

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES DEPARTMENT OF EARTH
SCIENCES



GROUNDWATER RECHARGE ESTIMATION USING WETSPASS MODEL IN UPPER
BILATE CATCHMENT: SOUTH WEASTERN ESCARPMENT OF MAIN ETHIOPIAN
RIFT

BY: BITSIET DEREJE ABEBE

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

June, 2015

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES DEPARTMENT OF EARTH
SCIENCES

**GROUNDWATER RECHARGE ESTIMATION USING WETSPASS MODEL IN UPPER
BILATE CATCHMENT: SOUTH WEASTERN ESCARPMENT OF MAIN ETHIOPIAN
RIFT**

By: Bitsiet Dereje Abebe

*A Thesis submitted to the School of Graduate Studies of Addis Ababa University In
Partial Fulfillment of the Requirements for the Degree of Master of Science in
Hydrogeology*

Approved by the Board of Examiners:

Chairman, person: Dr. Dereje

Advisor: Dr. Dessie Nedaw

Examiner: Dr. Seifu Kebede

Examiner: Prof. Tenalem Ayenew

Jun, 2015

Acknowledgement

Before anything, glory and thanks be to God who gives me full health, peace, knowledge and wisdom to accomplish this thesis work and He is still in my side throughout my life.

My deepest feeling of gratitude goes to my advisor Dr.Dessie Nedaw, for his worthless advice, nice consultation, and provision of important reference materials that are much useful for this research work and helped me to complete this research work successfully. I never ever forget his admirable patience and full time devotion to help me from beginning to the end of this research.

I would like to express my special and sincere appreciation to my instructors Dr. Seifu Kebede, Prof. Tenalem Ayenew and to all Addis Ababa University, School of Earth Sciences instructors including Biniyam Tesfa, Behailu Birhanu, Degelo Sendebo, who supported me in gaining valuable knowledge about the subject matter and related fields. I would like to extend my thanks for secretary office members Tsion, Beti , Worku, and the Science faculty library staff members all of them helped me in providing valuable information and reading materials.

My special thanks also go to my employer Hadiya Zone Water, Mines and Energy Development Bureau, for allowing me to pursue my postgraduate studies.

I am also grateful to National Meteorological Service, Geological survey of Ethiopia, Mapping Agency and South Region Water Works Design Enterprise (SWWDE) for their support in providing me important data including groundwater level data, meteorology data, and relevant documents, which helped me to carry out my research work.

I have the pleasure to thank all my lovely friends Bereket Fentaw, Hirut Girma, Emmenuel Shiferaw, Yoseph Bizuneh and Ato Demitew, who have been by my side during the thesis work. Bereket your support courage and follow-up gave me decisive strength; really I would like to appreciate your devotion, encouragement and advice. God Bless You!

Last but not least I owe my deepest gratitude to my family, who has humble heart, understanding, and courage, each other. My father Dereje Abebe and my mother Aberash Argudo, they are role models to me regarding to social life and academic achievements. You are always thinking my future becomes bright. My parents, I wish you long live. I would like to appreciate my lovely sisters and brothers for their support and lovely advice. Finally, I become happy in finalizing this work, **Praise the Lord!!**

ABSTRACT

The study area, upper Bilate Catchment, is strongly dependent on groundwater like other rural catchments in the country. The main objective of this thesis is to quantify the amount of groundwater recharge in upper Bilate catchment. Recharge was estimated using physically based distributed recharge model called Wetspass. As input to the model precipitation, potential evapotranspiration, temperature and wind speed were estimated using data collected from meteorological stations located within and nearby the basin, The physical environmental data including land use, soil type, and groundwater depth are evaluated from field observation and existing maps. Slope and topography were generated from SRTM data. .

The mean annual recharge of the catchment using the model was found to be 9.4 % of the precipitation, whereas the direct runoff was found to be 20 % of the precipitation. The study area is characterized by lower groundwater recharge relative to surface runoff due to the effect of impermeable soils, morphology of land and land use/land cover of the study area. The western and northern parts of the area are identified as recharging zone and the central and southern part is discharge zone. The resulted groundwater recharge zoning map was validated using base flow separation method and also compared with previous groundwater recharge works of the study area. Finally, it is concluded that the groundwater recharge estimation using Wetspass model is reasonable and useful for quantification of annual groundwater recharge with special and seasonal variation and also capable in the identification of groundwater recharge Zones.

Key words: Upper Bilate River, Groundwater Recharge, Wetspass Model Runoff and Evapotranspiration.

Table of Contents

ABSTRACT	ii
chapter 1.....	1
1.1 Background.....	1
1.2 Statements of Problem.....	2
1.3 Objective of the study	2
1.3.1 General objective	2
1.3.2 Specific objectives	3
1.4 Significance of the Study	3
chapter 2.....	4
2. Literature Review	4
2.1 Groundwater Recharge	4
2.1.1 Groundwater recharge estimation using Wetspass.....	5
2.1.2 Relevant Literatures Review.....	5
2.1.4 Previous works	6
chapter 3.....	9
Study Area Description.....	9
3.1 Location of Study area	9
3.2 Physiographic and Drainage	10
3.3.1 Physiography	10
3.3.2 Drainage	12
3.3.3 Climate.....	14
3.3 Land use/ land cover	15
3.4 Soil Type.....	16
3.5 Regional Geological set up	18
3.6 Local Geology	21
3.7 Structural Set Up	23
3.8 Hydro geological characteristics.....	24
3.9 Recharge, Discharge Conditions and Groundwater Flow System	26
chapter 4.....	28
4. Research Methodology and materials.....	28
4.1 Data collection and data analysis	28

4.1.2	Methods of recharge estimation.....	28
4.2.1	Parameter table (dbf data).....	29
4.2.2	Grid maps	29
4.2.3	Materials and equipment.....	30
chapter 5.....		32
5. Results and Discussions		32
5.1	Hydro-meteorological data analysis.....	32
5.1.1	Precipitation	32
5.1.2	Temperature.....	34
5.1.3	Wind speed.....	35
5.1.4	Potential Evapotranspiration.....	36
5.2	Out puts of WetSpass	39
5.2.1	Annual evapotranspiration.....	39
5.2.2	Surface runoff.....	40
5.2.3	Groundwater Recharge	42
5.3	Recharge estimation using Baseflow records	46
5.4	Limitations.....	49
chapter 6.....		51
6. Conclusions and Recommendations		51
6.1	Conclusions.....	51
6.2	Recommendations.....	53
References.....		55
Appendix 1 Runoff coefficient parameters		58
Appendix 2 Summery of climatologically parameters		65
Summary of mean monthly rainfall at different metrological stations (mm).....		65
Appendix 3 Summer land use parameter table modified for upper Bilate catchment.....		67
Appendix 4 Winter land use parameter table modified for upper Bilate catchment.....		68
Appendix 5 Soil parameter table of upper Bilate catchment.....		69
Appendix 6 Depth to water table of upper Bilate catchment.....		69
Appendix 7 (October to May) winter actual evapotranspiration map of Upper Bilate catchment		72
Appendix 9 Winter interception map of upper Bilate catchment		73
Appendix 10 Summer interception map of upper Bilate catchment		73

Appendix 11 Yearly interception map of upper Bilate catchment.....	74
Appendix 12 Winter Transpiration map of upper Bilate catchment.....	74
Appendix 13 Summer Transpiration map of upper Bilate catchment	75
Appendix 14 Yearly Transpiration map of upper Bilate catchmet	75
Appendix 15 Winter soil evaporation map of upper bilate catchment	76
Appendix 16 Summer soil evaporation map of upper bilate catchment	76
Appendix 17 Yearly soil evaporation map of upper bilate catchment.....	77
Appendix 18 Summery of the basic seasonal wetpass output parameters	77
Appendix 19 Mean monthly flow of Bilate River	78

List of Figures

Figure 3.1 Location map of the study area.....	9
Figure 3.2 Phisography map of upper Bilate catchment.....	11
Figure 3.3 Hill shade map of Upper Bilate.....	11
Figure 3.4 3-D visualization of upper Bilate catchment.....	12
Figure 3.5 Drainage map of upper Bilate catchement.....	13
Figure 3.6 Slope map of upper Bilate catchment.....	14
Figure 3.7 Landuse/Landcover map of upper Bilate chatchmnet (prepared from FAO, 1988 world Landuse/Landcover map and field observation).....	16
Figure 3.8 Soil map of Upper Bilate catchment.....	18
Figure3.9 Outcrop of Ignimbrite (Top) and poorly welded tuff (bottom) around Hossaina area Anlemo woreda quarry site.....	22
Figure 3.10 Geological map of upper Bilate catchment	23
Figure 3.11 Hydrogeological map of upper Bilate catchment.....	25
Figure 3.12 Groundwater flow system and contour map of upper Bilate catchment.....	27
Figure 4.1 Flow chart of the methodology.....	31
Figure 5.1 Long term mean monthly precipitation of the study area (1971-2014).....	33
Figure 5.2 Rain fall distribution map of upper Bilate catchment.....	34
Figure 5.3 Monthly maximum, minimum and average temperature of the study area.....	35
Figure 5.4 Maximum and minimum temperature variation in different stations (Indibir, Hossaina and Halaba kulito).35	
Table 5.1 Potential evapotranspiration Calculated using Penman combination method.....	38
Figure 5.8 Annual evapotranspiration map of upper Bilate catchment.....	40
Figure 5.9 Annual surface runoff map of upper Bilate catchment.....	42
Figure 5.10 Summer season recharge (mm) map of upper Bilate catchment.....	43
Figure 5.12 Winter season groundwater recharge map of upper Bilate catchment.....	44
Figure 5.12 Annual groundwater recharge map of upper Bilate catchment.....	45

(Water balance = PP-ETP –RO-RE = 4).46
Table 5.3 Analysis result of Time plot at Bilate gauging station.47
Figure 5.13 Baseflow separations of Billate river near Halaba kulito.47
Figure 5.14 Baseflow separations of Gududer river near Hossaina.48
Table 5.5 Baseflow and Run off at Bilate and Guder gauging stations.48

List of Tables

Table 5.1 Potential evapotranspiration Calculated using Penman combination method.....38
Table 5.2 Annual water balance of upper Bilate catchment (mm) based on the WetSpas model (Water balance = PP-ETP –RO-RE = 4).46
Table 5.3 Analysis result of time plot at Bilate gauging station.47
Table 5.4 Analysis result of time plot at Guder gauging station.....47
Table 5.5 Base flow and Run off at Bilate and Guder gauging satations.48

List of abbreviations and Symbols

BARE_AREA	Bare Area
dbf	data base files
DW	Deep Well
EVAPODEPTH	Bare soil evaporation depth
ETP	Evapotranspiration
FAO	Food and Agricultural Organization of the United Nation
FIELDCAPAC	Field capacity
GIS	Geographic Information Systems
GPS	Global Positioning System
HDW	Hand Dug Well
IMP_AREA	Impervious Area
INTERC_PER	Interception Percentage
LAI	Leaf Area Index

LANDUSENUM	Number of runoff class for land use
LANDUSERO	Runoff class for land use
LUSE_TYPE	Land Use Type
MIN_STOM	Minimum Stomatal Opening
No	Soil type number
NUM_IMP_RO	Impervious Runoff class for impervious area types
NUM_VEG__RO	Runoff class for vegetation type
OPENW_AREA	Open-water Area
PAW	Plant available water content
PET	Potential evapotranspiration
P_FRAC_SUM	Fraction of summer precipitation contributing to Hortonian runoff
P_FRAC_WIN	Fraction of winter precipitation contributing to Hortonian runoff
PP	Precipitation
RE	Recharge
RESIDUALWC	Residual water content
RF	Rain Fall
ROOT_DEPTH	Root depth
RO	Runoff
RUNOFFCOEF	Runoff coefficient
RUNOFF_VEG	Runoff Vegetation
S	Soil sample
Sandy claylo	Sandy clay loam
SHW	Shallow Well

SOILNUM	Soil class
SLOPE_ [%]	Slope
SLOPENUM	Slope class
SRTM	Shuttle Radar Topography Mission
Std dev	Standard deviation
TENSIONHHT	Tension saturated height
USA	United State of America
USDA	United States Departments of Agriculture
UTM	Universal Transvers Mercator
VEG_AREA	Vegetated Area
VEG_HEIGHT	Vegetation Height
WetSpass	Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State
WILTINGPNT	Wilting Point
SWWCE	South water works and Construction Enterprise

Chapter 1

1. INTRODUCTION

1.1 Background

Groundwater is a precious resource of limited extent. In order to ensure its judicious use, proper evaluation is required. Groundwater has emerged to be one of the major sources of potable water for various purposes in both urban and rural areas.

Groundwater recharge is the process, by which water percolates down the soil and reaches the water table, either by natural or artificial methods to replenish the aquifer with water from the land surface. In arid and semi-arid areas, its assessment is a key challenge in determining sustainable yield of aquifers (Yongxin and Beekman, 2003).

Groundwater Recharge has been estimated by water-balance method, water budget model method or by multiplying the magnitude of water-level fluctuations in wells with the specific yield of the aquifer material as well as using conservative geochemical tracers like chloride. But commonly groundwater recharge is determined to a large extent as an imbalance at the land surface between precipitation and evaporative demand (Gebreryfael Hailu, 2008). Now, with the advent of Geographic Information Systems (GIS), physical-based hydrologic modeling has become important in contemporary hydrology for assessing these parameters as well as the impact of human intervention and/or possible climatic change on basin hydrology and water resources. Hence, WetSpass was built as a physically based methodology for estimation of the long-term average, spatially varying, water balance components: surface runoff, actual evapotranspiration and groundwater recharge (Batelaan and De Smedt, 2001, 2007)

From a volume perspective, most water use in upper Bilate catchment is appropriated from groundwater. Hence, this forces the local communities to use subsurface water not only for drinking but also for domestic and in some cases for irrigation purpose. Though this groundwater is recharged from precipitation, utilization of this resource is going on without a basic understanding of the recharge amount and its areal distribution as well as the temporal and spatial variation of the other water balance components which creates a critical problem for its management in the catchment. Hence, estimation of rates of groundwater recharge in the area is

crucial for sustainable utilization of the resource as well as its protection against pollution and depletion. In this study groundwater recharge, surface runoff and evapotranspiration was estimated in upper Bilate river catchment using WetSpass model.

1.2 Statements of Problem

Though Ethiopia is presumed to have a large quantity of fresh groundwater resources; the country is still yet not made detail studies in quantifying the groundwater resources in spatial distribution (Yirga,Tadessa 2004). Utilization of this resource proceeded without a basic understanding of the hydrological distribution (conditions) and recharge system becomes a critical problem in the water resource management. In such circumstances, development of the resource requires conventionally calculated water balance and come up with the annual groundwater recharge.

The water supply for domestic use is entirely dependent on groundwater. Both the cattle and human population get water from the available groundwater resource which is not studied systematically (Dessie Nedaw, 2010).

The occurrence, origin, movement and chemical constituents of groundwater are dependent on geology/ lithology, Geomorphology /Landforms, drainage density, rain fall, Geological structures/lineaments, slope, Land use/Land cover and soil of groundwater regime. It is common to have problem in estimate of groundwater recharge. Improper evaluation of groundwater and site selections is mostly expected to pose the problems. Since the groundwater occurs out of our sight, deep in the subsurface, there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the groundwater occurrence, groundwater recharge estimation and distribution controlling parameters. Thus, in order to ensure wise use of groundwater, a systematic evaluation of groundwater is required.

1.3 Objective of the study

1.3.1 General objective

The general objective of this research is to estimate ground water recharge of upper Bilate river catchment using WetSpass model.

1.3.2 Specific objectives

- To generate soil, slope, topography, land use/land cover map from existing data
- To generate groundwater level distribution map
- To compile hydro metrological data
- To compile hydro geological map of the area
- To estimate groundwater recharge using Wetspass model

1.4 Significance of the Study

The proposed research study is expected to produce a groundwater recharge zone map that demarcates the study area into different zones according to their groundwater recharge. The resulted detail map (land use/ land cover, soil, hydrometeorological, topography) of the area can be one input for understanding of distributed recharge values.

Estimation rates of groundwater recharge in the area is crucial for sustainable management and utilization of the resource as well as their protection against pollution and depletion. Furthermore, the finding of this research will also serve as a base line information and reference for those who want to conduct further research on the area.

Chapter 2

2. Literature Review

2.1 Groundwater Recharge

Groundwater recharge is the processes of percolation of water from precipitation, canals, rivers, lakes and streams through the soil to the subsurface water system. And, the proportion of precipitation percolating to the water table depends upon a large numbers of factors, including the characteristics of the precipitation, vegetation, topography, soils and geology (Teklebirhan Arefaine et al., 2012).

The groundwater recharge may be defined in general sense as the downward flow of water reaching the water table, forming an addition to the groundwater reservoir. Recharge may occur naturally from precipitation, river, canals, lakes, as man induced phenomena (Tenalem Ayenew and Tamiru Alemayhu, 2001).

How much groundwater exists in the subsurface is therefore the function of the amount of the open spaces in rocks and the spatial extent of these rocks. Difference in groundwater potential between regions, countries, and continents is intrinsically linked to the rock type, extent of the rocks and the recharge rates and conditions. Recharge here refers to the amount of water that joins the groundwater from external sources such as rivers, rainfall, lakes, or from any other adjacent aquifer (Seifu Kebede, 2013).

Recharge is an important factor in evaluating groundwater resources but it is often difficult to quantify (Batelaan, O. and De Smedt, F., 2007) .The WetSpaas model determines the long-term average spatially distributed recharge as a spatial variable dependent on the soil texture, land-use, slope, and meteorological conditions, taking into account the influence of the spatial variability of the land surface on the groundwater system (Batelaan, O. and De Smedt, F., 2004).

All fresh water found underground must have had a source of recharge. This is normally precipitation (rainfall/snow-melt), but can also be seepage from rivers lakes and canals. The recharge typically travels down wards through the unsaturated zone and the aquifer fills up until water reaches the land surface, where flows from the ground as springs or seepage, providing the

dry weather flow (or base flow) of low land rivers. Thus, the aquifer becomes saturated to a level where the out flow matches recharge (Tesfamichael Gebreyohannes, 2009).

2.1.1 Groundwater recharge estimation using Wetspass

WetSpass the acronym for Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State is a method for estimating spatially distributed, long-term average recharge developed by Batelaan, O. and De Smedt, F. (2001, 2007). It uses long-term average climatic data together with an elevation, land use and soil map of an area to simulate average spatial patterns of surface runoff, actual evapotranspiration and groundwater recharge in the area. This model is fully integrated or embedded in the GIS Arc View (version 3.2) as raster model, coded in Avenue. Inputs for this model include grids of land-use, groundwater depth, precipitation, potential evapotranspiration, wind speed, temperature, soil and slope, where by parameters such as land-use and soil types are connected to the model as attribute tables of their respective grids (Batelaan, O and Woldeamlak, 2007).

2.1.2 Relevant Literatures Review

There are verities of researches undertaken in groundwater recharge based on the application Wetspass model and other modeling methods. Very few of the relevant literatures reviewed are summarized below.

Integrated hydrogeological investigation was carried out in the upper Bilate river catchment by Sentayehu Legesse (2009), to assess hydrogeological system, recharge estimation, and groundwater potential investigation. In the investigation both hydrological and hydrogeological parameters was included in detail ,which shows the western and northern part of the area is recharging zone and the central and southern part is discharge zone thus, this qualitative result needs modeling to quantify groundwater recharge and water resource management.

Using WetSpass regional groundwater flows modeling of the Geba basin, Northern Ethiopia had been studied by Tesfamichael Gebreyohannes (2009), the main objective of his thesis was to develop groundwater flow model and identify groundwater resources potentials of the basin.

Therefore, he estimated groundwater recharge of the Geba basin about 37mm/year using the WetSpa modeling which make up about 6% of the total annual precipitation in the basin. As cited in Teklebirhan Arefaine et al., (2012).

Biruk kifle (2009) had been assessed groundwater potential assessment and numerical flow modeling of Guder-Batena river catchment (sub catchments of upper Bilate) The research concluded that groundwater modeling helps in the study of groundwater flow behavior/system and provides decision support system for sustainable water resources utilization.

Tesfaye Tessema (2010), focused on the evaluation of groundwater potential zone in south Ethiopia rift escarpment, the Bilate River catchment in SNNPR, based on integrated Geographical Information System (GIS) and remote sensing techniques. The research mentioned that the water supply in the study area is highly dependent on groundwater sources. Thus to assure the sustainable exploitations of this resource the research recommended a groundwater modeling study in the area.

Teklebirhan Arefaine et al. (2012) estimated groundwater recharge, evapotranspiration and Surface Runoff by using WetSpa modeling method in Illala Catchment, Northern Ethiopia. The largest amount of evapotranspiration simulated for the catchment, relative to the groundwater recharge and the surface runoff, indicates that much effort is needed to change the environmental conditions of the catchment by applying some soil and water conservation practices.

2.1.4 Previous works

Previously the study area had been assessed by governmental and non-governmental organizations for different purpose at different time but there is no groundwater recharge work done by using Wetspass model, except groundwater recharge estimated using water balance and other methods.

Sinteyehu Legessa (2009) had been conducted integrated hydrogeological investigation of upper Bilate catchment. In his study using water balance and base flow separation he calculated the recharge value. The estimated recharges of the area are 129 and 96.18mm using base flow separation and water balance approaches. The average of the two values is taken as the annual recharge of the area which is 9.2% of the total precipitation of 1231.6mm.

There are published and unpublished groundwater recharge related studies conducted on Bilate areas which include:-

Tesfeye Tessema (2010) conducted a study on the title of evaluation of groundwater potential zone in south Ethiopia rift escarpment, the Bilate River catchment in SNNPR, based on integrated Geographical Information System (GIS) and remote sensing techniques. The main objective of his thesis was to identify groundwater resources potentials of the Bilate catchment. Therefore, the research estimated groundwater recharge of the Bilate basin about +125.92 and 133mm using water balance method and base flow separation respectively. He receives an average rain fall of 1145.82mm per year.

Kefale Tilahun (2013) estimated the groundwater recharge of Bilate River at the Halaba river gauge station using base flow separation method in period between 1980 to 2007. The estimated recharge of the area is 174mm this accounts for 15% of the annual precipitation 1131mm.

Geology, geochemistry, and gravity survey of the Hossaina area including Bilate is previously conducted by Basalfew Zenebe et al. (2012).

Water Resource Potential Assessment of the two neighboring river basin namely Omo –Gibe and Bilate river basin which covers 10 Woredas of SNNPR Zones was conducted in regional scale by AG Consult Consulting Hydrogeologists & Engineers Plc. (2007) based on the request of Southern Nation, Nationalities and Peoples Regional State Water Resource Development Bureau. The objective of the study is to ensure a high success for the development of the water resources of the region for economic and social benefits of the people, allocation and apportionment of water, based on comprehensive and integrated plans and optimum allocation principles that incorporate efficiency of use, equity of access, and sustainability of the resources.

Analysis of Biomass Degradation as an indicator of Environmental challenge of Bilate water shade using GIS techniques was carried out by Degelo Sendabo (2007). The research investigated the remarkable land use land cover change and vegetation loses in relation with the increase of the rural population. Expansion of farmlands including the river bank is very common especially in the upper and middle courses. According to the research the lower course of the river which is covered by the sediment is associated with woodlands, wetlands, extensive farming areas grazing areas and so on. The research also indicated some of the tributaries are on

the transformation from perennial to intermittent. At the mouth and around Lake Boyo in the middle course of the river the sedimentation area is increasing from time to time. Such problems are directly related with biomass degradation followed by erosion.

Chapter 3

Study Area Description

3.1 Location of Study area

Upper Bilate River Catchment is found in SNNPRG about 230 km South West of Addis Ababa and 130 Km North West of the regional town Awassa. This river catchment covers portion of four SNNPRG Zones; Hadiya, Gurage, Silte, and Kenbata Tembaro zones and Halaba Special Woreda. The river catchment starts from the highlands of Gurage and Hadiya Zones to the river gauging station Halaba Special Woreda.

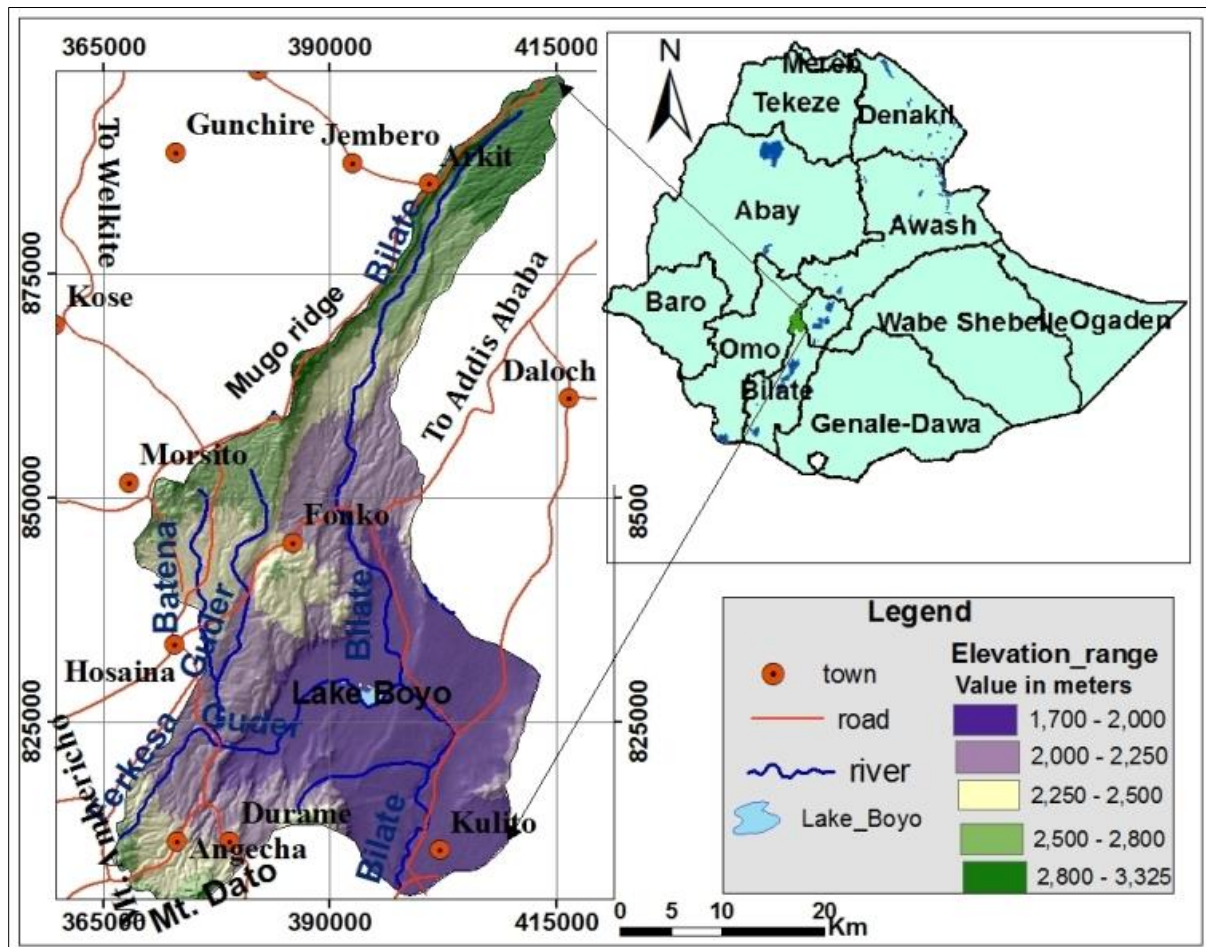


Figure 3.1 Location map of the study area.

Geographically the study area extends 07° 30' 35'' N to 08° 06' 55''N and 37° 48' 17''E to 38° 12' 45''E. Elevation ranges from 1,700 to 3,325 m. a. s. l. This river catchment encompasses an area of about 2,075 Km² and a Perimeter of 295 km. (figure 1).

3.2 Physiographic and Drainage

3.3.1 Physiography

The physiographic set up of the study area is the result of volcano- tectonic, rifting and erosion and deposition processes. Owing to these Earth Processes, the area falls within the elevation range of 1,712 - 3,326 m.a.s.l (figure 3.2). The catchment can be divided into three physiographic regions: the rift, the transitional escarpment and highlands. The middle part of the basin which totally covers Shashogo and Ana Lemo Woredas is the rift floor bounded to the west by Mt. Ambericho, Mt. Dato, to the north Mugo Ridge and to the east Ambericho fault line. Danboya, Lemo, woredas is categorized under the transitional escarpment zones. These areas are characterized by steep faults and fractures dip towards the rift. The rugged topography which incorporates Misha Woreda to the North West, Meserake and Meerab Azernet Berbere, Muhur Aklil, Gumere, and Alichu Wiriro Woreda to the North and part of Angacha and Danboya woredas to the south west is classified under the highlands.

Almost all springs in the study area emanate from the shoulder of this mountainous areas .The lowest elevation is (1,712 m.a.s.l) and the highest is Alichu Wiriro Woreda (3,326 m.a.s.l) (figure 3.3). There is a large topographic difference between the rift floor and the plateau. The catchment is characterized by flat, gentle and steep slope with cliff topography.

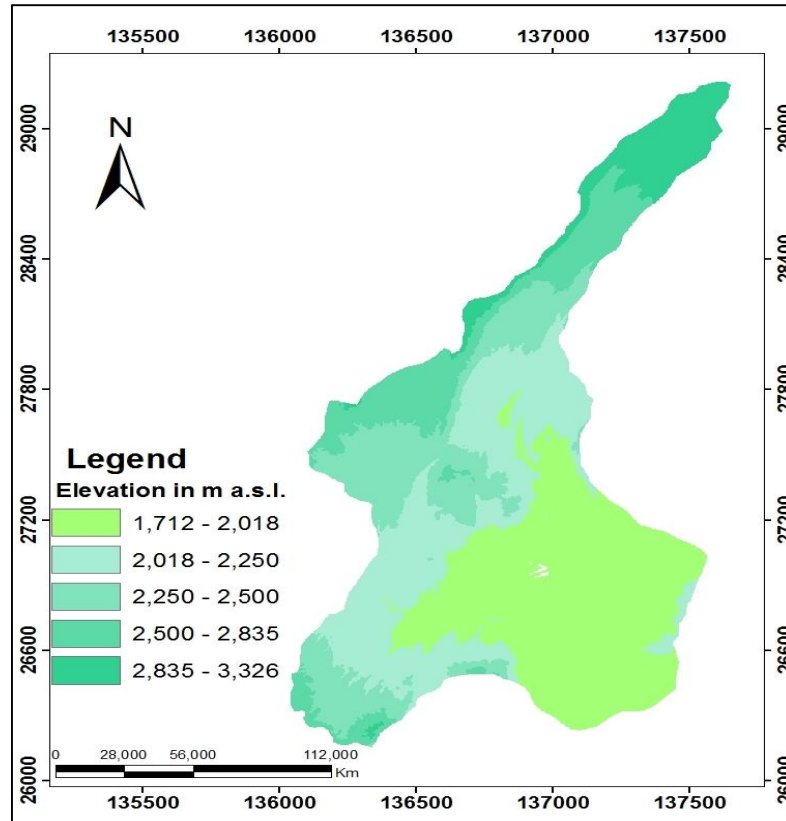


Figure 3.2 Phisography map of upper Bilate catchment.

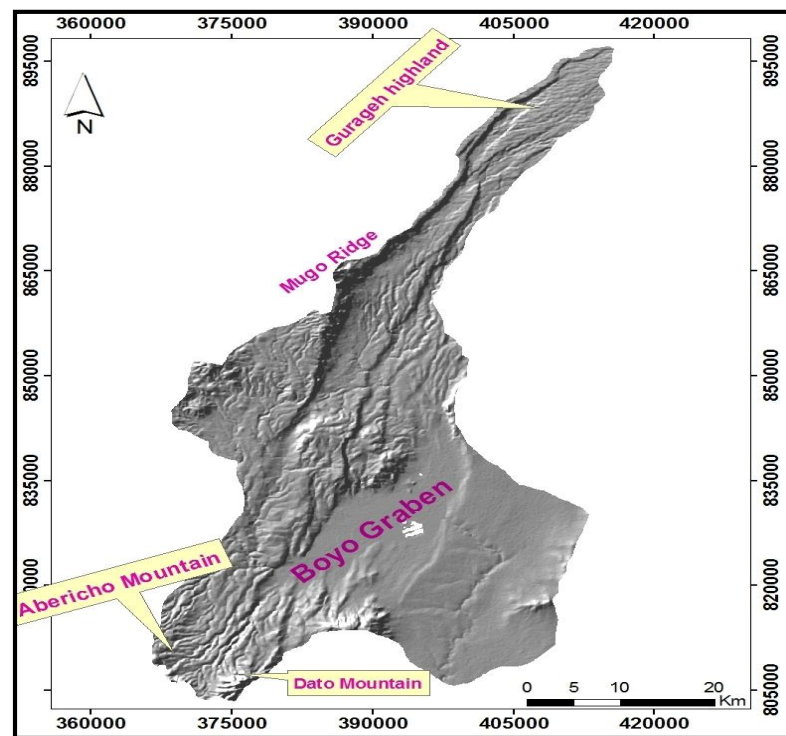


Figure 3.3 Hill shade map of Upper Bilate.

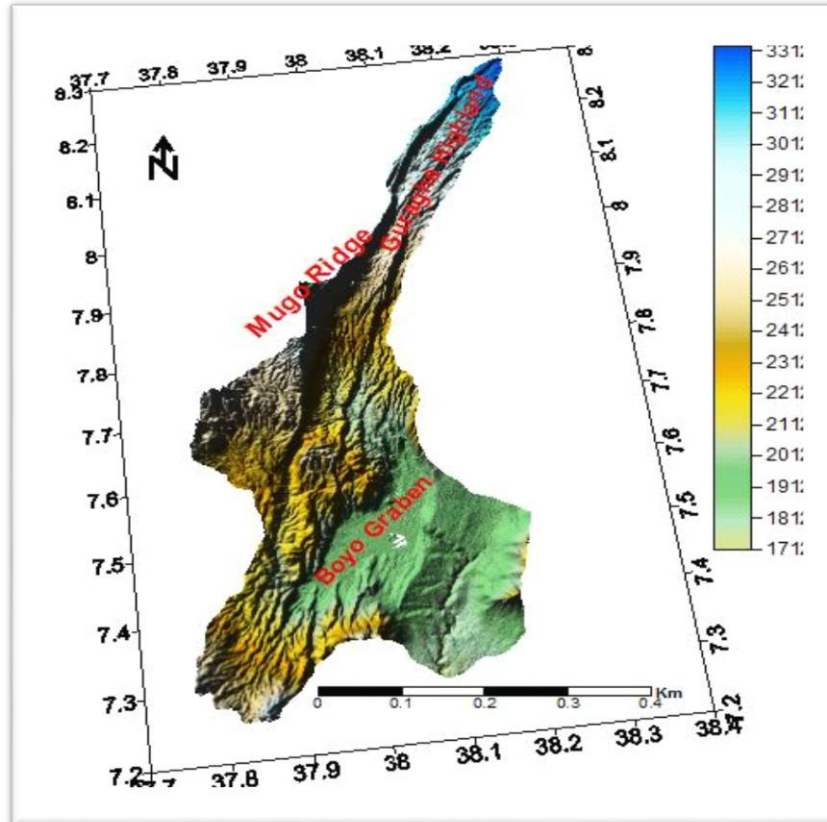


Figure 3.4 3-D visualization of upper Bilate catchment.

3.3.2 Drainage

Guder and Weira Rivers are the two perennial rivers which feed the main Bilate River. These rivers emanate from the shoulder of mountain ridges that boarder the area from the west and north respectively. The intermittent Batena and Konkoye rivers from the western and eastern part of area also feed Guder and Weira rivers respectively. There are also intermittent rivers.

The drainage pattern of the area is characterized by dendritic and rectangular pattern. The drainage density is high in the plateau and escarpment area and very low in the rift floor Tenalem Ayenew (1998). It is due to intensive faulting and volcanic activities in the area.

Drainage density indicates rock permeability and infiltration capacity, and therefore recharges capacity. They are indicators of the rate that precipitation infiltrated compared to surface runoff. Where rocks are highly permeable, infiltration to groundwater is high, and less water is transported in rivers as surface water; but where rocks have low permeability there is little infiltration and more surface water runoff.

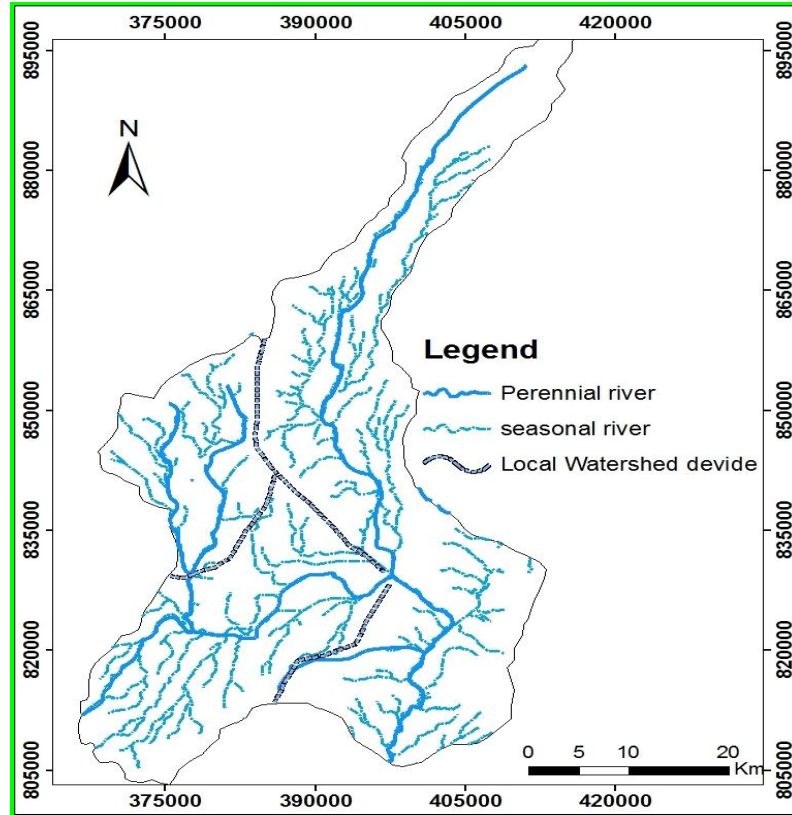


Figure 3.5 Drainage map of upper Bilate catchment.

According to the slope map of upper Bilate catchment (figure 3.6), the slope ranges from 0 to 56% with a mean value of 3% and standard deviation of 3%. This variation in slope is caused due to the presence of faults. Steeper the slope, greater will be the runoff and thus lesser is the groundwater recharge.

Digital Elevation model (DEM) is derived using contour information from the topographical map for estimation of slope in percentage.

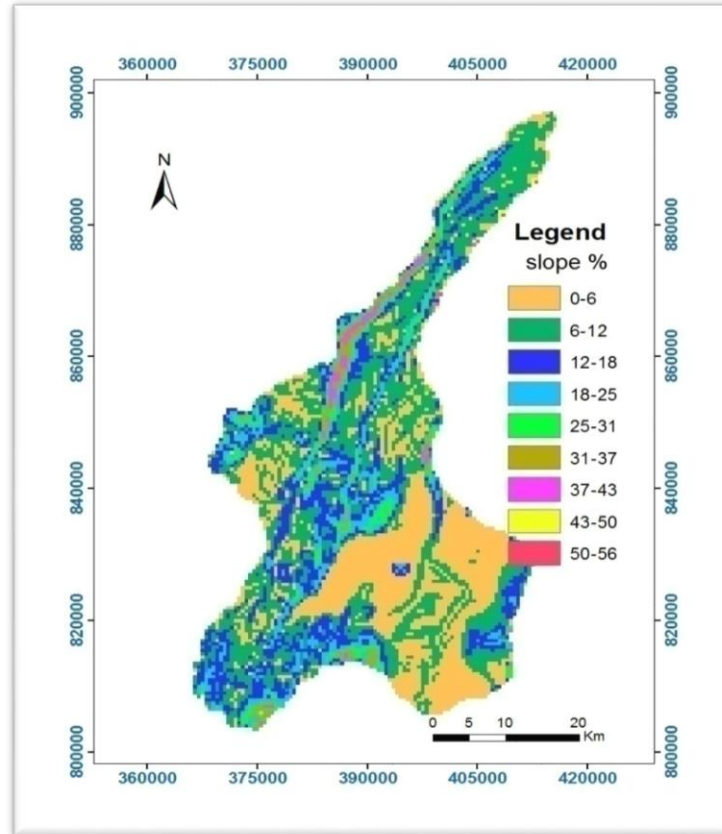


Figure 3.6 Slope map of upper Bilate catchment.

3.3.3 Climate

The climate of the area is humid to sub-humid in the highlands and semi – arid in the rift valley. The lowest temperature occurs during the main rainy season; and high in winter season.

Temperature of the area shows strong altitudinal variations. The minimum and maximum temperatures of the area are 10.2⁰C and 26⁰C respectively.

The study area shows two rainfall pattern zones; the northern and north western unimodal pattern zone and the central and southern bimodal pattern zone. The unimodal pattern zone receives relatively higher precipitation than the bimodal rainfall pattern zone. In general, the long term average mean annual rainfall of the area is estimated to be 1228 mm. The main rainy season is June through September.

The long term mean annual wind speed at 2m above the ground level 1.4m/s. The potential and actual evaptranspiration of the area are 1207mm and 860 mm respectively.

3.3 Land use/ land cover

Poor land use practices, improper management systems and lack of appropriate soil conservation measures have played a major role in causing land degradation problems in the country. Because of the rugged terrain, the rates of soil erosion and land degradation in Ethiopia are high.

Land use is an important characteristic of the runoff process that affects infiltration, erosion, and evapotranspiration.

In terms of areal coverage the important land cover units are cultivated land, wood land, bare land, grass land, perennial marsh and open water body (Lake Boyo) figure 3.7. The cultivated land consists about 53%, which is the largest portion of the total area. This is largely under taken all most in major parts of the upper Bilate catchment. Besides, it is the principal land-use of the study area. This type of land-cover mainly concerns areas of intensively cultivated for agricultural crop production.

The main crops grown in the area are wheat, barley, maize, sorghum and different types of grains and vegetables. A large portion of the land in the rift is covered with grass, bushes and shrubs. Most part of the area is characterized by Eucalyptus tree which has deep rooting.

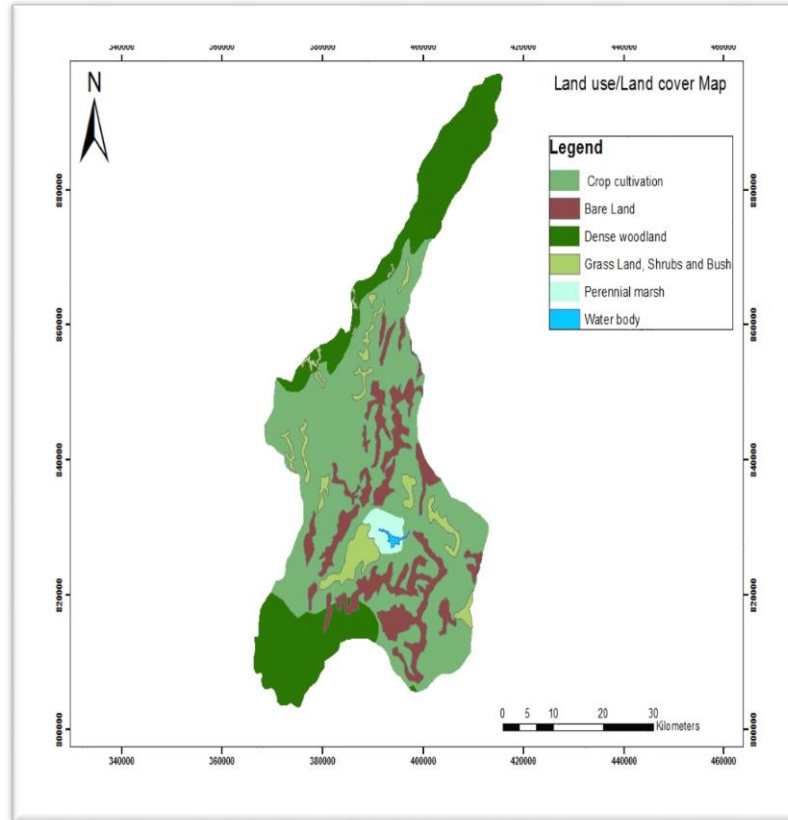


Figure 3.7 Landuse/Landcover map of upper Bilate chatchmnet (prepared from FAO, 1988 world Landuse/Landcover map and field observation).

Crop cultivation 53%, wood land 25 % and bare land 14% which includes areas covered by eucalyptus trees, wheat, barley, maize, sorghum and different types of vegetations. Grass land, shrub, and bush about 6 % and perennial marsh 2% and open water 0.19% of the catchment which is dominated by aloe and acacia species (figure 3.7).

Wood lands are common south western parts Mt.Ambericho, around Angecha, Northern Gurahge highland and North West Mugo ridge portions of the area. Agricultural lands are dominated in the middle parts of the Bilate and south eastern parts of the catchment.

3.4 Soil Type

Soil stores rainwater in its pores before it infiltrates to greater depths and recharges the aquifer system. The amount of evapotranspiration from soil is controlled by soil attributes such as soil texture, soil structure and soil moisture content therefore the ability of soil to store and transport water is different for every soil type.

Soil properties influence the relationship between runoff and infiltration rates which in turn control the degree of permeability; it shows the influence of soil parent material and the spatial variability in the degree of weathering. Soils are formed on account of the climate, physiographic, geology, living organisms, and other factors responsible for soil formation and development.

Those soils associated with lacustrine sediments, river alluvium and pumice are weakly developed and unconsolidated which are high permeable and likely to generate little surface runoff Tenalem Ayenew (1998). Unconsolidated sediments are common below the rift shoulder slopes and at the foot of volcanic mountains. Many areas bordering the rift bear well-developed soils overlying weathered ignimbrite and pumice.

Due to the various soil forming factor (parent materials, climate, topography, living organisms and time); soils of upper Bilate show a variation throughout the catchment. Hence, as result of these factors, soils of the study area are classified in to five classes based on their grain size (FAO, 2003) textural classification. The major soil types of the area are: - silty loam, clay loam, silty clay, and loam and sandy clay soils.

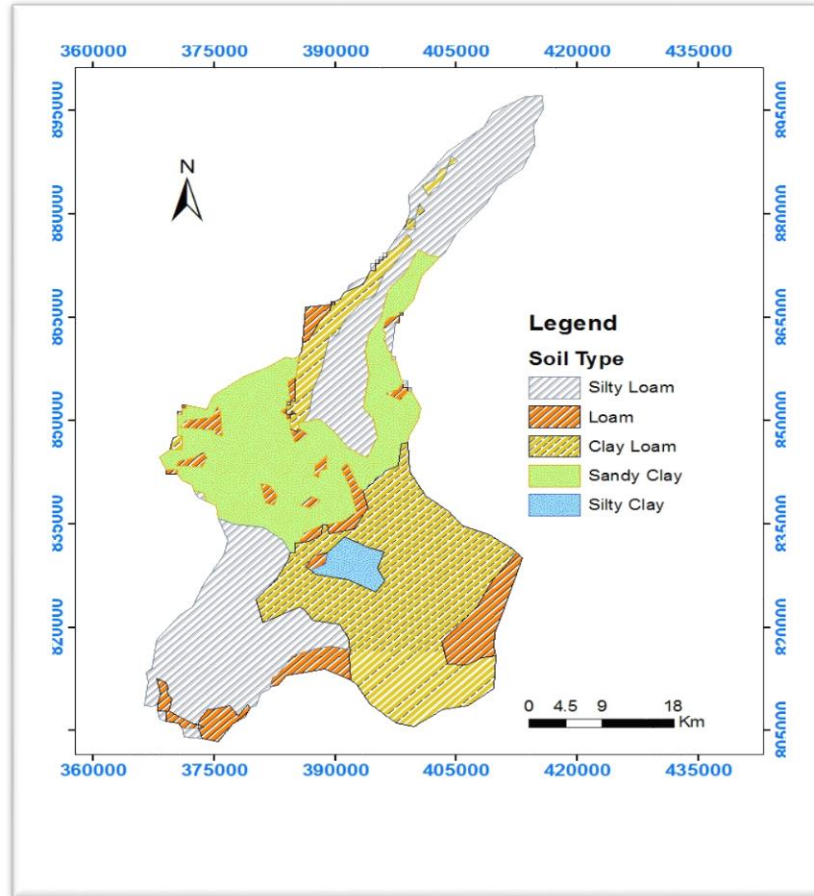


Figure 3.8 Soil map of Upper Bilate catchment.

silty loam and loam are found on the hill where as there is more silty clay and clay loam in the valleys and flat areas (Fig 3.8). And, the most dominant soil types of the area are silty loam, clay loam, and sandy clay respectively. They account about 34% silty loam, clay loam 32%, sandy clay 23%, loam 9% and 0.19% silty clay portions of the catchment (figure 3.8).

3.5 Regional Geological set up

Bilate basin lies within the Main Ethiopian Rift, The rift floor and escarpments are highly faulted. The Rift floor is affected by several faults that form smaller horst and graben structures. The Main Ethiopian Rift Valley (MER) contains abundant acidic lavas and ignimbrites and they are associated with central volcanoes containing wide calderas. On the MER, ignimbrites, unwelded pyroclastics and minor lavas related to fissured eruptions of regional extent are the most abundant volcanic rocks.

The rift floor along the Bilate River drainage system blanketed by welded tuff, lacustrine strata, and fessural basalt (Yodit Teferi, 2005).

The general stratigraphy of Bilate Basin which has been investigated by Ethiopian Geological Survey and comprises volcanic and sedimentary units. The stratigraphy summary of the river basin from the oldest to the youngest is as follows;

A. Pre – Rift Basaltic succession with minor silica members (Jima volcanic – Tertiary volcanic) are well exposed on the plateau and escarpments adjoining the Bilate River Valley which rests unconformable on the Precambrian basement. The basalt flows form an unbroken succession and several hundred meters thick in some places. They are intensely jointed, hydrothermally altered and spherically weathered basalts out crop in the western escarpment of Lake Abaya graben. Tertiary volcanic succession has been down faulted into rift floor which in part is covered by rift valley lakes including Abaya and Boyo.

B. Nazret Group: The name Nazereth Series was given to a thick succession of welded ignimbrites with fiamme, pumice, ash and rhyolite flows and domes with rare intercalations of basalt flows which occur in the MER, rift margins and adjacent plateaus (Meyer et al.1978 as cited Mengesha Tefera et.al., 1996). The Nazereth Group volcanic products are exposed over the surrounding areas along the rift margins and escarpments. The ignimbrite of the Nazereth series is considered to be products of eruptions mainly from marginal centers in the rift.

C. Mursi and Bofa Basalt: flood basalt volcanism is widespread in MER rift and other related rifts (Mengesha et al. 1996). According to Kazmin et al. (1981) cited in Mengesha Tefera et al. (1996), the Bofa basalts are well developed in the northern and central part of the MER forming a wedge between Nazereth Series and Dino formation and a lower age limit of 3.5 Ma. In the rift floor, the Nazereth Group is overlain by succession of flood basalt of Pliocene age.

D. Dino Formation (Qdi, Qdp, Qws and NQs): These units are coarse unwelded pumiceous pyroclastics mainly of light tuff and ignimbrite outcropped in most part of Sheshogo and Haleba woreda to the southwest, west and north of the woreda and Hossaina area. The pyroclastics of the Dino Formation may have sources from axial felsic volcanic eruptions complexes.

E. Quaternary Ignimbrite – this formation overlay Bofa Basalt of Pliocene age. It comprises of Quaternary bimodal transitional basalt/peralkaline felsic volcanic products of Wonji Group. The volcanic products of Wonji Group (including those from axial volcanic centers) are intimately associated with lacustrine sediments related to ancestral lakes in the rift floor (in the fluvial periods of Pleistocene). The out crop of this is observed near Hossana town and also in the river valleys.

F. Pumacious Pyroclastic (Qwpu) :They are grey and yellowish colored, poorly sorted and consist of accidental fragments of rhyolites and basalt. This pumacious pyroclastic belong to the explosive episode of the older rhyolitic volcanic centers.

G. Abaya Rhyolite (Qwa) :The Quaternary central volcanic complexes which are situated along the axial zones of MER (Wonji - Fault Belt) (Tefera et al. 1996).They are strongly banded in situ with alignment of fine vesicles and brittle thinly banded layers of few centimeters.

H. Alkaline Olivine Basalt: The basalts are clearly controlled by extensional fractures with chains of scoria cones aligned along fractures and generally displaying fresh surfaces (Tefera et al. 1996). The NNE trending fault along the axis of the rift floor has been a conduit for basaltic eruptions with lines of scoria cones making fault traces. They are interstratified with the earlier succession of lake sediments. They are_ exposed over a broad area between Lake Abaya and Dugna – Fango and all along Bilate river bed and banks with adjoining rift floor being covered by the overlying intensely denuded lacustrine sediments.

I. Dugna – Fango Rhyolite – These outcrop mainly at the base of Dugna – Fango volcano.

Exposures are concentrated along the N – E to S - W trending, intensely tectonized stripe of land in the central part of the Wonji - Fault belt axis upon which the mountain building activities of Dugna – Fango took place.

J. Recent Basalt – The younger episode of basaltic eruption outcrops along an axial zone of more recent volcano – tectonic activity.

The Sedimentary sequences of the area are:-

Volcano – Sediments Rocks: -Lacustrine sediments intercalated with volcanic mainly ashes and tuffs, which in places are extensively developed and the sequence is shown as volcano sedimentary (Kazmin et al., 1980).

They are generally yellowish – grey colored, horizontally bedded and poorly sorted with fragments of rhyolites, obsidian and basalt in a matrix of ash and silty clay.

Holocene Lake Beds – they outcropped in localities surrounding Lake Abaya and Boyo.

Lithologically they are mainly constituted by poorly compacted, well sorted and friable and fairly reworked yellowish clay and silt material.

Recent Alluvial and Fluvial deposits – the lower course of bilate River covered with fluvial deposits along its gentler slope. There are also lacustrine deltas on the northern part of Lake Abaya which are a few kilometers wide. Colluvial and outwash debris is found widespread in the area particularly along the foothills of the major fault scarps. Recent deposits in the area include soils and alluvial sand deposits. The soils are mainly residual weathering deposits, whose composition is controlled more by the physical condition of formations than by the type of rock form which they were derived. On the older basaltic area dark brown cotton soil is common while the soil outcrop of the ignimbrites is red lateritic.

3.6 Local Geology

In the present study geological map was prepared using previous data from different studies, and field verification.

The major formations which cover the area are; the Nazereth group, Dino Formation, Pleistocene Volcano – Sediments, and Recent Alluvial and lacustrin deposits.

The study area comprises of variety of volcanic and volcano-sedimentary rocks that exhibit different ages and composition of stratigraphic sequence.

Recent acidic volcanic rocks mostly characteristics the south eastern part of area around Halaba it is comprises of enormous accumulation pyroclastic products consists of pumice and ash and the flows and domes are more massive pumice or obsidian.

The lacustrine sediments are located in topographical low places, where the rainfall amount is low, thus recharge comes from high runoff in the escarpments and around Boyo plain.

Ash flow, tuffs, ignimbrites and unwelded tuff (Nazerethe – group) this formation widely covered the northern and some part of western part of the study area and the Western part of the study area including Angacha, Doyogena and Lemo woredas.

The alteration product of the ignimbrite, ash flow and pumacious pyroclastics exposed at quarry sites around Anlemo worada which have been used for construction materials.



Figure3.9 Outcrop of Ignimbrite (Top) and poorly welded tuff (bottom) around Hossaina area Anlemo woreda quarry site.

Dino – Formation is associated unwelded pyroclastics mainly tuff, ignimbrite, pumice and waterlain pyroclastics with occasional intercalated lacustrine beds. This formation is widely exposed at quarry sites and at Bilate river bed of Shashogo and Alaba Special woreda.

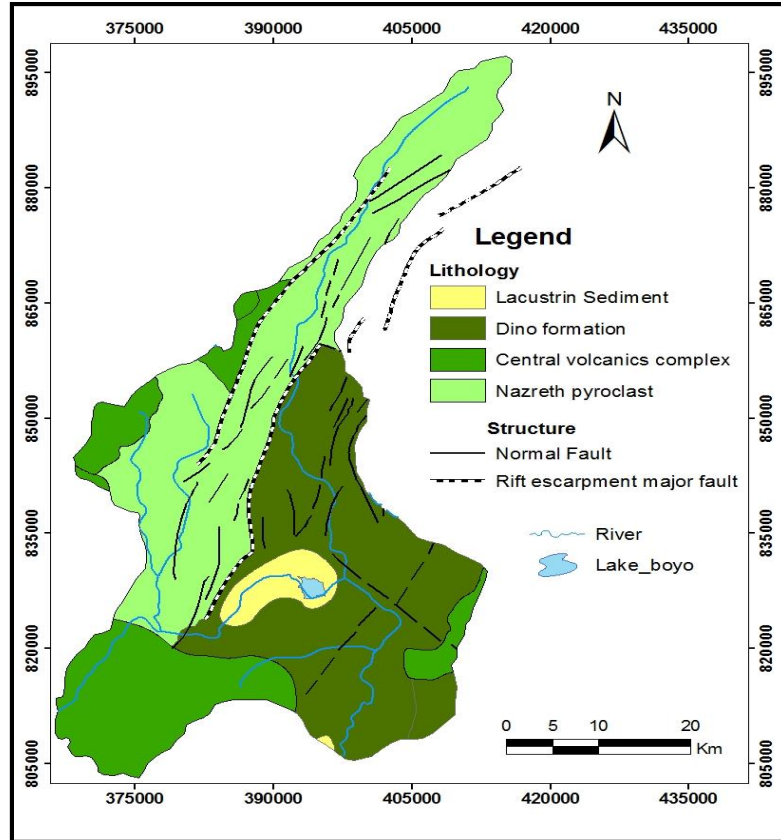


Figure 3.10 Geological map of upper Bilate catchment

3.7 Structural Set Up

Upper Bilate river catchment is located in the south western escarpment of MER. Main geologic structures characterizing to the area is fractures, from the MER system. Being within the Main Ethiopian Rift, the structural features associated are faults.

The central sector of the MER is a symmetrical rift, mostly characterized by well-defined synthetic rift margins having variable throws along the strike of the boundary faults. These margins are marked by high angle normal faults with large throws that comprise several step-faulted blocks.

The rift within a rift formation with in the central part of the study area forms horst and graben structures. The Graben which is presently occupied by Boyo plain is the result of rift within a rift structure. This structure in association with the Ambericho fault scarp makes the whole Shashogo and Ana Lemo woredas Natural Reservoir.

The faults in the escarpment areas which comprises the older undifferentiated rocks of Nazret Group and Dino Formation down faulted towards the rift floor resulted in the development of Boyo plain which is graben.

In general, the northern and western part of the area is highly affected by tectonic activity and rifting. The lineaments in the study area are oriented dominantly in the, E-W, N-S, NE-SW, and NW-SE direction.

3.8 Hydro geological characteristics

Groundwater occurs in many types of geological formations; those known as aquifers are of the most important. Hydrogeological field observations such as the distribution and magnitude of spring discharges, the degree of fracturing of the rock units, the thickness of the formations, the grain size rounding and sorting, the clay proportions, the type and degree of cementation, and the extent of weathering are some of the significant field observations which provided indirect evidence as to whether a rock unit is likely to be an aquifer of low, moderate or high productivity (Tesfeye Chernet, 1993).

The principal hydrologic properties of rocks are porosity, effective porosity or specific yield and permeability. Porosity is the percentage of a gross volume of soil or rock that is filled by air or water; the soil or rock containing such pores is called a porous medium. When the pores have their origin in the genesis of the rock, the rock is said to have primary porosity (sedimentary deposits, weathered hard rocks). When their origin is from events that occurred during a later stage (jointing, faulting, and dissolution) the porosity is said to be secondary.

These properties control the entrance of water in the water – bearing formations or rock, their capacity to hold, transmit and deliver water, and confinement and concentration of percolation to the direction of maximum cause of movement. The occurrence of water in rocks of any region is therefore determined by the character, distribution, and structural setting of the rock it contains.

Porosity of volcanic formations is generally high, due to voids created by exsolved gases and to the frequent scoriaceous and brecciated parts, as well as to their often clastic nature.

The study area dominated by volcanic rocks, Groundwater occurs in fractures and joints formed during formation or after the formation of the rocks. These fractures come mostly in

unpredictable pattern in spacing, aperture opening, and length. These make volcanic aquifers very complex, anisotropic and heterogeneous. Degree of fracturing in these rocks is the determinant of storage potential of the rocks. These rocks occupy highlands forming isolated volcanoes, volcanic shields, plateaus, volcanic cones etc. The geomorphology that is formed by the volcanic rocks is favorable for the emergence of groundwater as springs along the foothills of the volcanic shields (Seifu Kebede, 2013).

Many springs in the area discharge ground water into the land surface from the mainly along the fault and fracture zones of the area at higher elevations within the low lands and/or graben. These have mostly high rates in the escarpments and most are scattered along fault scarps in the west and north of the area.

In the upper Bilate, the western and northern part of the area is recharging zone and the central and southern part is discharge zone while the area just southeast of Boyo plain is categorized under deep groundwater zone due to the damming effect of Ambericho fault (Sinteyeh Legessa 2009).

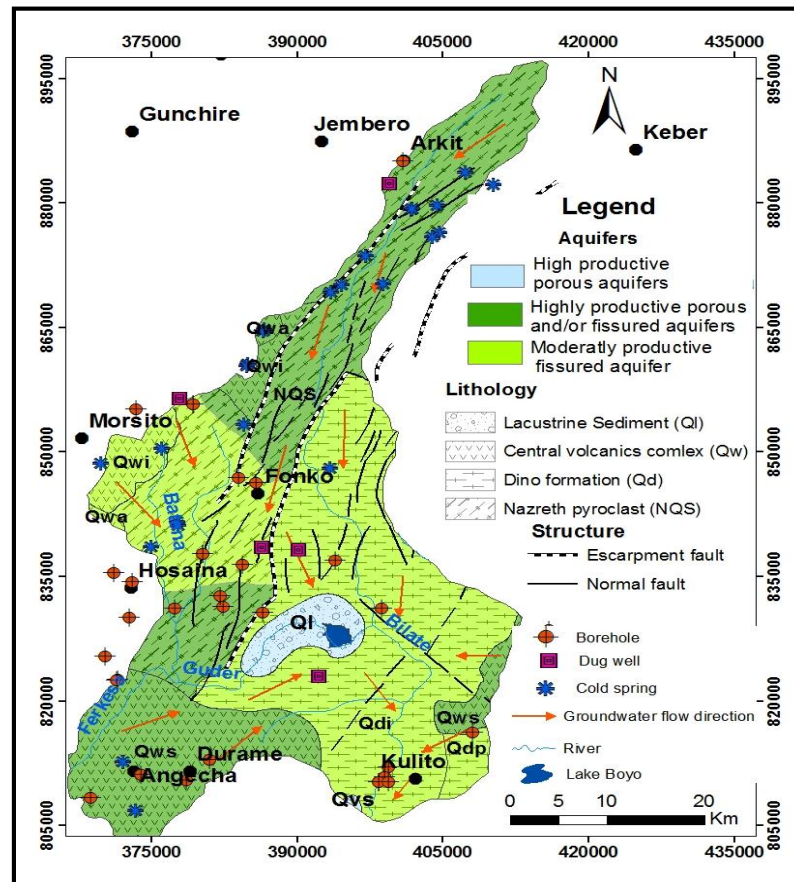


Figure 3.11 Hydrogeological map of upper Bilate catchment.

The aquifer classes are categorized under widespread aquifers with fracture permeability of volcanic rocks such as basalts, ignimbrites, rhyolites, trachytes and alluvial and lacustrine sediments.

The study area is highly covered with volcanic rocks of different episode. These include the Nazereth Series, Dino formation of Quaternary period and Quaternary Ignimbrite.

All this are subjected to varying degrees of secondary activities such as weathering, fracturing, and jointing. The rift is characterized by fractured basaltic and ignimbrite aquifers. The most important aquifers are localized in the fractured and weathered volcanic.

Structural discontinuities in the rift and escarpments are known to provide the best aquifers (Tesfeye Chernet, 1993).

The Ignimbrite of Nazereth Series which covers northern and western part of the area is highly faulted and fractured in association with rifting. The northern and western part of the area is densely faulted due to tectonic activity. Despite the occurrence of permeable rocks and high recharge rates in highlands adjacent to steep escarpments. In general, this part of the area is categorized as highly productive aquifer.

3.9 Recharge, Discharge Conditions and Groundwater Flow System

Recharge areas are usually in topographic high places; discharge areas are located in topographic lows. In recharge area, there is often a rather deep unsaturated zone between the water table and the land surface. Conversely, the water table is found either close to or at the land surface in discharge area (Fetter, 2001). However, using only topographic setup of the area could not be enough to classify the area as recharge and discharge zones. Close evaluation of Hydrochemical trend, land use/land cover, morphology of land and soil types are equally important in classification of the area into recharge and discharge zones.

A Water - table contour map can often be used to locate groundwater recharge and discharge areas (Fetter 1994). The groundwater contour map (figure 3.12) of the area was constructed using the field inventory data that have static water level and elevation above sea level. It clearly shows zone of recharge and zone of discharge. The diverging groundwater flow lines from the

highland towards the rift suggesting that the northern and western part of the area are recharging zones while the lowland situated at the foot of the highlands is discharging zones.

The groundwater flow lines or stream lines diverge to Boyo plain making it discharge zone. There are many deep, shallow and hand dug wells which were drilled by different organization at and surrounding Boyo Plain. In this plain the piezometric surface is very shallow (an average) and the water is relatively fresh. In this part of the area the rift within a rift structure forms horst and graben. The graben currently occupied by Boyo Lake/Swamp is filled by Alluvial Fluvial sediments while the horst or the uplift is composed of massive Dino formation ignimbrite with scoracious basalt.

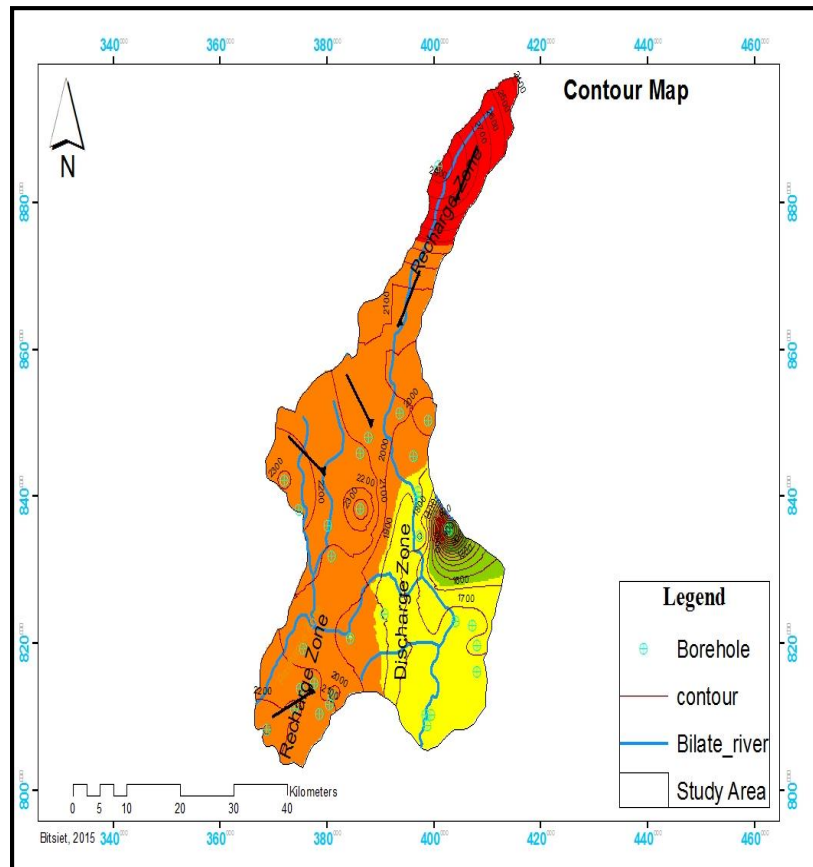


Figure 3.12 Groundwater flow system and contour map of upper Bilate catchment.

Chapter 4

4. RESEARCH METHODOLOGY AND MATERIALS

This chapter includes methods of groundwater recharge and data collection of the research as well as ways of their analysis. In addition to this, detail descriptions on input parameters of the WetSpass and material used for the study are given.

4.1 Data collection and data analysis

Various available data were gathered from concerned deferent organizations, persons and different websites. Among them the different organizations and institutes as well as agencies are Geological Survey of Ethiopia (GSE), and Addis Ababa University. Meteorological data were collected from National Meteorological Agency (NMA), groundwater related data were collected from South Water Works and Construction Enterprise (SWWCE), Regional, Zonal and Woreda water Resource development offices.

The collected data were analyzed using: MS-Excel, Arc-view GIS 3.2, GIS ArcMap, 10, Global Mapper 11 and Surfer 10, 3-DEM softwares.

4.1.2 Methods of recharge estimation

4.1.2.1 Wetspass modeling method

As WetSpass modeling was developed for temperate regions by Batelaan and DeSmedt (2001; 2007), which has different climatic and land conditions compared to the tropics, some input parameters modification is used to apply it in tropical region. In temperate region, summer and winter have six month each while in Ethiopia summer contains four months and winter covers eight months. In addition to this, the seasons of rainfall period and land-use/land-cover are not the same. So, to apply the Wetspass for upper Bilate catchment, input of the meteorological grid map was done using eight months of winter and four months of summer. Also, modified summer and winter land-use parameter tables were used.

4.1.2.2 Wetpass data input

Two types of inputs are required so as to run the WetSpass model: Parameter tables (dbf data) and grid map. ArcView (version 3.2) together with its spatial analyst extensions were used in order to prepare these input parameters.

4.2.1 Parameter table (dbf data)

Inputs of land-use, soil and runoff characteristics parameter table were required. Then, these tables were added/joined to the maps as attribute.

4.2.1.1 Land use parameter tables

Modified summer and winter land-use, parameter tables were prepared as; either crop, forest, grass, bare soil and open water as given in (Appendix 3 and 4). The table has also values for rooting depth, leaf area index, minimum stomata opening, interception Percentage and vegetation height.

4.2.1.2 Soil attribute table

The soil attribute table contains soil type of the area, field capacity, permanent wilting point, plant available and residual water content of these soils (Appendix 5).

4.2.1.3 Runoff characteristics parameter table

The runoff characteristics parameter table contains runoff coefficient, slope and soil type for each corresponding land-use. Values in these tables are considered to be universal; no modifications are required for parameters of these tables (Appendix 1).

4.2.2 Grid maps

Topography, slope, land-use, soil, reference evapotranspiration and groundwater level maps were prepared. Hence, the topographic grid map, which is used to characterize the horizontal hydrological characteristics of the land surface and the slope data layer, describes the maximum change in elevations were derived from SRTM using Global Mapper 11 (figure 3.2 and 3.6 respectively).

Temperature, precipitation, and wind speed parameters were prepared using the available meteorological data from National Meteorological Agency (NMA). The meteorological data are

converted to special grid maps by grouping the data in to winter and summer seasons for WetSpas modeling.

Potential evapotranspiration (PET) is among the important input parameters of WatSpas model and were calculated using the Penman combination method. The monthly estimated PET values were used to prepare the summer and winter PET grid map.

In addition to this, Parts of the area within the catchment having no stations are represented by stations which are located near the catchment area having similar topographic setup and climatic conditions. While doing so, to evenly distribute the metrological data for the whole catchment, interpolation has been done incorporating those stations by giving careful attention to weather there they have similarity in the hydrological situation, topographic setup and climatic conditions of the catchment.

4.2.3 Materials and equipment

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

- Topographic Maps (Scale 1:25000 and 1:5000) and geological maps (Scale 1:250000),
- Garmin GPS, Computer, Compass, digital camera,
- Landsat TM7Satellite imagery (30 by 30 resolution), digital elevation model data (90 by 90 resolution),
- Geological hammer, stationary materials.

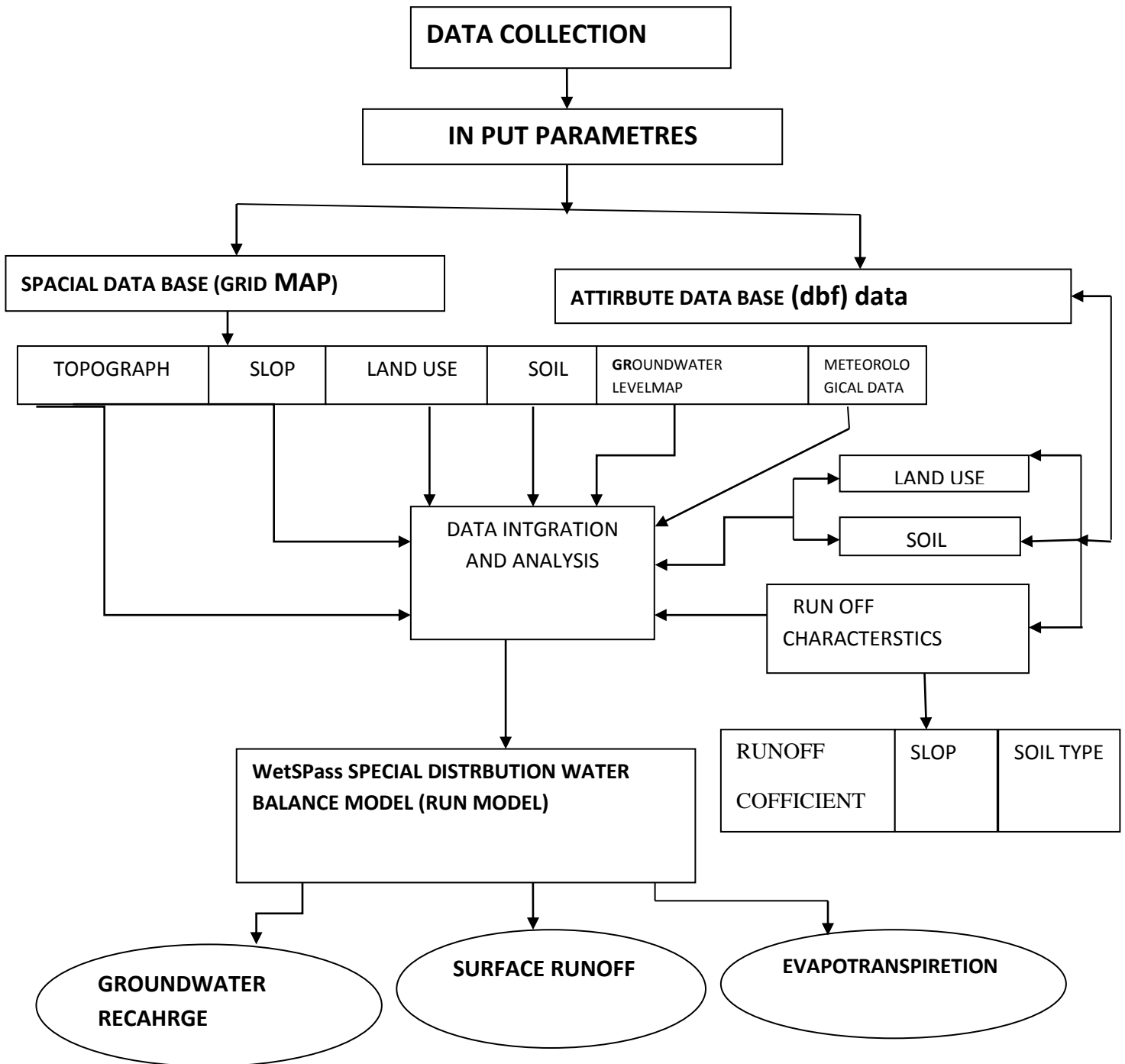


Figure 4.1 Flow chart of the methodology.

Chapter 5

5. Results and Discussions

In this chapter, different results which were obtained related to the hydrological component, the WetSpass outputs of the annual water balance component of the catchment are identified and discussed. Furthermore, the seasonal and annual areal distribution WetSpass results of the groundwater recharge as well as result of base flow separation average recharge were assessed and elaborated.

5.1 Hydro-meteorological data analysis

In the broadest sense, hydrology addresses the occurrence, distribution, movement of all waters of the earth (Fetter, 2001). Hence, to estimate hydrologic balance for a given basin, each of the hydro-meteorological elements has to be quantified. Accordingly, rainfall, actual evapotranspiration, runoff and groundwater recharge have been estimated

5.1.1 Precipitation

Rainfall distribution analysis and its temporal variability which was done based on rainfall data Obtained in and nearer the catchment metrological stations of NMA the study area is characterized by two rainfall pattern zones.

The Northwestern part which covers Guraghe and Silte highlands is characterized by unimodal (single peak) rainfall pattern. The main rainy season in this part from June to September The unimodal pattern zone receives relatively higher precipitation 1294mm than the bimodal rainfall pattern zone 1128.7mm.

The south and southwestern part of the study area which covers Boyo plain, Lemo and Kenbata highlands is characterized by bimodal (double peak) rainfall pattern. The main rainy season in this part is from July to October. The climate of the area is humid to sub-humid in the highlands and semi-arid to arid in the rift valley.

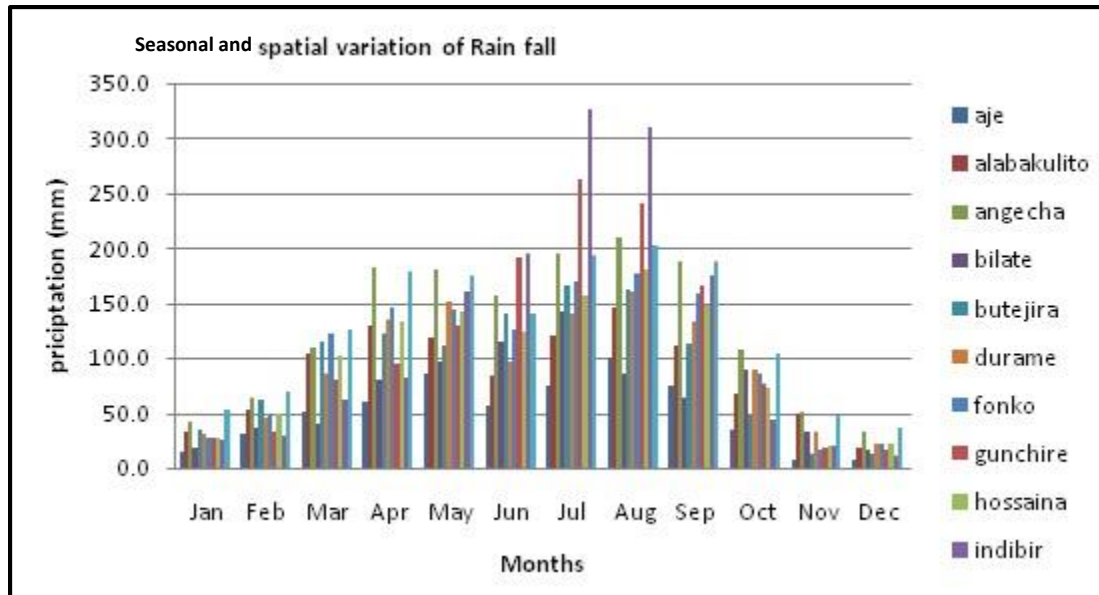


Figure 5.1 Long term mean monthly precipitation of the study area (1971-2014).

There are many physical factors controlling the depth and distribution of precipitation in a given catchment. Surface elevation is one of the powerful factors affecting the depth of precipitation in a given area.

Precipitation forms the principal source of direct recharge which occurs in areas with a surplus of rain fall over evapotranspiration (Tenalem Ayenew, 1998) and it can be governed by the rainfall distribution.

The Isohyetal and Thiessen polygon techniques are conventional techniques that are usually applied to estimate the areal precipitation. While Isohytal contour map method is the most appropriate method of estimation of areal depth of precipitation for the study area. This is due to the unevenly distributed meteorological stations and the presence of high orographic effect over the area. Accordingly the annual areal depth of precipitation using Isohytal method is estimated to be 1228 mm.

The minimum rainfall occurs during driest months from October to February. Summary of mean monthly rainfall amounts falling on the stations taken into consideration is given on (Appendix 2). The area receives a minimum and maximum mean annul rainfalls of 1034 to 1518 respectively (figure 5.2). This rainfall amount is high in high land area of southwester parts of catchment around Angecha, Durame and northern part to northwest of the catchment while the

lower part of the catchment around Halaba kulito and central areas of the catchment get a lower mean annual rainfall and this variation seems due to orographic effect.

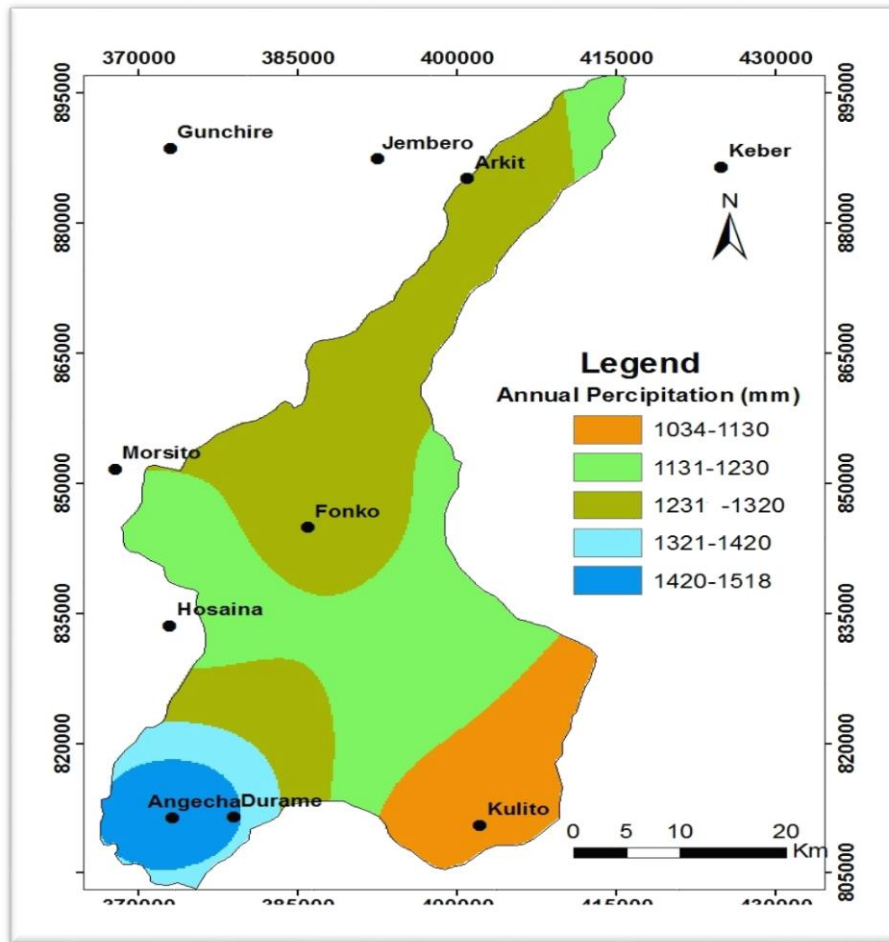


Figure 5.2 Rain fall distribution map of upper Bilate catchment.

5.1.2 Temperature

One of the factors affecting evaporation is temperature of the evaporating surface. Temperature controlled the rate of evapotranspiration through exerting reasonable heat on the surrounding air transfer energy of the crop. In sunny, warm weather the loss of water by evapotranspiration is greater than in cloudy and cool weather (FAO, 1998).

Mean annual minimum temperature of the study is 10.2⁰C and Mean annual maximum temperature of the study area is 26⁰C. The mean monthly temperature high February/Mararch and low in July/August (figure 5.3) with mean value of 18⁰C.

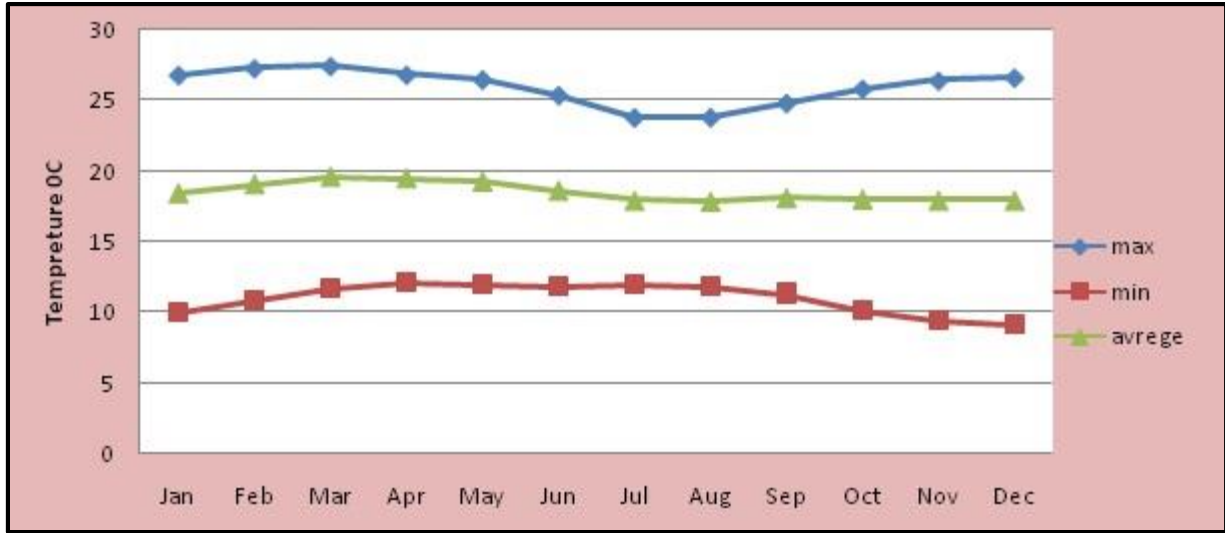


Figure 5.3 Monthly maximum, minimum and average temperature of the study area.

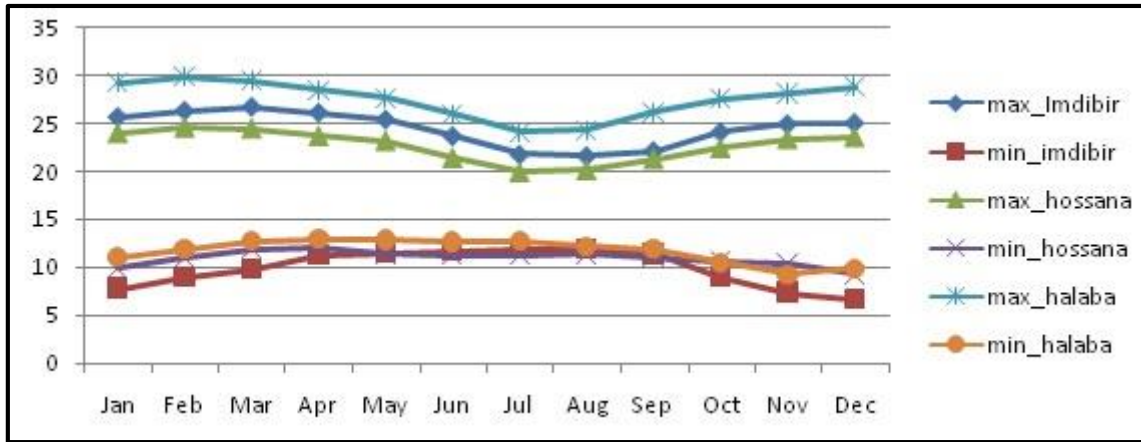


Figure 5.4 Maximum and minimum temperature variation in different stations (Indibir, Hossaina and Halaba kulito).

5.1.3 Wind speed

Wind speed is the driving force for water vapor removal, hence, strongly affect rate of evaporation, and evapotranspiration in the area. Though wind speed is an important factor in controlling the rate of evaporation, in the study area there is shortage of data. The wind speed is analyzed from the nearby stations. Accordingly, the average wind speed 2m above the surface of the earth of the study area is 1.4 m/s.

5.1.4 Potential Evapotranspiration

Evapotranspiration is an important parameter in water budget which abstracts water from the system and controls the soil moisture content, groundwater recharge and stream flow components of a certain basin. Regarding to the calculation of this parameter there are several approaches and formulas. Among these methods the Penman combination formula has been used widely and helps to provide a more realistic evaluation of moisture content of a certain catchment (E.M. Shaw, 1994). Accordingly the monthly PET of Upper Bilate catchment is calculated using the Penman formula (Equation 5.1). The monthly results are subdivided in to two main seasons (4 months of summer and 6 months of winter). Finally the summed PET values of each season, which is prepared in the form of dbf, are converted to spatially distributed grid maps. The grid maps of PET for both seasons are incorporated with other input parameters in WetSpace model to estimate the recharge as well as actual evapotranspiration (AET).

The Penman combination method for PET calculation related potential evaporation from both vegetated land surface and open water body (E.M. Shaw, 1994) and is calculated using the following equation.

$$PET = \left[\left(\frac{\Delta}{\gamma} \right) HT + Eat \right] / (\Delta\gamma + 1) \dots\dots\dots Eq 5.1$$

Where

PET = evapotranspiration rate in mm/day.

HT = is net radiation in units of mm/day of evaporation and considers the incoming and outgoing radiations and can be determined using equation.....

(Δ/γ) is (weighting factor) is a function of Temperature values of penman dimensionless parameter and is obtained from standard meteorological tables.

Eat is a term in describing the contribution of mass transfer to evaporation which incorporates the wind speed and saturation deficit and can be determined empirically using equation.....

$$HT = R1(r-1) - Ro \dots\dots\dots Eq 5.2$$

$$R1(r-1) = 0.75Ra * f(n/N) \dots \dots \dots \text{Eq 5.3}$$

$$f(n/N) = 0.16 + 0.62 (n/N) \dots \dots \dots \text{Eq 5.4}$$

$$Ro = \sigma Ta^4 (0.47 - 0.075\sqrt{ed})(0.17 + 0.83n/N) \dots \dots \dots \text{Eq 5.5}$$

$$Eat = 0.35(1 + U^2/100)(ea-ed) \dots \dots \dots \text{Eq 5.6}$$

Ra = solar radiation adjusted by latitude and season, it is constant for a given latitude & season obtained from standard meteorological table.

n = mean monthly sunshine hour in miles/day.

N = day light factor adjusted by latitude and season constant for a given latitude and season and obtained from standard tables.

(ea - ed) = saturation deficit in mmHg.

The estimated PET using the above penman formula is tabulated here below.

Table 5.1 Potential evapotranspiration Calculated using Penman combination method.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year
T (Kelvin)	292.58	293.02	293.17	292.97	292.9	292.31	291.4	291.37	291.72	291.9	291.88	291.88	
RH(%)	61.24	61.61	64.2	70.48	73.2	73.41	79.8	78.6	77.5	72.1	63.2	60	
Ra (mm/day)	12.8	13.9	14.8	15.2	15	14.8	14.9	15	14.8	14.2	13.1	12.5	
N (hr/day)	8.09	8.24	7.89	6.74	7.51	5.88	4.36	4.74	6.05	7.73	9.15	9.04	
N (hr/day)	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5	
n/N	0.697	0.698	0.66	0.548	0.596	0.463	0.346	0.382	0.5	0.655	0.789	0.786	
fa(n/N)	0.592	0.593	0.57	0.499	0.53	0.447	0.375	0.397	0.47	0.57	0.65	0.647	
R1(1-r) (mm/day)	5.69	6.18	6.3	5.8	5.95	4.96	4.2	4.5	5.23	6.03	6.37	6.07	
$\bar{\sigma}Ta_4$ (mm/day)	14.69	14.75	14.81	14.73	14.7	14.6	14.46	14.45	14.47	14.58	14.5	14.5	
ea (mm/day)	16.98	17.48	17.66	17.4	17.27	16.7	15.75	15.74	16.1	16.37	16.25	16.25	
ed (mm/day)	10.4	10.77	11.34	12.25	12.66	12.26	12.57	12.37	12.47	11.81	10.27	9.75	
ea-ed (mm/day)	6.58	6.71	6.32	5.13	4.61	4.44	3.18	3.37	3.63	4.56	5.98	6.499	
Ro (mm/day)	2.51	2.48	2.3	1.91	1.98	1.677	1.35	1.45	1.74	2.21	2.75	2.82	
HT	3.2	3.71	3.99	3.79	3.98	3.29	2.84	3.01	3.48	3.82	3.62	3.25	
U ₂ (miles/day)	67.04	74.2	69.9	65.6	61.1	62.7	58.1	53.5	44.14	56.9	70.5	65.6	
Eat (mm/day)	3.85	4.09	3.76	2.97	2.61	2.53	1.76	1.81	1.83	2.51	3.57	3.78	
Δ/Y	2.14	2.22	2.23	2.23	2.2	2.13	2.02	2.02	2.04	2.1	2.07	2.066	
PET(mm/day)	3.39	3.83	3.92	3.54	3.55	3.04	2.48	2.62	2.94	3.4	3.61	3.42	
PET(mm/month)	105.08	107.11	121.62	106.06	109.9	91.31	76.89	81.09	88.11	105.3	108.19	105.99	1207

5.2 Out puts of WetSpass

The WetSpass model produces seasonal and annual hydrological parameters like grid maps of groundwater recharge, actual evapotranspiration, surface runoff, interception loss, evaporation, etc. Annual groundwater recharge, annual actual evapotranspiration and annual surface runoff are the main outputs of the WetSpss model. A brief description of this output is given below:-

5.2.1 Annual evapotranspiration

The annual evapotranspiration is calculated by WetSpass as a sum of evaporation from bare soil, transpiration of the vegetated cover, interception loss by vegetation and evaporations of open water body.

Evapotranspiration is the process which returns water to the atmosphere and therefore completes the hydrologic cycle. And, it includes evaporation from open water, vegetation and ground surface. Also transpiration, which is the removal of water from the soil by plant roots, transport of the water through the plant into the leaf as well as evaporation of the water from the leaf's interior in to the atmosphere Teklebirhan et al. (2012).

Actual evapotranspiration is one components of water balance to determine groundwater recharge of upper Bilate catchment using the WetSpass model. About 860 mm of water is lost through evapotranspiration from the catchment. This accounts for 70% of the catchment annual precipitation. About 55% of the total annual evapotranspiration is lost during winter season while the rest 45% is released in the summer season (Appendix7, 8). This variation occurs due to high temperature in winter than summer season. As a result the winter evapotranspiration is higher than the summer.

According to the WetSpass simulated results of annual evapotranspiration, its value ranges from 542 to 1482 mm in the catchment. The output annual evapotranspiration grid map (figure 5.8) shows that low annual evapotranspiration is observed in northern, middle parts of catchment around Fonko, Shashogo woreda and southern parts of the catchment around Halaba kulito which receives lower annual rainfall (figure 5.2). Moreover, when consider the whole catchment; the highest evapotranspiration is observed the lower part of the catchment has low evapotranspiration value which is due to low rainfall while the upper part has high

evapotranspiration due to high precipitation, though the land-use and soil types. High evapotranspiration value is observed in eastern Lake Boyo area and southwestern highland of the catchment around Angecha, and Durame because these areas covered by cultivated crop, woodland, and also the presence of high rainfall in southwestern highland areas (figure 5.2). As shown in figures 3.7, 5.2 and 5.8, this higher value of annual evapotranspiration of upper Bilate catchment varies with precipitation and land-use/land-cover. Hence, precipitation and land-use/land-cover are the main controlling factors of evapotranspiration in the catchment.

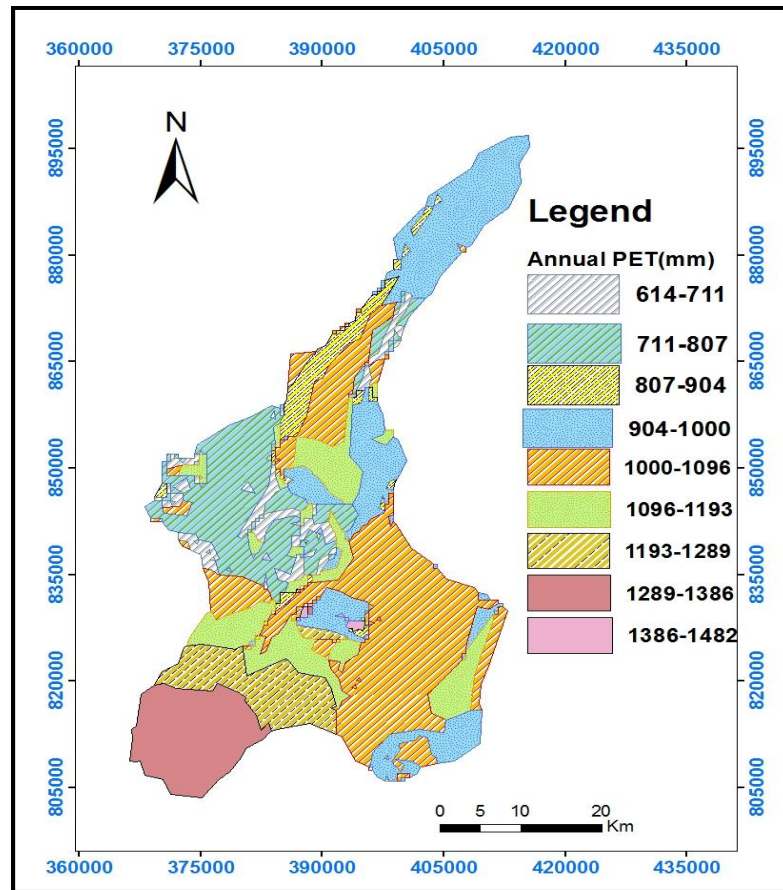


Figure 5.8 Annual evapotranspiration map of upper Bilate catchment.

5.2.2 Surface runoff

To estimate the surface runoff of upper Bilate catchment WetSpass uses runoff coefficient which varies its value with vegetation type, soil type and slope (Appendix 1). The surface runoff of upper Bilate catchment shows variation with land-use, soil type, slope, topography, precipitation and the other meteorological parameters (figure 5.9).

The amount of surface runoff also shows variation in summer and winter season. Surface runoff in the upper Bilate basin ranges from 12 to 690 mm with 256 and 190 mm of mean and standard deviation value respectively. The mean value represents 20% of the total annual precipitations of upper Bilate. From this, about 54% of the surface run off occurs during the wet season (June to September) while the remaining 46% occurs during the dry season (October to May). This variation is comes from rainfall difference in the two seasons. The amount of wet month's rainfall is higher than the dry months which exceed the infiltration capacity of the soil. This leads to high surface runoff. While in the dry months, the incoming rainfall is less than the infiltration capacity of the catchment's soils which leads to less surface runoff.

According to the annually simulated surface runoff of the catchment (figure 5.9), the north eastern part of the catchment, middle parts around Analemo, Shashogo woreda and Lake Boyo area has highest surface runoff due to the high clay content of soil which has a low permeability that enhance for surface runoff. On the other hand, the northern high land parts around Alichoweriro, western high land area around Angecha, Durame, and same how southeast have less surface runoff. This is caused due to, clay loam and loam soil types associated with woodland and grass coverage of the area which hinder surface runoff. This shows that the parameter soil types have great impact on annual surface runoff of upper Bilate catchment in addition with land use/land cover. All land-use with, silty loam and loam soil yield the lowest surface runoff while agricultural land use types with sandy clay soil yield the highest amounts of surface runoff in the catchment. Therefore, surface runoff is more governed by soil type when compared to land-use/land-cover type and slope in the study area.

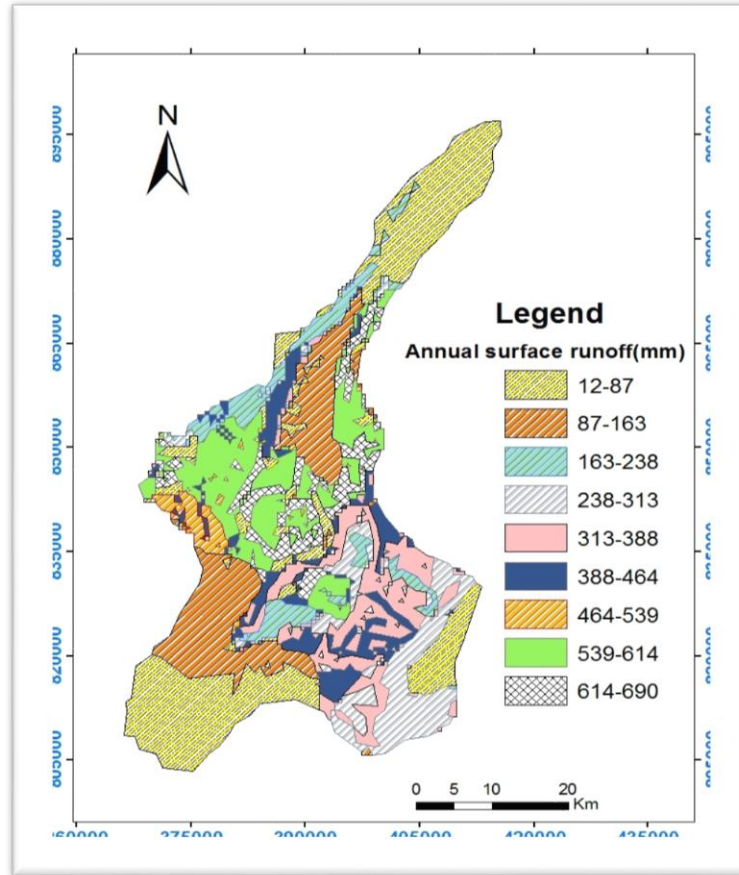


Figure 5.9 Annual surface runoff map of upper Bilate catchment.

5.2.3 Groundwater Recharge

There are different models to estimate recharge in a given area depending on actual areal conditions. In this case the WetSpass model estimates seasonal and annual long term spatial distribution amounts of groundwater recharge of upper Bilate catchment by subtracting the seasonal and annual surface runoff and evapotranspiration from the seasonal and annual precipitation respectively. The annual groundwater recharge of upper Bilate catchment varies from 0 to 384mm with 116mm mean value (9.4 % of the annual precipitation). The result obtained has a similarity with the groundwater recharge estimated by (Sinteyehu Legesse, 2009) for upper Bilate which accounts 9.2% of the total precipitation using base flow separation and water balance approaches. 95% of the annual groundwater recharge of the catchment occurred during the wet season (summer) while the rest 5% is occurred in dry seasons (winter) (figure 5.10, 5.11).

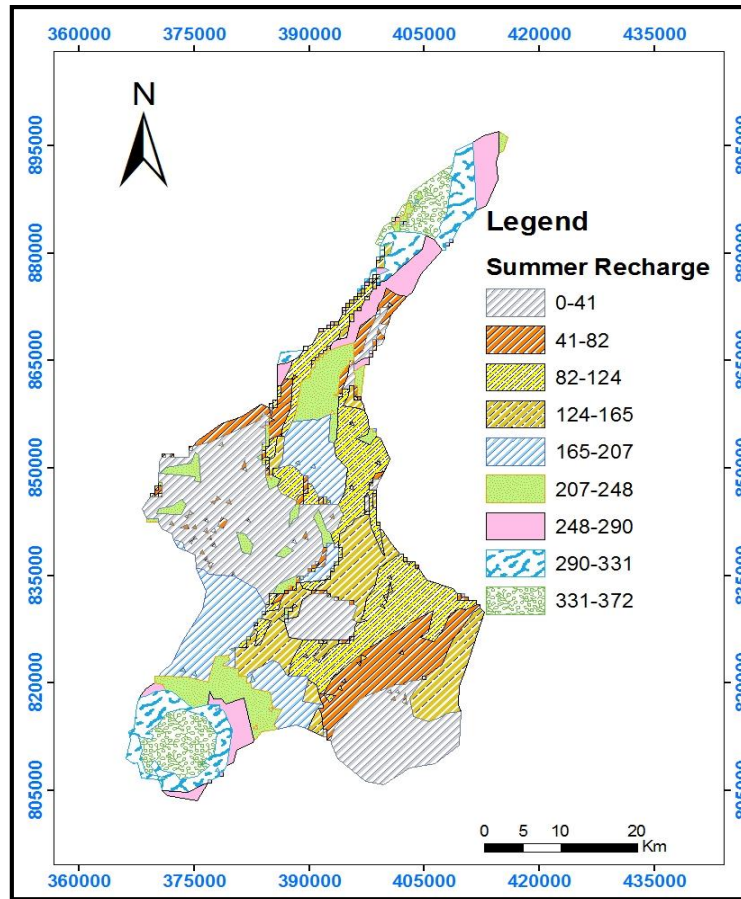


Figure 5.10 Summer season recharge (mm) map of upper Bilate catchment.

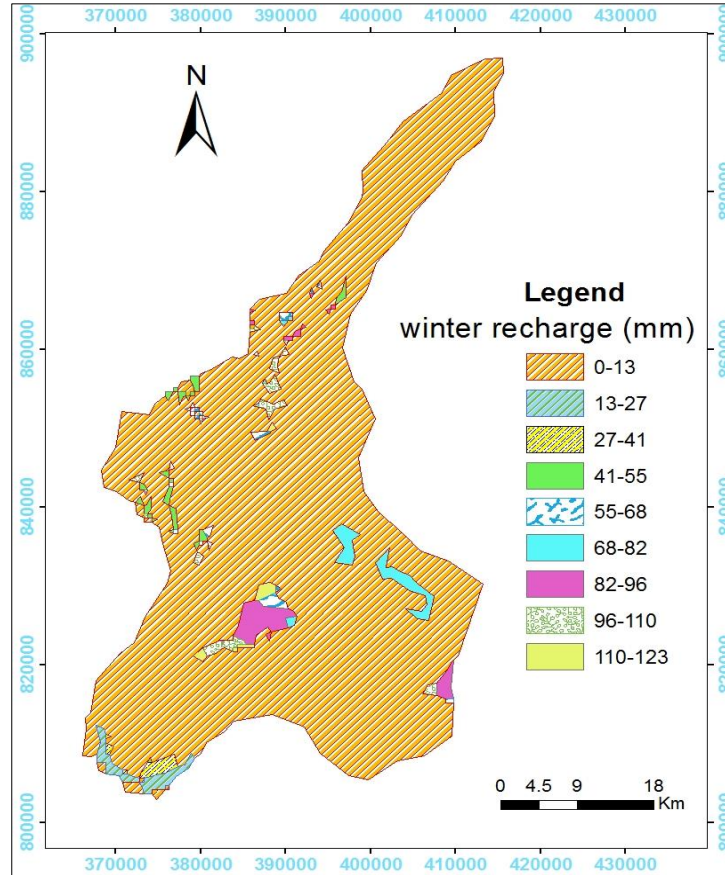


Figure 5.12 Winter season groundwater recharge map of upper Bilate catchment.

Usually it has been known recharge areas are usually in topographic high places; discharge areas are located in topographic low. Using only topographic setup of the area could not be enough to classify the area as recharge and discharge zones. Land use/land cover, soil types and morphology of land are equally important in classification of the area into recharge and discharge zones. The highland area gets relatively higher precipitation than the lowland. The Ethiopian rift is bounded by western and eastern highlands which are characterized by high rainfall amount. The main source of water to the rift lakes and rivers is the rainfall in the eastern and western highlands (Tenalem Ayenew, 2007).

The northern high land parts around Alichoweiriro, south western near to Mt. Amibercho and Mt. Dato parts around Angecha and Durame of the area have generally high annual groundwater recharge ranges between 256-384mm due to the presence of permeable soils, high precipitation, deeply weathered and fractured volcanic which are associated with tectonic activity and ultimately flow to the floor of the rift forming high discharge springs at the escarpment. On the contrary the middle part of the basin which totally covers Shashogo and Ana Lemo Woreda ,

eastern parts around lake Boyo and southeast near to Halaba kulito of the catchment have less amounts of recharge ranges between 0-128mm due to low precipitation, impermeable soils, morphology of land and overcrowded settlements.

Moderate groundwater recharge has been quantified ranges between 170-256mm in loam, and silty loam soil in middle parts of the catchment around hosanna, Fonko, Shashogo worada and, somehow south east mountain parts of catchment.

As one can see from figure 3.7, 3.8, and 5.12, high values of groundwater recharge are observed in the wood land and cultivated crop land with silty loam and loam soils. This is due to good permeability of these soils and gentle slope topography.

But, all types of soils with bare land, and grazing lands-use areas (grass land) have resulted low amounts of groundwater recharge. This is caused due to the release of higher amounts of transpiration through the plant and grass leaf stomata respectively.

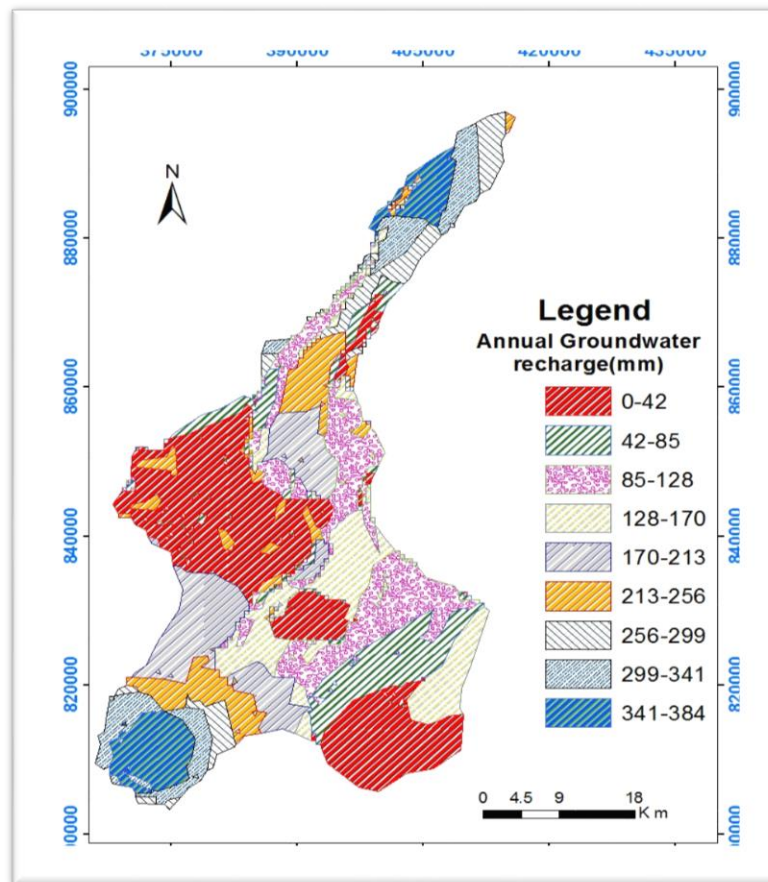


Figure 5.12 Annual groundwater recharge map of upper Bilate catchment.

In open water bodies, such as in Lake Boyo and the surrounding area since the groundwater is close to the surface of the earth, recharge value is zero. This shows that there is no groundwater recharge or the area is saturated with enough water up to the surface which does not permit to percolate additional water through the soil.

As one can see from table (5.2,) 116mm of the total precipitation infiltrate to the underground as recharge while the remaining portion of the annual rainfall are lost as surface runoff and evapotranspiration from the catchment. In addition to this, the table shows that, water balance of the simulated WetSpas model of the catchment.

Table 5.2 Annual water balance of upper Bilate catchment (mm) based on the WetSpas model.

Water balance component (element)	Minimum	Maximum	Mean	Std.dev
PP	1034	1518	1228	93
ETP	542	1482	860	139
RO	12.4	690	256	190
RE	0	384	116	120

(Water balance = PP-ETP –RO-RE = 4).

5.3 Recharge estimation using Baseflow records

In estimating recharge for a given catchment from base flow the assumption is that the base flow of a river is equal to the total groundwater recharge of the catchment upstream of the discharge measuring site (Tenalem Ayenew, 1998). In this case any loss upstream of the gauging station is considered to be negligible.

Two gauging stations were used to estimate recharge over the entire upstream catchment and the area to downstream of the last gauging station recharge estimated Bilate River near Halaba kulito and Guder gauging station near Hossian (table 5.3,5.4 and 5.5).

Summary of long-term annual average base flow and surface runoff gauging stations described in the following figures:

Table 5.3 Analysis result of Time plot at Bilate gauging station.

	Total flow	Base flow	Runoff
m3/s	10.326	5.914	4.412
hm3	7123.81	4080.09	3043.72

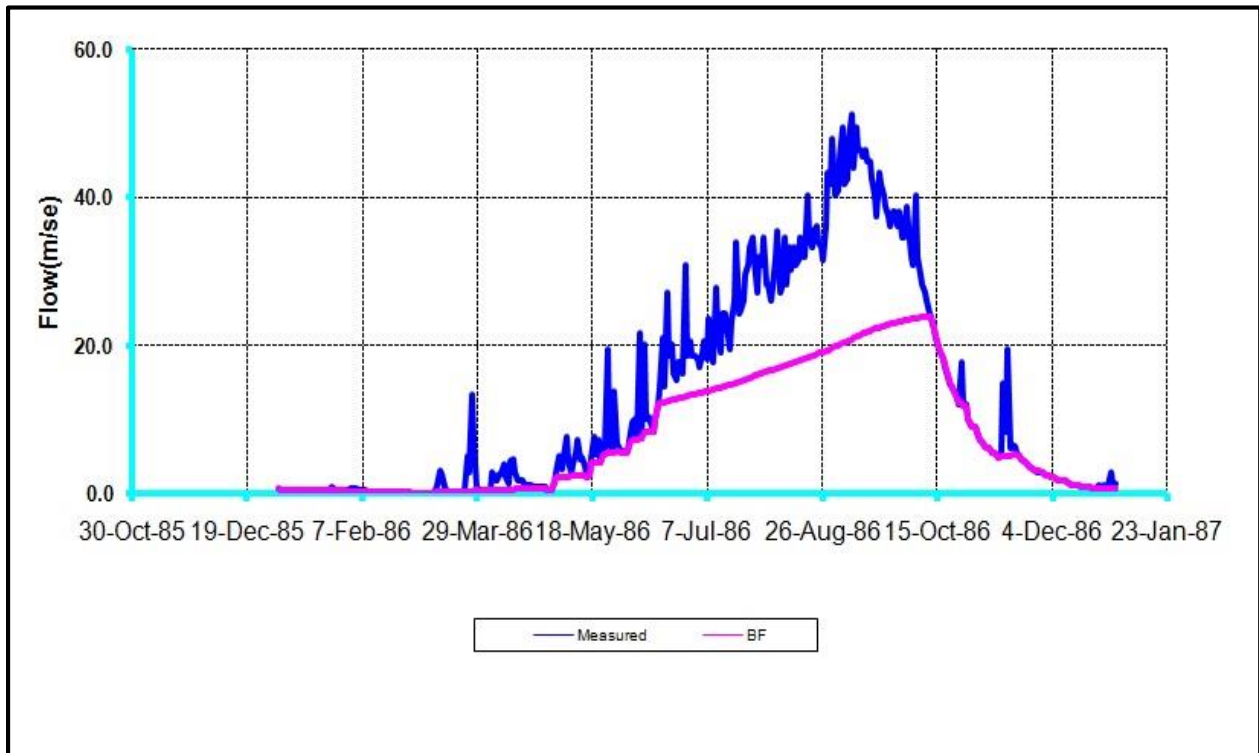


Figure 5.13 Baseflow separations of Billate river near Halaba kulito.

Table 5.4 Analysis result of time plot at Guder gauging station.

	Total flow	Base flow	Runoff
m3/s	1.620	0.592	1.028
hm3	397.10	145.13	251.97

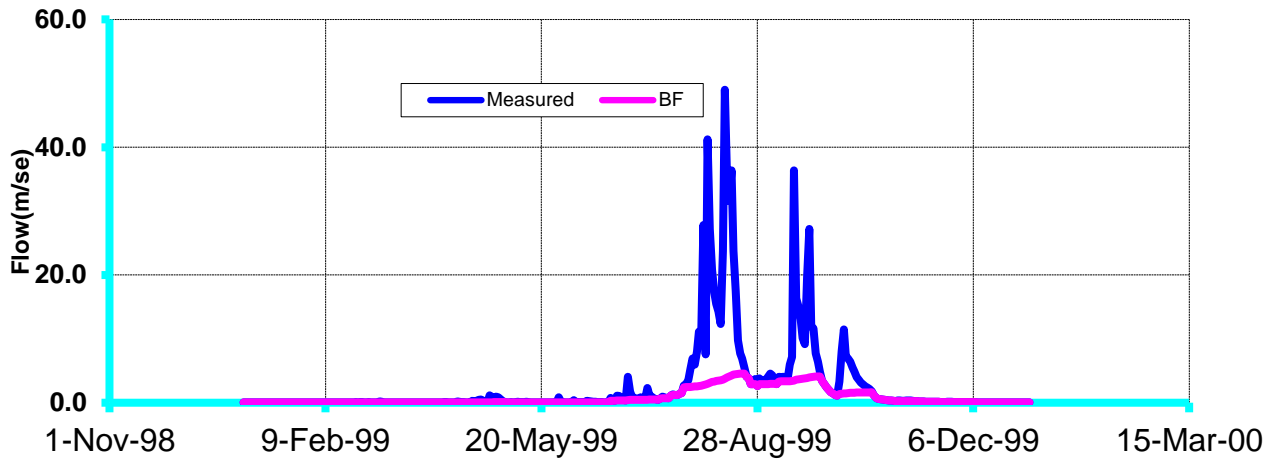


Figure 5.14 Baseflow separations of Gududer river near Hossaina.

Table 5.5 Baseflow and Run off at Bilate and Guder gauging stations.

Gauging	Location		Duration	Area(sq km)	Baseflow (mm/year)	Surface runoff (mm/year)	Recharge estimated from base flow (mm/year)
	Easting	Northing					
Bilate	397562	805236	1971-2007	2075	90	67	90
Guder	380218	838064	1999-2006	106	176	305	176

The Separation of surface runoff and base flow has been made using a computer code (Time Plot). This computer code uses daily flow values and an attenuation coefficient which ranges from 0.9 to 0.995 based on slope and land use and land cover conditions the bigger the attenuation coefficient the bigger the surface runoff the lesser the base flow.

According to baseflow and Runoff separation method Gududer River has high recharge than Bilate.

Guder river emanates north of Hossana town is also structurally affected with moderately fractured pyroclastic and volcanic rock, the area receives 176 mm recharge annually and this accounts for 14% of the annual precipitation. This value is good estimate based on the assumption 10-20% of the annual rainfall of the region is recharge for volcanic aquifers

While at Bilate gauging station the recharge of the river are small as compared to Guder. This is due to the damping effect Guder River to Boyo lake/swamp which is covered with alluvial and lacustrine deposits. However, estimated recharge of the catchment is 90mm/year and this accounts for 7.3% of the annual precipitation and the current work using Wetspass model has resulted an annual recharge of 116mm/year which accounts 9.4% of the annual precipitation (1228mm). This shows that both the WetSpass and the Baseflow separation methods predict well the water balance condition in the catchment. The difference might be due to the various assumptions employed in both methods and possibly the base flow separation method assumption which could not account any channel loss at the upstream and the deep groundwater flows beneath the river channel.

Baseflow separation and conventional water balance approaches were used to estimate groundwater recharge in upper Bilate by Sinteyehu Legessa (2009). The estimated recharges of the area are 129 and 96.18mm using base flow separation and water balance approaches respectively. The average of the two values is taken as the annual recharge of the area which is 9.2% of the total precipitation of 1231.6. It has been comparable the value of my reach groundwater recharge The estimated groundwater recharge of the area is 116 and 90mm using Wetspass and base flow separation method. The average of the two values is taken as the annual recharge of the area which is 8.3 % of the total precipitation of 1228.

5.4 Limitations

Groundwater recharge zone of this study was constructed with available site specific hydrologic, hydrogeologic, hydrometeorology and physiographic data of the study area.

To produce groundwater level grid map, static water level data which are taken at different seasons are required. With this regard well completion report is helpful, which is lacking in most part of the study area. Moreover available groundwater level data are not well organized and also there is no GPS coordinate. In addition it was not possible to collect the current groundwater

level information because most wells do not have made the field work to measure static water level difficult.

WetSpas the acronym for Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State is a method for estimating spatially distributed, long-term average recharge developed by Batelaan and De Smedt (2001, 2007). It uses long-term average climatic data together with an elevation, land use and soil map of an area to simulate average spatial patterns of surface runoff, actual evapotranspiration and groundwater recharge in the area but for result validation it is difficult to calibrate, for this reason a comparison was made with groundwater recharge estimation using base flow separation and the resulted groundwater recharge map validated based on previous groundwater recharge study at different method of the study area.

Chapter 6

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In order to evaluate the groundwater recharge of the upper Bilate catchment, the land-use, soil type, hydro-meteorology, topography, slope and geology of the catchment has been investigated. Emphasis was made to collect primary field information and gather existing data to produce full information relevant for quantifying areal distribution recharge and the other water balance component of the catchment.

Nazreth pyroclast, Dino formation, volcanic complex and alluvial and lacustrine sediments are the main geologic units of upper Bilate catchment. Geologic structures like faults, fractures, horst, and graben are the major geological structures.

About 53 % of the catchment is a crop cultivation land while the rest is covered mainly by wood land, bare land, grass land, perennial marsh and water body (lake).

Silty loam, clay loam and sandy clay are the major dominant soil type of the area.

A GIS based WetSpas water balance model study was carried out for the entire catchment of upper Blate. The WetSpas input of grid maps and parameter tables were prepared based on the upper Bilate catchment condition.

Based on the WetSpas model, the study has resulted the annual groundwater recharge map, annual evapotranspiration map and surface runoff map. Accordingly within the catchment different areas are identified as high, moderate and low groundwater recharge zones. The high groundwater recharge observed in highlands which represented in the woodland, and crop cultivation land with silty loam and loam soils. This is due to good permeability of these soils and gentle topography.

Upper Bilate catchment receives 52 % of the precipitation in summer season while the rest 48% falls in winter season.

The result of the WetSpass model shows that evapotranspiration value of the upper Bilate catchment ranges from 542 to 1482 mm/year. This represents 70% of the mean annual precipitation of the basin. The annual surface runoff of the area ranges from 12 to 690mm with 256 mean annual values and this represents 20% of the precipitation. From this, about 54% of the surface run off occurs during the wet season (June to September) while the remaining 46% occurs during the dry season (October to May).

The highest surface runoff the in the catchment is observed in sandy Clay soil with bare land, bush land and around swap area/Lake Boyo. Generally the area has high surface runoff relative to groundwater recharge because the catchment is dominated by impermeable soil materials.

Based on the WetSpass model results, annual groundwater recharge of upper Bilate catchment ranges from 0 to 384mm with 116mm mean value (9.4 % of the annual precipitation). Agricultural land and wood lands with silty loam and loam soils promote the highest groundwater recharge in the catchment.

The highly variable distributions of the climatic parameters associated with variations of land-use/land-cover, soil type, topography and slope are responsible for variations of the water balance element within the catchment.

The highest amount of evapotranspiration simulated for the catchment, relative to the groundwater recharge and the surface runoff indicates that much effort is needed to change the environmental conditions of the catchment, say it could be by re-forestation programs, which will enhance the rainfall amount.

According to the baseflow separation method, the area revives 90 mm recharge annually and this accounts for 7.3% of the annual precipitation.

The acceptable difference shows that both the WetSpass and the baseflow separation methods predict well the water balance condition in the catchment. The difference could be because of the various assumptions and limitations of the base flow separation method which resulted in under estimated value as compared to WetSpass model because Base flow separation method could not account any channel loss at the upstream and the deep groundwater flows beneath the river channel.

The finding of this research shows that, the groundwater recharge is low. This is mainly due to the presence of high evapotranspiration rate associated with high temperature and high surface runoff due to impermeable soil and change in land use/land cover impact.

6.2 Recommendations

The groundwater recharge of upper Bilate catchment has been determined and aerial distributions of the water balance component have also been quantified. Finally, for future studies the following recommendations have been forwarded:

- ❖ Groundwater modeling study is recommended to the sustainable exploitations of groundwater resource and to quantify groundwater recharge. Estimation rates of groundwater recharge in the area is crucial for sustainable management and utilization of the resource as well as their protection against pollution and depletion.
- ❖ Further groundwater modeling studies should be conducted to predict the effects of different stress conditions on the groundwater resource.
- ❖ Observation pipe (Groundwater monitoring) wells should be constructed so as to control the groundwater fluctuation of the area as well as to conduct further detail groundwater flow modeling.
- ❖ Detail geological and structural investigation should be conducted to identify the structures which controlled the groundwater flow direction, recharge and discharge conditions and mechanisms.
- ❖ The groundwater recharge map along with other thematic maps can serve as a source of information database which can be updated from time to time by adding new information. Therefore there should be well organized data base system in different governmental organization so as to provide accurate data about the hydrogeological as well as hydrological systems for feature studies.
- ❖ The use of more than one methods of recharge estimation is crucial to check the accuracy of the result; regarding to this most of the methods do not account for the

spatial variation and distribution of recharge. While WetSpas model is better since it gives recharge value with spatial and temporal variations.

- ❖ The occurrence of high amount of evapotranspiration simulated for the catchment, relative to the groundwater recharge and the surface runoff is the effect of activities in which natural vegetation has been greatly affected by agricultural practice and deforestation. For that matter the detailed land use land cover study should be conducted for rehabilitation.

REFERENCES

- AG Consult Consulting Hydrogeologists and Engineers Plc. (2007). Water Resource Potential Assessment of the two Neighboring River Basin Namely Omo-Gibe and Bilate River Basin. Unpublished Report,
- Batelaan, O. and Desmedt, F. (2007). GIS based recharge estimation by coupling surface-subsurface water balance. *Journal of hydrology*. **337**: 337-355.
- Batelaan, O. and Desmedt, F. (2001). WetSpass: a flexible, GIS based, distributed recharge methodology for regional groundwater modeling. **In:** Proceedings of the 6th IAHS scientific Assembly, pp. 269:117. IAHS, Maastricht, the Netherlands.
- Batelaan, O. and Woldeamlak, S.T. (2007). Arc view interface for Wetspass, user manual, version 13-06-2007, Department of Hydrology and Hydraulic engineering, Vrije Universiteit Brussel, Belgium.
- Biruk Kifle, (2009). Groundwater potential assessment and numerical flow modeling of Guder-Batena River Catchment. Unpublished MSc thesis, Aribaminch University, Arbaminch, Ethiopia, 102 pp.
- Degelo Sendabo. (2007). Analysis of Biomass degradation as an indicator of environmental challenge of Bilate watershed using GIS techniques. Unpublished MSc thesis, Addis Ababa University, Addis Ababa, Ethiopia,
- Dessie Nedaw. (2010). Water balance and ground water quality of Koraro Area. *MEJS*, **2** (2):110-127. Mekelle University, Ethiopia.
- Elizabeth M. Shaw (1994). *Hydrogeology in practice*, 3rd ed., London, 613 pp.
- Fetter, C. W. (1994). *Applied Hydrogeology*, 3rd ed., Prentice – Hall, New Jersey, 695pp.
- Food and Agriculture Organization (FAO)(1998). *Crop evapotranspiration Guidelines for computing crop water requirement irrigation and drainage paper*, 56.Rome, Italy.
- Food and Agriculture Organization (FAO)(1998). *Land use/Land cover map of the world*, 56.Rome, Italy.

Food and Agriculture Organization (FAO) (2003). The Digital Soil map of the world and derived soil properties, version 3.6. CD-ROM, information Division, FAO, Rome, Italy. Retrieved from <http://www.fao.org/ag/agl/agll/dsmw.stm>. on 14.03.2015.

Gebrerufael Hailu Kahsay.(2008). Groundwater resource assessment through distributed steady-state flow modeling Aynalem well field. Unpublished report, Mekele, Ethiopia.

GSE (Geological Survey of Ethiopia) (2012). A report on Geology, Geochemistry and Gravity Survey of the Hossaina area including Bilate. Unpublished Report, Addis Ababa, Ethiopia.

Kefale Tilahun (2013), Hydrogeological and Hydrochemical maps of Hossaina NB 37-2, AQATEST as., Geologicka 4, 152 Prague, Czech Republic.

Kazmin, V. (1980). Transform faults in the East African Rift System. In: Geodynamic Evolution of the Afro – Arabian Rift System, Accademia Nazionale dei Lincei, Rome, Atti dei Convegni Lincei, 47, 65 – 73.

Mengesha Tefera., Tesfay Chernet, Workineh Haro. (1996). Explanation of the Geological Map of Ethiopia, 1:2,000,000 scale. Unpublished technical report, Ethiopian Institute of Geological Survey, 79 pp.

Saifu Kebede, (2013). Groundwater in Ethiopia, Springer-Verlag Berlin Heidelberg, 293pp.

Sentayehu Legese. (2009). Integrated hydrogeological investigation of upper Bilate river catchment: Southern rift valley of Ethiopia. Unpublished MSc thesis, Addis Ababa University, Addis Ababa, Ethiopia, 111pp.

Teklebirhan Arefayene, Dessie Nedaw and Tesfamichael Gebre (2012). Groundwater Recharge, Evapotranspiration and Surface Runoff Estimation by Using WetSpas Modeling Method in Illala Catchment, Northern Ethiopia, MEJS. 4(2), pp.96-110. Mekele, Ethiopia.

Tenalem Ayenew, (1998). The Hydrogeological system of the Lake District basin, central Main Ethiopian Rift. Published PhD thesis (ISBN.9061641586), Free University of Amsterdam, ITC, The Netherlands, 259 pp.

Tenalem Ayenew and Tamiru Alemayehu (2001). Principle of Hydrogeology, Addis Ababa University, Department of Geology and Geophysics, Addis Ababa.

Tenalem Ayenew, (2007). Water management problems in the Ethiopian rift: Challenges for development, *Journal of African Earth Sciences* 48 (2007) 222–236.

Tesfamichael Gebreyohans.(2009). Regional ground water flow modeling of the Geba basin, Northern Ethiopia, Vrije Universiteit Brussel.

Tesfaye Tesemma. (2010). Groundwater potential Evaluation based on integrated Geographical information system (GIS) and remote sensing techniques in Bilate River catchment: South rift valley of Ethiopia, SNNPR. Unpublished MSc thesis, Addis Ababa University, Addis Ababa, Ethiopia, 93 pp.

Tesfay Chernet, (1993). Hydrogeology of Ethiopia and water resources development, (EIGS) Ethiopian Institute of Geological Surveys, Addis Aababa, 222 pp.

Yodit Teferi. (2005). Evaluation of land degradation and landslide using integrated remote sensing and GIS approach around Wolayita Sodo-Shone area, southern Ethiopia. Unpublished MSc thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Yongxin, X., & Beekman, H. E. (2003). Groundwaters recharge estimation in southern Africa, United Nations Educational Scientific and Cultural Organization, Paris.

Yirga, Tadessa. (2004). Ground water modeling a case study on volcanic water supply aquifer/Akaki well field of the city Addis Ababa. Unpublished report, Addis Ababa, Ethiopia.

Appendix 1

Appendix 1 Runoff coefficient parameters

LANDUSERO	LANDUSENUM	SLOPE_ [%]	SLOPENUM	SOILTYPE	SOILNU M	RUNOFFCOEF
crop	1	<0.5	1	Silty-loam	4	0.43000
crop	1	0.5-5	2	Silty-loam	4	0.48000
crop	1	5-10	3	Silty-loam	4	0.53000
crop	1	>10	4	Silty-loam	4	0.58000
grass	2	<0.5	1	Silty-loam	4	0.23000
grass	2	0.5-5	2	Silty-loam	4	0.28000
grass	2	5-10	3	Silty-loam	4	0.33000
grass	2	>10	4	Silty-loam	4	0.38000
forest	3	<0.5	1	Silty-loam	4	0.13000
forest	3	0.5-5	2	Silty-loam	4	0.18000
forest	3	5-10	3	Silty-loam	4	0.23000
forest	3	>10	4	Silty-loam	4	0.28000

Groundwater Recharge estimation using wetspass model in upper Bilate river catchment

bare soil	4	<0.5	1	Silty-loam	4	0.53000
bare soil	4	0.5-5	2	Silty-loam	4	0.58000
bare soil	4	5-10	3	Silty-loam	4	0.63000
bare soil	4	>10	4	Silty-loam	4	0.68000
open water	5	<0.5	1	Silty-loam	4	1.0000
open water	5	0.5-5	2	Silty-loam	4	1.0000
open water	5	5-10	3	Silty-loam	4	1.0000
open water	5	>10	4	Silty-loam	4	1.0000
Crop	1	<0.5	1	Loam	5	0.4000
Crop	1	0.5-5	2	Loam	5	0.4500
Crop	1	5-10	3	Loam	5	0.500
Crop	1	>10	4	Loam	5	0.5500
Grass	2	<0.5	1	Loam	5	0.2000
Grass	2	0.5-5	2	Loam	5	0.2500
Grass	2	5-10	3	Loam	5	0.3000
Grass	2	>10	4	Loam	5	0.3500

Groundwater Recharge estimation using wetspass model in upper Bilate river catchment

Forest	3	<0.5	1	Loam	5	0.1000
Forest	3	0.5-5	2	Loam	5	0.1500
Forest	3	5-10	3	Loam	5	0.2500
Forest	3	>10	4	Loam	5	0.5000
bare soil	4	<0.5	1	Loam	5	0.5500
bare soil	4	0.5-5	2	Loam	5	0.6000
bare soil	4	5-10	3	Loam	5	0.6500
bare soil	4	>10	4	loam	5	0.6500
open water	5	<0.5	1	loam	5	1.0000
open water	5	0.5-5	2	loam	5	1.0000
open water	5	5-10	3	loam	5	1.0000
open water	5	>10	4	loam	5	1.0000
Crop	1	<0.5	1	Clay loam	9	0.4800
Crop	1	0.5-5	2	clay loam	9	0.5300
Crop	1	5-10	3	Clay loam	9	0.5800
Crop	1	>10	4	Clay loam	9	0.6300

Groundwater Recharge estimation using wetspass model in upper Bilate river catchment

Grass	2	<0.5	1	Clay loam	9	0.2800
Grass	2	0.5-5	2	clay loam	9	0.3300
Grass	2	5-10	3	Clay loam	9	0.3800
Grass	2	>10	4	Clay loam	9	0.4300
Forest	3	<0.5	1	Clay loam	9	0.4300
Forest	3	0.5-5	2	clay loam	9	0.1800
Forest	3	5-10	3	Clay loam	9	0.2300
Forest	3	>10	4	Clay loam	9	0.2800
bare soil	4	<0.5	1	Clay loam	9	0.3300
bare soil	4	0.5-5	2	clay loam	9	0.5800
bare soil	4	5-10	3	Clay loam	9	0.6300
bare soil	4	>10	4	Clay loam	9	0.7300
open water	5	<0.5	1	Clay loam	9	1.0000
open water	5	0.5-5	2	Clay loam	9	1.0000
open water	5	5-10	3	Clay loam	9	1.0000
open water	5	>10	4	Clay loam	9	1.0000

Groundwater Recharge estimation using wetspass model in upper Bilate river catchment

Crop	1	<0.5	1	Sandy clay	10	0.5000
Crop	1	0.5-5	2	Sandy clay	10	0.5500
Crop	1	5-10	3	Sandy clay	10	0.6000
Crop	1	>10	4	Sandy clay	10	0.6500
Grass	2	<0.5	1	Sandy clay	10	0.3000
Grass	2	0.5-5	2	Sandy clay	10	0.35000
Grass	2	5-10	3	Sandy clay	10	0.4000
Grass	2	>10	4	Sandy clay	10	0.4500
Forest	3	<0.5	1	Sandy clay	10	0.200
Forest	3	0.5-5	2	Sandy clay	10	0.2500
Forest	3	5-10	3	Sandy clay	10	0.3000
Forest	3	>10	4	Sandy clay	10	0.3500
bare soil	4	<0.5	1	Sandy clay	10	0.6000
bare soil	4	0.5-5	2	Sandy clay	10	0.6500
bare soil	4	5-10	3	Sandy clay	10	0.7000
bare soil	4	>10	4	Sandy clay	10	0.7500

Groundwater Recharge estimation using wetspass model in upper Bilate river catchment

open water	5	<0.5	1	Sandy clay	10	0.7500
open water	5	0.5-5	2	Sandy clay	10	1.0000
open water	5	5-10	3	Sandy clay	10	1.0000
open water	5	>10	4	Sandy clay	10	1.0000
Crop	1	<0.5	1	Silty clay	11	0.5300
Crop	1	0.5-5	2	Silty clay	11	0.5800
Crop	1	5-10	3	Silty clay	11	0.6300
Crop	1	>10	4	Silty clay	11	0.6800
Grass	2	<0.5	1	Silty clay	11	0.3300
Grass	2	0.5-5	2	Silty clay	11	0.3800
Grass	2	5-10	3	Silty clay	11	0.4300
Grass	2	>10	4	Silty clay	11	0.4800
Forest	3	<0.5	1	Silty clay	11	0.2300
Forest	3	0.5-5	2	Silty clay	11	0.2800
Forest	3	5-10	3	Silty clay	11	0.3300
Forest	3	>10	4	Silty clay	11	0.3800

Groundwater Recharge estimation using wetspass model in upper Bilate river catchment

bare soil	4	<0.5	1	Silty clay	11	0.6300
bare soil	4	0.5-5	2	Silty clay	11	0.6800
bare soil	4	5-10	3	Silty clay	11	0.7300
bare soil	4	>10	4	Silty clay	11	0.7800
open water	5	<0.5	1	Silty clay	11	1.0000
open water	5	0.5-5	2	Silty clay	11	1.0000
open water	5	5-10	3	Silty clay	11	1.0000
open water	5	>10	4	Silty clay	11	1.0000

Appendix 2 Summary of climatologically parameters

SUMMARY OF MEAN MONTHLY RAINFALL AT DIFFERENT METROLOGICAL STATIONS (MM)

stations	Duration	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
aje	1971-2014	14.7	30.7	51.7	59.8	86.2	56.1	75.3	100.8	74.7	35.3	6.6	8.0	599.9
alabakulito	1971-2014	32.43	52.266	104	129.79	118.61	83.127	119.78	145.2	111.37	68.17	50.01	18.83	1033.536
angecha	1982-2014	41.56	63.241	109.5	181.76	180.65	156.8	195.05	209.54	188.19	108.3	50.156	33.05	1517.8091
bilate	1971-1985	17.82	35.95	40.2	80.917	97.06	115.63	142.07	86.2	64.683	89.77	32.75	16.29	819.33417
butejira	1971-2014	34.684	62.634	115.3	121.92	111.94	140.74	166.2	161.34	113.81	48.12	13.432	13.52	1103.617
durame	1954-2014	30.571	45.9	86.22	135.09	152.18	97.146	139.77	160.84	132.38	88.49	32.69	22.74	1124.0211
durameW.R	1954-1960	88	254	176	148	94	143.9	129.07	139.53	111.2	188	0		1471.7
fonko	1986-2014	27.068	48.882	121.5	146.14	144.04	125.82	168.98	176.56	158.13	85.77	17.118	22.25	1242.2307
gunchire	1988-2013	27	32.908	79.4	94.868	129.67	190.9	262.52	241.45	165.07	75.75	18.5	16.92	1334.9951
hossaina	1977-2014	28.114	48.997	101.6	133.76	143.02	123.8	156.69	180.24	147.98	73.09	20.271	21.06	1178.5838
indibir	2005-2014	26.083	29.867	61.28	81.617	160.88	195.83	326.9	310.22	175.74	44.24	20.189	11.02	1443.85
shone	1971-2014	53.218	68.685	125.1	179.09	175.44	141.18	193.96	202.84	187.21	104.1	46.849	36.29	1513.9461
	Mean	35.1	64.5	97.6	124.4	132.8	130.9	173.0	176.2	135.9	84.1	25.7	20.0	1198.6

Groundwater Recharge estimation using wetspass model in upper Bilate river catchment

Mean Monthly Temperature (°C)												
station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Dec	Annual
Aje	19.44	20	20.46	21	20.75	20.39	19.42	18.53	19.2	19.1	19.7	19.7896
Halaba	19.97	21	21.32	21	20.26	19.39	18.51	18.24	19.08	19	19.4	19.6359
Angacha	19.75	19.5	19.28	19	18.96	18.58	18.41	18.3	18.52	19.2	19.8	19.0872
Bilate	23.55	22.7	21.64	22	23.17	22.2	20.09	20.67	20.6	21.6	20.5	21.4815
Durame	20.79	21.5	22.27	20	19.77	20.21	19.35	19.57	19.78	20.2	20.4	20.4141
Gudar	16.66	17.6	18.76	19	18.92	18.42	17.97	17.59	17.18	16.1	15.6	17.4434
Hossaina	16.78	17.8	18.14	18	17.09	16.25	15.55	15.7	15.98	16.5	16.3	16.7267
Indbir	16.78	17.7	18.27	19	18.46	17.68	16.84	16.83	16.84	16.6	15.9	17.2365
Biutajira	18.36	18.8	19.12	19	19.16	18.64	17.69	17.91	18.56	18.6	17.9	18.5327
mean	19.12	19.6	19.92	20	19.62	19.08	18.2	18.15	18.42	18.5	18.4	18.9275
Mean Monthly Relative Humidity (%)												
station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Dec	Annual
Bilate	50.4	52.8	60.5	69	71.3	72.4	73.5	70.6	71	67	51.8	63.9
Hossaina	70.2	62.2	67.9	72	75.7	82.9	86	86.7	84.1	77.1	67.5	75.1
Mean	60.3	57.5	64.2	71	73.5	77.65	79.75	78.65	77.55	72	59.7	69.5
Mean Monthly Wind Speed (U) 2m above ground level (m/s)												
station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Dec	Annual
Bilate	1.5	1.7	1.4	1.2	1.3	1.3	1.1	10.9	0.8	0.9	1.2	24.8
Hossaina	1.361	1.49	1.525	1.4	1.2	1.332	1.383	1.214	0.941	1.43	1.61	16.4898
Indibr	0.886	0.96	0.983	1	0.914	0.871	0.763	0.686	0.725	0.85	0.86	10.3946
Mean	1.249	1.38	1.303	1.2	1.138	1.168	1.082	4.267	0.822	1.06	1.22	17.2281
Mean Monthly Sunshine Hour (hour/day)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Dec	Annual
Hossaina	8.407	8.64	7.888	6.8	6.806	5.625	3.574	4.016	5.468	8.43	8.81	83.5847
Indibir	7.4	7.13	7.175	5.9	5.7	4.383	2.54	3.04	3.56	5.87	7.84	68.03
Mean	7.904	7.88	7.531	6.4	6.253	5.004	3.057	3.528	4.514	7.15	8.33	75.8074

Appendix 3 Summer land use parameter table modified for upper Bilate catchment

No	LUSE_TYPE	RUN OFF_ VEG	NUM_VEG _RO	NUM_ IMP_R O	VEG_AR EA	BARE_A REA	IMP_AR EA	OPENW _AREA	ROOT_DE PTH	LAI	MIN_S TOM	INTERC _PER	VEG_HEIG HT
21	Crop cultivation	crop	1	0	0.8000	0.2000	0.0000	0.0000	0.4000	4.00	180.00	15.00	0.6000
7	Bare land	Bare soil	4	0	0.0000	1.0000	0.0000	0.0000	0.0500	0.00	110.00	15.00	0.0010
33	Woodland	fores t	3	0	1.0000	0.0000	0.0000	0.0000	2.0000	5.00	375.00	35.00	16.0000
36	Grass,shrubs, &bush land	grass	2	0	1.0000	0.0000	0.0000	0.0000	0.6000	6.00	110.00	15.00	2.0000
44	Perennial marsh	Open water	5	0	0.4000	0.2000	0.0000	0.0000	0.4000	2.00	110.00	10.00	0.5000
52	water body (Lake)	Open water	5	0	0.0000	0.0000	0.0000	1.0000	0.0500	0.00	110.00	0.00	0.0000

Appendix 4 Winter land use parameter table modified for upper Bilate catchment

No	LUSE_TY E	RUNOFF_ VEG	NUM_VEG _RO	NUM_ IMP_R O	VEG_AR EA	BARE_ AREA	IMP_AR EA	OPENW _AREA	ROOT_D EPTH	LAI	MIN_ST OM	INTERC _PER	VEG_HEI GHT
21	Crop cultivation	crop	1	0	0.0000	1.0000	0.0000	0.0000	0.3500	0.00	180.00	0.00	0.6000
37	Bare land	Bare soil	4	0	0.3000	0.7000	0.0000	0.0000	0.0500	2.00	110.00	15.00	1.0000
33	Woodland	forest	3	0	0.5000	0.5000	0.0000	0.0000	2.0000	4.50	500.00	38.00	15.0000
36	Grass,shru bs,&bush land	grass	2	0	0.2000	0.8000	0.0000	0.0000	0.6000	0.00	110.00	5.00	2.0000
44	Perennial marsh	Open water	5	0	0.2000	0.8000	0.0000	4.0000	0.3000	2.00	110.00	10.00	0.5000
52	water body (Lake)	Open water	5	0	0.0000	0.0000	0.0000	1.0000	0.0500	0.000	110.00	0.00	0.0000

Appendix 5 Soil parameter table of upper Bilate catchment

No	SOIL	FIELD CAP AC	WILTI NGPNT	PAW	RESIDUA LWC	A1	EVAPO DEPTH	TENSIONH HT	P_FRAC_ SUM	P_FRAC_ WIN
4	Silty loam	0.29	0.10	0.19	0.015	0.40	0.05	0.021	0.01	0.07
5	loam	0.25	0.12	0.13	0.027	0.37	0.05	0.11	0.15	0.02
9	Clay loam	0.33	0.19	0.14	0.075	0.27	0.05	0.26	0.62	0.41
10	Sandy clay	0.32	0.23	0.09	0.109	0.25	0.05	0.29	0.80	0.68
11	Silty clay	0.43	0.27	0.16	0.056	0.23	0.05	0.34	0.84	0.75

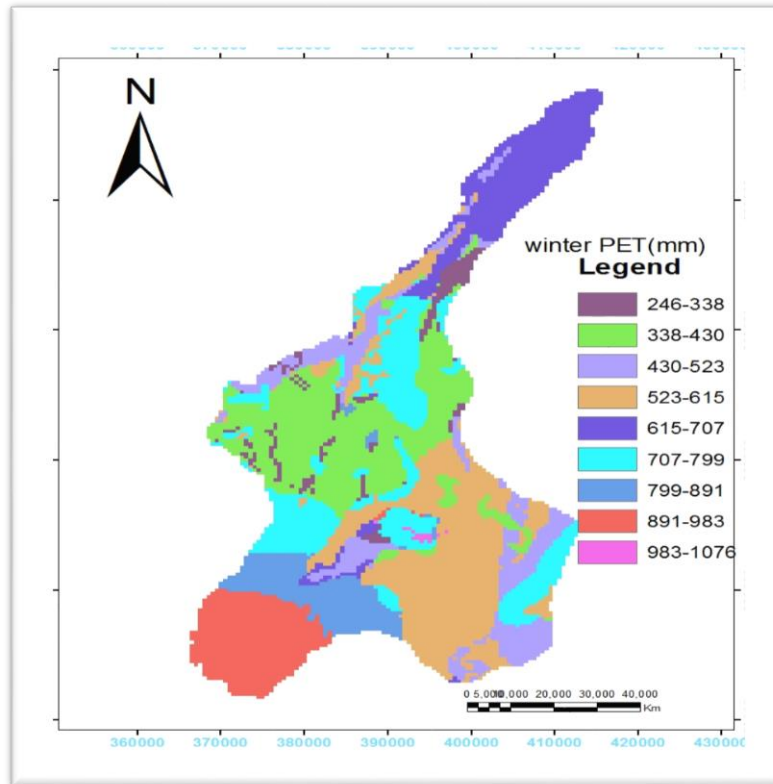
Appendix 6 Depth to water table of upper Bilate catchment

No	Latitude	Longitude	Elevation	Groundwater level(m)	Head
1	417220	810667	1840	242.7	1597.3
2	408031	816211	1960	210	1750
3	415951	828627	1874	151	1723
4	391043	899069	2334	135	2199
5	381019	812998	2088	164	1924
6	363483	813176	2305	38	2267
7	387636	773697	2016	160	1856
8	368736	808334	2470	164	2306
9	378596	810496	2224	65	2159
10	439013	870652	1966	243	1723
11	433726	868414	1860	74	1786
12	398425	810279	1762	46	1717
13	399435	810276	1765	53	1712
14	417016	835224	1840	51	1789
15	498006	892978	3130	10	3120
16	460335	900046	1934	244	1690
17	400908	885068	2984	49	2935
18	365444	923342	1695	35	1660

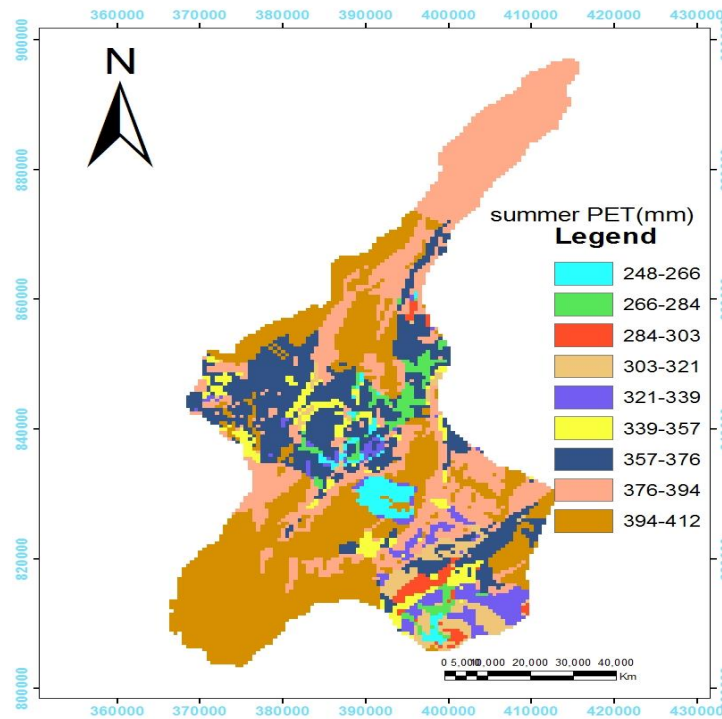
19	371477	822577	2186	111	2075
20	371398	822513	2184	112	2072
21	370232	825456	2153	88	2065
22	373954	811140	2293	57	2236
23	408815	864631	2097	94	2003
24	407942	819799	1935	255	1680
25	407117	822518	1912	177	1735
26	398725	808936	1786	82	1704
27	404755	847131	2004	94	1910
28	399004	850346	2091	42	2049
29	403963	823095	1841	111	1730
30	402651	835554	1969	158	118
31	383279	810877	2169	228	1941
32	381012	831847	2166	89	2077
33	386196	845921	2233	111	2122
34	384391	820769	1930	12	1918
35	390701	824093	1905	7	1898
36	396945	840676	1932	21	1911
37	396971	839360	1925	10	1915
38	397275	834657	1913	14	1909
39	380496	811701	2167	11	2156
40	375034	813821	2190	45	2145
41	375639	819314	2090	49	2041
42	373029	825466	2207	19	2188
43	377705	814550	2160	42	2118
44	372170	837610	2270	39	2231
45	386220	838319	2381	30	2351
46	374864	838210	2290	33	2256
47	387776	848148	2111	52	2059
48	372018	842250	2332	19	2313
49	380237	836029	2152	23	2130
50	396229	845563	1981	7	1974
51	393674	851433	2050	45.8	2004.2
52	380093	803146	2097	8	2089

River and springs

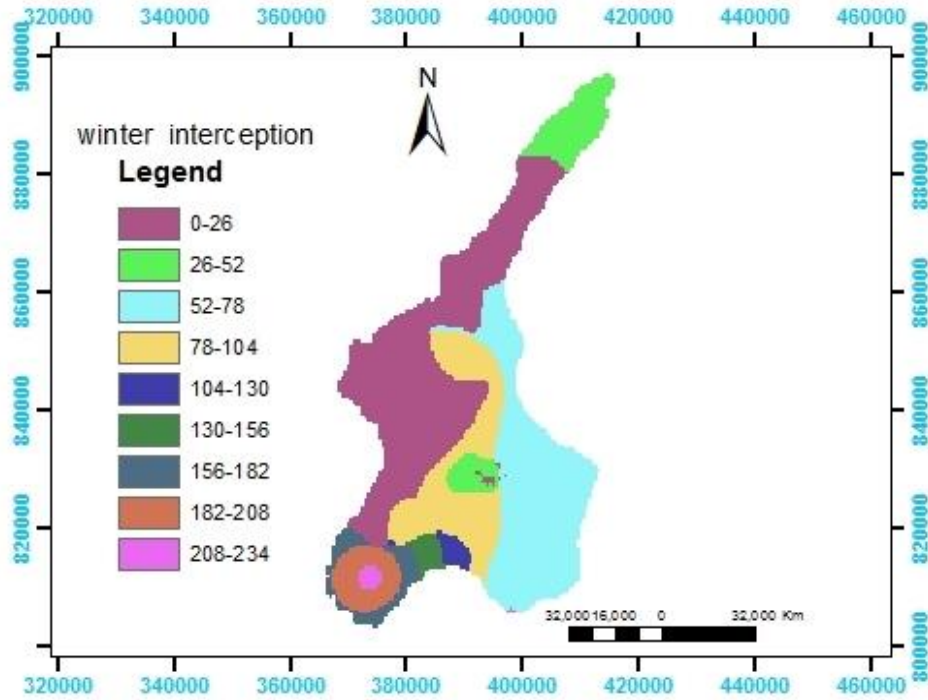
No	Latitude	Longitude	Groundwater level (m)
1	393892.9	828125.5	1891
2	394287.9	826527.6	1893
3	393032.3	827021.7	1892
4	395333.4	828030.2	1893
5	398706.1	828514.4	1900
6	402040.6	825282.8	1858
7	400120.9	815919.6	1781
8	397680.8	807202.5	1735
9	396119.9	837426.5	1903
10	393466.4	843114.1	1983
11	392064	846250	1987
12	391994.3	855955.4	2095
13	397852.2	872987.7	2584
14	397852.2	872987.7	2750
15	409832.4	891942.6	3116
16	373461.9	845220.9	2364
17	378889.4	822325	2229
18	383947.7	822312.7	1907
19	375584	812443.5	2187
20	372745.7	817641.4	2148
21	374229.4	822306.1	2129
22	394081.9	816331.5	1896
23	386229.7	814905.6	2326
24	369235.2	811907	2420



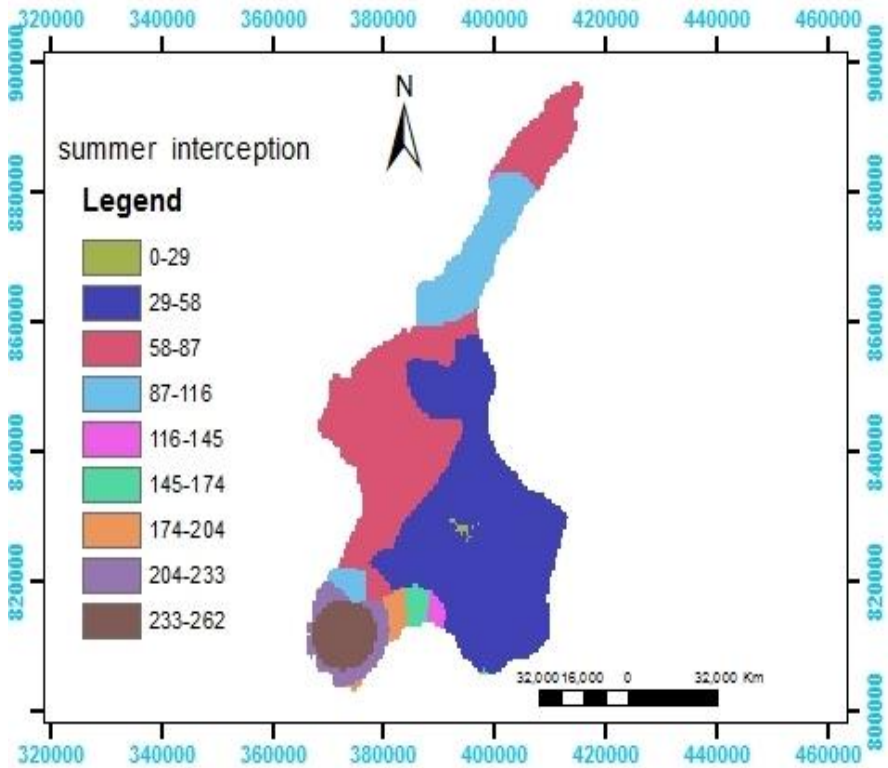
Appendix 7 (October to May) winter actual evapotranspiration map of Upper Bilate catchment



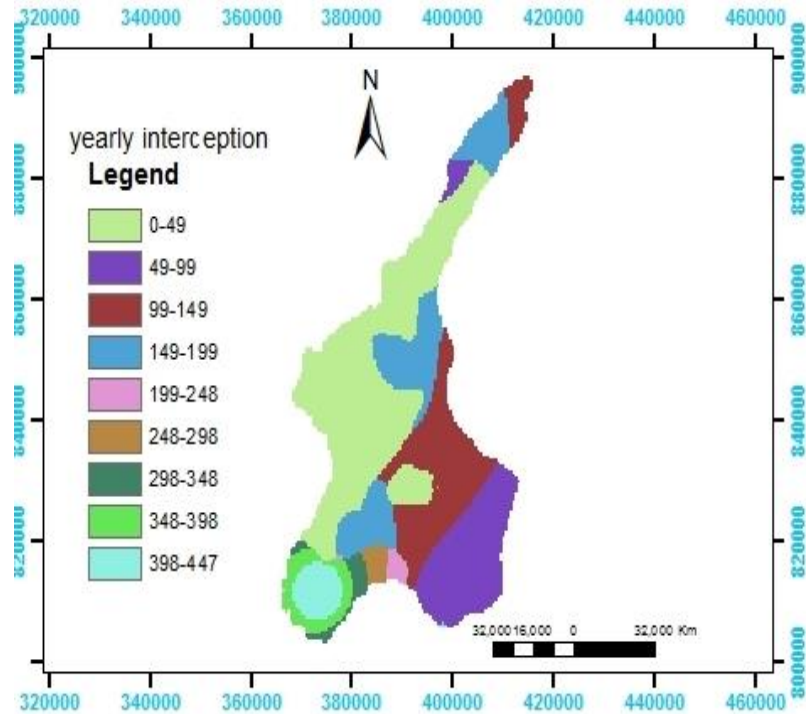
Appendix 8 (June to September) Summer actual evapotranspiration map of Upper Bilate catchment



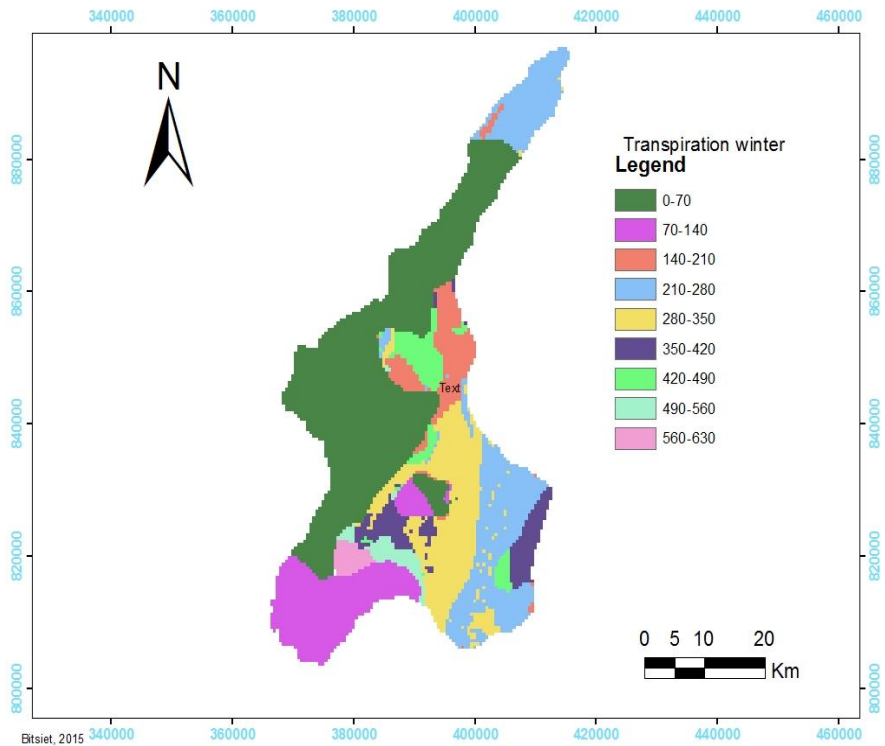
Appendix 9 Winter interception map of upper Bilate catchment



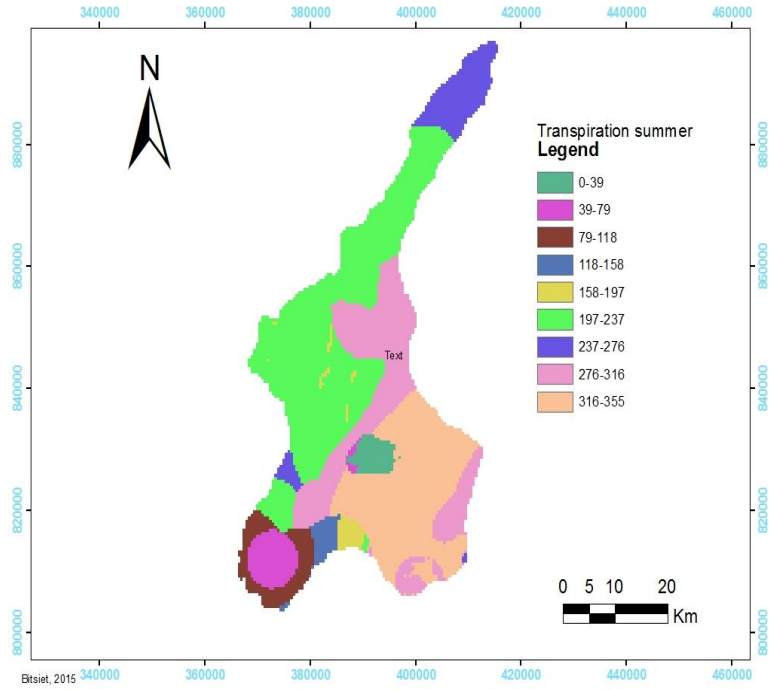
Appendix 10 Summer interception map of upper Bilate catchment



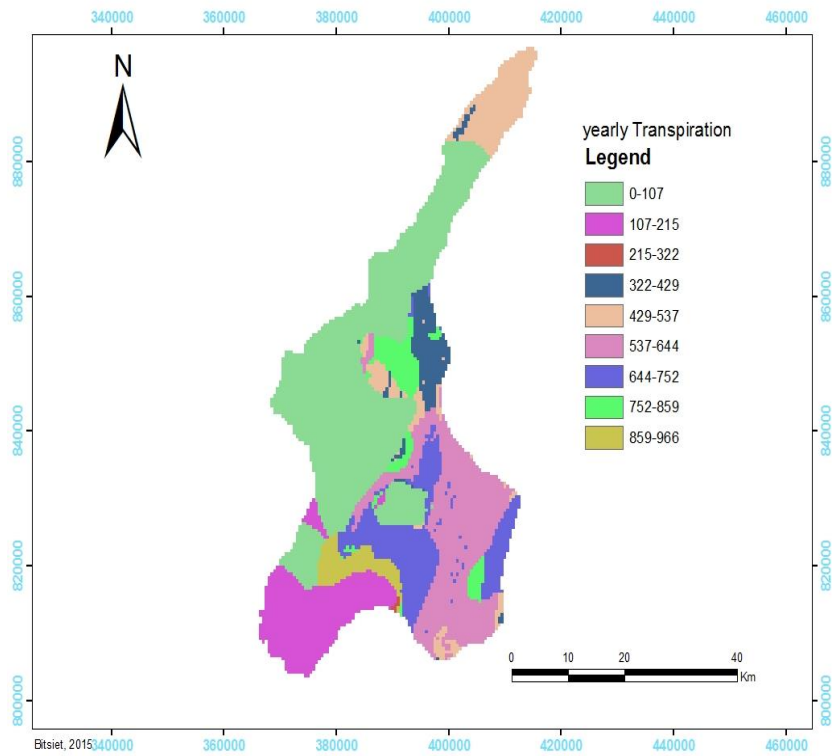
Appendix 11 Yearly interception map of upper Bilate catchment



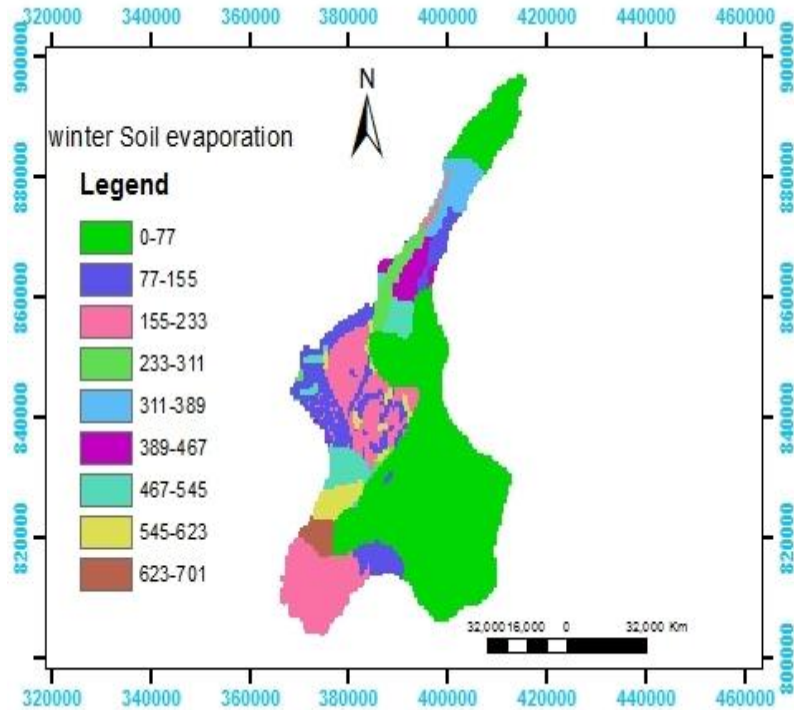
Appendix 12 Winter Transpiration map of upper Bilate catchment



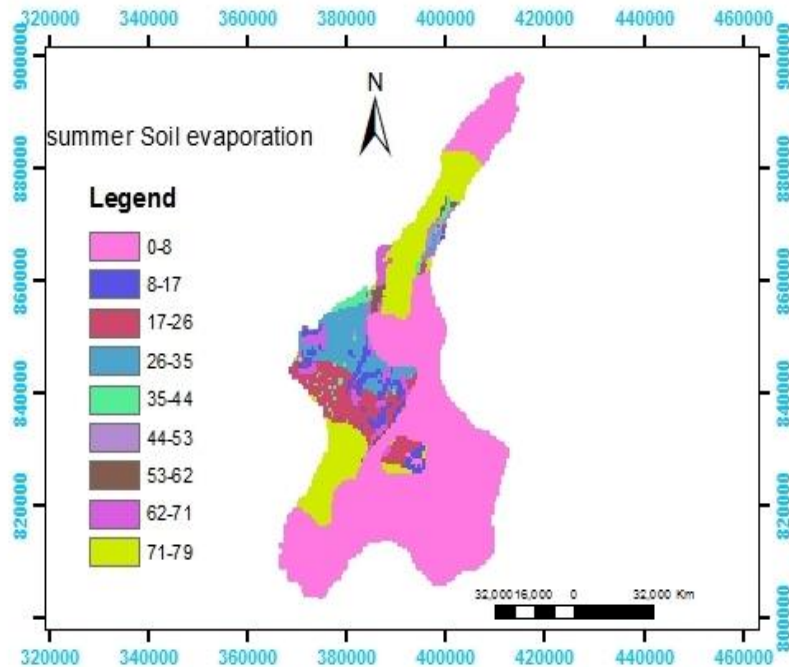
Appendix 13 Summer Transpiration map of upper Bilate catchment



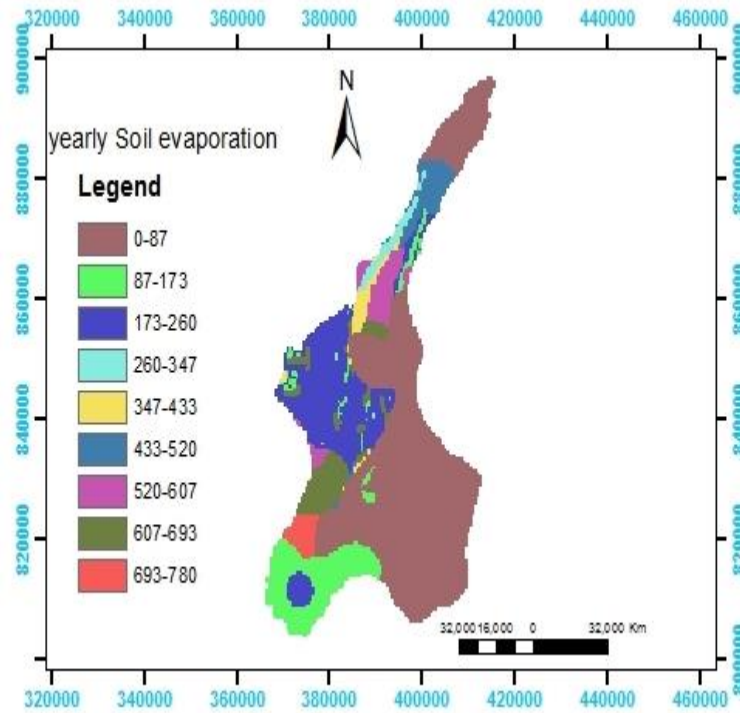
Appendix 14 Yearly Transpiration map of upper Bilate catchment



Appendix 15 Winter soil evaporation map of upper bilate catchment



Appendix 16 Summer soil evaporation map of upper bilate catchment



Appendix 17 Yearly soil evaporation map of upper bilate catchment

Appendix 18 Summary of the basic seasonal wetpass output parameters

Seasonal Wet Spass output parameters	Minimum (mm)	Maximum (mm)	Mean(mm)	Mean (%)	Std. deviation
Summer PP	459	793	630	51	55
Winter PP	499	768	598	49	69
Summer ETP	242	412	382	45	29.85
Winter ETP	246	1076	478	55	124.75
Summer RO	8.45	338.97	120.5	57	88.18
Winter Ro	8.4	401	137	54	96.16
Summer RE	0	372	110	95	117.8
Winter RE	0	123	5.7	5	23.01

Appendix 19 Mean monthly flow of Bilate River

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1971	0.6049	0.468	1.498	1.77	5.887	14.87	25	33.59	42.1	20.98	6.043	1.55	154.36
1972	0.752	3.377	3.09	11.611	8.08	5.114	14.749	35.135	34.141	14.601	2.379	0.606	133.635
1973	0.509	0.262	0.166	0.179	2.26	1.986	7.64	24.97	43.174	26.314	7.36	1.227	116.047
1974	0.329	0.38	0.496	3.233	1.766	4.325	16.251	32.674	47.091	24.508	5.653	0.956	137.662
1975	0.329	0.38	0.496	3.233	1.766	4.325	16.251	32.674	47.091	24.508	5.653	0.956	137.662
1976	0.401	0.277	0.663	1.5	3.707	3.641	13.001	26.055	31.328	13.712	10.92	2.588	107.79
1977	3.056	4.084	1.473	2.786	3.85	7.726	24.033	36.414	41.491	24.105	24.94	5.743	179.705
1978	0.509	1.217	3.615	1.145	2.226	4.096	20.281	41.89	42.715	31.393	7.149	1.789	158.025
1980	1.403	3.134	2.143	4.988	8.805	8.425	14.982	22.559	24.313	14.948	5.384	0.555	111.639
1981	0.325	0.286	0.509	2.872	13.265	4.738	11.608	16.916	22.11	12.642	3.31	0.471	89.052
1982	0.257	0.179	5.298	10.711	4.949	1.536	5.351	14.135	-	17.358	2.364	0.222	62.36
1983	-	-	1.021	2.984	4.8	2.846	5.38	19.45	26.774	25.015	12.65	3.599	104.522
1984	0.468	0.834	3.217	15.622	18.913	20.68	10.25	29.968	43.917	34.208	12.81	3.496	194.383
1985	0.444	0.249	0.277	0.168	3.578	6.357	9.653	20.011	27.553	11.191	0.657	0.366	80.504
1986	0.176	0.115	0.128	3.969	11.275	3.552	3.524	20.916	17.736	8.503	1.003	0.244	71.141
1987	0.266	1.324	1.917	5.715	7.136	12.633	25.124	28.292	25.957	13.127	1.829	0.516	123.836
1988	0.331	0.704	5.887	20.977	23.916	35.061	17.171	13.946	26.54	10.69	0.886	0.517	156.626
1989	0.531	0.583	0.529	2.267	2.432	3.741	9.328	40.732	43.015	35.714	10.92	2.501	152.296
1990	0.5	2.726	1.606	9.911	6.185	4.637	8.656	16.505	34.639	21.523	5.034	3.807	115.729

Groundwater Recharge estimation using wetspass model in upper Bilate river catchment

1991	1.219	3.025	8.067	15.313	7.175	9.339	16.949	20.626	23.539	16.179	3.56	0.773	125.764
1992	0.429	0.602	2.221	1.454	0.962	2.199	8.998	19.252	22.413	7.319	1.778	1.084	68.711
1993	0.85	2.88	0.619	4.918	19.389	28.386	16.286	26.102	29.677	22.281	13.03	3.213	167.626
1994	4.529	3.742	3.958	4.06	6.166	8.843	21.259	41.597	37.962	15.672	4.657	1.588	154.033
1995	2.389	0.653	9.594	10.23	27.219	42.732	31.984	42.698	30.476	11.759	3.159	1.713	214.606
1996	2.059	0.678	0.778	4.914	2.441	4.016	9.336	23.46	16.586	25.807	23.54	4.709	118.32
1997	3.095	2.269	4.112	10.329	9.081	6.054	15.398	48.542	29.022	31.502	7.007	2.509	168.92
1998	1.674	0.736	1.611	0.534	1.321	2.395	8.329	11.336	13.83	36.867	9.012	2.22	89.865
1999	0.502	2.665	1.606	9.911	6.185	4.643	8.656	16.505	34.639	21.523	5.05	3.807	115.692
2000	1.778	1.312	4.847	2.011	6.514	12.592	26.24	40.875	30.967	7.398	2.485	1.597	138.616
2001	1.906	1.037	2.34	1.33	1.29	2.185	3.876	13.778	15.698	4.279	1.367	3.379	52.465
2002	1.853	1.23	0.967	6.744	1.89	2.789	8.597	12.402	20.452	-	-	-	56.924
2003	-	-	-	-	-	1.36	9.012	17.296	17.099	14.748	2.04	1.006	62.561
2004	1.097	0.548	2.086	9.754	19.142	5.297	14.887	26.746	50.413	29.961	14.66	10.091	184.679
2005	7.949	7.866	21.209	39.714	27.996	30.633	52.259	86.107	67.303	32.226	17.62	12.974	403.851
2006	11.502	19.826	14.016	23.606	36.004	44.929	69.346	83.8	83.52	59.352	26.64	21.548	494.09

Declaration

This is to certify that the thesis prepared by **Bitsiet Dereje** entitled: *Groundwater recharge estimation using WetSpass model in upper Bilate river catchment* and submitted in partial fulfillment of the requirements for the Degree of Master of Science in Hydrogeology complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

The Thesis has been submitted for the examination with my approval as University advisor.

Dr. Dessie Nedaw
Addis Ababa University

Jun 2015

