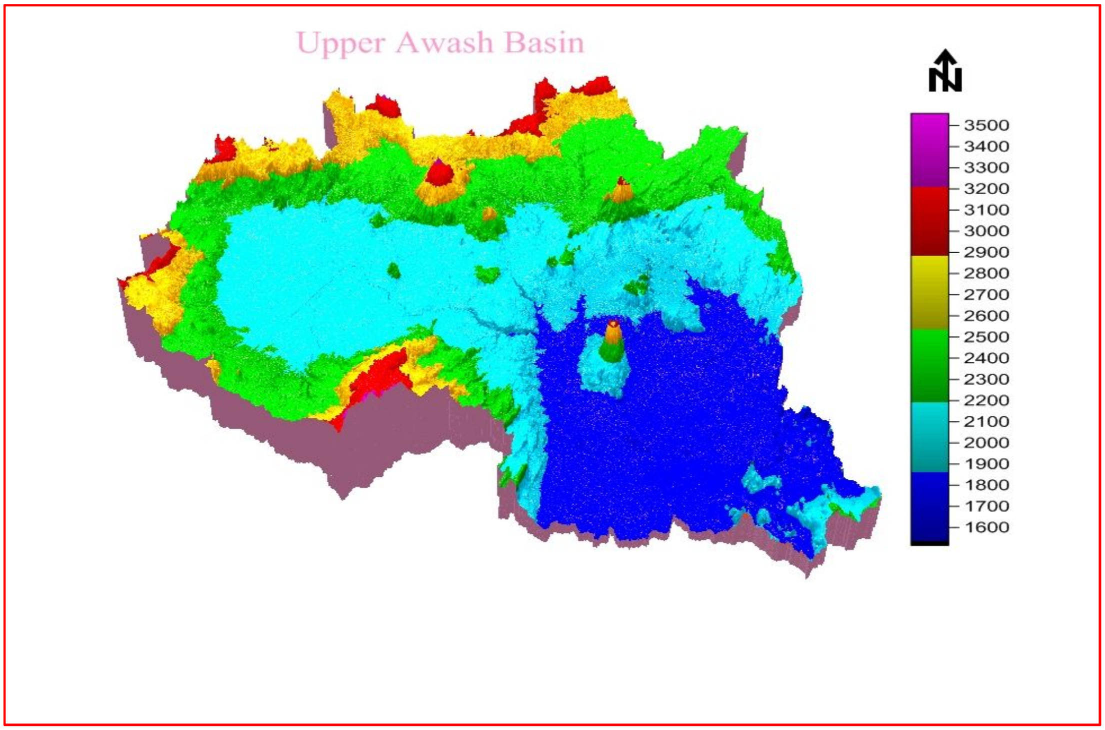
Addis Ababa University

School of Graduate studies

College of natural sciences

Groundwater recharge Estimation of Upper Awash Basin using WETSPASS Model



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

By

Tsegaye Amisew Zerefu

Advisor:

Dessie Nedaw (PhD)

June, 2019

Addis Ababa, Ethiopia

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Statement of the Author

By my signature below, I declare and confirm that this thesis is my own work. I have followed all ethical and technical principles of research to accomplish this thesis work. Any scholarly article that is included in the thesis has been given acknowledgment through reference.

Name: Tsegaye Amisew

Signature: ----------------

June, 2019

This thesis has been submitted for examination with approval form.

Name: Dr.Dessie Nedaw

Signature:______________

Date:__________________

Addis Ababa University

School of Graduate studies

School Of Earth Sciences

The present research study is conducted in the Upper Awash River Basin, Central Ethiopia Entitled as Groundwater Recharge Estimation of Upper Awash Basin Using WETSPASS model.

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Tsegaye Amisew Zerefu

Approved by the Examining Committee:

Dessie Nedaw (PhD)	______________	______________
(Advisor)	**Signature**	**Date**
Prof. Tenalem Ayenew	______________	______________
(Examiner)	**Signature**	**Date**
Dr. Seifu Kebede	______________	______________
(Examiner)	Signature	Date
____________________	______________	______________
Chair of School or graduate program coordinator	Signature	Date

Abstract

The Present research study is conducted in the upper awash basin which is located in central Ethiopia at the western margin of the main Ethiopian rift. Nowadays the consumption of water for the industrial, domestic and agricultural usage in the upper awash basin dominantly depends on Groundwater**.** Government organizations and several private companies are engaged in construction of deep wells in the study area due to increasing population. However there is no well-organized system to monitor and manage groundwater resource of the study area. Abstraction of groundwater in the study area is increasing without giving proper attention to important hydrogeological factors. One such factor is recharge. To use the groundwater without adversely affecting the groundwater table and the potentiometric level, the abstraction rate need to be proportional to the groundwater recharge. The main objective of this research is to estimate the ground water recharge and recommend the sustainable yield of the upper awash basin. To accomplish this thesis Wetspass model method is applied. Wetspass model is water and Energy transfer between soil, plants and atmosphere under quasi-steady state which is a physical based model for estimation of long term average spatial patterns of groundwater recharge, surface runoff, interception, soil evaporation and evapotranspiration from long term average meteorological data.

Mean monthly and annually recharge, actual Evapotranspiration and surface runoff was estimated using wetspass model by preparing grid maps with 200m cell size of land use, Ground water depth, soil, slope, topography and major meteorological parameters such as temperature, wind speed, rainfall and potential evapotranspiration. From the wetspass model output the mean annual recharge of upper awash basin is about 110mm which accounts about 11% of the total mean annual precipitation which means 1,292,280,000.00 m^3/year of water stored in the Upper Awash Basin. In addition to wetspass model baseflow separation method was applied to estimate the recharge of Upper Awash Basin which is about 95mm/year.

Mean annual actual evapotranspiration and Mean annual surface runoff of the study area is about 603mm and 310mm respectively which accounts 60% and 30% of the mean annual precipitation of the study area.

The sustainable yield of a certain area ranges from 10% to 70% of the groundwater recharge. For the upper awash basin the sustainable yield is assumed to be 40% of the mean annual recharge which is about 44mm/year.

Key words: - Abstraction Rate, Groundwater Recharge, Sustainable yield, Upper Awash Basin Wetspass Model

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Finally, I would like to thanks to my heartfelt wife Asegedech Atrsaw for her all support and my lovely boys Robel and Yared for their patience during my thesis work. This thesis work is dedicated to my late father Amisew Zerefu.

Acronyms

AAWSA	**Addis Ababa Water and Sewerage Authority**
asl	**Above sea level**
Adbch	**Adaa Becho**
ECDSWC	**Ethiopian Construction Design and Supervision Works Corporation**
FAO	**Food Aid Organization**
GPPT	**Global Precipitation**
LLA –PW	**Legedadi Legetafo Ayat Production Well**
l/s	**Liter per Second**
m	**meter**
mm	**mili meter**
m^3/day	**Cubic meter per day**
m^3/year	**Cubic meter per year**
m^3/s	**Cubic meter per second**
MPPT	**Meteorological Precipitation**
NMA	**National Meteorological Agency**
NPPT	**New loc clime precipitation**
PET	**Potential Evapotranspiration**
PETM	**Potential Evapotranspiration of Pennman Monteith**
PETN	**Potential Evapotranspiration of New Loc Clime**
SANF-PW	**South Ayat North Fenta Production Well**
S.N	**Serial Number**
ST	**Sebeta Tefki**

So **Soil**

SWL **Static Water Level**

UAB **Upper Awash Basin**

USGS **United States Geological Survey**

UTME **Universal Transverse Mercator Easting**

UTMN **Universal Transverse Mercator Northing**

Wetspass **Water and Energy Transfer through soils and plants under a quasi steady state**

WEDSWS **Water Works Design and Supervision Works Sector**

WF **Well Field**

WWDSE **Water Works Design and Supervision Enterprise**

ZGW **Elevation of Groundwater**

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CHAPTER ONE

INTRODUCTION

1.1 Background

This thesis research is Groundwater recharge estimation of the upper awash basin using wetspass modeling method. The budget of this research is covered by the project entitled Sound Groundwater Management under a Changing Climate for the Upper Awash Basin (UAB) Using Isotope Enabled Water Balance Modeling through Addis Ababa University, collage of natural sciences, hydrogeology stream. The recharge amount of this research will be an input of the above mentioned project. Estimating of groundwater recharge of a certain area is used to manage the abstraction rate, groundwater system and well field's water resources for that area. The Upper Awash basin is located in the central highlands of Ethiopia with the altitude that ranges from 1510 m.a.s.l to 3560 m.a.s.l at the western margin of the Main Ethiopian Rift. The area is highly affected by geological structures and it has different geological formations with different ages.

Groundwater is a vital resource in steadily increasing demand by human. In history of water use in the country in general in Addis Ababa in particular, groundwater is one of the major resource supplies for domestic, industrial and agricultural consumption. The groundwater of Upper awash basin is highly abstracted until now by different stakeholders without understanding the effect of different factors such as recharge, climate change, abstraction rate, Geology of the area, Hydro geological system, Geological structures/setting, recovery time and different contaminants.

Recharge is one of the most important components in hydro geological characterization of aquifer systems and the major objectives in hydro-meteorological studies it is the process of the vertical downward entry of water from rainfall into the subsurface and joins the groundwater table through the water bearing geological formation. Nowadays the abstraction rate of groundwater of upper awash basin is increased in alarming rate from time to time and the usage of surface water relatively decreased. Surrounding the city of Addis Ababa and within the Addis Ababa city, Upper Awash groundwater basin supports about 60% of domestic water supply of the city and it is becoming major source for domestic and industrial uses in the region **(Behailu et al., 2017)**. Almost all the towns and rural villages surrounding

Addis Ababa within 100 km radius in addition to the capital city of Ethiopia use this groundwater for their domestic water supply source (**Behailu et al., 2017**).

Currently the groundwater of upper awash basin supports about 60% of the total water supply system of Addis Ababa city. After installation of the drilled deep wells at the suburbs of Addis Ababa into the water supply system the contribution of Groundwater will increased to about 70 % of the total volume of water in the city.

To use the groundwater without adversely affecting the groundwater table and the potentiometric level, the abstraction rate need to be proportional to the groundwater recharge to this end estimation of groundwater recharge using different modeling methods. Groundwater recharge of Upper Awash basin is estimated by using different methods with different researchers, but the result shows greater variations because commonly groundwater recharge is determined to a large extent as an imbalance at the land surface between precipitation and evaporative demand (Gebreryfael, 2008, as cited in Teklebirhan Arefaine et al.,2015). The results are varying from 47mm/year to 238mm/year. Those researchers use Water balance, Base flow separation, chloride mass balance technique and hydrous 1D model. In addition to the above methods Wetspass modeling is one type of Groundwater recharge estimation GIS based method. So Wetspass modeling used for recharge estimation upper awash basin by using major meteorological data from new loc clime software by comparing the meteorological data of Ethiopian National Meteorological Agency and Global weather data generator sources. The new loc clime and Ethiopian meteorological data are almost all similar.

Wetspass model is water and Energy transfer between soil, plants and atmosphere under quasi-steady state which is a physical based model for estimation of long term average spatial patterns of groundwater recharge, surface runoff, interception, soil evaporation and evapotranspiration from long term average meteorological data(Batelaan and De Smedt, 2001, 2007,as cited in Teklebirhan Arefaine et.al, 2015) . By applying the wetspass model the recharge, runoff and actual evapotranspiration of upper awash is estimated as 110mm/year, 310mm/year and 603mm/year respectively. Based on the result 11% of the annual precipitation is percolated into the subsurface water table as a Groundwater recharge. The safe yield of upper awash basin is 44mm/year which is 40% of the annual recharge to use the groundwater in sustainable manner.

This research will give insight for understanding of the behavior of ground water system of the study area such as recharge amount, Groundwater flow system, sustainable yield, abstracted amount of water from the basin which are very essential for future water resources management of the catchment.

1.2 statement of the problem

Due to Immigration from rural to urban center and high birth rate, the population of cities increased at alarming rate. The increasing of urban population affects the water supply system of the area. To solve the shortage of water supply, government and private sectors drilled several deep boreholes in the study area. However there is no well-organized system to monitor and manage groundwater resource of the upper Awash River basin.

The consumption of water for the industrial, domestic and agricultural usage in the upper awash basin dominantly depends on Groundwater and usage of surface water is minimized. The consumption of the groundwater is not based on understanding of groundwater recharge effect and groundwater management. Simply Every user extracts the groundwater without understanding the impact of abstraction rate and the effect of climate change. Abstraction of groundwater without groundwater management, highly affect the groundwater table and potentiometric level. According to (Tenalem et al., 2008) increasing in pumping rate results in substantial regional groundwater level decline, which will lead to the drying of springs and shallow hand dug wells. For example in Akaki well field before five years the static water level was 40-60m below ground surface and now it lowered to 100-115m from monitoring data of AAWSA water wells. Especially in Addis Ababa city the population is grown in alarming rate from time to time and the government utility unit focuses on providing more supply from groundwater to fulfill the demand of the population , but it does not consider how over abstraction rate affect the groundwater table and groundwater recharge .

Some research papers reviewed that estimate groundwater recharge of upper awash basin and the result shows greater variation and water level of well fields at Addis Ababa city and its suburbs show lowering trend from monitoring data.

The recharge of Upper Awash basin is estimated by using different methods but not estimated by using Wetspass model. Therefore this research is intended to estimate the recharge of Upper Awash Basin using wetspass model.

1.3 Objectives

1.3.1 General Objective

The general objective of this research is to estimate the groundwater recharge of the Upper Awash Basin using wetspass model and recommend the sustainable yield of the study area.

1.3.2 Specific Objectives

- To identify recharge and discharge Zones of the study area
- To check the abstraction rate is whether balanced or not with the recharge from the inventory well data
- To determine the sustainable yield of Upper Awash Basin

1.4 Significance of the research

After estimating the amount of recharge at Upper Awash Basin, the result helps us to manage the ground water of well fields and to balance the demand and supply at the study area. In addition to ground water resources management, this paper will help for other researchers for reference. Some significances of this research are listed below.

- More experienced counterpart institutes able to independently conduct assessments of abstraction rate impacts on water resources using wetspas model.
- Enhanced interaction between wetspass experts and water management agents.
- Stakeholders will use groundwater with understanding of sustainable yield of the area.
- Government water offices will monitor and manage well fields for future utilization of groundwater.

1.5 Structure of the thesis

The structure of the thesis is classified into six chapters and organized from chapter one to chapter six. Each chapter discussed turn by turn from introduction to conclusion and recommendations. Under the introduction part background of the study area, objectives of the research and significance of the study described. Under chapter two previously conducted research studies reviewed in the study area and relevant researches related to the study. Next to chapter two chapter three is followed which is the methodology of the study identified. Description of the study area is described under chapter four. The major contents which described under chapter four are location of the study area, climate, drainage, physiography, Geology and Hydrogeology of the study area, Soil types and land use land cover condition of the study area. The results and discussions of the research discussed in chapter five. In this chapter estimation of groundwater recharge, Annual evapotranspiration and surface runoff conducted by applying wetspass modeling method for the study area. Finally, chapter six is set for conclusion and recommendation. Under this chapter the results of the study concluded and recommendations followed.

CHAPTER TWO

LITERATURE REVIEWS

A number of studies conducted at upper Awash River basin. These research studies conducted on recharge estimation, Aquifer characterization, Geological and Hydro geological mapping and other different researches. Previously estimated amount of upper awash basin groundwater recharge ranging from 47 mm/year to 238 mm/year. In addition to the research studies which conducted at upper awash basin, there are a number of studies conducted and reviewed below out of the upper awash basin in related to research titles using wetspass modeling method. The recharge amount of Upper Awash basin is estimated as 131mm/year using water balance method, 135mm/year using chloride mass balance method, 91.25mm/year using base flow separation and 157 using Hydrous 1D mode Therefore the recharge estimates using different techniques based on surface water and unsaturated zone data provide estimates of potential recharge ranging from 91 mm/year to 157 mm/year for the Upper Awash (Behailu et al., 2017).

Tilahun Azagegn (2014):-identified that the recharge amount of upper awash basin is different with different methods. The recharge is 82.5mm/year using water balance method, 135mm/year using chloride mass balance method and 103mm/year using base flow separation method.

Abel Abebe (2017) estimated the recharge of Upper Awash basin by applying water balance method and base flow separation technique on his MSC thesis research. He estimated that the recharge of Upper Awash basin is 130mm/year and 238mm/year by using base flow separation and water balance method respectively.

Andarge Yitbarek (2009) evaluates the recharge of Upper Awash basin using groundwater table fluctuation method which is 90mm/year.

WWDSE, 2008 Estimated that the recharge amount of upper awash basin is 47mm/year using water balance method stated by Andarge yitbarek (2009).

Teklebirhan Arefaine et al., 2015 by applying wetspass modeling method estimated that the Recharge, Evapotranspiration and Surface Runoff in illala catchment, Northern Ethiopia.

Tesfamichael Tewolde, 2009 estimated that the Recharge, annual evapotranspiration and surface runoff for the Geba basin, Northern Ethiopia using wetspass modeling.

Andarge Yitbarek (2009) identified that 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 belong to the basaltic volcanic.

Geological and geophysical investigations have clearly indicated the distinctive geometric architecture of the litho-strata of aquifers and aquicludes in the sub-basins. Such a unique geometry is strongly dependent on the interplay between the tectonic zones defined by the Yerer Tulu Wolel Volcanic Lineament zone and the Main Ethiopian Rift margin. The regional fault systems dislocated sedimentary rock units and resulted in fragmentation of sedimentary aquifer systems and forms structural depressions and adjoining highs prior to the formation of the volcanic rock units. The horsts defined by the NW-SE trending fault system together with adjoining highs define the groundwater divide and aquifer distribution within the Middle Blue Nile basin into Guder, Muger and Jema groundwater sub-basins. The E-W trending mudstone caped horst defines aquifer distribution between the Middle Blue Nile and the Upper Awash basin. This impermeable mudstone caped horst located across the middle of the Muger sub-basin and extending to the southern tip of the Jema sub-basin forms a barrier to the regional groundwater flow in volcanic aquifers. The barrier channels the regional groundwater flow in volcanic aquifers to its either side to the north and south. In this manner, significant portion of the Muger sub-basin (1770 km2) and small part of the Jema sub-basin (304km2) contribute to recharge the volcanic aquifer of the Upper Awash basin (Tilahun Azagegn, 2014).

Tenalem et al., 2008 conclude that increase in pumping rate results in substantial regional groundwater level decline, which will lead to the drying of springs and shallow hand dug wells using 3D steady-state finite difference groundwater flow model in the Akaki catchment. Kebede et al., 2008 States that the disruption of lithologies by cross-cutting faults and the variability in volcanic structures make the hydrogeology of the rifted volcanic terrain in Ethiopia very complex. Along the selected transects the Aquifer Characteristics, groundwater conditions and topographic features identified in Ethiopian Rift. The identified Aquifers are mainly basaltic, ignimbrite, scoracious basalts and rhyolitic aquifers.

The recharge amount of Upper Awash basin is estimated by different methods and different researchers as shown below in the table.

S.N	Researcher	Annual Recharge, mm	Method of Estimation	Year
1.	WWDSE	47	Water Balance	2008
2.	Andarge Yitbarek	90	Groundwater Table Fluctuation	2009
3.	Tilahun Azagegn	82.5	Water Balance	2014
4.	Tilahun Azagegn	135	Chloride Mass Balance	2014
5.	Tilahun Azagegn	103	Base flow Separation	2014
5.	Behailu et al.	131	Water Balance	2017
6.	Behailu et al.	135	Chloride mass Balance	2017
7.	Behailu et al.	91.25	Base flow separation	2017
8.	Behailu et al.	157.7	Hydrous 1D	2017
9.	Abel Abebe	130	Base flow Separation	2017
10.	Abel Abebe	238	Water Balance	2017

Table 1: Previous Recharge amount of upper awash using different methods

CHAPTER THREE

METHODOLOGY

3.1 DESK STUDY

To accomplish this research I used the following procedures under this phase.

3.1.1 Review of Existing Literatures, Reports and Maps

Geological and hydrogeological map of Ethiopia and associated reports were reviewed to understand the regional geological and hydrogeological offsetting of the Upper Awash Basin. Land use, soil and topography map of Ethiopia were collected to prepare inputs for wetspass model in addition to thesis and research papers which conducted in the study area and elsewhere on the relevant research study.

3.1.2 Data Collection and organization

The necessary data for this thesis work were collected from different governmental and nongovernmental organizations. Different research papers, Groundwater wells data, Monitoring data of well fields, Completion reports and necessary software for the completion of this research collected and organized from Ethiopian Construction Design and Supervision Works Corporation (Former WWDSE). From Addis Ababa university different research papers and thesis materials were collected. Regional geology collected from Ethiopian Geological survey. Different river gauge stations data and major meteorological parameters collected from Ministry of water and Energy and Ethiopian National Meteorological Agency respectively. The meteorological data which collected from Ethiopian meteorological agency are rainfall, Relative humidity, Sunshine Hours, Temperature and wind speed. However the data which collected from National meteorology agency are not fully measured. On the other hand the meteorological parameters collected from Global Weather Data generator and Online New loc clime software. By Comparing these three data sources using graph, new loc clime software data was selected to prepare inputs for wetspass model because the data from Ethiopian meteorological agency does not measure all meteorological parameters a lot of missing data and the data from Global Weather Data Generator is under estimated. Websites also play a great significance to get published thesis papers and books.

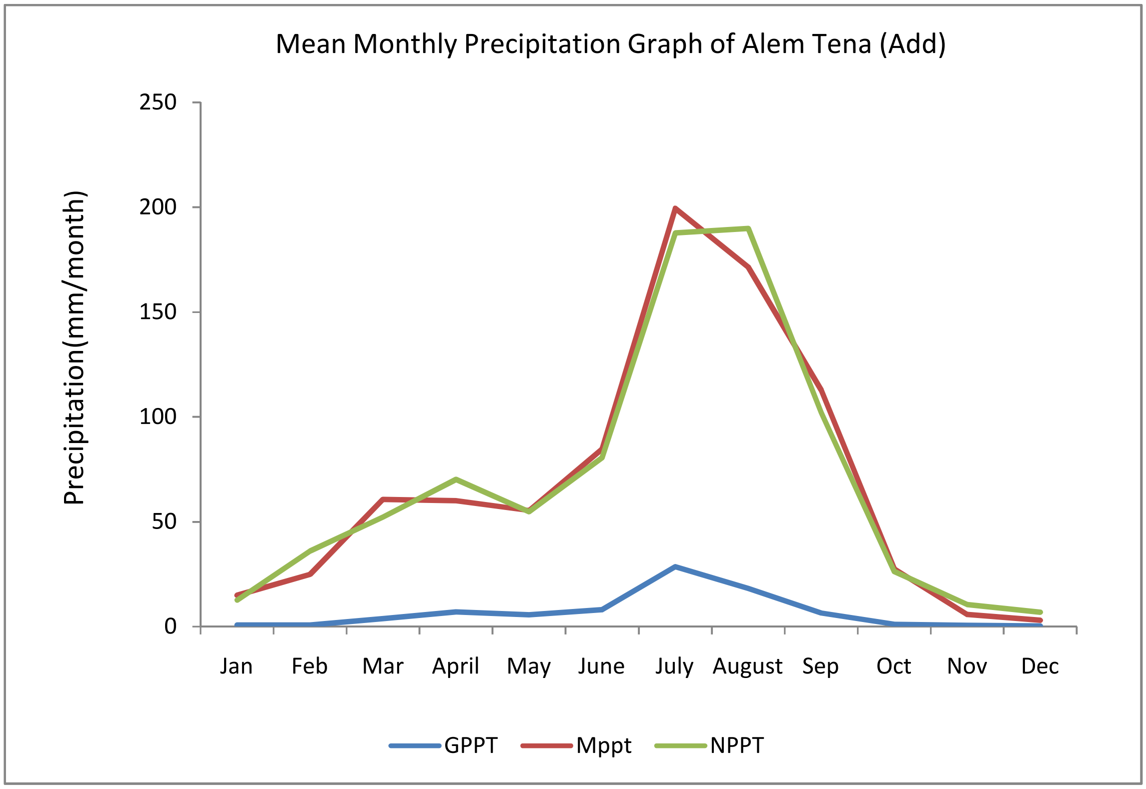


Figure 1:Precipitation graph of Alem Tena(Add)

3.2 FIELD WORK

In this stage, field work was conducted from 02/03/2019 to 08/03/2019 to collect soil samples for laboratory analysis test. During field work sixteenth soil samples were collected based on soil type, area coverage of soil type, land use land cover and geology of the study area. In addition to collection of soil samples, land use and the outcropped geology in the study area also identified and in-situ measurements like (WL, PH, EC, and T) measured for groundwater, lakes and rivers in the study area. The soils samples locations/sites are proportionally distributed all over the study area and they were collected by digging pits until we get fresh soils by removing the weathered soils. The collected soil samples were analyzed in Ethiopian construction design and supervision works corporation laboratory sector. The field work was delineated by using GIS and GPS and the location of soil samples in the study area shown below in the map and table.

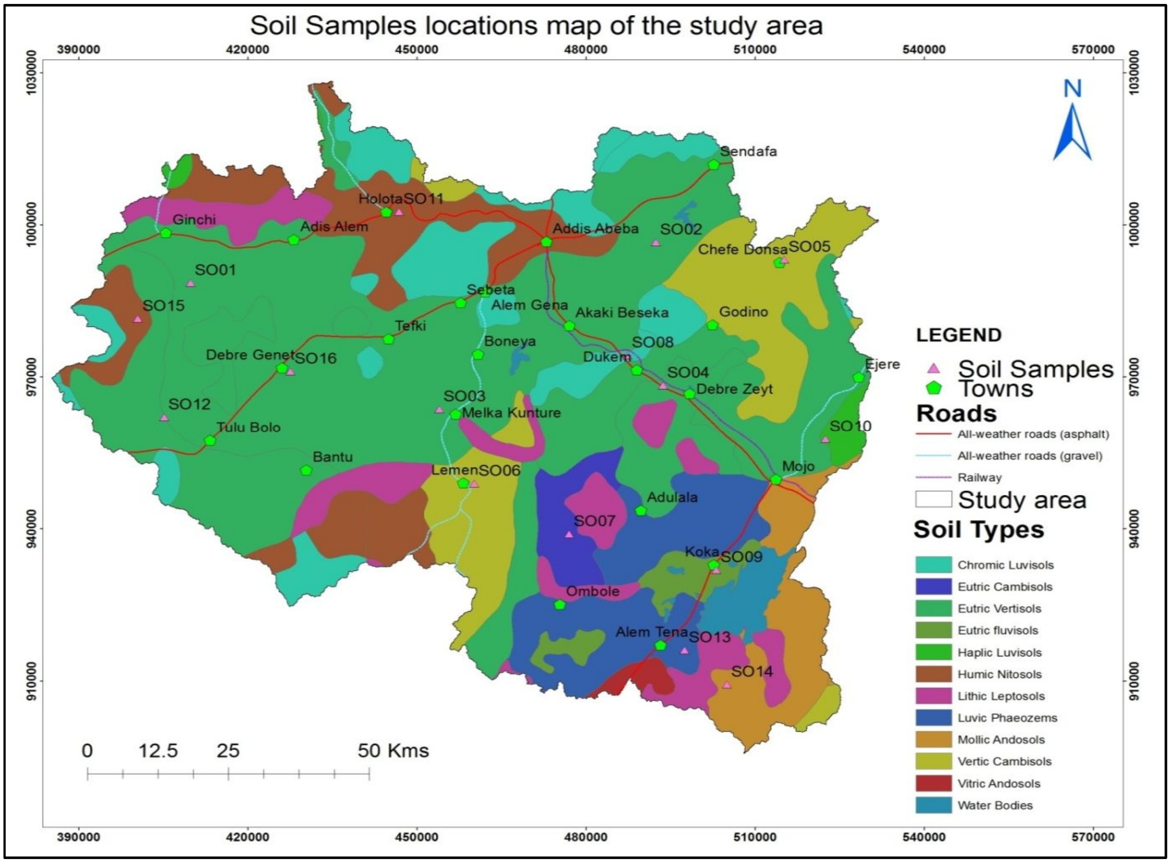


Figure 2: soil samples location map

S. N	Sample ID	UTME	UTMN	Elevation ,mm	Zone	Woreda	Kebele	Collection date
1	SO-01	410049	988521	2133	W/Shoa	Dendi	Lukluka	8/3/2019
2	SO-02	490884	997336	2415	Special Zone	Legetafo	Landfill	5/3/2019
3	SO-03	453993	963653	2021	W/Shoa	Sebeta Awas	Balchi jimjima	6/3/2019
4	SO-04	493677	968315	1914	E/shoa	Adaa	Bishoftu-01	3/3/2019
5	SO-05	515183	993193	2393	E/shoa	Gimbrian	Chefedonsa	5/3/2019
6	SO-06	460202	948895	2108	Special Zone	Lemen	Mazorya golba	6/3/2019
7	SO-07	477044	938910	1812	E/shoa	Libel chiko	Agemza Arogicha	3/3/2019
8	SO-08	487426	974275	2016	E/shoa	Dukem	Mendelo	3/3/2019
9	SO-09	503112	931847	1596	E/shoa	Lume	Qoka	2/3/2019
10	SO-10	522527	957709	2032	E/shoa	Lume	Kara Finchawa	3/3/2019
11	SO-11	446826	1002584	2399	W/shoa	Ana wolmera	Sademo	4/3/2019
12	SO-12	405176	962079	2229	SW/shoa	Dawo	Nano gebrele	7/3/2019

13	SO-13	497495	916113	1664	E/shoa	Bora	Tube Sutl	2/3/2019
14	SO-14	505105	909576	1656	E/shoa	Bora	Betie dabi	2/3/2019
15	SO-15	400524	981465	2482	W/shoa	Dendi	Faji Borele	4/3/2019
16	SO-16	427280	971042	2083	SW/shoa	Elu	Weserbi besi	7/3/2019

Table 2: Soil Samples With Locations

Plate 1:Soil sampling Photo

3.2.1Materials and tools

The materials and tools used to complete this thesis both in office and field work are the following: -

- High capacity computer for data storage ,synthesis and manipulation
- Light field vehicle for field work during data collection
- Garmin GPS; to determine the position of soil and water samples in the catchment
- Deep Meter; to measure the depth of water level
- Digging materials such as Sprinkle, pick axe

3.3 POST FIELD WORK

At this stage two methods are applied to accomplish the research. These methods are Wetspass modeling and Base flow separation methods. Wetspass model is water and Energy transfer between soil, plants and atmosphere under quasi-steady state which is a physical based model for estimation of long term average spatial patterns of groundwater recharge, surface runoff, interception, soil evaporation and evapotranspiration from long term average meteorological data (Batelaan and De Smedt, 2001, 2007,as cited in Teklebirhan Arefaine et.al, 2015). This model needs two types of inputs which are grid maps and parameter tables summarized in figure 3. Grid maps topography map, slope map, GW depth, Soil map, land use land cover map and major meteorological maps like rainfall, wind speed, temperature and potential evapotranspiration which prepared using GIS applications after organization of meteorological data using Excel sheets. The other inputs are parameter tables which are land use table, Soil table, Vegetation runoff coefficients, bare land runoff coefficients and impervious runoff coefficients. Inline of organization of meteorological data using excel sheet, soil samples textural classification test was conducted in the Ethiopian construction design and supervision works corporation laboratory service sector. At the end of soil laboratory test, soil samples texture interpreted and classified. After preparation of input parameters, WetSpass model method was applied for estimation of groundwater recharge, surface runoff and actual evapotranspiration of the study area. Generally the methodology that followed to accomplish this research is summarized in the flow chart below in figure 3.

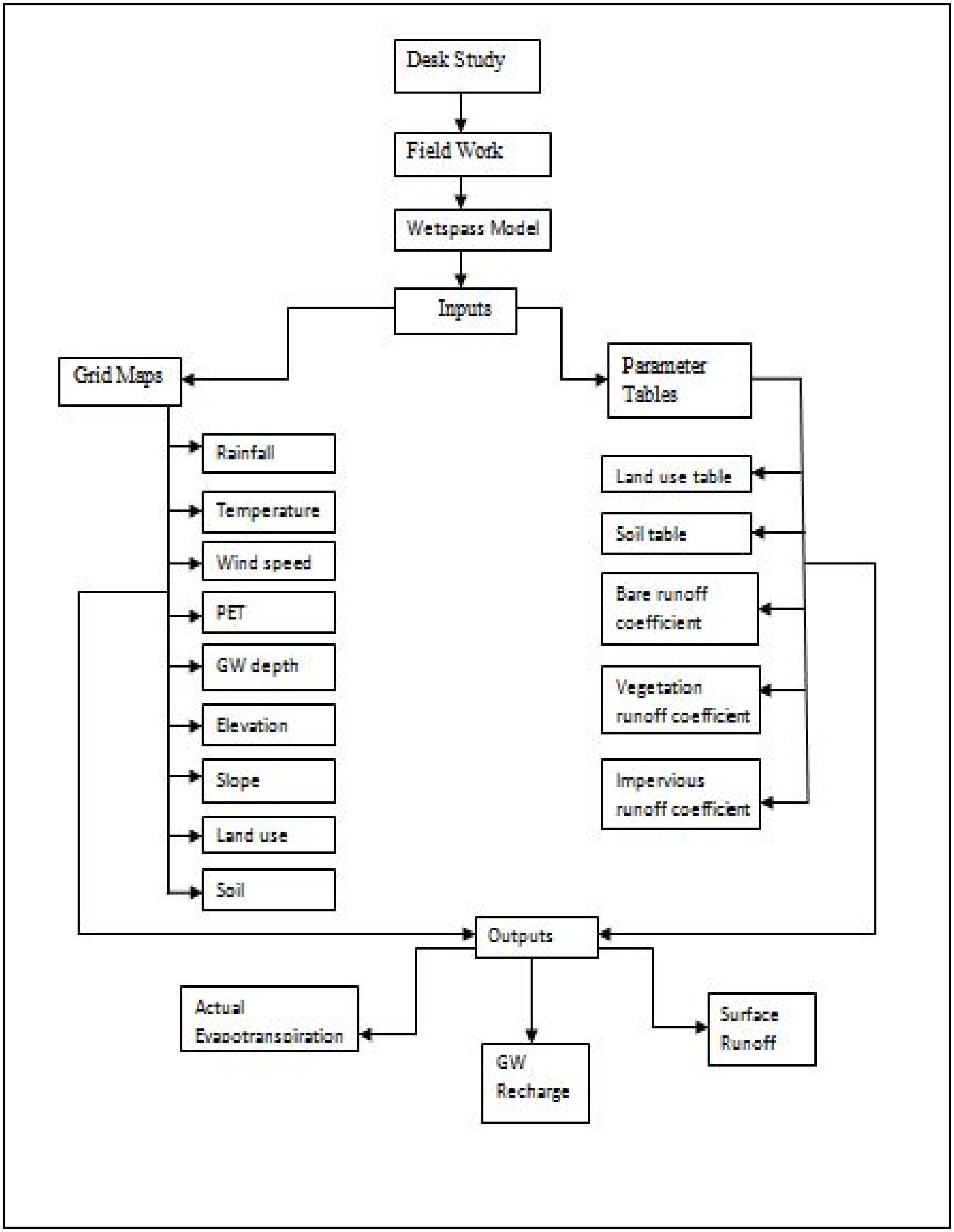


Figure 3:Flow chart of methodology

CHAPTER FOUR

OVERVIEW OF THE STUDY AREA

4.1 Location and accessibility

The Upper Awash basin is located in the central highlands of Ethiopia with the altitude that ranges from 1510 m.a.s.l to 3560 m.a.s.l at the western margin of the Main Ethiopian Rift. The basin covers an area of about 11748 square kilometer. Its geographic location is bounded approximately by 8° 6' to 9° 2' N latitude and 37°56'to 39° 2'E longitude. The study area can be accessed in four directions from Addis Ababa city. In the north direction the study area can be accessed from Addis to Chefe Donsa through legetafo, legedadi, sendafa and beke. In the south it can be accessed from Addis Ababa to Lemen through Alem gena, Boneya and Melkakunture and also in the south west direction through Sebeta, Debre genet and Tulubolo to Guraghe highlands. In the East direction it can accessed from Addis Ababa to Ejere, Alem tena, Ombole and Koka through Tulu dimtu, dukem and debre zeit. In the west from Addis Abeba to Weliso highlands through Ashewa meda, Burayu, Holeta , Addis Alem and Ginchi.

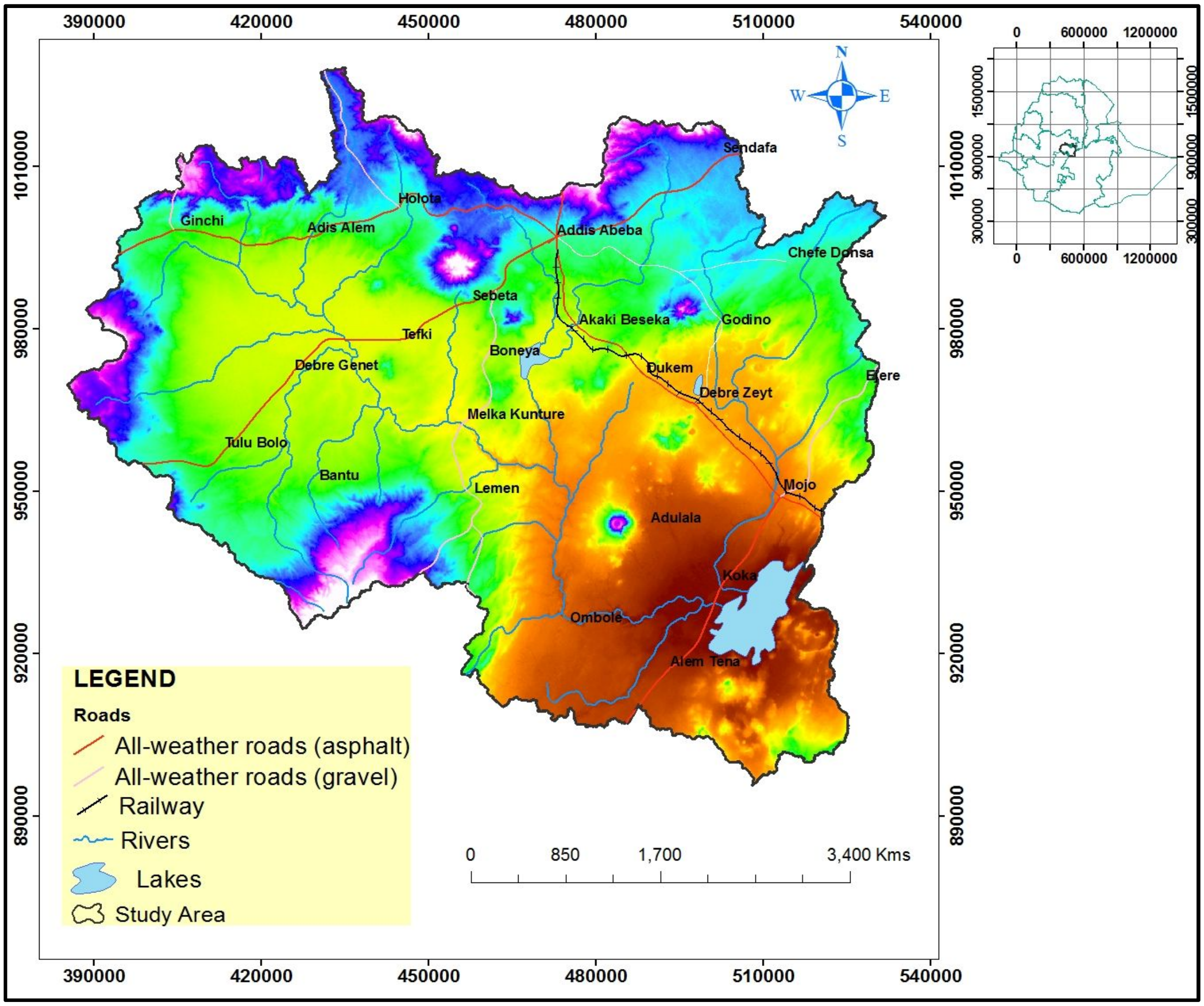


Figure 4: Location Map of the study area

4.2 Physiography and drainage pattern

4.2.1 Physiography

The physiographic features of upper awash basin are varying from high elevation to low elevation. High elevation places are dominantly located in the north (intoto ridge); in the North West (woliso highlands), in the west and South west direction gurage highlands and some mountains which distributed in the central part of the upper awash basin which are called central volcanic features. Low elevation places dominantly located in the central and south east direction of the basin. Due to these elevation variations surface water flows from high elevation places to low elevation places towards Koka dam. According to Andarge Yitbarek (2009) Upper Awash Basin is dominated by chain of volcanic mountains forming the watershed divide. Isolated acidic volcanic ridges are also common features known by compartmentalizing the basin acting as local divides. It 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 by the Koka reservoir. The physiography of the basin is shaped by volcano-tectonic and erosional processes. The basin is characterized by very steep slope in the northern, eastern and western part, undulating topography in the central and gentle to flat in the southern part. The major volcanic centres and ridges within the upper awash basin are Wechecha, Furi, Guji, Bedegebaba, Ziquala and Yerer which shown below in the map. The study area is characterized by the plateau and mountainous ridges in addition to flat lands.

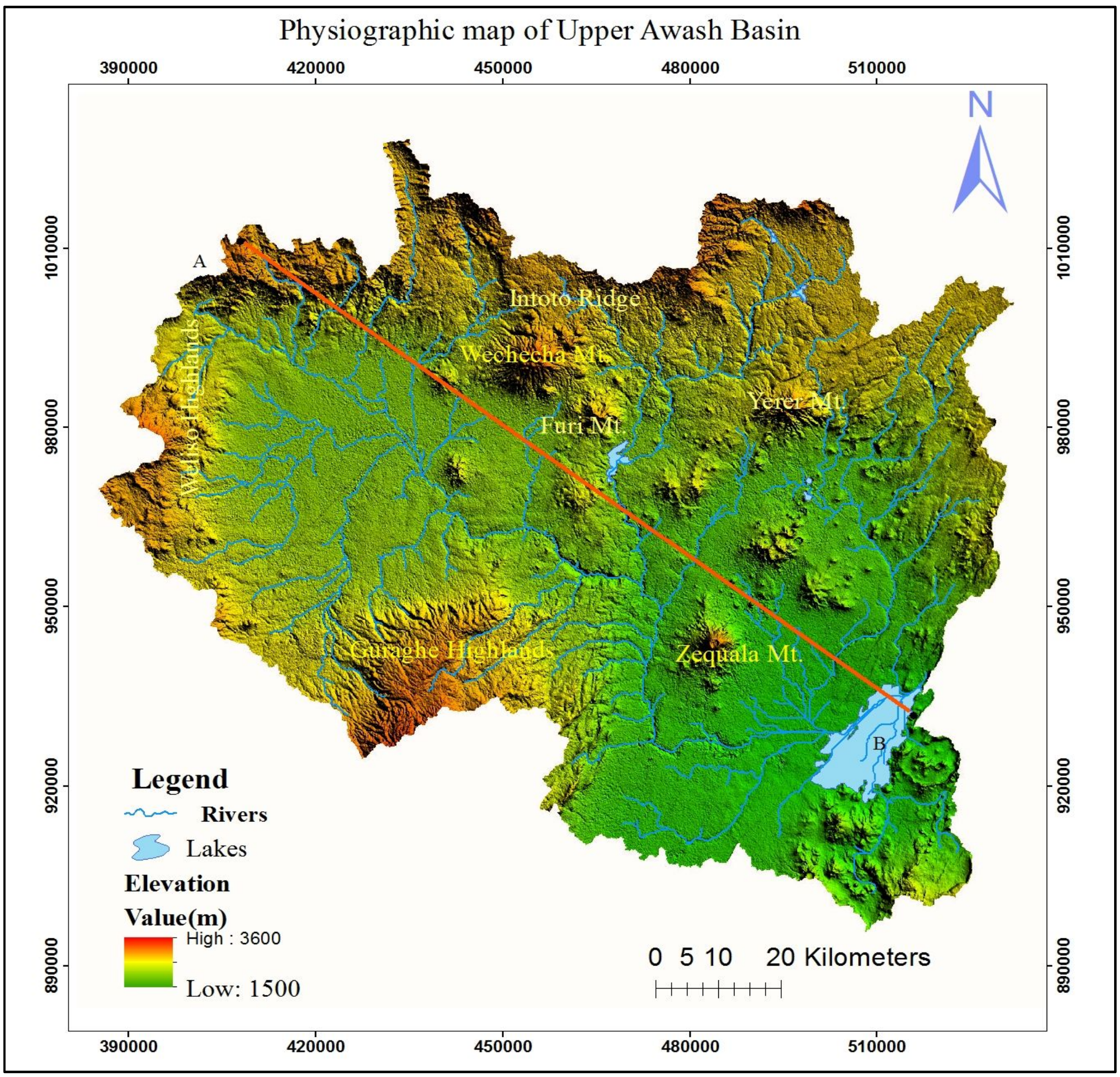


Figure 5:Physiographic map of Upper Awash Basin

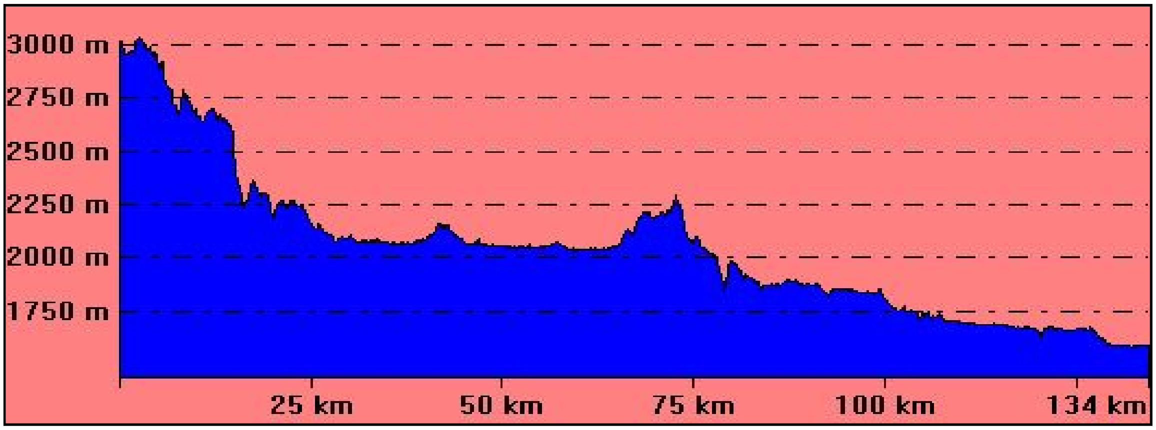


Figure 6:Profile of the study area from Ginchi (A) to Koka dam(B)

4.2.2 Drainage pattern

The drainage pattern of upper awash basin is dendritic type of flow because the main rivers and tributaries make tree like structure. The flow direction of Upper Awash River begins from the highest altitude towards to SW (South Western) and finally joins to Koka dam which is lowland area. The streams of upper awash basin generally flow towards south eastern and south western direction of the basin.

The longest flow distance is from weliso highlands to lowland area which is koka dam (shown below in the form of map).

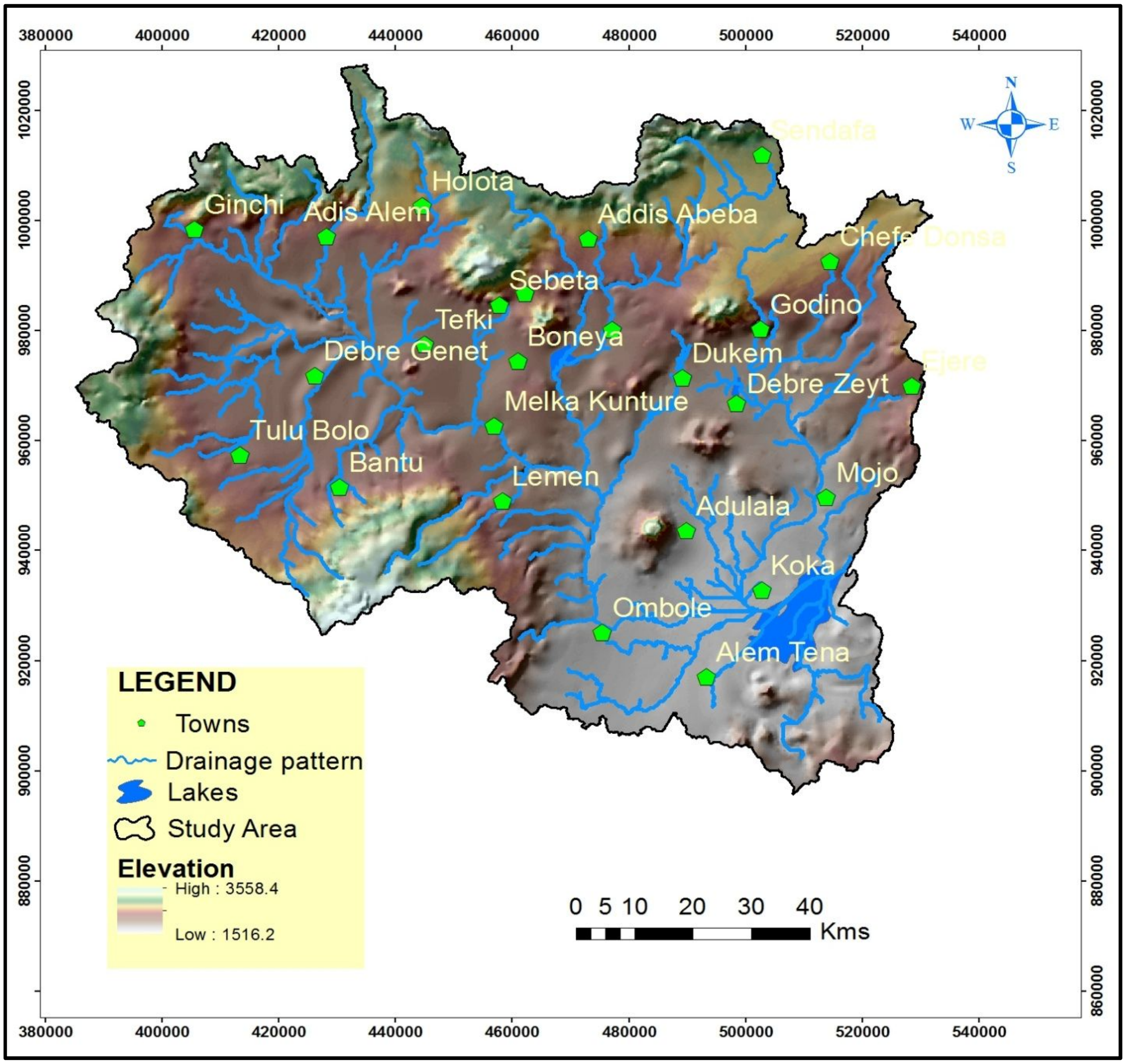


Figure 7:Drainage map of upper awash basin

4.3 Climate of the study area

The climate condition of upper awash basin is classified as kola, woina dega and dega based on elevation. According to Ethiopian treasures on http://www.ethiopiantreasures.co.uk/pages/climate.htm, Ethiopia is in the tropical zone laying between the equator and the tropic of cancer which has three different climate zones related to elevation. The first climate is Kolla (tropical zone) which occurred the lowest elevation less than 1830m(<1830m), the second elevation is Woina Dega (Sub tropical zone) with elevation of 1830-2440m and the third climate is Dega (Cool zone) at high altitude greater than 2440m. Therefore from the map shown below the elevation from 1516-1956m is considered as kola, 1956-2389m is Woina dega and 2389-3559m is dega. Based on rainfall, the climate of the upper awash basin is categorized in to two broad seasons: the dry season (winter) covers eight months from October to May and the wet season (summer) which covers four months from June to September with autumn and spring receiving a slight amount of rain. From meteorological data the total annual rainfall in the study area is 1024.3 mm on average, the mean annual temperature is 17.8 °c, the maximum and minimum temperatures recorded are 33.3 and 5.3 ºc in May and November at Koka and Addis Ababa observatory respectively.

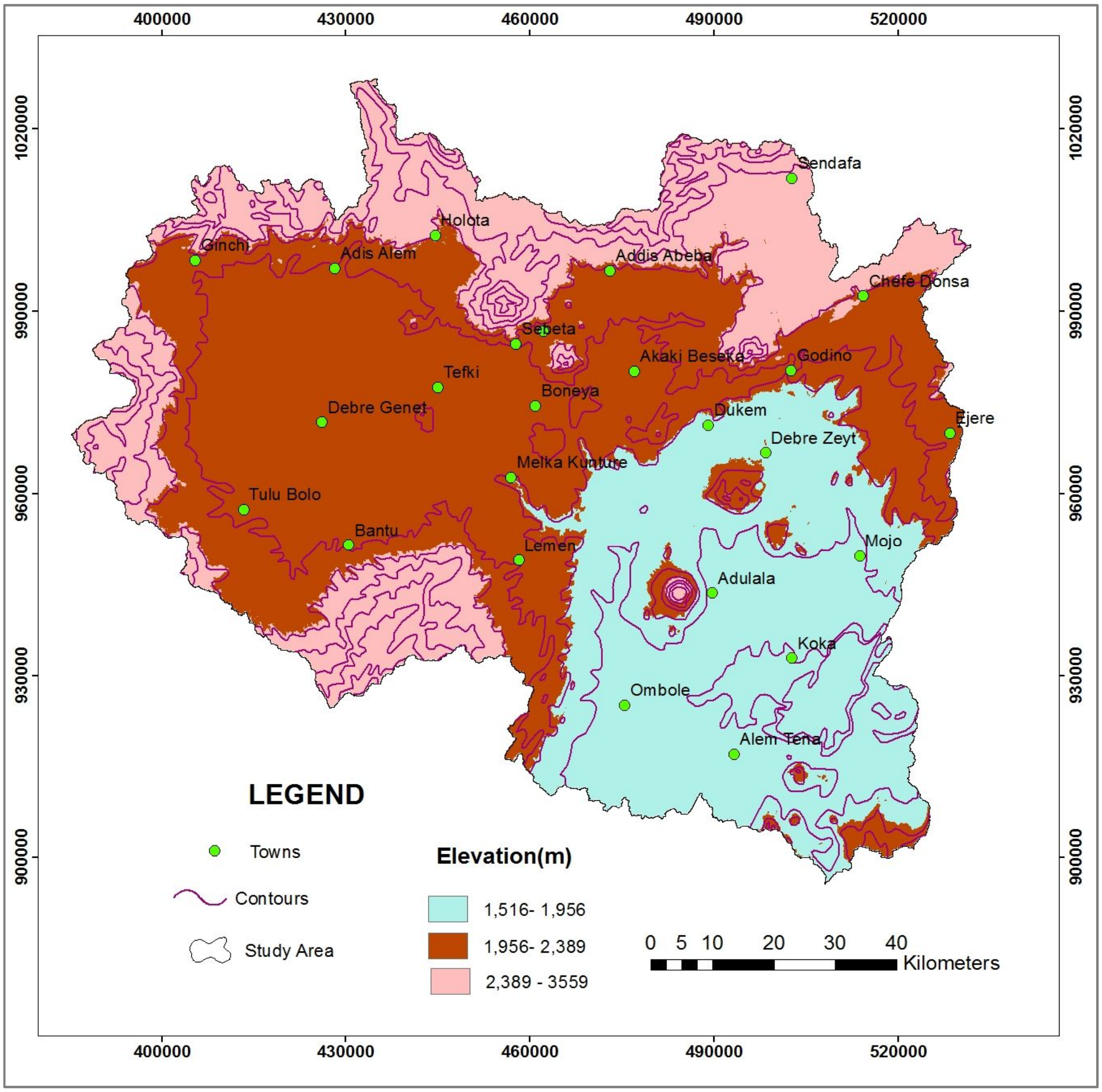


Figure 8:Climate map of the study area produced from DEM

4.4 Geology

4.4.1 Regional Geology

Ethiopia can be divided in to four major physiographic regions, widely known as the western plateau, southeastern plateau, the main rift and the afar depression. The Ethiopian plateau is underlain at depth by Precambrian rocks of the Afro-Arabian Shield (Mohr, 1967, as cited in Abel Abebe,2017).

According to Andarge Yitbarek (2009) the formation of the Ethiopian Rift is during the Miocene period. During this period the eastern and western highlands were separated and forming the great Ethiopian rift system. The Western and North Western plateau of upper Awash is mainly covered with early Cenozoic Trap Series of the Magdala and the Ashenghe group. This group mainly composed of rhyolites, ignimbrites, Basalts and trachytes. According to Tenalem Ayenew et al. (2007) the upper part of the basin is covered by Cenozoic volcanics that include the Ashenghe Group basalts interbedded with pyroclastics and rare rhyolites intruded by dolerite sills, acidic dykes and gabbro-diabases. The Upper Awash basin is exclusively confined within the north-central plateau and the adjacent escarpment and rift. The adjacent central plateau is drained due west by the Blue Nile River drainage system and due north-east by the Awash River drainage system (Andarge Yitbarek, 2009). As a result of various geo-tectonic activities, there are complex geological formations in the rift floor of the basin. The rift floor is widely covered by Afar group of Pleistocene to Holocene volcanic age deposits. These formations are basalts that are subordinated with acidic lavas and ignimbrites. On the top of the presence of rift volcanics, the region is covered with thick lacustrine and alluvial deposits and with limited Mesozoic sedimentary rocks that exist in the east. These include the Adigrat Sandstone and the Hamanlei Formations consisting of dolomites, limestones, the Amba Aradam sandstones and shale and marl formations (Tenalem Ayenew et.al, 2007). The acidic volcanics of the Nazreth Group is relatively younger basic volcanics of the Afar Group (Zanettin et al., 1980, as cited in Tsedenya Aregu, 2018).

The conceptual connection between fissure volcanic conditions gave rise to the force out of the Trap Series succession (plateau volcanism) which is considered to be the up-doming (Mohr, 1967, as cited in Abel Abebe, 2017). The Regional geologic settings of upper awash basin are formed at different time series. The Geological formations/settings which formed at different time series are Mesozoic sedimentary succession, Tertiary and Quaternary age groups of acidic and basic volcanic rocks and Quaternary Lacustrine and alluvial deposits.

4.4.1.1 Mesozoic sedimentary succession

The Mesozoic sedimentary rocks comprise Adigrat Sandstone, Amba Aradam Sandstone, Antalo limestone and Mugher mudstone. These sediments have the form of the transgression and regression of the Indian Ocean during Triassic to Cretaceous.

4.4.1.2 Tertiary volcanic rocks

These tertiary volcanic rocks comprised of Addis Ababa Basalt, Addis Ababa Ignimbrite, Nazret Unit and Central Volcanic Unit. The Tertiary volcanic rocks are composed of basalts and silicic of Miocene to Pliocene age. Tertiary volcanic rocks unconformably overlay on top of the Mesozoic sediments. The Central Ethiopian plateau geology is controlling influence over by Tertiary volcanic made up of Aiba basalts, Alaji Rhyolites and basalts, Tarmaber basalts and Balchi Rhyolites (B. Zanettin *et al.,* 1974, as cited in Abel Abebe, 2017).

4.4.1.2.1 Addis Ababa basalt

This Formation is fine to coarse grained basalt constitute of olivine and plagioclase phenocrysts. In major component of the visible rocks observed in the area it is relatively thin (20m) lava flow overlying the ignimbrite. The length of time of the this basalt unit is 7.5-4.5 Ma (Chernet *et al*., 1998 and Morton *et al.,* 1979, as cited in Abel Abebe, 2017)

4.4.1.2.2 Addis Ababa ignimbrite

Ignimbrite formation is Cover greater extent in the study area. This formation is exposed in areas of flat surface area like Addis Ababa and its suburbs, legedadi legetafo ayat, Ada &Becho plain, Mojo, zequal. It is composed of welded tuff (ignimbrite), non-Welded pyroclastic fall (Ash and tuff. According to (Morton et al., 1979) the age of Addis Ababa ignimbrite formation is 5.11-3.26 Ma.

4.4.1.2.3 Nazret group

According to (Morton *et al.,* 1979) this formation is exposed in the southeastern part of the upper awash basin and forms rift floor and the age of this formation accounts about 5.4 to 3.11Ma. It is overlay on Addis Ababa basalts and composed of a thick succession of Non-welded tuffs, ignimbrite, ash flows, Rhyolites and trachytes out cropping for the most part on the rift floor reach a thickness of above 250m and to some degree in the rift escarpments and on the adjacent plateau border.

4.4.1.2.4 Akaki basalt

This basalt unit is exposed in the areas around Akaki, Abasamuel, Dukem, Tuludimtu. This basalt unit is highly vesicular and the vesicles or pore spaces are filled with carbonate minerals or secondary materials. Scoria and Scoracious basalt exposed in the form of quarry in the study area near to tulu dimtu, Salo near to Gelan condominium and in Akaki areas at dewera and merino areas. The age of the Akaki basalt is 2.9-2.0 Ma (Tesfaye Chernet et al 1998 and Morton *et al.,* 1979, as cited in Abel Abebe, 2017).

4.4.1.2.5 Central volcanoes unit

The central volcanic rock units include highly elevated areas such as Entoto ridges, Furi Mountain, Yere Trachyte Mountain, Wechecha Mountain, and Chefa Donsa Unit. According to Kazmin (1979) as cited in Abel Abebe (2017) the age of central volcanic rock units is 10-3 Ma.

4.4.1.3 Quaternary volcanic rocks

This Quaternary volcanic rock contains the following rock units.

4.4.1.3.1 Bishoftu volcanic unit

This Bishoftu volcanic rock unit configured a NNE trending belt outcropping for the most part in the central level surface areas of Debrezeyt (Tsegaye Abebe *et al.,* 1999). In the Bishoftu Volcanic splashed over the surface and cinder cones with conceptual connection with tabular basaltic lava flows and phreato-magmatic deposits are dignified in appearance. The basalt in this area is vesicular and coarse grained with olivine phenocrysts (Tsegaye Abebe *et al.,* 1999). The phreato-magmatic deposits are for the most part composed of surges and highly broken off deposits make conceptual connections with maars and Tuff ring. Bora-Bericha Rhyolites rock units is also outcrops in the north east around Debrezeyt area and eastern part of the investigation area (Tsegaye Abebe *et al.,* 1999). The Bora-Bericha Rhyolites rock consists of younger rift floor volcanoes such as Bedegebabe, Gedemsa, Bericha, Bora and Tullu-Moye (Morton *et al*., 1979). Products of these centers are for the most part are per-alkaline trachytes. This rhyolitic rock unit has high strength, light gray to pink in color constituents of alkali feldspar, quartz and mica (Tsegaye Abebe *et al.,* 1999).

4.4.1.3.2 Ziquala trachyte

This rock unit is exceptional, well maintained in its original cone standing about 1300m from the surrounding flat surface area, situated in the southern part of the detailed investigation area. It has a highest point of hill caldera 1.5 km wide and existing only in part become full of water (Morton *et al.,* 1979). This Ziquala trachyte is grayish pink in color, coarse grained and petro-graphically constituents of anorthoclase, sanidine, minor clinopyroxene phenocrysts and glassy alkali-feldspar embedded in a porphyritic rock (Tsegaye Abebe *et al.,* 1999). The age of the Ziquala trachyte is 1.28-0.85 Ma (Morton *et al*., 1979).

4.4.1.3.3 Woliso Ambo basalts

The Woliso Ambo basalt rock unit is exposed at the western and northern extreme parts of the mapped area. It is lava flows make up of porphyritic basalt with relatively greater size crystals of plagioclase, olivine and pyroxene, basalt breccias' and little Tuff. (Tsegaye Abebe *et al.,* 1999) In the area of Woliso it is Scoracious .

4.4.1.3.4 Gash Megal rhyolites

This Gash Megal rock unit outcropped in a most important part of the detailed investigation area at the west of the Main Ethiopian Rift a point at which steep slope descends from highland area, on the top of Guraghe escarpment. This rock unit has medium strength, fine to medium grained, light gray color. This rock unit is constituents of feldspar, quartz, and Muscovite minerals (Tsegaye Abebe *et al.,* 1999).

4.4.1.3.5 Chafe-Donsa pyroclastic deposit

This rock unit outcropped in the North -East central part of the study area. It has low strength, light to dark gray color, fine grained unwelded to poorly welded, fine volcanic ash flows and fall deposit composed of mainly Rhyolites and mainly exposed in the rift floor (Morton *et al.,* 1979).

4.4.1.4 Quaternary lacustrine and alluvial deposit

4.4.1.4.1 Lacustrine deposits

The Lacustrine deposit is to higher degree dignified in appearance in the Adaa plain of the Lakes region. The Lacustrine sedimentations are the consequence of deposition in this large ancestral lake (Mohr, 1967) and (Tsegaye Abebe, *et al.,* 1999). The age of the lacustrine rift sediments is occurring at the same time with the Wonji volcanic (Morton *et al.,* 1979).Volcanic matrix; whose thickness varies from 5 to 8m. The thick layer of strata is written in the groundwater well drilling reports. They are for the most part of volcanoclastic sediments and tuffs with silts, clays and diatomites; silts and clays are the dominant once. Exposure of this the Eastern part of study area along the rift floor. The covers the largest area and forms flat topography and occur below an elevation of 1900 m.a.s.l. It consists of loose, light to yellowish grey color, sand and silt size sediments of volcanic origin such as pumice and volcanic ash plus obsidian, Rhyolites and basaltic rock fragments (Morton *et al.,* 1979).

4.4.1.4.2 Alluvial cover

Alluvial deposits are also common in the Rift, in connection with flood plains and at some places mixed with volcano clastics (Tsegaye Abebe, *et al.,* 1999). The alluvial cover mainly outcropped above the Tertiary volcanic on the plateaus, Becho Plain, Mojo and its surrounding areas and composed of regolith reddish brown soils, talus and alluvium with maximum thickness of about 7 m (from area hand dug well data).

4.4.2 Local Geology

The geology of Upper awash basin is highly affected by tectonic activities and formed at different time series. The geological units which constitutes upper awash basin are Alage formation (Pna); Alluvial and lacustrine deposits(Q); Basalt flows, spatter cones and hyalolo clasitites (Qb); Bishoftu formation(NQtb); Chilalo formation(Lower part): Trachyte, trachy_basalt, peralkaline rhyolite with subordinate alkaline basalt(Nc);Dino formation: Ignimbrite, tuff, coarse pumice, water lain pyroclastic rocks with rare intercalation of lacustrine sediments(Qd); Nazret Series: Ignimbrites, unwelded tuffs, ash flows, rhyolitic flows, domes and trachyte (Nn) , Rhyolitic volcanic centers ,obsidian pitchstone, pumice , ignimbrite, tuff, subordinate trachytic flows (Qr) and Tarmaber Megezez formation(Ntb).These formations discussed below turn by turn.

4.4.2.1Alage Formation

The name Alajae basalt is taken from Tefera et al., 1996. The Alajae basalt covers northern part of the study area near to intoto ridge. It forms relatively flat topped topography on the plateau, and cliff along the escarpment and in the river gorges. The contact with the underling Alagae basalt is marked by reddish brown paleo-soils. They are dark gray, fine to medium grained and porphyritic with olivine and pyroxene phenocrysts.

4.4.2.2 Alluvial and lacustrine deposits

Alluvial and lacustrine deposits include sandy silt, clay, and diatomite limestone &beach sand. This formation covers the large area of the study area and forms flat lands in the south eastern and north western parts of the study area. These deposits are quaternary deposits and recent in age because they transported from high elevated areas to low land areas and deposited.

4.4.2.3 Basalt Flows

Basalt is compositionally mafic and volcanic type of igneous rock which formed at a rapid cooling of basaltic flows during volcanic eruptions. The flow during eruptions is basaltic flows and it exposed at the earth's surface. These basaltic flows are formed in the central and south eastern edge of the study area which includes spatter cones and hyalolo clastites.

4.4.2.4 Bishoftu Formation

The Bishoftu Basalt unit outcrops in the area on the Ethiopian main rift which includes Alkaline basalt and trachyte . Dominantly occur between mojo and debrezeit.

4.4.2.5 Chilalo Formation

Lower chilalo formation found in the upper awash basin which is resulted by Ethiopian main rift .This formation comprises of Trachyte, trachy basalt, peralkaline rhyolite with subordinate alkaline basalt.

4.4.2.6 Dino Formation

The contents of dino formation are Ignimbrite, tuff, coarse pumice, water lain pyroclastic rocks with rare intercalation of lacustrine sediments.

4.4.2.7 Nazret Series

The nazret series includes Ignimbrites, unwelded tuffs, ash flows, rhyolitic flows, domes and trachyte shown below in the form of photo.

Plate 2: Photo of Ignimbrite taken near to Mojo town

Plate 3: Photo of tuff taken near to Zequala

4.4.2.8 Rhyolitic volcanic centers

This geological formation is dominantly composed of obsidian pitchstone, pumice, ignimbrite, tuff, subordinate trachytic flows. These formations cover Zequala Mountain and its surrounding in addition to SE of the study area and mojo. The mountains near to Alem tena and Ombole area composed of Ryolitic Volcanic centers. The following photos are taken during field work.

Plate 4: Photo of Tuff taken near to Zequala Mountain

4.4.2.9 Tarma ber Megezez Basalt (TMB)

Tarmaber basalt is found in the plateau extending from Addis Ababa to Guder valley. It is composed of basalts whose texture varies from aphanitic to completely porphyritic. Tarmaber-Megezez basalt is exposed in the north and northeastern part of the study area. This formation is extended from Addis Ababa to chefedonsa through sendafa and outcropped in the Ginchi area starting from welenkomi.There are thin layers of ignimbrite inter bedded within the flows. The basalt has dark grey fresh color and columnar jointed basalt shown below in the form of photo.

Plate 5: Photo of basalt

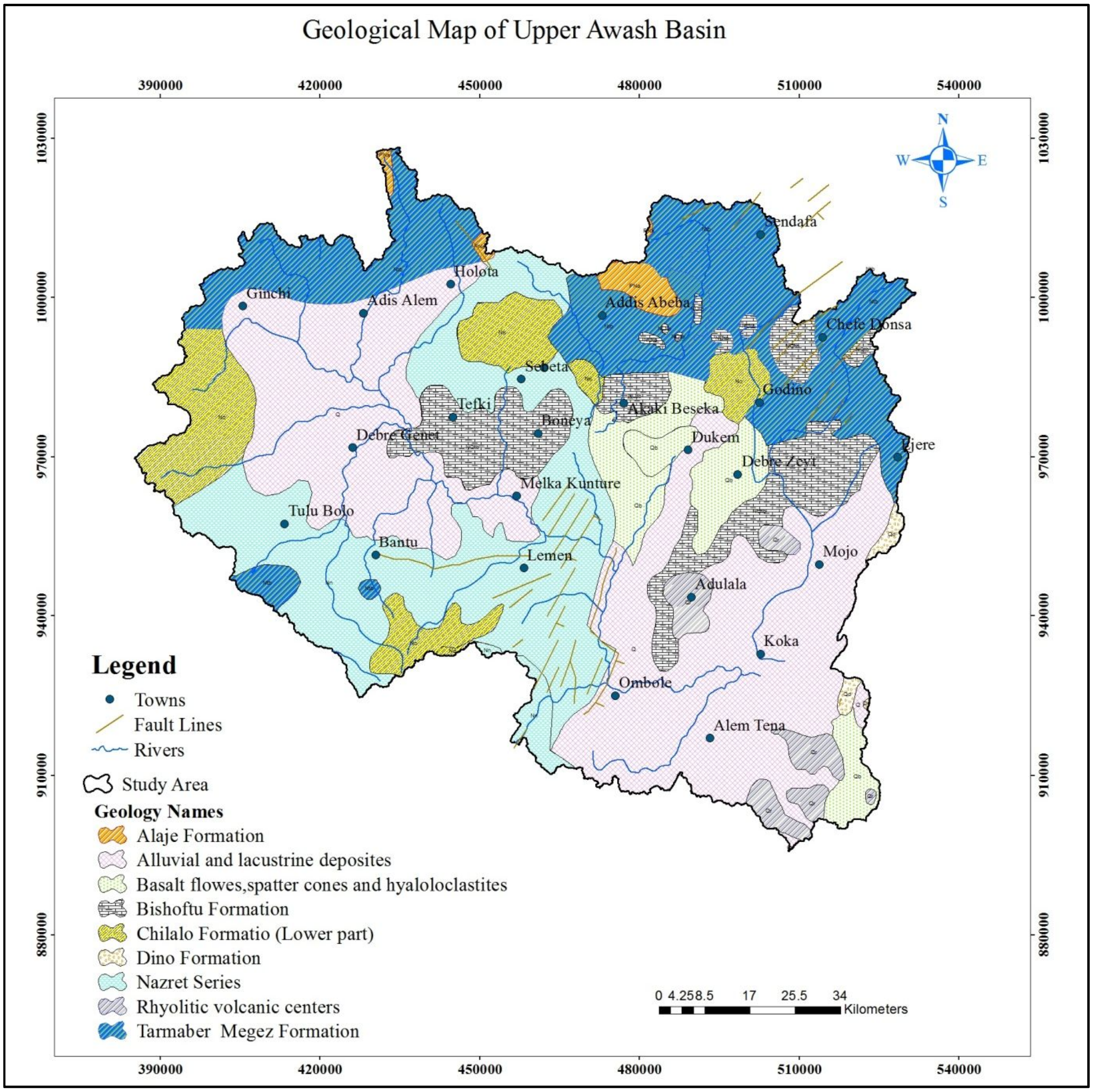


Figure 9:Geological map of the study area modified from Oromiya geology and Ethiopian geology (2007)

4.4.3 Structural setting of upper awash basin

The East African Rift System (EARS), configured as a consequence of the hard but liable to break easily African continental 'plate' as a reaction to elastic forces that are speeded up by very slow creep of rocks hundreds of kilometers deep in the Earth, is a region of continental break up that provide the comparative movement between the African and Somalian Plates. In the EARS, the Main Ethiopian Rift (MER) constitutes an understanding of the area as it brings together the afar sunken place to the Kenya Rift. The MER is described distinctively by a fault arrangement (sequence) trending in the direction of a NE-SW border fault system and an N-S to N20°E-trending system, comprised of step-up right-stepping faults obliquely influencing the rift floor Wonji Fault Belt (Tsegaye Abebe, 1995; Tsegaye Abebe et al., 1998).

Upper Awash basin is located at the intersection of two important regional structures, that is to say the NNE-SSW trending MER and the East-West trending Addis Ababa-Nekemt volcanic lineament (Andarge Yitbarek, 2009). According to Andarge Yitbarek (2009) the volcanic rocks of the upper awash basin have subjected to large area faulting often experienced a general direction of NE – SW, E-W and at places NW-SE also the majority of the linear features along the general direction of the rift. The Addis Ababa-Nekemit fault has moved downwards to the south in the Addis Ababa area and the Intoto silicic rocks are enclosed within this fault (Haileyesus Girmay and Getaneh Assefa, 1989, as cited in Andarge Yitbarek, 2009). Additionally, important fault trending in the direction of NE-SW (Morton, 1974, Haileyesus Girmay and Getaneh Assefa, 1989) is the Filwoha fault which is down-thrown to the south of Addis situated at central Addis Ababa and many hot springs and thermal wells be found along this fault. Groundwater recharges and flows in the aquifers of the upper awash basin most likely controlled by the geometry of the faulted aquifers dipping direction of the underlying litho logy, porosity and permeability of the different lithologies. In the study area the oldest and underlying sedimentary rocks are dipping in the southeast direction. The volcanic rocks resting over these sedimentary secessions have also following the dipping direction of the underlying sedimentary rocks. These volcanic rocks in the area are highly affected by four different faults and fracture systems and solution cavities below the surface facilitate flow through the aquifers. According to WWDSE (2008) there are four types of fault features are distinguished throughout the interpretation of satellite imagery lineaments data. The widespread brittle deformation consisting of fractures and dislocations are also observed during the field survey.

4.4.3.1 North West fault system

The NW fault system, the oldest fault system have extended history affects all the rock type in the western escarpment. They are crustal scale served as a conduit for the extensive volcanic formation in the area and their age may go up to early Paleozoic, but becomes reactivated latter with the main tectonic event in the region (Tsegaye Abebe, 1995; Tsegaye Abebe et al., 1998). The trend of the Bede Gebaba -Wechecha volcanic belt can be associated with this NW fault system.

4.4.3.2 East West fault system

The EW fault system, which is the upper boundary of the Ethiopian rift margin, is running approximately E-W north of the Addis Ababa Ambo road. They are major fault on the western plateau part and densely affected the Tarmaber basalt in the area.

4.4.3.3 Northeast Southwest fault system

The NE-SW fault system runs parallel to the principal system of fissures in rift floor north east of Debrezeit and Modjo and extending to Nazeret. This fault system is densely affecting the volcanic rocks and served as a conduit to younger eruption (Tulu Rie basalt). The fault system of the rift margin exhibit step like block faults.

4.4.3.4 North-South fault system

The NS fault system is the recent fault system which serves as a conduit for young volcanic (Addis Ababa basalt).

4.5 HYDROGEOLOGY

4.5.1 Aquifer Characterization

The volcanic aquifer of East Africa is the most complex and the least understood in the hydrogeologic system compared to other aquifers found in Africa (UNESCO, 2006, as cited in Tsedenya Aregu, 2018). Hydrogeological setting of the upper Awash Basin (UAB) is affected and the lithologies are disrupted by tectonic activities because the study area is located in the central Ethiopia on the main Ethiopian rift system. The hydrogeological conditions of a certain area depend on geological processes, geomorphology, lithologic formations, tectonic structures such as faults, fractures, cracks etc. The lithologic units of the study area are basalts, ignimbrites and tuff, clay, Rhyolites, scoria and scoracious basalts as evidenced from drilling lithological logs. From drilling of deep wells in the upper awash basin, the lithological logs show that the aquifer of the upper awash basin is dominantly volcanic aquifers which can yield high discharge water up to 150L/S. The discharge of the study area is depending on degree of weathering, degree of fracturing and availability of pore spaces of rocks. These aquifers are weathered and fractured basalts, ignimbrites, scoria and weathered and fractured scoracious basalts. According to MWR (2007), as cited in Tsedenya Aregu (2018) most of the Upper Awash Basin aquifer system composed of basalts that are covered with ignimbrites and volcanic Ashes. The lithologies of the upper awash basin are from drilling log shown below in figure10 for selected deep wells. The aquifer systems of some places in the upper awash basin classified as follows:-

Central Addis Ababa (AA)

Mainly laterally discontinuous fractured ignimbrite and basaltic aquifers of various ages; locally the presence of volcanic ash leads to confined and semi-confined groundwater conditions; depth to water table ranges from 20 to 120 m; flat rolling plain dissected by streams emerging from the plateau; elevation ranges between 1,900 to 2,400 m.a.s.l (Kebede et al., 2008)

Akaki

Aquifers mainly permeable and porous Quaternary scoracious basalts; in deep wells ignimbrites and massive basalts can be encountered; from drilling of deep wells the aquifers can yield a discharge up to 150 L/S. There are three well fields in Akaki area; from these well fields the aquifers provide about 235000m^3/day which accounts about 55% of water supply in Addis Ababa city; well depths vary from 300 to 623 m; flat laying area with elevation ranging between 1,800 and 1,900 m.a.s.l; the Akaki area is dotted by several scoria cones.

Dukem

Aquifers mainly low to medium permeability fractured basalts overlain by thick volcanic ash deposit; groundwater under semi-confined condition; well depths vary between 100 and 300 m; a flat area with elevation ranging between 1,800 and 1,900 m; the plain is dotted by several scoracious cones and prominent volcanoes (Kebede et al., 2008).

Legedadi Legetafo Ayat

As evidenced from drilling lithologic logs in the Legedadi Legetafo Ayat prospective sites, highly permeable and porous scoracious basalt, Weathered and Fractured basalts and ignimbrites encountered. In deep wells massive basalts and soft formations like tuffs and pyroclastic materials can be encountered. The aquifers in this area are highly productive and can yield a discharge of 150 L/S. Recently drilled wells at legetafo Legedadi Ayat prospective areas yield a discharge of 20 to 117L/S. Depth to static water level is varying from 40 to 70m below ground surface. In addition to legetafo legedadi Ayat prospective sites there are also well fields Akaki, south Ayat North Fenta, Adaa becho, Sebeta tefki and Addis Ababa pocket areas prospective sites with a discharge of 5l/s to 100 l/s. As we have seen below figure 10 the lithologic formation of legetafo well is dominantly scoracious basalt which is 100m thick out of 158m depth, so the aquifer of this well is scoracious basalt.

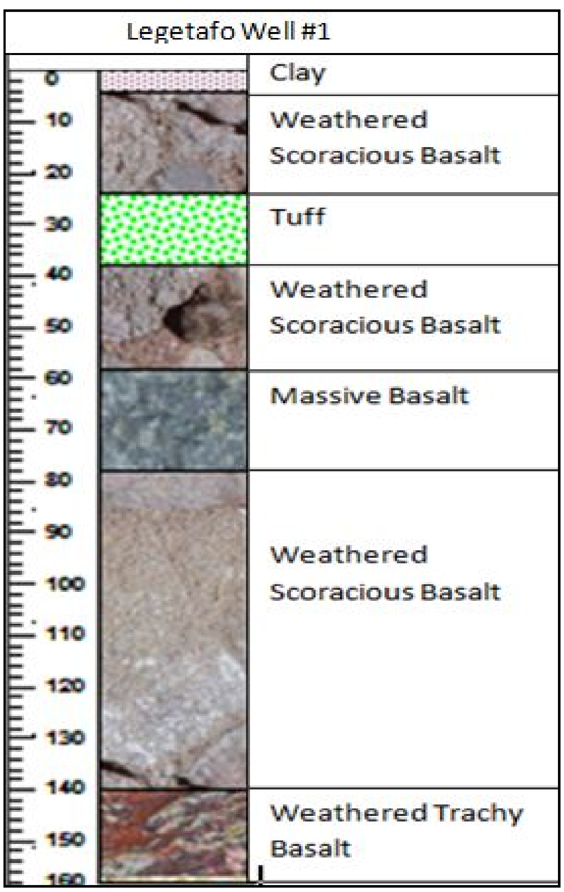
DebreZeyt

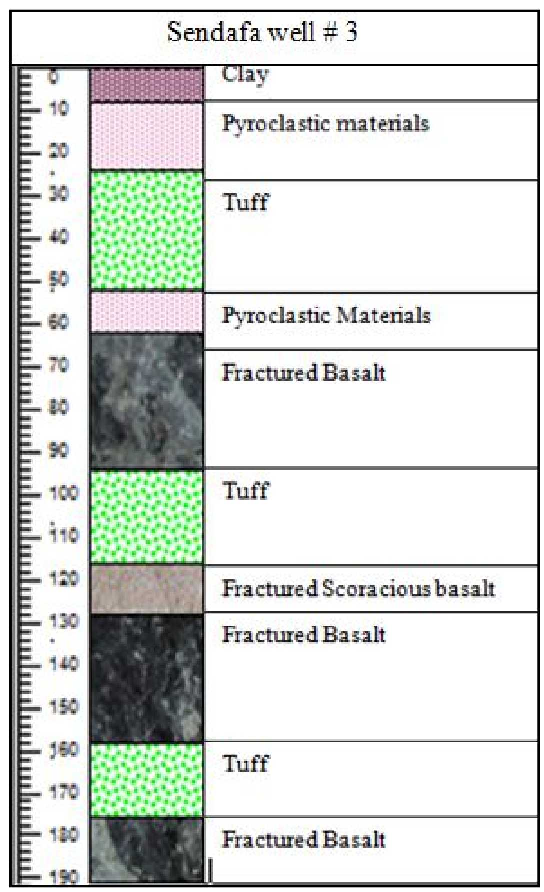
Aquifers mainly highly permeable Quaternary scoracious basalts with high primary permeability; in deep wells ignimbrites and poorly fractured basalts can be encountered; this aquifer is equivalent to the Akaki aquifers geologically; flat area with elevation ranging between 1,800 and 1,900 masl; the plain is dotted by several scoracious cones and maar lakes; rivers emerging from the plateau disappear in the scoracious basalts ((Kebede et al., 2008).

Mojo

Aquifers are basalts at shallow depths and ignimbrites at deeper levels; NNE oriented rift faults are truncated by the plateau and crosses the Mojo area in several localities; water-table depth ranges between 40 and 120 m; a flat area surrounded by scoria cones, elevation ranges between 1,700 and 1,800 m.a.s.l ((Kebede et al., 2008).

From the figures below the productivity of the aquifers is high. The aquifer of the following wells is dominantly weathered and fractured basalt and scoracious basalt. Therefore the main aquifers in the Upper awash basin are scoracious basalt, basalt, ignimbrite and lacustrine deposits.





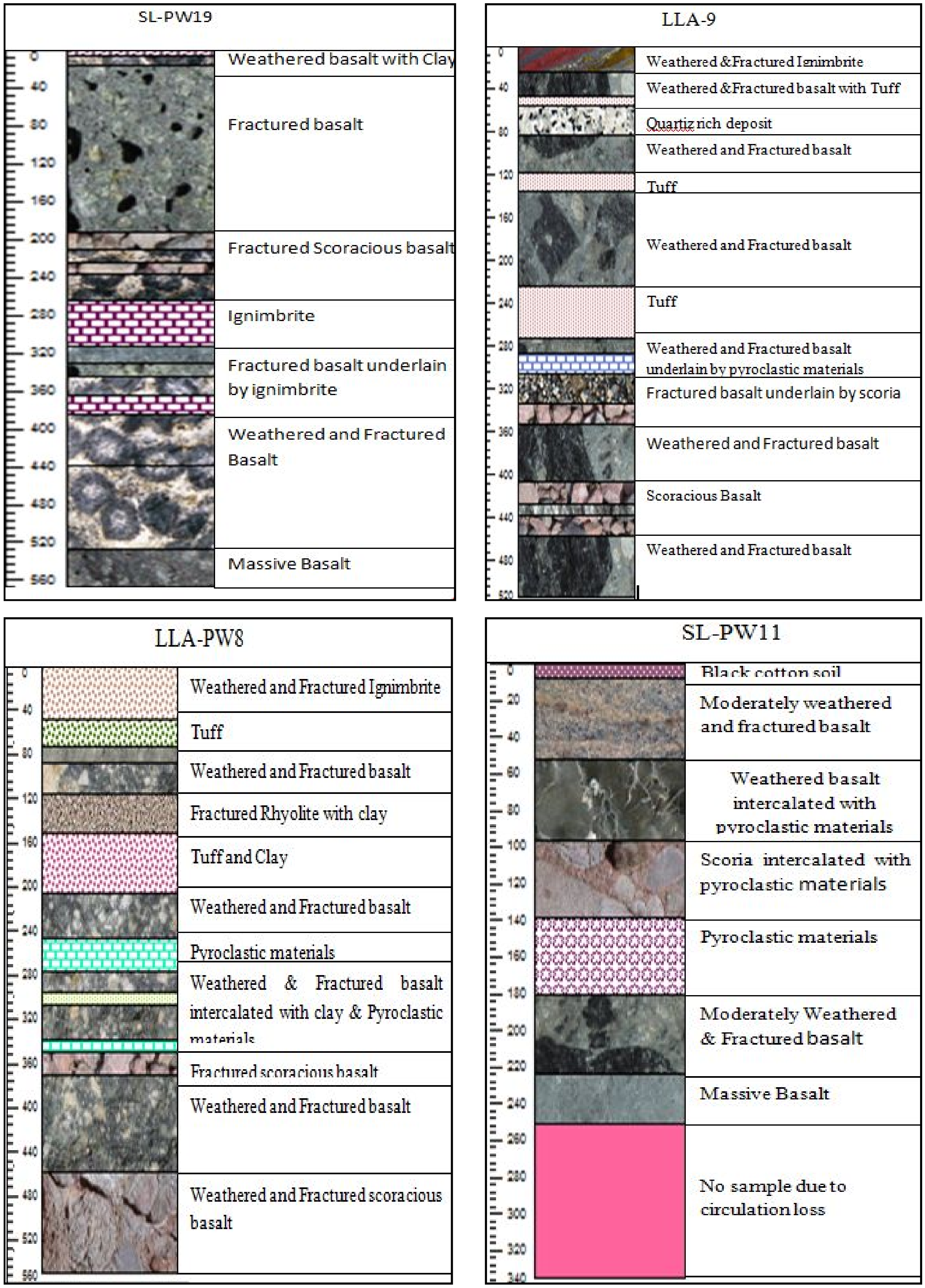


Figure 10: Lithologic Description of selected wells

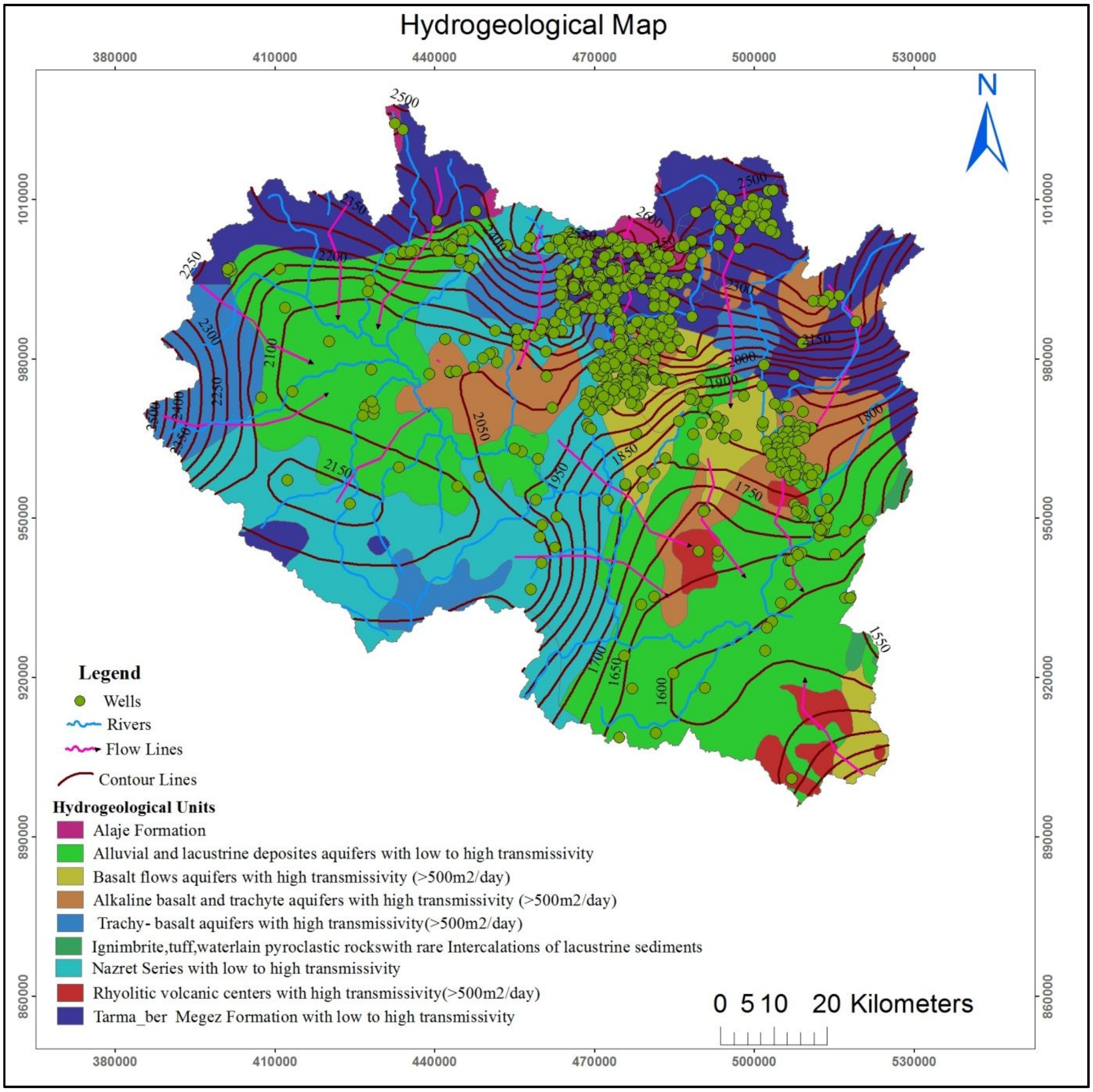


Figure 11: Hydrogeological map of the study area

The Hydrogeological map of the study area organized in the above figure 11 with geological lithologies because the hydrogeology of the study area and geology are strongly related. The geological symbols with descriptions discussed on table 3 under the geological map of the study area.

4.5.2 Recharge and Discharge Conditions

Recharge is one of the elements of a hydrologic process that determines deep drainage or deep percolation in an aquifer. It is generally defined as the process of the movement of water from the surface through the saturated zone (Balek, 1988, as cited in Tsedenya Aregu, 2018). From the Physiographic features discussed in part 4.2.1 and figure 3 the recharge areas are located at the high elevated areas in the study area. Generally recharge is defined as the down ward movement of water in to the saturated zone and joins the ground water table. According to (Fetter, 1988, as cited in Tsedenya Aregu, 2018) in recharge areas, there is often a rather deep unsaturated zone between the water table and the land surface. In discharging areas, the regions are found either close to or at the land surface of the water table. There are physical manifestations in which when the groundwater is released to the surface it can take the form of springs, lakes or streams.

The amount, Occurrence and Distribution of groundwater is depends on major meteorological parameters such as precipitation, temperature, evapotranspiration, wind speed in addition of physiography of the study area, geological structures, soil types and land use land cover of the study area. Rain fall is the main source of recharge for both surface water bodies and groundwater (Tsedenya Aregu, 2018).

The principal geological formation in upper Awash is the Ashenghe group, which mainly comprises fractured volcanic rocks. The main sources of recharge in volcanic rocks on highlands are direct recharge from precipitation (Guppta, 2010). Precipitation and surface water that percolate through the soil and reach the aquifer are called recharge. Ground water slowly flows through the aquifer from areas of recharge (usually uplands) to areas of discharge (usually lowlands), such as springs, streams, or wetlands. Under natural conditions (prior to development by wells), aquifers are in a state of approximate dynamic equilibrium, which means there is a balanced inflow and outflow of water in the system(WWDSE,2016).

Seepage from streams and return flow from irrigation are also other sources of recharge to the groundwater. In addition to precipitation the geological formations can determine the ability of an aquifer to store and transmit water through them. On the other hand the physiographic setup of a certain area determines the recharging and discharging conditions of water of that area. Upper Awash is characterized by a chain of ridges in east-west direction and as Ketema Wogari (2003) noted 80% of upper Awash Basin is characterized by flat topography. The recharge areas of upper awash basin are high elevation areas which are ridges and mountains and distributed volcanic centers namely weliso highlands, Guraghe highlands, Furi Mountains, Intoto rigdes, Zequala Mountains. The discharge areas in the study area are dominantly flat topography such as ada'a plain, becho plain, legedadi areas, mojo areas and akaki areas. Based on the above factors the upper awash basin is rich in groundwater potential. The main lithological formations hosting groundwater in the upper awash basin are fractured basalts, fractured scoracious basalts, scoria and fractured ignimbrites. In contrary massive geological formations are poor aquifers in nature which hampers groundwater movement. There are various mechanisms in which aquifers can get recharge such as diffuse (direct) or preferential (localized/indirect) recharge (Andarge Yitbarek, 2010). As we have seen below in the map below the flow lines direction indicated that the flow lines flows from recharge areas towards the discharge areas. In addition to the flow lines the contour lines also used to identify the recharge and discharge areas. In recharge areas in the high elevation areas the space between them is narrow and in discharge areas in low elevation (lowland) area the space between the contour lines is wide.

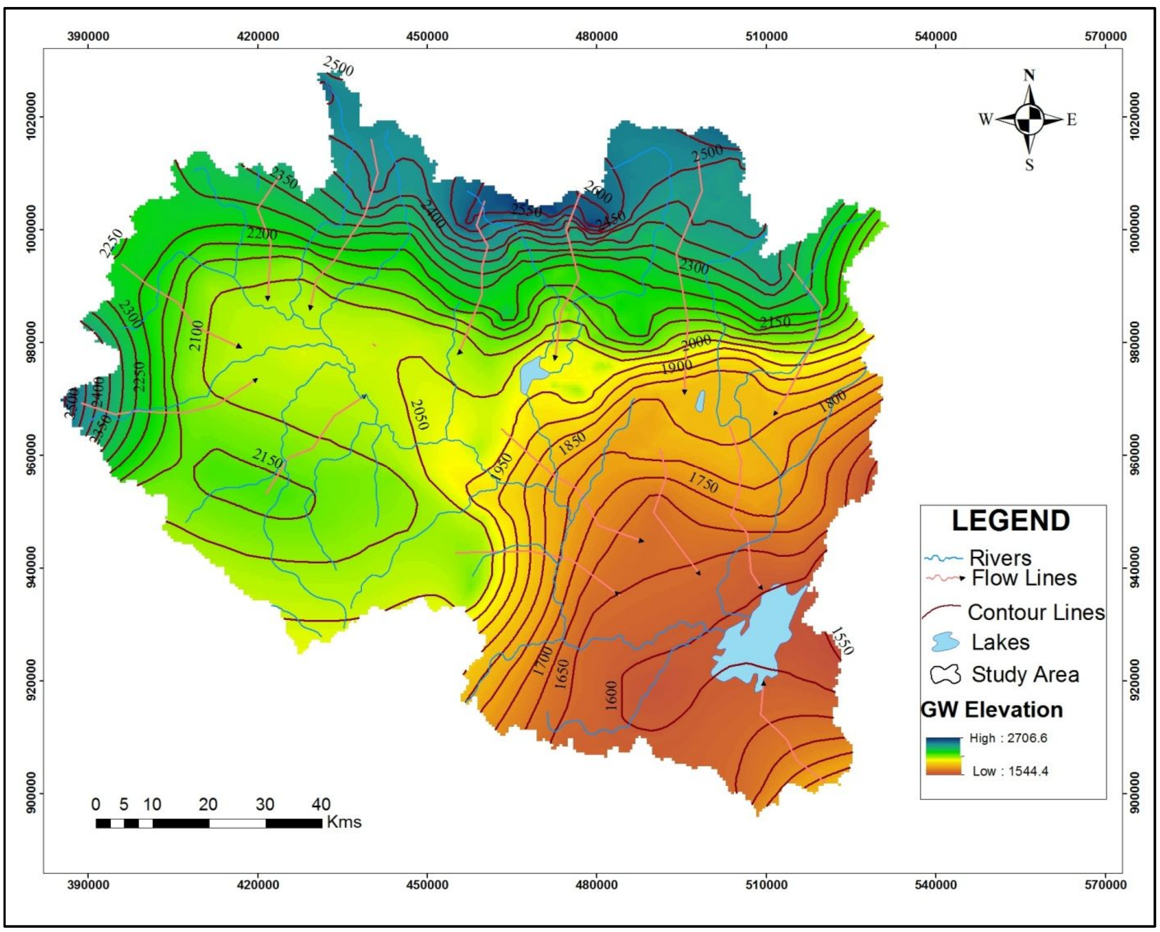


Figure 12: Contour and Flow lines map of the study area

4.5.3 Abstraction Rate from Inventory Wells

In the Upper Awash Basin there are a number of wells that drilled for water supply purpose. From the inventory wells data the discharge of each well vary and there are wells that can yield up to a discharge of 150L/S. The collected abstraction rate of the well fields in the Upper Awash Basin is summarized below in the table. This abstraction rate in the Upper Awash Basin used to check the balance of the recharge and the abstraction rate in the study area. The total abstraction rate of the upper awash basin wells is about 635,197m³/day which is about 231,846,905m³/year. The inventory wells which collected from the Upper Awash Basin are attached in the annex part.

S.N	Well field name	Discharge (l/s)	Discharge (m³/day)	Discharge(m³/year)
1	Akaki WF01	810	70000	25,550,000.00
2	Akaki WF02	521	45000	16,425,000.00
3	Akaki WF03	810	70000	25,550,000.00
4	Old Akaki	579	50000	18,250,000.00
5	SANF	787	68000	24,820,000.00
6	LLA-Phase I	463	40000	14,600,000.00
7	LLA-Phase I	995	86000	31,390,000.00
8	Private	307	26559	9,694,035.00
9	Ginchi	107	9253.4	3,377,491.00
10	Holeta	62	5331	1,945,815.00
11	ADBH	1156	99875	36,454,375.00
12	STH	286	24721	9,023,165.00
13	AMW	179	15458	5,642,170.00
14	AA City	289	25000	9,125,000.00
	Total	7352	635,197	231,846,905.00

Table 3: Abstraction rate in the study area

Based on Wetspass mode the recharge of the Mean annual recharge of Upper Awash Basin is 110mm/year. To check the balance of recharge (depth) and Abstraction rate in the study area, the recharge is need to change in to volume (m³/year). According to (Baumgartner &Reichel, 1975) the relation of Volume, Area and Depth (Recharge) of the study area is as follows.

D=V/A where: - D: depth (m) which is recharge

A: area of the study area

V: Volume of water (m^3)

Therefore: V=D*A=110mm/year*11748km²=0.11m/year*11748*10^6m^2= 1,292,280,000.00 m^3/year. From the result amount of both Abstraction rate and the mean annual recharge of Upper Awash Basin the present Abstraction rate is safe in a regional condition.

4.6 LAND USE AND LAND COVER

4.6.1 INTRODUCTION

Agricultural or Farming land in the Upper Awash basin is the Major land use. In addition to farming land, the upper awash basin is covered by reservoirs, forests, wetland, Grass land, Urban, etc. Consequently the urban land use pattern is farther separated into designed to live in, people living areas, a house used for growing flowers, parks, markets, industrial, petrol stations, parking lots, garages, cemeteries and sporting grounds(Abel Abebe,2017).

The majority of the mountainous areas in the upper awash basin are covered by natural forests. These mountains are located at the highland places such as Intoto ridges, Zequala Mountains, Furi Mountain, Weliso highlands, guraghe highlands and distributed high elevated areas like lemen, ombple, tulubolo, ejere and holota areas. The agricultural land use covers largely gentle slopping areas like becho plain, ada'a plain, legedadi legetafo ayat areas , Alem Tena and other places in the study area. The most common cereal crops which grow in the study area are Teff, wheat, barley, beans, oilseeds, maize and Vegetables, Root crops etc. Land use is one of the major factor that affects surface erosion, runoff, and evapotranspiration in the basin. Land use /land cover classification and soil types in the upper awash basin discussed below.

4.6.2 LAND USE/ LAND COVER CLASSIFICATION

The land use/ Land cover of upper awash basin is classified by using Erdas software from USGS landsat images shown below in the form of map. The classified land uses in the upper awash sub basin are shown below in the table.

S/No	Short form	Land use Classes
1	AGRL	Agricultural land-Generic
2	AGRR	Agricultural land-Row crops
3	AGRC	Agricultural land-Close grown
4	RNGE	Range-Grasses
5	RNGB	Range-Brush
6	FRSE	Forest-Ever green
7	FRSD	Forest-Deciduous
8	FRST	Forest-Mixed
9	WETL	Wetlands-Mixed
10	WEWO	Wooden Wetland
11	SHRB	Shrub land
12	PAST	Pasture
13	GRAS	Grass land
14	WETN	Wet lands-Non Forested
15	WETF	Wet lands-Forested
16	URBN	Urban
17	BARR	Barren
18	BSVG	Barren or Sparsely Vegetated
19	WATR	Water Bodies

Table 4: Table of Land use/ land cover

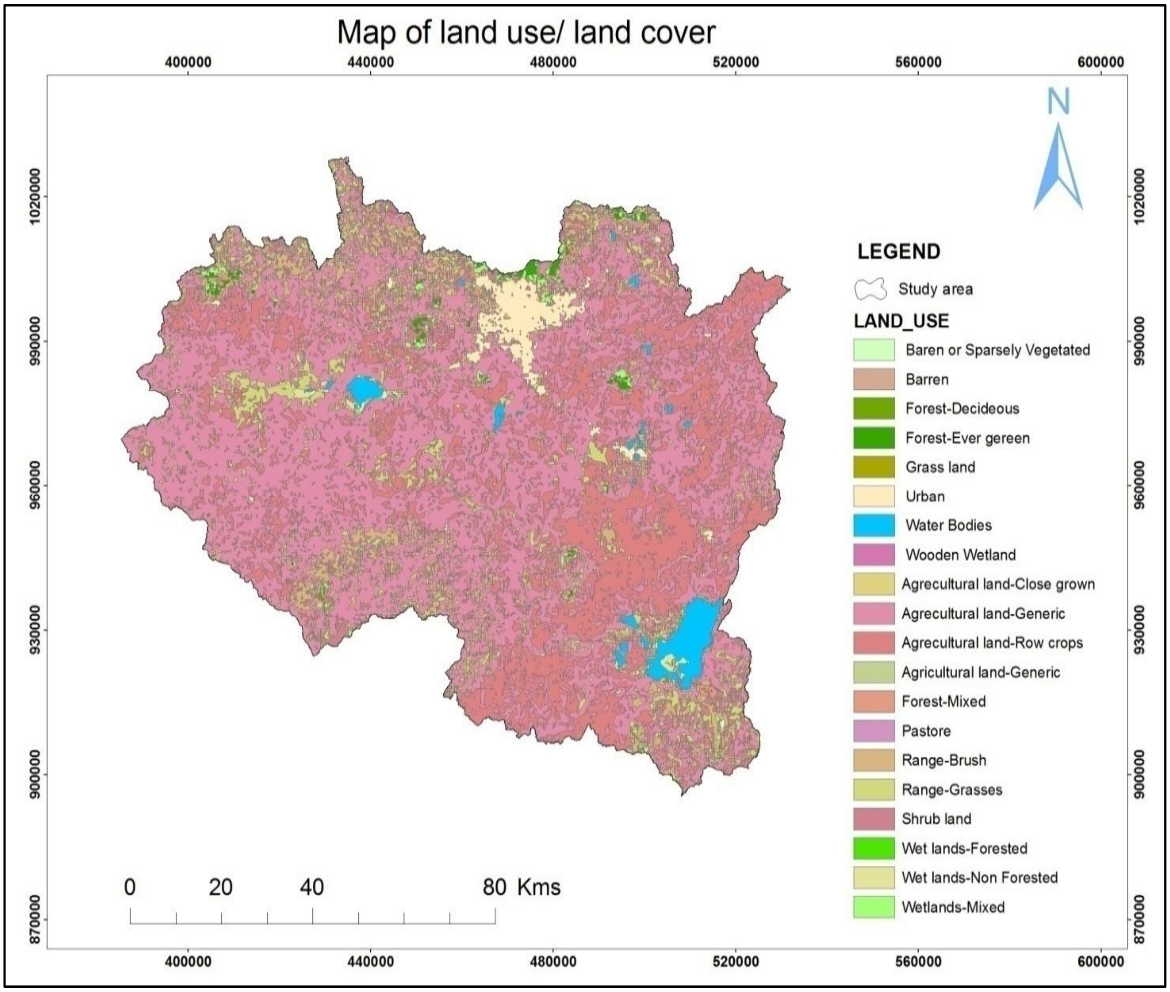


Figure 13: Map of land use/land cover

4.7 SOILS IN THE STUDY AREA

In the upper awash basin there are eleven soil types including water bodies classified from FAO soil. From these eleven soil types sixteenth soil samples were collected from different places based on soil types, areal coverage of soil types, and geology and land use conditions of the study area by removing the top part of the weathered soils until we get fresh soils. These collected soil samples analyzed in Ethiopian construction design and supervision works corporation- laboratory sector. The tested parameters are clay content, sand content and silt content in percentage which used to classify texture of each soil types. The result of the laboratory test is shown below in the table. The soil types are listed below in table 5 and 6 and shown in figure16. As shown below in the map (figure 14) the dominant soil type in the study area is Eutric vertisols. The soil types play a great role on recharge amount of a certain area. Based on the soil laboratory test result textural map is produced in figure15. Texture classification method is Hydrometry with ASTEM standard.

S.N	Sample ID	UTME	UTMN	Elevation	Soil Type	Clay (%)	Sand (%)	Silt (%)	Texture
1	SO-01	410049	988521	2133	Eutric Vertisols	6.08	73.79	20.12	Clay
2	SO-02	490884	997336	2415	Eutric Vertisols	37.2	45.47	17.32	Clay
3	SO-03	453993	963653	2021	Eutric Vertisols	5.76	71.8	22.44	Clay
4	SO-04	493677	968315	1914	Eutric Vertisols	24.59	38.78	36.63	clay loam
5	SO-05	515183	993193	2393	Vertic Cambisols	16.59	63.12	20.29	Clay
6	SO-06	460202	948895	2108	Vertic Cambisols	38.56	31.78	29.66	clay loam
7	SO-07	477044	938910	1812	Eutric Cambisols	30.33	48.56	21.11	Clay
8	SO-08	487426	974275	2016	Chromic Luvisols	27.24	48.51	24.25	Clay
9	SO-09	503112	931847	1596	Eutric Fluvisols	28.36	36.91	34.74	clay loam
10	SO-10	522527	957709	2032	Haplic Luvisols	20.33	53.83	25.84	Clay
11	SO-11	446826	1002584	2399	Humic Nitosols	8.82	69.47	21.71	Clay
12	SO-12	405176	962079	2229	Eutric Vertisols	24.25	47.61	28.13	Clay
13	SO-13	497495	916113	1664	Luvic Phaoezems	45.92	18.72	35.36	Loam
14	SO-14	505105	909576	1656	Mollic Andosols	10.07	48.25	41.67	silty clay
15	SO-15	400524	981465	2482	Humic Nitosols	16.63	58.58	24.78	Clay
16	SO-16	427280	971042	2083	Eutric Vertisols	21.75	60.86	17.39	Clay

Table 5: Table of soil samples at different locations

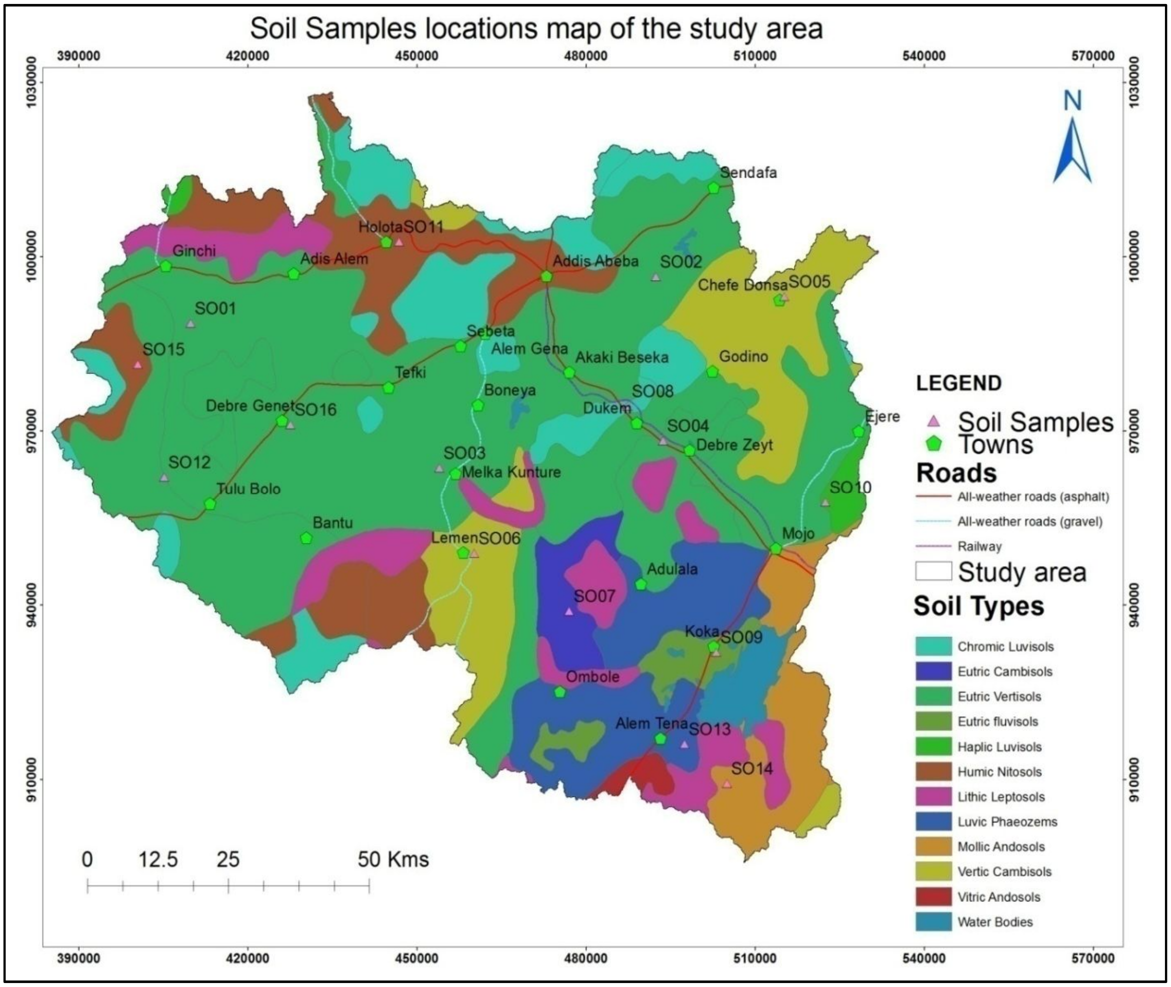


Figure 14: Soil Samples Location Map modified from (FAO, 1997)

S.N	Soil types	S.N	Soil types
1	Chromic Luvisols	7	Lithic Leptosols
2	Eutric Cambisols	8	Luvic Phaeozems
3	Eutric Vertisols	9	Mollic Andosols
4	Eutric Fluvisols	10	Vertic Cambisols
5	Haplic Luvisols	11	Vitric Andosols
6	Humic Nitosols	12	Water Bodies

Table 6: Table of Soil types based on FAO

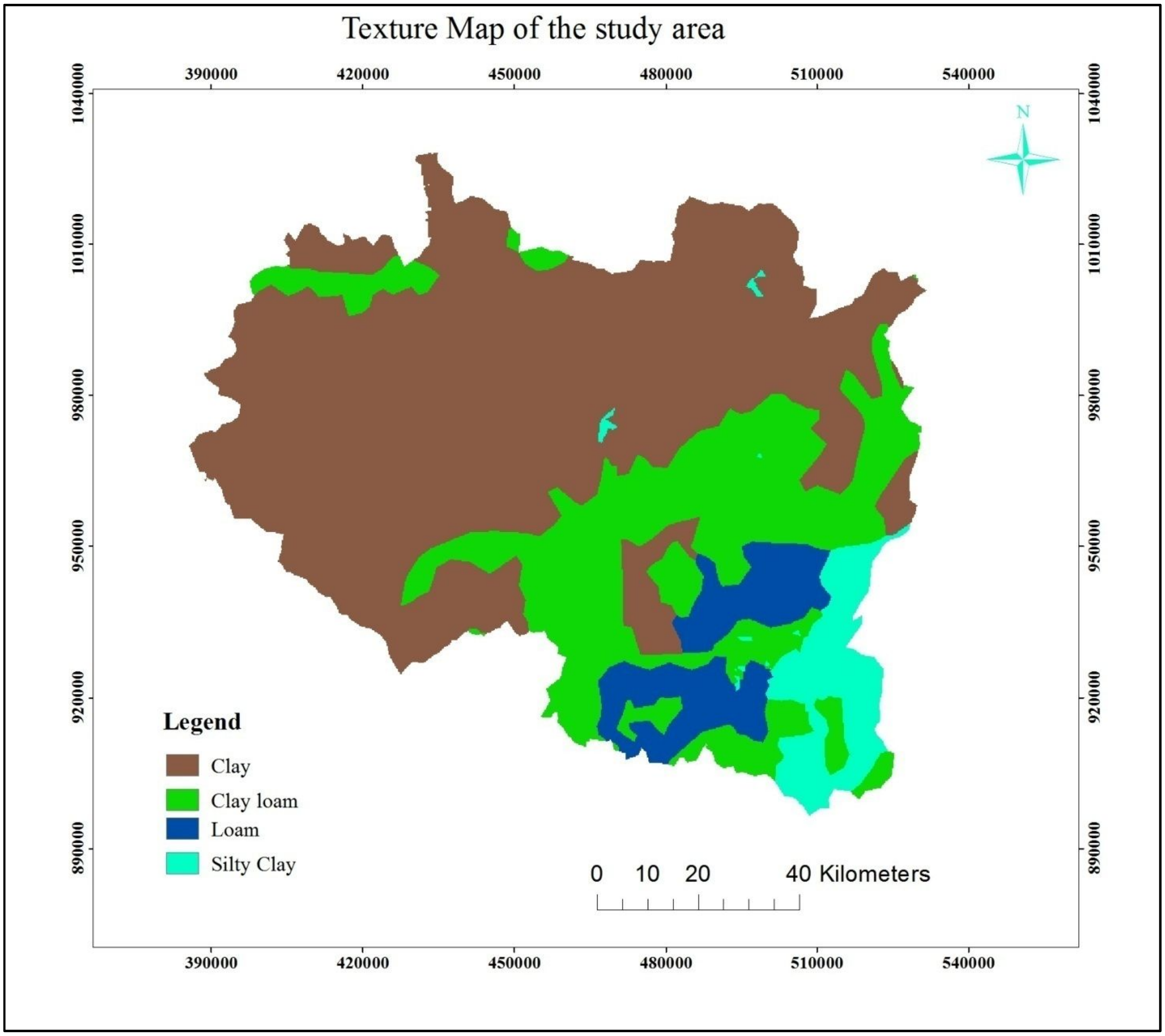


Figure 15: Soil Texture map of UAB

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1 INTRODUCTION

Recharge is a very crucial component for groundwater potential which limits the discharge amount of a certain area. Recharge is the downward movement of water into groundwater table through subsurface formations that come from Precipitation. The amount of recharge which reached to the water table depend on some factors such as soil type and texture, Land use and land cover conditions, Slope, Topography, Climatic parameters(Temperature, Rain fall, Wind speed and Evapotranspiration). Therefore by collecting these parameters from trusted sources groundwater recharge of Upper awash basin is estimated by using wetspass model method. WetSpass is a physically based model for estimation of long term average spatial patterns of groundwater recharge, surface runoff and evapotranspiration from long term average meteorological data, together with land-use, soil, and groundwater depth maps, by employing physical and empirical relationships.

WetSpass was originally developed for conditions in temperate regions in general and Belgium in particular. Land-use and soil types and length of dry and wet seasons of a year is that of conditions prevailing in Europe. However, land-use classes and soil textural classification of upper awash basin (central Ethiopia) are different from temperate regions. Moreover, some land-use classes exist in both conditions, but do not have the same characteristics. For example, forest in the Upper awash basin cannot be the same as in Belgium. Hence, leaf area index, vegetation height, root depth, and interception capacity have to be modified. In tropical regions, especially in Central Ethiopia, the winter season spans eight months (October to May) while the summer season is four months (June to September) in Ethiopian context. Figure 16 shows the annual variation of major meteorological parameters averaged over the available stations. Potential evapotranspiration in the Upper Awash Basin is relatively low during summer season because of reduced sunshine hours and the variation of temperature in the study area is show slight difference throughout the year. Average Precipitation of Upper Awash Basin is high against the two months which are July and August. Hence, some modification have to be made in the WetSpass parameter tables, and input maps are prepared with the same cell size 200mX200m, in order for the model to be applicable for conditions in the Upper Awash Basin. To produce appropriate result using wetspass model, the model needs two types of inputs. Such types of inputs are Arcview/Arc info grid files and tables (dbf) which briefly described in the following sub topics.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec
Average PPT	16.9	32.5	57.4	74.6	67.8	97.5	226	226	123.9	25.9	10.9	8.7
Average PET	108.1	107.8	129.4	124	126	112.3	99.2	100	100.6	118.1	111.8	106
Average WS	4.3	4.4	4.5	4.1	4.2	4.2	3.8	3.2	2.9	4.2	4.6	4.6
Average Temp.	17	18.1	19.3	19.5	19.7	18.9	17.5	17.4	17.7	17.4	16.8	16.3
Average SH	8.3	8.2	7.8	7.4	7.2	6.4	4.9	5.4	5.9	8	9.1	8.7

Table 7:Table of Average Major Meteorological Parameters

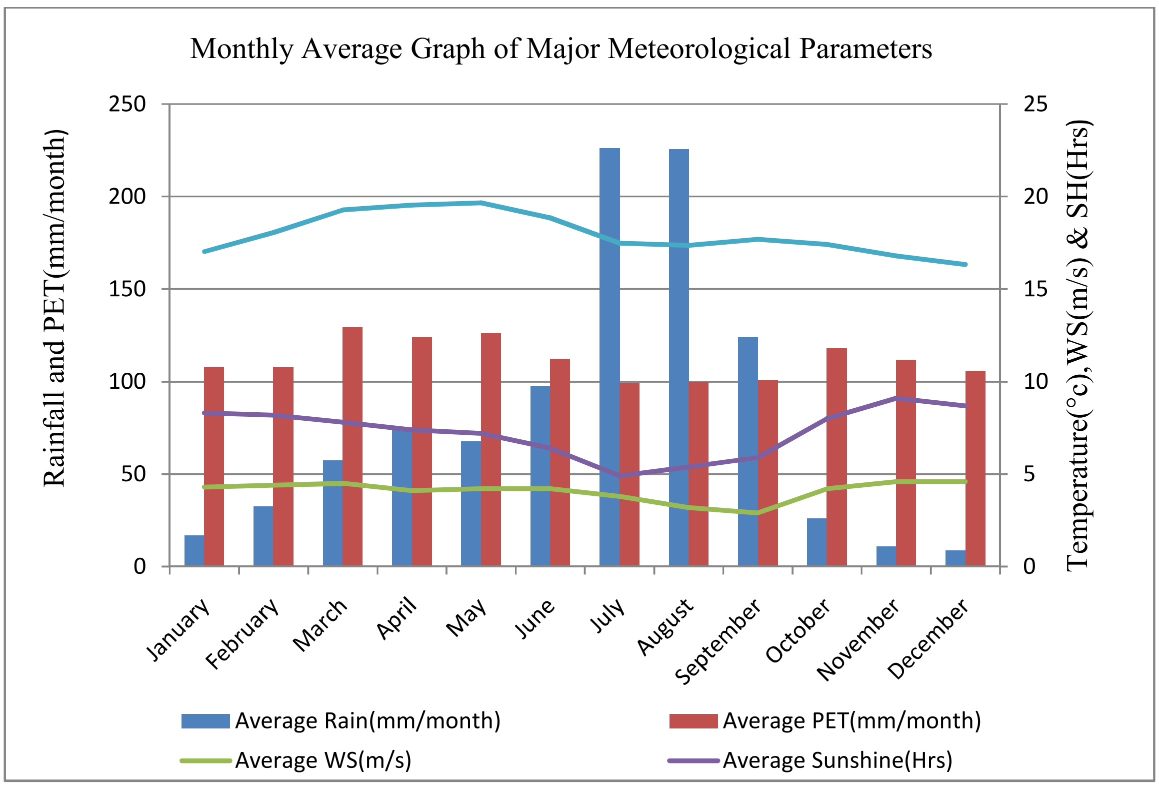


Figure 16: Mean monthly graph of meteorological parameters From New loc clime software

S.N	Station Name	X	X	Z	S.N	Station Name	X	X	Z
1	Addis Ababa_Bole	473623	998178	2460	14	Ginchi	404646	996601	2340
2	Akaki	476399	980257	2260	15	Holeta Genet	445053	1002629	2520
3	Alem Gena	435075	947363	2460	16	Intoto	469231	1003709	2903
4	Alem Tena	489758	916152	1660	17	Koka Dam	516880	935980	1600
5	Asgori	426683	971493	3320	18	Lemen	455987	950653	2082
6	Bantuliben	428480	951796	2167	19	Mojo	511809	951014	1840
7	Busa	301485	877147	1993	20	Sebeta	458223	986029	2500
8	Butajira	439406	896500	2120	21	Sendafa	502270	1011468	2820
9	Chefedonsa	513450	991331	2460	22	Sululta	472535	1014762	2560
10	Debre zeit	494408	965164	2100	23	Tefki	439300	977208	2063
11	Dire gidib	493408	1011436	2560	24	Tulubolo	411983	956250	2190
12	Dukem	489003	972742	2240	25	Zequala	483959	944219	3050
13	Ejere	528541	970096	2362					

Table 8: Locations of selected stations

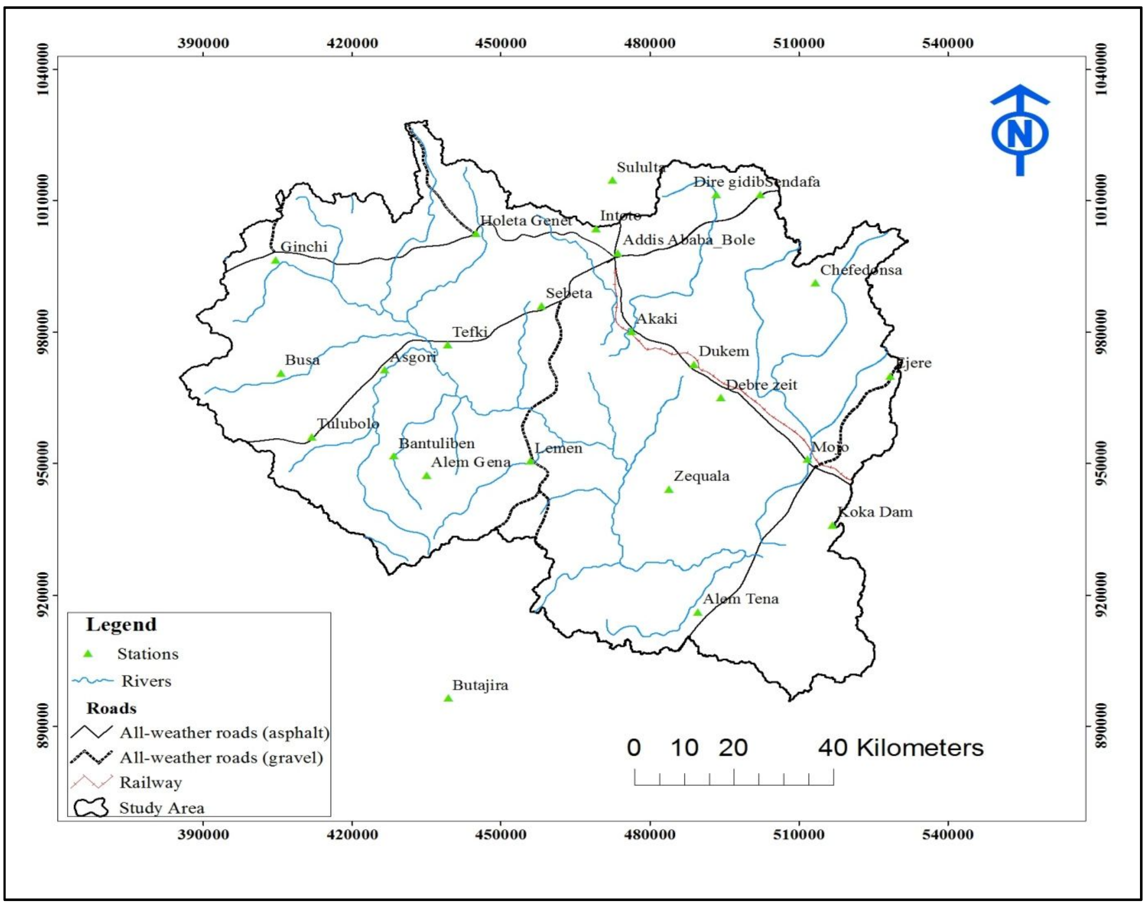


Figure 17:Meteorological stations in the study area

5.2 INPUT DATA PREPARATION

To estimate groundwater recharge of Upper Awash Basin using wetspass model, two types of inputs are required: grid maps and parameter tables. Grid maps are groundwater level depth, soil, Elevation, land-use, slope and meteorological maps like precipitation, potential evapotranspiration, wind speed and temperature which are prepared with the help of GIS applications in the form of (.asc). The other type of input parameters (tables) are prepared in database (.dbf) format for soil, Land use, daily rainfall summarized in the table and Figure below.

Arc View/Grid maps	Tables(dbf)
Elevation	Land use
Slope	Soil
Soil	Vegetation Runoff coefficient
Land Use	Bare runoff coefficient
GW depth	Impervious Runoff coefficient
Rain	
Temperature	
Rain	
Potential Evapotranspiration	

Table 9: Input Parameters

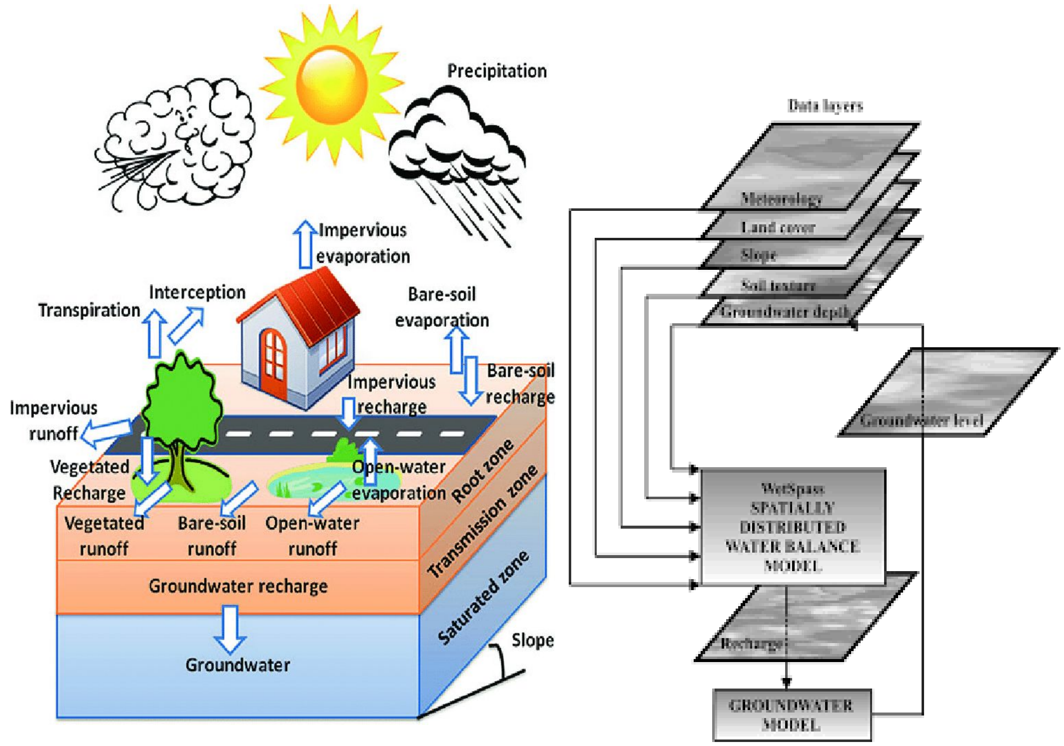


Figure 18 :Wetspass concept & Input layers adapted from(Batelaan and De Smedt, 2001, 2007)

5.2.1GRID MAPS

To use wetspass model nine grid maps are required which prepared by using GIS based applications with similar cell size. The cell size of each grid maps is 200 X 200meter. These nine grid maps are Slope, Elevation, GW depth, Land use, Soil maps and Major meteorological parameters map. Each grid maps discussed as follows.

5.2.1.1 Slope Map

Slope is one of the grid map input for recharge estimation using wetspass model because it is one of controlling factor for groundwater recharge. The slope map produced from DEM shape of the Upper Awash Basin using GIS applications in the form of ascii file. From slope we can differentiate the recharge and discharge areas of the study area. The recharge areas have the highest slope value and the discharge areas have the lowest slope values which means the elevation and the slope of the study area are directly related. The slope of the study area is variable which ranges from 0 to 44 degrees and the mean and standard deviations are 3.36 and 3.61 degrees respectively. Zero values indicate that the area is lowland area and flat land and 44 degrees indicate that the area is highland area or highly elevated area in the study area.

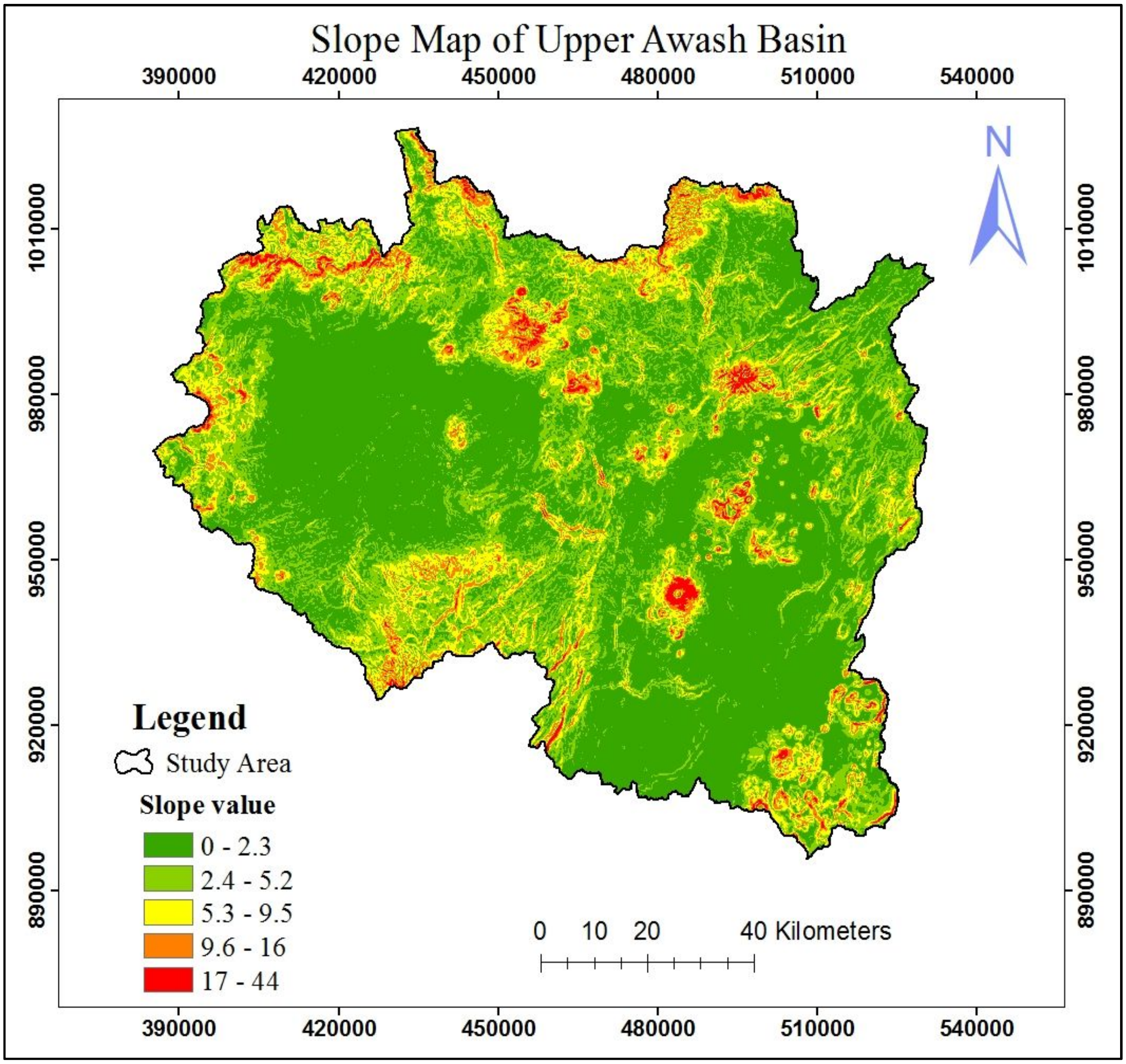


Figure 19: Slope map of the study area

5.2.1.1 Elevation map

Elevation map is one type of grid map for the input of the wetspass model because it is one of the major factor which affects the groundwater recharge in the study area. The recharge in the higher area is fast and slow in the lowland area. The elevation of the study area shows greater variation which ranges from 1542m to 3555m as shown below in the map. The mean elevation value of the study area is 2155m.

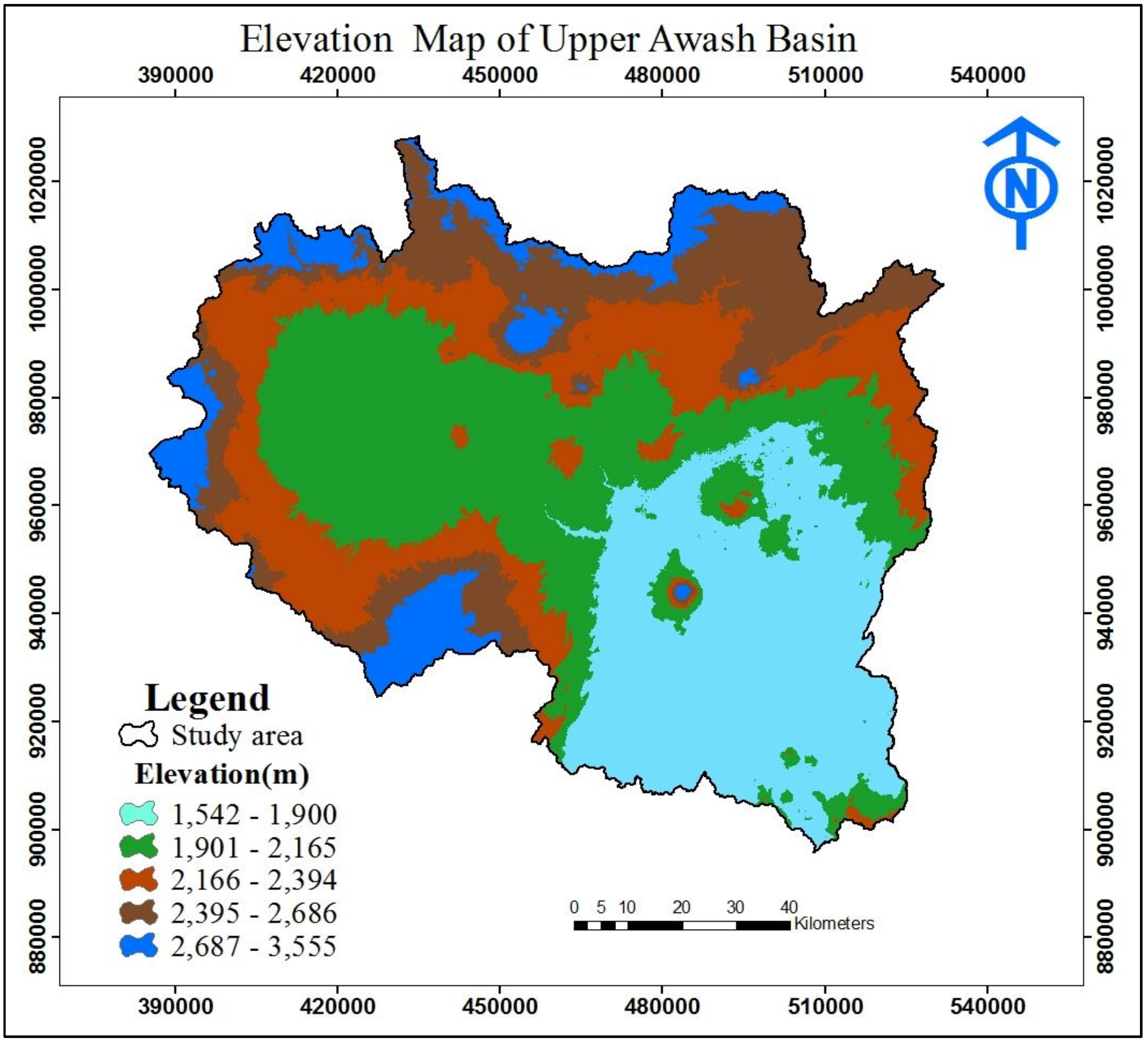


Figure 20: Elevation Grid map of UAB

5.2.1.3 Groundwater Depth Map

Groundwater level map is one input grid map to the WetSpass model. Around 1052 wells data were collected and used from the vicinity and suburbs of Upper Awash Basin to produce groundwater depth grid map and interpolated. After interpolation the map is clipped by the boundary of the study area. Generally the static water level in the Upper Awash Basin is deep, in the order of 20 to 100 m and sometimes even deeper than 100m. There are wells which have static water level below 20m and some wells are artesian wells. The Groundwater level depth map which is produced by deducting the static water level from the surface elevation from collected wells is shown below and the data is attached at Annex I. As shown below in the map the values of groundwater elevation ranges from 1490m to 2738m and the mean value is 2037m.

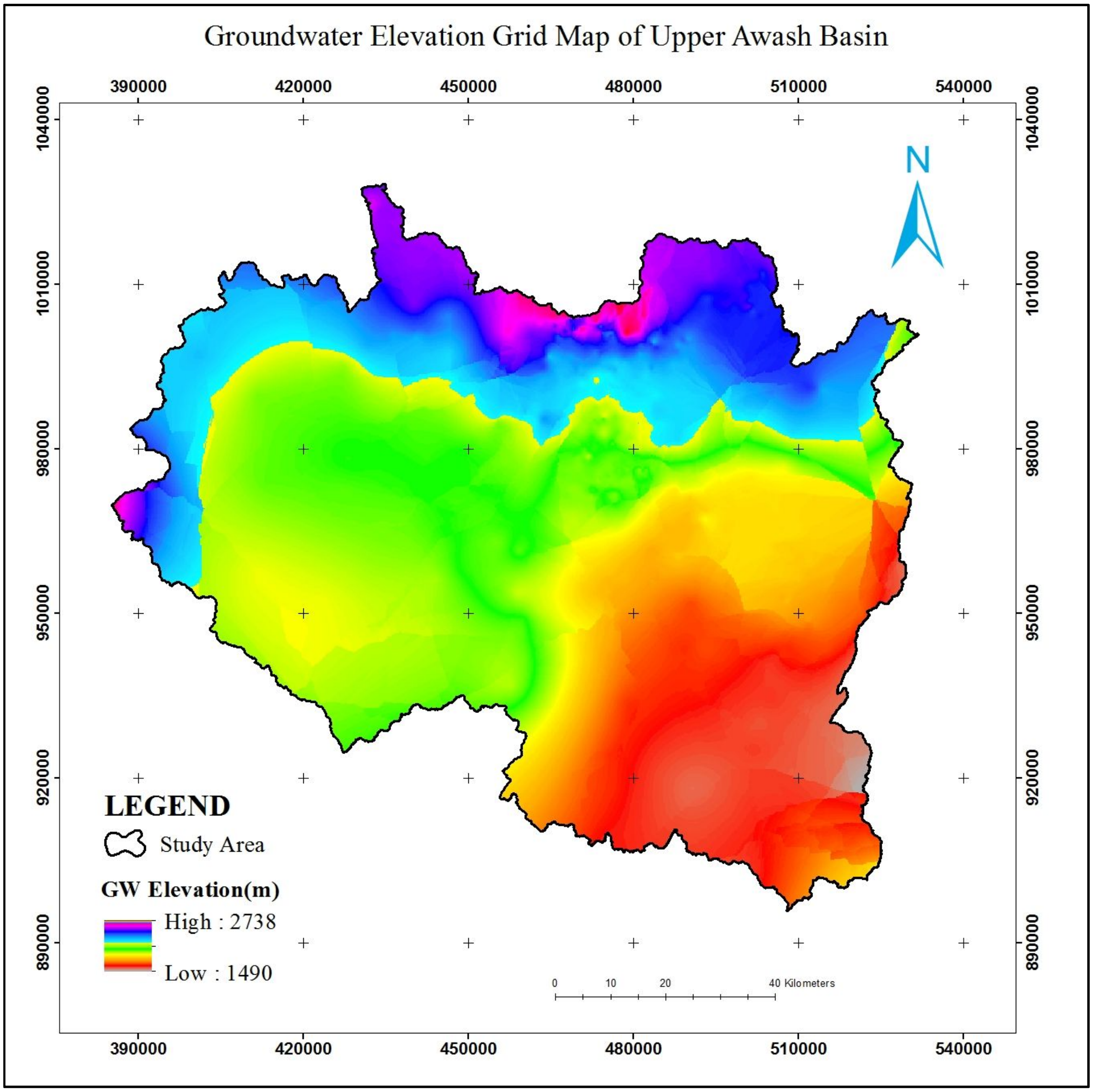


Figure 21: Groundwater Elevation Grid Map

5.2.1.4 Soil and Land Use Grid Map

Soil and Land use Grid maps also an important inputs for Wetspass Model. Both land use and soil grid maps discussed on topic 4.6 and 4.7 respectively.

Soils affect the infiltration amount of water in a certain area. To prepare soil grid map sixteenth soil samples were collected from the study area and textural classification analyzed. Based on laboratory soil test result textural grid map of the study area is produced by correlating the texture of each soil sample with their soil code from soil table parameter.

Land use land cover determines the groundwater recharge, evapotranspiration and surface runoff of the study area. In bare areas the runoof is high; in the vegetation areas

Evapotanspiration is high. In similar way to soil grid map preparation, land use land cover grid map of the study area is produced by correlating each land use type with the code from land use table parameters.

5.2.2 PARAMETRE TABLES

The wetspass model requires table parameters such as soil, land use, vegetation runoff coefficient, bare land runoff coefficients and impervious coefficients. These parameter tables need some modifications and modified based on Ethiopian context because these attribute tables prepared for temperate areas.

5.3 RESULTS AND DISCUSSIONS

5.3.1 Hydro-meteorological data analysis

For calculation of hydrologic balance for a given catchment, the hydro-meteorological elements such as rainfall, actual evapotranspiration, runoff and groundwater recharge has to be quantified. By using wetspass modeling method Recharge, Actual evapotranspiration, and Surface runoff amounts of the study area has been estimated. To estimate the above parameters, the meteorological data that collected from the study area are properly analyzed and prepared as input for wetspass model. These meteorological data are rainfall, potential evapotranspiration, temperature, and wind speed and sunshine hours discussed below turn by turn.

5.3.1.1 Rainfall

In the Upper Awash basin the rainfall distribution is variable throughout the year. Rainfall is the main controlling factors in the study area which limits the recharge amount. As shown below in figure 25, the maximum rainfall is occurred at the two months namely July and August and the minimum rainfall is occurred from October to February. The rainfall pattern of the basin is mono-modal type with 70% of the rainfall occurring in wet season (i.e. June-September). The rest 30 % occurs in the dry season from October to May shown below in figure 25 and figure 26. Based on new loc clime data the Minimum, Maximum and Mean Annual precipitation of the study area is 884mm, 1113mm and 1010mm respectively. From meteorological data the mean annual precipitation is about 1024mm.

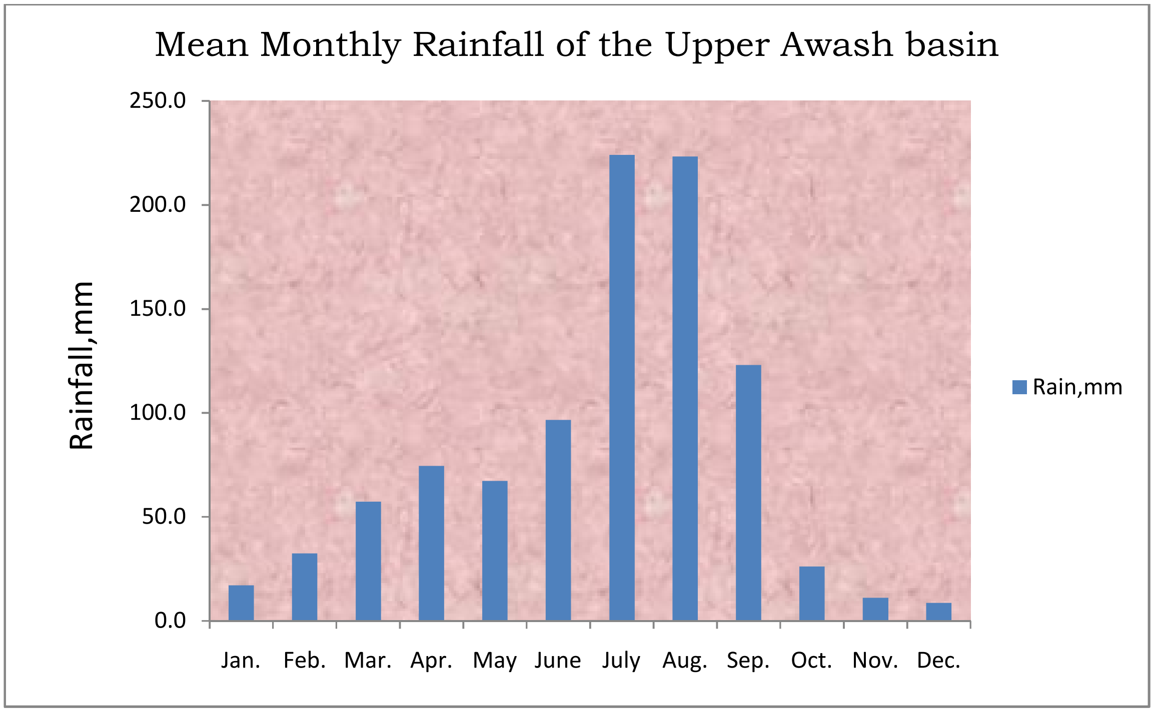


Figure 22:Mean Monthly Rainfall graph of the basin

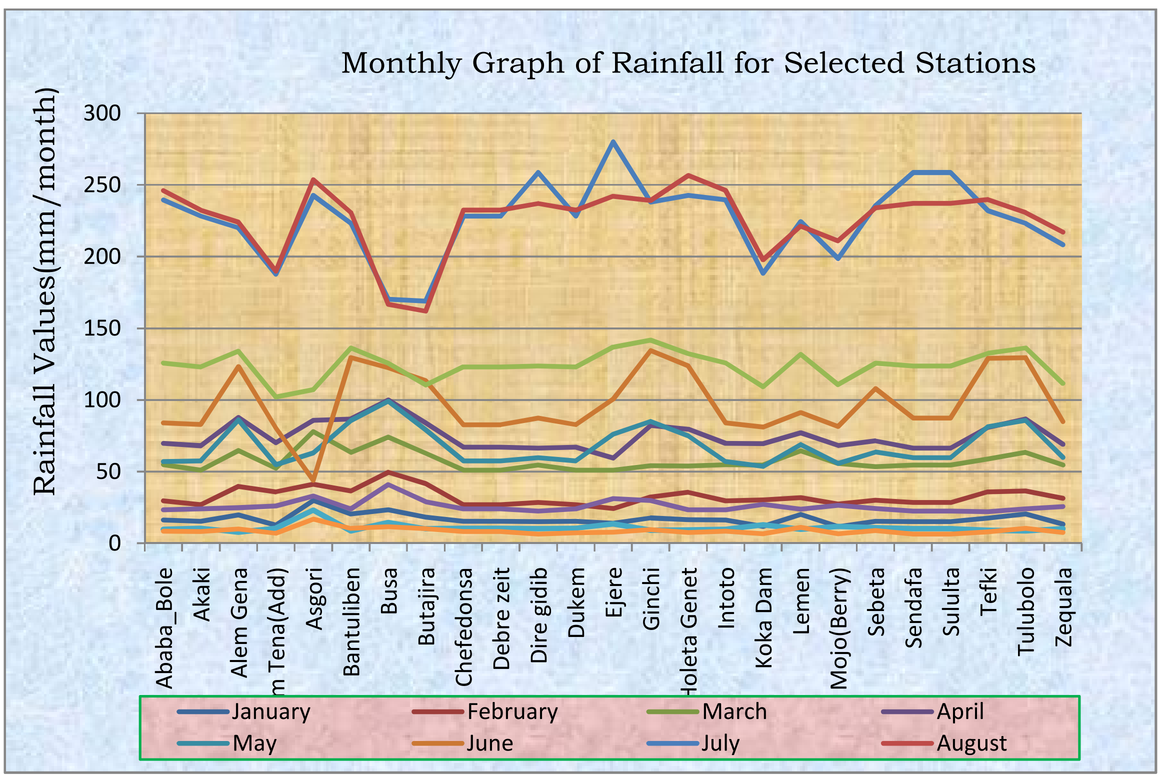


Figure 23: Monthly Graph of Rainfall for Selected stations

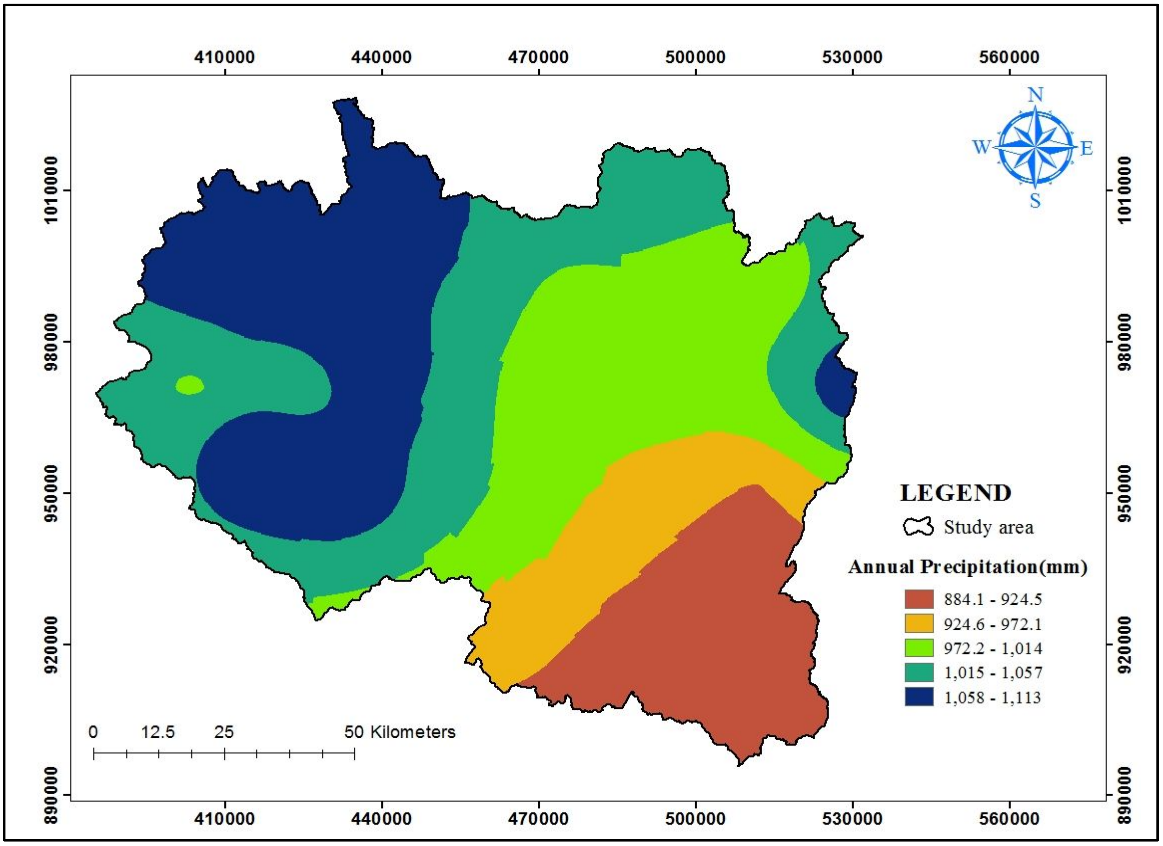


Figure 24:Rainfall Distribution map of upper awash basin

5.3.1.2 Potential Evapotranspiration (PET)

Potential Evapotranspiration is a combination process of evaporation and transpiration which is the process where vapor is transferred from both surface and vegetation. It can be computed by using different methods. One method is penman monteith to compute potential evapotranspiration. This method needs some meteorological parameters such as rainfall, Temperature, wind speed, sunshine hours and relative humidity. But the stations in the upper awash basin are not fully recorded all meteorological parameters. Based on penman monteith method the potential evapotranspiration computed for two stations only and shown below in table 10. By comparing the potential evapotranspiration of Pennman Monteith and new loc clime, potential evapotranspiration of new loc clime data used because the data of these two methods is more or less similar.

Station	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Dec
AAO	PETM	107.3	111.4	125.9	116.1	114.7	94.2	80.0	81.8	91.5	113.5	105.0
	PETN	107.7	108.3	131.1	125.6	127.0	110.0	97.3	99.5	101.1	119.6	113.2
Debre Zeit	PETM	122.7	143.7	147	146.7	147.3	124.2	103.5	97.5	115.2	135.6	129
	PETN	108.2	107.6	130.3	125.0	126.9	117.3	104.0	103.4	102.5	118.6	112.5

Table 10: Potential Evapotranspiration of AAO & Debre Zeit Using Pennman Moiteth and New Loc Clime

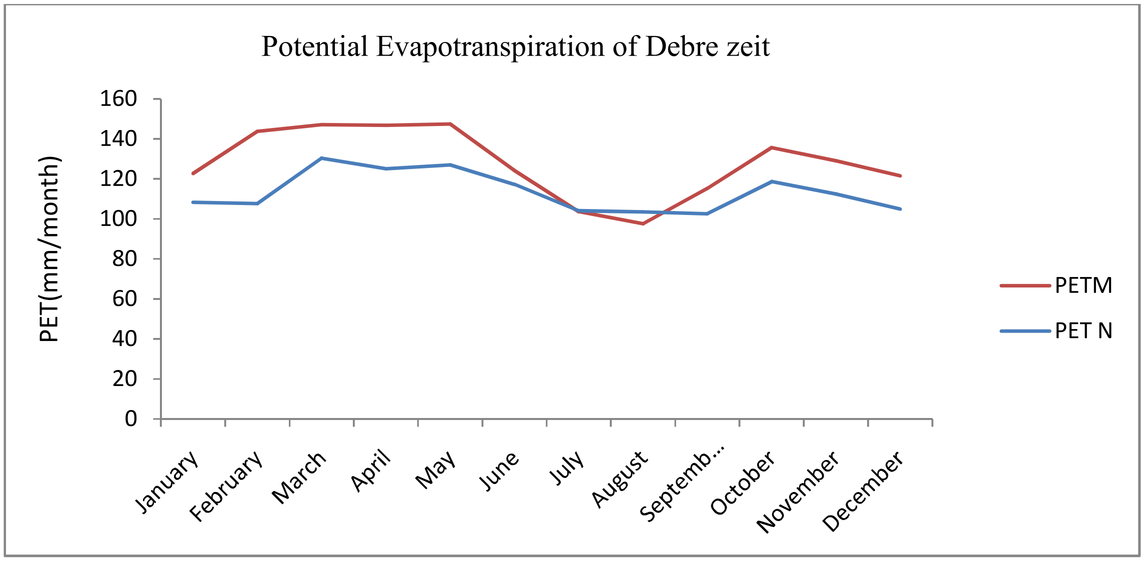


Figure 25:Graph of Evapotranspiration using Pennman Monteith and New loc clime

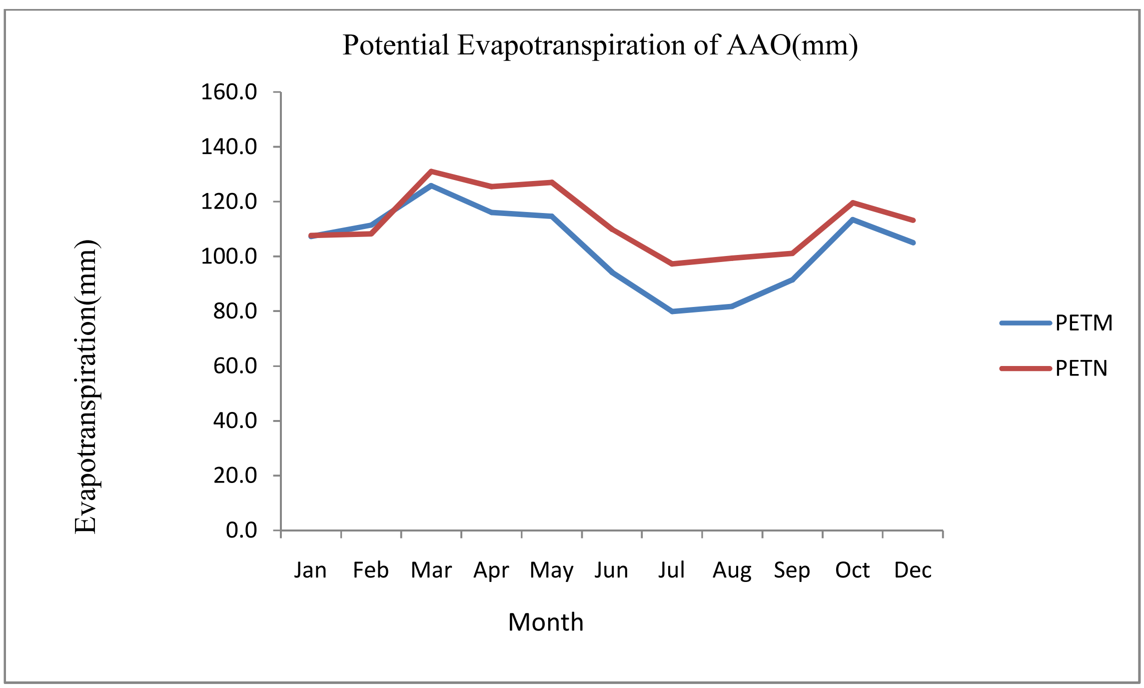


Figure 26: Graph of Evapotranspiration for AAO using Pennman Monteith and New loc clime data

Potential Evapotranspiration data of the upper awash basin is collected from selected new loc clime meteorological stations in the vicinity of the study area shown below in the table and figure. The Maximum Potential Evapotranspiration is recorded in the month of March and the minimum potential evapotranspiration is recorded in the month of July. Generally the minimum potential evapotranspiration is during in the wet season and the maximum potential evapotranspiration is occurred during the dry season which is shown below in figure 27.

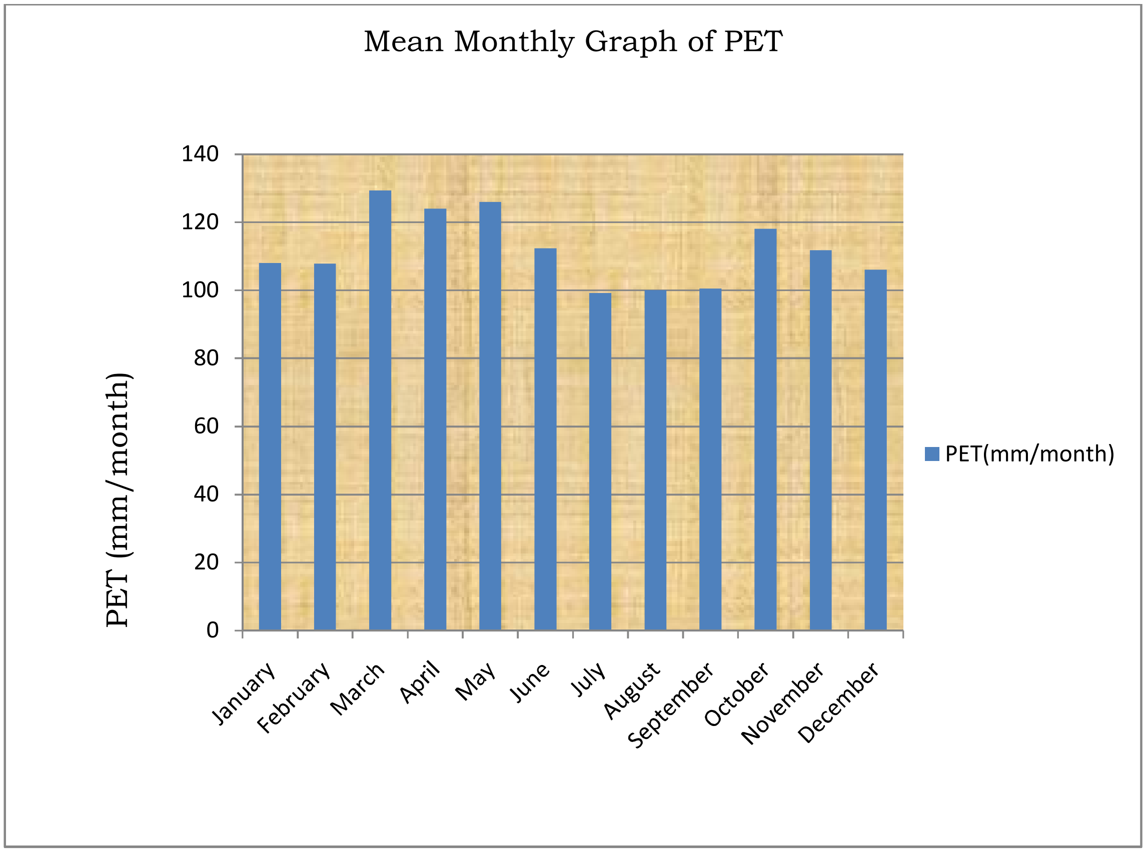


Figure 27: Mean Monthly graph of Potential Evapotranspiration

S.N	Station Name	January	February	March	April	May	June	July	August	Septembe	October	Novembe	December	Total Annual PET	Mean Annual PET
1	Addis Ababa_Bole	107.7	108.3	131.1	125.6	127	110	97	99.5	101.1	119.6	113.2	106.6	1346.9	112.2
2	Akaki	107.3	106.7	129.2	123.3	125.3	114.5	102	101.6	101.3	117.8	111.3	104.5	1344.8	112.1
3	Alem Gena	111.1	110.5	132.4	125.8	125.8	108.3	96	99.3	99.7	120.3	113.9	110.2	1353.5	112.8
4	Alem Tena	107.2	106.7	128	123.4	124.7	117.4	105	104.2	101.1	116.1	110.4	103.2	1347.3	112.3
5	Asgori	104.7	106.9	125.4	123.1	138.6	127	104	100.3	101.2	118	109.3	104.5	1363.1	113.6
6	Bantuliben	111.1	110.5	132.4	125.8	125.8	108.3	96	99.3	99.7	120.3	113.9	110.2	1353.5	112.8
7	Busa	109.4	108.2	126.5	118.3	117.2	104.4	94	96.2	94.5	111.8	108.3	105.7	1294.4	107.9
8	Butajira	107.9	106.1	124.6	118	119	108.9	95	96.1	94.2	112	108	104.1	1293.8	107.8
9	Chefedonsa	106.8	106	129.3	124.1	128	119.9	107	105.8	106	118.7	111.3	104	1367.1	113.9
10	Debre zeit	108.2	107.6	130.3	125	126.9	117.3	104	103.4	102.5	118.6	112.5	105	1361.3	113.4
11	Dire gidib	106.2	106	129.6	125	128.9	118.1	106	103.9	106	119	111.3	104	1364	113.7
12	Dukem	108.2	107.6	130.3	125	126.9	117.3	104	103.4	102.5	118.6	112.5	105	1361.3	113.4
13	Ejere	109.1	109.8	126.4	123.9	125.1	100.7	83	86.1	93.2	117.5	112.9	107.7	1295.7	108
14	Ginchi	110.4	109.7	128	123.2	122.6	99.1	86	89.2	94.1	117.5	112.6	109.6	1301.6	108.5
15	Holeta Genet	109.4	109.2	131	125.5	126.6	107.8	95	97.7	100.3	119.5	113.5	108.3	1343.9	112
16	Intoto	107.7	108.3	131.1	125.6	127	110	97	99.5	101.1	119.6	113.2	106.6	1346.9	112.2
17	Koka Dam	107.3	105.9	126.8	122.8	123.9	117.7	105	104	101.3	115.1	109.7	102.5	1341.5	111.8
18	Lemen	107.7	108.1	131.4	125.4	126.5	112.9	102	101.1	102.3	119.4	112.2	106.2	1355	112.9
19	Mojo	107.5	105.9	128	122.6	124.6	114.8	101	101.5	101.5	116.8	110.6	103.9	1339	111.6
20	Sebeta	108	108.6	131.5	125.1	125.7	109.9	99	101.1	101.4	119.8	112.6	106.7	1348.9	112.4
21	Sendafa	106.2	106	129.6	125	128.9	118.1	106	103.9	106	119	111.3	104	1364	113.7
22	Sululta	105.2	106.1	128.9	123.9	126.8	111.8	99	101	102	118.1	111.4	104.1	1337.9	111.5
23	Tefki	109.8	109.5	131.4	125	125.3	107.8	96	99.4	100.7	119.6	112.9	108.5	1345.9	112.2
24	Tulubolo	111.1	110.5	132.4	125.8	125.8	108.3	96	99.3	99.7	120.3	113.9	110.2	1353.5	112.8
25	Zequala	108.2	107.6	130.3	125	126.9	117.3	104	103.4	102.5	118.6	112.5	105	1361.3	113.4
Average PET(mm/month		108.1	107.8	129.4	124	126	112.3	99	100	100.6	118.1	111.8	106	1343.4	112

Table 11:Table of Potential Evapotranspiration for Selected stations

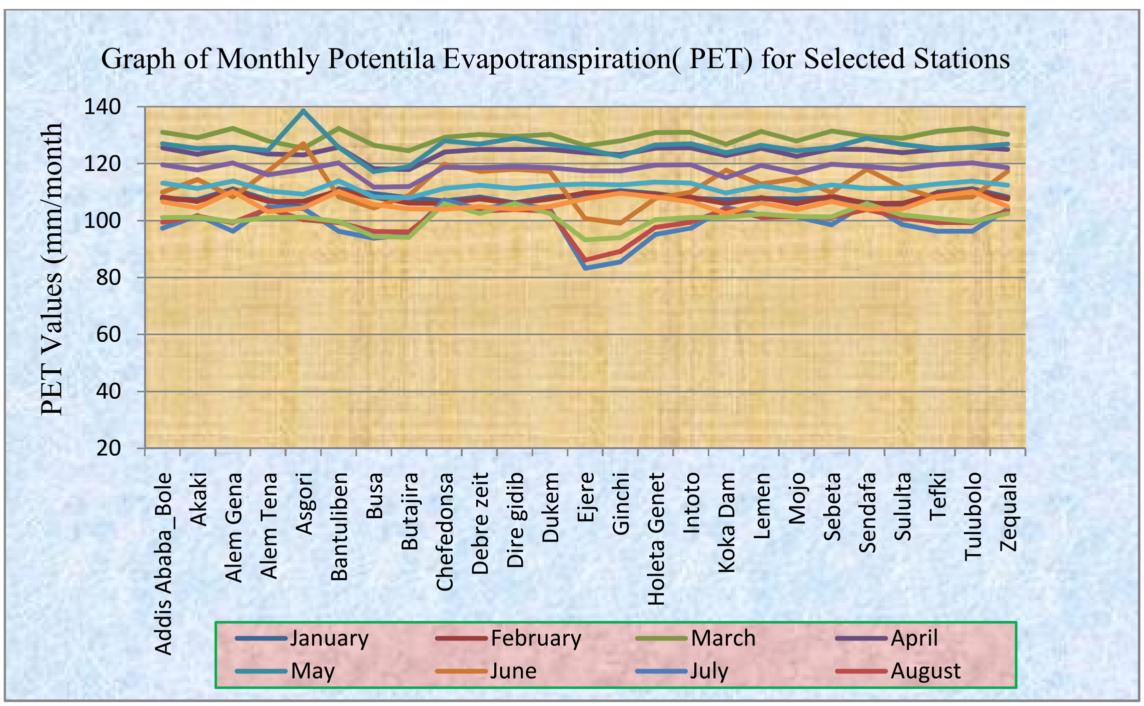


Figure 28 : Graph of Monthly potential Evapotranspiration for Selected stations

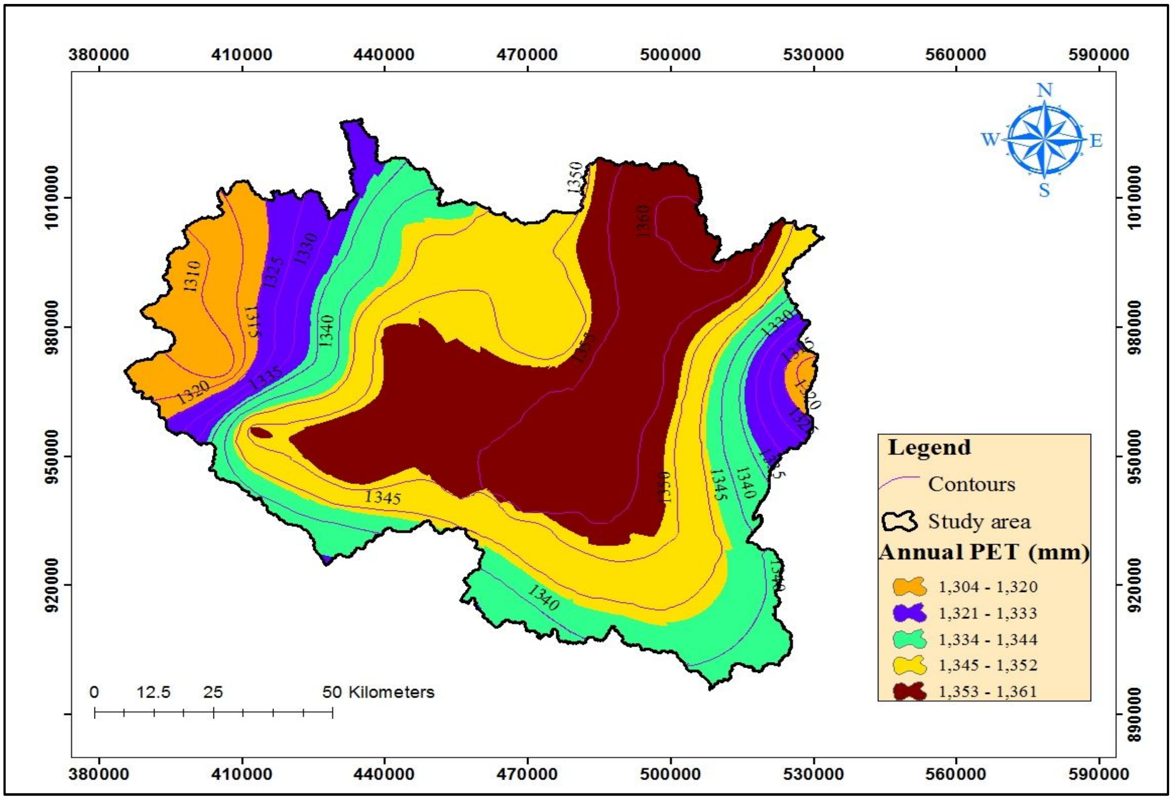


Figure 29:Annual Potential Evapotranspiration map

5.3.1.3 Temperature

Temperature is one of controlling factors which affects the evaporation of the study area. High amount of temperature leads to high amount of evaporation. As we observed from the table and figure below the maximum Average mean temperature is recorded at the month of May which is 19.7°c and the minimum Average mean Temperature is recorded at the month of December which is 16.3°c.The maximum Mean temperature recorded at the month of May at Mojo station which is 21.1°c and the minimum mean temperature recorded at the month of December in three stations such as Dire gidib, Sendafa and Sululta which is 15.2°c. The maximum Temperature affects the groundwater recharge of the study area by removing water through Evaporation process. During dry season the groundwater recharge of the study area is low due to high temperature and low precipitation. Based on the above concept temperature is one of important input parameter for Wetspass model application. Mean Monthly temperature grid maps of selected stations are prepared by using GIS based applications.

SN	Station Name	January	February	March	April	May	June	July	August	September	October	November	December	Mean Annual Temperature
1	Addis Ababa_Bole	17.0	18.1	19.7	20.0	20.1	19.4	17.9	17.7	18.2	17.6	16.9	16.3	18.2
2	Akaki	17.3	18.5	20.0	20.3	20.5	19.7	18.3	18.2	18.5	18.1	17.3	16.7	18.6
3	Alem Gena	17.2	18.2	19.1	19.1	19.2	18.1	16.9	16.8	17.2	17.4	16.9	16.7	17.7
4	Alem Tena	17.6	18.6	20.0	20.5	20.6	20.1	18.8	18.6	18.7	18.4	17.5	16.7	18.8
5	Asgori	16.1	17.4	18.1	18.9	19.5	20.1	18.6	18.0	18.2	17.3	16.2	15.8	17.8
6	Bantuliben	17.2	18.1	19.0	18.9	19.0	17.6	16.5	16.5	16.8	17.0	16.7	16.7	17.5
7	Busa	17.3	18.2	18.7	18.7	18.4	17.5	16.7	16.5	17.0	17.1	16.8	16.5	17.4
8	Butajira	17.1	18.0	18.6	18.8	18.6	17.8	16.9	16.7	17.0	17.2	16.7	16.4	17.5
9	Chefedonsa	17.2	18.3	19.8	20.1	20.6	19.9	18.3	18.3	18.6	17.9	17.2	16.6	18.5
10	Debre Zeit	17.3	18.5	20.0	20.3	20.5	19.7	18.3	18.2	18.5	18.1	17.3	16.7	18.6
11	Dire gidib	15.9	17.0	18.4	18.8	19.1	18.3	16.7	16.9	17.1	16.5	15.9	15.2	17.1
12	Dukem	17.3	18.5	20.0	20.3	20.5	19.7	18.3	18.2	18.5	18.1	17.3	16.7	18.6
13	Ejere	16.0	17.0	18.2	18.6	18.6	17.7	15.6	15.7	16.2	16.0	15.6	15.3	16.7
14	Ginchi	17.3	18.0	19.0	18.9	19.1	17.7	16.6	16.5	16.8	16.9	16.5	16.5	17.4
15	Holeta Genet	17.0	17.9	19.1	19.2	19.1	17.9	16.7	16.5	16.8	16.9	16.3	16.0	17.4
16	Intoto	16.6	17.6	19.1	19.5	19.7	19.0	17.4	17.4	17.8	17.2	16.5	15.8	17.8
17	Koka Dam	17.7	18.6	20.1	20.5	20.7	20.3	19.0	18.8	19.0	18.4	17.5	16.9	18.9
18	Lemen	17.3	18.2	19.5	19.7	19.9	18.8	17.5	17.3	17.8	17.7	17.1	16.7	18.1
19	Mojo	17.8	18.9	20.5	20.9	21.1	20.5	19.1	18.9	19.1	18.7	17.8	17.1	19.2
20	Sebeta	17.6	18.7	20.0	20.2	20.3	19.3	17.9	17.9	18.2	18.0	17.4	16.9	18.5
21	Sendafa	15.9	17.0	18.4	18.8	19.1	18.3	16.7	16.9	17.1	16.5	15.9	15.2	17.1
22	Sululta	15.9	17.0	18.4	18.8	19.1	18.3	16.7	16.9	17.1	16.5	15.9	15.2	17.1
23	Tefki	17.6	18.5	19.5	19.5	19.6	18.3	17.1	17.0	17.2	17.3	16.9	16.7	17.9
24	Tulubolo	17.2	18.1	19.0	18.9	19.0	17.6	16.5	16.5	16.8	17.0	16.7	16.7	17.5
25	Zequala	17.3	18.5	20.0	20.3	20.5	19.7	18.3	18.2	18.5	18.1	17.3	16.7	18.6
Average Temperature		17.0	18.1	19.3	19.5	19.7	18.9	17.5	17.4	17.7	17.4	16.8	16.3	17.9

Table 12: Table of Mean Temperature for Selected Stations

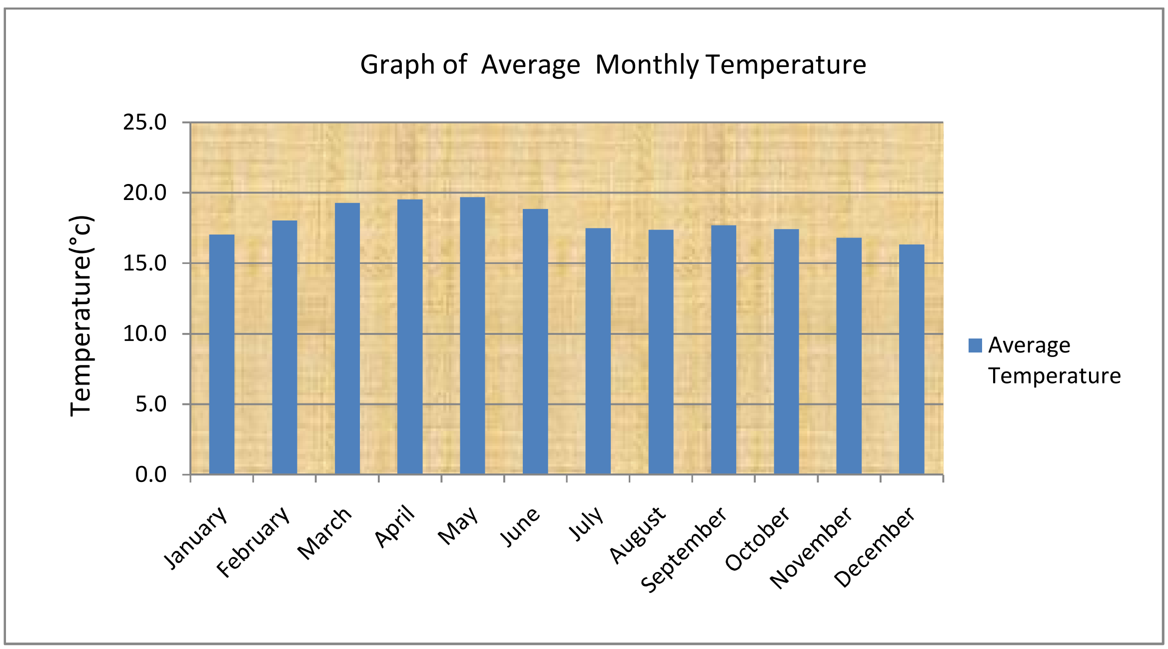


Figure 30: Average Monthly Temperature

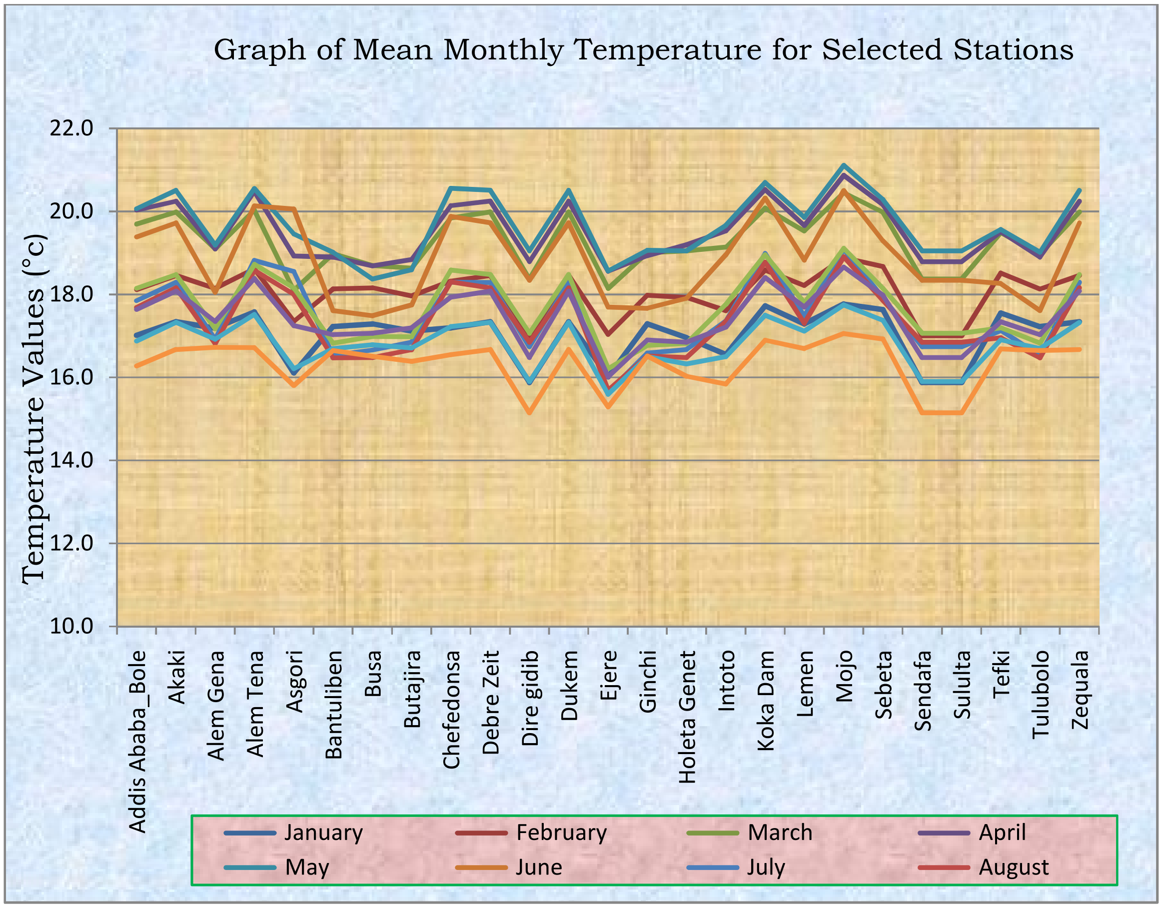


Figure 31:Mean monthly Temperature graph of selected stations

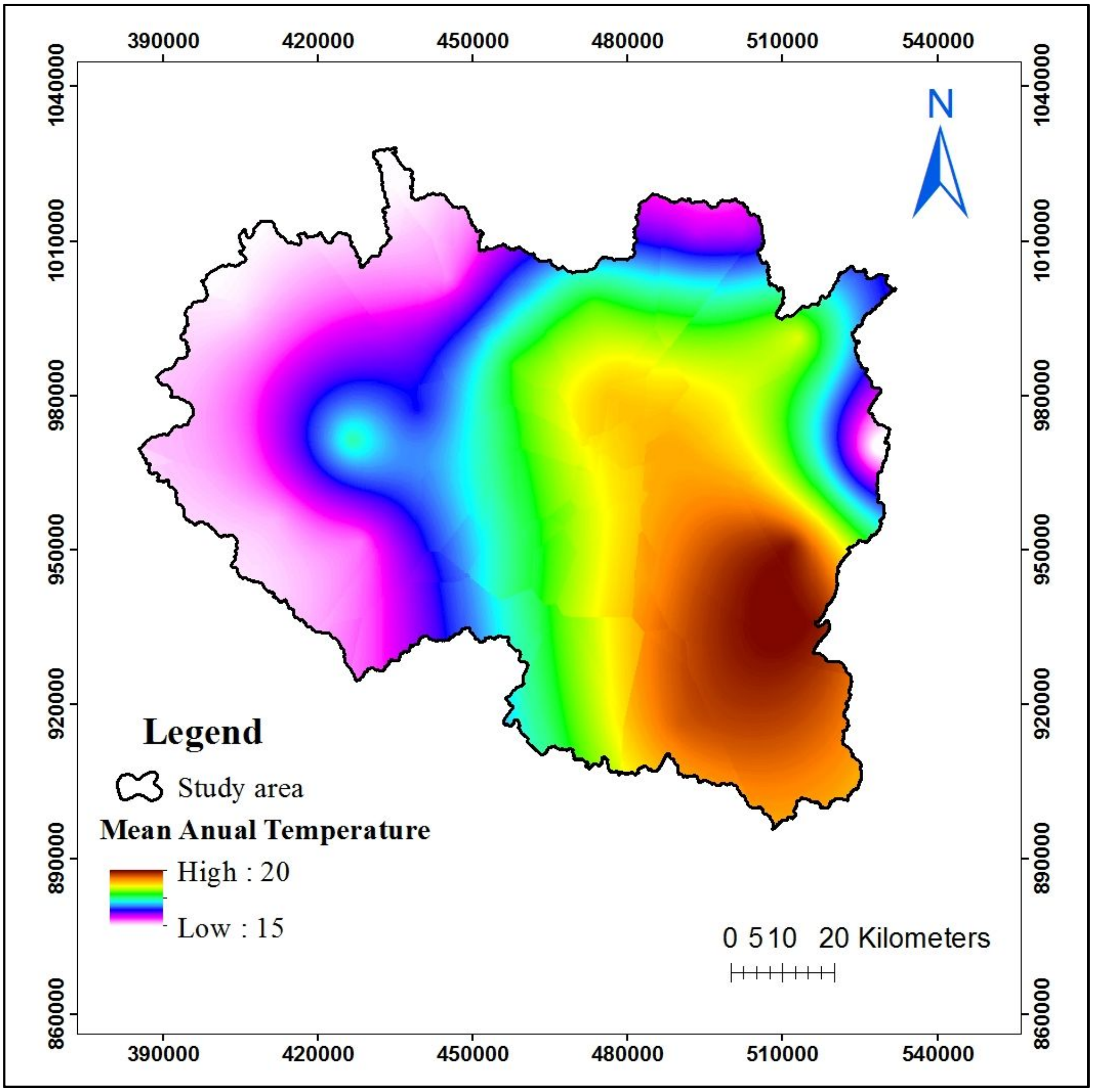


Figure 32: Mean Annual Temperature of the study area(°c)

5.3.1.4 Wind Speed

Wind speed is one of controlling factor which is the driving force evaporation to remove the moisture content in the study area. As observed from the table and figure below the maximum average Wind speed is 4.6m/s recorded at the month of December and the minimum average Wind Speed is 2.9m/s recorded at the month of September. Wind speed is one of input parameter for Wetspass model to estimate recharge of the study area which is prepared as a grid map with 200m cell size using GIS based applications. From the table and graph below the highest wind is observed at the dry season and the minimum wind speed is observed at the wet season. The mean annual wind speed ranges from 3.71m/s to 5.54m/s and the average mean annual wind speed is about 4.06m/s. The highest wind speed in the dry season affects recharge of the study area by removing the moisture content from the soil and vegetation.

SN	Station Name	January	February	March	April	May	June	July	August	Septembe	October	November	December	Mean Annual WS
1	Addis Ababa_Bole	4	4.2	4.4	4	4.1	3.9	3.6	3.1	2.7	4.3	4.5	4.6	3.9
2	Akaki	4.1	4.3	4.4	3.9	4	3.9	3.6	3.1	2.7	4.3	4.6	4.5	3.9
3	Alem Gena	4.6	4.6	4.6	4.3	4.3	4.2	3.7	3.1	2.7	4.4	4.9	4.9	4.1
4	Alem Tena	4	4	4.2	3.7	3.7	4.1	3.7	3.2	2.7	3.9	4.3	4.2	3.7
5	Asgori	5.4	5.7	6.1	5.6	6.3	6.2	5.5	4.7	4.4	5.2	5.2	5.6	5.5
6	Bantuliben	4.6	4.6	4.6	4.3	4.3	4.2	3.7	3.1	2.7	4.4	4.9	4.9	4.1
7	Busa	4	4	4.3	3.8	3.8	4.5	3.4	3	3.1	3.6	4.3	4.3	3.8
8	Butajira	3.8	3.9	4.1	3.7	3.8	4.3	3.4	2.8	3.1	3.8	4.4	4.3	3.7
9	Chefedonsa	3.9	3.9	4	3.7	3.7	4.4	4	3.4	2.7	3.6	4	4	3.7
10	Debre Zeit	4	4	4.2	3.7	3.7	4.1	3.7	3.2	2.7	3.9	4.3	4.2	3.7
11	Dire gidib	4.3	4.4	4.6	4.2	4.3	4.3	4.1	3.4	2.9	4.3	4.6	4.6	4.1
12	Dukem	4	4.1	4.3	3.8	3.9	4	3.6	3.1	2.7	4.1	4.5	4.3	3.8
13	Ejere	5	5.2	5.1	5.2	5.2	4.1	3.8	3.4	3.8	5.5	5.7	5.3	4.8
14	Gichi	5.2	5.4	5.3	5.2	5.2	4	3.8	3.4	3.9	5.8	6.1	5.7	4.9
15	Holeta Genet	4.4	4.4	4.4	4.2	4.3	3.9	3.6	2.9	2.7	4.3	4.6	4.8	4
16	Intoto	4.3	4.3	4.3	4.1	4.3	4.1	3.6	3	2.7	4.1	4.4	4.6	3.9
17	Koka Dam	4.1	4.1	4.2	3.9	3.8	4.3	3.9	3.5	3	3.9	4.3	4.1	3.8
18	Lemen	4.1	4.3	4.4	3.9	4	3.9	3.6	3.1	2.7	4.3	4.6	4.5	3.9
19	Mojo(berry)	4	4	4.1	3.7	3.6	4.3	4	3.4	2.8	3.7	4.1	4	3.7
20	Sebeta	4.4	4.4	4.4	4.2	4.3	3.9	3.6	2.9	2.7	4.3	4.6	4.8	4
21	Sendafa	4.1	4.1	4.3	3.9	4	4.4	4	3.4	2.7	4	4.4	4.3	3.9
22	Sululta	4.3	4.3	4.3	4.1	4.3	4.1	3.6	3	2.7	4.1	4.4	4.6	3.9
23	Tefki	4.4	4.4	4.4	4.2	4.3	3.9	3.6	2.9	2.7	4.3	4.6	4.8	4
24	Tulubolo	4.6	4.6	4.6	4.3	4.3	4.2	3.7	3.1	2.7	4.4	4.9	4.9	4.1
25	Zequala	4	4	4.2	3.7	3.7	4.1	3.7	3.2	2.7	3.9	4.3	4.2	3.7
Average WS(m/s)		4.3	4.4	4.5	4.1	4.2	4.2	3.8	3.2	2.9	4.2	4.6	4.6	4

Table 13: Monthly Wind Speed of Selected Stations

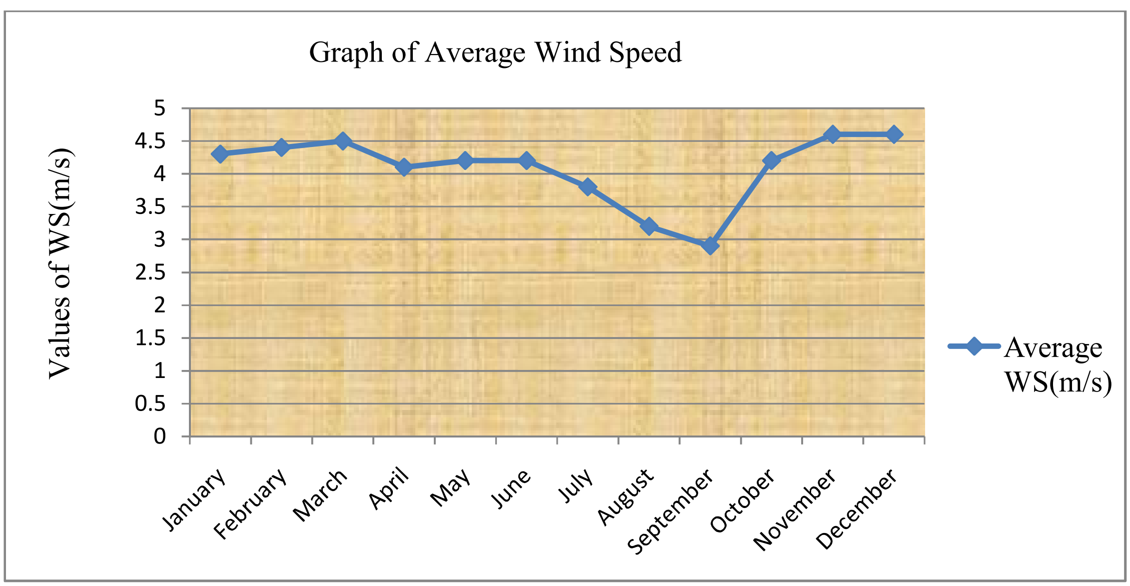


Figure 33: Monthly Average Wind Speed Graph

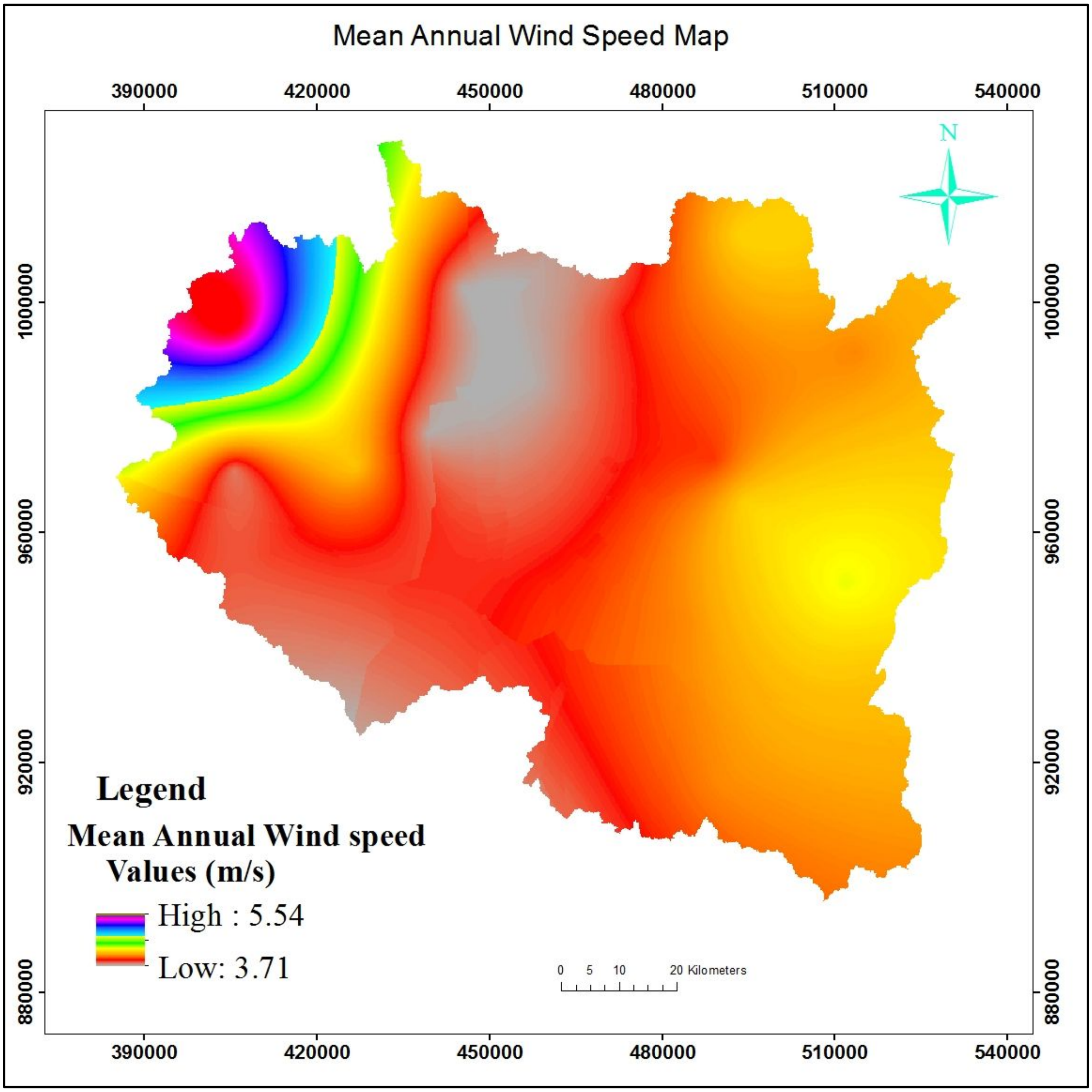


Figure 34: Mean Annual Wind Speed of UAB

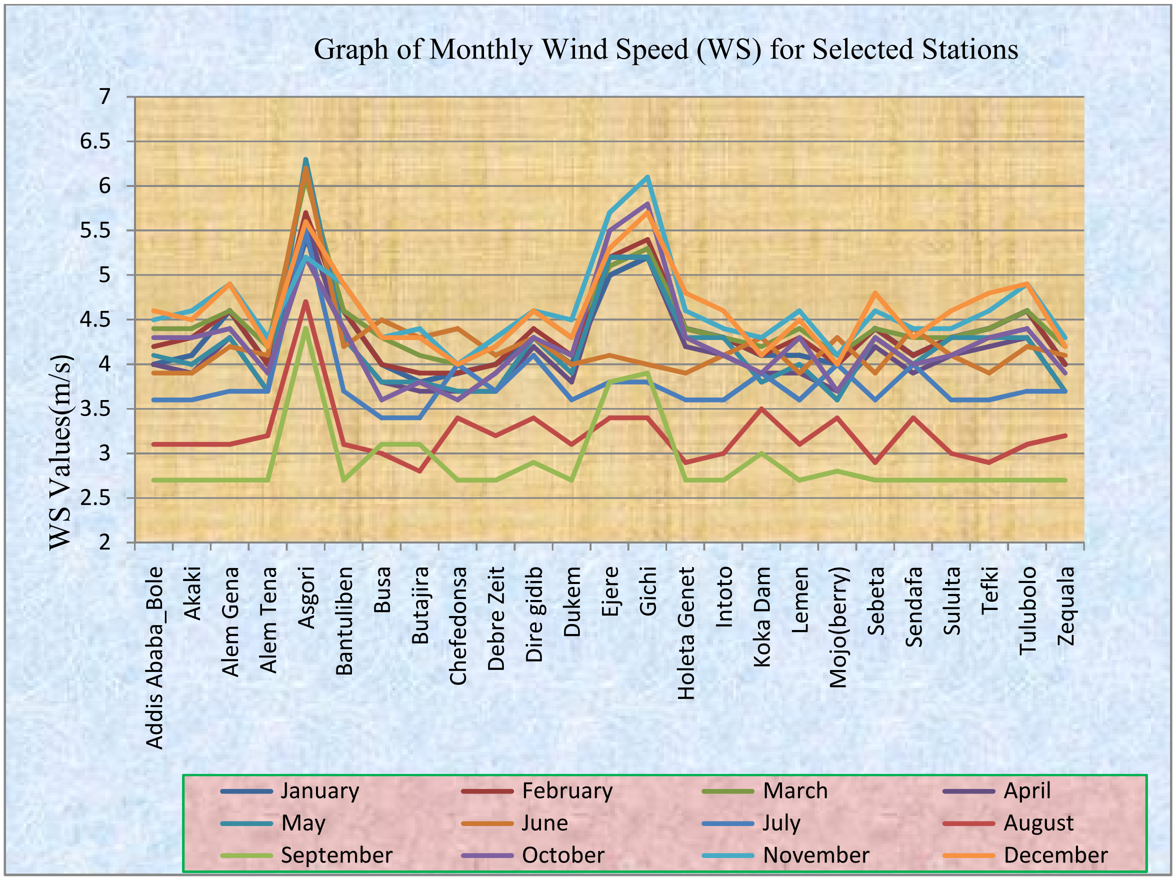


Figure 35:Graph of Monthly Wind Speed for Selected Stations

5.3.1.5 Sunshine Hours

Sunshine also one factor which affect the recharge amount of water because it causes to removal of water through evaporation process. As observed from the table and figure below the sunshine hours are high in the dry season and Low in summer season. The maximum sunshine hours recorded in the month of November and the minimum sunshine hours recorded in the month of July and August.

S.N	Station Name	January	February	March	April	May	June	July	August	Septembe	October	Novembe	Decembe	Mean Annual Sunshine
1	Addis Ababa_Bole	8.3	8.1	7.8	7.4	7.2	6.2	4.8	5.4	6	8	9.2	8.7	7.3
2	Akaki	8.4	8.3	7.9	7.5	7.3	6.7	5.3	5.6	6	8.1	9.1	8.6	7.4
3	Alem Gena	8.4	8.1	8	7.4	7.1	6.2	4.7	5.4	5.8	8.2	9.1	8.9	7.3
4	Alem Tena	8.4	8.1	8	7.4	7.1	6.2	4.7	5.4	5.8	8.2	9.1	8.9	7.3
5	Asgori	7.5	7.6	6.7	6.7	7.1	5.9	4.1	4.6	5.3	7.6	8.8	8	6.7
6	Bantuliben	8.4	8.1	8	7.4	7.1	6.2	4.7	5.4	5.8	8.2	9.1	8.9	7.3
7	Busa	8.5	8.2	7.9	7.2	7.2	6.5	5	5.3	5.3	7.7	8.8	8.7	7.2
8	Butajira	8.5	8.2	7.7	7.2	7.2	6.6	5	5.2	5.3	7.7	8.9	8.6	7.2
9	Chefedonsa	8.2	8.2	7.8	7.4	7.3	6.7	5.4	5.7	6.2	8	9.1	8.6	7.4
10	Debre zeit	8.4	8.3	7.9	7.5	7.3	6.8	5.4	5.6	6	8	9.1	8.6	7.4
11	Dire gidib	8.3	8.2	7.8	7.4	7.4	6.6	5.2	5.5	6.3	8.1	9.2	8.7	7.4
12	Dukem	8.4	8.3	7.9	7.5	7.3	6.8	5.4	5.6	6	8	9.1	8.6	7.4
13	Ejere	8.1	7.9	6.7	6.9	6.7	5.2	3.3	4	5.1	7.6	9.1	8.7	6.6
14	Ginchi	8.3	7.9	7.5	7.1	6.7	5.5	3.7	4.5	5.4	7.9	9.1	8.9	6.9
15	Holeta Genet	8.4	8.1	7.8	7.3	7.1	6.1	4.6	5.3	6	8.1	9.2	8.9	7.3
16	Intoto	8.3	8.1	7.8	7.4	7.2	6.2	4.8	5.4	6	8	9.2	8.7	7.3
17	Koka Dam	8.4	8.3	7.8	7.5	7.3	7	5.6	5.8	5.9	7.9	8.9	8.5	7.4
18	Lemen	8.4	8.2	8	7.6	7.3	6.5	5.3	5.4	6	8.1	9.1	8.7	7.4
19	Mojo	8.3	8.2	7.8	7.4	7.2	6.7	5.2	5.5	6	7.9	9	8.6	7.3
20	Sebeta	8.3	8.2	8	7.5	7.2	6.3	5	5.6	6	8.1	9.1	8.7	7.3
21	Sendafa	8.3	8.2	7.8	7.4	7.4	6.6	5.2	5.5	6.3	8.1	9.2	8.7	7.4
22	Sululta	8.3	8.2	7.8	7.4	7.3	6.4	4.9	5.6	6.1	8.1	9.3	8.7	7.3
23	Tefki	8.4	8.2	8	7.5	7.1	6.2	4.8	5.5	6	8.2	9.2	8.9	7.3
24	Tulubolo	8.4	8.1	8	7.4	7.1	6.2	4.7	5.4	5.8	8.2	9.1	8.9	7.3
25	Zequala	8.4	8.3	7.9	7.5	7.3	6.8	5.4	5.6	6	8	9.1	8.6	7.4
	Average Sunshine(Hrs)	8.3	8.2	7.8	7.4	7.2	6.4	4.9	5.4	5.9	8	9.1	8.7	7.3

Table 14: Table of Sunshine Hours for Selected Stations

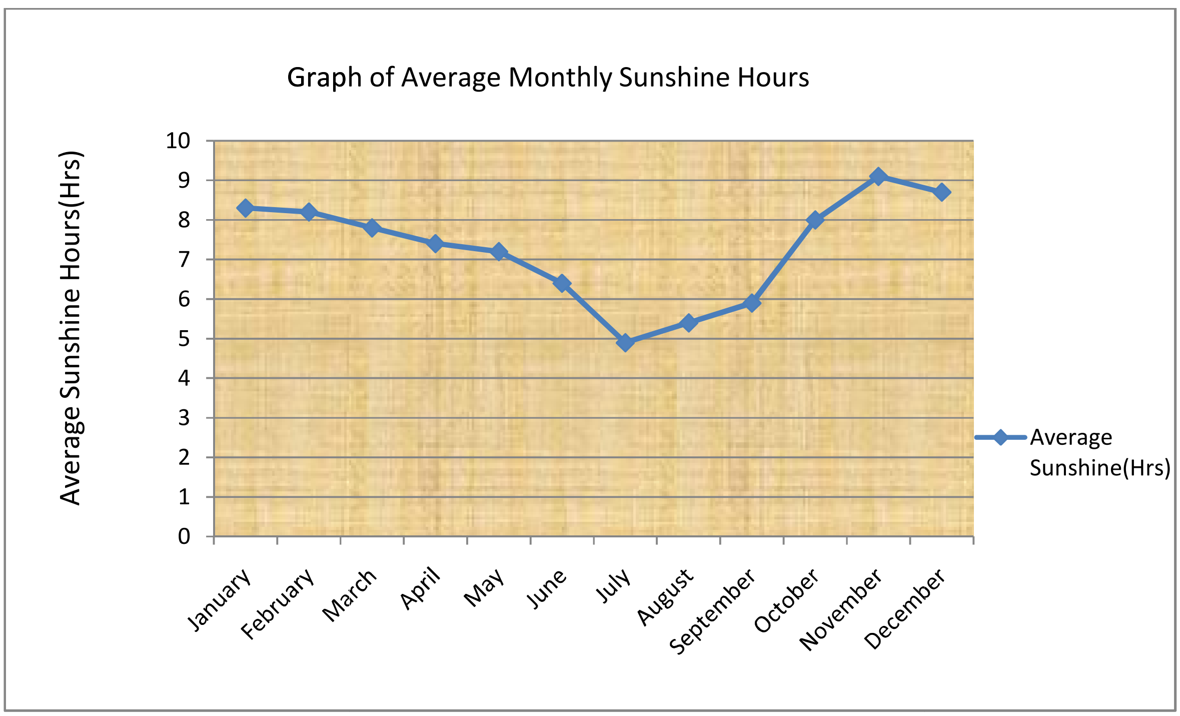


Figure 36:Average Monthly Sunshine Graph

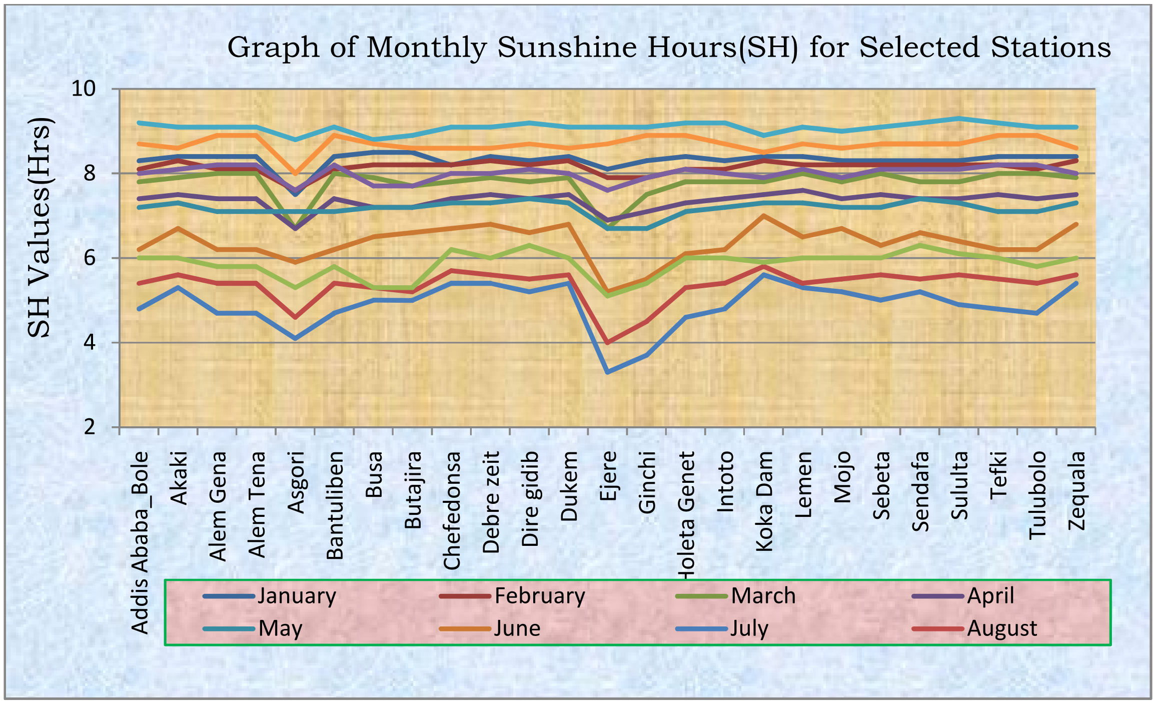


Figure 37:Graph of Monthly Sunshine Hours for Selected Stations

5.3.2 WETSPASS OUTPUTS

The WetSpass model result comprises seasonal, Annual and monthly hydrologic outputs. This model generated the outputs of Groundwater recharge; Annual Actual Evapotranspiration and Surface Runoff of the study area. The results are provided in the form of grid maps of 200 m resolution. The mean annual recharge, Evapotranspiration and Runoff of the study area is 110mm, 603mm and 310mm respectively. The water balance of the components is balanced by 99%.

P(mm)	Recharge (mm)	EPT(mm)	Runoff(mm)	p-(R+ EPT+ Ru)
1010	110	603	310	-13

Table 15: Water balance table of Wetspass outputs

5.3.2.1 GROUND WATER RECHARGE

The ground water recharge of Upper Awash Basin is estimated using wetspass model method. Wetspass model estimates monthly, seasonal and annual long term spatially distributed amounts of groundwater recharge of upper awash basin by subtracting evapotranspiration and surface runoff from Monthly, seasonal and annual precipitation respectively. The annual distributed recharge amount of Upper Awash Basin ranges from 0 to 369 mm/year with standard deviation of 62mm. The estimated mean annual groundwater recharge of Upper Awash Basin is 110mm/year and it accounts about 11% of the total mean annual precipitation (1010mm) in the study area which is within the range of previously conducted recharge by different researchers using different methods. The estimated mean annual recharge of the Upper Awash Basin is proportional to 1,292,280,000m³/year water. Previously estimated recharge of upper awash basin is ranging from 47mm/year to 238mm/year by using different methods. The mean annual recharge map of the study area is produced below. From the produced map below, there is no recharge at water bodies in the study area. The minimum value of recharge is observed dominantly in the lowland areas in the SE direction and sparsely distributed all over the study area. The high recharge observed in the high land areas which have high rainfall and permeable loam and clay loam soils in the study area such as Ginchi, Intoto ridges ,Eastern part and volcanic centers

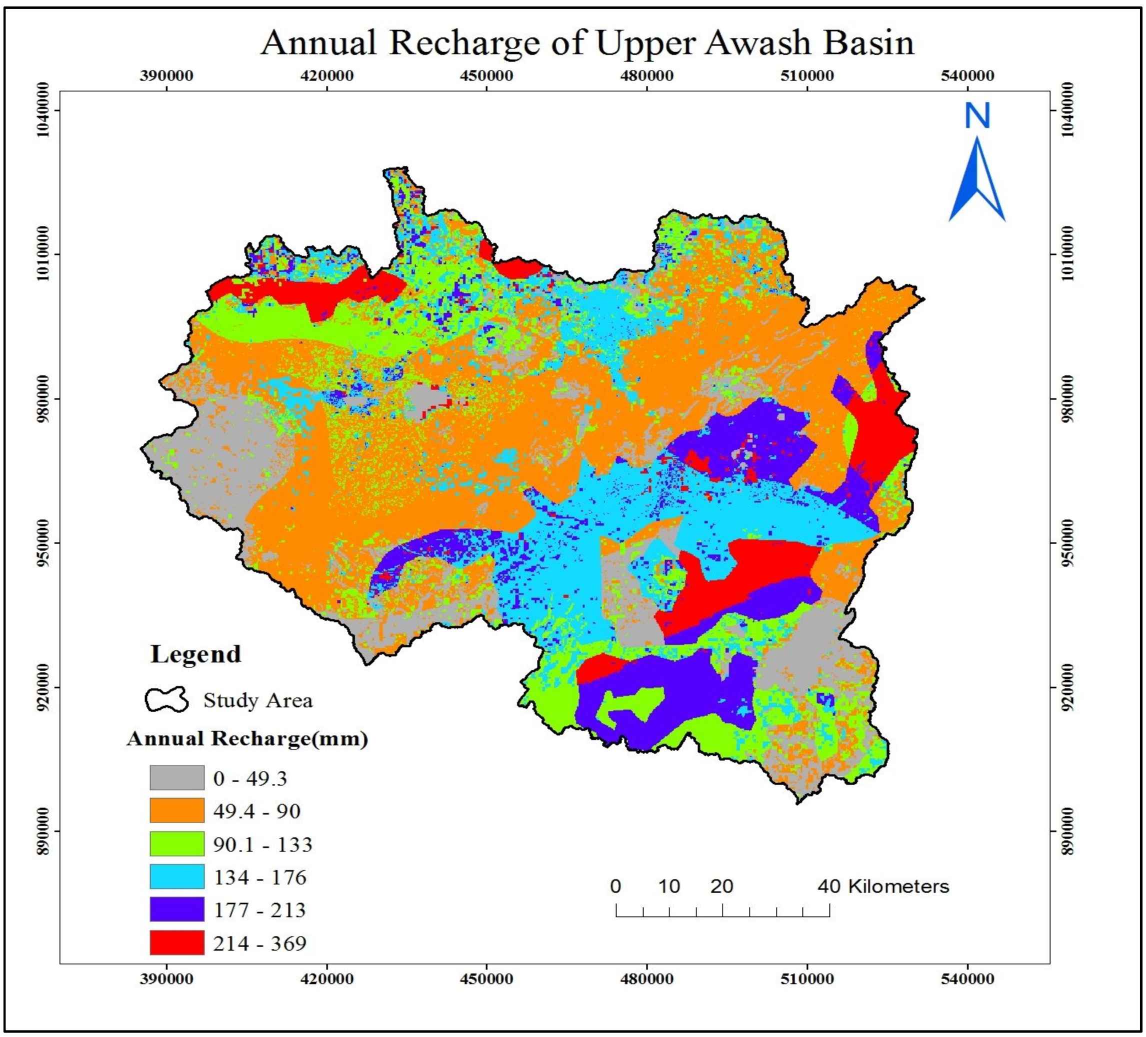
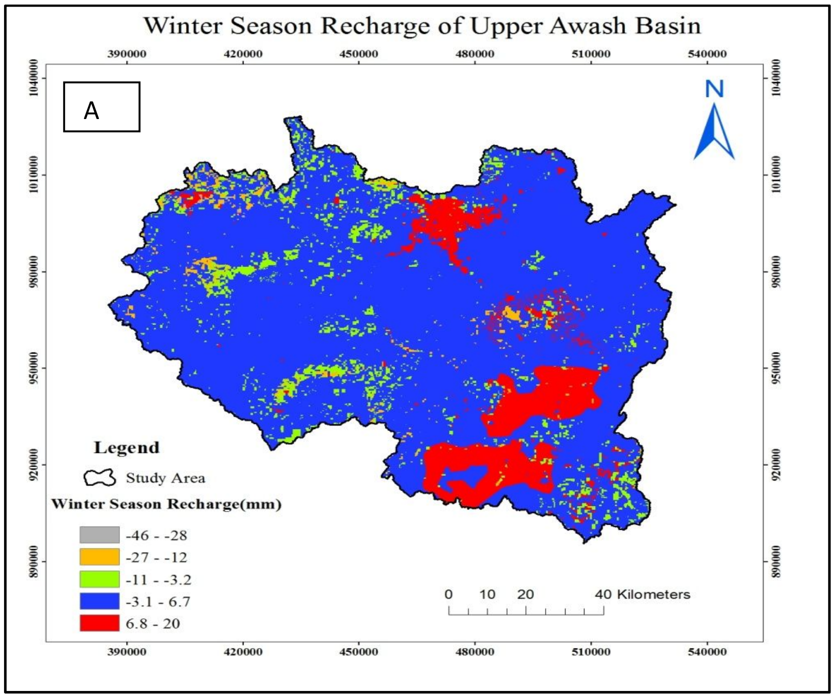


Figure 38:Mean Annual Recharge of Upper Awash Basin

From the annual mean recharge of the upper awash basin the maximum recharge is observed in the summer season which is about 108mm and it accounts about 99% of the mean annual recharge. The rest recharge observed in winter season which is about 2mm and it accounts only 1% of the mean annual recharge of the study area. The recharge of winter season shows that negative values. These negative values indicate that the flow of water reversed to surface from groundwater. The maximum recharge in the summer season shows that the recharge is direct recharge from precipitation means the water that comes from rainfall is directly infiltrate through volcanic structures. The recharges of the two seasons are shown below in the map.



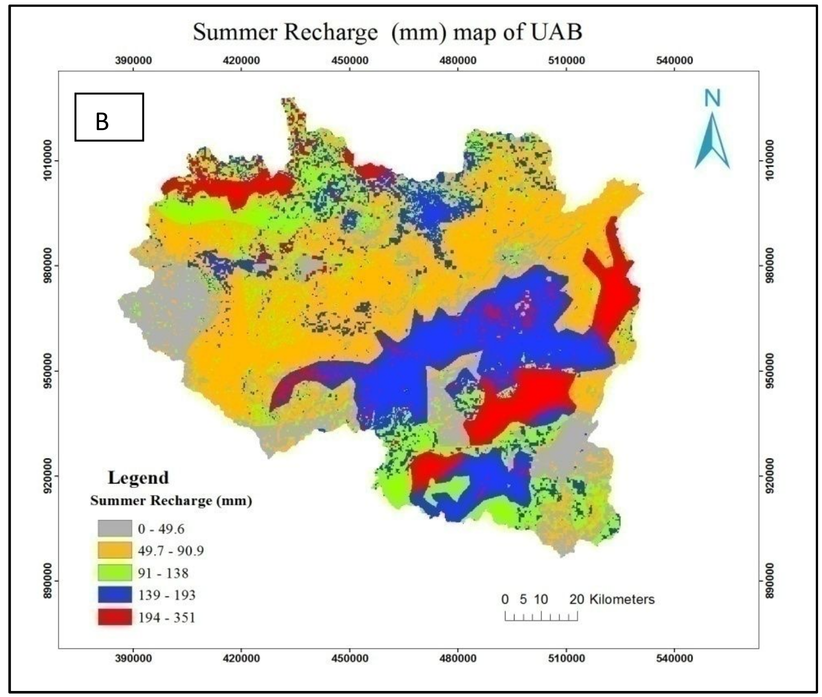


Figure 39: Winter (A) and Summer(B) Recharge map of Upper Awash basin

5.3.2.2 SURFACE RUNOFF

Wetspass model estimates surface runoff of the upper awash basin from long term average meteorological parameters using runoff coefficients which varies with soil types, textures, vegetation types, slope and elevation of the study area. Surface runoff of a certain area has direct relationship with the amount of rainfall for that area. The estimated amount of runoff of upper awash basin is ranges from 1.05 to 572mm/year. The mean annual surface runoff of upper awash basin is 310mm which accounts about 30% of the mean annual precipitation of the study area with standard deviation of 147.87mm. As we have seen the map below the minimum runoff is observed South Eastern part of the study area near to koka dam with clay loam soil texture type and the highest runoff value observed at the location on water bodies and becho plane with the presence of clay soil which has a low permeability that enhance surface runoff.

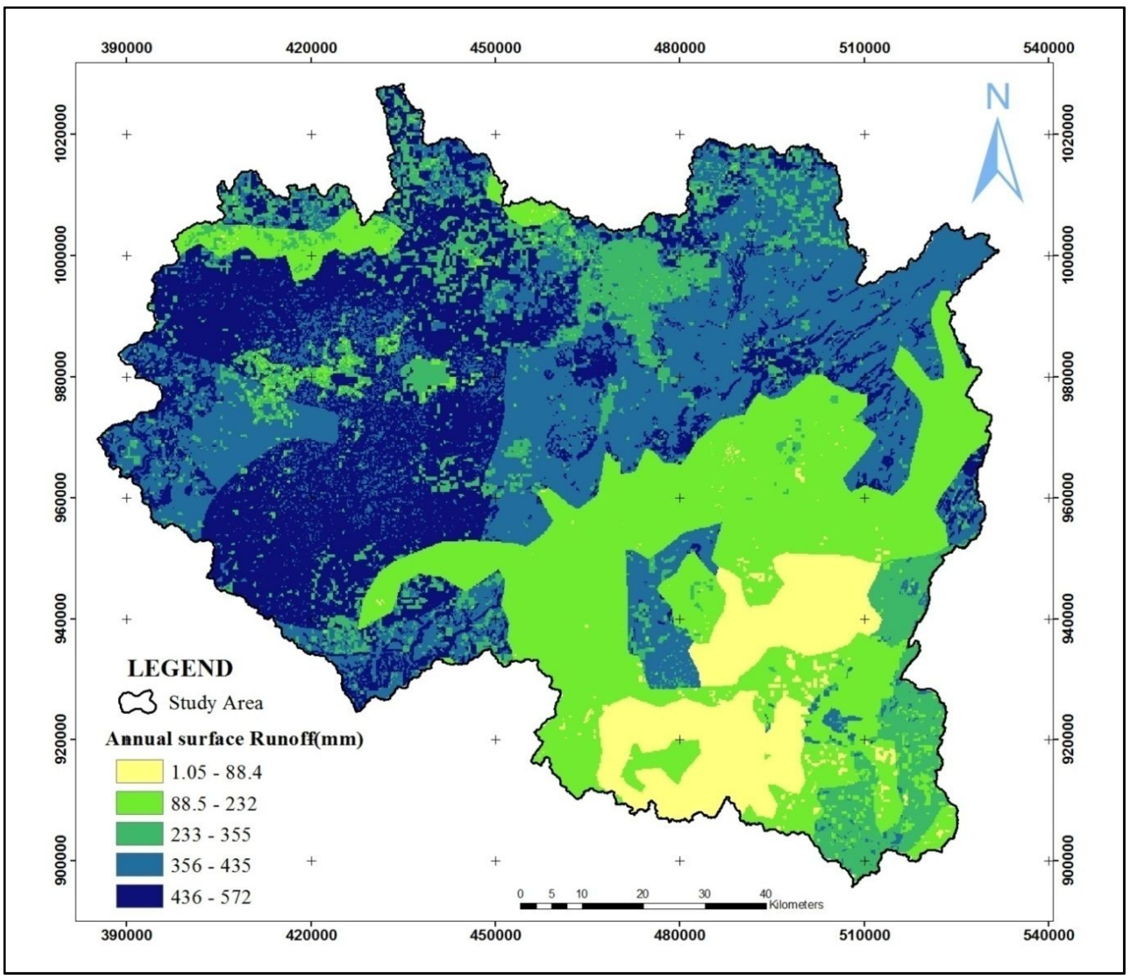


Figure 40:Annual Surface Runoff map for the UAB

From the above mean annual surface runoff of the study area the maximum surface runoff occurred in the summer season which accounts 67% and the rest 33% occurred in the winter season shown below in figure 40.The highest runoff occurred in the summer season because high rainfall is occurred in the summer season.

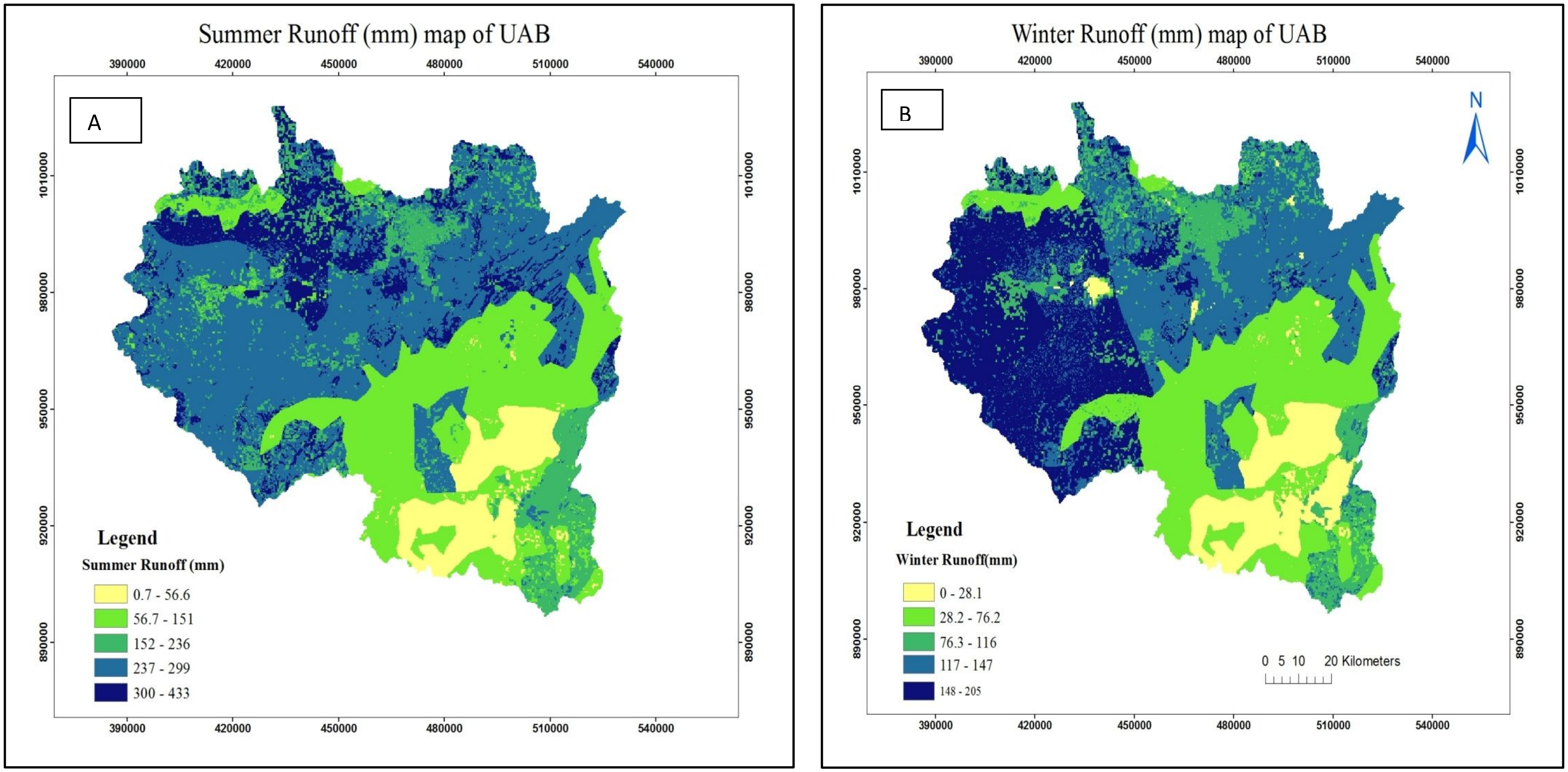


Figure 41: Summer(A) and Winter(B) Surface runoff of UAB

5.3.2.3 ANNUAL ACTUAL EVAPOTRANSPIRATION

The Annual Actual Evapotranspiration is one of the output water balance component which estimated by using wespass model. The wetspass model result of Annual Actual Evapotranspiration of upper awash basin is ranges from 447.7mm to 1360 mm with standard deviation of 122mm. The mean Annual Actual Evapotranspiration of UAB is 603mm which accounts about 60% of the mean annual precipitation of the study area. As shown below in the map the minimum value of the Annual Actual Evapotranspiration observed at the central and North western and North Eastern parts of the study areas and sparsely distributed all over the study area and the maximum value of Annual Actual evapotranspiration observed at the water bodies, vegetated areas at elevated areas and in areas of clay loam texture.

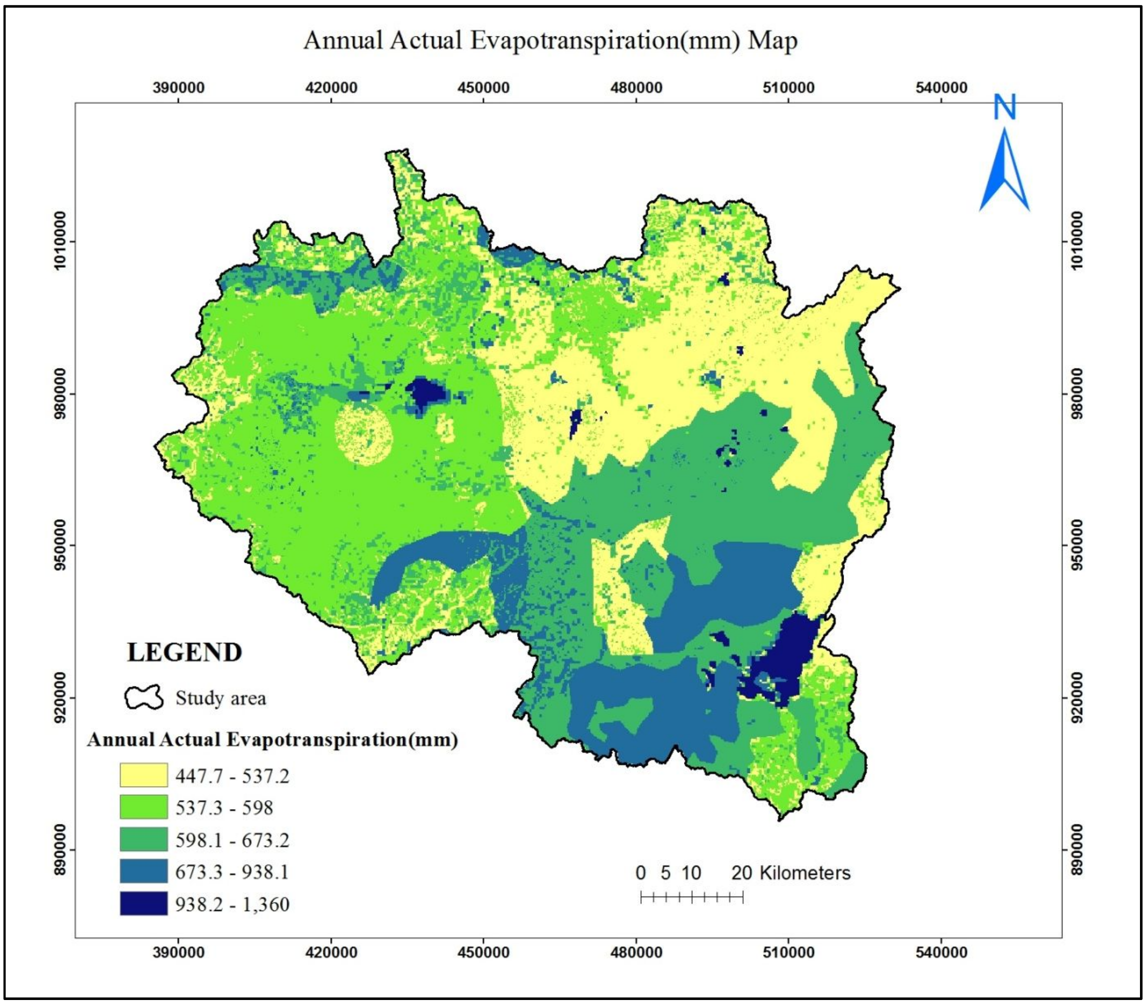


Figure 42: Mean Annual Actual Evapotranspiration of UAB Map

Like Recharge and Surface runoff the mean summer Actual Evapotranspiration of the upper awash basin is greater than the mean winter Actual evapotranspiration as shown below in figure 42. Mean summer Actual evapotranspiration accounts about 348mm and mean winter Actual Evapotranspiration accounts the rest 255mm from the mean annual Actual evapotranspiration which accounts about 57% and 43% respectively.

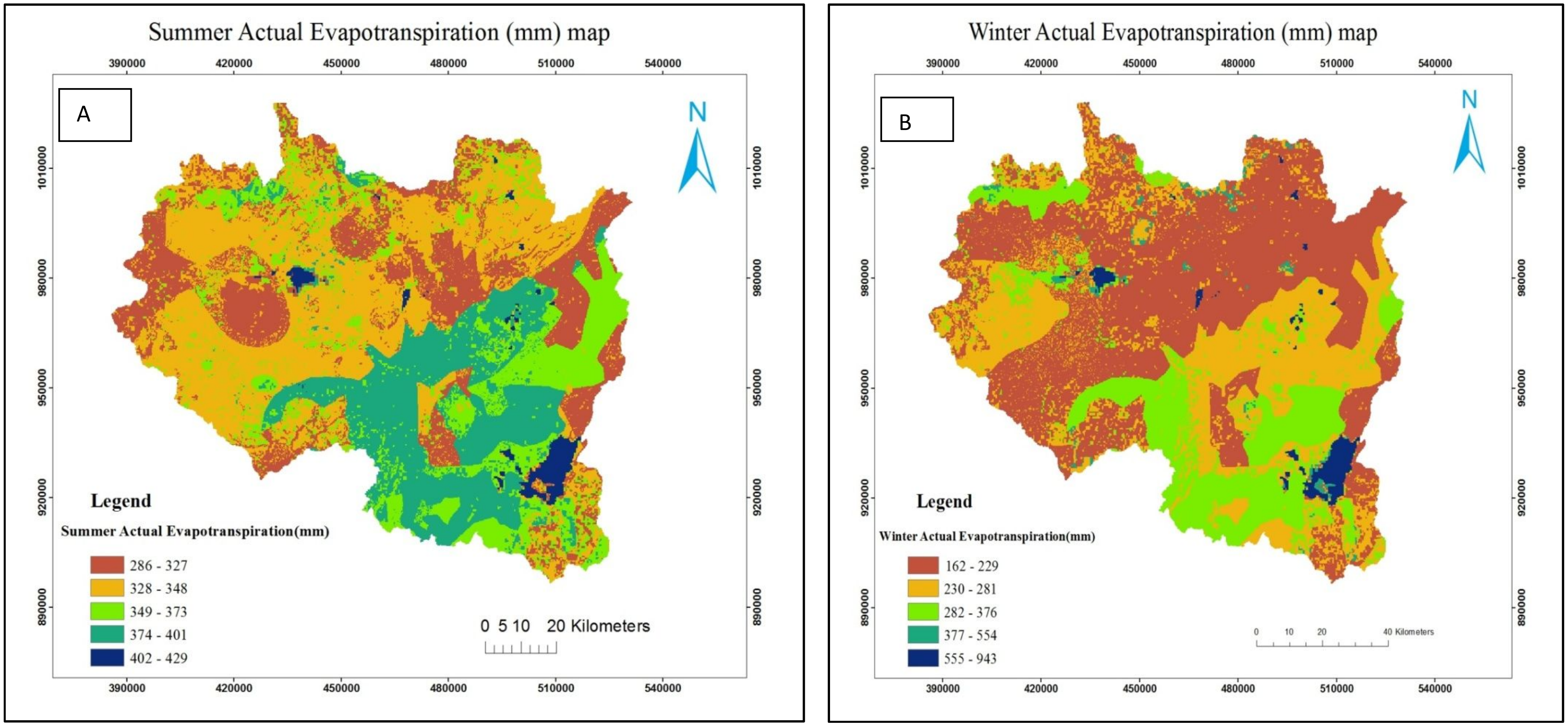


Figure 43:Summer(A) and Winter(B) mean AET map of UAB

5.3.3 Base flow separation method

Base flow separation is one technique to estimate groundwater recharge of a certain area using river flow data. The recharge of upper awash basin is about 95mm/year. The graph below shows the base flow of upper awash basin.

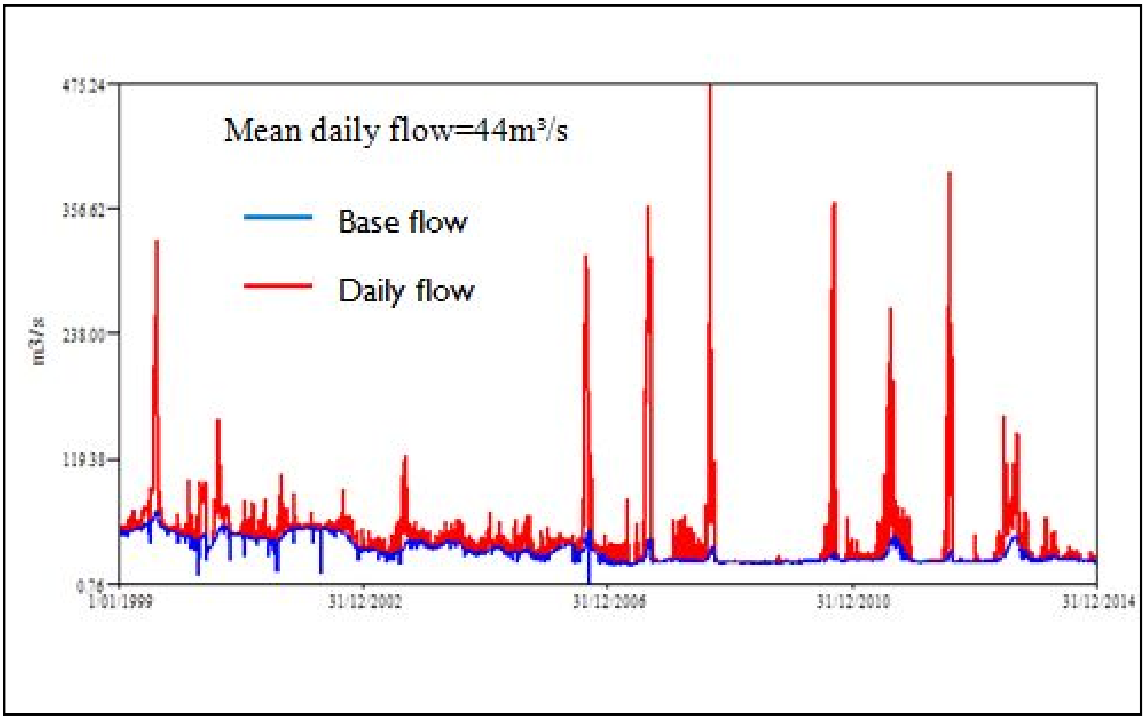


Figure 44: Graph of base separation for river flow data

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSIONS

Abstracting of groundwater in the upper awash basin is increased in alarming rate due to increasing of demand on water and widening of urban population within and suburbs of Upper Awash Basin. The abstraction rate of groundwater is without understanding of the recharge amount of the basin and different factors which affect the recharge of the study area. In the Upper Awash Basin different government water sectors and private companies engaged in drilling of deep water wells. The abstraction rate that abstracted from the upper awash basin is about 231,846,905m³/year collected from inventory wells. However, there is no well organized system to manage and monitor the groundwater system of the basin. Upper awash basin is located in the central Ethiopia at the western margin of the main Ethiopian rift. To manage groundwater resources of Upper Awash Basin, estimating groundwater recharge is important.

Recharge is the down ward movement of water in to the water table at the subsurface through the water bearing formations that comes from rainfall. Recharge depends on different factors such as soil type, land use land cover, slope, groundwater depth, topography and meteorological parameters (rainfall, evapotranspiration, temperature and wind speed). Groundwater recharge of Upper Awash basin was estimated by different researchers with different methods. The results of previously conducted recharge amount of Upper Awash Basin ranging from 47mm/year to 238mm/year. The average recharge of previously conducted groundwater recharge of Upper Awash Basin is 115mm/year.

The present research is groundwater recharge estimation of Upper Awash Basin using Wetspass model. The main objective of this research is to estimate the recharge of upper awash basin and recommend the sustainable yield of the abstraction rate. The specific objectives are to determine the sustainable yield, determine the recharge and discharge areas and to check the balance of the abstraction rate and recharge of the upper awash basin. WetSpass model is a physically based model for estimation of long term average spatial patterns of groundwater recharge, surface runoff and evapotranspiration from long term average meteorological data, together with land-use, soil, and groundwater depth maps, by employing physical and empirical relationships.

Two types of inputs prepared to apply wetspass model which are grid maps and parameter table of the above mentioned parameters. After preparation of inputs wetspass model is applied to estimate the recharge of the study area. wetspass model estimates the mean annual Actual evapotranspiration, Mean annual surface runoff and mean annual recharge of upper awash 603mm, 310mm and 110 mm respectively. It accounts about 60%, 30% and 11% of the mean annual rainfall respectively. The estimated amount of recharge is within the range of previously estimated recharge. The highest recharge, Actual evapotranspiration and Annual Runoff of the study area are occurred in summer season.

From the result the recharge areas are highly elevated areas which are intoto ridges, ginchi areas and volcanic centers. On the other hand discharge areas lowland areas in the study area such as Akaki area, Becho plain, Adaa plain and koka areas. Rivers in the study area flows from highly elevated areas to lowland areas.

The recharge of upper awash basin which is stored in the ground as a groundwater is about 1,292,280,000m^3/year. By comparing the abstraction rate and the recharge of the study area the annual abstraction rate is about 17% of the mean annual recharge.

6.2 RECOMMENDATIONS

The abstraction rate of Groundwater in the upper awash basin is sustainable in general but the well fields concentrated at Addis Ababa and its suburbs. Therefore the sustainable yield of the well fields at Addis Ababa and its suburbs need to be checked using a detailed research.

According to Sophocleas (1997) the sustainable yield of a certain area is range from 10 to 70%. For the upper awash basin 40% of the groundwater recharge is assumed to be sustainable yield which is about 44mm/year.

The well fields of upper awash basin have to be managed and monitored to use ground water without affecting the water table. Based on the estimated recharge of the upper awash basin and the abstraction rate, the government offices have to be drill water supply wells proportionally all over the study area to avoid well interference.

In addition to Government offices every person has to be save water from extravagancy.

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Annexes

Annex I: Groundwater elevation data

ID	X	Z	ZGW	ID	X	Z	ZGW
BH1	477052	995894	2262.596	BH531	462260	984901	2204.652
BH2	474556	983625	2123.505	BH532	471500	990500	2212.563
BH3	557000	989000	1539.849	BH533	477515	997474	2386.268
BH4	513157	1025381	2807.74	BH534	464031	1002909	2579.515
BH5	490513	951595	1672.425	BH535	465578	999808	2471.245
BH6	490444	951336	1673.288	BH536	466050	993650	2294.538
BH7	506464	941989	1613.721	BH537	483453	994606	2337.467
BH8	427395	992768	2093.458	BH538	482896	991871	2233.728
BH9	427126	971361	2078.062	BH539	484152	989566	2204.272
BH10	456314	962592	2017.884	BH540	481230	992312	2239.592
BH11	478990	955803	1795.683	BH541	467135	989840	2240.829
BH12	455620	1026514	2594.634	BH542	484900	990700	2228.557
BH13	473911	1031930	2517.921	BH543	468261	990357	2235.868
BH14	484152	989566	2204.272	BH544	470277	989578	2205.105
BH15	493518	1004421	2436.517	BH545	469245	990260	2231.893
BH16	476790	981229	2077.992	BH546	465741	989188	2250.412
BH17	430759	1035489	2335.205	BH547	468512	989680	2229.469
BH18	430128	1037894	2336.204	BH548	469458	990594	2232.944
BH19	430592	1037170	2333.863	BH549	468196	990422	2237.133
BH20	474424	1001212	2468.258	BH550	467723	990028	2232.074
BH21	475068	1001254	2436.264	BH551	470790	990330	2219.077
BH22	475945	1000580	2443.887	BH552	465591	989872	2260.569
BH23	475638	999991	2430.553	BH553	465295	990132	2264.092
BH24	474238	1002373	2474.776	BH554	463985	991540	2296.69
BH25	482850	989900	2221.689	BH555	489127	999697	2401.684
BH26	470504	1002135	2637.544	BH556	480029	998401	2446.287
BH27	470218	1001886	2616.413	BH557	466600	1001250	2524.706
BH28	472608	1002066	2578.59	BH558	486712	1001378	2446.48
BH29	471026	1002023	2620.035	BH559	470450	990125	2208.125
BH30	466842	993128	2269.528	BH560	471125	989636	2199.437
BH31	482682	994124	2255.809	BH561	470070	991000	2222.849
BH32	481681	994296	2277.515	BH562	469500	989600	2219.775
BH33	482349	995063	2273.689	BH563	463800	994650	2419.254
BH34	482109	993423	2237.983	BH564	463595	995915	2421.213
BH35	484883	994701	2304.493	BH565	482850	989900	2221.689
BH36	484900	990700	2228.557	BH566	466308	989421	2245.208
BH37	485228	994341	2299.617	BH567	466200	988800	2248.188
BH38	485664	994125	2293.988	BH568	469322	1001428	2570.091
BH39	481462	998906	2398.369	BH569	464031	1002909	2579.515
BH40	480321	997370	2389.06	BH570	491980	965840	1818.193
BH41	482994	998429	2397.11	BH571	468196	998300	2399.124

BH42	482696	990537	2214.983	BH572	520353	939385	1558.74
BH43	482849	991509	2230.89	BH573	470530	991988	2199.876
BH44	480604	992935	2265.637	BH574	460295	986769	2274.932
BH45	481101	991646	2225.091	BH575	447549	1007893	2479.855
BH46	481061	992052	2224.028	BH576	501798	978894	1992.32
BH47	482896	991871	2233.728	BH577	431584	998853	2310.401
BH48	480760	992453	2238.772	BH578	431584	998853	2310.401
BH49	467660	996912	2339.348	BH579	410870	997013	2190.158
BH50	468268	996584	2326.438	BH580	459831	985582	2222.442
BH51	468505	995156	2302.075	BH581	455287	985619	2214.892
BH52	487881	997599	2371.316	BH582	459285	961268	2075.51
BH53	486723	1000881	2420.09	BH583	468338	1076180	2735.148
BH54	464527	990017	2265.267	BH584	463070	1073409	2829.675
BH55	484273	976154	2018.597	BH585	464032	1073742	2796.973
BH56	478130	982300	2117.733	BH586	466350	1074642	2763.669
BH57	477252	982872	2074.36	BH587	469877	1077013	2737.07
BH58	481230	992312	2239.592	BH588	483180	1073086	2450.828
BH59	480847	981623	2152.473	BH589	482960	1066600	2584.447
BH60	481828	981943	2159.4	BH590	485000	1048933	2636.683
BH61	465724	1002753	2541.78	BH591	486182	1045145	2529.12
BH62	468110	1001421	2503.135	BH592	455664	1027096	2597.89
BH63	476692	982390	2072.01	BH593	412197	957215	2174.673
BH64	470994	987635	2153.259	BH594	451249	985378	2148.395
BH65	466130	994219	2285.718	BH595	378072	985329	2489.652
BH66	468148	989664	2230.728	BH596	374782	971227	3078.729
BH67	477550	997650	2400.807	BH597	514504	990570	2305.28
BH68	469150	1001150	2562.751	BH598	488234	988003	2231.488
BH69	475750	993650	2216.714	BH599	373852	992800	2097.691
BH70	480999	999648	2519.161	BH600	460950	976800	2107.335
BH71	481519	999648	2506.271	BH601	507013	968324	1859.631
BH72	468753	1006112	2742.116	BH602	503928	965114	1858.193
BH73	433977	1023222	2531.869	BH603	507887	960487	1843.268
BH74	401157	996412	2274.239	BH604	501470	974992	1883.319
BH75	401801	996649	2273.638	BH605	510700	967019	1849.562
BH76	401587	997298	2274.33	BH606	465517	1002276	2490.486
BH77	400975	997008	2276.428	BH607	421795	1040108	2430.752
BH78	442811	977625	2058.928	BH608	507086	1012954	2553.287
BH79	444000	977700	2052.295	BH609	501332	1068067	2508.633
BH80	476963	994106	2268.038	BH610	490336	970789	1838.587
BH81	464387	1034248	2439.223	BH611	490409.4	970989.9	1839.484
BH82	464612	1034331	2430.377	BH612	474421	1013070	2588.608
BH83	463376	1036388	2487.357	BH613	450359	981037	2065.24
BH84	463292	1037141	2461.005	BH614	484821	994284	2283.197
BH85	476800	994200	2293.133	BH615	433200	959670	2110.01
BH86	484821	994284	2283.497	BH616	440274	1006055	2513.647
BH87	475300	983800	2121.252	BH617	413137	973900	2077.366

BH88	477463	994346	2235.076	BH618	506765	957179	1836.934
BH89	475600	994500	2282.342	BH619	507343.1	957381.7	1831.694
BH90	483750	994550	2293.001	BH620	504878	970766	1861.638
BH91	483453	994606	2337.467	BH621	504972	970974.3	1863.532
BH92	476235	995275	2268.389	BH622	513157	1025381	2808.13
BH93	487300	995300	2276.152	BH623	490444	951336	1672.938
BH94	478450	995600	2271.254	BH624	506464	941989	1624.121
BH95	482770	997150	2349.145	BH625	506464	942018.4	1624.284
BH96	477515	997474	2386.268	BH626	427395	992768	2095.458
BH97	481650	997725	2372.977	BH627	427126	971361	
BH98	475300	984000	2115.374	BH628	456314	962592	2017.884
BH99	480029	998401	2446.287	BH629	478990	955803	1795.213
BH100	480431	998457	2439.641	BH630	455620	1026514	2532.884
BH101	484190	998500	2446.488	BH631	473911	1031930	2517.921
BH102	483350	999064	2441.913	BH632	493518	1004421	2436.767
BH103	489127	999697	2401.684	BH633	476790	981229	2077.992
BH104	482070	999823	2458.633	BH634	465769	866769	1596.764
BH105	476105	1000050	2425.644	BH635	506500	960464	1844.013
BH106	481878	1000148	2501.237	BH636	501438	967332	1861.353
BH107	485925	1000975	2478.279	BH637	505455	963968	1858.479
BH108	481337	1001017	2612.246	BH638	495728	105686	- 1000031
BH109	474648	985501	2057.417	BH639	505259.6	971168	1861.46
BH110	486200	1001042	2453.191	BH640	506232.7	971047.9	1863.833
BH111	486200	1001042	2461.191	BH641	507937.2	943553.6	1647.929
BH112	486000	1001115	2473.063	BH642	507647.1	958445	1827.665
BH113	475000	1001300	2470.893	BH643	504396.3	960886.2	1856.321
BH114	486712	1001378	2446.48	BH644	503567.3	961178.5	1855.964
BH115	475800	1001500	2472.893	BH645	509416.1	958136.3	1833.469
BH116	488161	1002129	2411.267	BH646	503820.3	971559.8	1864.914
BH117	488150	1002300	2449.48	BH647	467840	1001410	2456.273
BH118	493518	1004421	2436.517	BH648	509416.1	958136.3	1820.659
BH119	494036	1010902	2519.107	BH649	508750.7	943390.9	1646.88
BH120	474641	985622	2146.189	BH650	511522.8	957561	
BH121	502600	1011700	2487.504	BH651	509083.4	970103.1	1855.045
BH122	502554	1011850	2474.646	BH652	505951	960688	1845.926
BH123	507086	1012954	2553.777	BH653	510098.1	957592.9	1819.346
BH124	507408	1013586	2556.188	BH654	508565.8	959257.2	1824.687
BH125	513157	1025381	2807.74	BH655	506775.3	961520.5	1840.209
BH126	559432	1066077	2757.088	BH656	508570.8	961349.8	1830.944
BH127	559369	1067725	2761.353	BH657	507645.3	961277.2	1841.054
BH128	501332	1068067	2508.633	BH658	511693.7	959223.4	1831.508
BH129	561897	1069503	2783.139	BH659	506298.7	968314.5	1863.33
BH130	562106	1070685	2777.768	BH660	507427.1	976959.8	1926.938
BH131	475000	985800	2163.589	BH661	508514.6	967493.9	1854.989
BH132	536681	929942	1426.816	BH662	509360	967190.8	1857.748

BH133	529224	943393	1526.525	BH663	491142.2	972025.6	1897.375
BH134	528318	941952	1506.524	BH664	505373.2	966303.9	1855.435
BH135	527435	942998	1523.305	BH665	506265.7	966324.2	1854.639
BH136	546000	986000	1673.232	BH666	508224.3	966414.4	1852.921
BH137	540000	978000	1783.481	BH667	509261.6	966321	1855.216
BH138	557000	989000	1539.849	BH668	501604.3	968045.6	1857.888
BH139	540000	978000	1783.481	BH669	497952.5	973072.6	1874.059
BH140	512000	948000	1717.822	BH670	505426.9	965286.9	1855.237
BH141	512000	948000	1713.822	BH671	507162.5	965376.8	1851.296
BH142	476750	985800	2096.684	BH672	508283.1	965463.3	1855.568
BH143	529000	944000	1518.6	BH673	509303.8	965180.7	1857.951
BH144	529000	944000	1518.6	BH674	502182.4	964419.7	1856.838
BH145	530000	944000	1595.281	BH675	504470	964326	1857.136
BH146	528000	941000	1518.528	BH676	506257.6	964356.9	1854.059
BH147	527000	944000	1548.186	BH677	507270.4	964344.1	1857.273
BH148	519000	936000	1565.036	BH678	508259.5	964551.5	1860.357
BH149	518000	935000	1564.889	BH679	504789.5	959857	1844.946
BH150	517000	935000	1574.979	BH680	508697	959616	1838.917
BH151	518000	935000	1568.889	BH681	507721.4	959797.1	1838.765
BH152	521000	935000	1526.885	BH682	502549.1	963000.9	1857.144
BH153	546000	986000	1673.232	BH683	504203	963366	1859.524
BH154	535000	920000	1419.386	BH684	505191.6	963154.1	1856.186
BH155	518000	887000	2102.488	BH685	506303.2	963318.5	1855.73
BH156	525000	898000	1950.784	BH686	504844.9	958680.6	1841.699
BH157	501000	892000	1611.665	BH687	505948.6	958710.3	1840.81
BH158	507000	901000	1664.234	BH688	503318.6	962327.9	1854.289
BH159	518000	887000	2112.488	BH689	503318.6	962327.9	1865.339
BH160	421795	1040108	2428.852	BH690	505077	962314.3	1849.165
BH161	507086	1012954	2553.777	BH691	506200.5	962350.7	1839.654
BH162	501332	1068067	2508.633	BH692	507557	962302	1835.828
BH163	477741	965964	1938.879	BH693	503105	959685	1851.482
BH164	475000	987800	2135.943	BH694	506575.1	957977.8	1837.1
BH165	490336	970789	1840.457	BH695	511613.7	956641.5	1804.928
BH166	474421	1013070	2588.808	BH696	493136	942944	1669.978
BH167	450359	981037	2065.24	BH697	513677	953555	1767.782
BH168	484821	994284	2283.497	BH698	493128	943793	1669.925
BH169	433200	959670	2110.01	BH699	510705	956674.6	1817.71
BH170	440274	1006055	2513.977	BH700	510059	959387.5	1819.099
BH171	413137	973900	2075.866	BH701	507076.8	960831	1841.832
BH172	506765	957179	1837.134	BH702	506814.7	942064.7	1652.329
BH173	505014	970969	1862.992	BH703	508097.6	943036.6	1646.281
BH174	504878	970766	1862.088	BH704	510747	958191	1817.919
BH175	479033	993298	2245.063	BH705	573000	923000	2278.438
BH176	465635	1001021	2484.067	BH706	576000	924000	2218.032
BH177	563000	917000	2338.779	BH707	575000	923000	2357.717
BH178	563000	917000	2338.779	BH708	559243	1066639	2750.167

BH179	472400	953500	1819.426	BH709	559341	1065874	2750.168
BH180	467618	868830	1610.622	BH710	503706	1006430	
BH181	478772	958888	1803.725	BH711	464460	834226	1626.045
BH182	475705	956271	1797.997	BH712	558000	900000	2597.491
BH183	481178	958488	1790.096	BH713	560000	905000	2502.298
BH184	488305	960746	1834.099	BH714	558776	1065907	2746.281
BH185	454568	880156	1684.333	BH715	550000	989964	1626.316
BH186	457077	888976	1645.784	BH716	547922	959185	1319.981
BH187	462052	883164	1624.376	BH717	479055	976033	1999.985
BH188	484764	920771	1597.924	BH718	478780	977307	2000.941
BH189	475571	924071	1651.967	BH719	478679	976462	2002.245
BH190	490632	918070	1567.428	BH720	538774	953120	1422.257
BH191	503210	930527	1591.125	BH721	478585	976053	2003.687
BH192	506728	937459	1605.721	BH722	548235	989763	1631.126
BH193	512159	946729	1699.227	BH723	538498	950940	1408.532
BH194	489485	943724	1649.022	BH724	550004	989962	1614.487
BH195	480641	977009	2020.776	BH725	549622	989375	1632.065
BH196	483567	976037	2009.321	BH726	535918	945906	1380.951
BH197	496479	965700	1848.999	BH727	550714	991252	1604.602
BH198	521269	949730	1693.793	BH728	547304	984122	1633.153
BH199	493545	968537	1848.806	BH729	559357	1064678	2760.001
BH200	482463	976154	2083.5	BH730	537928	957417	1468.017
BH201	483243	961360	1780.212	BH731	537294	959643	1480.855
BH202	488463	965890	1807.15	BH732	477628	975889	2005.008
BH203	494320	965101	1870.783	BH733	534890	932712	1449.394
BH204	494054	968452	1860.132	BH734	532673	932328	1482.007
BH205	493179	968613	1838.232	BH735	536580	929743	1437.295
BH206	488798	972371	1926.271	BH736	551014	1052479	2763.742
BH207	487881	973470	1925.694	BH737	536813	930293	1441.929
BH208	492987	967055	1905.984	BH738	539213	940271	1347.047
BH209	507491	952694	1786.851	BH739	559600	1064728	2761.894
BH210	508079	952013	1810.847	BH740	530954	949680	1531.858
BH211	508995	951614	1773.808	BH741	547062	958304	1346.736
BH212	509385	950325	1768.047	BH742	541516	949046	1332.706
BH213	509020	950736	1767.149	BH743	542960	956854	1386.917
BH214	508684	951058	1777.167	BH744	544896	938818	1267.675
BH215	507950	951364	1788.495	BH745	559580	1065011	2753.857
BH216	512957	947774	1734.536	BH746	515465	1078129	2587.169
BH217	512602	947821	1723.341	BH747	509654	1078712	2498.293
BH218	511927	948292	1753.176	BH748	528555	1082232	2560.272
BH219	513423	948940	1740.531	BH749	528226	1084982	2517
BH220	513773	949998	1746.942	BH750	538581	929142	1404.094
BH221	469342	901807	1638.91	BH751	536761	930841	1446.898
BH222	530525	947181	1489.123	BH752	536336	930961	1438.177
BH223	536113	947062	1341.073	BH753	537322	928164	1442.664
BH224	534801	932504	1461.483	BH754	558266	1064888	2768.813

BH225	536492	929529	1437.546	BH755	543079	942366	1351.49
BH226	536720	930085	1442.246	BH756	559030	1065573	2756.54
BH227	537332	928166	1442.078	BH757	548162	987559	1631.954
BH228	532590	932122	1461.638	BH758	548106	988662	1629.064
BH229	530429	941358	1438.414	BH759	547229	986019	1632.03
BH230	530748	940960	1451.744	BH760	560297	968988	1012.886
BH231	523310	928661	1534.835	BH761	476933	994457	2280.454
BH232	527667	941523	1514.892	BH762	502000	925000	1606.992
BH233	526928	943518	1484.084	BH763	481640	988602	
BH234	481495	909593	1614.366	BH764	482712	988854	
BH235	477019	917872	1641.846	BH765	481934	989797	
BH236	469725	895830	1628.674	BH766	482712	989717	
BH237	474554	908761	1623.585	BH767	485135	993003	
BH238	477286	906903	1626.06	BH768	521000	936000	1550
BH239	479313	905790	1622.294	BH769	553000	913000	2004.542
BH240	502329	929321	1591.368	BH770	569000	922000	2323.295
BH241	457823	1002833	2610.029	BH771	535000	888000	2627.788
BH242	447200	998889	2290.145	BH772	426362	969316	2078.86
BH243	446338	997431	2243.815	BH773	426873	970945	2075.659
BH244	453522	1001474	2507.603	BH774	426362	969316	2080.86
BH245	457162	1001115	2622.477	BH775	428420	969695	2076.781
BH246	446266	1004147	2354.186	BH776	428539	970788	2075.296
BH247	445099	1003816	2370.066	BH777	428060	972015	2075.598
BH248	443050	1001649	2378.337	BH778	428016	978061	2041.731
BH249	442635	1001366	2380.767	BH779	454868	963109	2009.348
BH250	443132	1000869	2352.164	BH780	450887	981258	2068.948
BH251	444677	998215	2276.991	BH781	451632	979475	2061.961
BH252	444677	998808	2286.114	BH782	450187	981027	2065.762
BH253	481337	1001017	2612.246	BH783	418679	988365	
BH254	378447	991365	2150.384	BH784	423439	988990	
BH255	434015	1000129	2334.36	BH785	420071	983317	2067.775
BH256	440110	1001337	2380.668	BH786	411777	989671	2093.17
BH257	465419	987294	2248.364	BH787	411189	983944	
BH258	460810	981473	2152.067	BH788	462033	853564	1588.957
BH259	461930	970844	2060.439	BH789	463259	1002487	2600.429
BH260	458959	953532	1949.014	BH790	468500	967750	1963.052
BH261	448328	957872	2047.488	BH791	497061	1000901	2451.599
BH262	460062	948743	2059.469	BH792	473693	1032100	2530.478
BH263	459658	946538	2077.939	BH793	514000	992000	2357.857
BH264	444245	956023	2121.587	BH794	512000	991000	2439.384
BH265	462875	950361	1956.03	BH795	509000	983000	2241.787
BH266	462554	944481	2024.619	BH796	516000	992000	2335.465
BH267	459928	941554	2092.819	BH797	511000	991000	2430.446
BH268	457905	936566	2129.579	BH798	513000	991000	2414.902
BH269	479021	977596	2022.14	BH799	429503	841996	1640.266
BH270	426788	887491	2022.871	BH800	562012	1070477	2775.918

BH271	435268	897823	1955.951	BH801	561898	1069503	2783.151
BH272	462743	1002521	2586.469	BH802	560712	1070580	2772.044
BH273	458775	911576	1781.394	BH803	463973	991974	2295.696
BH274	469672	993830	2306.991	BH804	463590	992116	2285.537
BH275	455450	983014	2092.632	BH805	513000	885000	1911.991
BH276	455426	982736	2086.376	BH806	492774	1008914	2474.518
BH277	481162	935226	1657.278	BH807	558000	938000	1342.323
BH278	478740	933707	1655.169	BH808	539000	893000	2374.804
BH279	466233	1031004	2520.104	BH809	481338	997163	2313.129
BH280	488161	1002129	2411.267	BH810	503185	962173	1864.579
BH281	494036	1010902	2519.107	BH811	466600	1001990	2572.651
BH282	517022	947564	1700.98	BH812	477230	995069	2253.48
BH283	502554	1011850	2474.646	BH813	477495	995065	2269.501
BH284	507408	1013586	2556.188	BH814	475466	1000729	2371.329
BH285	492803	969204	1842.608	BH815	475976	1001005	2365.496
BH286	442842	977555	2054.017	BH816	481273	981768	2179.094
BH287	442811	977625	2058.828	BH817	479600	981100	2145.903
BH288	386183	943986	2032.46	BH818	473238	996706	2344.889
BH289	386987	945156	2050.867	BH819	520000	936000	1563.905
BH290	387305	945410	2056.215	BH820	481417	976193	2110.128
BH291	407400	972711	2114.748	BH821	478866	974615	2000.106
BH292	461412	986324	2229.595	BH822	501085	1005802	2499.559
BH293	459676	984947	2175.535	BH823	521000	936000	1550
BH294	460937	986565	2225.057	BH824	520000	936000	1563.905
BH295	463599	988583	2262.723	BH825	520000	936000	1563.905
BH296	463742	985378	2340.715	BH826	520000	936000	1563.905
BH297	427635	994816	2110.376	BH827	520000	936000	1563.905
BH298	436160	1000453	2320.486	BH828	520000	936000	1563.905
BH299	435382	1000251	2341.505	BH829	519000	987000	2300.545
BH300	488408	973431	1936.681	BH830	477067	1001053	2494.389
BH301	512282	951356	1761.612	BH831	525000	888000	2409.494
BH302	512282	951356	1761.612	BH832	521000	887000	2323.298
BH303	512355	951516	1763.776	BH833	471925	990400	2192.418
BH304	512356	947895	1724.595	BH834	474402	1001122	2375.531
BH305	466050	993650	2294.538	BH835	525000	887000	2489.149
BH306	445180	1002459	2366.689	BH836	545000	887000	2888.998
BH307	454730	928240	1988.083	BH837	546000	886000	3090.111
BH308	432432	1024464	2587.576	BH838	548000	890000	2863.369
BH309	561897	1069503	2783.139	BH839	550000	890000	2917.994
BH310	474125	1001050	2537.163	BH840	454331	832210	1585.263
BH311	467200	1001017	2500.923	BH841	478897	983875	2153.039
BH312	475000	1001300	2470.893	BH842	525328	936530	1535.405
BH313	474200	997400	2427.191	BH843	526208	936077	1552.188
BH314	441831	983807	2070.002	BH844	539000	897000	2135.574
BH315	471300	998200	2435.896	BH845	543000	899000	2264.51
BH316	530792	940526	1437.917	BH846	539000	897000	2135.574

BH317	478007	971121	2045.367	BH847	539000	897000	2135.574
BH318	478450	995600	2271.254	BH848	476287	1000116	2383.947
BH319	427000	1095000	2572.257	BH849	441257	852390	1554.499
BH320	515109	943100	1667.847	BH850	468750	967100	1959.437
BH321	440595	1000333	2302.208	BH851	543000	892000	2553.422
BH322	469725	994250	2310.643	BH852	479316	999941	2523.723
BH323	471300	995050	2326.402	BH853	479310	999940	2534.897
BH324	562106	1070685	2777.768	BH854	496239	830841	2621.664
BH325	469700	994500	2333.13	BH855	474716	985017	
BH326	559369	1067725	2761.353	BH856	482076	999660	2491.131
BH327	559432	1066077	2757.088	BH857	472720	1002256	2530.214
BH328	424000	952736	2171.674	BH858	520000	936000	1563.905
BH329	381500	933000	1917.269	BH859	520000	937000	1553.297
BH330	474395	995211	2292.325	BH860	505000	934000	1611.602
BH331	473000	992700	2178.314	BH861	518000	935000	1595.889
BH332	472900	992500	2189.369	BH862	478850	1000950	2735.661
BH333	474300	992700	2189.95	BH863	474203	1002351	2386.326
BH334	475600	994500	2282.342	BH864	483763	999358	2287.49
BH335	473100	991900	2172.4	BH865	447374	842165	1582.467
BH336	473848	990072	2216.195	BH866	448961	846001	1581.046
BH337	473600	988300	2181.749	BH867	454385	849044	1579.112
BH338	473900	989000	2189.898	BH868	462521	844810	1579.044
BH339	475000	987800	2135.943	BH869	460669	837865	1577.796
BH340	475335	980717	2058.122	BH870	456436	831978	1579.845
BH341	476600	981500	2057.065	BH871	466027	837270	1588.47
BH342	481507	976220	2009.65	BH872	467615	845935	1587.002
BH343	476400	980700	2009.264	BH873	472642	848184	1605.014
BH344	473900	1001050	2551.198	BH874	478793	844083	1578.517
BH345	475300	984000	2115.374	BH875	480381	835381	1585.21
BH346	467200	1001017	2500.923	BH876	488348	998915	2320.767
BH347	468400	1001016	2544.858	BH877	493247	1001478	2431.219
BH348	466600	1001003	2492.694	BH878	508312	1013331	2497.868
BH349	468900	1001007	2475.88	BH879	489977	1000102	2334.331
BH350	486200	1001042	2453.191	BH880	496269	1004908	
BH351	473400	996400	2354.15	BH881	498961	1005177	
BH352	473400	996300	2351.09	BH882	497374	1006185	2474.239
BH353	473100	996400	2348.335	BH883	497470	1006388	2473.845
BH354	473200	996400	2345.8	BH884	508870	1001615	2465.871
BH355	477162	976038	2023.449	BH885	503946	1003745	2447.543
BH356	477856	976402	2023.789	BH886	502084	1008222	2452.029
BH357	471300	995400	2330.898	BH887	497270	1004423	2457.594
BH358	470900	994800	2306.55	BH888	501119	1009538	2451.643
BH359	469300	995500	2342.315	BH889	501042	1006819	2448.061
BH360	481205	976968	2022.986	BH890	495424	1009989	2478.789
BH361	471200	995700	2339.271	BH891	493723	1008258	2462.507
BH362	466300	993100	2275.588	BH892	502267	1009162	2453.791

BH363	466250	993050	2288.684	BH893	503292	1005372	2448.261
BH364	473334	997204	2365.767	BH894	499627	1010263	2490.77
BH365	473500	992900	2183.341	BH895	501684	1004947	2424.12
BH366	481650	997725	2372.977	BH896	498656	1008943	2475.524
BH367	474300	993300	2192.562	BH897	493571	1007179	2432.162
BH368	473100	991900	2172.4	BH898	500497	1007598	2480.047
BH369	473050	991800	2186.832	BH899	494679	1006306	2466.384
BH370	470465	991100	2207.052	BH900	496594	1006485	2470.191
BH371	473750	990050	2201.532	BH901	499750	1008782	2471.479
BH372	482770	997150	2349.145	BH902	499253	1006931	2471.802
BH373	473900	989000	2179.898	BH903	496943	1007787	2463.565
BH374	474100	989000	2185.497	BH904	501959	1007278	2450.539
BH375	474050	996650	2373.128	BH905	472456	995639	
BH376	473300	987700	2115.006	BH906	513000	885000	1911.991
BH377	473300	987300	2121.306	BH907	466336	1000658	2422.28
BH378	468100	1016250	2575.574	BH908	466841	1000105	2409.161
BH379	475000	985800	2163.589	BH909	478350	996700	2373.305
BH380	466050	993650	2294.538	BH910	469300	966775	1955.831
BH381	476400	980600	2044.831	BH911	429469	848820	1791.587
BH382	465243	1003393	2608.723	BH912	470682	987316	
BH383	465507	1002282	2559.409	BH913	477495	995065	2269.501
BH384	470950	995225	2319.113	BH914	473446	991371	2195.117
BH385	472700	996500	2353.097	BH915	538000	888000	2686.214
BH386	470500	994500	2283.922	BH916	516697	852135	2370.988
BH387	466900	1001005	2516.954	BH917	485313	984138	2200.38
BH388	478462	977721	2033.749	BH918	482852	987470	2205.117
BH389	477608	978689	2024.22	BH919	483560	983856	2180.084
BH390	474225	982650	2123.596	BH920	480370	984380	2146.821
BH391	474429	986829	2142.992	BH921	488166	981466	2234.12
BH392	475300	983800	2121.252	BH922	485707	983544	2213.988
BH393	480431	998457	2439.641	BH923	484161	982223	2207.752
BH394	455000	985200	2181.735	BH924	478634	987263	2193.844
BH395	474050	1000875	2548.146	BH925	481467	986506	2179.634
BH396	478462	977506	2031.841	BH926	483963	985000	2217.622
BH397	474648	985501	2057.417	BH927	481129	989896	2228.951
BH398	502600	1011700	2487.504	BH928	484553	986685	2249.647
BH399	483093	976323	2018.029	BH929	481887	984954	2162.14
BH400	462500	987000	2221.135	BH930	482141	982240	2167.452
BH401	464000	997000	2458.072	BH931	477224	981760	2094.949
BH402	463700	988500	2261.384	BH932	479454	985457	2158.479
BH403	486200	1001042	2461.191	BH933	480385	986784	2194.192
BH404	481200	980000	2149.126	BH934	482636	985971	2203.289
BH405	470800	982900	2108.921	BH935	477891	987018	2180.619
BH406	473566	978610	2042.224	BH936	484001	987465	2241.041
BH407	487300	995300	2276.152	BH937	481012	984597	2186.825
BH408	481600	982900	2175.656	BH938	465819	1002574	2511.078

BH409	461500	1001023	2510.28	BH939	469302	1001458	2424.725
BH410	466200	988800	2248.188	BH940	503048	1004201	2462.655
BH411	466400	987600	2237.218	BH941	503521	1011796	2443
BH412	481200	980000	2151.126	BH942	488938	1007707	2516.31
BH413	481600	982900	2173.656	BH943	498395	1005673	2454.667
BH414	479400	981400	2125.742	BH944	472585	982237	2051.469
BH415	480900	978800	2047.067	BH945	558000	914000	2340.922
BH416	479340	981400	2128.411	BH946	551000	910000	2065.836
BH417	481600	982850	2176.983	BH947	550000	908000	2187.774
BH418	479740	981400	2143.152	BH948	555000	915000	2029.426
BH419	473069	979881	2054.649	BH949	560000	919000	2059.479
BH420	473108	979851	2055.91	BH950	550000	906000	2412.639
BH421	477972	974859	2025.491	BH951	548000	906000	2159.636
BH422	478399	975589	2024.348	BH952	560000	913000	2483.707
BH423	480517	977974	2039.562	BH953	475276	976930	2003.952
BH424	478713	974977	2023.051	BH954	476037	976861	2007.177
BH425	477992	975552	2024.986	BH955	475058	976100	2006.757
BH426	476574	975607	2022.715	BH956	475528	975870	2006.685
BH427	479696	976936	2025.412	BH957	476098	976183	2003.382
BH428	479405	976735	2023.532	BH958	474528	975585	2008.785
BH429	479061	976370	2023.967	BH959	473954	975244	1993.423
BH430	479246	977104	2022.193	BH960	473954	975244	2008.683
BH431	479058	976020	2023.621	BH961	471453	974241	2005.344
BH432	478780	977307	2022.281	BH962	475507	974697	2028.445
BH433	478808	976867	2028.459	BH963	472078	974359	2005.904
BH434	478694	976490	2027.984	BH964	472640	973882	2004.391
BH435	478580	976051	2025.944	BH965	473428	973584	2008.091
BH436	478347	976752	2023.917	BH966	474702	974792	2006.526
BH437	478199	976361	2023.297	BH967	474733	973382	2008.202
BH438	478154	975966	2024.543	BH968	477023	973986	2006.044
BH439	478019	977985	2024.445	BH969	476375	974046	2000.976
BH440	477945	976985	2023.602	BH970	477959	974168	2002.831
BH441	477651	975923	2024.056	BH971	475507	974679	2001.296
BH442	477477	977216	2023.312	BH972	475941	975137	2004.088
BH443	477330	976793	2022.546	BH973	473071	974284	2007.035
BH444	477181	975680	2020.846	BH974	478528	973384	2001.145
BH445	476454	976951	2020.632	BH975	476725	973381	2002.667
BH446	476972	976152	2025.118	BH976	477415	973284	2000.249
BH447	477185	975729	2023.733	BH977	473314	1002774	2578.159
BH448	479526	977468	2022.314	BH978	542000	929000	1397.366
BH449	479021	977596	2015.14	BH979	542000	929000	1397.366
BH450	478998	977937	2026.39	BH980	542000	929000	1397.366
BH451	487900	972421	1876.162	BH981	542000	929000	1397.366
BH452	488391	961066	1802.583	BH982	476370	983392	
BH453	473350	1003000	2676.711	BH983	438871	977186	2049.275
BH454	484190	998500	2446.488	BH984	422802	976337	

BH455	485925	1000975	2478.279	BH985	447224	978514	2047.992
BH456	486000	1001115	2473.063	BH986	448984	980202	2052.657
BH457	482070	999823	2458.633	BH987	445565	983665	2072.997
BH458	465900	1002875	2597.161	BH988	450949	1000247	
BH459	483750	994550	2293.001	BH989	427193	976742	
BH460	455350	985100	2112.328	BH990	431873	978996	
BH461	455300	985250	2150.38	BH991	507556	958248	1835.332
BH462	455525	984000	2080.757	BH992	472772	1018752	2553.053
BH463	455550	983750	2087.675	BH993	475936	978248	2015.721
BH464	444000	977700	2052.415	BH994	475697	979915	2050.683
BH465	460850	985850	2205.681	BH995	471027	973709	2010.655
BH466	460500	986500	2262.719	BH996	472846	980785	2053.676
BH467	468650	995450	2317.018	BH997	472836	980785	2053.666
BH468	468650	999800	2417.109	BH998	472779	978788	2050.313
BH469	467100	1000550	2498.992	BH999	475945	978251	2010.81
BH470	474500	995450	2280.3	BH1000	470158	1001882	2548.986
BH471	468800	996600	2322.247	BH1001	470503	1002189	2538.115
BH472	468200	1001600	2525.133	BH1002	542000	900000	2178.125
BH473	469050	994450	2301.992	BH1003	4480887	997740	-1000062
BH474	469280	993350	2283.445	BH1004	534000	887000	2652.529
BH475	468875	993750	2293.496	BH1005	529000	887000	2630.76
BH476	473900	993100	2194.355	BH1006	531000	889000	2444.184
BH477	470950	993300	2278.618	BH1007	528000	889000	2413.117
BH478	474250	996800	2346.196	BH1008	466306	1008828	2671.85
BH479	474175	996550	2337.056	BH1009	565000	921000	2150.22
BH480	472700	999800	2493.849	BH1010	473597	981135	2051.363
BH481	476800	994200	2293.133	BH1011	472245	977865	2032.528
BH482	476105	1000050	2425.644	BH1012	471476	977396	2022.388
BH483	468100	1001625	2550.463	BH1013	472233	976508	2019.528
BH484	463850	993100	2313.05	BH1014	471521	976630	2019.428
BH485	466050	993650	2294.538	BH1015	473944	978722	2038.916
BH486	475750	993650	2216.714	BH1016	473386	980122	2054.951
BH487	465600	1001855	2542.299	BH1017	472460	981553	
BH488	478347	976752	2023.917	BH1018	471918	979657	2048.313
BH489	475780	956477	1815.108	BH1019	470557	976837	2001.109
BH490	472150	993300	2227.313	BH1020	474204	980459	2050.726
BH491	473576	972821	2021.596	BH1021	471289	977837	2027.281
BH492	484475	975622	2009.417	BH1022	474918	980486	2055.427
BH493	489950	976019	1979.786	BH1023	471185	979580	2017.467
BH494	485798	968308	1836.473	BH1024	470469	979211	2039.307
BH495	463266	1001971	2546.92	BH1025	472630	979912	2055.34
BH496	465243	1003930	2664.06	BH1026	471909	979461	2051.274
BH497	470110	993850	2286.778	BH1027	473583	979260	2048.583
BH498	474957	982383	2123.041	BH1028	469612	978592	2032.786
BH499	483350	999064	2441.913	BH1029	472446	974756	2012.068

BH500	466350	1001000	2525.586	BH1030	469239	972866	1988.143
BH501	469727	993542	2291.59	BH1031	469738	971752	1989.494
BH502	460121	985966	2208.965	BH1032	470153	970500	
BH503	470316	991064	2217.24	BH1033	469257	970946	1993.922
BH504	467000	996300	2313.122	BH1034	468453	973497	2001.299
BH505	463908	995127	2421.175	BH1035	469835	978303	2000.956
BH506	465410	1002944	2592.127	BH1036	468849	970179	1989.097
BH507	476963	994106	2268.038	BH1037	468353	972311	1992.454
BH508	490000	968000	1810.204	BH1038	468006	971498	2006.125
BH509	475800	1001500	2472.893	BH1039	472286	971308	1988.207
BH510	469804	993691	2295.112	BH1040	473576	972379	2044.978
BH511	476235	995275	2268.389	BH1041	470352	972510	
BH512	477463	994346	2235.076	BH1042	470717	971442	1991.823
BH513	474556	983625	2123.505	BH1043	476795	971654	2093.72
BH514	481878	1000148	2501.237	BH1044	471351	970556	1994.152
BH515	474000	1001000	2530.758	BH1045	472576	972379	2076.719
BH516	488150	1002300	2449.48	BH1046	471576	972958	2010.861
BH517	457030	984617	2119.17	BH1047	469163	973946	2005.926
BH518	480895	977403	2040.82	BH1048	473955	974576	2011.652
BH519	474788	982924	2135.321	BH1049	473596	974154	1979.936
BH520	458646	984363	2142.326	BH1050	473636	974157	1984.493
BH521	472975	1011144	2601.401	BH1051	477362	973887	2007.833
BH522	480965	977576	2027.787	BH1052	471909	978486	1950.014
BH523	471799	999371	2470.089				
BH524	481337	982304	2175.684				
BH525	479700	981700	2121.094				
BH526	479000	981400	2117.971				
BH527	473209	996728	2354.772				
BH528	465600	1001855	2532.299				
BH529	463972	1000788	2513.468				
BH530	464721	996788	2276.229				

Annex II: Transmissivity values of wells

S.N	ID	X	Y	Z	RWL	DEPTH(M)	Q(L/S)	SWL(M)	T(M2/D)
1	BH1	493247	1001478	2439	2431	432	15	7	14
2	BH2	489977	1000102	2344	2334	500	20	10	11
3	BH3	496269	1004908	2466	2466	598	52	0	3200
4	BH4	498961	1005177	2466	2466	181	Artesian	0	….
5	BH5	497374	1006185	2501	2474	182	50	28	408
6	BH6	497470	1006388	2506	2474	440	38	32	195
7	BH7	500497	1007598	2509	2480	372	97	29	3000
8	BH8	494679	1006306	2486	2466	504	88	20	2940
9	BH9	496594	1006485	2484	2470	550	45	14	725
10	BH10	499750	1008782	2520	2470	504	84	50	…
11	BH11	499253	1006931	2506	2472	378	80	34	1200
12	BH12	472456	995639	2349	2349	500	-	0	…
13	BH13	466336	1000658	2508	2411	420	53	97	728
14	BH14	466841	1000105	2461	2387	392	52	74	0
15	BH15	466336	1000658	2519	2422	420	53	97	728
16	BH16	470682	987316	2218	2218	357	50	0	14
17	BH17	426868	899213	2144	2081.5	600	17	62.5	38.75
18	BH18	443675	909350	1899	1874.87	411.5	60	24.13	235.5
19	BH19	446946	888984	1825	1807.54	591	73.7	17.46	2100
20	BH20	421268	876639	2087	1911.5	500	16	175.5	123
21	BH21	434900	871870	1863	1808.4	502	50	54.6	553
22	BH22	477495	995065	2321	2256	422	12	64	35
23	BH23	473446	991371	2281	2187	507	72	93	347
24	BH24	465724	1002753	2602	2517	332	56	85	…
25	BH25	469302	1001458	2564	2417	550	6	147	0.97
26	BH26	503048	1004201	2499	2465	157	26	34	…
27	BH27	498938	1007707	2510	2494	200	25	16	…
28	BH28	472585	982237	2075	2034	537	16	41	30300
29	BH29	475276	976930	2058	2004	582	75	54	448
30	BH30	476037	976861	2062	2007	595	88	55	150
31	BH31	475058	976100	2056	2007	502	91	49	822
32	BH32	475528	975870	2059	2007	600	87	52	747
33	BH33	476098	976183	2057	2003	550	47	54	309
34	BH34	474528	975585	2058	2009	569	95	49	138
35	BH35	473954	975244	2058	1993	600	70	65	1000
36	BH36	475128	975184	2068	2003	600	70	65	612
37	BH37	473954	975244	2058	2009	591	55	49	255
38	BH38	471453	974241	2055	2005	335	113	50	635
39	BH39	475507	974697	2077	2028	320	113	49	140
40	BH40	470835	974233	2046	1996	320	114	50	669
41	BH41	472078	974359	2058	2006	319	106	52	1020
42	BH42	472640	973882	2075	2005	519	85	70	1010
43	BH43	473428	973584	2079	2008	623	32	71	86
44	BH44	474702	974792	2077	2007	595	98	70	761
45	BH45	474733	973382	2087	2008	501	35	79	91
46	BH46	477023	973986	2091	2006	503	66	85	1020
47	BH47	476375	974046	2091	2001	568	27	91	33

S.N	ID	X	Y	Z	RWL	DEPTH(M)	Q(L/S)	SWL(M)	T(M2/D)
48	BH48	477959	974168	2101	2003	501	90	98	4040
49	BH49	475507	974679	2077	2001	515	72	77	1020
50	BH50	475941	975137	2069	2004	551	102	65	2450
51	BH51	473071	974284	2062	2006	552	109	56	792
52	BH52	478528	973384	2134	2001	518	46	132	18700
53	BH53	476725	973381	2113	2003	170	48	110	438
54	BH54	477415	973284	2116	2000	453	37	116	242
55	BH55	473314	1002774	2634	2549	287	36	85	25900
56	BH56	475697	979915	2060	2050	448	55	10	58
57	BH57	471027	973709	2055	2011	379	90	44	1970
58	BH58	472846	980785	2062	2054	120	30	8	606
59	BH59	472836	980785	2062	2054	481	90	8	12900
60	BH60	472779	978788	2060	2050	486	90	10	34400
61	BH61	475945	978251	2056	2011	416	12	45	48
62	BH62	470158	1001882	2611	2549	506	32	62	45
63	BH63	470503	1002189	2637	2538	410	30	99	1
64	BH64	442811	977625	2054	2044	179	…	10	…
65	BH65	444000	977700	2058	2041	100	0	17	
66	BH66	473597	981135	2073	2051	500	11	22	87
67	BH67	472245	977865	2059	2032	500	62	28	105
68	BH68	471476	977396	2056	2022	480	101	34	5810
69	BH69	472233	976508	2060	2020	400	22	40	166
70	BH70	471521	976630	2059	2019	552	76	40	2220
71	BH71	473944	978722	2070	2040	492	40	30	177
72	BH72	473386	980122	2066	2055	549	31	11	65
73	BH73	472460	981553	2067	2067	500	49	0	107
74	BH74	471918	979657	2058	2048	272	140	9	16200
75	BH75	470557	976837	2056	2001	269	67	54	251
76	BH76	474204	980459	2072	2051	250	62	21	203
77	BH77	471289	977837	2054	2028	500	40	27	263
78	BH78	474918	980486	2077	2056	480	28	22	575
79	BH79	471185	979580	2055	2017	500	122	37	97
80	BH80	470469	979211	2054	2039	506	140	15	66
81	BH81	472630	979912	2064	2055	533	73	8	1590
82	BH82	471909	979461	2060	2051	501	7	9	27
83	BH83	473583	979260	2066	2049	484	50	18	106
84	BH84	469612	978592	2056	2033	514	70	23	82
85	BH85	472446	974756	2054	2012	468	102	42	886
86	BH86	469239	972866	2107	1996	501	49	111	72
87	BH87	469239	972866	2073	1988	500	50	85	171
88	BH88	469239	972866			501	50	85	171
89	BH89	469738	971752	2073	1989	341	70	83	164
90	BH90	469257	970946	2059	1994	342	61	65	384
91	BH91	468453	973497	2055	2001	500	60	53	445
92	BH92	469835	978303	2054	2001	540	142	53	301
93	BH93	469835	978303	2064	1922	550	53	142	301
94	BH94	468849	970179	2045	1990	493	83	55	520
95	BH95	468353	972311	2054	1992	480	81	62	321
96	BH96	468006	971498	2063	2006	496	77	58	663
97	BH97	472286	971308	2071	1988	550	26	83	167
98	BH98	473576	972379	2096	2044	453	20	52	50

S.N	ID	X	Y	Z	RWL	DEPTH(M)	Q(L/S)	SWL(M)	T(M2/D)
99	BH99	473576	972379	2089	2037	453	20	52	50
100	BH100	470352	972510	2082	1990	511	9	92	…
101	BH101	470717	971442	2064	1992	550	11	72	412
102	BH102	476795	971654	2174	2094	499	50	80	1600
103	BH103	471576	972958	2064	2010	550	75	54	925
104	BH104	469163	973946	2052	2006	502	50	46	2020
105	BH105	473598	974154	2056	1966	250		90	…
106	BH106	477362	973887	2097	2008	306	65	89	59300
107	BH107	471909	978486	2058	1950	480	43	108	116

Annex III: Data of inventory wells in the upper awash basin

ID	X	Y	Z	RWL	DEPTH	SWL(M)
BH1	474702	974792	2077	2007	60	70
BH2	559243	1066639	2756	2751	100	5
BH3	486200	1001042	2472	2453.8	100	18
BH4	486200	1001042	2472	2461.6	100	10
BH5	559369	1067725	2773	2766.3	100	6
BH6	503210	930527	1600	1592.6	100	8
BH7	513423	948940	1779	1741.9	100	37
BH8	469342	901807	1724	1639.1	100	85
BH9	444677	998215	2288	2282.2	100	6
BH10	444677	998808	2309	2288	100	21
BH11	442842	977555	2067	2053	100	14
BH12	387305	945410	2055	2055.3	100	0
BH13	427000	1095000	2577	2570	100	7
BH14	559369	1067725	2773	2766.3	100	6
BH15	381500	933000	1921	1913.8	100	7
BH16	473848	990072	2255	2215.6	100	39
BH17	486200	1001042	2472	2453.8	100	18
BH18	473200	996400	2347	2346.6	100	0
BH19	464000	997000	2510	2458.6	100	51
BH20	486200	1001042	2472	2461.6	100	10
BH21	466200	988800	2249	2248.6	100	0
BH22	479400	981400	2130	2126.9	100	3
BH23	444000	977700	2068	2050.7	100	17
BH24	460500	986500	2296	2269.1	100	27
BH25	466200	988800	2249	2248.6	100	0
BH26	519000	936000	1613	1567.7	100	45
BH27	518000	935000	1598	1566.7	100	31
BH28	518000	935000	1598	1570.7	100	27
BH29	444000	977700	2058	2040.88	100	17.12
BH30	381500	933000	1925	1918	100	7
BH31	381713	933854	1904	1896	100	7
BH32	387305	945410	2056	2056	100	0
BH33	469342	901807	1724	1639	100	85
BH34	445180	1002459	2390	2366.6	101	23
BH35	471300	995400	2332	2331.6	101	0
BH36	455300	985250	2198	2160.8	101	38
BH37	315829	996213	1752	1750	101	2
BH38	559341	1065874	2758	2750	102	8
BH39	488161	1002129	2475	2411.6	102	63
BH40	559432	1066077	2760	2757.4	102	3
BH41	507491	952694	1827	1787.2	102	40
BH42	479313	905790	1707	1622.2	102	85
BH43	460810	981473	2229	2162.1	102	67
BH44	488161	1002129	2475	2411.6	102	63
BH45	559432	1066077	2760	2757.4	102	3
BH46	473600	988300	2192	2180.5	102	11
BH47	501000	892000	1692	1609	102	83
BH48	365073	916373	1880	1853	102	27

BH49	459658	946538	2126	2076	103	50
BH50	473300	987700	2160	2115.3	103	45
BH51	473108	979851	2063	2055.7	103	7
BH52	365427	923242	1697	1694	103	3
BH53	496479	965700	1907	1850	104	57
BH54	457823	1002833	2619	2616.5	104	3
BH55	465600	1001855	2555	2541.5	104	13
BH56	480895	977403	2124	2039.1	104	85
BH57	363186	891568	1961	1919	104	42
BH58	377560	895880	2031	1998	104	33
BH59	476105	1000050	2477	2427.3	105	50
BH60	493545	968537	1916	1848.9	105	67
BH61	481495	909593	1698	1614	105	84
BH62	435268	897823	2000	1959.1	105	41
BH63	476105	1000050	2477	2427.3	105	50
BH64	527000	944000	1650	1555.2	105	95
BH65	518000	887000	2190	2110.4	105	80
BH66	435268	897823	1995	1954	105	41
BH67	460850	985850	2251	2208.1	106	43
BH68	560712	1070580	2779	2771	107	7
BH69	469300	995500	2356	2339.5	107	16
BH70	562012	1070477	2789	2776	108	13
BH71	562106	1070685	2793	2779.9	108	13
BH72	462052	883164	1706	1624.9	108	81
BH73	493179	968613	1912	1837.7	108	74
BH74	492987	967055	1948	1905.1	108	42
BH75	386183	943986	2032	2031.8	108	0
BH76	562106	1070685	2793	2779.9	108	13
BH77	521000	935000	1554	1525.1	108	29
BH78	365128	915879	1872	1840	108	32
BH79	386183	943986	2032	2032	108	0
BH80	460062	948743	2103	2055	109	48
BH81	479340	981400	2130	2128.9	109	1
BH82	507408	1013586	2587	2557.4	110	29
BH83	469725	895830	1708	1628.9	110	79
BH84	507408	1013586	2587	2557.4	110	29
BH85	461500	1001023	2590	2507.9	110	82
BH86	465900	1002875	2613	2597	110	16
BH87	469725	895830	1707	1628	110	79
BH88	463266	1001971	2604	2550.7	111	53
BH89	424000	952736	2176	2170.5	112	5
BH90	466300	993100	2336	2275.8	112	60
BH91	424000	952736	2175	2170	112	5
BH92	511927	948292	1764	1755.6	114	8
BH93	523310	928661	1547	1539.8	114	7
BH94	460937	986565	2277	2230.5	114	46
BH95	512356	947895	1753	1727.5	114	26
BH96	471300	995050	2326	2325.9	114	0
BH97	470800	982900	2109	2108.9	114	0
BH98	477185	975729	2071	2024.4	114	47
BH99	472975	1011144	2614	2602.1	114	12
BH100	471799	999371	2478	2469.8	114	8

BH101	512000	948000	1752	1716.7	114	35
BH102	512000	948000	1752	1712.7	114	39
BH103	488463	965890	1902	1808.5	115	94
BH104	508079	952013	1818	1810.6	115	8
BH105	453522	1001474	2568	2510.2	115	58
BH106	457162	1001115	2625	2618.2	115	7
BH107	465243	1003393	2635	2608.6	115	26
BH108	470950	995225	2319	2319.4	115	0
BH109	465243	1003930	2689	2662.7	115	26
BH110	490000	968000	1905	1810.6	115	95
BH111	453522	1001474	2567	2509	115	58
BH112	483350	999064	2501	2441.8	116	59
BH113	443132	1000869	2386	2355.9	116	30
BH114	492803	969204	1907	1842.7	116	64
BH115	468900	1001007	2548	2476.2	116	72
BH116	477608	978689	2082	2024.4	116	58
BH117	473069	979881	2061	2055.5	116	6
BH118	477181	975680	2072	2021.4	116	51
BH119	483350	999064	2501	2441.8	116	59
BH120	479700	981700	2141	2120.9	116	20
BH121	474648	985501	2144	2058.6	117	86
BH122	482070	999823	2539	2459.9	117	80
BH123	512602	947821	1761	1721.8	117	39
BH124	466233	1031004	2575	2519.9	117	55
BH125	474648	985501	2144	2058.6	117	86
BH126	482070	999823	2539	2459.9	117	80
BH127	528000	941000	1620	1516.4	117	104
BH128	515465	1078129	2594	2588	118	7
BH129	470900	994800	2307	2306.9	119	1
BH130	478694	976490	2078	2028	119	50
BH131	475000	985800	2164	2163.7	120	0
BH132	487300	995300	2364	2276.3	120	88
BH133	472846	980785	2062	2054	120	8
BH134	474554	908761	1720	1623.5	120	96
BH135	465419	987294	2263	2247.9	120	15
BH136	455450	983014	2110	2095.2	120	15
BH137	473300	987300	2157	2121.4	120	35
BH138	475000	985800	2164	2163.7	120	0
BH139	476400	980600	2062	2045.1	120	17
BH140	487300	995300	2364	2276.3	120	88
BH141	481600	982900	2211	2175.9	120	35
BH142	481600	982900	2211	2173.6	120	37
BH143	476972	976152	2065	2024.3	120	40
BH144	469050	994450	2329	2302.1	120	27
BH145	470950	993300	2298	2278.7	120	19
BH146	474175	996550	2377	2337	120	40
BH147	472700	999800	2503	2491.4	120	12
BH148	469727	993542	2314	2292	120	22
BH149	460121	985966	2254	2214	120	40
BH150	479000	981400	2128	2117.6	120	10
BH151	529224	943393	1628	1527.8	120	100
BH152	529000	944000	1619	1518.7	120	100

BH153	518000	887000	2190	2100.4	120	90
BH154	473000	992700	2289	2178.3	121	111
BH155	473566	978610	2066	2042.8	122	24
BH156	478399	975589	2078	2024.7	122	53
BH157	469280	993350	2303	2283.8	122	20
BH158	477019	917872	1721	1642.7	123	79
BH159	512282	951356	1774	1766.2	123	7
BH160	478462	977506	2081	2031.3	123	50
BH161	502600	1011700	2569	2487.4	124	82
BH162	470465	991100	2223	2207.5	124	16
BH163	502600	1011700	2569	2487.4	124	82
BH164	455525	984000	2146	2082.5	124	63
BH165	468800	996600	2372	2321.5	124	50
BH166	465410	1002944	2604	2593.2	124	11
BH167	474788	982924	2159	2135.3	124	24
BH168	561898	1069503	2792	2783	125	9
BH169	561897	1069503	2793	2783.3	125	9
BH170	446338	997431	2259	2245.4	125	13
BH171	463742	985378	2363	2344.3	125	18
BH172	427635	994816	2119	2112	125	7
BH173	512355	951516	1776	1766.3	125	9
BH174	561897	1069503	2793	2783.3	125	9
BH175	466400	987600	2255	2237	125	18
BH176	427635	994816	2117	2110	125	7
BH177	537332	928166	1523	1435	126	88
BH178	447200	998889	2295	2294.7	126	0
BH179	479021	977596	2088	2022.3	126	66
BH180	476600	981500	2061	2057.7	126	4
BH181	476400	980700	2062	2008.9	126	53
BH182	474100	989000	2221	2185.8	126	35
BH183	455000	985200	2238	2187.6	126	51
BH184	479740	981400	2144	2140.8	126	3
BH185	479021	977596	2088	2014.9	126	73
BH186	468650	995450	2342	2316.1	126	26
BH187	505014	970969	1884	1863.5	126	21
BH188	535918	945906	1483	1383.7	126	100
BH189	537322	928164	1529	1441.3	126	88
BH190	505014	970969	1884	1863.5	126	21
BH191	490632	918070	1646	1567.4	127	79
BH192	462554	944481	2111	2019.7	127	91
BH193	455350	985100	2188	2118.3	128	70
BH194	527435	942998	1633	1525.3	128	108
BH195	429000	960500	2140	2128	128	12
BH196	475300	984000	2115	2115.3	129	0
BH197	474300	992700	2280	2190.7	129	89
BH198	475300	984000	2115	2115.3	129	0
BH199	476454	976951	2063	2021.2	129	42
BH200	479526	977468	2094	2022.1	129	72
BH201	486000	1001115	2483	2473.3	130	10
BH202	506728	937459	1660	1606.3	130	53
BH203	494054	968452	1925	1858.9	130	66
BH204	532590	932122	1548	1465.1	130	83

BH205	502329	929321	1598	1592.9	130	5
BH206	445099	1003816	2400	2370.5	130	30
BH207	443050	1001649	2407	2383.3	130	24
BH208	378447	991365	2183	2150.1	130	33
BH209	458959	953532	2027	1960.3	130	67
BH210	463599	988583	2283	2263.4	130	19
BH211	463700	988500	2278	2259.2	130	19
BH212	478713	974977	2087	2023.5	130	64
BH213	479058	976020	2095	2023.1	130	72
BH214	478580	976051	2085	2025.4	130	59
BH215	477330	976793	2066	2023.1	130	43
BH216	478998	977937	2099	2025.1	130	73
BH217	486000	1001115	2483	2473.3	130	10
BH218	468875	993750	2304	2292.8	130	11
BH219	468512	989680	2230	2230.3	130	0
BH220	378447	991365	2184	2151	130	33
BH221	373700	990500	2163	2130	131	33
BH222	476963	994106	2341	2268.5	132	73
BH223	488798	972371	1957	1927	132	30
BH224	481507	976220	2130	2010.5	132	120
BH225	477992	975552	2073	2024.5	132	48
BH226	475780	956477	1904	1814.5	132	89
BH227	467000	996300	2364	2312.5	132	52
BH228	476963	994106	2341	2268.5	132	73
BH229	480965	977576	2129	2030.5	132	99
BH230	532673	932328	1558	1476	132	82
BH231	486712	1001378	2448	2448.2	133	0
BH232	487881	973470	1986	1926.4	133	60
BH233	386987	945156	2053	2053.5	133	0
BH234	477972	974859	2084	2025.3	133	59
BH235	486712	1001378	2448	2448.2	133	0
BH236	386986	945147	2050	2050	133	0
BH237	546000	986000	1801	1671.7	134	129
BH238	480641	977009	2119	2020.5	134	98
BH239	512957	947774	1773	1736.1	134	37
BH240	459928	941554	2167	2089.3	134	78
BH241	465741	989188	2254	2251.2	134	3
BH242	546000	986000	1801	1671.7	134	129
BH243	459928	941554	2172	2094	134	78
BH244	481337	1001017	2637	2613.6	135	23
BH245	481337	1001017	2637	2613.6	135	23
BH246	477162	976038	2066	2023.7	135	42
BH247	487900	972421	1951	1874.8	135	76
BH248	474957	982383	2147	2123.3	135	24
BH249	481337	982304	2199	2175.3	135	23
BH250	536720	930085	1554	1443.2	136	111
BH251	473050	991800	2281	2186.6	136	94
BH252	481600	982850	2210	2176.5	136	33
BH253	466050	993650	2366	2294.5	136	71
BH254	482770	997150	2387	2352	137	35
BH255	466050	993650	2366	2294.5	137	71
BH256	482770	997150	2387	2352	137	35

BH257	462500	987000	2309	2225.4	137	84
BH258	369771	993886	2006	2006	138	0
BH259	478780	977307	2084	2022.4	138	61
BH260	475600	994500	2323	2282.6	139	41
BH261	448328	957872	2130	2044.9	139	85
BH262	475600	994500	2323	2282.6	139	41
BH263	448328	957872	2136	2050	139	85
BH264	559600	1064728	2768	2763	140	5
BH265	475300	983800	2122	2121.6	140	0
BH266	484190	998500	2492	2447	140	45
BH267	481878	1000148	2577	2500.6	140	76
BH268	481178	958488	1848	1789.9	140	58
BH269	489485	943724	1723	1648.5	140	75
BH270	466050	993650	2366	2294.5	140	71
BH271	475300	983800	2122	2121.6	140	0
BH272	478154	975966	2079	2024.8	140	54
BH273	484190	998500	2492	2447	140	45
BH274	481878	1000148	2577	2500.6	140	76
BH275	457030	984617	2218	2129.6	140	89
BH276	470450	990125	2224	2208	140	16
BH277	529000	944000	1619	1518.7	140	100
BH278	559580	1065011	2775	2754	141	22
BH279	512159	946729	1770	1697.4	141	73
BH280	558266	1064888	2777	2769	142	8
BH281	469725	994250	2328	2310.8	142	17
BH282	466250	993050	2338	2288.5	142	50
BH283	476574	975607	2074	2022.5	142	51
BH284	477651	975923	2072	2024	142	48
BH285	467100	1000550	2514	2502.4	142	12
BH286	378444	991683	2184	2094	143	89
BH287	480029	998401	2466	2446.3	144	20
BH288	479061	976370	2091	2023.4	144	67
BH289	478199	976361	2070	2024.1	144	46
BH290	480029	998401	2466	2446.3	144	20
BH291	481650	997725	2416	2372.9	145	43
BH292	534801	932504	1578	1461.6	145	116
BH293	461412	986324	2277	2232.2	145	45
BH294	481650	997725	2416	2372.9	145	43
BH295	479696	976936	2093	2025.7	145	68
BH296	477477	977216	2068	2024.3	145	44
BH297	537928	957417	1572	1468.1	145	104
BH298	536813	930293	1556	1439.2	145	116
BH299	542960	956854	1482	1386.8	145	95
BH300	369681	993860	2011	2011	145	0
BH301	508684	951058	1802	1777.7	146	24
BH302	473750	990050	2253	2201.8	146	52
BH303	479246	977104	2081	2022	146	59
BH304	421795	1040108	2447	2426.2	146	20
BH305	421795	1040108	2447	2426.2	146	20
BH306	366637	921104	1756	1726	146	29
BH307	434015	1000129	2341	2335.9	147	5
BH308	463908	995127	2463	2422.8	147	40

BH309	463800	994650	2460	2419	147	41
BH310	355538	900934	1848	1731	147	117
BH311	513773	949998	1787	1747.4	148	40
BH312	446266	1004147	2391	2354.5	148	37
BH313	478347	976752	2071	2023.9	148	48
BH314	477945	976985	2073	2023.4	148	50
BH315	475750	993650	2313	2216	149	97
BH316	475750	993650	2313	2216	149	97
BH317	358975	892500	1918	1811	149	107
BH318	359617	895285	1893	1812	149	81
BH319	548235	989763	1758	1631	150	127
BH320	508995	951614	1804	1773	150	31
BH321	509385	950325	1792	1765.9	150	26
BH322	509020	950736	1796	1767.1	150	29
BH323	507950	951364	1816	1790.5	150	26
BH324	536492	929529	1549	1436.2	150	113
BH325	455426	982736	2105	2088.7	150	16
BH326	488408	973431	1980	1937.5	150	43
BH327	512282	951356	1774	1766.4	150	7
BH328	467200	1001017	2536	2500.6	150	35
BH329	466900	1001005	2537	2516.5	150	20
BH330	478462	977721	2084	2034	150	50
BH331	481200	980000	2159	2148.3	150	11
BH332	478019	977985	2077	2025.1	150	52
BH333	473350	1003000	2685	2675.3	150	10
BH334	468200	1001600	2572	2526.1	150	46
BH335	468100	1001625	2582	2550.4	150	32
BH336	463850	993100	2403	2318.9	150	84
BH337	472150	993300	2278	2227.4	150	51
BH338	473576	972821	2095	2021.1	150	74
BH339	470110	993850	2322	2287.2	150	35
BH340	469500	989600	2224	2220.2	150	4
BH341	536580	929743	1549	1435.5	150	113
BH342	464612	1034331	2439	2420	150	19
BH343	476800	994200	2344	2291.6	151	52
BH344	476235	995275	2353	2268.7	151	84
BH345	477856	976402	2068	2023.6	151	45
BH346	479405	976735	2090	2023	151	67
BH347	476800	994200	2344	2291.6	151	52
BH348	476235	995275	2353	2268.7	151	84
BH349	530000	944000	1624	1592.7	151	31
BH350	365447	922747	1708	1654	152	54
BH351	340304	943271	1828	1780	152	48
BH352	364905	923161	1694	1683	152	12
BH353	527667	941523	1613	1514.3	152	99
BH354	467200	1001017	2536	2500.6	152	35
BH355	469700	994500	2339	2332.6	152	7
BH356	478808	976867	2076	2028.6	152	48
BH357	494320	965101	1982	1871.5	153	110
BH358	440110	1001337	2422	2384.9	153	37
BH359	436160	1000453	2360	2322.9	153	37
BH360	474395	995211	2352	2292.5	153	59

BH361	466600	1001003	2518	2495.5	153	23
BH362	466350	1001000	2541	2525.3	153	16
BH363	465600	1001855	2555	2532.1	153	23
BH364	471125	989636	2211	2199.8	153	11
BH365	536681	929942	1577	1452.3	153	125
BH366	494036	1010902	2541	2519.5	154	21
BH367	475571	924071	1745	1653	154	92
BH368	494036	1010902	2541	2519.5	154	21
BH369	474125	1001050	2565	2536.6	154	28
BH370	473100	991900	2285	2172.4	154	113
BH371	473100	991900	2285	2172.4	154	113
BH372	536761	930841	1569	1444.2	154	125
BH373	363347	886391	1980	1933	154	47
BH374	478740	933707	1772	1654.9	155	117
BH375	472900	992500	2280	2190.1	156	90
BH376	474050	1000875	2560	2545.6	156	15
BH377	503048	1004201	2499	2464.7	156.7	34.3
BH378	506989	960627	1858	1842	157	16
BH379	538774	953120	1514	1422.7	157	91
BH380	444245	956023	2219	2122.2	158	96
BH381	463595	995915	2486	2419.6	158	66
BH382	460295	986769	2314	2282.8	158	31
BH383	528318	941952	1611	1507.6	159	104
BH384	515109	943100	1738	1670.2	160	68
BH385	480900	978800	2134	2048	160	86
BH386	507000	901000	1794	1665.7	160	128
BH387	534890	932712	1582	1449	160	133
BH388	548162	987559	1750	1632	161	118
BH389	432432	1024464	2607	2595.2	161	11
BH390	458646	984363	2190	2145.9	161	44
BH391	467723	990028	2236	2232.4	161	4
BH392	432432	1024464	2598	2586	161	11
BH393	473500	992900	2306	2183	162	123
BH394	538498	950940	1495	1411	164	84
BH395	558776	1065907	2761	2746	165	15
BH396	484764	920771	1687	1596.5	165	90
BH397	469672	993830	2324	2307.1	167	17
BH398	482850	989900	2222	2222.1	168	0
BH399	475000	1001300	2545	2471.1	168	74
BH400	475000	1001300	2545	2471.1	168	74
BH401	482850	989900	2222	2222.1	168	0
BH402	544896	938818	1421	1267.4	168	153
BH403	548106	988662	1746	1629	169	117
BH404	477463	994346	2328	2236.3	170	92
BH405	476725	973381	2113	2003	170	110
BH406	483243	961360	1880	1780.6	170	99
BH407	440595	1000333	2386	2305	170	81
BH408	470500	994500	2326	2284.3	170	42
BH409	480517	977974	2106	2040.7	170	65
BH410	470316	991064	2228	2219	170	10
BH411	469804	993691	2322	2295.6	170	27
BH412	477463	994346	2328	2236.3	170	92

BH413	470070	991000	2233	2223.7	170	10
BH414	470530	991988	2235	2200.6	170	35
BH415	559030	1065573	2762	2756	171	5
BH416	478450	995600	2358	2271.4	171	87
BH417	478450	995600	2358	2271.4	171	87
BH418	475000	987800	2164	2136	172	28
BH419	407400	972711	2134	2114.9	172	19
BH420	475000	987800	2164	2136	172	28
BH421	468650	999800	2488	2419.3	172	69
BH422	367270	905131	1887	1808	172	80
BH423	407400	972711	2133	2114	172	19
BH424	509654	1078712	2580	2498	173	82
BH425	483567	976037	2133	2008.1	173	125
BH426	481200	980000	2159	2150.4	173	9
BH427	426788	887491	2093	2021	174	72
BH428	426788	887491	2098	2026.1	174	72
BH429	463972	1000788	2517	2517.1	174	0
BH430	377000	942000	1987	1972	174	15
BH431	488150	1002300	2476	2449.7	175	26
BH432	488150	1002300	2476	2449.7	175	26
BH433	393894	886062	2768	2675	175	93
BH434	484900	990700	2233	2228.6	177	4
BH435	484900	990700	2233	2228.6	177	4
BH436	465507	1002282	2562	2560.5	178	2
BH437	474225	982650	2155	2123.8	178	31
BH438	490513	951595	1774	1672.6	178	101
BH439	490513	951595	1774	1672.6	178	101
BH440	454568	880156	1816	1684.2	179	131
BH441	442811	977625	2065	2055.1	179	10
BH442	475335	980717	2074	2057	179	17
BH443	442811	977625	2054	2044.1	179	9.9
BH444	454568	880156	1814	1683	179	131
BH445	550000	989964	1734	1626	180	108
BH446	488305	960746	1956	1835	180	121
BH447	488391	961066	1951	1802.8	180	148
BH448	462260	984901	2284	2201.5	180	83
BH449	468196	990422	2241	2236.6	180	5
BH450	538581	929142	1553	1403.4	180	150

Annex IV:Land use parameter table

NUMBER	LUSE_TYPE	RUNOFF_VEG	NUM_VEG_RO	NUM_IMP_RO	VEG_AREA	BARE_AREA	IMP_AREA	OPENW_AREA	ROOT_DEPTH	LAI	MIN_STOM	INTERC_PER	VEG_HEIGHT
1	city center build up	grass	2	1	0.2	0	0.8	0	0.3	2	100	10	0.12
2	build up	grass	2	2	0.5	0	0.5	0	0.3	2	100	10	0.12
10	open build up	grass	2	3	0.6	0.1	0.3	0	0.3	2	100	10	0.12
4	infrastructure	grass	2	4	0.6	0.1	0.3	0	0.3	2	100	10	0.12
201	highway	grass	2	5	0.6	0.1	0.3	0	0.3	2	100	10	0.12
202	district road	grass	2	6	0.6	0.1	0.3	0	0.3	2	100	10	0.12
5	sea harbour	grass	2	7	0.6	0.1	0.3	0	0.3	2	100	10	0.12
6	airport	grass	2	8	0.2	0	0.8	0	0.3	2	100	10	0.12
3	industry	grass	2	9	0.4	0	0.6	0	0.3	2	100	10	0.12
7	excavation	bare soil	4	0	0	1	0	0	0.05	0	110	0	0.001
21	agriculture	crop	1	0	0	1	0	0	0.35	0	180	0	0.6
27	maize and tuberous p	crop	1	0	0	1	0	0	0.4	0	180	0	1.5
23	meadow	grass	2	0	1	0	0	0	0.3	2	100	10	0.2
28	wet meadow	grass	2	0	1	0	0	0	0.3	2	100	10	0.3
29	orchard	forest	3	0	0.2	0	0.8	0	0.8	0	200	10	3
31	deciduous forest	forest	3	0	0.2	0.8	0	0	2	0	250	10	18
32	coniferous forest	forest	3	0	0.9	0.1	0	0	2	4.5	500	45	15
33	mixed forest	forest	3	0	0.5	0.5	0	0	2	4.5	500	38	15
36	shrub	grass	2	0	0.2	0.8	0	0	0.6	0	110	5	2
35	heather	grass	2	0	0.2	0.8	0	0	0.2	4	110	15	0.75
54	sea	open water	5	0	0	0	0	1	0.05	0	110	0	0
53	estuary	open water	5	0	0	0	0	1	0.05	0	110	0	0
44	mud flat/salt marsh	open water	5	0	0.4	0.2	0	0.4	0.3	2	110	10	0.5
37	beach/dune	bare soil	4	0	0.3	0.7	0	0	0.5	2	110	15	1
51	navigable river	open water	5	0	0	0	0	1	0.05	0	110	0	0
55	unnavigable river	open water	5	0	0	0	0	1	0.05	0	110	0	0
52	lake	open water	5	0	0	0	0	1	0.05	0	110	0	0
301	spruce	forest	3	0	0.9	0.1	0	0	2	11	320	55	13
302	pine	forest	3	0	0.9	0.1	0	0	2	4.5	550	40	15
303	beech	forest	3	0	0.2	0.8	0	0	2	0	320	10	20
304	birch	forest	3	0	0.2	0.8	0	0	2	0	320	10	16
305	oak	forest	3	0	0.2	0.8	0	0	2	0	150	10	17
306	poplar	forest	3	0	0.2	0.8	0	0	2	0	250	10	18
307	reference grass	grass	2	0	1	0	0	0	0.3	2	140	10	0.12

Annex V: soil parameter table

-999	1	2	3	4	5	6	7	8	9
1	0.12	0.05	0.07	0.02	0.51	0.05	0.07	0.09	0.01
2	0.15	0.07	0.08	0.035	0.47	0.05	0.09	0.09	0.01
3	0.21	0.09	0.12	0.041	0.44	0.05	0.15	0.09	0.01
4	0.29	0.1	0.19	0.015	0.4	0.05	0.21	0.26	0.07
5	0.25	0.12	0.13	0.027	0.37	0.05	0.11	0.15	0.02
6	0.3	0.1	0.2	0.04	0.35	0.05	0.61	0.09	0.01
7	0.26	0.16	0.1	0.068	0.32	0.05	0.28	0.54	0.3
8	0.36	0.19	0.17	0.04	0.29	0.05	0.33	0.62	0.41
9	0.33	0.19	0.14	0.075	0.27	0.05	0.26	0.62	0.41
10	0.32	0.23	0.09	0.109	0.25	0.05	0.29	0.8	0.68
11	0.43	0.27	0.16	0.056	0.23	0.05	0.34	0.84	0.75
12	0.46	0.33	0.13	0.09	0.21	0.05	0.37	0.95	0.85