quad (5.6)$$

Where RI is the incoming radiation, and Ro is the outgoing radiation.

RI is a function of Ra, the solar radiation (fixed by latitude and season) modulated by a function of the ratio, n/N, of measured to maximum possible sunshine duration. And “n” is bright Sunshine over the same period, h/day

$$Eat = 0.35(1+u^2/100) (ea-ed) \quad (5.7)$$

Where u<sub>2</sub> – mean wind speed at 2m above the surface, miles per day

ea-saturated vapor pressure at air temperature Ta

ed - mean vapor pressure of the air.

The saturated vapor pressure at air temperature ea (Ta) is given to good approximation by:

$$ea (Ta) = 6.11 \exp (17.3Ta/Ta+237.3) \quad (5.8)$$

With vapor pressure in mb and temperature in °C

The vapor pressure of the air (ed) depends on the relative humidity, RH, as well as the air temperature Ta:

$$ed = RH ea (Ta) \quad (5.9)$$

Where RH is expressed as a ratio

The empirical equation for the incoming radiation, RI, takes the form

$$RI (1-r) = 0.75 Ra.fa (n/N) \quad (5.10)$$

r-is the albedo (reflection coefficient for incident radiation; r = 0.25 for the catchment covered with mature forest, bushes and shrubs, grasses and cultivated crops).

fa (n/N) takes several forms. The study area, located south of 54 1/2° N (10°N), thus fa (n/N) takes the form:

$$fa (n/N) = (0.16 + 0.62 n/N) \quad (5.11)$$

The empirical equation for the outgoing radiation takes the form:

$$Ro = \sigma Ta^4 (0.47 - 0.075\sqrt{ed}) (0.17 + 0.83 n/N) \quad (5.12)$$

Where  $Ta^4$  is the theoretical black body radiation at  $Ta$  which is then modified by functions of the humidity of the air ( $ed$ ) and the cloudiness ( $n/N$ ).

In calculating PET, the following equation for  $H$  is used:

$$H = 0.75 Ra (0.18 + 0.55 n/N) - 0.95 \sigma Ta^4 (0.10 + 0.90 n/N) (0.56 - 0.092 \sqrt{ed}) \quad (5.13)$$

Using this empirical formula potential evapotranspiration of Becho area was 1071.10 mm/year.

Table 5.6 potential evapotranspiration of becho area calculated by penman method

	Jan	Feb	May	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T	17.2	17.5	18.0	18.1	18.0	17.8	17.4	17.6	17.5	16.8	16.4	16.5
K	290.4	290.7	291.2	291.2	291.1	291.0	290.6	290.7	290.6	289.9	289.5	289.6
n	8.6	8.4	7.6	6.5	7.0	5.2	3.2	3.5	5.1	8.1	9.2	8.8
N	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
n/N	0.7	0.7	0.6	0.5	0.6	0.4	0.3	0.3	0.4	0.7	0.8	0.8
H(100)	55.8	52.4	53.6	58.9	57.2	65.5	74.7	75.9	70.5	56.5	54.7	55.6
U1(m/s)	1.6	1.7	1.8	1.8	2.0	1.8	1.5	1.5	1.5	1.5	1.4	1.6
U2(mil/day)	3.6	3.8	4.0	4.0	4.5	4.0	3.4	3.4	3.4	3.4	3.1	3.6
Ea (mmhg)	14.8	15.1	15.5	15.6	15.5	15.3	14.9	15.1	15.0	14.3	14.0	14.1
Ed(mmmhg)	8.2	7.9	8.3	9.2	8.8	10.0	11.2	11.5	10.6	8.1	7.6	7.8
Ea-Ed	6.5	7.2	7.2	6.4	6.6	5.3	3.8	3.6	4.4	6.2	6.3	6.3
$\Delta/r$	1.9	1.9	2.0	2.0	2.0	2.0	1.9	2.0	1.9	1.9	1.8	1.8
Ra(mm/day)	12.8	13.9	14.8	15.2	15.0	14.8	14.9	15.0	14.8	14.2	13.1	12.5
Eat	2.4	2.6	2.6	2.3	2.4	1.9	1.4	1.3	1.6	2.3	2.3	2.3
F(ed)	0.3	0.3	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.3	0.3	0.3
F(b)	0.8	0.8	0.7	0.6	0.6	0.5	0.4	0.4	0.5	0.7	0.8	0.8
Ri(1-r)	6.0	6.3	6.1	5.6	5.7	4.6	3.6	3.8	4.7	6.2	6.4	6.0
Ro	2.8	2.8	2.5	2.1	2.2	1.7	1.2	1.2	1.6	2.6	3.0	2.9
Fa(n/N)	0.6	0.6	0.6	0.5	0.5	0.4	0.3	0.3	0.4	0.6	0.7	0.6
$\sigma Ta^4$	13.9	13.9	14.0	14.0	14.0	14.0	13.9	13.9	13.9	13.8	13.7	13.7
Ht	3.2	3.5	3.7	3.5	3.5	2.9	2.4	2.6	3.0	3.6	3.4	3.1
PET(mm/d)	2.9	3.2	3.3	3.1	3.1	2.6	2.0	2.1	2.6	3.2	3.0	2.8
PET(mm/m)	89.8	89.8	102.8	89.9	97.1	77.8	59.1	66.1	76.5	91.3	90.6	86.4

### 5.1.7.2 Estimation of Actual Evapotranspiration (AET)

Actual evapotranspiration is the real evapotranspiration that take place from vegetal cover under the existing soil moisture supply. A value of the actual evapotranspiration over a catchment is obtained by first calculating the potential evapotranspiration, and then modifying the answer by accounting for the actual soil moisture content (Shaw, 1985;

Dunne and Leopold, 1978). Actual evapotranspiration is the amount of evapotranspiration that occurs under field conditions. If there is abundant moisture in the soil, the actual evapotranspiration rate equals to potential evapotranspiration rate. When the moisture content in the soil is limited and vegetation is unable to abstract enough water from the soil, then actual evapotranspiration becomes less than potential evapotranspiration. Thus the relationship between AET and PET depends on the soil moisture content. As soil moisture deficit increases, AET becomes increasingly less than PET. The values of AET depend on soil and vegetation types (Shaw, 1985). The values of AET become larger during dry period and less during rainy periods of the year. Always,  $AET \leq PET$ . The actual evapotranspiration of the study area is calculated using two methods; Turc's empirical formula and Thornthwaite Mather soil water balance method.

#### A. Turc method (empirical formula)

The formula derived by Turc (1954) which is used to determine (actual evapotranspiration) AET assumes that the main parameters affecting AET to be precipitation and temperature. The Turc empirical formula is written as:

$$AET = P / [0.9 + (P/L)^2]^{1/2} \quad (5.14)$$

$$\text{Where } L = 300 + 25 T + 0.05 T^3 \quad (5.15)$$

T = annual average temperature (°C)

P = the annual rate of precipitation in mm

AET = Annual actual evapotranspiration

The actual evapotranspiration calculated by this method for the Koka and Becho area are 742.67 and 765.30mm respectively.

#### B. Thornthwaite and Mather soil water balance method

This method computes actual evapotranspiration through calculation of potential evapotranspiration. To calculate actual evapotranspiration, the proportion of vegetation cover with its soil moisture and soil type of the catchment must be known. A soil moisture budget can be made on a monthly basis for various types of vegetation classified according to their root constant (RC), which defines the amount of soil moisture (mm-depth) that can be extracted from the soil without difficulty by given vegetation. This

method needs monthly rain fall (Pm) and monthly potential evapotranspiration (PETm) as an input (Shaw, 1985; and Dunne and Leopold, 1978).

Table 5.7 Estimation of Actual evapotranspiration by using Thornthwaite and Mather soil water balance method, Koka area.

Soil moisture Water Balance Thornthwaite method for deep rooted, Clay Soil, W=200													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
PP	10.9	21.0	45.6	59.4	61.1	90.4	226.2	220.9	107.8	25.0	6.5	3.7	878.5
PET	66.1	76.7	88.4	93.9	97.9	92.3	79.4	75.3	76.9	70.6	64.1	59.5	941.1
P-PET	-55.2	-55.7	-42.8	-34.5	-36.8	-1.9	146.8	145.6	30.9	-45.6	-57.6	-55.8	
APWL	-	-269.9	-	-	-	0.0	0.0	0.0	0.0	-45.6	-	-	
	214.2		312.8	347.3	384.1						103.2	159.0	
SM	68.5	51.9	41.9	35.2	23.8	200.0	200.0	200.0	200.0	159.2	119.4	90.3	
CSM	-21.8	-16.7	-10.0	-6.6	-11.4	176	0.0	0.0	0.0	-40.8	-39.8	-29.1	
AET	32.7	37.7	55.6	70.9	71.9	92.3	79.4	75.3	76.9	65.8	46.3	32.8	737.5
SMD	33.4	39.1	32.8	23.0	26.0	0.0	0.0	0.0	0.0	4.8	17.8	26.8	203.7
SMS	0.0	0.0	0.0	0.0	0.0	0.0	146.8	145.6	30.9	0.0	0.0	0.0	323.3

Table 5.8 Estimation of Actual evapotranspiration by using Thornthwaite and Mather soil water balance method, Becho area.

Soil moisture Water Balance Thornthwaite method for deep rooted, Clay Soil, W=200													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
PP	13.1	34.3	59.6	85.7	79.4	146.5	273.3	274.8	124.1	26.9	8.5	4.5	<b>1130.5</b>
PET	89.8	89.8	102.8	89.9	97.1	77.8	59.1	66.1	76.5	91.2	90.6	86.4	<b>1017.2</b>
P-PET	-76.7	-55.5	-43.2	-4.2	-17.7	68.6	214.2	208.7	47.6	-64.4	-82.1	-82.0	
APWL	-	-	-	-	-	0.0	0.0	0.0	0.0	-64.4	-	-	
	305.1	360.7	403.9	408.1	425.8						146.5	228.4	
SM	43.5	32.9	26.5	26.0	23.8	200.0	200.0	200.0	200.0	144.9	96.1	63.8	
CSM	-20.3	-10.5	-6.4	-0.6	-2.2	176.2	0.0	0.0	0.0	-55.1	-48.8	-32.3	
AET	33.4	44.9	66.0	70.9	71.9	77.8	59.1	66.1	76.5	81.9	57.3	36.8	<b>742.6</b>
SMD	56.4	45.0	36.8	19.0	25.2	0.0	0.0	0.0	0.0	9.3	33.3	49.6	<b>274.6</b>
SMS	0.0	0.0	0.0	0.0	0.0	0.0	214.2	208.7	76.5	0.0	0.0	0.0	<b>499.4</b>

Where

PPT-average monthly rainfall values (mm)

PET-potential evapotranspiration values, mm.

PPT-PET- the difference between rainfall and potential evapotranspiration. Positive values are showing additions of moisture to the soil while the negative values are showing the monthly demand of moisture by the vegetation which is not satisfied by the monthly rainfall.

APWL= the accumulated potential water loss. The summation begins with October, the first month of the dry season, until May

SM=soil moisture .The soil moisture content during the dry months is calculated using accumulated potential water loss by the following formula;

$$SM=W.exp (-APWL /w) \tag{5.16}$$

Sm=soil moisture during month M (mm).

APWL =accumulated potential water loss at month M (mm).

W=available water capacity of the root zone (mm).

Soil moisture values for each wet month are obtained by adding the excess of rainfall of the current month to the soil moisture of the month before. This sum may not exceed the soil moisture capacity, an eventually excess is booked as surplus.

$$\Delta SM=SM - S (M-1) \tag{5.17}$$

$\Delta SM$  =difference in soil moisture between month M and month M-1 (mm).

AET= Actual evapotranspiration. For the wet months the actual evapotranspiration equals the potential evapotranspiration, because it is assumed that all the rain which falls is available for the plants. For the dry month, the actual evapotranspiration is the sum of the monthly rainfall and the monthly amount of water extracted from the soil.

$$AETM= PPM+ \Delta SM \tag{5.18}$$

AETM=actual evapotranspiration during month M (mm).

PPM= average precipitation of month M (mm).

$\Delta SM$  =difference in soil moisture between month M and month M-1 (mm).

SMD=soil moisture deficit. The monthly soil moisture deficit is the difference between the monthly potential evapotranspiration and the monthly actual evapotranspiration

The actual evapotranspiration calculated by this method for the Koka and Becho area were 737.5 and 742.6 mm/year respectively.

Table 5.9 summarized value of PET, AET, and PPT

Area	Method	PET(mm)	AET(mm)	P(mm)
	Thornthwaite	941.13	742.6	
Becho	Penman	1017.2		
	Turc		765.30	
	Average	979.2	754	1130.5
Koka	Thornthwaite	941.1	737.7	
	Penman	-		
	Turc		742.6	
	Average	941.1	740	878.5

### 5.1.8 Direct Runoff

Direct runoff is water not absorbed by soil or that does not soak into the soil but flows into surface waters. Geology, slope, and topography are the most controlling factors of runoff and area, actual evapotranspiration/ rainfall and vegetation cover least control runoff. In general, low rainfall, high evapotranspiration, gentle slope, very permeable volcanic falls and disappearing drainage pattern can confirm the lowest runoff.

Direct runoff is that part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers. And it consists of precipitation that neither evaporates, transpires nor penetrates the surface to become groundwater. It occurs when the rate of rainfall on a surface exceeds the rate at which water can infiltrate the ground, and any depression storage has already been filled. This more commonly occurs in arid and semi-arid regions, where rainfall intensities are high and the soil infiltration capacity is reduced because of surface sealing, or in paved areas. The runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the catchment i.e. the larger the size of the catchment the larger the time of concentration and the smaller the runoff efficiency.

The Upper Awash river basin is part of the Awash River basin covers a total catchment area 10,841 of km<sup>2</sup>. The river originates on the high plateau near Ginch town west of Addis Ababa and flows along the rift valley into the Koka dam. Before entering the artificial lake (reservoir), Koka the upper Awash River basin has two main tributaries in the study area Mojo and Teji Rivers. There are also many intermittent tributary streams. The main Awash River is gauged at two points in the upstream of Lake Koka. The first gauging station is at Bello which is west of Addis Ababa with a total upstream catchment area of 2568.8 km<sup>2</sup> and the second station is at Hombole with a catchment area of 7656 km<sup>2</sup>.

Table 5.10 Mean monthly Discharges of main rivers (m<sup>3</sup>/s)

Flow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	mean
Mojo	3.6	3.9	4.8	4.8	6.8	11.9	37.1	69.7	29.2	4.9	3.6	3.5	11.95
Awash at Hombole	0.7	0.6	0.9	1.7	1.7	6.8	24.9	35.2	26.4	8.0	1.9	0.9	3.3
Awash at Bello	4.1	4.3	5.7	8.8	8.4	18.7	95.4	206.8	114.5	18.1	8.9	4.4	41.5
Teji	0.3	0.3	0.4	0.5	0.7	2.1	10.7	16.6	6.0	1.3	0.6	0.4	9.9

The actual pattern of flow during the year depends on precipitation, evapotranspiration, soil and geological characteristics of the catchment. The greater the infiltration in the storage capacity of a given catchment, the high flow is sustained through the dry seasons, and peak flows after period of highest precipitation. Depending on geology, topography, climate and other factors each catchment in the study area is characterized by its distinct percentage of monthly flow. The variation in monthly percentage of rivers flow reflects the differences in hydrology and hydrogeology of the catchments.

In the study area the main Awash River and its major tributaries are gauged at different locations. Major tributaries: Mojo River and Teji River are gauged at their outlets before joining Awash. The main Awash River is gauged at Bello and Hombole.

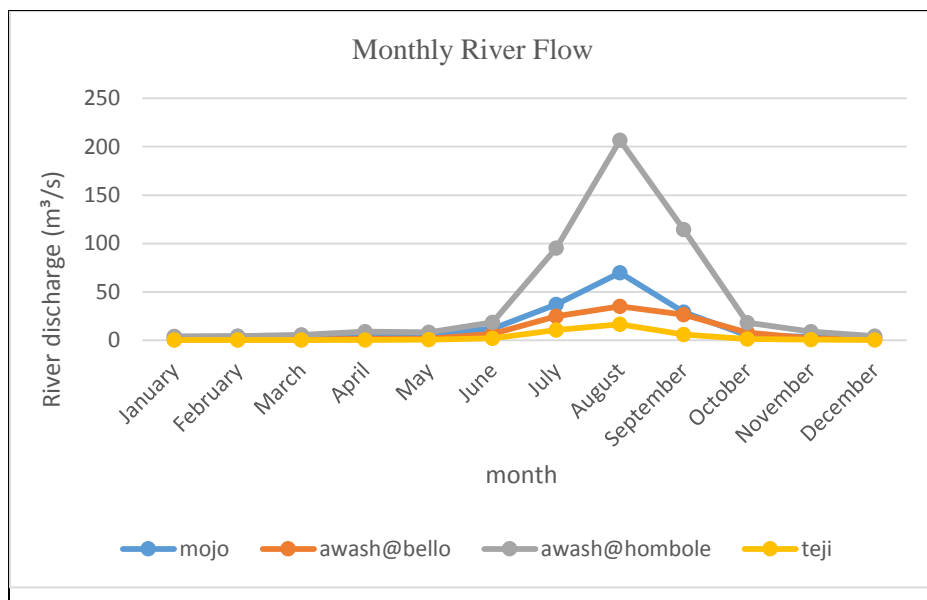


Figure 5.8 Long-term mean monthly discharges of main rivers in the study area.

The discharge records exhibit similar trends, the highest flow corresponding with the wettest months of June, July, August and September (Figure 5.8). From this relationship, even though there is high rainfall in June its river discharge is low, showing most part of the rainfall infiltrates to subsurface to saturate or up to the infiltration capacity of soils.

## 5.2 Groundwater recharge estimation

There are different types of methodologies that are used to estimate groundwater recharge as discussed in section 2.3. In this study baseflow separation using excel spread sheet program and water balance method were used.

### 5.2.1 Water balance/ water budget method

The concept of water balancing is a fundamental concept in water resources planning and management. However, the ability to perform the water balance calculations can be a tedious and labor intensive process. Water balance techniques have been extensively used to make quantitative estimates of water resources and the impact of man's activities on the hydrologic cycle. On the basis of the water balance approach, it is possible to make a quantitative evaluation of water resources and its dynamic behavior under the influence of man's activities. The study of water balance is defined as the systematic presentation of data on the supply and use of water with in a geographic region for a specified period. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to changes in components of the system.

The basic concept of water balance is:

Input to the system - outflow from the system = change in storage of the system (over a period of time)

The general form of the water balance of a given basin or catchment is given by:-

$$P+I+ Ar + Qi = R + Et + D + Qo + W + \Delta S \quad (5.19)$$

P = precipitation

I = infiltration from surface water

Ar = artificial recharge

Qi = ground water inflow

R = surface runoff

Et = evapotranspiration

D = drainage

Qo = ground water out flow

W = withdrawal

$\Delta S$  = change in storage Where

But water balance method follows certain assumptions such as:-

- Surface water divide coincides with ground water divide
- No inflow from out and no out flow from catchments
- And abstraction by human is insignificant.

Therefore, the estimation of water reaching the ground water table can be calculated by:

$$R = P - SRO - AET \quad (5.20)$$

Where

R = estimated recharge to the ground water

P = the precipitation

SRO = surface runoff

AET= the actual evapotranspiration

Therefore, the annual groundwater recharge of the Mojo River, Teji River and Awash River at Bello and Hombole using water balance method were 22 mm, 284 mm, 355 mm and 77.1 mm.

### **5.2.2 Baseflow separation method**

Baseflow is the long-term discharge into a stream from natural storage, such as groundwater, usually sustaining flow between rainfall events. Streams that flow continuously throughout the year have a high baseflow component. Techniques, many of which give subjective results, have been developed to estimate baseflow as a record of groundwater discharge under the stream flow hydrograph (Erickson and Stefan, 2008).

The major assumption in using base flow for estimating recharge is that baseflow equals groundwater discharge from the aquifer storage and that groundwater discharge is approximately equal to recharge, assuming that losses from gauged watersheds caused by underflow, groundwater evapotranspiration and abstraction are minimal (Andarge Yitbarek,2009).

In this study indirect groundwater recharge or baseflow for the Becho and Koka area is estimated by applying baseflow separation excel spreadsheet program using daily river flow records of 45 years (1968-2013) Mojo River flow, 34 years (1975-2009) Awash

River flow at Hombole, 20 years (1987-2007) Awash River flow at Bello and 33 years (1976-2009) Teji River flow as an input.

The summary of annual recharge and/or baseflow rates associated with the available annual historical stream flow records were shown in (appendix 1 and table 5.11). Figure 5.9, 5.10, 5.11 and 5.12 shows hydrographs of Mojo River, Awash River at Hombole, Teji River and Awash River at Bello indicating total flow and baseflow by using baseflow excel spread sheet program.

The total recharge or baseflow of the study area by using excel spread sheet program shows that about 98.1 mm/year of the Mojo River which amounts to 10.3% of the mean annual areal precipitation of the study area ,110.4mm/year of the Awash River at Hombole which amounts to 12.5% of the mean annual areal precipitation of the study area, 97.1mm/year of the Awash River at Bello which amounts to 9.7 % of the mean annual areal precipitation of the study area and 65.7mm/year of the Teji River which amounts to 6.5% of the mean annual areal precipitation of the study area .

The groundwater recharge in the study area has been estimated by different researchers and organizations using different approaches as discussed in the literature review. Using the water balance modelling (WATBAL) the mean annual recharge over the Mojo river and Awash River at Bello is 85.9 mm and 72 mm (WWDSE, 2008). It is slightly comparable with the mean annual recharge over the Mojo and Awash River at Bello as shown in the (table 5.12) which is 98.4 mm and 97.1 mm using base flow separation excel spread sheet method.

As it observed from the two method, the results doesn't match .The difference might be due to the various assumptions employed in both methods and possibly the baseflow separation method could not account any channel loss at the upstream and the deep groundwater flows beneath the river channel. As discussed in (section 2.3) estimation of groundwater recharge using water balance method is difficult in the Koka area due to low rainfall and high evapotranspiration.

Table 5.11 mean monthly baseflow, surface runoff, baseflow index and total flow of River in the study area.

	Rivers		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	mean	
Koka area	MR	MRF	3.6	3.9	4.8	4.8	6.8	11.9	37.1	69.7	29.2	4.9	3.6	3.5	11.9	
		MBF	3.5	3.6	3.5	2.9	4.2	6.2	6.2	8.6	27.6	11.5	2.8	3.5	3.5	3.95
		MSRO	0.1	0.3	1.2	1.9	2.6	5.7	28.6	42.1	17.7	2.1	0.1	0.1	0.1	7.9
		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	1.0	0.33
	AR@H	MF	4.1	4.3	5.7	8.8	8.4	18.7	95.4	206.8	114.5	18.1	8.9	4.4	41.5	
		MBF	3.5	3.3	3.4	4.6	5.1	9.6	52.5	136.9	77.8	11.8	6.7	4.1	26.6	
		MSRO	0.6	0.9	2.3	4.3	3.3	9.1	42.9	69.9	36.7	6.3	2.2	0.3	14.9	
		BF/TF	0.9	0.8	0.6	0.5	0.6	0.5	0.6	0.7	0.7	0.7	0.8	0.9	0.7	
Becho area	AR@B	MF	0.3	0.3	0.4	0.5	0.7	2.1	10.7	16.6	6.0	1.3	0.6	0.4	9.2	
		MBF	0.2	0.2	0.2	0.3	0.3	0.8	3.8	5.9	2.9	0.9	0.5	0.3	7.5	
		MSRO	0.0	0.1	0.1	0.2	0.4	1.4	6.9	10.6	3.1	0.4	0.1	0.0	1.7	
		BF/TF	0.8	0.8	0.7	0.6	0.5	0.4	0.4	0.4	0.5	0.7	0.9	0.9	0.6	
	TR	MF	0.7	0.6	0.9	1.7	1.7	6.8	24.9	35.2	26.4	8.0	1.9	0.9	3.3	
		MFB	0.6	0.5	0.5	0.9	0.9	4.5	19.1	31.8	21.8	6.1	1.8	0.9	1.9	
		MSRO	0.1	0.2	0.4	0.8	0.8	2.3	5.8	3.4	4.7	1.9	0.1	0.1	1.4	
		BF/TF	0.9	0.7	0.6	0.5	0.5	0.7	0.8	0.9	0.8	0.8	0.9	0.9	0.7	

Where, MR, TR, MRF, AR@H, AR@B, MBF, MSRO, BF, and TF stands Mojo River, Teji River, mean River flow, Awash River at Hombole, Awash River at Bello, mean baseflow, mean surface runoff, baseflow and total flow respectively.

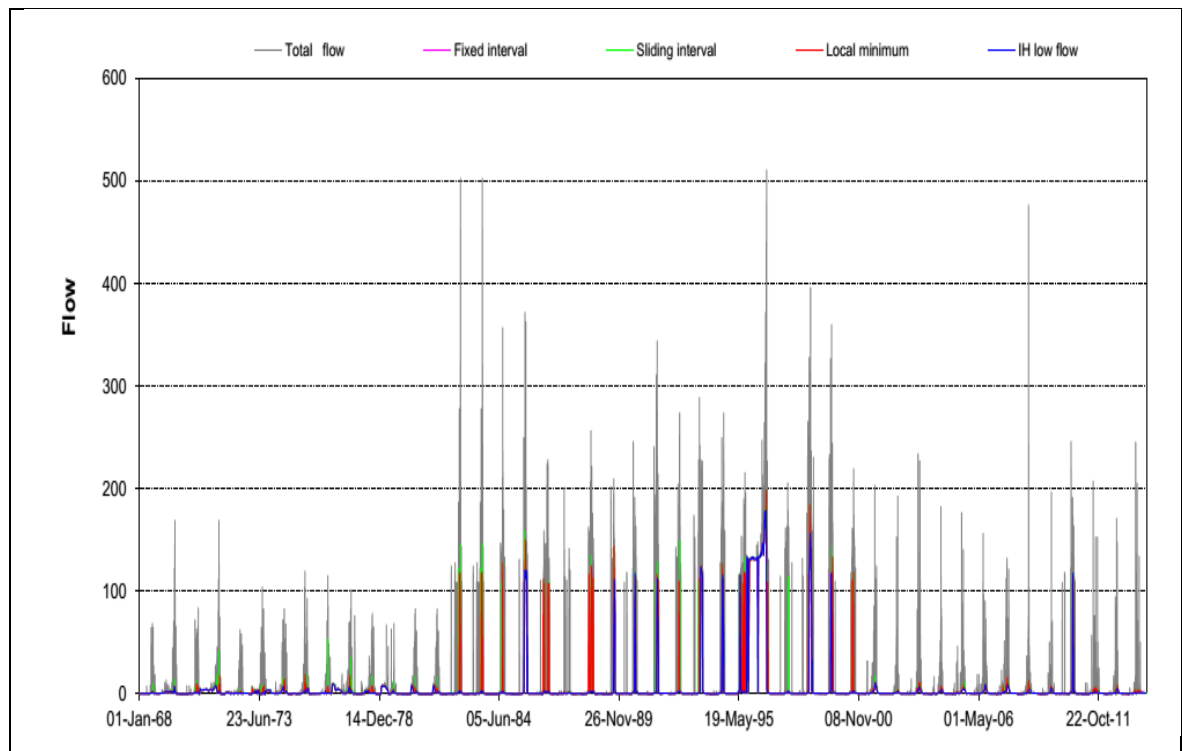


Figure 5.9 Baseflow separation of Mojo River

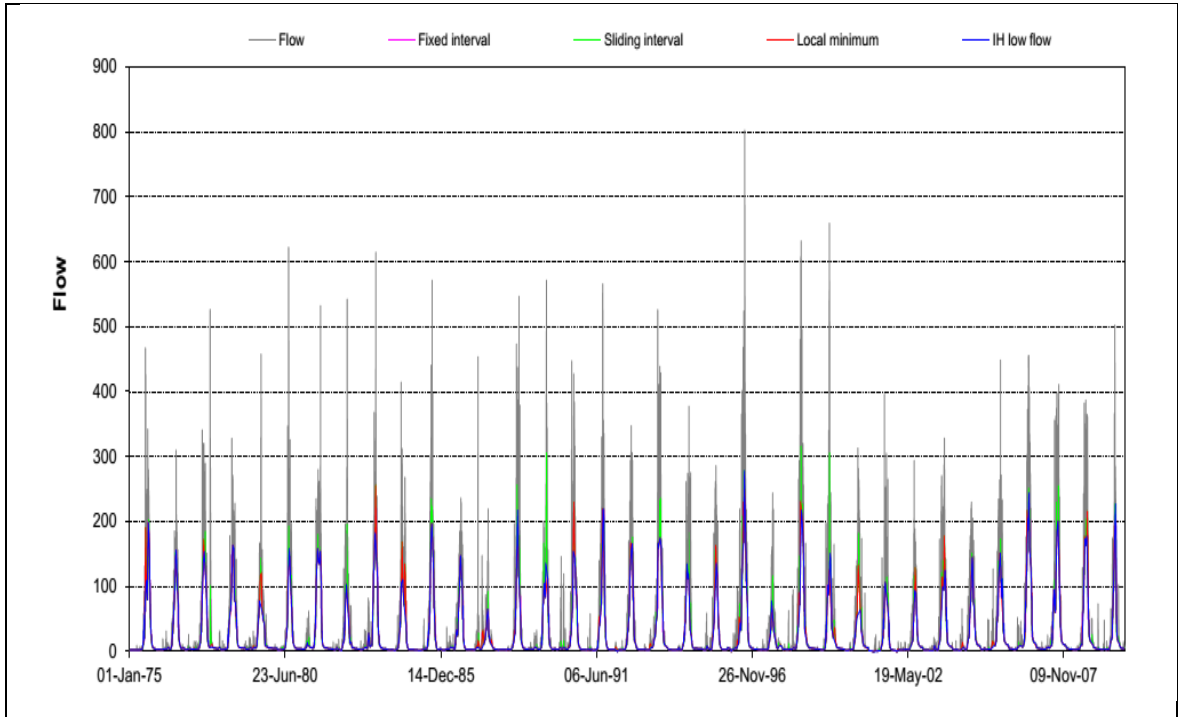


Figure 5.10 Baseflow separation of Awash River at hombole

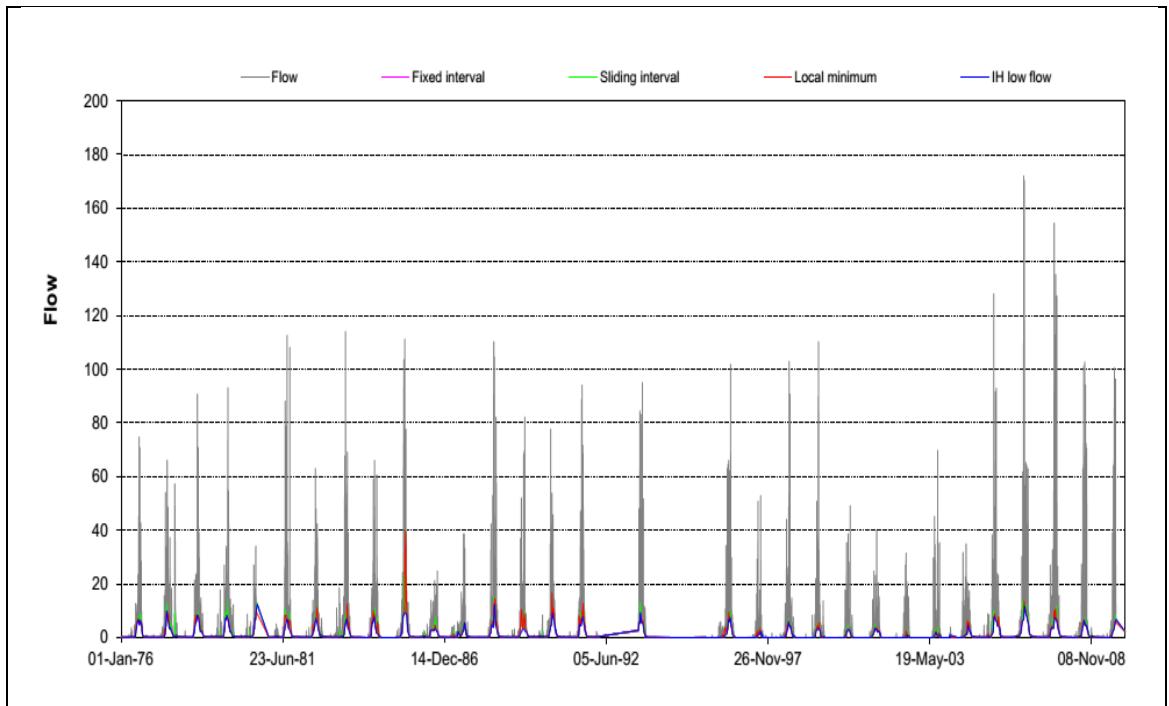


Figure 5.11 Baseflow separation of Teji River

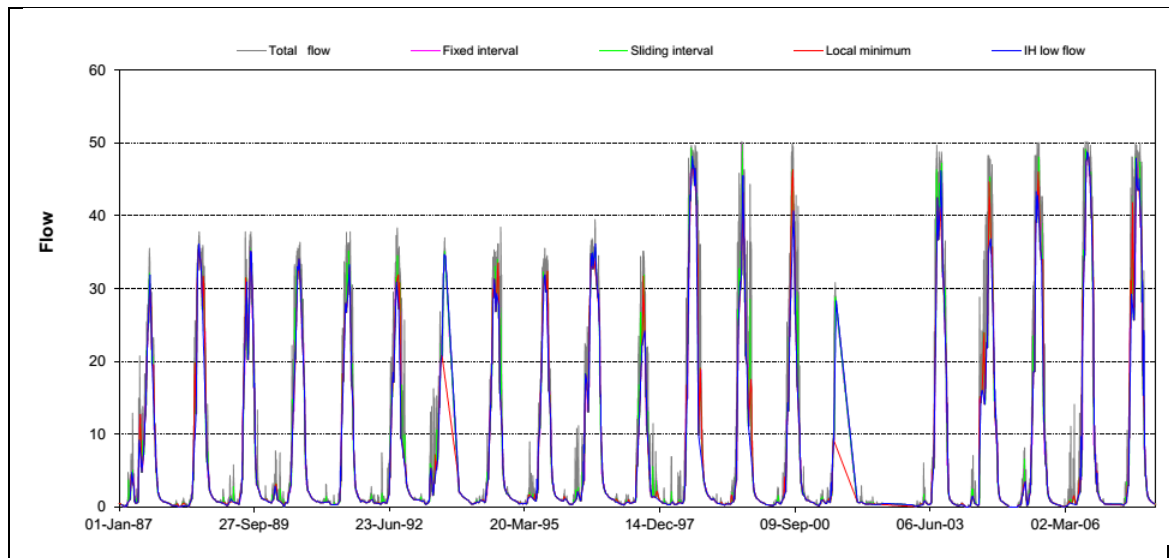


Figure 5.12 Baseflow separation of Awash River at Bello

Table 5.12 Baseflow, surface runoff and precipitation at Mojo, Hombole, Teji and Bello gauging stations using baseflow excel spread sheet.

Catchment	Duration	Area (km <sup>2</sup> )	BF (mm/y)	SRO (mm/y)	R (mm/y)	PP (mm/y)	BF/RF (%)
Awash River at Hombole	1975-2009	7656.0	110.4	61.4	110.4	878.5	12.5
Awash River at Bello	1987-2007	2568.8	97.1	21.0	97.1	945	9.7
Mojo River	1968-2013	1264.4	98.1	192	98.1	953.9	10.3
Teji River	1976-2009	662.5	65.7	92.4	65.7	1017	6.5

Baseflow is part of precipitation representing water which has percolated through the soil and the vadose zone to the groundwater table and subsequently discharges to rivers. From the above table 5.12 we can understand that Rivers gauged at high altitude have higher rainfall produces low baseflow and rivers gauged at low altitude have lower rainfall produces higher baseflow. This is due to the fact that they have greater chance of producing higher surface runoff than baseflow during high intensity precipitation because of the catchment relief and other hydrogeological settings.

Awash River at Bello and Teji rivers have low percentage of baseflow to precipitation due to the fact that the presence of impermeable soils and rocks such as reddish brown clay, tuff and the bed rock is acidic volcanics such as (rhyolite, ignimbrite and trachyte) and tuff which is distributed in the most part of the study area with different thickness and depths. Acidic volcanics and tuffs in the Becho area are characterized by low permeability and porosity, except along weathered and fractured zones; in this case, direct

recharge is limited and is restricted to the zones of fracturing and weathering. The depth of the groundwater in the Becho area varies seasonally indicating the possibility of direct recharge from the swamp.

Awash River at Hombole and Mojo Rivers have high percentage of baseflow to precipitation than Awash River at Bello and Teji rivers. But as we go downstream to rift floor, there is decrease in precipitation, increase in evapotranspiration. This is due to the fact that in the Koka area, where there exists significantly thick alluvial/lacustrine deposit, direct recharge is possible due to primary porosity and permeability of this unit. In areas where this unit is directly underlain by weathered, fractured scoriaceous basalt, the recharge in the alluvium percolates to the underlying basaltic unit. As we go downstream to rift floor, there is decrease in precipitation, increase in evapotranspiration and more importantly channel loss above the gauging stations (Tenalem Ayenew, 1998) but table (5.12) shows that baseflow of Awash River at Hombole exceeds Awash River at Bello.

Table 5.13 Mean monthly specific discharge ( $l/s/km^2$ ) for gauged rivers in the study area

River	area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	mean
AR@ H	7656.0	0.5	0.6	0.7	1.2	1.1	2.4	12.5	27.0	15.0	2.4	1.2	0.6	5.4
AR@ B	2568.8	0.3	0.2	0.3	0.7	0.7	2.7	9.7	13.7	10.3	3.1	0.7	0.4	3.6
Mojo	1264.4	0.6	0.8	1.2	1.5	2.1	5.0	25.5	49.4	20.9	1.9	0.6	0.6	9.2
Teji	662.5	0.4	0.4	0.5	0.8	1.1	3.2	16.2	25.0	9.1	1.9	0.9	0.5	5.0

Where, AR@H and AR@B stands Awash River at Hombole and Awash River at Bello.

When we talk about river and aquifer interactions one may consider that in dry months the dominant flow is from the unconfined aquifer to the river, whereas in rainy months of June-September during high flows the unconfined / confined aquifer is possible fed through fractured river banks. There is also a possibility that the aquifer feeds the river in the remaining reaches. Detailed field observations in dry and wet months are required to identify rivers reaches that recharge aquifer and aquifer zones that discharge into rivers.

As can be observed from the table 5.13 there is no significant relationship between dry month's specific discharge and catchment area. This might be caused by different sources of base flows in the study area.

Dry month's specific discharge of Awash River is increase as we go downstream to rift floor e.g.; Hombole and Bello (December 0.6 and 0.4  $l/s/km^2$ ) but one may not expect this

value due to the fact that Awash River at Hombole has low rainfall and larger catchment. The low value of Awash River in the upper part there is Possibility of recharging of its river adjoining aquifer during wet seasons.

Dry months specific discharge of Mojo river is high (up to 0.6 l/s/km<sup>2</sup>) as compared to Teji river specific discharge (e.g., December 0.5 l/s/km<sup>2</sup>). It may expected Lower specific discharge for Mojo as it has low rainfall and larger watershed. However, base flow of the Mojo River is replenished perhaps from extensive aquifer along its route, although there is a possibilities of the river recharging the aquifer in wet months (WWDSE, 2008).

### **5.3 Hydrograph analysis**

Hydrograph is a graph showing changes in the discharge of a river over a period of time. It represents how a catchments responds to rainfall. It is a composite flow curve of the base flow, the interflow and the direct runoff. It is a useful technique in a variety of water resource investigations. Separation of stream flow hydrographs into baseflow and surface runoff components is used to estimate the ground-water contribution to stream flow.

Hydrograph-separation techniques also have been used to quantify the groundwater component of hydrologic budgets and to aid in the estimation of recharge rates. In addition, base-flow characteristics determined by hydrograph separation of hydrographs from streams draining different geologic terrains have been used to show the effect of geology on baseflow (Sloto and others, 1991).

The shape of a hydrograph is a response from a particular catchment to a series of unique conditions, ranging from the underlying geology and catchment shape to the antecedent wetness and storm duration. The temporal and spatial variations in these underlying conditions make it highly unlikely that two hydrographs will ever be the same. Although there is great variation in the shape of a hydrograph there are common characteristics of a storm hydrograph that can be recognized. The shape of hydrograph depends on climate, topography, geology, soil etc. of the catchment. The shape of rising limb depends mainly on the duration and intensity distribution of rainfall; and the peak discharge in the crest segment represents the highest concentration of runoff from the basin while the recession limb represents withdrawal of water from storage within the channel system.

When we compare the shape of river hydrograph from the figure 5.13 in the Koka area, hydrographs of Awash River at Hombole shows high irregularities, fast rising limbs and fast response to rainfall than Mojo River because Mojo River catchments have permeable rocks and soils causing low surface runoff as response to daily precipitation.

In the Becho area hydrographs of Awash River at Bello shows smooth irregularities and medium responses to rainfall as compared to Teji River this due to Awash River at Bello flowing from highland areas due to this there is high amount of precipitation and less permeable rock in the area which favor's high flood runoff in responses to daily precipitation.

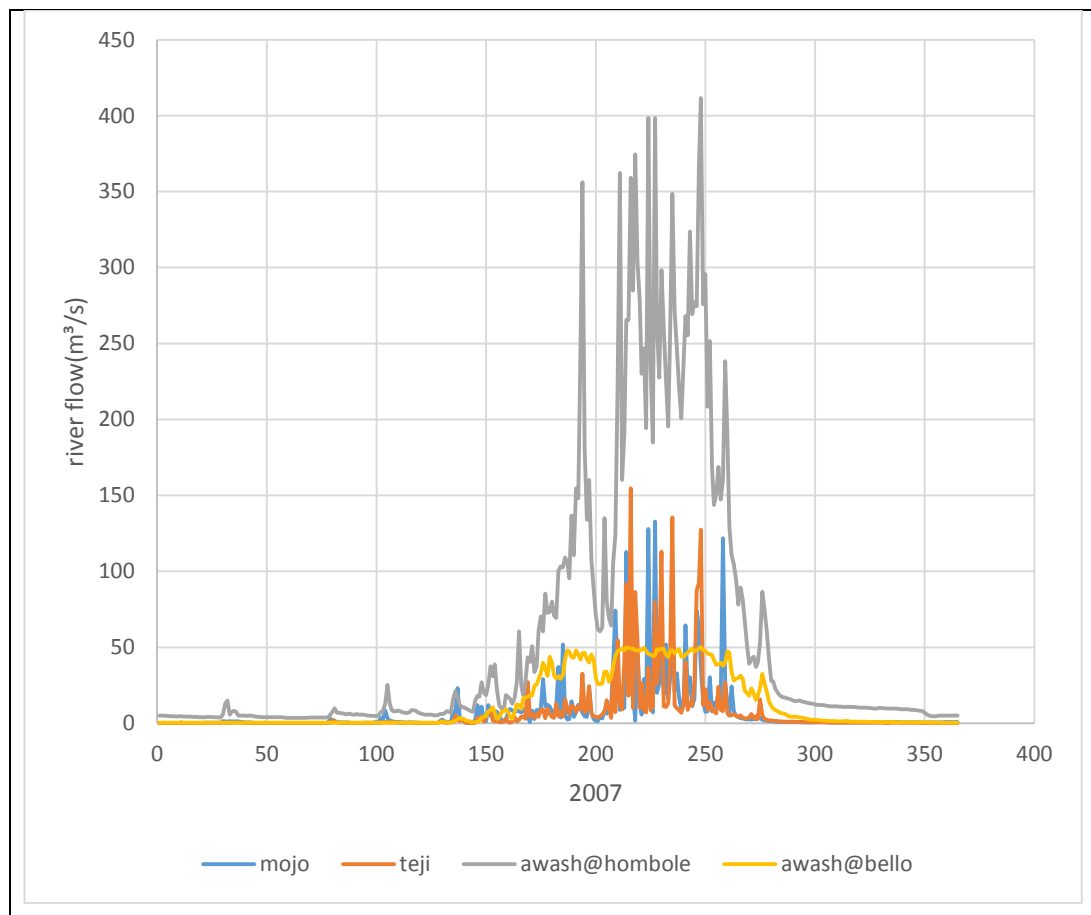


Figure 5.13 Hydrographs of different River systems showing distinct shapes

#### 5.4 Analysis of temporal changes in hydrological environments of the catchments

In Sub-Saharan Africa growing demands for water, intrinsic variability of climatic and surface conditions, variation in recharge rates can occur daily, seasonally, year to year, and over longer periods of time as climate and land-use patterns change (Reese and

Riser,2010). Temporal fluctuations of recharge and discharge rates are normal and represent the dynamic balance between precipitation, infiltration, evaporation, transpiration, runoff, groundwater storage, withdrawal, and base-flow discharge. The season, precipitation timing, and rate of precipitation also will affect the rate of recharge. To detect any trends that would indicate a changing hydrology in the upper Awash River basin, hydrologic variables such as precipitation (mm/y), evapotranspiration (mm/year), annual river flow (m<sup>3</sup>/s), annual baseflow (m<sup>3</sup>/s), and surface runoff (m<sup>3</sup>/s) were plotted as a time-series. These plots are used to explore (1) if a trend is present, (2) what might cause this trend if it is present, (3) if the trend is due to changes in the hydrology of the catchment, and (4) if the trend is due to urbanization of the watershed.

Table 5.14 Summarized ten years average Precipitation, River flow, Baseflow and Surface Runoff of Mojo, Awash River at Hombole, Awash River at Bello and Teji River in the study area obtained from baseflow separation excel spreadsheet method.

	Mojo River				Awash River at Hombole			Awash River at Bello		Teji River		
year	1970-1980	1981-1991	1992-2002	2003-2013	1981-1990	1991-2000	2001-2009	1987-1997	1998-2007	1976-1986	1987-1997	1998-2009
precipitation	888.1	745.5	961.7	950.1	725.5	1012	963.2	1313	983.2		1313.1	966.7
Trends		Dec	Inc	Dec		Inc	Dec		Dec			Dec
River flow	5.7	20.9	19.5	4.9	39.6	45.3	42.0	8.6	10.0	4.0	2.7	3.4
Trends		Inc	Dec	Dec		Inc	Dec		Inc		Dec	Inc
Baseflow	1.9	7.1	6.8	1.3	25.8	27.9	27.3	7.1	8.1	1.9	1.2	1.1
Trends		Inc	Dec	Dec		Inc	Dec		Inc		Dec	Dec
surface runoff	3.8	13.8	12.7	3.6	13.9	17.4	14.7	1.5	2.0	2.1	1.5	2.2
Trends		Inc	Dec	Dec		Inc	Dec		Inc		Dec	Inc

Where, Inc and Dec stands for increasing and decreasing respectively.

#### 5.4.1 Changes in Precipitation due to long term and recent climatic conditions

Climate change is anticipated to cause significant changes to the hydrological cycle. Logically climatic variables such as precipitation and temperature that have a strong control over the amount of groundwater recharge. Changes to these factors over the long term will affect groundwater recharge. Higher temperatures allows for increasing evaporation and decreasing in precipitation due to this it is a limiting factor on groundwater recharge. As it observed from figure 5.6 and 5.7 in the study area the general

pattern of temperature data shows overall increasing in temperature with time over the years thus favors increasing in evapotranspiration and in decreasing precipitation.

From the figure 5.14 as can be observed that there is slightly increasing pattern in long term mean annual precipitation over the considered stations and the catchment in the Koka area (Fig. 5.14). This may be inconsistency in the precipitation data of Koka in 1992 and 1993 but decreasing in recent annual precipitation over the considered stations and catchment (Fig. 5.15). Declining trends of recent precipitation was due to change in the climatic conditions such as increasing in temperature with time (Fig. 5.6) in the area and this affects ground water recharge in the study area.

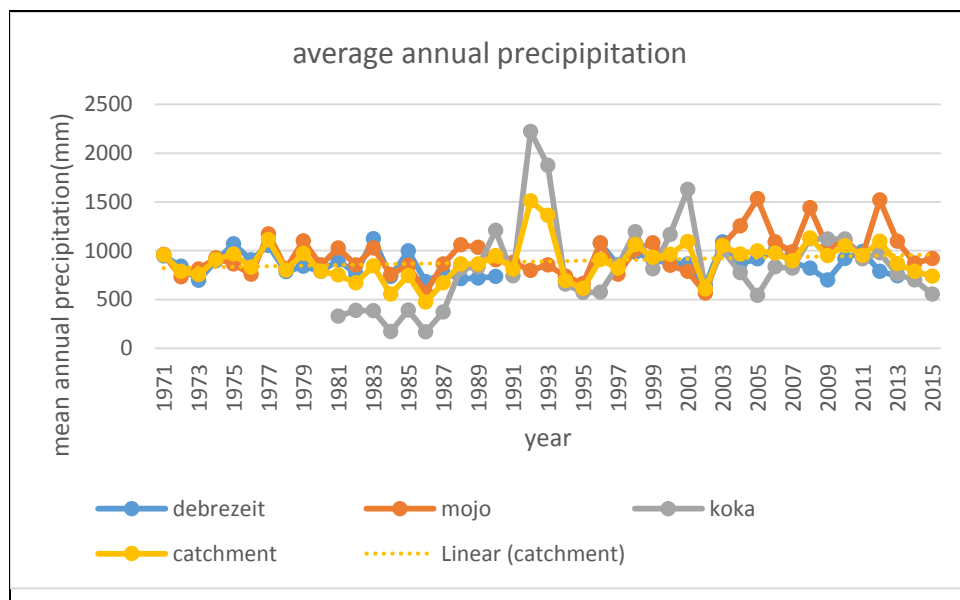


Figure 5.16 Long term trends of precipitation in Becho area

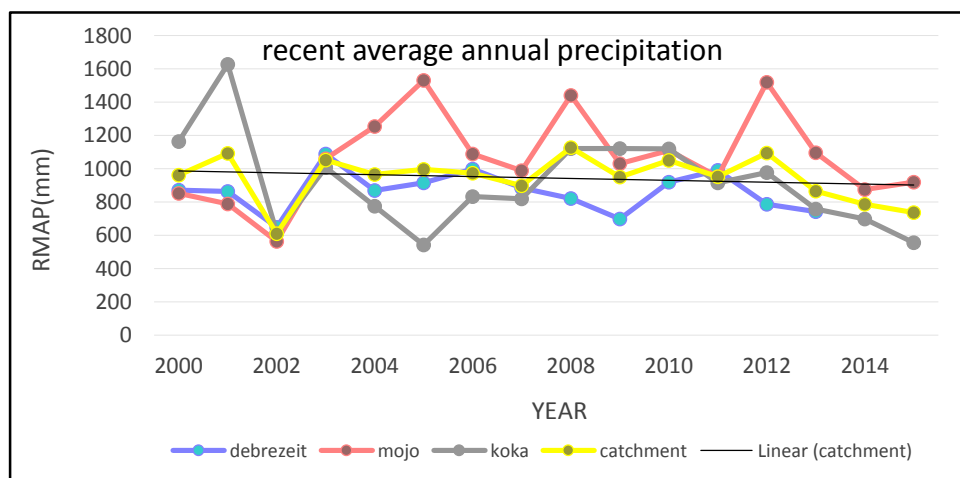


Figure 5.15 trends of recent mean annual precipitation in koka area

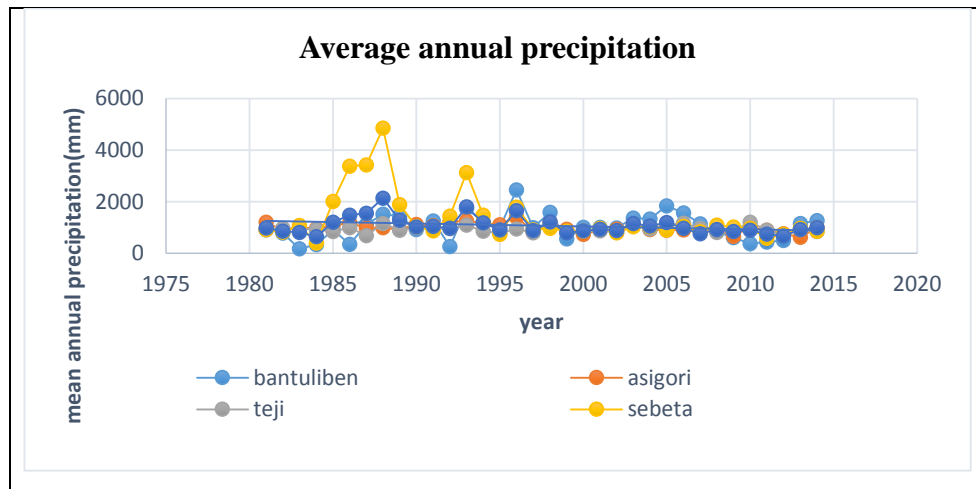


Figure 5.16 Long term trends of precipitation in Becho area

Figure 5.16 shows that that trends in precipitation is continuously declining. This due to change in long term and recent climatic conditions such as increasing in temperature with time (Fig. 5.7) in the catchment.

#### 5.4.2 Changes in evapotranspiration due to long term climatic conditions.

Evapotranspiration is one of the more consistent elements in the hydrological cycle. Change in climate of a given area will greatly affect the rate of evaporation from the surface and in turn brings hydrological imbalance. Change in evaporation of the study area was assessed using Penman combined, Thornthwaite and Turc method. Using this method, as can be observed from the (Fig. 5.17 and 5.18) Trends in ten years moving average evapotranspiration shows increasing with time in both area.

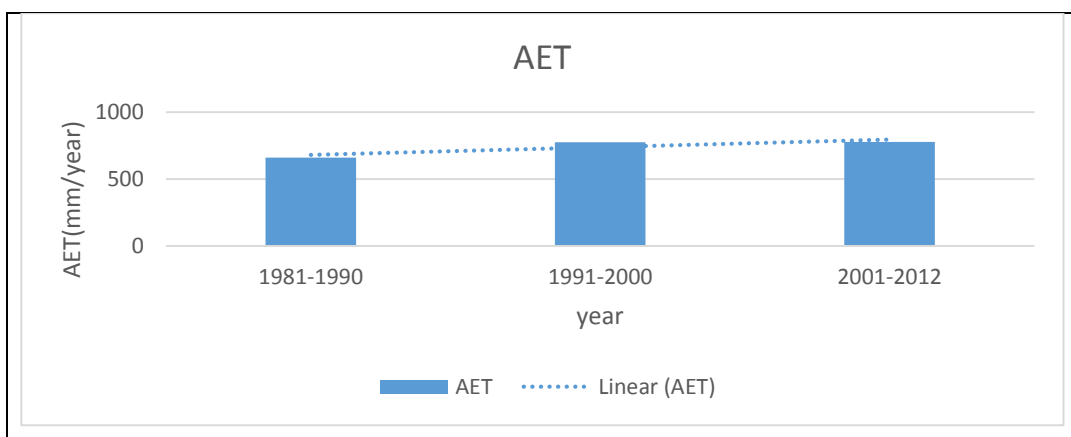


Figure 5.17 Trend in ten years moving average evapotranspiration in the Koka area

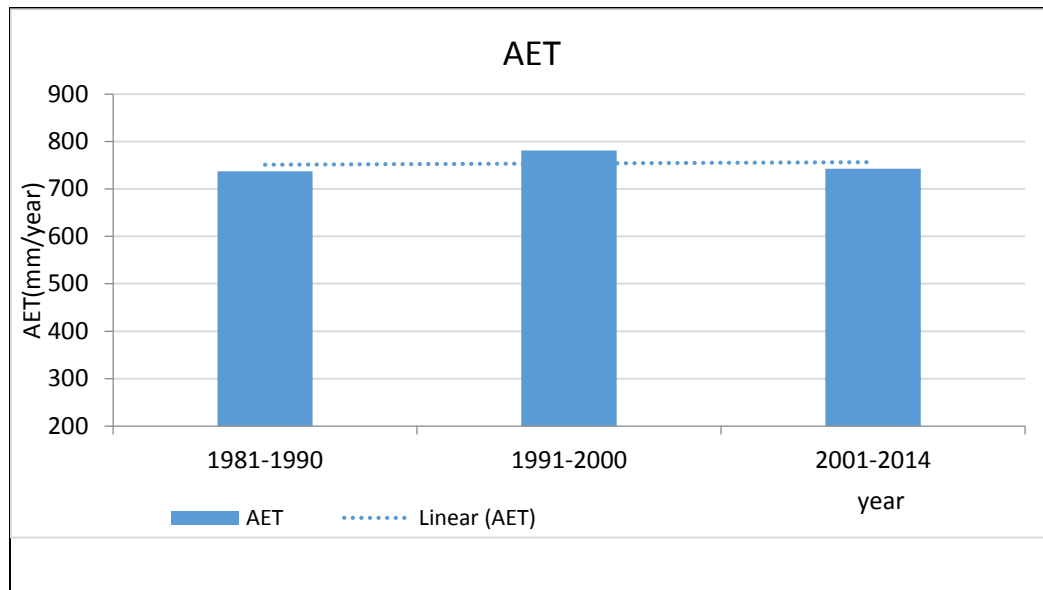


Figure 5.18 Trend in ten years moving average evapotranspiration in the becho area

#### 5.4.4 Change in Groundwater Recharge and River flow due to combined effects of climate and human activity

Recharge is controlled by weather, climate, soil, and land-cover characteristics. In addition, recharge also can be affected by human patterns of development and water use. Logically, it is the climatic variables such as precipitation and temperature that have a strong control over the amount of groundwater recharge. Changes to these factors over the long term will affect groundwater recharge (Reese and Riser, 2010).

Changes in groundwater recharge in the study area can be mainly resulted from spatial and temporal variability in rainfall, global climate change, deforestation, land degradation, and high population growth rate. The effect of land degradation in hydrology is manifested by increasing the rate of surface runoff and evaporation; and reducing infiltration and percolation to the subsurface.

Factors that affects amount of river flows are Intensity and duration of rainfall in the catchment, Amount of water lost from the catchment area, Size of catchment, Average height of catchment, Vegetation cover and Geology.

In recent years, scarcity of water has been widely recognized due to a growing population and its related purposes. Water in the watershed is basically imminent through runoff and stream flow. In some cases, the stream flow is seasonally available only on the basis of

precipitation and is sometimes dependent on the adequacy of groundwater recharge behavior. Groundwater recharge refers to the replenishment of an aquifer with water from the land surface which is usually expressed as an average rate of water per year, similar to precipitation (Sophocleous and Schloss, 2000).

Recently overall, surface water use in the study area is significantly affecting baseflow at the catchment scale. However, the potential for impact by individual water users is high, as local impacts on baseflow were noted in several areas. In particular koka area contain a number of surface water users whose local and cumulative impacts are considerable.

With regard to baseflow volumes and surface water use, the predictions of climate change are not encouraging. Ultimately, what feeds natural baseflow is groundwater recharge. If the groundwater balance is in a deficit (outflow > inflow) then aquifers and the related water table will lower. With a lowered water table there is a high potential for many first and second order streams to dry up as they are no longer hydrologically connected to the groundwater system. This deficit due to climate change can occur in a twofold manner (TRC, 2009). With rainfall patterns showing longer dry periods, water use would likely increase and extended dry periods would not allow recharge to occur, resulting in an increased strain on the baseflow system. Added to this are the short duration and high intensity rainfall events. In a rain event with these characteristics the majority of the precipitation runs off with a reduced potential for infiltration into the groundwater system.

Figure 5.19 shows that river and shallow groundwater use trends in Mojo and Koka area for irrigation purposes. As discussed in the sections 5.4.1 there is decline in precipitation figure 5.16, increase in precipitation and rise in evaporation trends (Fig.5.17and 5.18). Both of these characteristics have their own contribution to changes in recharge. Direct groundwater recharge of a given area is fixed ratio of precipitation and hence affected by its change while increase in evaporation affects the recharge by depleting soil moisture surplus of the area. Table 5.14 shows that summarized ten years average precipitation, annual flow rate, baseflow and surface runoff of Mojo, Awash River at Hombole, Bello and Teji River obtained from baseflow separation excel spreadsheet program. Figure 5.20 and 5.21 shows that long term trends of river flow and base flow of Awash River at Hombole, Mojo River, Teji River and Awash River at Bello.

Figure 5.21 (b) shows that baseflow of Mojo river catchment is sensitive to average area precipitation than Mojo rainfall. As can be seen from the (figure 5.21 b ) trend lines of the baseflow and average area precipitation(figure 5.14) they shows slightly similar trends during the considered period however ,when we see long term trends precipitation increases ,baseflow and river flow decrease . One might expect that with increasing precipitation, more water would be available for groundwater recharge, but the groundwater recharge (baseflow) is trending downward which confirms that a less percentage of the precipitation is reaching the saturated zones indicates that appearance of anthropogenic effects and changes in evapotranspiration (section 5.4.2) in the catchment. Increases in long term trend analysis of average area precipitation is may be due to inconsistency of data in (1992 and 1993). Table 5.14 shows that from 2003-2013 river flow and baseflow of Mojo river dramatic decreasing trends with decreasing precipitation indicates effects of both climate changes and intensive human activity exists recently such as Irrigation from river, groundwater abstraction from upstream.

From Figure5.20 (a) and 5.21(a) as can be observed river flow and baseflow of Awash River at Hombole over the past year shows slightly rising trend this due to increasing in precipitation. Therefore, one might expect that with increasing precipitation, more water would be available for groundwater recharge. When we observe ten years average precipitation, river flow and baseflow in (table 5.15) increasing from 1981-2000 and decreasing from 2001-2009 resulting from change in climate such as increasing temperature (figure 5.6), increasing evaporation (figure 5.17) and excessive human interferences in the area currently.

Figure 5.21(c) and table 5.15 shows that trends in baseflow of Teji River is declining annually when we consider linear moving average. This could be a potential reflection of combined effects of many factors including increased water withdrawal practices, increased impervious cover, decreasing in precipitation (figure 5.16) and increasing in temperature (figure5.7) in the catchment.

Figure 5.20 (d), and 5.21(d) and table 5.14 shows that there is a slightly decreasing trend in average area precipitation and an increasing trend in river flow and baseflow. In reality these opposing trends indicate that a larger percentage of the precipitation is reaching the saturated zone and the hydrology of the catchment not changed, a decrease in annual

precipitation would be expected to result in a lower baseflow and river flow. This evidence is however, weak because the relationship has much uncertainty because in the becho area recently there is a lot of human activity in the area which increased impervious land cover and surface water uses. Increasing in river flow and base flow of Awash River at Bello is might be flooding effects and from the data that I received from minister of water, irrigation and electricity (there is inconsistency).

Therefore currently, plenty of moveable capacity pumps are abstracting fresh water from the rivers and shallow groundwater by investors and private commercial farms throughout the year. Even during the rainy season's water demand of the crops is supplemented by irrigation due to high evapotranspiration and less precipitation to satisfy soil moisture .this indicates declining trend of groundwater recharge in recent years is attributed both to climate change and excessive human interferences in hydrologic cycle in the study area



Figure 5.19 River and shallow groundwater use trends in Mojo and Koka area.

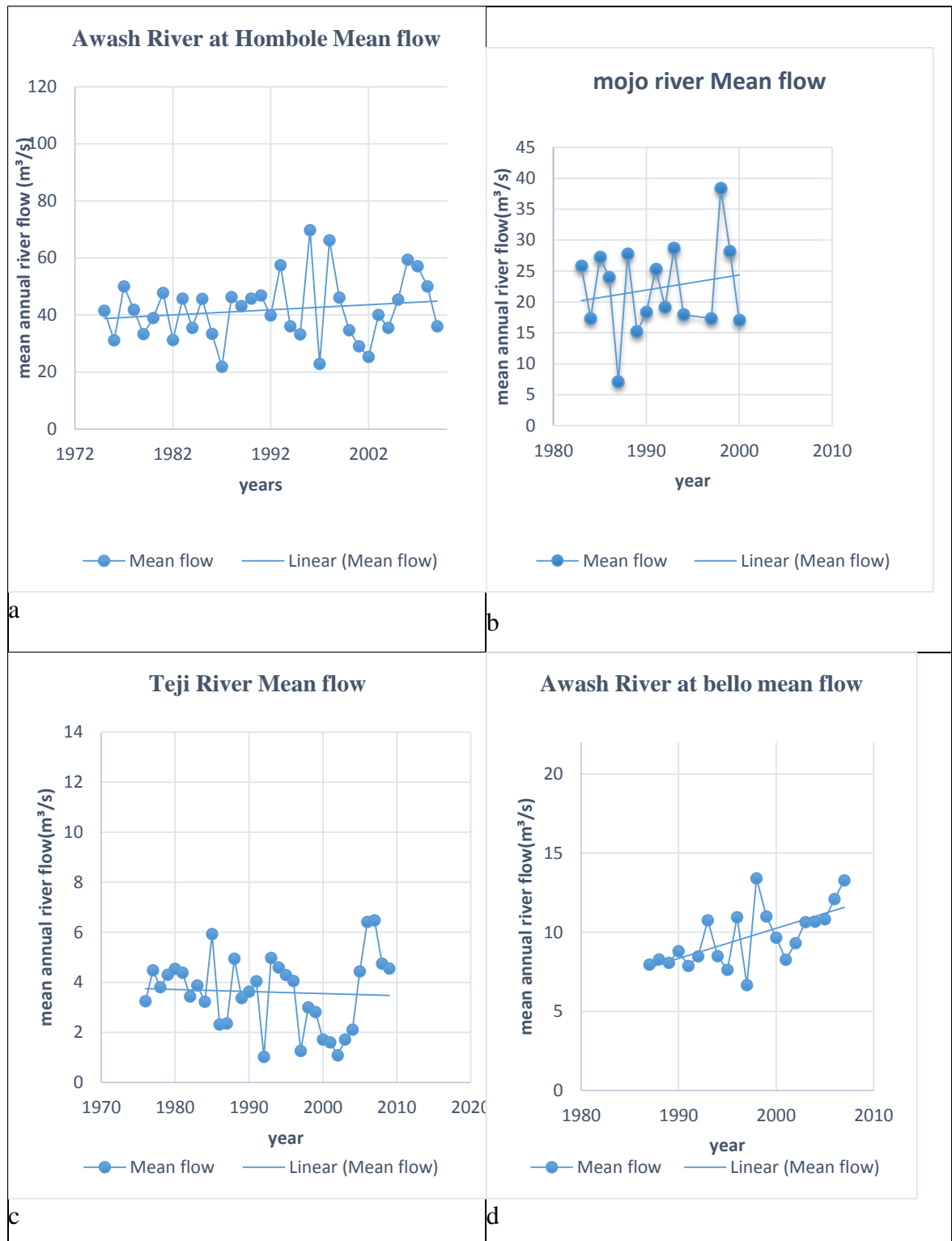


Figure 5.20 Trends in long term mean annual flow of: (a) Awash River at Hombole, (b) Mojo River, (c) Teji River and (d) Awash River at Bello

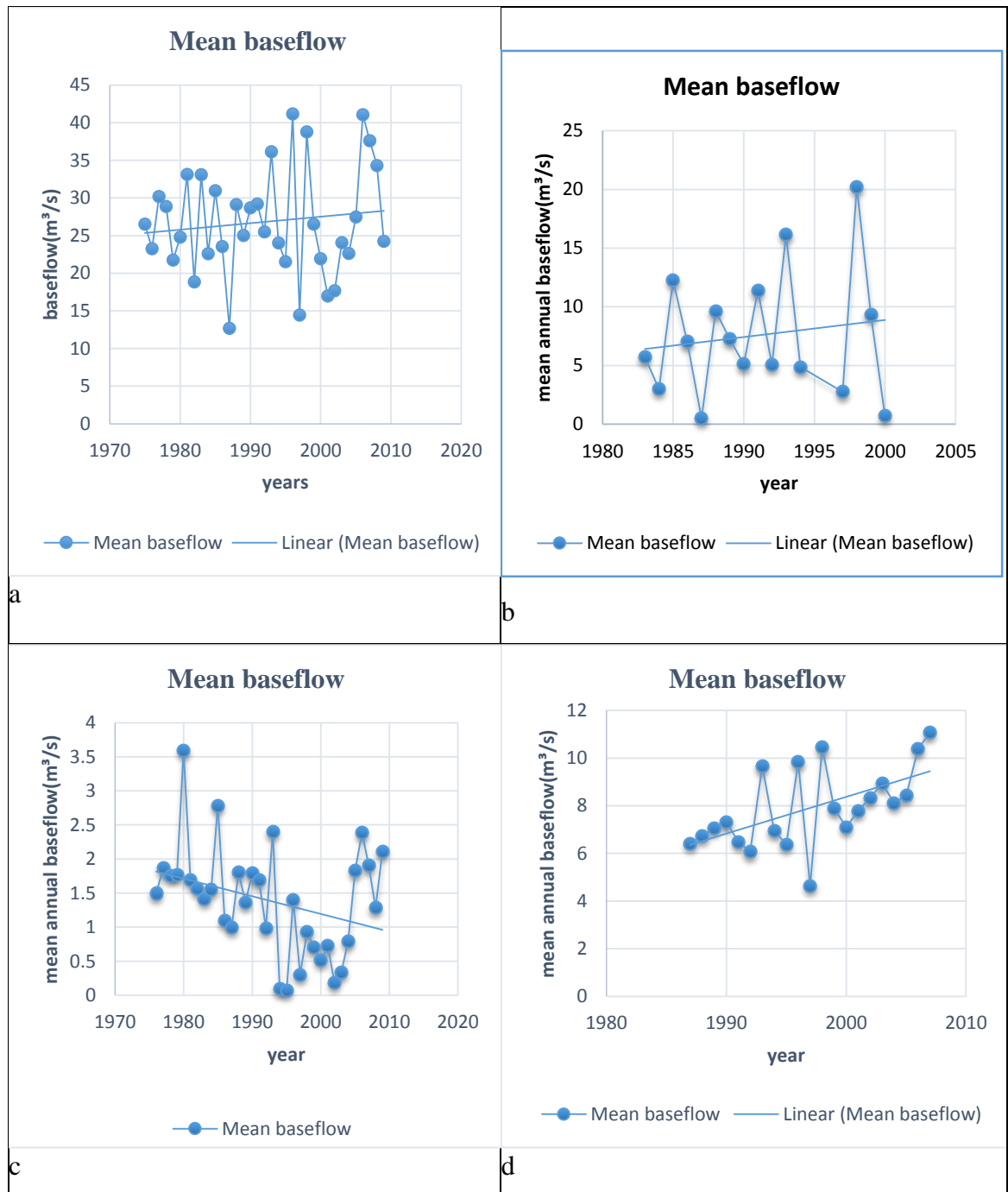


Figure 5.21 Trends in long term mean annual baseflow of: (a) Awash River at Hombole, (b) Mojo River, (c) Teji River and (d) Awash River at Bello

## Chapter 6. Conclusions and Recommendations

### 6.1 Conclusions

The studied Becho and Koka areas are found in the upper part of the Awash River Basin situated in Central Ethiopia, in Oromia Regional State. The elevation ranges from 1599 to 2998 m.a.s.l. Becho plain occupies a total area of about 1552 km<sup>2</sup>. While the total area of the Koka plain is 1461 km<sup>2</sup>. The area gets the highest rainfall from June to September. Due to large variations of altitude there is differences in rainfall from place to place. The maximum annual rainfall recorded is 1395 mm at Sebeta and the minimum record is 826.6 mm at Koka. The river flow and indirect recharge occurs during the rainy season.

The general objective of this study is to evaluate the temporal changes of groundwater recharges in the upper awash basin with particular emphasis to Becho and Koka areas. To achieve this objective the land-use and land cover, hydro-meteorology, hydrogeology and geology of the study area has been investigated.

The main rock units in the study area are ;Lacustrine cover and alluvial deposits, Ignimbrite, Quaternary Trachyte, Quaternary Rhyolite, Tulu Rie Basalt and Tarmaber basalts. These rocks are affected by different faults. There are many regional faults in the basin. The lacustrine sediments are compact and fairly welded tuff, ashes, silts, and clay. The alluvial deposits are consisting of sandy clay and silty clay with gravel at the lower bed with brown, red or black color and showing variation in thickness from place to place. The basalts range from fresh, dense and massive type to highly fractured, jointed or vesicular type. Ignimbrite range from massive, dense, and fresh to highly weathered and fractured. Quaternary Trachyte is grayish pink in color, coarse grained poorly fractured. Quaternary Rhyolite light brownish grey to white soft material and poorly fractured and weathered.

The main aquifer types in the study area are Quaternary alluvial and lacustrine deposits, Upper Basaltic and Lower Basaltic There are also Localized and regional aquicludes.

As part of the effort in estimating recharge the precipitation distribution has been assessed. The annual mean precipitation was analyzed by arithmetic mean using this method the average rainfall over the Becho and Koka areas is calculated to be 1130.5 and

878.5mm respectively. Analysis of potential evapotranspiration and actual evapotranspiration has been carried out using Thornthwaite, Penman and Turc methods. The result is found to be as summarized in the following table.

Area	Method	PET(mm)	AET(mm)
	Thornthwaite	941.13	742.6
Becho	Penman	1017.2	
	Turc		765.30
	Average	979.2	754
Koka	Thornthwaite	941.1	737.7
	Penman	-	
	Turc		742.6
	Average	941.1	740

The amount and distribution in time of river flow depends on precipitation, evapotranspiration, soil and geological characteristics of the catchments. Direct groundwater recharge was estimated using groundwater balance methods. The annual groundwater recharge of the Mojo River, Teji River, and Awash River at Hombole and Awash River at Bello were found to be 22, 284, 77.1 and 355mm respectively. The average aerial annual recharge of the Koka area is estimated to be 49.5 mm, which accounts about 5.6 % of the mean annual aerial precipitation of the area. The average aerial annual recharge of the Becho area is estimated to be 319.5 mm, which accounts about 28.3% of the mean annual aerial precipitation of the same area.

Climate change and human activity in the study area is anticipated to cause significant changes into the hydrological cycle. Changes in groundwater recharge in the study area can be mainly resulted from spatial and temporal variability in rainfall, global climate change, deforestation, land degradation, and high population growth rate. Long term trends of River flow and baseflow in the Mojo and Teji River show a decreasing trend and main Awash River at Hombole and Bello shows increasing trends. The recent trends it shows decreasing except Awash River at Bello. This is mainly due to the effects of climate such as presence of low rainfall, high evapotranspiration rate associated with increase in temperature and human activity such as intensive human activity exists recently such as Irrigation from river, groundwater abstraction from upstream.

## **6.2 Recommendations**

Baseflow separation method is a relatively easy method for estimating the groundwater recharge and provides information in long-term temporal changes in groundwater recharge. However it is not that much accurate. Therefore, Groundwater modeling study is recommended to estimate the more accurate temporal changes in groundwater recharge of the study area in order to identify groundwater recharge/discharge areas and those in need of protection from further development

Groundwater monitoring wells should be constructed to control the temporal groundwater Fluctuation of the area as well as to conduct further detail groundwater Flow modeling.

In order to decrease losses during irrigation, efficient irrigation techniques like drip irrigation should be employed especially by investors irrigating large area to minimize the excess water lost due to evaporation. Such technique can help to develop more area using the same amount of water.

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Appendix-1 Annual flow summary of study area

Year	MF	MBF	BFI	MF	MBF	BFI	MF	MBF	BFI	MF	MBF	BFI
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	41.5	26.5	0.6						
1976	6.3	2.4	0.4	31.1	23.3	0.7	3.2	1.5	0.5			
1977	7.4	2.4	0.3	50.0	30.2	0.6	4.5	1.9	0.4			
1978	5.2	1.5	0.3	41.9	28.9	0.7	3.8	1.8	0.5			
1979	4.8	2.7	0.6	33.3	21.8	0.7	4.3	1.8	0.4			
1980	4.2	1.6	0.4	39.0	24.8	0.6	4.5	3.6	0.8			
1981	No data			47.7	33.2	0.7	4.4	1.7	0.4			
1982	No data			31.3	18.8	0.6	3.4	1.6	0.5			
1983	25.8	9.5	0.4	45.8	33.1	0.7	3.9	1.4	0.4			
1984	17.3	2.9	0.2	35.5	22.6	0.6	3.2	1.5	0.5			
1985	27.3	14.1	0.5	45.7	31.0	0.7	5.9	2.8	0.5			
1986	24.0	5.0	0.2	33.4	23.6	0.7	2.3	1.1	0.5			
1987	7.1	0.5	0.1	21.9	12.7	0.6	2.4	1.0	0.4	8.0	6.4	0.8
1988	27.8	12.2	0.4	46.3	29.2	0.6	5.0	1.8	0.4	8.3	6.7	0.8
1989	15.2	7.4	0.5	43.1	25.0	0.6	3.4	1.4	0.4	8.1	7.1	0.9
1990	18.3	5.1	0.3	45.8	28.7	0.6	3.6	1.8	0.5	8.8	7.3	0.8
1991	25.3	7.3	0.3	46.8	29.2	0.6	4.1	1.7	0.4	7.9	6.5	0.8
1992	19.2	7.1	0.4	39.8	25.5	0.6	1.0	1.0	1.0	8.5	6.1	0.7
1993	28.7	16.2	0.6	57.5	36.2	0.6	5.0	2.4	0.5	10.8	9.7	0.9
1994	18.0	4.8	0.3	36.0	24.0	0.7	0.1	0.1	1.0	8.5	7.0	0.8
1995				33.2	21.5	0.6	0.1	0.1	1.0	7.6	6.4	0.8
1996				69.7	41.2	0.6	4.1	1.4	0.3	11.0	9.8	0.9
1997	17.3	0.7	0.0	22.9	14.5	0.6	1.3	0.3	0.2	6.7	4.6	0.7
1998	38.4	16.9	0.4	66.2	38.8	0.6	3.0	0.9	0.3	13.4	10.5	0.8
1999	28.1	10.4	0.4	46.1	26.5	0.6	2.8	0.7	0.3	11.0	7.9	0.7
2000	17.0	2.8	0.2	34.7	21.9	0.6	1.7	0.5	0.3	9.7	7.1	0.7
2001	6.2	1.8	0.3	29.1	17.0	0.6	1.6	0.7	0.5	8.3	7.8	0.9
2002	2.9	0.7	0.3	25.3	17.7	0.7	1.1	0.2	0.2	9.3	8.4	0.9
2003	7.8	1.7	0.2	40.0	24.1	0.6	1.7	0.3	0.2	10.7	8.9	0.8
2004	3.7	1.1	0.3	35.5	22.6	0.6	2.1	0.8	0.4	10.7	8.1	0.8
2005	4.8	1.5	0.3	45.4	27.5	0.6	4.4	1.8	0.4	10.8	8.4	0.8
2006	4.9	1.4	0.3	59.4	41.1	0.7	6.4	2.4	0.4	12.1	10.4	0.9
2007	7.0	2.1	0.3	57.1	37.6	0.7	6.5	1.9	0.3	13.3	11.1	0.8

2008	5.8	1.5	0.3	50.0	34.3	0.7	4.7	1.3	0.3			
2009	3.2	0.9	0.3	36.1	24.2	0.7	4.6	2.1	0.5			
2010	3.1	0.9	0.3									
2011	5.4	1.2	0.2									
2012	3.9	1.2	0.3									
2013	4.3	0.9	0.2									
mean	11.7	3.9	0.3	41.8	26.8	0.6	3.4	1.4	0.4	9.7	7.9	0.8

## Appendix-2 Meteorological Data

### Mean annual rainfall of the study area

Year	Koka area				Becho area				
	Debrezeit	Mojo	Koka	Mean	Bantuliben	Asigori	Teji	Sebeta	Mean
1971	946.6	963.8		955.2					
1972	842.3	731.9		787.1					
1973	697.2	811.6		754.4					
1974	895.7	925.6		910.6					
1975	1069.0	865.1		967.0					
1976	905.8	759.0		832.4					
1977	1055.0	1172.7		1113.9					
1978	786.6	817.8		802.2					
1979	841.7	1100.0		970.9					
1980	787.8	855.0		787.8					
1981	904.3	1027.0	328.1	753.1	917.7	1203.5	914.0	925.3	990.1
1982	765.2	855.0	389.3	669.8	781.8	885.4	974.4	821.7	865.8
1983	1122.7	1027.5	386.0	845.4	177.5	1006.5	960.4	1077.7	805.5
1984	735.1	756.0	172.2	554.4	334.2	962.5	919.9	400.4	654.3
1985	998.1	849.6	390.8	746.2	906.1	1084.1	844.1	2013.7	1212.0
1986	682.2	571.8	169.3	474.4	356.5	1188.6	998.6	3379.4	1480.8
1987	770.8	865.0	370.8	668.9	1115.6	989.6	685.3	3433.2	1555.9
1988	712.6	1061.5	818.9	864.3	1523.1	991.1	1152.8	4862.1	2132.3
1989	720.3	1033.6	833.0	862.3	1442.1	925.9	898.2	1884.0	1287.6
1990	735.3	908.0	1208.4	950.6	922.9	1115.9	990.8	1031.7	1015.3
1991		879.6	742.1	810.8	1254.5	1073.7	961.0	877.2	1041.6
1992		798.0	2222.6	1510.3	270.5	1224.8	962.0	1442.6	975.0
1993		855.1	1872.9	1364.0	1739.8	1255.8	1093.6	3131.1	1805.1
1994	685.5	740.1	656.1	693.9	1222.2	1169.9	866.1	1479.4	1184.4
1995	611.4	663.1	573.0	615.8	986.5	1111.3	786.8	739.1	905.9
1996	1077.4	1079.4	573.6	910.1	2467.2	1409.0	946.1	1790.2	1653.1
1997	854.4	760.3	852.2	822.3	998.3	848.7	794.7	908.9	887.7
1998	984.7	1011.2	1193.7	1063.2	1595.4	1197.8	1135.7	971.7	1225.2
1999	904.8	1078.8	814.6	932.7	556.9	928.4	833.8	860.9	795.0

2000	872.2	852.1	1164.7	963.0	1007.7	734.1	866.1	857.5	866.4
2001	864.5	788.1	1628.2	1093.6	1007.7	895.6	872.5	967.2	935.8
2002	648.3	564.3	615.6	609.4	984.2	932.9	811.1	793.9	880.5
2003	1089.3	1060.1	1007.5	1052.3	1363.8	1126.6	1082.0	1034.5	1151.7
2004	869.1	1254.5	776.4	966.7	1329.1	917.1	941.9	1030.6	1054.7
2005	915.3	1532.1	542.6	996.7	1843.1	900.9	1112.6	906.7	1190.8
2006	999.2	1089.5	833.0	973.9	1569.2	910.0	1170.2	1043.4	969.4
2007	884.7	989.4	819.7	897.9	1151.1	920.0	969.3	835.3	762.9
2008	821.0	1441.4	1122.1	1128.2	833.8	940.3	806.5	1092.6	918.3
2009	698.5	1032.1	1121.1	950.6	605.9	656.8	874.4	1020.0	850.4
2010	919.1	1110.4	1120.1	1049.9	378.0	1022.8	1202.8	967.0	892.7
2011	990.9	952.3	916.7	953.3	436.9	893.1	902.5	590.1	746.3
2012	787.9	1520.1	978.3	1095.4	495.8	763.3	711.9	736.7	676.9
2013	742.1	1096.4	758.4	865.6	1152.2	628.1	965.4	967.4	928.3
2014		875.1	698.7	786.9	1272.6	995.5	844.8	858.0	992.7
average	854.9	954.1	843.3	894.9	1029.4	994.4	936.8	1345.0	1067.4

Mean annual temperature of the study area

Year	Koka	Mojo	Debrezeit	Average	Asigori	Tulubolo	Average
1971			18.3				
1972			18.2				
1973			18.7				
1974			18.4				
1975			18.3				
1976			18.7				
1977			18.4				
1978			18.7				
1979			18.8				
1980			18.9				
1981			18.6		15.9		15.9
1982	26.3	21.0	18.6	22.0	15.8		15.8
1983	26.1	19.5	19.1	21.7	17.6		17.6
1984	25.5	20.4	18.8	21.6	16.9		16.9
1985	22.1	20.1	18.4	20.2	17.2		17.2
1986	21.3	19.2	18.7	19.7	17.2		17.2
1987	21.6	20.6	19.0	20.4	17.9		17.9
1988	21.8	20.4	18.9	20.4	18.0	15.6	16.8
1989	22.1	20.1	19.0	20.4	17.0	15.0	16.0
1990	23.0	20.0	19.1	20.7	17.7	14.4	16.0
1991	22.7	20.5	19.1	21.6	17.3	15.2	16.3
1992	22.7	20.4	19.1	21.6	17.5	16.1	16.8
1993	22.7	20.2	19.4	21.4	17.5	18.5	18.0

1994	21.9	20.2	19.1	20.4	18.0	18.5	18.2
1995	22.2	20.5	19.7	20.8	17.8	18.6	18.2
1996	21.3	20.1	19.2	20.2	18.0	17.4	17.7
1997	21.1	20.5	19.8	20.5	18.8	16.7	17.8
1998	20.9	20.5	19.9	20.4	17.1	16.6	16.8
1999	22.6	20.7	19.3	20.9	16.9	15.8	16.4
2000	23.2	20.2	19.4	20.9	16.9	15.1	16.0
2001	23.3	20.2	19.8	21.1	17.5	16.7	17.1
2002	21.8	20.3	20.6	20.9	18.5	18.0	18.3
2003	22.9	19.6	19.9	20.8	18.3	17.7	18.0
2004	22.2	19.4	18.5	20.0	18.3	17.7	18.0
2005	21.1	19.0	18.5	19.5	18.4	17.4	17.9
2006	22.6	19.8	18.8	20.4	18.2	17.7	18.0
2007	21.8	20.7	19.1	20.5	17.8	17.3	17.5
2008	21.9	20.0	18.5	20.1	18.2	17.5	17.8
2009	22.3	20.5	19.1	20.6	19.5	17.7	18.6
2010	22.0	20.4	18.8	20.4	19.9	18.1	19.0
2011	21.9	20.6	18.7	20.4	19.3	17.7	18.5
2012	22.2	20.1	17.8	20.1	19.3	18.1	18.7
2013	22.4	20.3		21.4	19.7	17.7	18.7
2014	22.9	20.6		21.8	18.8	17.6	18.2
	22.5	20.2	18.9	20.7	17.9	17.0	17.5