**ADDIS ABABA UNIVERSITY**

**COLLEGE OF DEVELOPMENT STUDIES (CDS)**

**WATER RESOURCE MANAGEMENT PROGRAM**

# GROUNDWATER RECHARGE ESTIMATION USING GIS BASED WETSPASS MODEL. A CASE OF JEWHA WATERSHED, MIDDLE AWASH RIVER BASIN, ETHIOPIA


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A Thesis to Submitted to School of Graduate Studies of

ADDIS ABABA UNIVERSITY

In Partial Fulfilment of The Requirements for the Degree of Master of Science in

Water Resource Management

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## STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this Thesis. Any scholarly matter that is included in the thesis has been given recognition through citation.

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**SCHOOL OF GRADUATE STUDIES**

I hereby certify that I have read and evaluated this thesis entitled **Groundwater Recharge Estimation using GIS based WetSpass Model. A Case of Jewha watershed, Middle Awash River Basin, Ethiopia** prepared under my guidance by **Yigrem Enedeg Ayele**. I recommend that it be submitted as fulfilling the thesis requirement.

Ermias Teferi (PhD) -------------------- -------------------------

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As a member of the Board of Examiners of the MSc Thesis Open Defense Examination, I certify that I have read and evaluated the Thesis prepared by **Yigrem Enedeg Ayele** and examined the candidate. I recommend that the thesis be accepted as fulfilling the Thesis requirement for the degree of Master of Science in Water Resource Management.

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Final approval and acceptance of the thesis is contingent up on the submission of the final copy of the thesis to the Council of Graduate Studies (CGS) through the College of Development Studies Graduate Council.

## Abstract

Understanding the hydrological environment and groundwater availability leads to plan, design, develop and manage the available water resources effectively. There are different physical and empirical models to understand the water balance components of a given watershed. One of the spatially distributed physical models is WetSpass model. The WetSpass-M model has been simulated the seasonal and annual water balance components of Jewha watershed successfully. Based on the model, the annual ground water recharge in Jewha watershed is 0 and 404mm as a minimum and maximum value with a mean of 124mm, which is represent 15% of the total annual rainfall. This mean annual groundwater recharge is equivalent to 67,450,240m$^3$/year. 87% (107.7mm) of the recharge is occurred in summer (Jun to September) and the rest 13% (16.5mm) of recharge percolate in winter (October to May).The model result also shows that the annual value of runoff in Jewha watershed is vary in range from 79.75mm to 831.5mm as a minimum and maximum value respectively, with a mean of 299.5mm. The mean value accounts about 35% of the total annual rainfall of the watershed. The annual evapotranspiration from the watershed is simulated as a minimum and maximum value of 277.9mm and 2857mm with the mean value of 436mm respectively, and the standard deviation is 211.8. About 71% of the total annual evapotranspiration is lost during rainy season and the remaining 29% is released in dry season.

The sensitivity analysis of the different input variables was conducted and most of the variables are highly sensitive in Jewha watershed. The results of the analysis show that rainfall, potential evapotranspiration and slope are the most important hydrologic process in the study area in terms of affecting the amount and rate of the different water balance components. The parametric coefficient of alfa coefficients, interception coefficients and Lp coefficient also relatively sensitive. The calibration was made between the simulated and observed water balance component value of the watershed. The calibration process has been performed through coefficient of determination($R^2$) and the Nash- Shuttle efficiency (NSE). The result shows that, the observed and simulated value is in good fit by $R^2$ of 0.91 and NSE of 0.74.

**Keywords:** Jewha watershed, Recharge, Runoff, WetSpass model, Water balance

## Acknowledgment

First of all, I would like to praise 'God', for his ultimate help since I commenced and finalized this research and as well as the whole my studies in the University.

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# Acronyms

| | |
|---|---|
| ADSWE | Amahara Design and Supervision Enterprises |
| AET | Actual Evapotranspiration |
| ASCII | American Standard Code for Information Exchange |
| DEM | Digital Elevation Model |
| FAO | Food and Agricultural Organization |
| GIS | Geographic Information System |
| GPS | Geographic Positioning System |
| GWD | Global Weather Data |
| LULC | Land use/ Land cover |
| m.s.l | Mean Sea Level |
| MoWR | Ministry of Water Irrigation and Energy |
| NLC | New_LocClim estimator |
| NMA | National Meteorological Agency |
| PET | Potential Evapotranspiration |
| SRTM | Shuttle Radar Topography Mission |
| SWL | Static Water Table |
| TBL | Table of Values |
| USDA | United States Department of Agriculture |
| USGS | United States Geological Survey |
| WLRC | Water and Land Resource Center |
| WetSpass | Water and energy transfer between soil, plant and atmosphere at quesi-steady stat |

# CHAPTER ONE

## 1. Introduction

### 1.1 Background

Groundwater is a long-term reservoir of the natural water cycle, which originates from rainfall or snow. Except fossil water, groundwater is a part of hydrological cycle which is moves through the soil and rocks beneath the earth surface and back to surface streams, lakes or oceans. Groundwater flow follows topography, in detail the situation can be more complicated and the flow is not only occurring near the water table, but does penetrate deep into the aquifer. It is the actual entering of water into an aquifer (Leap, 1999). the recharge cannot be measured directly and is difficult to accurately estimate it.

According to Kebede et al. (2016) recharge in Ethiopia is highly variable. Between 0 to 300mm/yr. The majority of aquifers in the two transects contain modern waters which are recharged from rain, floodwaters, stream channel loss or from groundwater inflow from the mountains (Kebede, et al., 2007)

There is groundwater resource in Jewha watershed and therefore the community uses for various domestic and agricultural activities. but no information on the source, amount and extent of groundwater on the particular watershed for sustainable utilization and proper management of available water resources. Thus, estimation of groundwater recharge in Jewha watershed has its own role in solving the issues associated with the management and planning of water resources for sustainable development using physical hydrological models.

There are different hydrological zones in groundwater recharge process (Scanlon et al.,2002). which is surface water and soil zone, zone of aeration (unsaturated zone) and saturated zone (the area which is completely filled by water). The groundwater recharge estimation methods are also classified into physical techniques and empirical (tracers and numerical modeling).

WetSpass is one of physical hydrological model which is a spatiotemporally distributed computation model for water and energy transfer between soil, plants, and atmosphere under quasi-steady state. It simulates spatial and temporal patterns of actual evapotranspiration lost from a given watershed, surface runoff, and groundwater recharge on a regional scale (Batelaan and De Semdit, 2007). The WetSpass model was applied in different authors, according to those authors, the model was simulating the groundwater recharge estimation and it gives a good and accepted results. Therefore, this research study was aimed to implement the model in coordination of tools of geographic information system/science (GIS) for estimation of groundwater recharge for Jewha watershed.

## 1.2 Problem Statement

Jewha watershed has huge potential of groundwater which needs investigation of its annual or seasonal recharge to quantify the availability of groundwater. the consumption of water for the domestic and agricultural usage in the jewuha watershed dominantly depends on groundwater. The abstraction and consumption of the groundwater in the area is not based on understanding of of the amount of recharge that the area received as well as the effect of land use change on the recharging process.

Several Authors in Ethiopia (Tesfamichael, et al., 2010) in Geba watershed, (Dereje and Nedaw, 2019) in Upper Bilate catchment southern Ethiopia, (Arefaine et al., 2012) in Illala Catchment northern Ethiopia and (Mersa and Taye, 2018) in Briki Watershed eastern zone of Tigray were used WetSpass model for their recharge estimation studies in different part of Ethiopia and suggested that the model gives a reasonable result both annually and seasonally. Most of the Authors have been described the calibration of the WetSpass model result by comparing with the previous studies conducted by different researchers with different methods in their study area. However, the groundwater recharge and runoff as well as the actual evapotranspiration of Jewha watershed has not been estimated by using WetSpass modeling and other methods. In this research, the main water balance components of the watershed were estimated with this model and it has calibrated with ground observed data.

The previous study of the area was high lightly addressed it have generally low to high groundwater potential zone concentrated with alluvial deposit (ADSWE, 2016). But there are no sufficient and satisfactory researches that quantify and present groundwater recharge, actual evapotranspiration and runoff specifically in Jewha watershed.

Generally, this research work will fill the above mentioned gaps and solve the problem related to future proper utilization of groundwater system of Jewha watershed by estimating the actual recharge value based on the biophysical and meteorological characteristics of the watershed.

## 1.3 Research Questions

What is the amount of the local recharge?

Is the groundwater abstraction rate of the area being proportional to the actual recharge?

Can we identify appropriate factor for effective estimation of the groundwater recharge of the area?

## 1.4 Objectives

### 1.4.1 General objective

The main objective of this study was to estimate groundwater recharge of Jewha watershed using GIS based WetSpass model.

### 1.4.2. Specific objective:

The specific objectives of this thesis were: -

To identify recharge and discharge Zones of the study area.

To investigate the spatial and temporal pattern of groundwater recharge in Jewha watershed.

To quantify actual evapotranspiration and surface runoff of the watershed.

To determine the Sustainable Yield of Jewha watershed

## 1.5. Scope of the study

The study was aimed to understand the source, process and availability of the main water balance components of a given watershed (Jewha watershed). Which includes the recharge, runoff, interception and the actual evapotranspiration lost from the watershed. The study was tried to address the hydrometeorological and biophysical characteristics of the watershed, which is very important for hydrological processes. this is related to analyze the spatiotemporal parameters that governs those components. The sustainable yield of the watershed also determined after estimated groundwater recharge and other hydrological components.

## 1.6. Significance of the study

The population of Jewha watershed is used waters for drinking, irrigation and other livestock consumptions from rivers. The decrease rainfall trend of dry zone and increase of population size and demands of water for irrigation and other livelihood requirement's calls sustainable exploitation of the groundwater resources in the basin.

Understanding the groundwater recharge and parameters of both biophysical and hydrometeorological meteorological elements is important for development, management and proper utilization of water resources for sustainable development. This study will provide a baseline information about groundwater resource controlling factors as well as the possible abstraction rate of the watershed for water resource experts and policymakers.

The research is significant to: -

Making best use of available water and enhance water sources.

Prevent water shortage problems by managing water resources efficiently.

Moreover, this study will be inputs for further investigation of water resources, design, and developmental activities and for planning purpose in the area and across the country.

## 1.7. Limitations

The study was limited spatially in the north eastern part of the country located in the upper western margin of rift valley, Awash River basin. It was difficult to collect the necessary field data which is very important parameters for hydrological modelling. This is due to the high escarpment of the study area. in Jewha watershed more than half of the area is cliff and mountainous. No access road is available for data collection through the escarpment. The available boreholes in the watershed is also limited. In addition to this, the absence of monitored wells were big challenges to conduct model validation test. The meteorological data collection was also a big problem to get a full, reliable, representing and consistent data.

## 1.8. Structure of the thesis

The thesis is subdivided in to five chapters and the contents are summarized briefly as follows.

**Chapter one**: discussed about introduction of the research that includes background of the study, problem statement, research questions, research objectives and significance of the study.

**Chapter two**: presented the literature reviews related to the principle of groundwater modeling and recharge estimation methods are discussed

**Chapter three**: description of the study area which includes; physiography, drainage, climate, hydrometeorological description, geology and hydrogeological characteristics of the study area. the methodology, materials and software's used, WetSpass modelling application and input data for model processing have been discussed in this section.

**Chapter four**: briefly describes the results and findings includes; sensitivity analysis of input data, the WetSpass model calibration, output of the modelling (seasonal and actual evapotranspiration of the study area, runoff and groundwater recharge), sustainable yield of the area and identification of groundwater recharge and discharge areas have been discussed.

**Chapter five**: is discussed about conclusion and recommendation depending on the result and findings analysis. In this chapter, matters which cannot be addressed are also recommended to be implemented in the feature.

# CHAPTER TWO

## 2. Literature Review

### 2.1 Water Resource and Hydrologic cycle

Water is transported from land, open water bodies and plants as a water vapor to the atmosphere through evaporation and transpiration and back to the Earth ‘s surface as precipitation, falling as either rain or snow. Nowadays, the global hydrological cycle has been responding to the observed effects of global warming, which include increasing atmospheric water vapor content and changing precipitation patterns (Chen & Grasby, 2014).

Understanding of the hydrologic cycle is central to analyze and identify the occurrence of water and the development and management of water supplies. Although the hydrologic cycle has neither a beginning nor an end (Fitter, 1994), it is convenient to discuss its principal features by starting with evaporation from vegetation, exposed surfaces including the land surface, and from the ocean (Rechard, 1998). This moisture forms clouds which, under favorable conditions, return the water to the land surface or oceans in the form of precipitation. The first rain wets vegetation and other surface materials and then infiltrate into the ground. Infiltration rates vary widely depending on land use, topographic slope, Soil type, and precipitation intensity. When and if the rate of precipitation exceeds the rate of infiltration, overland flow occurs. (Ralph C., 1980)

### 2.2 Groundwater resources

Groundwater occurs in two different zones. first zone, which occurs immediately below the land surface. it contains both water and air and is referred to as the unsaturated zone. Second zone, which occurs below unsaturated zone is contains full of water and referred to as the saturated zone. it is the only underground water that is available to supply wells and springs. Recharge of the saturated zone occurs by percolation of water from the land surface through the unsaturated zone. Ground water occurs in aquifers under two different ways. Where water partly fills an aquifer, the upper surface of the saturated zone is free to rise and decline. The water in such aquifers is said to be unconfined and the aquifers are referred to as unconfined aquifers. Where water completely fills an aquifer that is overlain by a confining bed, the water in the aquifer is said to be confined. Such aquifers are referred to as confined aquifers. (Ralph C. , 1980).

## 2.3 Rainfall-Runoff-Recharge Relationship

Understanding rainfall-runoff relationship is critical in order to quantify ground water recharge. Because the source of most natural ground water recharge is precipitation (Neven, 2009). the principal factors to the rainfall-runoff relationship is the land cover, the soil type and the antecedent moisture condition. Soils that are well drained generally have high effective porosities and high hydraulic conductivities, whereas soils that are poorly drained have higher total porosities and lower hydraulic conductivities (Neven, 2009). Wet and poorly drained soils will readily produce runoff, while dry, well-drained soils will readily contribute to groundwater recharge. Land use landcover also affect the rainfall runoff relationship. after subtracting what is lost to overland flow (runoff) and evapotranspiration (ET) from rainfall the amount of ground water recharge will be known.

## 2.4 Groundwater Recharge

Groundwater recharge as water that percolates to aquifer from any direction, i.e., down from surface through zone of aeration , up from confined aquifers, or laterally (Lerner D. , 1997).Recharge is the actual entering of water into an aquifer. Usually, the recharge source is precipitation and to a lesser degree, irrigation or artificially constructed recharge pit or losing streams. recharge from precipitation is the most important category of recharge (Lerner D. , 1990). focus will be given to it in the study area The actual recharge rate is controlled by several factors: precipitation intensity, soil moisture content, elevation of the area, the horizontal hydraulic conductivity of the aquifer and its hydraulic gradient and the vertical hydraulic conductivity of the soil (Jacques, 1999)

Water enters to ground-water systems in recharge areas and moves through them, as dictated by hydraulic gradients transmissivity and hydraulic conductivities, to discharge areas. The identification of recharge areas is becoming increasingly important because of the expanding use of the land surface for waste disposal. Recharge rates vary from year to year, depending on land cover types of the area, the intensity of precipitation and its seasonal distribution, air temperature, and other factors. Among the other factors are land use. For example, recharge rates are much higher in highly vegetated area than in impermeable cities and asphalt roads (Ralph C. , 1980).

In humid areas with porous and permeable soils, 1/4$^{th}$ of annual rainfall may recharge the aquifer. In contrast, in desert regions recharge is very small — 1% of rainfall or less (Johon, 2002). Aquifers in these areas may contain very old water, which has accumulated over centuries under different climatic conditions.

## 2.5 Middle Awash groundwater recharge zone

Heavy rainfall, mountain blocks, small streams, floods from highlands and rivers are the main source of groundwater recharges in the middle awash river basin (Kebede, 2012).

The middle Awash groundwater recharge zone is five categories (Lammesa, 2017). which are very high, high, moderate, low and very low of groundwater potential zone. High to very high groundwater potentials are covers 9890 km2 and 10575 km2, respectively to the main rift floor lowland of the river basin. The main source of groundwater in the area is the rainfall of the northwestern and southeastern highlands the river basin due to mountain block and slope and Jewha watershed has been found in this zone.

## 2.6 Remote Sensing and GIS for groundwater recharge estimation

GIS and remote sensing are the latest, time and cost-effective technology for groundwater exploration by acquiring full information and access all parameters of factors which controls groundwater potentials and recharge zone areas by using different software's easily. (Lammesa, 2017).

GIS can be utilized to evaluate and delineate patterns of recharge within a region by incorporating available information about observed temporal fluctuations of recharge at specified locations. Continuous remote acquisition of water table depths combined with GIS capabilities for distributing the flux spatially across the study area can result in near-real-time monitoring of spatial variability in recharge flux. Recharge can also be estimated using information including current climate, soil, and vegetation/land use patterns and estimates of recharge for various soil-vegetation combinations. (Jacques, 1999).

## 2.7. Estimation of recharge, runoff and actual evapotranspiration

### 2.7.1. Estimation of groundwater recharge

Groundwater recharge is difficult to estimate directly, because recharge is a result of various parameters and highly variable depending on different factors of the area (Neven, 2009). Therefore, it should be applying another indirect method. Recharge can be expressed as a percentage of the annual rainfall or as an average rate of water in millimeters per year. The volume of recharge, expressed as cubic meters per year, can be obtained by multiplying the recharge rate by the land area under consideration (Adane, 2014).

There are different methods to estimate ground water recharge depending on actual physical processes of the recharge. According to Scanlon et al. (2006) the three hydrological zones of study are surface water, unsaturated zone and saturated zones. Physical, numerical modelling, and tracer techniques are among the methods. Physical methods, e.g., channel-water budget, seepage meters and base flow discharge; tracer methods, e.g., stable isotopes of oxygen and hydrogen; numerical modelling methods, e.g., Groundwater flow numerical models are included in methods based on groundwater studies. (Healy, 2010). To select an appropriate method, the possible flow mechanisms and the important features influencing the recharge in an area should be identified. This is because the recharge processes vary from one place to another, this is true for methods working for one area may be invalid for other.

### 2.7.2 Estimation of actual evapotranspiration and runoff

Evapotranspiration (ET)is a sum of evaporation from open water bodies and bare soil, interception loss by vegetation and transpiration through plants (Dereje & Nedaw, 2019). atmospheric humidity, net radiation, wind speed and temperature of the area are the governing factors (Craig et al., 2010). It is important for hydrological basin in order to control groundwater recharge, overland flow and soil moisture. It is expressed by potential evapotranspiration (PET) which is the possible water to evaporate from the watershed through plant and directly from open water bodies as well as bare soil from land surface, and actual evapotranspiration (AET) which is the actual water that is evaporate to the atmosphere.

The runoff coefficient which is a function of soil texture, slope and vegetation type is inputs for competing actual surface runoff (Mustafa & Ali, 2013). It is an idea of how much water from precipitation will flow on land surface through rivers and streams.

## 2.8 Hydrological models

Hydrological models are simplified systems to compute the processes of the hydrological cycle (Precipitation, Infiltration, Interception, Evaporation, Runoff, etc.) in an entire river basin based on a set of interrelated equations that try to convert the physical laws, which governs the complex natural phenomena (Barbara , 2008).

Based on the description of physical process, the hydrological models can be classified into three groups. conceptual models, physically based distributed models and empirical models (Beven, 2001). physically based distributed models (sometimes called white-box models) presumably are the consequences of the most important laws governing the phenomena. The model has a logical structure similar to the real-world system and may be helpful under changed circumstances. It is designed by the principles of physical processes based on continuity and the conservation of mass, energy and momentum. This model uses a number of model parameters that represents the different heterogeneities in the catchment. e.g. infiltration model, evaporation model, SHE models. In the recent time, advances have been made in hydrological process understanding and modeling using topography driven, conceptual, flexible, semi-distributed model structures (Gharari et al., 2013).

Regional groundwater models used for identifying and analyzing groundwater system (infiltration-percolation-discharge relations) are often quasi-steady state and therefore it needs a long-term average input data. Thus, WetSpass, which yields spatially varying groundwater recharge using spatially varying soil, land-use, and meteorological inputs, can be used for the purpose of understanding the characteristics of groundwater recharge (Batelaan and Woldeamlak, 2003). Empirical models (Black box) which mathematical correlations are obtained based on the observed data analysis rather than based on the physical processes in the catchment e.g. Unit hydrograph-based model, Linear regression model. Conceptual models (sometimes called grey-box models) are intermediate between theoretical and empirical models which is consider physical laws in highly simplified form (Dandy & Maier, 2005)

## 2.9 The WetSpass Model

WetSpass was built as a physically distributed based methodology for estimation of the long-term average, spatiotemporally varying, water balance components: groundwater recharge, surface runoff, and actual evapotranspiration. It is an acronym for water and energy transfer between soil, plants and atmosphere under quasi-steady state that was built upon the foundations of the time dependent spatially distributed water balance model (Batelaan & DeSmedt, 2001) . The WetSpass model estimates seasonal and annual long-term spatial distribution amounts of groundwater recharge by subtracting the seasonal and annual surface runoff and evapotranspiration from the seasonal and annual precipitation respectively (Arefaine et al., 2012).

The model computes different water balance components, surface runoff, actual evapotranspiration and groundwater recharge based on distributed data. WetSpass was successfully applied in Belgium (Batelaan and De Smedt, 2001), Geba watershed, Ethiopia (Tesfamichael, et al., 2010) and in Werii watershed in Ethiopia. Based on those authors groundwater recharge was successfully simulated which is the main interest of this research. In Ethiopia, several authors were used WetSpass model for their groundwater recharge estimation studies.

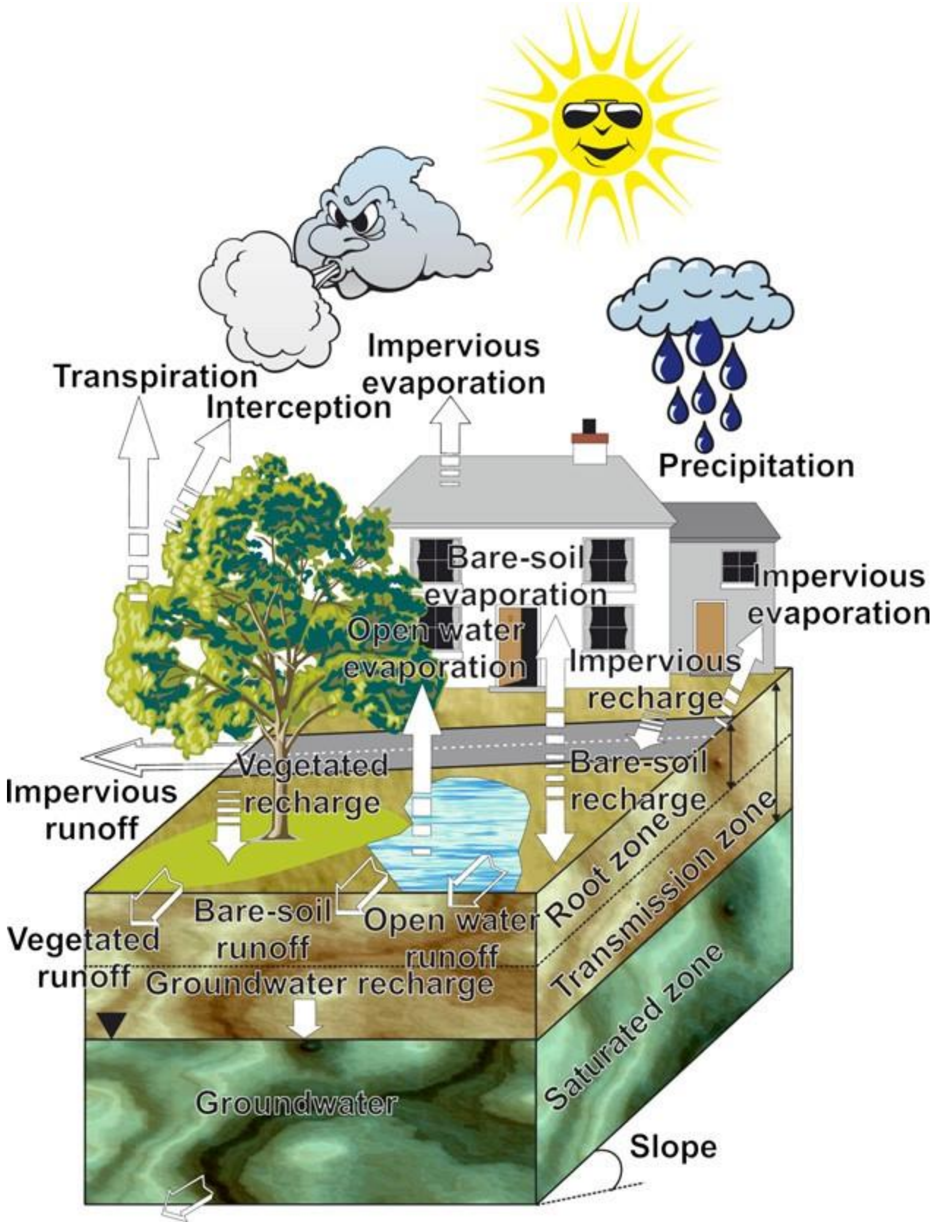



Figure 2.1 schematic water balance of hypothetical raster cell *(Batelaan & DeSmedt, 2001)*

# CHAPTER THREE

## 3. Material and Methods

### 3.1 Description of the study area

Jewha watershed is located in the Middle River Awash Basin of northeastern part of Ethiopia in Amhara Regional state, North Showa zone (fig 2). It is positioned with the geographic coordinates between 39°44'49" to 39°59'23"E and 9°59'22" to 10°21'32"N. with elevation ranges from 1109 to 3554m above sea level with the area of 519.76km$^2$. The average distance from the capital city Addis Ababa is 240km to north east and accessed through Addis Ababa-Debrebrhan to Jewha town.

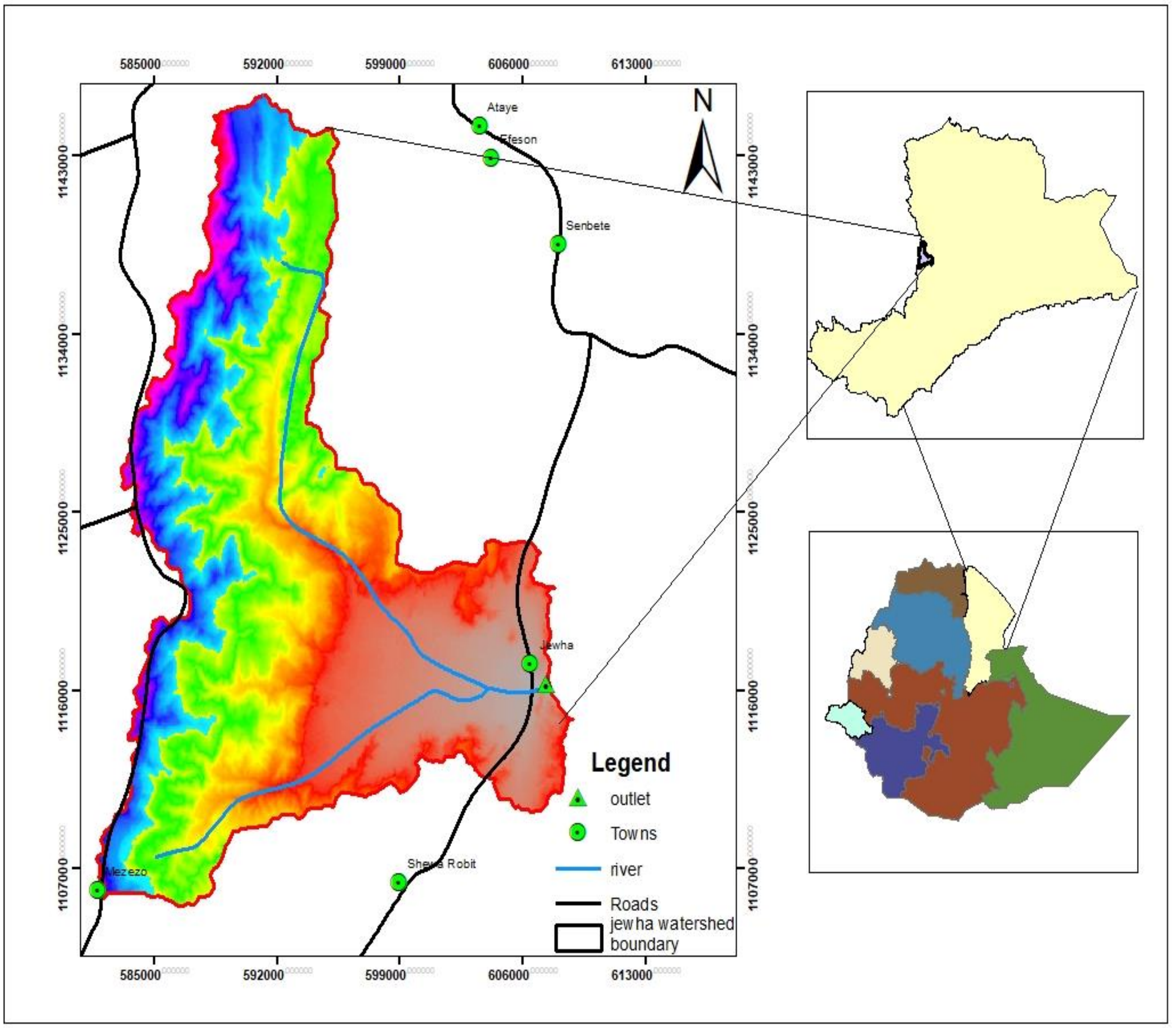



Figure 3.1: Location Map of the study area

### 3.1.1 Physiography

Jewha watershed is characterized by diverse topographic conditions. The upperpart of the watershed is characterized by mountainous and highly separated terrain with steep slopes and the downstream part is gentle slopes that is suitable for agricultural activity with elevation ranges from 1101 to 3540m (Figure 3.2). The general topography of the catchments is undulating hills, flat and valley. It gradually decreases in elevation to east. Volcanic and tectonic activities as well as erosional processes shaped the landscape (geomorphology) of the area.

### 3.1.2 Drainage

Numerous narrow and shallow river valleys originated from mountain areas and merge subsequently and form Jewha (Negesso) Perennial river. Jewha river is one of the major tributaries of Awash river. Drainage generally form high drainage density in the plateau and escarpment areas and low in the plain. In rainy season, most of these rivers and streams are dumping most of its coarse sediments in the plain before reaching their outlet. However, in heavy rainy season leads its way to the Awash river through Jewha river outlet (Figure. 2.3). The Jewha River is drained to Awash River Basin starting from the plateau (the western margin of rift valley). The study area is characterized as semi-arid plain lowland that receive high runoff from the plateau.

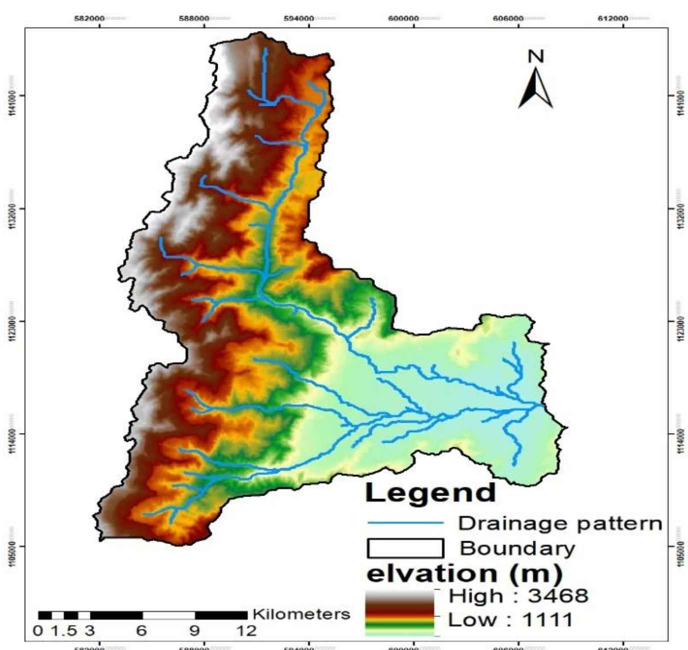



Figure 2.2: Drainage Map of Jewha watershed

### 3.1.3 Climate

The Ethiopian Agroclimatic zone is classified based on altitudinal range. Which is Kola, Woyna-dega, Dega and Wurch. The Kola zone is hot region which is less than 1500 m altitudes. And Woina-Dega zone that has an optimum temperature which ranges from 1500 to 2300 m altitude. Dega and Wurch zones are found in highland regions with 2300 to 3200 and greater than 3200m altitudes respectively (NMA, 2001). Thus, Climate of the study area ranges from hot temperate (Kola) around low land of Jewha town area to cool temperate (Wurch) in the mountains and escarpment. Rainfall distribution over the area is Bimodal, characterized by a short rainy season (Belg) and the long rainy season (Meher) that occurs in February-April and (kiremt) July-October, respectively with a short dry influence. (Figure 3.3).

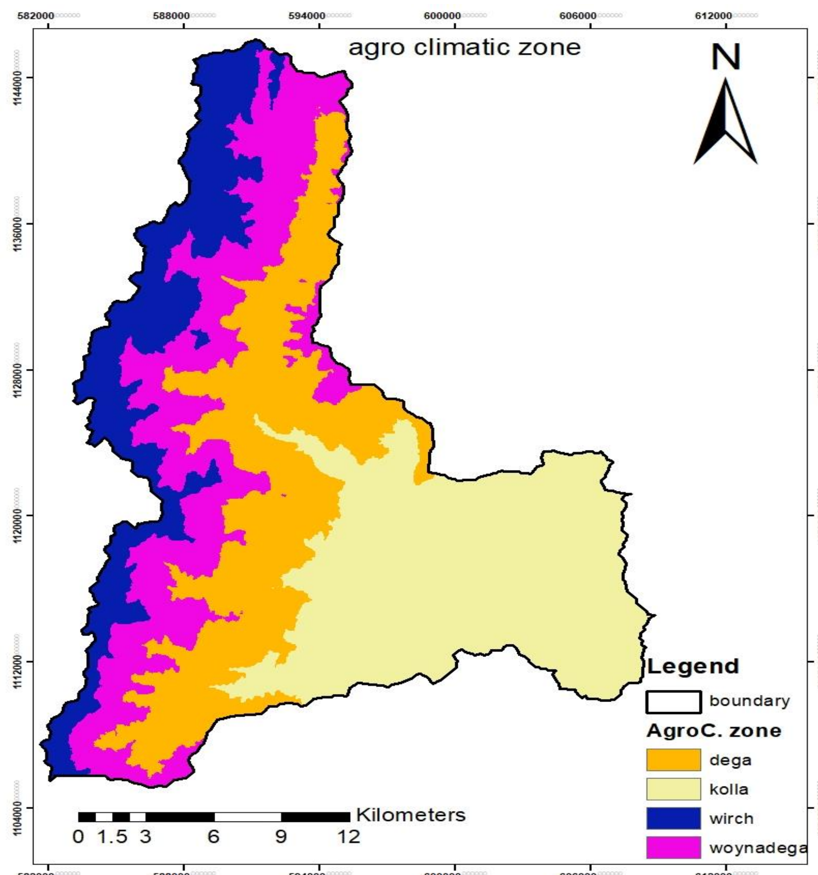



Figure 3.3: Agroclimatic zone of Jewha watershed

### 3.1.4 Hydro-meteorological description of the study area

Understanding of a hydrologic balance of a given watershed is highly depends on identifying and analyzing of the available water balance components. These components are a result of the necessary hydro-meteorological elements rainfall, potential evapotranspiration, temperature and windspeed.

**Rainfall**

Rainfall is one of the significant elements of a hydrological water balance model. The spatial and temporal distribution of rainfall characteristics is very important factors on recharge and runoff generation of the watershed. The Jewha watershed have received highly divers and variable rainfall patterns throughout the year. Temporal variability and rainfall distribution analysis of the watershed were done using point data obtained from in and around the study area meteorological stations. Jun, July, August and September are rainy(wet) season in Jewha watershed and the rest months are considered as dry (summer) season in WetSpass model processing. In dry season, the rainfall value of the study area ranges between 218 and 259mm where as in wet season the value ranges between 539and 629 mm and annually ranges between 760 and 854 mm. About 71% of the total rainfall in Jewha watershed is occurred during wet season (Jun to September) and 29% of the rainfall occurred in dry season (October to May). Figure 3.4 shows that the seasonal and annual average value of Jewha watershed.

The spatial rainfall distribution analysis over the Jewha watershed were done after interpolating the available point data using Kriging spatial analysis techniques. Topographically high elevated areas (escarpment) have received high level of rainfall and lowland areas are received relatively low rainfall amounts.

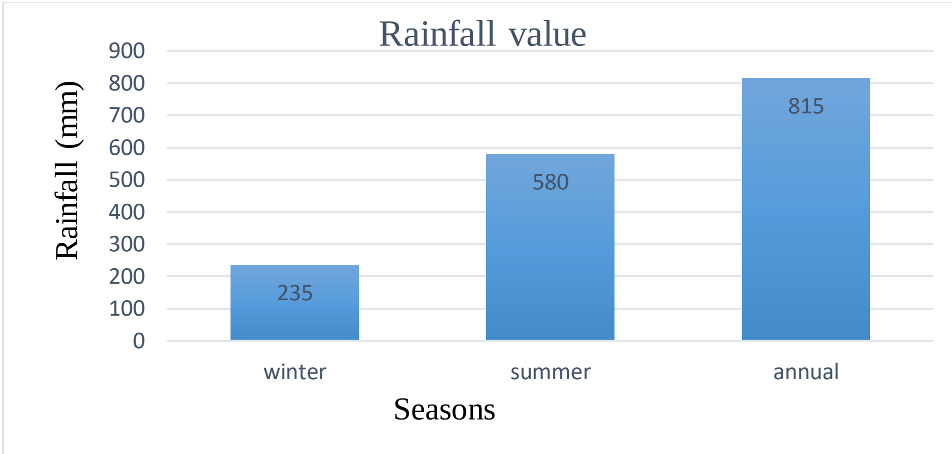



Figure 3.4: Seasonal and annual rainfall value of Jewha watershed

**Temperature**

Another critical parameter of the water balance is temperature. Temperature is very important in understanding and modeling hydrologic system of a given watershed. It is responsible for the amount of evapotranspiration. When high temperature occurred, the evapotranspiration is high too through evaporation from open water bodies and transpiration through plants depending on the available water. In Jewha watershed, temperature is highly influence on evapotranspiration and recharge. Unlike evapotranspiration, Recharge is low when temperature is high. The average value (Jewha) 20.6$^o$c has been recorded in summer season and 12.57$^o$c has been recorded in winter (dry season). Whereas the total average value of temperature in Jewha watershed is 19.32$^o$c

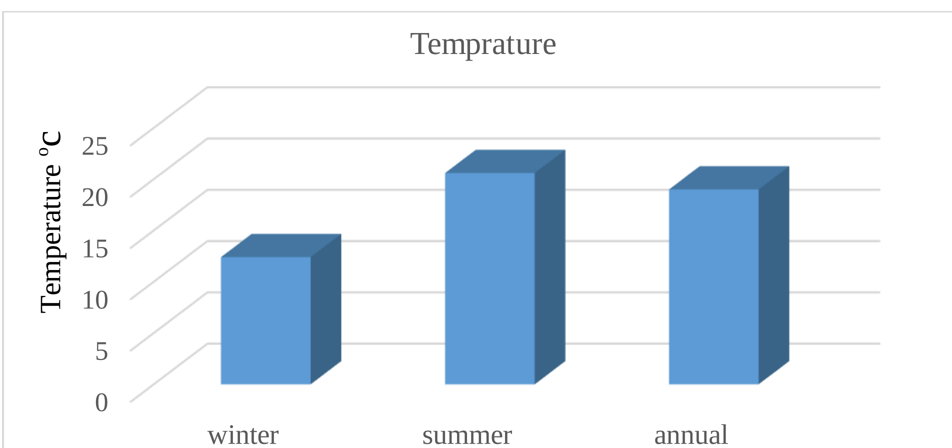



Figure 3.5: Temperature value of Jewha watershed

**Potential evapotranspiration**

Potential evapotranspiration can be quantified and understand after knowing the amount of rainfall and temperature of the study area. The average potential evapotranspiration of summer is 462.62mm, where the winter is 946.98 mm, and the average annual potential evapotranspiration is 1409.66 mm with 1382.1 mm and 1430.9mm as the minimum and maximum annual PET respectively.

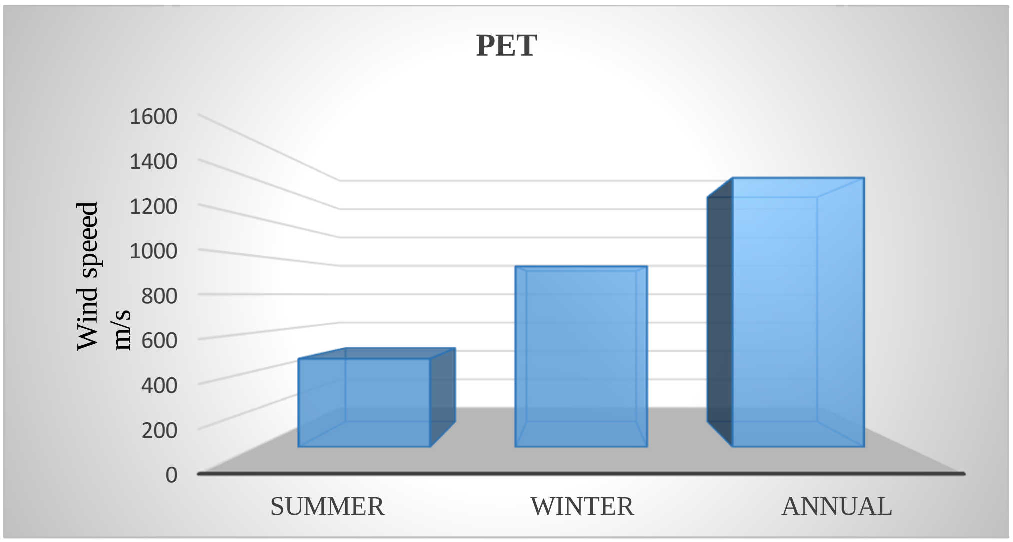



Figure 3.6: Average PET value of Jewha watershed

**Wind speed**

In addition to temperature, wind speed governs the amount of evapotranspiration and other hydrologic cycle processes.

In dry season, the minimum and maximum wind speed is recorded 2.75 and 3.86m/s respectively. Where as in wet season the minimum and maximum wind speed is recorded 1.22 and 3.04m/s respectively and the average value is 2.8 and 2.1m/s in winter (dry) and summer (wet) season.

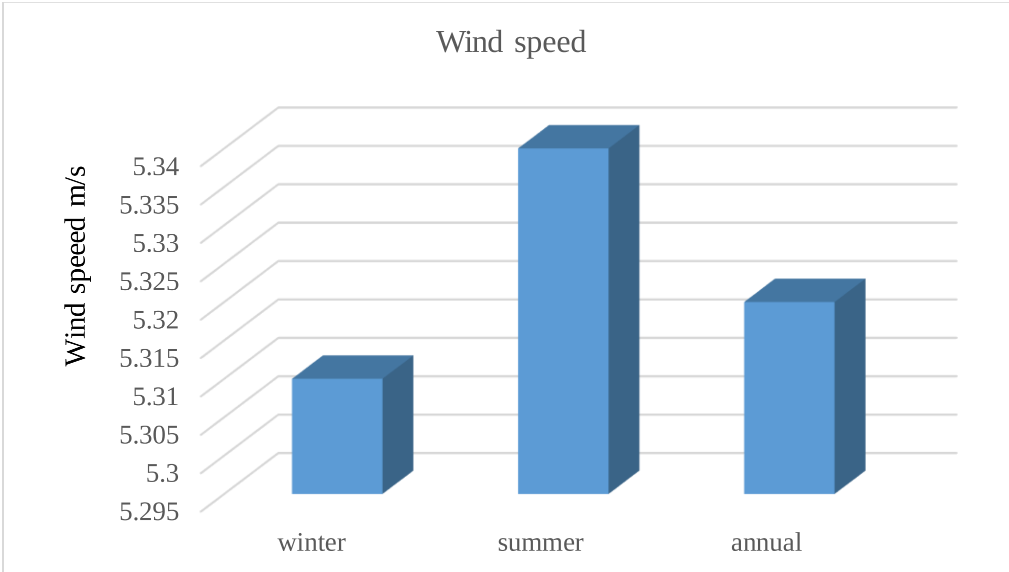



Figure 3.7: Seasonal and annual average wind speed value of Jewha watershed

**Land use/ land cover**

The land use is one of the major controlling factors for a given watershed hydrological processes mainly recharge, evapotranspiration, interception and runoff (Pan, et al., 2011). The land use land cover map of Ethiopia was produced by WLRC. the Jewha watershed the land use was modified from this map. The reliability of this data was checked during study area/ filed observation and it is almost the same with ground truth.

Different land cover types have found in the study area. in terms of areal coverage; the important land cover units are trees, shrubs, grassland, crop land, vegetation aquatic or regularly flooded, bare areas and built up areas. The agricultural /cropland which consists 55% of the land cover is distributed throughout the study area and it is the principal land-use of the watershed. whereas Natural forest covers 15%, shrubs 14%, bare land 6%, and plantation 5%. Grassland and other minor land use types covers 3% of the total (Figure 3.27).

### 3.1.5 Regional Geology

The lithologic and tectonic characteristics of the bedrock play dominant roles in aquifer recharge (Neven, 2009). Ethiopia lies at the northern tip of the continental part of the great East African Rift System. The stratigraphic classification of Volcanic rocks of Ethiopia took the beginning of Rifting as a threshold and classified the volcanism as: (i) The Trap Series and (ii) The Aden Series (Mohr, 1962).

The term Trap Series also known as pre-rift volcanism represents the age of Oligocene to Miocene volcanic rocks and covers the whole pile of the Tertiary fissural flood basalt sequence with intercalations of felsic lava (commonly on the upper part) and pyroclastic of the northwestern and southeastern plateaus of the country. The Aden Series also known as post-rift volcanism which includes Mid Miocene to Quaternary Volcanic rocks of the Main Ethiopian Rift Valley, Afar Depression, Omo Valley and Some parts of Plateau basalt (e.g. Tana Rift Volcanics) (Mohr, 1962). The pre-rift Cenozoic volcanic rocks of Ethiopia consist of the following major stratigraphic units: (i) Ashangie Group (ii) Aiba Basalts (iii) Alagie Formation and (iv) Tarmaber Gussa and Tarmaber-Megezez Formations (Menegesha, et.al 1996).

**Ashangie group**

It is a group name for pre-Oligocene pre-rift volcanic rocks based on mode of occurrence and stratigraphy (Mengesha et al., 1996) The Ashangie Basalts represent the earliest fissural flood basalt volcanism on the northwestern Ethiopia. The basalts are several hundreds of meters to a kilometer thick (the thickest being at Debrebrhan) and has a number of flows ranging from 5 to 6 (Zanetin et al., 1980). Generally, the flows are horizontally bedded; however, exposures along the escarpment and within the marginal grabens are inclined with amount of dip measured between 200 and 60° towards northwest and southeast (Geological Servey of Etiopia, 2009). In Jewha river section within the marginal graben, the Ashangi basalt is compositionally plagioclase phyric and it is cut by 10 m thick aphanitic basaltic dike.

**Aiba Basalt**

The Aiba Basalts represent the second major pulse of fissural basalt volcanism on the northern Ethiopia. It represents a late Oligocene to early Miocene volcanism absolute dating from 34 to 28 Ma. These rocks are unconformably overlies the Ashangie formation. They are characterized by Basalt, fresh, at places showing stratification with interflow acidic layers/mainly tuff. The basalts show a distinctive tholeiitic nature with transitions to mildly alkaline varieties ( Zanetti, 1992).

**Alagie Formation**

The Alagie Formation is the third pre-rift major pulse in Ethiopia represents Oligocene to Miocene volcanic rocks ( Zanetti, 1992). It is conformably overlay Ashange and Aiba, in some places (e.g. Kessem gorge, Mugher Canyon and in most outcrops on the southeastern plateau) it directly overlies Mesozoic sediments. At the quarry close to Ataye town, the Alajae basalt overlies the Ashangi basalt along an angular unconformity (Geological Servey of Etiopia, 2009). Rounded basalt and glass shard fragments are usually found incorporated within it. Rarely, it shows columnar jointing and fracturing; and thin inter-layering of ignimbrite (Jiri, 2019).

**Tarmaber-Gugsa and Tarmaber – Megezez formation**

Tarmaber Formation represents Oligocene to Miocene basaltic shield volcanism on the northwestern and southeastern plateaus of the country. The central type Tarmaber Formation basaltic volcanism was followed by fissural eruptions particularly along the escarpments of northwestern and southeastern plateau. There are thin layers of ignimbrite interbedded within the flows (Geological Servey of Etiopia, 2009).

**Structural geology**

Different structures namely fault and fractures are prominent in the study area one major fault trending North West to south east and North east to south west is evident. Different set of fractures is common on the basaltic unit. The dominant fracture is the vertical fracture while horizontal and inclined fractures are also observed on the basalt unit which is situated beneath the deposited) (Geological Servey of Etiopia, 2009).

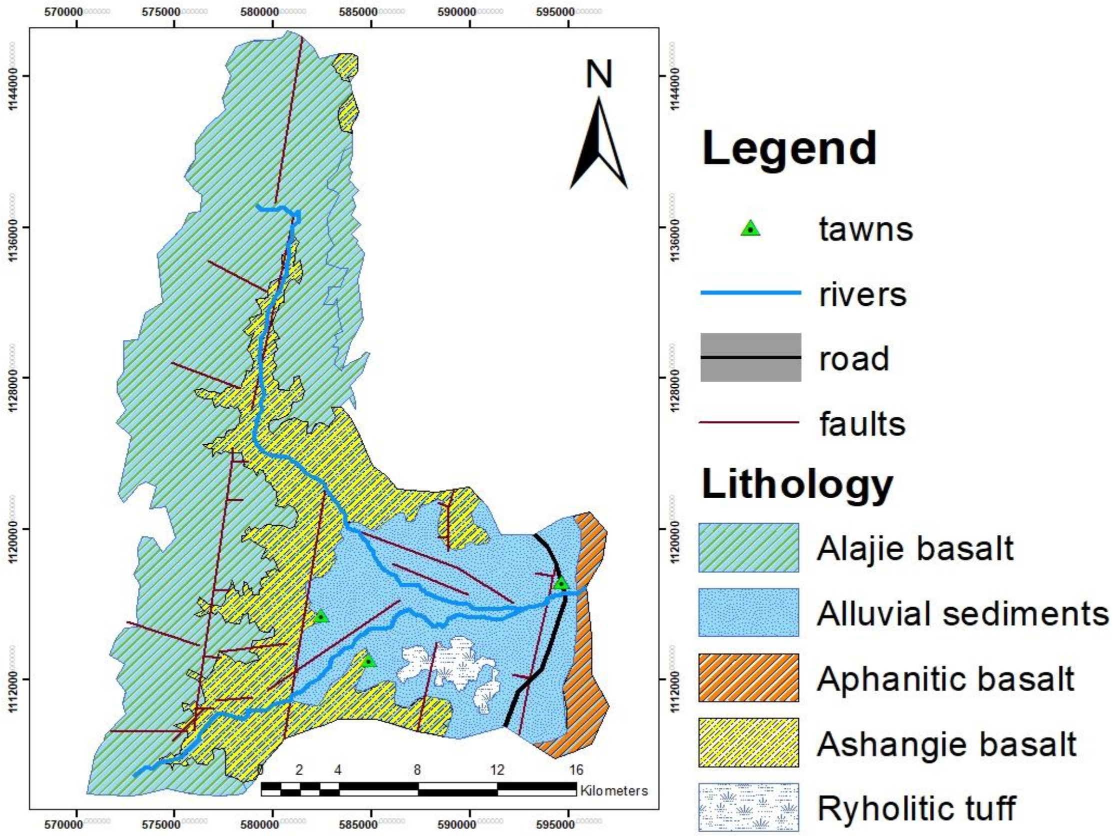



Figure 3.8: Geological map of the study area modified from Geological Survey of Ethiopia

### 3.1.6 Local Geology of the area

This area of interest is mainly covered with different geological formations and those geological formations are aphanitic basalt, trachyte and rhyolite covering mainly the mountainous part of the study area and low laying part of this area is covered with alluvial deposit.

**Aphanitic basalt**

The study area is rarely covered by aphanitic alkaline basalt in southwestern part which is part of Ashangie formation and late shield fissural flood basalt Tarmaber-Megezez group. It is characterized by fine grained and highly affected by weathering. As a result, the Jewha is covered in some area by highly weathered and fractured basaltic rocks.

**Rhyolite and trachyte**

The main geological formation that covers the study area is Alagie formation mainly of rhyolite and trachyte and this formation is highly fractured and moderately weathered. The most important exposures that were used to study the geology of the study area using the field traverses are road cuts quarry areas and the natural exposures at different parts of the mountains surrounding the area. In most part of the study area rhyolite is found underlying the basaltic unit. Around the study area in addition to those exposures there is also a rail road which is under construction currently at which the geology of the area is exposed well. As observed from the different exposures those main geological formations of the area (rhyolite and trachyte) are highly fractured and slightly weathered.

**Alluvial deposit**

On the other hand, the sediment at the low laying area around in study area is found to be composed of thick deposit reaching over 150m (ADSWE, 2016) and is characterized by different degree of gradation from clay to boulders. Even though those that are drilled at this catchment most of them are down stream of this area (well site) there are many wells that are drilled at this (Jewha-Negesso) catchment and most of them shows that there is a thick alluvial deposit with different gradation. Apart from this well there were also a chance to observe the thickness and sorting of this geologic material from a river channel.

### 3.1.7 Hydrogeological set up

The amount of groundwater recharge depends in the intensity of precipitation, temperature, land use land cover (vegetation) slope, wind speed, rock and soil types (permeability) (Jiri, 2017). the precipitation in Jewha watershed is controlled mainly by the direction of the moisture bearing wind, elevation, temperature and topography. This means that areas with high elevation can receive high rainfall and low elevation areas receive low precipitation, and areas with high temperatures receive low precipitation and low temperature areas receive a higher amount of precipitation. Topography is also a parameter that controls the amount of precipitation; hence plateau areas receive a high amount of precipitation and the other side of the lowland areas receive a low amount of precipitation.

Jewha watershed is bounded between Sembete (north) and Shewarobit *(*south) sub-basins. Jewha stream begins from escarpment of the western adjacent of Ata*ye* sub basin and flows southward to the western adjacent of Sembete sub basin. After Jewha stream reaches to the wide plain area, it joins with other small intermittent and perennial streams of Sewur, Ashmic and Jewha and flows eastward to afar region.

These streams convey huge volume of sediments from the tectonically affected western escarpment, and form the alluvial fan at the starts of the plain area and then leave coarse size first, medium and fine size sediments gradually. The nature and distribution of hydrogeologic units (aquifers and aquitards) in a geologic system are controlled by the lithology and structure of the geologic deposits and formations. The alluvial deposit in the watershed is thick and is comprised of coarser and finer sediments, the rhyolitic units located at the upland areas have hydrogeologic significance in facilitating infiltration through their fractured, jointed and weathered part that in turn recharge the low-lying sediments. The thick alluvial deposit at Jewha-Negeso catchment are mainly composed of coarser sediments. The catchment has an advantage of getting recharge from seasonal floods coming from the surrounding mountainous area through the intermittent streams mainly Jewha river.

Due to the favorable geomorphology and the presence of thick coarser sediments at Jewha-Negeso watershed together with the presence of good annual rainfall the watershed is considered to be favorable for the occurrence and accumulation of potential groundwater. According to ADSWE, (2016) the main aquifer of the test well is sand and fine to coarse gravel.

Table 1: Boreholes with hydrogeological characteristics in Jewha watershed from ADSWE

| Well id | x | Y | Depth | SWL | Q | T | T class |
|---|---|---|---|---|---|---|---|
| JWTW1 | 602800 | 1117220 | 195 | 0 | 68 | 229 | Moderate |
| JWTW2 | 604659 | 1117744 | 220 | 5.6 | 40 | 60 | Moderate |
| Mutifecha1 | 604286 | 1117981 | 200 | 5.9 | 32 | 95 | Moderate |
| Mutifecha2 | 605981 | 1119894 | 151 | 20 | 3.5 | 44.8 | Low |
| Bete | 606586 | 1123564 | 84 | 48 | 3.5 | | |
| Jewuha1 | 606303 | 1116779 | 119.3 | 1 | 6.2 | 98.83 | Moderate |
| Jewuha2 | 606269 | 1116617 | 162 | 5.2 | 22 | 35.3 | Low |
| Balchi/Tikure | 601593 | 1114778 | 196 | 5.5 | 30 | 410 | Moderate |
| Balchi | 603637 | 1114883 | 203.3 | 11.1 | 28 | 475 | Moderate |
| Gimb | 596488 | 1122774 | 150.5 | 13.3 | 24 | 50.5 | Moderate |

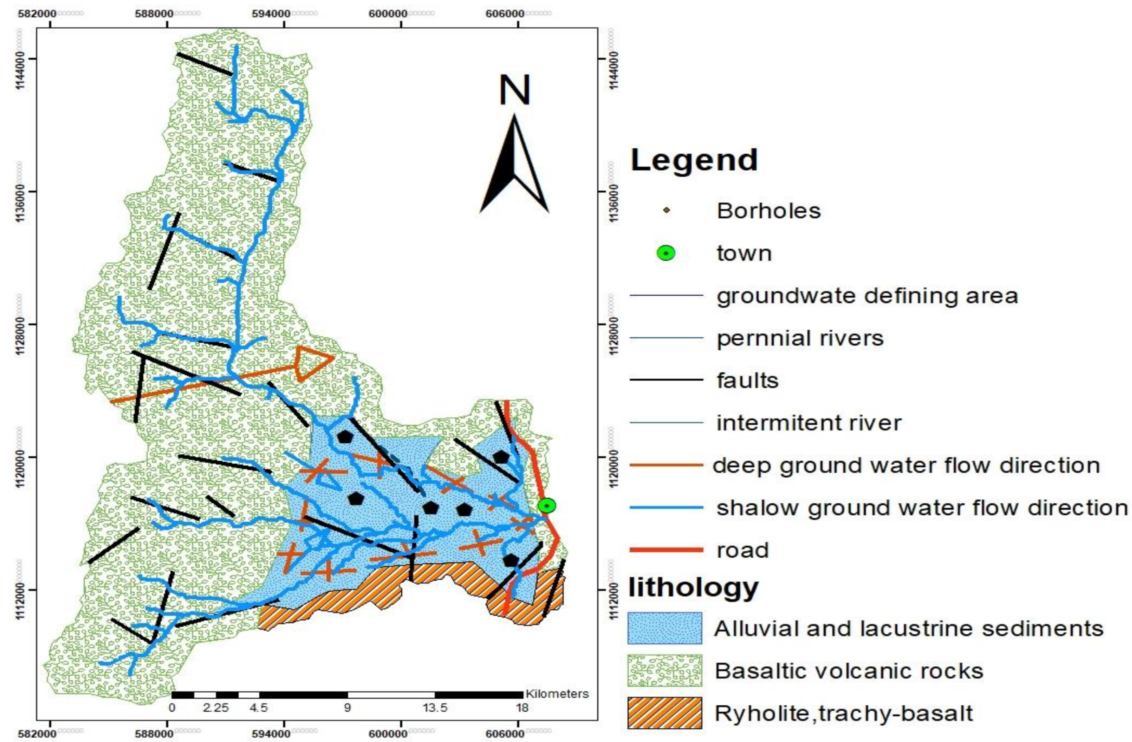



Figure3.9: Hydrogeological map of the study area modified from Geological Survey of Ethiopia)

The groundwater flow direction in Jewha watershed is controlled by both topography/geomorphology (most of the springs emerging from tertiary volcanic rocks) and structure made by tectonics (Jiri, 2017). in relation to this, the highlands of Jewha watershed can generally be considered as recharge areas and the lowlands as a discharge area in the form of spring, baseflow to rivers and boreholes.

Table 2: Basic statistics of the Jewha watershed

| Attribute | Unit | Max | Min | Mean |
|---|---|---|---|---|
| Elevation | Meter | 3468 | 1111 | 1941 |
| Slope | Degree | 68 | 0 | 17.6 |
| Rainfall | Mm | 854 | 760 | 815 |
| Temperature | $^{o}$C | 19.8 | 18.6 | 19.3 |
| PET | Mm | 1430 | 1382 | 1409 |

## 3.2 Methodology

The WetSpass model was used as a methodology to simulates the average temporal and spatial differences of surface runoff, actual evapotranspiration lost from the watershed, and groundwater recharge in seasonal and annual basis for Jewha watershed. Hydro-meteorological, biophysical and other necessary data related to the watershed were prepared.

There were three major steps to conduct this research. In the first step, the available literatures were reviewed to acquire the possible information about the study area. Then, the spatial data was collected from field survey and prepared for the recharge modeling. This collected data were consist of topographical data, meteorological data, soil data and satellite images to generate all necessary inputs for WetSpass model.

The ArcGIS 10.5 software was a promising tool to prepare, manipulate and analyze the digital data. Those data were adjusted and prepared to raster grid cell. The land-use and land-cover map of Jewha watershed was obtained from Water and Land Resource Center WLRC. Input data of the meteorological grid maps were prepared in two seasons, four months of summer and eight months of winter. Also, modified land-use, soil and number of days parameter tables was prepared.

Generally, to run the WetSpass model two types of inputs were required: Grid map (ASCII file format) and parameter tables (TBL file format). Inputs of land use, soil and number of rainy days parameter tables also required for the model. ArcGIS (version 10.5) with its Kriging spatial analyst extensions was used for data interpolation in order to prepare these input parameters, and parameter tables has been added to the maps as an attribute. Land use land cover, topography, slope, soil, potential evapotranspiration and groundwater level (groundwater depth) grid maps were prepared. Hence, the topographic/elevation grid map and the slope map have been derived from SRTM DEM 20*20m resolution using ArcGIS10.5. Next, all the raster data were converted to ASCII format which is used in the WetSpass model to calculate the annual and seasonal recharge maps, total runoff and actual evapotranspiration maps in the study area. the detailed way of computation to obtain the value of the different waters balance components of the watershed is discussed below (Section 3.6).

The sensitivity analysis for all input parameters were performed to identify which input parameters are sensitive to water balance components of the watershed. This is done through ArcGIS 10.5 and WetSpass model. The annual average raster map for each parameter were prepared, by increasing the value of a single parameter with different percentage, the model was processed to determine the sensitivity of a single input variable by keeping constant the value of other parameters. In the same way the process was frequently done for other parameters

Finally, the model results were calibrated to ensure weather the result is in an acceptable or not and correlate with water balance components and physical features, which are significant for groundwater recharge in the area. The WetSpass model was also simulated the surface runoff and base flow values to streams in a volumetric ratio, this is equivalent to stream flow data.

$$\textit{Stream flow (Q)} = base\ flow\ (Qb) \quad + surface\ runoff\,(Q_{surf})$$

A 10 years monthly stream flow data was obtained from ministry of water resources (MoWR) and converted to a long term monthly average data. The coefficient of determination ($R^2$) and the Nash– Sutcliffe efficiency ($EC_{NS}$) (Nash and Sutcliffe 1979) are used as a measure for model performance(calibration).

$$R^2 = 1 - \frac{SSr}{TSs} \qquad \textit{Eq. 3.1}$$

where $SSr$ is sum of squares of residuals between observed and simulated water balance component and $TSs$ is total sum of squares.

$$EC_{NS} = 1 - \frac{\sum_{i=1}^{n}(B^{i}o - B^{i}s)^2}{\sum_{i=1}^{n}(B^{i}o - B\bar{O})^2} \qquad \textit{Eq. 3.2}$$

where $B\bar{O}$ is the average of the observed water balance component, $B^{i}s$ is the simulated water balance component at month i and $B^{i}o$ is the observed water balance component at month i the calibration of model result was done through the simulated flow water balance component with the stream flow data that obtained from MoWR. After model processing and effective calibration process the result has been interpreted and discussed in the next chapters.

## 3.3 Data Collection

To conduct this research the following data were necessary; climatological data which includes monthly precipitation, potential evapotranspiration, minimum and maximum temperatures, sunshine hours, groundwater depth and wind speed data. Physical data of the area that include land use land cover of the area, soil textural type and slope of the study area were collected and use as an input for the model to compute groundwater recharge of the study area.

### 3.3.1 Meteorological Data

Long term measurements of meteorological data are very important to estimate groundwater recharge as well as for water balance computation of certain watershed. Due to the non-availability of all the necessary and accurate data of the conventional metrological station in the area, the New_LocClim estimator data and or the Global weather grid data was used instead. Four station which can represent the study area were selected and analyzed for all metrological parameters. In terms of this the rain fall, maximum and minimum temperature, sunshine hours and wind speed data were downloaded from Global weather grid data and New_LocClim estimator. In this research, all possible data from different sources were used and try to compared the reliability with the available recorded value that are obtained from the National Meteorological Agency (NMA). Finally, the New_LocClim estimator data has been used for model processing because this data has very close to the available data recorded by NMA. The compression has illustrated in (Figure 10).

All the data obtained from New_LocClim were prepared with the appropriate format that is suitable for WetSpass model. The point data were interpolated using ArcGIS 10.5-Kriging spatial interpolation technique. After preparation of the hydro-meteorological data incorporated with the other necessary physical data, the basic characteristics of the watershed (recharge, actual evapotranspiration, and runoff) were quantified.

**New_LocClim Estimator**

New_LocClim is a tool for spatial interpolation and interconnection of agroclimatic data. Since quite a different tool for spatial interpolation of any data already exist. New_LocClim is especially made for the interpolation of agroclimatic data, offering the possibility of producing climate maps from user provided station data. However, where such station data is unavailable or cannot be accessed, New_LocClim is also capable of producing climate maps of the average monthly input climate conditions (8 variables) taken from the Agro-climatic database of the Agro-meteorology Group of the Food and Agriculture Organization (FAO) of the United Nations.

To understand about the properties of different interpolation methods with respect to different spatial fields, the nine methods provided by New_LocClim can be compared with respect to pre-given spatial fields. New_LocClim allows for an extensive investigation of interpolation errors and the influence of different settings on the output results. This allows to optimize the interpolation with respect to the data analyzed. Furthermore, statistical analysis of the interpolated spatial fields is provided and detailed analysis for single geographic points can be drawn (New-LocClim Version 1.1, 2006).

**Precipitation**

Precipitation is the most important part of the hydrologic cycle that falls on the earth surface in the form of water droplets and its amount is one of the most fundamental factors to determine the density and amount of recharge of a certain watershed. The spatial and temporal variation of rainfall in Ethiopia is controlled by the movement of position of inter tropical convergence zone (ITCZ) (Ayenew & Alemayehu). when the inter tropical convergence, zone is positioned in north, the south west winds bring high rain from the Atlantic Ocean which is the wet season (Jun to September) and vice versa. Precipitation records of the study area is downloaded from 1984 to 2013 for all stations from global weather grid data, from New_LocClim estimator and From NMA ground observed data. The data obtained from NMA is not recorded consistently and not at all the necessary parameters (wind speed and temperature has recorded only in one station). By comparing the precipitation value of those data sources (Figure 3.10), the New-LocClim data has been used because it is more or less similar to the observed data.

In Ethiopia, the hydrological year is divided into two main seasons, a dry (winter) season from October to May and rainy (summer) season that runs for the rest of the year (Jun to September). Mean monthly values of precipitation were used to derive mean annual precipitation and those two seasons. Meteorological stations are representing the area of the specific locations that are around the measured point. Instead of this, the Spatial interpolation technique can be used to estimate meteorological parameters for other neighboring locations. One of the interpolation methods available in ArcGIS is Kriging spatial interpolation technique. Maps of for all necessary meteorological parameter were prepared by this method. According to the resulting map shown in (Figure 15). The heaviest precipitation over the area occurs during the period Jun to September (wet season).

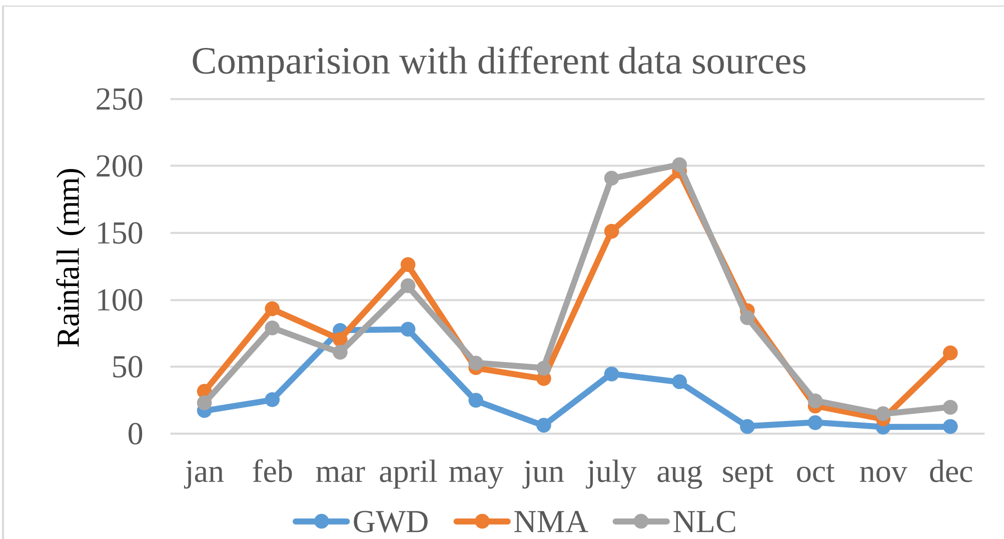



Figure3.10: Precipitation value comparison of different data sources for Jewha station

**Temperature**

Temperature is a critical parameter that control the evapotranspiration and other water balance components of a given watershed. In the same manner, the monthly minimum, maximum and average temperature was also obtained from New-LocClim for each weather station (Figure 3.17).

**Potential Evapotranspiration**

Evapotranspiration rates are governed by several factors, the most important of which are the temperature and humidity of the air and the availability of water on the surface and in the shallow subsurface (Charles, 2002) Evapotranspiration of the area can be analyzed in two ways as potential evapotranspiration and actual evapotranspiration. Potential evapotranspiration describes the water losses that will occur under a given climatic condition with no deficiency of water for vegetation. Since the actual evapotranspiration account the field condition, it depends on the availability of water. There are different methods to quantify potential evapotranspiration of a given watershed. The Hargreaves method (Hargreaves et al., 1985), the Priestley-Taylor method (Priestley and Taylor, 1972), and Penman-Monteith method (Monteith, 1965). For this research the PET data were obtained from New_LocClim estimator to produce a well distributed contour grid map of potential evapotranspiration. the Hargreaves method were selected for the reliability checking of the estimator. The Hargreaves method is available on DrinC software package and the PET is calculated using this software, the output value was almost the same.

The model to estimate ET after Hargreaves is a strongly empirical model. Both, radiation and temperature are used as input data. Advantageous is, that no radiation has to be measured, since the model works with calculated extraterrestrial radiation

$$PET=0.0135*Rs*conv*(T+17.8) \qquad \text{Eq. 3.3}$$

| | | |
|---|---|---|
| *PET* | *Evapotranspiration after Hargreaves* | *[mm day$^{-1}$]* |
| *T* | *Mean temperature of the day* | *[°C]* |
| *Rs* | *Solar radiation* | *[MJ m-2 day$^{-1}$]* |
| *Conv* | *Conversion to ET equivalent conv=4082 .0* | *[m2 mm MJ-1]* |

**Wind speed**

To simulate the necessary outputs, The WetSpass model needs the average speed of wind recorded in the watershed. For this research the wind speed data was obtained from New_LocClim estimator and prepared in two seasons; for dry (October to May) and wet season (Jun to September). This point data was prepared and the map has been produced using Kriging spatial analyst technique. The seasonal maps were converted to ASCII file format for model processing.

### 3.3.2 Physical Data

Biophysical data which are soil texture, groundwater level data is essential to understand the groundwater recharge aspects. It was collected from direct observation from field survey. The soil map was obtained from ministry of agriculture that performed in 2016. The groundwater level data were collected directly from accessible existing boreholes and from Amhara water works design and supervision enterprise Dessie branch and the groundwater elevation were calculated by subtracting static water level (SWL) from topographic elevation. After driving the groundwater elevation of the study area, the map was prepared by ArcGIS 10.5 environment using kriging spatial interpolation technique.

### 3.3.3 Remote Sensing data

As the methodology, the study was highly depending on remotely sensed data, which are land use land cover (LULC), topographic elevation and slope. LULC data was obtained from WLRC (Water and Land Resource Center) and the slope and topographic elevation data were obtained from ASTER DEM 20*20m process using ArcGIS 10.5.

## 3.4. Conceptual Framework

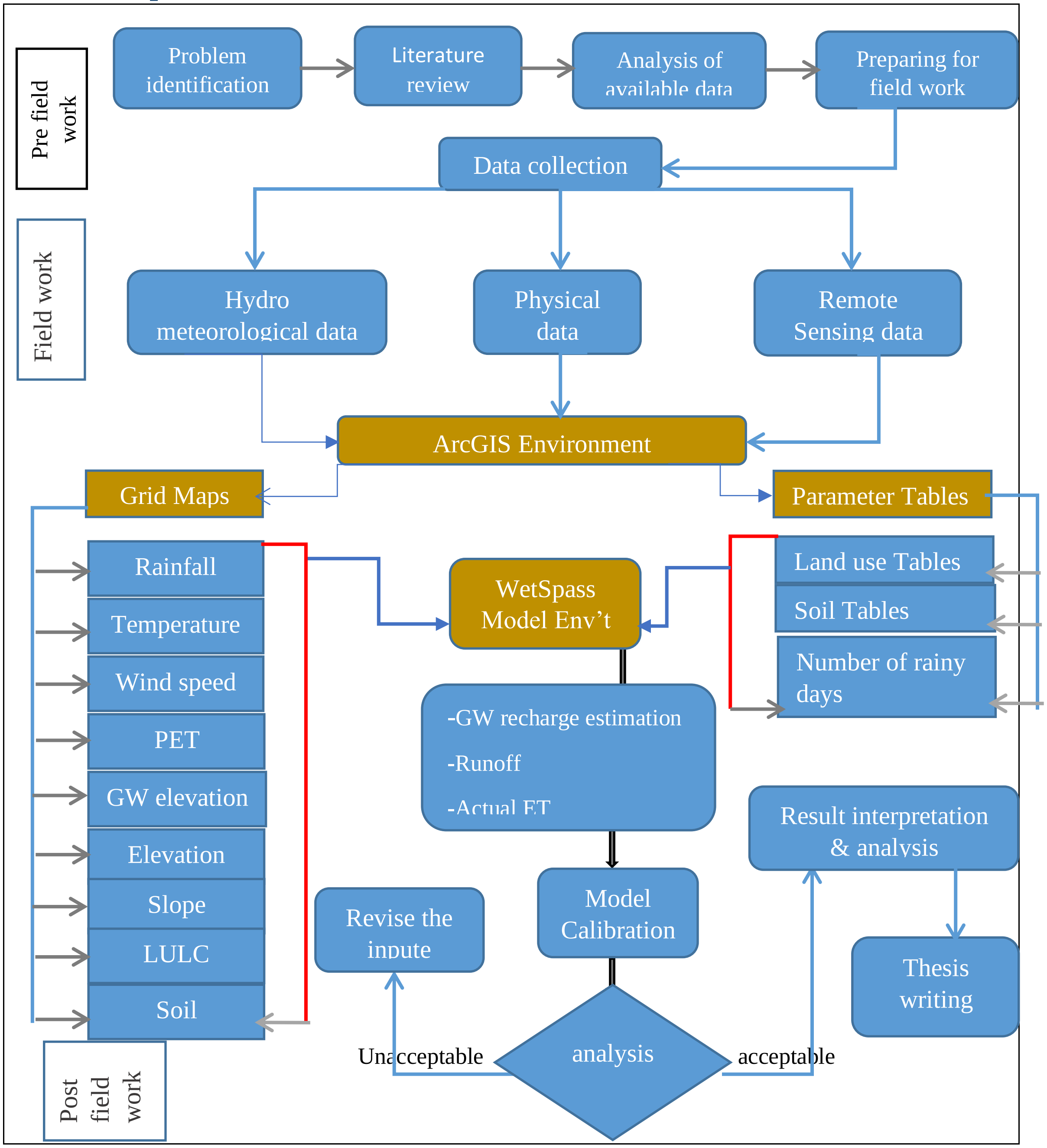



Figure3.11: Recharge estimation model processing flow chart

## 3.5 Materials and Software used

To conduct this study different software's and applications have been used. The different materials and software's used in the entire research work have been discussed as follows (Table 3).

Table 3: Materials and software's used in this research

| Materials & software's | Applications |
|---|---|
| GPS | Borehole, Soil sample data collection |
| Global Mapper 19.0 | DEM processing |
| ArcGIS 10.5 | Grid data preparation, interpolation of point data, spatial data analysis and interpretation of simulated results. |
| Drinc | Evapotranspiration estimation |
| New_LocClim Version1.1 | Meteorological data estimator |
| WetSpass Version 1.3 | Running and estimating the required data and give rise to the final output |
| Ms-Excel | Preparation of point data and parameter table/lookup tables |
| Ms-Word-2010 | Reporting and presentation of results |
| Google Earth | Ground truth collection & feature identification |

## 3.6 Application of WetSpass Model

**Water balance components**

**Surface runoff**

The WetSpass-M model calculates the monthly surface runoff $SR_m$ in (mm/month) using a rational method applied on a monthly time step using two coefficients:

$$SR_m = C_{sr} C_h (-) \qquad \textit{Eq. 3.4}$$

where $C_{sr}$ is an actual runoff coefficient (–) and Ch is a coefficient (–) representing soil moisture conditions (Bahremand et al. 2007):

$$Ch = \left(\frac{Ns}{Nsat}\right)^{b} \qquad \textit{Eq. 3.5}$$

Where $Ns$ is the cell soil moisture content ($m^3/m^3$), $Nsat$ is the soil porosity ($m^3/m^3$) and b is an exponent (–) representing the effect of rainfall intensity. For b = 1, a linear relation between $C_h$ and soil moisture is assumed. Bahremand et al. (2007) obtained an optimal value for b through calibration using discharge time series. For semiarid regions, where soil moisture is generally low and (potential) evapotranspiration is high, $C_h$ is included in Eq. 3.2 to avoid overestimation of surface runoff. As soil moisture data at monthly time step is scarce, Ch (between 0 and 1) can be approximated by integrating the evaporative efficiency ratio (Abdollahi, et al., 2017) And (Pistocchi, et al., 2008).

$$Ch=\frac{Pm}{Lp(P^{a}_{m}+ET^{a}_{m})^{1/a}} \qquad \text{if } ET_m > P_m \qquad Eq.\ 3.6$$

$$C_h=1\ ET_m\ if \leq P_m$$

where $ETm$ is the potential evapotranspiration (mm/month), LP is a calibration parameter (–) which reduces the potential evapotranspiration depending on the soil moisture (default is 0.65). (Pistocchi, et al., 2008) suggested a value of 1.5 for the exponent a as an average value at monthly scale. The runoff coefficient integrates many factors such as surface roughness, infiltration, and depression storage. Therefore, it is a critical input parameter in water balance modeling. To improve the estimation of the potential runoff coefficient per grid cell, it is calculated from the runoff coefficient for permeable areas ($C_{per}$) and the runoff coefficient for the impervious part ($C_{Imp}$) according to their area. $C_{per}$ is obtained from a weighted sum of land use/land cover, soil, and slope factors, respectively.

**Evapotranspiration**

WetSpass computes evapotranspiration per grid cell by summing up actual evapotranspiration from the vegetated ($ET_V$, open water ($ET_O$), bare soil (ETs) and impervious surface ($ET_i$) area fractions. In a similar approach, WetSpass-M uses potential evaporation at a monthly timescale and vegetation coefficients for estimation of actual evapotranspiration. For calculation of the reference transpiration from the potential evapotranspiration ($ETP$), a vegetation coefficient is required which is estimated as:

$$c=\frac{1+\frac{\gamma}{\Delta}}{1+\frac{\gamma}{\Delta}(1+\frac{rc}{ra})} \qquad Eq.3.7$$

where $c$ is the psychrometric constant (kPa/$^{o}$C), which is the gradient of the first derivative of saturated vapor pressure curve (slope of saturation vapor pressure at the temperature of atmosphere), $rc$ (bulk) surface resistance (s $m^{-1}$), and ra aerodynamic resistance (s $m^{-1}$).

$$ra = \frac{1}{K^2 UaZa}(\ln(\frac{Za-Zd}{Z0}))^2 \quad \textit{Eq. 3.8}$$

where K is the von Karman constant (0.41), $Ua$ (m/s) is the wind speed at elevation $Za$ (m), $Zd$ is zero displacement elevation (m) and $Z0$ is the aerodynamic roughness height of surface (m). For vegetated groundwater discharge areas, the vegetation coefficient is equal to 1. Therefore, the reference transpiration ($Trv$) is given by:

$$Trv = cETp \quad \textit{Eq. 3.9}$$

The total actual monthly evapotranspiration per grid cell [ETm (mm/month)] now becomes:

$$ET_m = {}_{av}ET_v + {}_{as}ET_s + {}_{ao}ET_o + {}_{ai}ET_i \quad \textit{Eq. 3.10}$$

Where $avETv$, area fraction and evapotranspiration for vegetated area, $asETs$, bare soil $aoETo$ open water and $aiETi$ is impervious surface (Batelaan and De Smedt 2001, 2007).

**Recharge**

Computation of long-term average spatial patterns of recharge was the main objective for development of the WetSpass methodology (Batelaan and De Smedt 2001). In WetSpass-M, monthly recharge [Rm (mm/month)] is calculated as the residual term of the water balance:

$$R_m = Pm - SRm - ETm \quad \textit{Eq. 3.11}$$

As recharge is a rather slow process, monthly base-flow for each cell is calculated based on the storage of the previous month and the recharge in the considered month:

$$Q_{b(t)} = BQ_{b(t-1)} + 0.001Nm(1-B)\emptyset R_m \quad \textit{Eq. 3.12}$$

where $B$ is a storage parameter (–) (between 0 and 1), $Q_{b}(_{t\,-\,1})$ is the base-flow from the previous month ($m^3$/month), Nm is number of days per month and $\emptyset$ (m2/day) is the recharge contribution parameter to current base-flow. For grid cell area A ($m^2$) with recession index k (day).

$$\emptyset = \frac{1.15A}{K} \qquad \textit{Eq.3.13}$$

The groundwater recharge is calculated from the following equation as the residual of the water balance and precipitation, (Aish et al., 2009).

$$P = I + Sv + ETv + Rs \qquad \textit{Eq. 3.14}$$

where $P$ is the average seasonal precipitation [$LT^{-1}$], $I$ is the interception by vegetation [$LT^{-1}$], $Sv$ is runoff over land surface beneath vegetation [$LT^{-1}$], $ETv$ is the actual transpiration [$LT^{-1}$] and $Rs$ is groundwater recharge [$LT^{-1}$]. The final duty for WetSpass model is estimating the spatially distributed groundwater recharge, which can be calculated from the water balance:

$$Rs = P - Sv - ETv - I \qquad \textit{Eq. 3.15}$$

Where, $P$ is precipitation, $Sv$ runoff over land surface beneath vegetation is interception by vegetation, and $ETv$ is the actual evapotranspiration [LT-1] calculated as the sum of transpiration Tv and Es (is the evaporation from bare soil found in between the vegetation).

Therefore, recharge is a function of precipitation regime, vegetation, soil type, slope, groundwater depth, and other climatic variables.

**Water balance per raster cell**

The water balance components of vegetated area, bare-soil, open-water bodies and impervious land surfaces are used to compute the total water balance of a raster cell for a given wateshed. The total evapotranspiration, surface runoff and groundwater recharge of a raster cell have been computed using the equations (*Eq 3.16,3.17, 3.18*) which had described by (Batelaan and De Smedt, 2001):

$$ET_{raster} = a_v ET_v + a_s E_s + a_o E_o + a_i E_i \qquad Eq.3.16$$

$$S_{raster} = a_v S_v + a_s S_s + a_o S_o + a_i S_i \qquad Eq.3.17$$

$$R_{raster} = a_v R_v + a_s R_s + a_i R_i \qquad Eq.3.18$$

Where $ET_{raster}$, $S_{raster}$ and $R_{raster}$ are the total evapotranspiration, surface runoff, and groundwater recharge of a raster cell respectively, each having a vegetated, bare-soil, open-water and impervious area component denoted by $a_v$, $a_s$, $a_o$, and $a_i$, respectively.

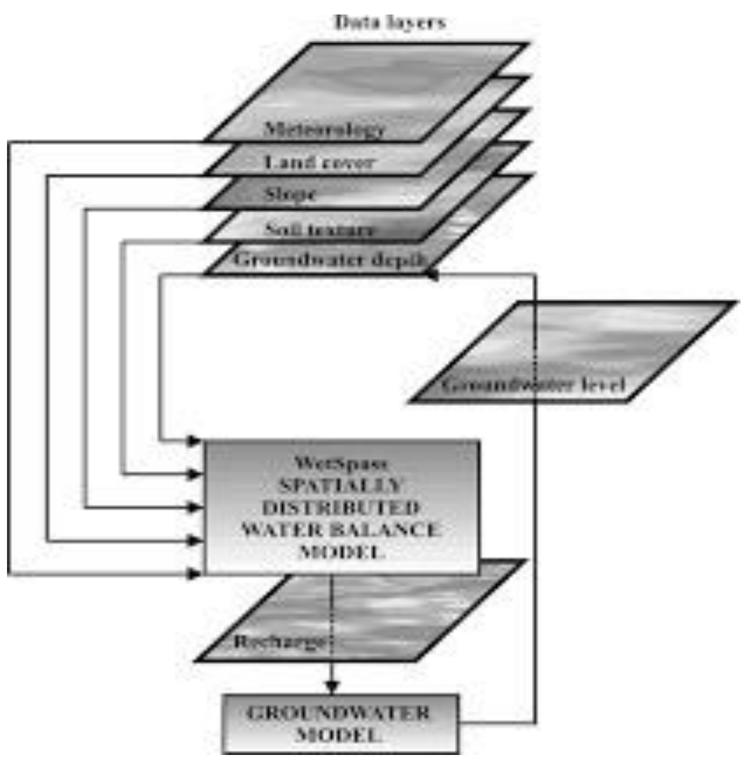



Figure 3.12: Schematic representation of the iteration process in the WetSpass model (Batelaan & DeSmedt, 2001).

### 3.7 WetSpass model input data

The WetSpass model needs different types of long-term average input data. Which are hydro-meteorological data (precipitation, wind speed, temperature, potential evapotranspiration, ground water elevation) and spatial patterns of watershed-based biophysical layer data (slope, land use/land cover, elevation and soil). The magnitude and even the direction of change in recharge depends on the local soil, vegetation and climatic region (Craig et al., 2010). WetSpass needs the input variables in monthly bases, as a result, four months summer (rainy) season and the remaining 8 months winter (dry seasons) in the case of Ethiopian condition specifically at the study area.

Grid maps and parameter tables are required as inputs for the model simulation and were prepared with the help of ArcGIS 10.5 tools. The grid maps were a land-use land cover, soil texture,topographic elevation, slope, topography and groundwater levels, precipitation, potential evapotranspiration and wind speed. The input files prepared as parameter tables were also prepared in a database file format (dbf); these are land use, soil texture and number of rainy days.

Table 4: Input variables for WetSpass model

| Input variables | | Sources |
|---|---|---|
| 1 | Topography | DEM (20*20m) resolution |
| 2 | Slope | DEM (20*20m) resolution |
| 3 | Land use land cover | Water and Land Resource Center (WLRC) |
| 4 | Temperature (summer & winter) | New-LocClim estimator |
| 5 | Precipitation (summer & winter) | New-LocClim estimator |
| 6 | PET (summer & winter) | New-LocClim estimator |
| 7 | Wind speed (summer & winter) | New-LocClim estimator |
| 8 | Groundwater depth | Regional water bureau |
| 9 | Soil parameter lookup table | WetSpass user guide |
| 10 | Number of rainy days lookup table | WetSpass user guide |
| 11 | Land use parameters | WetSpass user guide |

### 3.7.1 Grid maps

The WetSpass model requires all grid maps should be represented by the same raw and column as well as similar cell size. in terms of this, the input bio-physical and meteorological grid maps have similar cell size, columns and rows which is 30, 906 and 1367 respectively. All meteorological grid maps were prepared by seasonal (summer and winter) and annual bases. The rest of the necessary maps were no change in summer nor in winter. There for, soil, groundwater depth, slope, topographic elevation and land use/land cover maps are the same in summer and winter season.

Of course, in most areas land use/ land cover is different in separate season. but in my study area, most of the escarpments/topographically high areas are covered by the same shrubs and the graben/topographically lowland areas are covered by agricultural products in both seasons. Because the farmers produce using irrigation by groundwater as well as the available perennial rivers. In order to this, the suitable area in the watershed is more or less covered by crops in both seasons and the shrubs in the mountainous area are covered year to year.

**Precipitation**

Precipitation is one of the critical parameters of hydrologic cycle and most of groundwater stored in aquifer reservoir is part of it. Precipitation forms from open water bodies or snow /ice through evaporation and condensation as well as from shallow groundwater by means of transpiration through plants. After this, precipitation falling dawn to earth surface and distributed into runoff, back through evapotranspiration and to recharge. groundwater recharge of a certain watershed is highly depending on precipitation and it is a major source of recharge. the relationship between rainfall/precipitation and groundwater recharge is depending on several factors both meteorological and biophysical. including: wind speed, temperature, sunshine hours, slope, land use and soil types of the area.

Precipitation is taken as the starting point for the computation of the water balance of each of the components of a raster cell. There are two distinct hydrological seasons in the watershed. Those are a rainy season (summer) from Jun to September and a dry season (winter) that includes for the rest months of the year. Monthly rainfall distribution in and around the watershed are shown in Figure10.

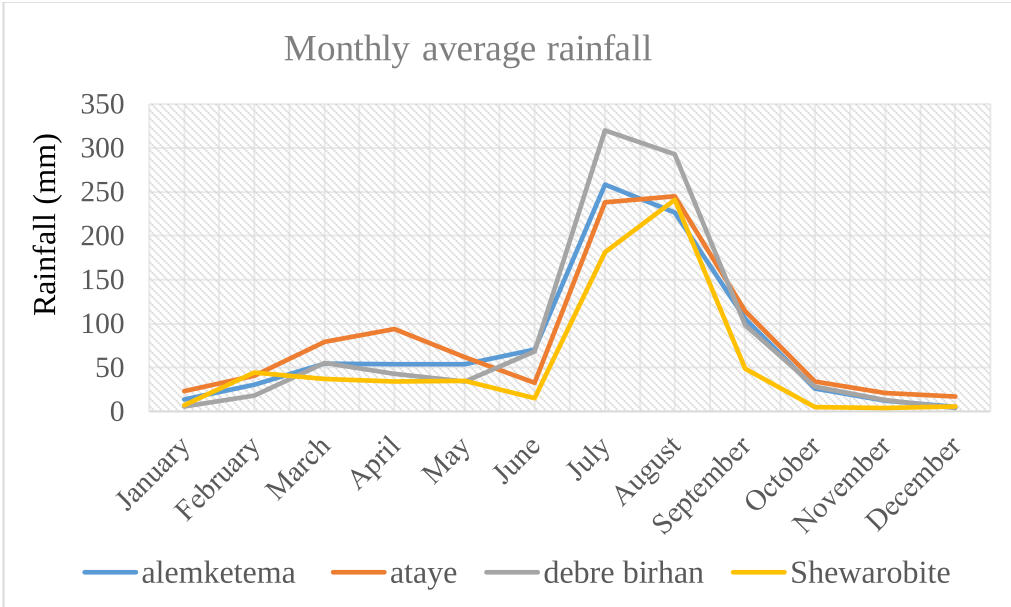
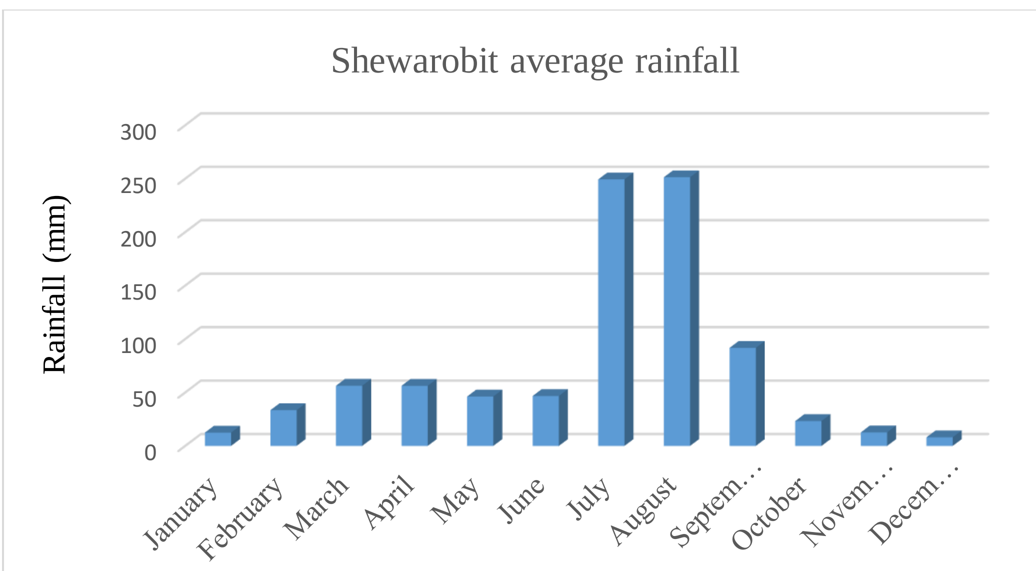



Figure 3.13: Monthly average rainfall for stations in and around the study area

The Shewa robit station that neighbors to Jewha watershed receives an average precipitation value of 248mm in winter season and 639mm in summer season. The total annual rainfall value of Shewa robit station is 887mm with a minimum and maximum value of 760.6 mm and 859.9mm.




Figurev3.13: Monthly average rainfall distribution of selected station (Shewa robit)

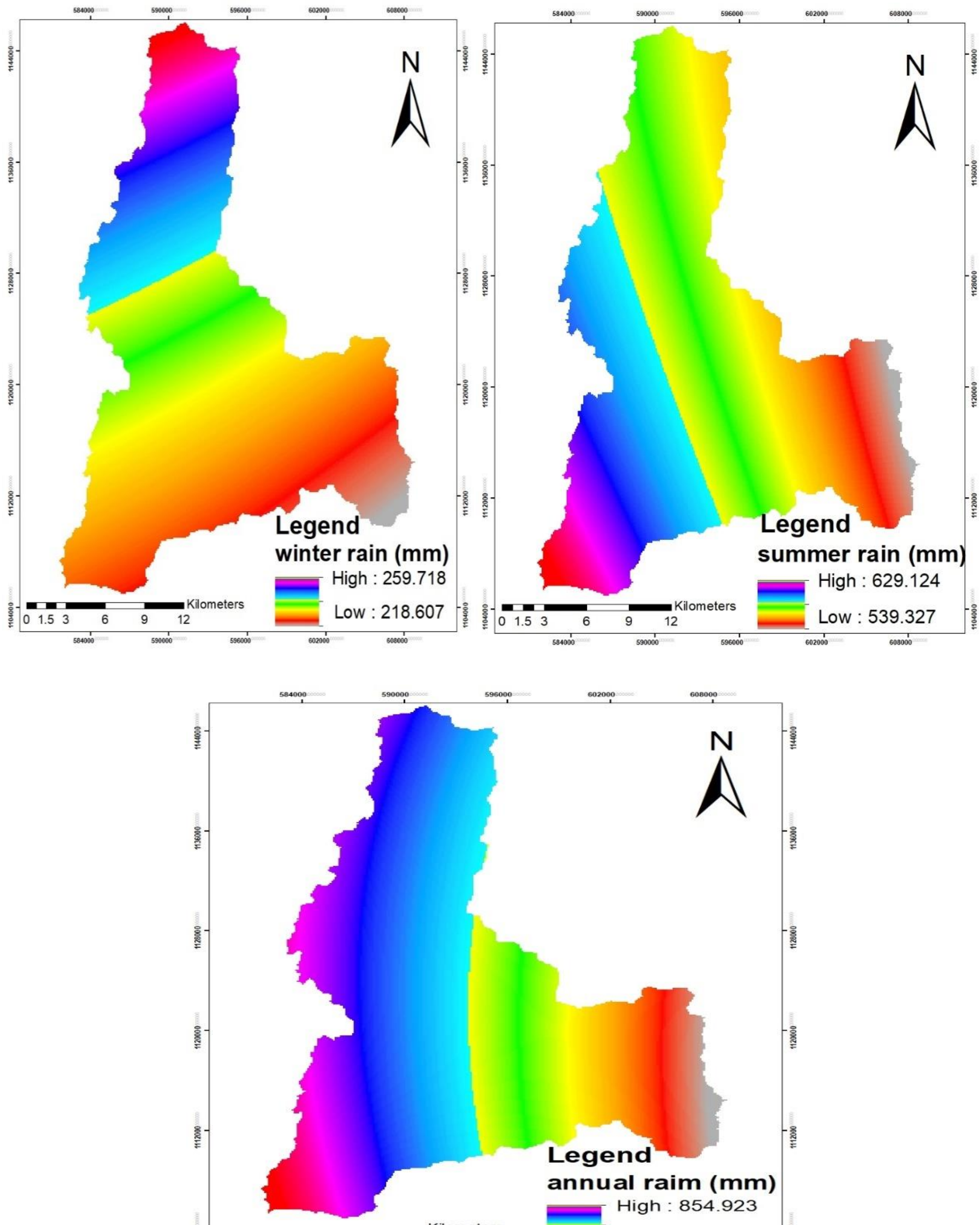



Figure 3.14: Seasonal and annual average rainfall map of Jewha watershed

### Temperature

Temperature is the main controlling factor of evapotranspiration in a certain watershed. in the study area, the New-LocClim estimator provides a temperature data for Shewarobit, Ataye, Alem ketema and Debre-birhan. After interpolation, The average temperature value ranges between 12.3$^o$c and 12.7$^o$c in the winter (dry) season the mean is 12.57$^o$c, it between 18.8$^o$c and 21.2$^o$c in the summer (rainy) season with a mean of 20.28$^o$c and the annual average ranges between 18.6$^o$c and 19.8$^o$c and the mean is 19.32$^o$c.

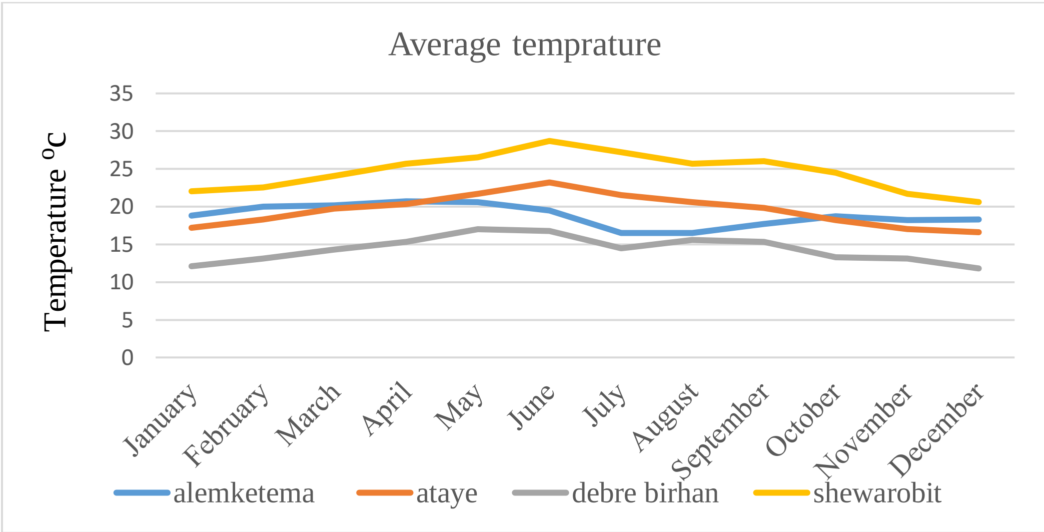



Figure 3.15: Monthly average temperature value of surrounding stations

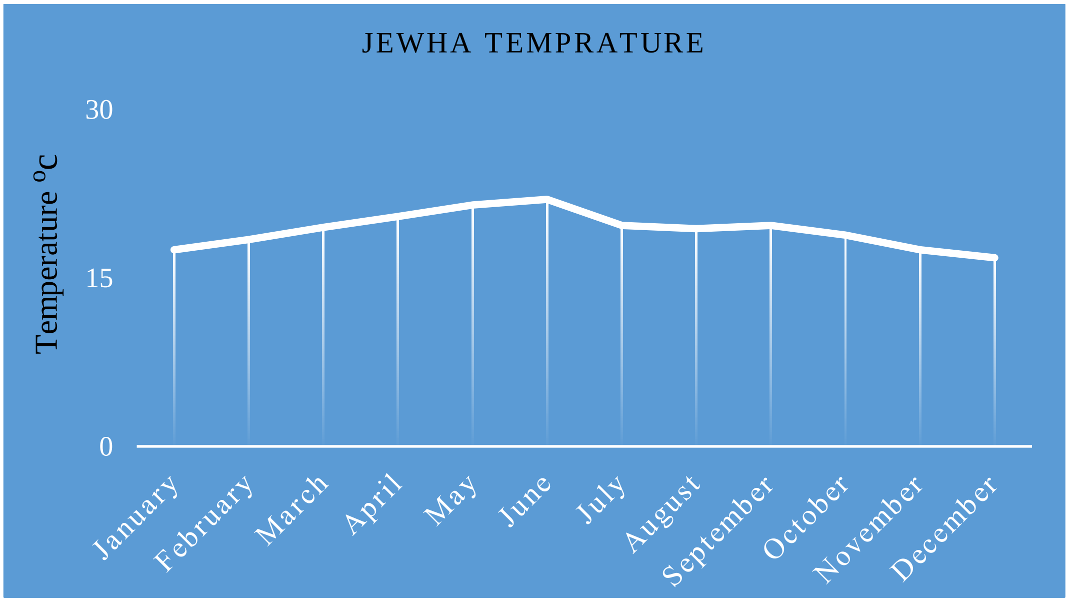



Figure 3.16: Average monthly temperature value of Jewha watershed

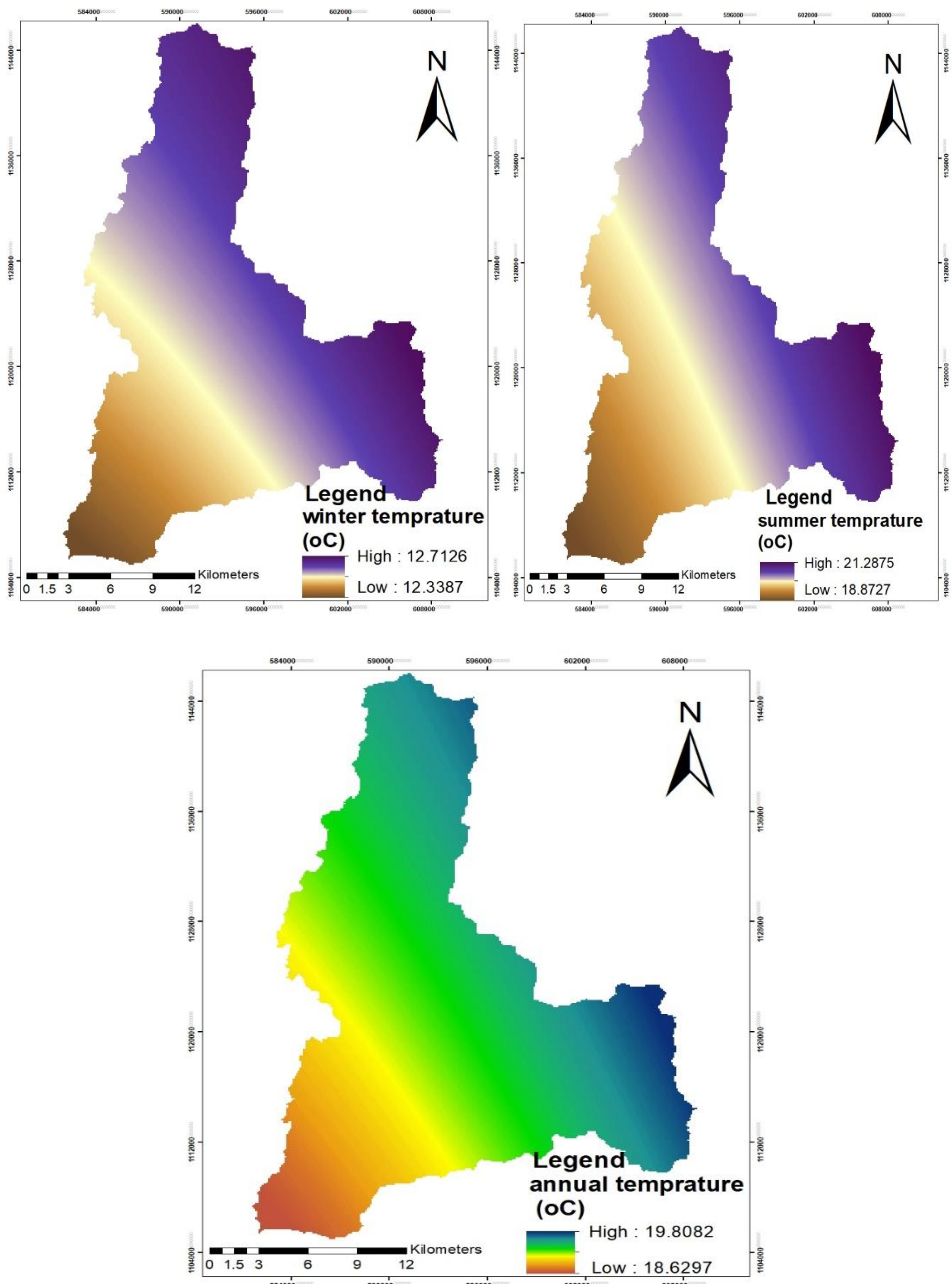



Figure 3.17: Seasonal and annual average temperature map of Jewha watershed

### Potential evapotranspiration (PET)

Potential evapotranspiration describes the water losses that will occur under a given climatic condition with no deficiency of water for vegetation. Since the actual evapotranspiration account the field condition, it depends on the availability of water. various methods exist to compute potential evapotranspiration.

Potential evapotranspiration (PET) in the Jiwa watershed was obtained from New-LocClim estimator. The monthly PET results were divided in to two hydrological seasons; 8 months of winter (dry season) and 4 months of summer (wet season). To get the distribution of PET of the watershed; Kriging spatial interpolation technique were used for both hydrological seasons to get the distribution value over an area. After interpolation, the raster map was converted into ASCII format and the resulting grid map were incorporated with other input parameters of WetSpass model to calculate recharge and actual evapotranspiration.

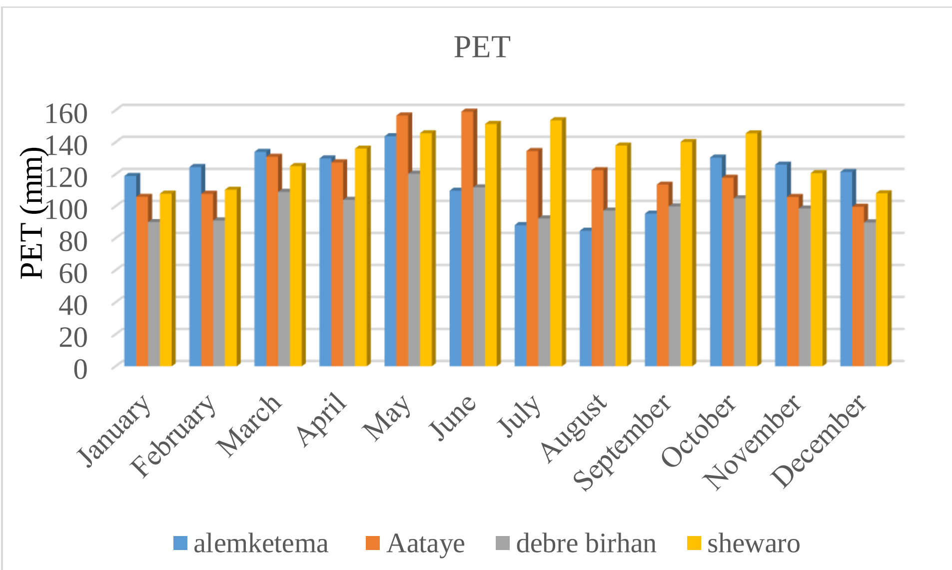



Figure 3.18: Potential evapotranspiration value of surrounding stations

The average potential evapotranspiration of summer is 462.62mm, where the winter is 946.98 mm, and the average annual potential evapotranspiration is 1409.66 mm with 1382.1 mm and 1430.9mm as the minimum and maximum annual PET respectively.

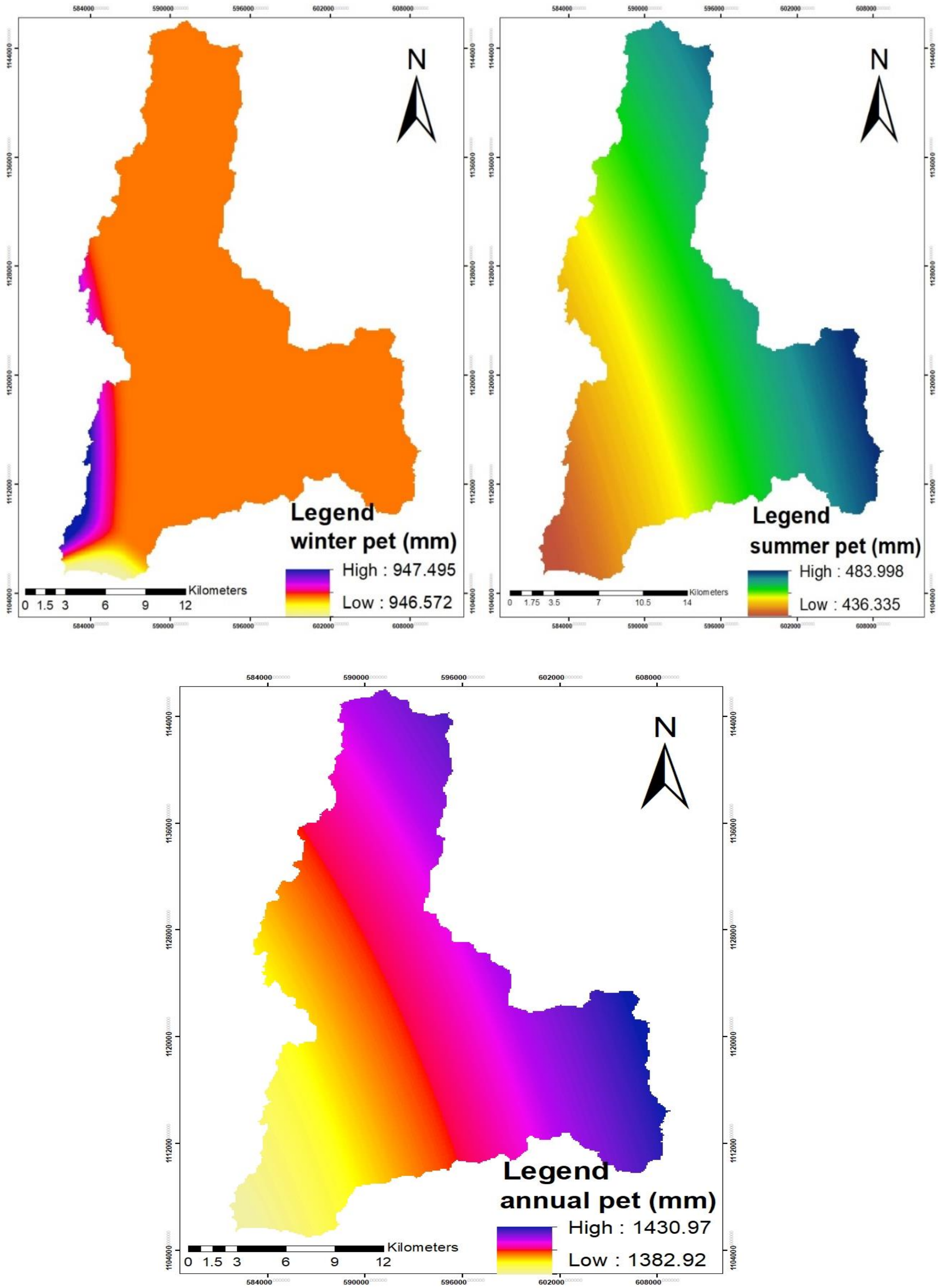



Figure 3.19: Seasonal and annual average evapotranspiration map of Jewha watershed

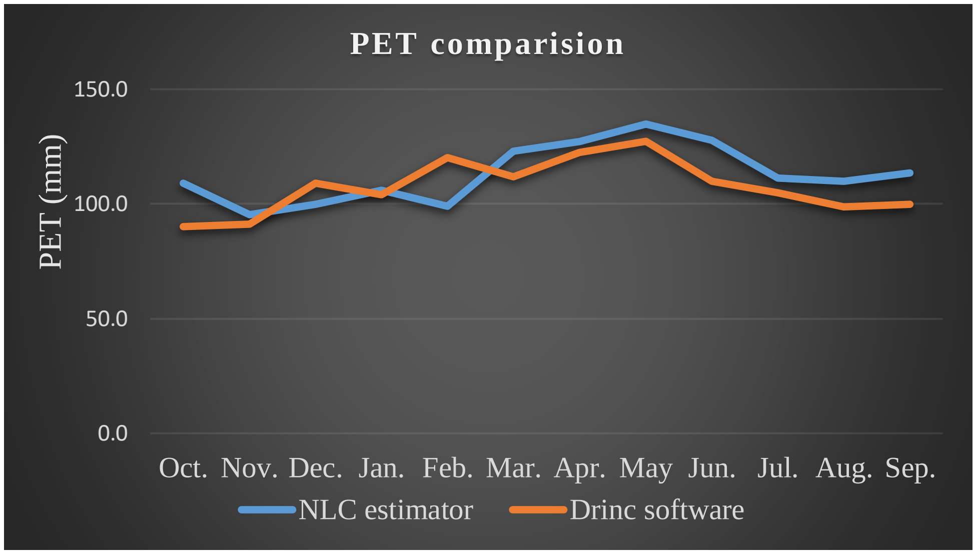



Figure 3.20: PET value comparison between New_LocClim estimator and DrinC software for selected station

**Wind speed**

Wind speed governs the rate and amount of evapotranspiration and other water balance components of a given watershed. With the same process of other WetSpass input parameters, the distribution of wind speed over the area were obtained using Kriging spatial interpolation method. The average speed of wind in Jewha watershed during summer is 5.34 m/s, in winter about 5.31 m/s, and the average annual wind speed is 5.32 m/s.

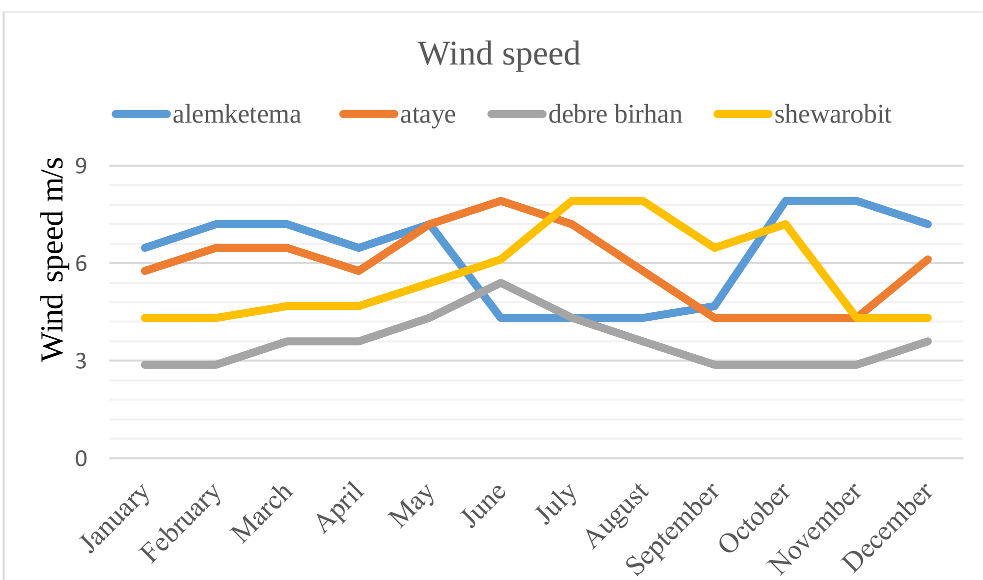



Figure3.21: Monthly average wind speed value of stations around Jewha watershed

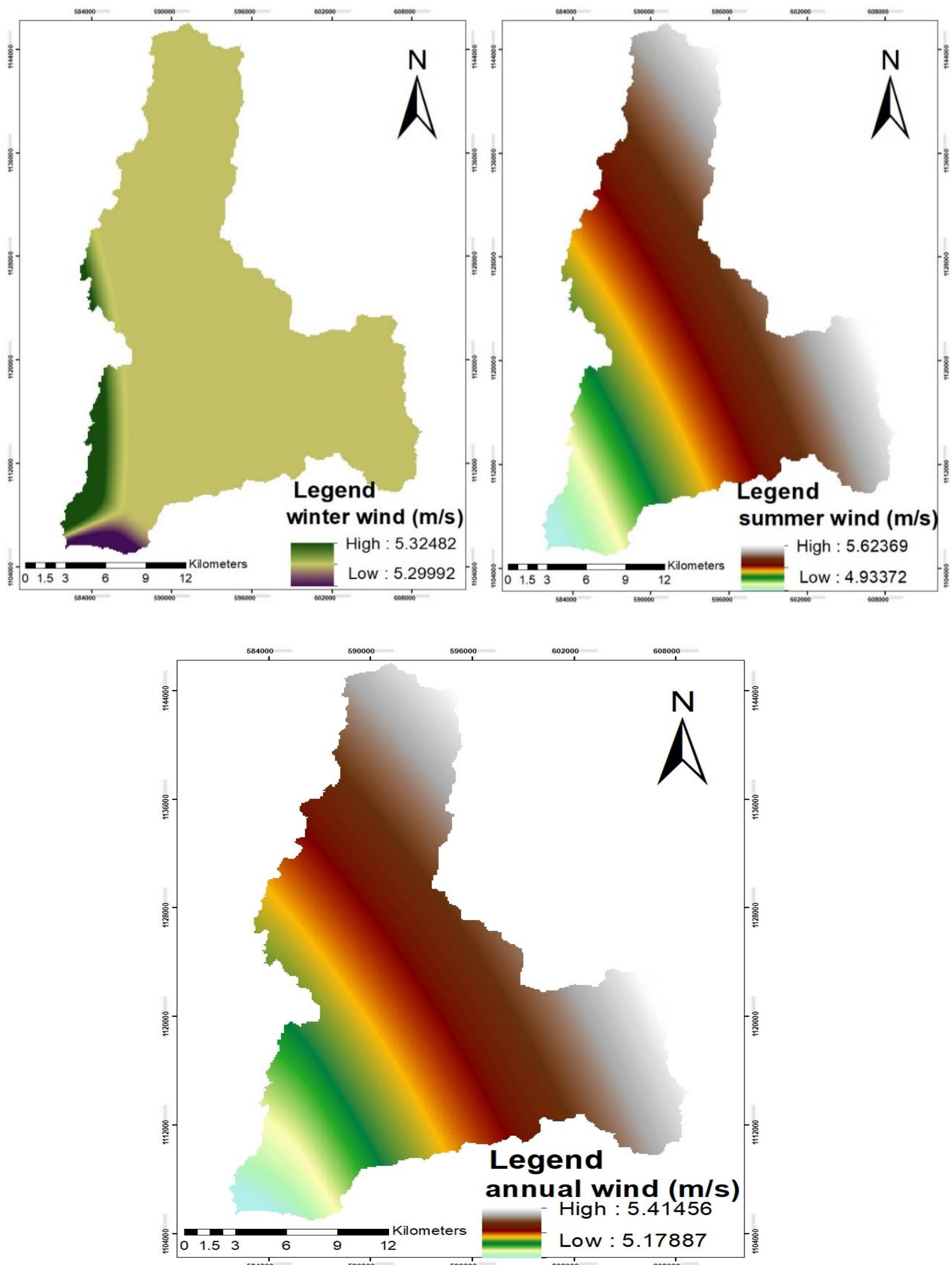



Figure 3.22: Seasonal and annual average wind speed of map of Jewha watershed

**Sunshine hours**

Energy is a critical element to takes place evaporation in a given watershed. The main energy source for this process is solar radiation. due to this, sunshine hours play a significant role in determining the rate and amount of evapotranspiration and other parameters.

**Topography**

Topographic map of the study area is processed from Shuttle Radar Topographic mission (SRTM) data set. The SRTM provides 20*20m resolution Digital Elevation Model (DEM). The highest point in the watershed is located on the top of escarpment/upstream with elevation of 3554m and the lowest point 1109m is located in the eastern/downstream part of the area. while the mean elevation of the watershed is 2331m. 31% of the total area of the watershed is between 1109 and 1500m elevation which is highly suitable for agriculture. Of course, most of the escarpment part of the study area is used for agricultural activity too.

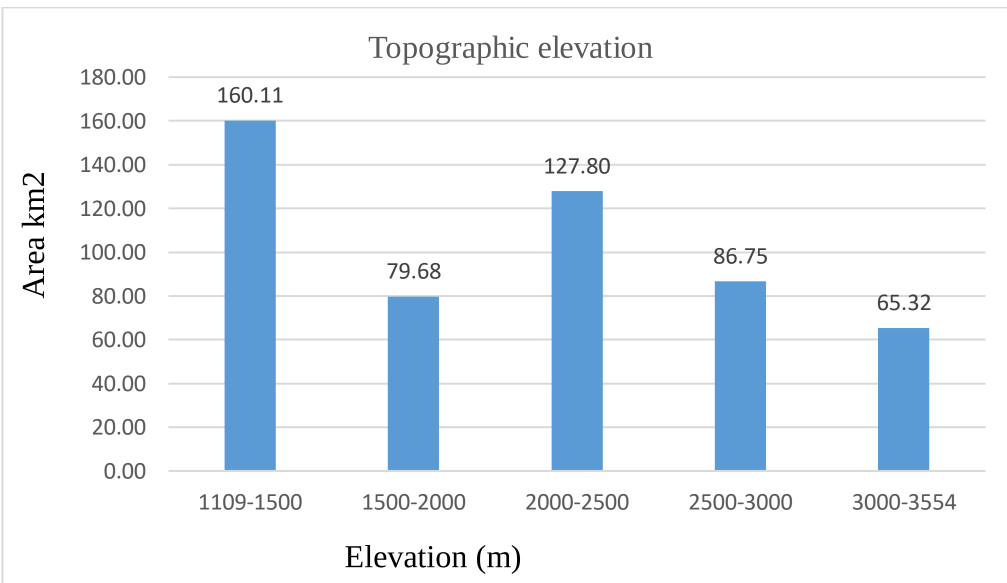



Figure 3.23: Elevation of Jewha watershed with area coverage

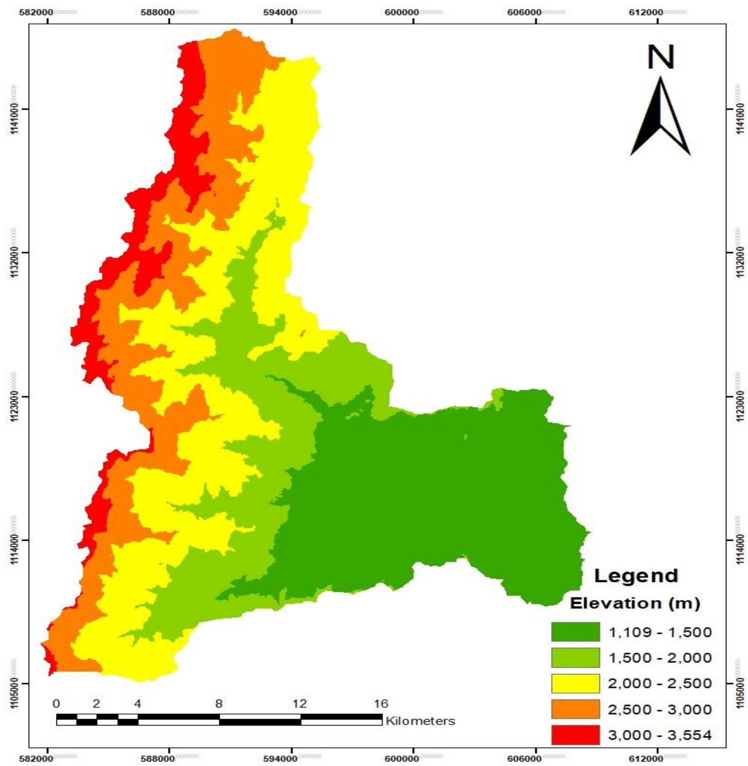



Figure 3.24: Topographic elevation map Jewha watershed with respect to area coverage

### Slope

Slope is an important parameter to identify the hydrological characteristics of the watershed. Steep slope part of the watershed is recharge areas where as gentle slope is considered to discharge areas. Most of the time it has a direct relation with topography. Slope map of the study area is also obtained from 20m*20m DEM using ArcGIS 10.5 slope spatial analyst tool. It is classified by degree of steepness ranging from 0 to 74. The vale 0 indicates gentle/lowland and 74 is represent steep/escarpment. The Jewha watershed contains both wide area of high slope/steep escarpment while not suitable for agricultural activities and flat/ gentle slope of lowland area/plane which is suitable for agricultural activities. About19% of the study area is below $8^{o}$ of slope which is highly suitable for recharge/discharge hydrological process.

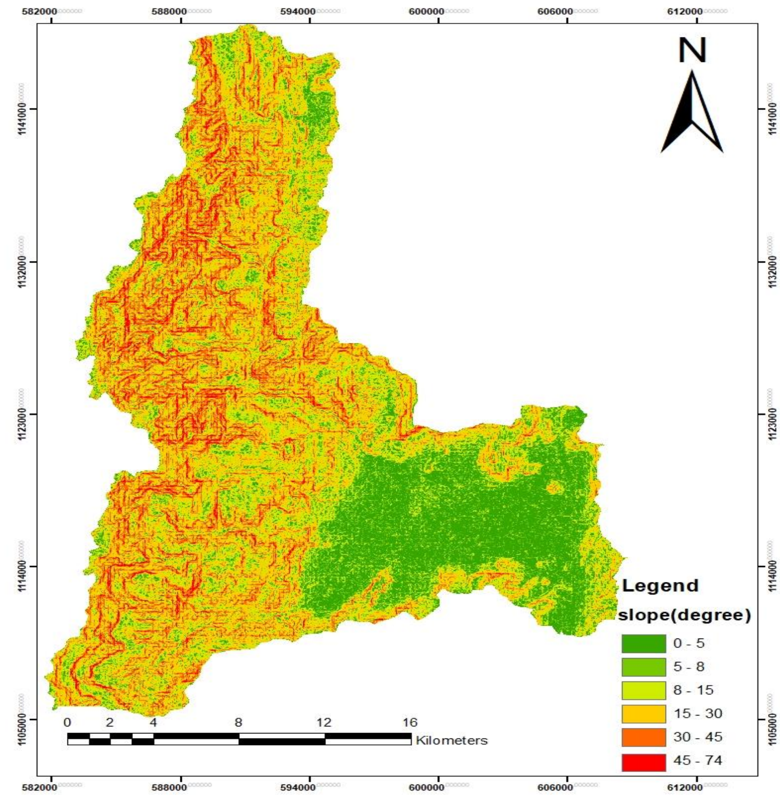



Figure 3.25: Slope map of the study area

**Land use Land cover**

Land use is an important characteristic to govern the surface runoff process that affects infiltration(recharge), evapotranspiration and erosion. Different land use types have different influencing capacities on recharge, runoff process and evapotranspiration rates, due to their different leaf area indices, root depth and size (Batelaan and DeSmedt, 2001). It is a highly sensitive parameter for recharge estimation using WetSpass modeling.

The land use/land cover map of Ethiopia were prepared by WLRC. The Jewha watershed land use land cover was derived and modified from this map. Jewha watershed is covered by different land use and vegetations. In terms of areal coverage, the important land cover units are trees, shrubs, grassland, crop land, vegetation aquatic or regularly flooded, bare areas and built up areas. The agricultural /cropland which consists 55% of the land cover is distributed throughout the study area and it is the principal land-use of the watershed. whereas Natural forest covers 15%, shrubs 14%, bare land 6%, and plantation 5%. Grassland and other minor land use types covers 3% of the total. There is no a significant change from summer to winter and thus it was not taken into account in the respective parameter tables for WetSpass modeling. Land-use/land-cover fractions are used as weighting factors for the calculation of the water balance at grid cell level. The total coverage of the watershed is showed below in table and map with all areal coverage.

Table 5: Land use types in Jewha Watershed

| Land cover types | Area km$^2$ | Area % |
|---|---|---|
| Natural forest | 76.37 | 14.8 |
| Cropland | 283.61 | 55.1 |
| Grassland | 17.76 | 3.5 |
| Bare land | 28.51 | 5.5 |
| Shrubs | 73.46 | 14.3 |
| Plantation | 24.16 | 4.7 |
| Riverine vegetation | 10.00 | 1.9 |
| Swamp | 0.01 | 0.0 |
| Urban & rural settlement | 0.88 | 0.2 |
| Total | 514.76 | 100.00 |

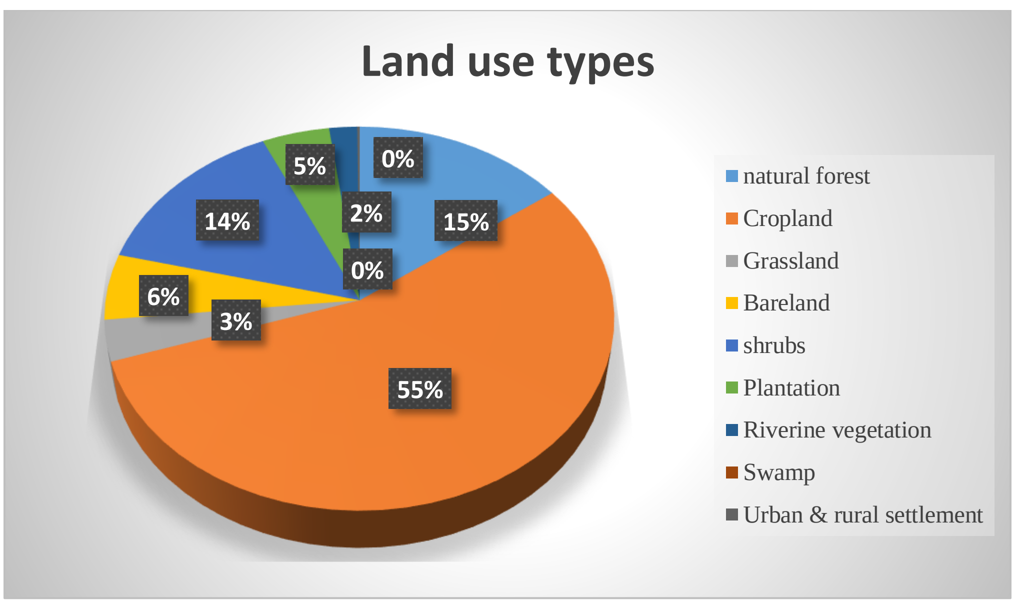



Figure 3.26: Land use percent coverage of the study area

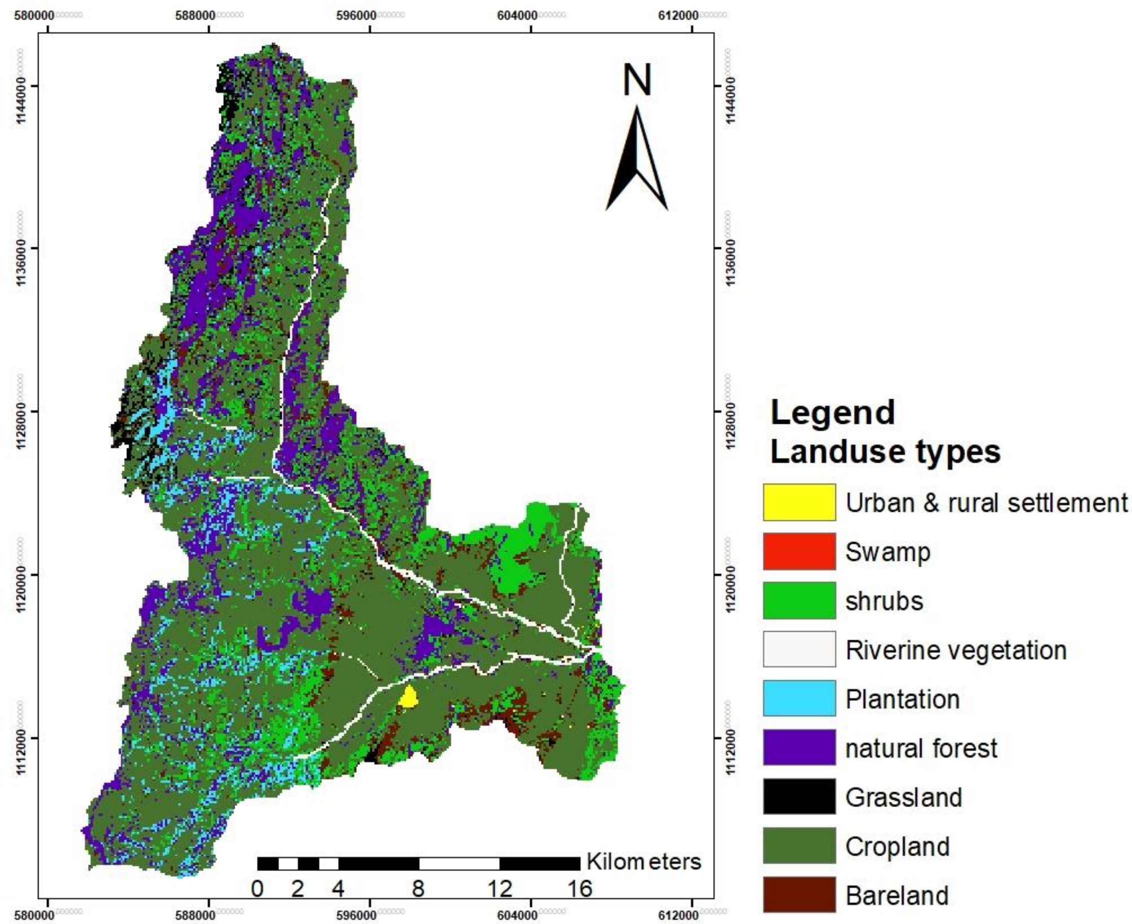



Figure 3.27: Land use types in Jewha watershed

**Soil data**

The second most important and sensitive parameter for recharge estimation process using WetSpass modelling is soil texture. The soil type map of the Jewha watershed was found from Ministry of agriculture. Soils texture of the study area are classified into three classes using the United States Department of Agriculture (USDA) textural classification methods, sandy loam, silty loam and clay (Figure 3.28). Most of the area is covered by silty loam. the WetSpass model has been prepared itself the attribute table for recognition of soil and other biophysical maps. the texture class obtained from USDA was prepared with respect to the model code. Finally, the raster grid map was converted to ASCII format for suitability of model processing with 30m*30m resolution.

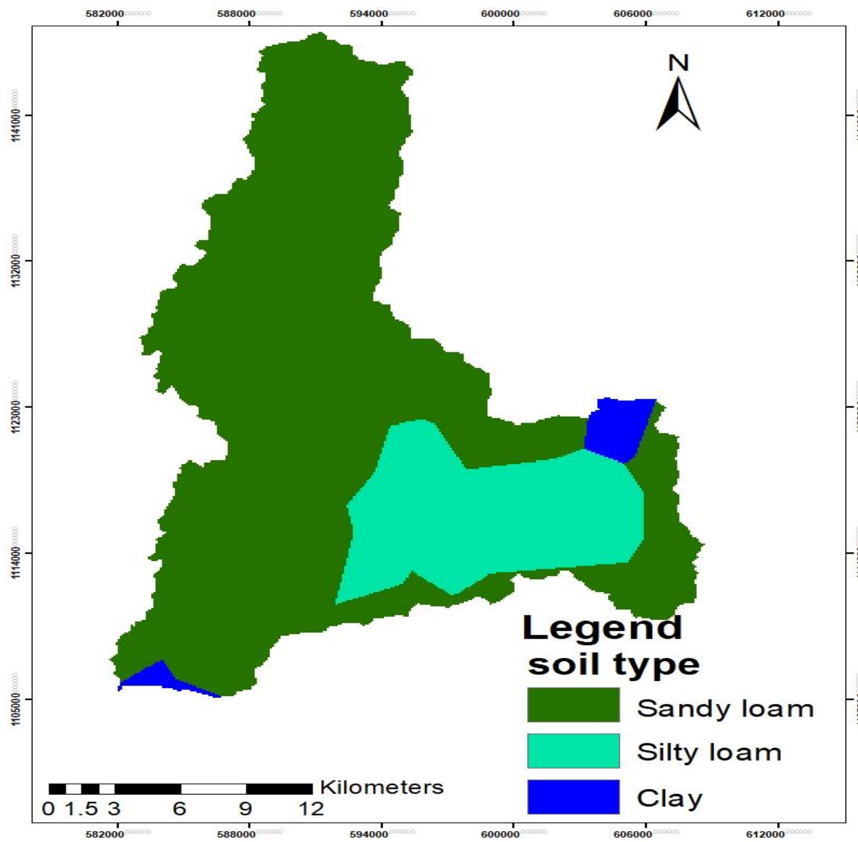



Figure 3.28: Soil map of the study area

### Groundwater Depth

Groundwater level map is a critical parameter to estimate groundwater recharge using WetSpass model. The groundwater depth in Jewha watershed is variable. 10 borehole's data were collected from ADSWE and from local water bureaus. The groundwater depth has been calculated by deducting static water level from topographic elevation and the map were produced. These data were interpolated using ArcGIS Kriging spatial analyst tool to represent the total area of the watershed. Most of the borehole data shows that the static water level is shallow and artesian well have recorded. Topographically low elevated areas have shallow groundwater level because mostly water tables in unconfined aquifers follows topography. In Jewha watershed the static water level varies from 0 to 48m below the surface which represents low elevated area of the watershed. Also, there are both seasonal and perennial Springs in the escarpment part of the study area.

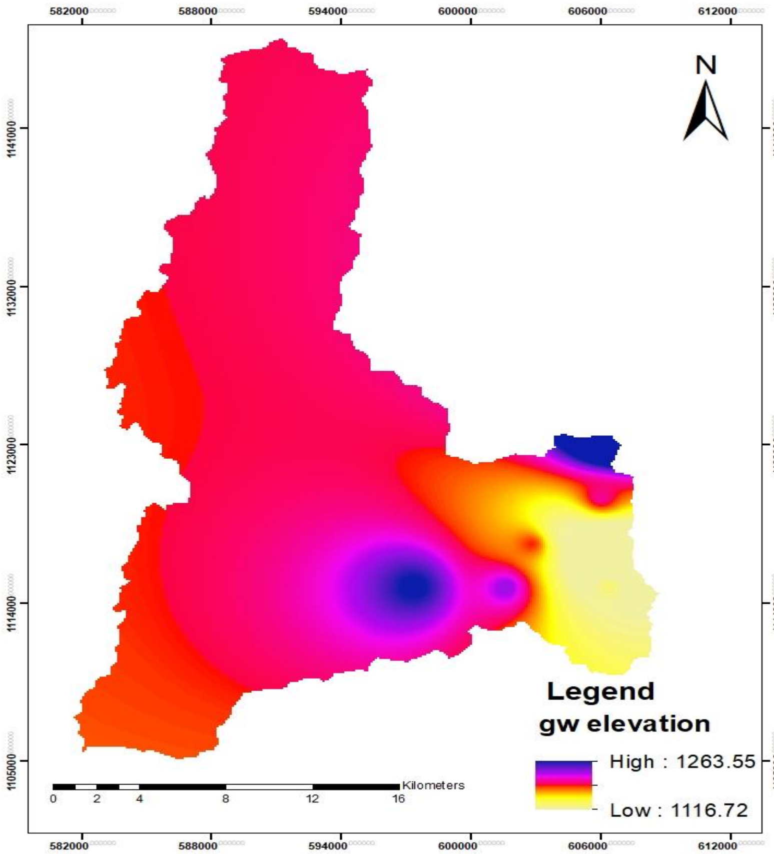



Figure 3.29: Groundwater depth map of Jewha watershed

### 3.7.2. Parameter tables/ Look up tables

In addition to grid maps, the WetSpass model needs different biophysical parameter tables for effective running process. which are; four months of number of rainy days, land use/land cover and soil parameter (**Annex VI** and **Annex IX** and **Annex X** respectively). Those parameter table were prepared in an appropriate and necessary table format (TBL). The model user guide and some other literature reviews were used to adjust and develop the parameter values to the Jewha watershed characteristics. After preparing both required grid maps/ASCII format and parameter tables the model were processed.

# CHAPTER FOUR

## 4. Result and discussion

### 4.1 Sensitivity Analysis

The WetSpass monthly model have different parameters and needs input variables to give a reasonable output for the understanding of water balance component of a given watershed. In order to use the parameters of WetSpass monthly model, the sensitivity of all parameters and input variables should be assessed. this is used to understand the model response in terms of the variation of parameters. A sensitivity analysis was carried out for the monthly model.

To conduct the sensitivity analysis of the parameters, the average value of all meteorological data in WetSpass -M model input data set should be prepared. The other biophysical data leaves as it is.in order to assess the parameter sensitivity ("a" interception, alfa coefficient, Lp coefficient etc.) the reasonable range has been assigned. In every run, the values of parameter were increased by 1% of the range compared to the previous run. All input variables and other parameters were kept the same except for the target parameters. To perform the sensitivity of different water balance component due to the variation of input variable, the target variable was increased by 25% to 100% and the other variable kept constant.

The result of sensitivity of the different water balance components/WBC to variation in parameters and input variables are shown and presented in (Figure 4.1 and Figure 4.2). The interception coefficient, alfa coefficient, and Lp coefficient parameter is relatively sensitive to the water balance components. The interception value with respect to changing the value of the parameters shows that generally low sensitivity in comparison with the other water balance components. Whereas Recharge and runoff responds to variations in a large number of factors probably because it is estimated as the residual of the water balance (Abdollahi, et al., 2017).

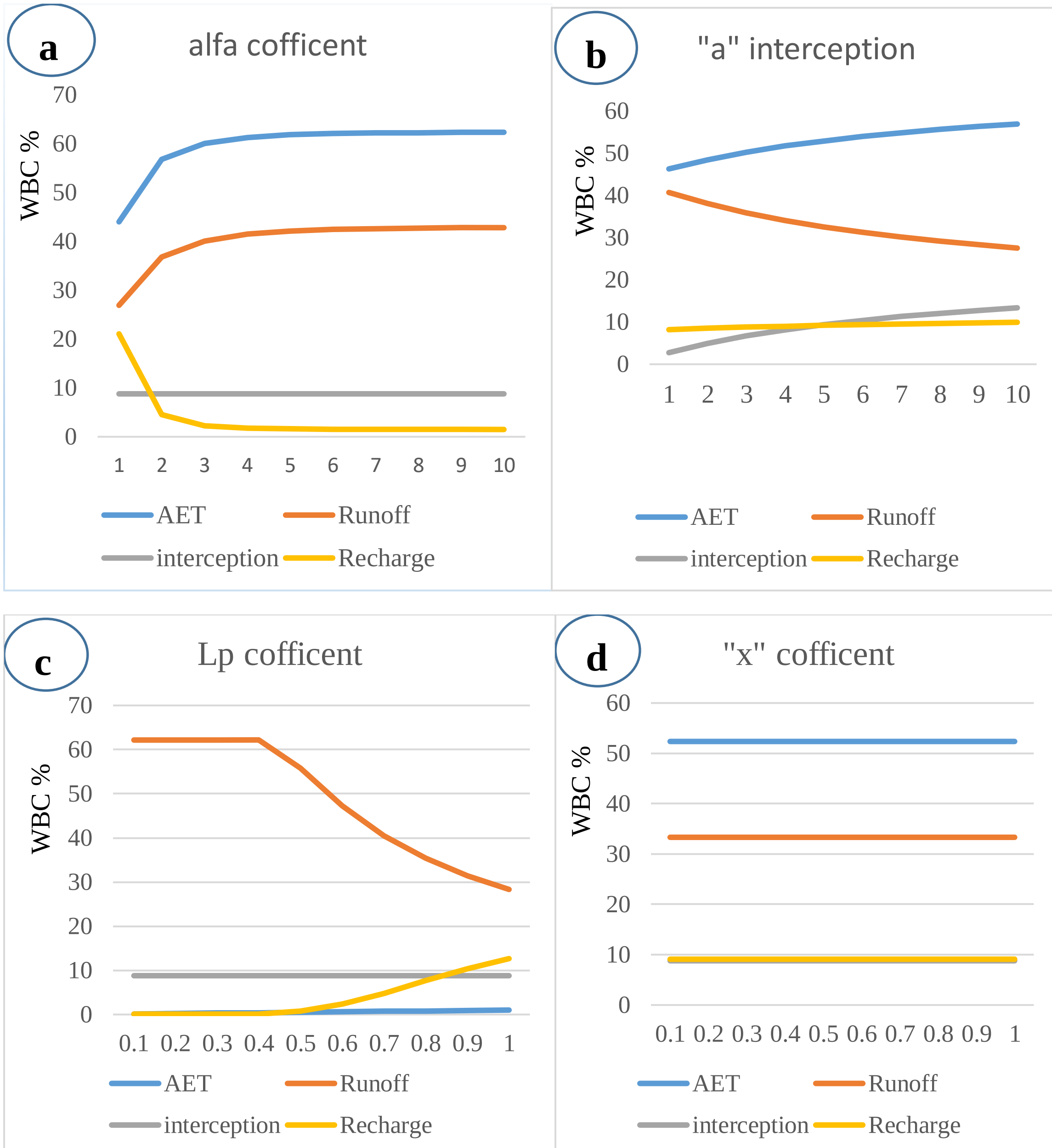



Figure 3: Sensitivity of water balance component with changing different model parameters; a) Alpha coefficient b) Interception coefficient c) Lp coefficient d) "X" coefficient

Input variables sensitivity analysis shows that the potential evapotranspiration (pet) and rainfall variables are the most critical input parameter. Whereas, the temperature and groundwater input variables are less sensitive to the model result (water balance components). groundwater is insensitive to water balance components because the effect of evapotranspiration on groundwater in the study area is low.

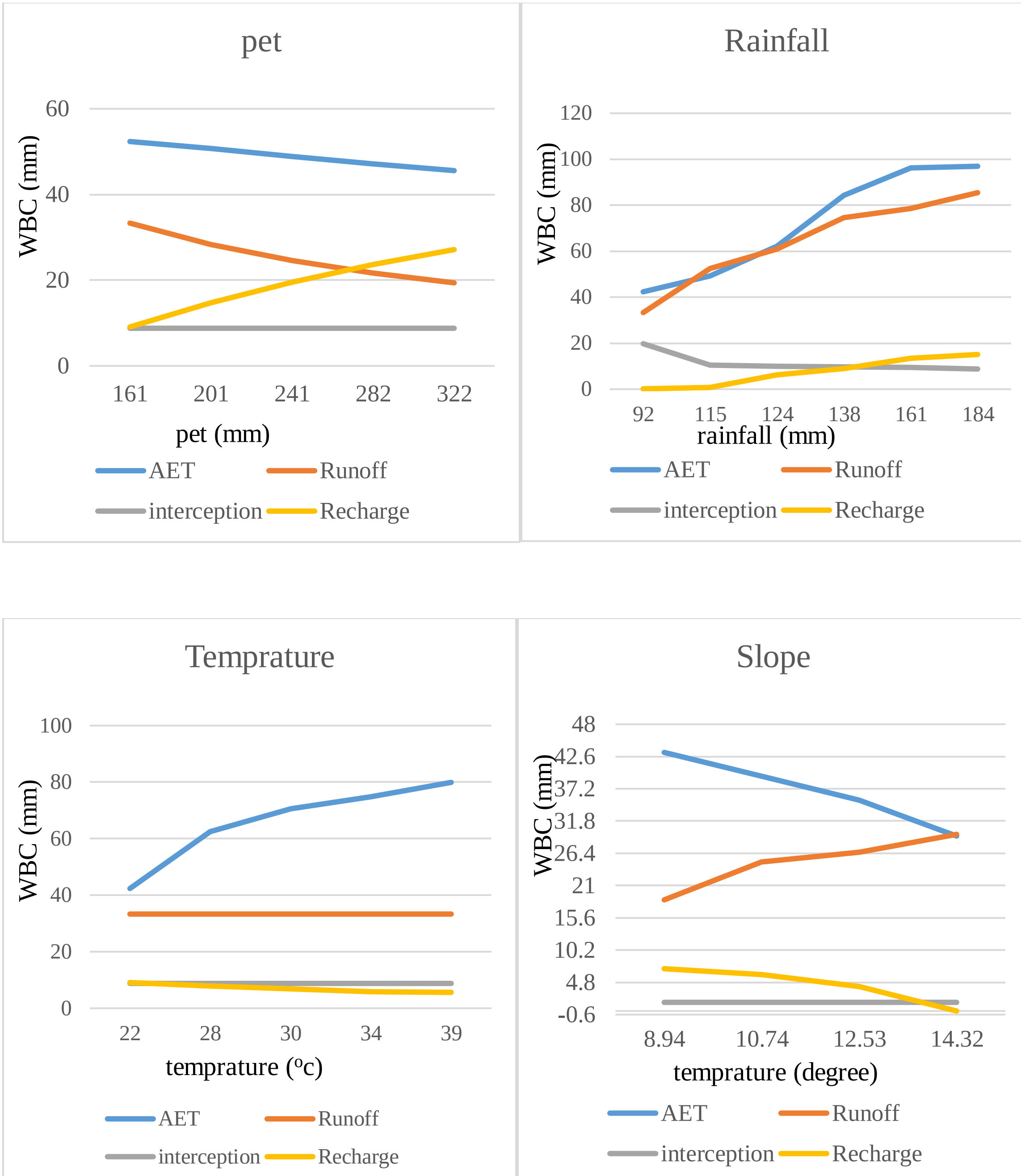



Figure 4.2: Sensitivity of water balance component with changing different input variables

## 4.2. WetSpass model Calibration

Calibration of the model result was performed based on manually adjusting the different parameters placed on the model with range values. The parameters are namely: alfa coefficient, “a” interception, Lp coefficient and runoff delay factor “x”. the parameters were kept optimizing up to reaching the goodness of fit between the simulated and observed stream discharge recorded at Jewha river gauge station.

The model calibration was done by simulated volumetric runoff and base flow Values. The model result shows that the annual value of runoff in Jewha watershed is vary in range from 79.75mm to 831.5mm as a minimum and maximum value respectively, with a mean of 299.5mm in depth ratio. The mean value accounts about 35% of the total annual rainfall of the watershed. The seasonal variation of runoff value in the watershed is 176.9mm and 122mm in summer (Jun to September) and winter (October to May) seasons respectively. Also, the volumetric ratio of the surface runoff and base flow to streams has been simulated by WetSpass model.

The surface runoff that flows to a stream in winter season is simulated as 65,487,498$m^3$ and the base flow values in the same season is 86,086,237$m^3$. Whereas, the flow of surface runoff and base flow in summer season is 10,483,417$m^3$ and 14,516,170 $m^3$. The result indicates that the base flow value is higher contribution than the surface runoff to Jewha-Negesso River. This is because, the perennial characteristics of the river. Which means, base flow to the river is occurred permanently. while surface runoff (overland flow) is seasonal depending on the amount of rainfall in the watershed.

The total flow in a stream or river from a watershed is a function of Q base flow and Q surface runoff which is equivalent to the long-term monthly average river discharge from the watershed (Abdollahi, et al., 2017). The summation of base flow and surface runoff simulated by WetSpass model is used to calibrate the model with ground observed stream flow data obtained from Jewha gage station. An $EC_{NS}$ of 0.74 and a correlation of coefficient of determination $R^2$ of 0.91 were obtained with the parameters of the optimal soil moisture alfa coefficient value of “x” = 9.5, LP = 0.1, interception parameter “a” = 9.5, and a runoff delay factor “x” = 0.57.

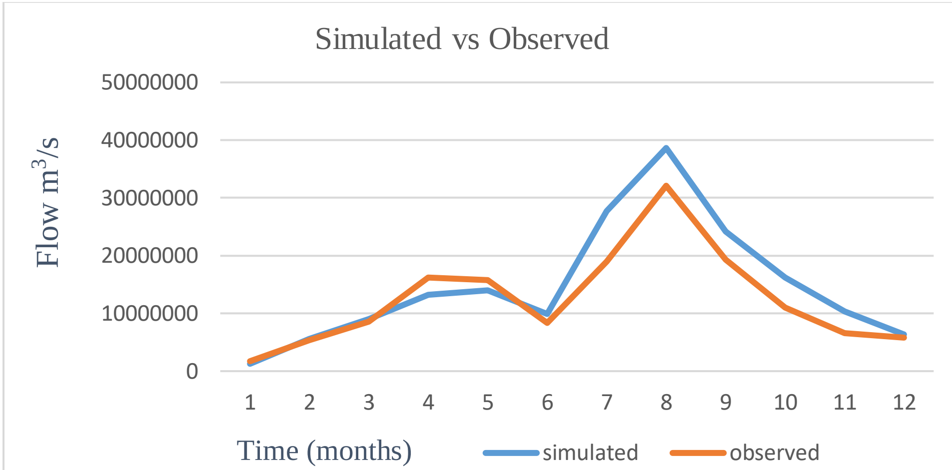



Figure 4.3: Compression between simulated and observed flow data

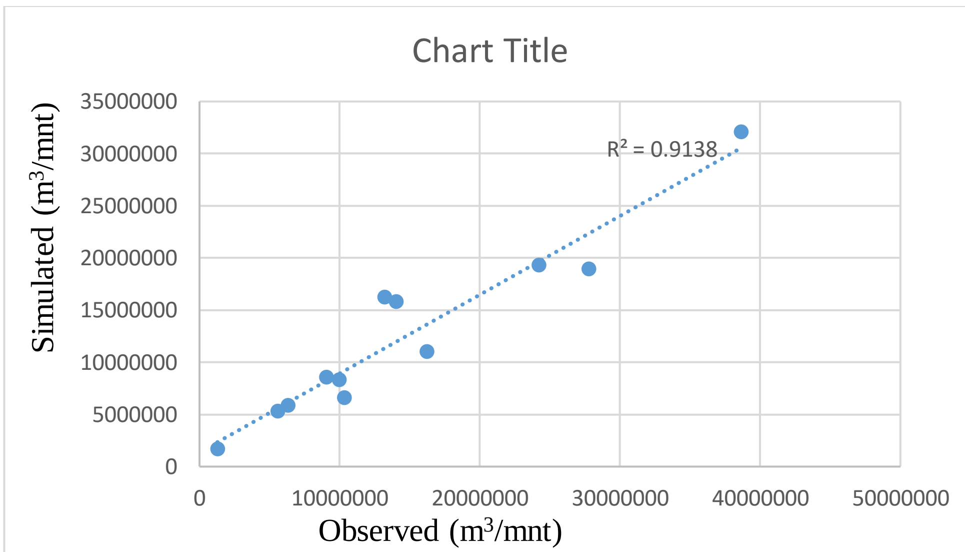



Figure 4.4: Model calibration using coefficient of determination

Table 6: Estimated water balance components with respect to rainfall in Jewha watershed

| **Evapotranspiration** | **Runoff** | **Interception** | **Recharge** | **Balance error** |
|---|---|---|---|---|
| 0.53 | 0.22 | 0.13 | 0.15 | 0.3 |

The annual contribution of water balance components as a percentage of the precipitation is presented in Table 6. Evapotranspiration comprise the highest percentage, runoff is the second highest contribution in the watershed. Recharge and interception have a small contribution relatively with the other water balance components. The monthly simulated raster maps were summed up to get seasonal and annual values.

## 4.3. Outputs of WetSpass-M model

Jewha watershed is described well by WetSpass-M model. Because the model is spatiotemporally distributed and represent all characteristics of the watershed (hydrological, physical and meteorological) and detects both spatially and temporal changes of the water balance components of the watershed.

Monthly water balance components of the watershed are the main output of the model. Based on specific objectives of this research, the seasonal and annual values can obtain by summing up the monthly results, which are; seasonal and annual actual evapotranspiration (AET), surface runoff and recharge. A seasonal result stands for wet (Jun to September) and dry (October to May) season of the watersheds climate condition. The outputs are raster grid maps in which each pixel represents the magnitude of different water balance components of the Jewha watershed.

### 4.3.1 Actual evapotranspiration (AET)

The WetSpass-M model is calculated the actual evapotranspiration as a sum of evaporations from open water body, transpirations through vegetated cover, interception loss by vegetation and evaporation from bare soil. Actual evapotranspiration is a major component of water balance to determine groundwater recharge of Jewha watershed. The result showed that a minimum and maximum value of 277.9 and 2857mm with average of 436mm water is lost through evapotranspiration in a year from the watershed. This accounts for 53% of the watershed's rainfall. This is happened due to the high rate of radiation and the dry wind availability as well as presence of different land use land covers in the study area. the Jewha watershed is mostly covered by different vegetations like shrubs, trees and crops. This facilitates evapotranspiration by reducing surface runoff in the watershed.

The WetSpass model simulates the actual evapotranspiration in monthly base. To get the seasonal values for the water balance components of the watershed the monthly results has to be added in summer (Jun -September) and winter (October-May) seasons. In the same manner, the average values for the different water balance components have been obtained from summing up of the monthly results. The actual evapotranspiration in rainy season is 308.4mm with the standard deviation of 67.08 and the mean evapotranspiration in winter season is 127mm with the standard deviation of 152. The annual evapotranspiration from the watershed is simulated as a minimum and maximum value of 277.9mm and 2857mm with the mean value of 436mm respectively, and the standard deviation is 211.8. About 71% of the total annual evapotranspiration is lost during rainy season and the remaining 29% is released in dry season. The variation is made due to the difference in precipitation and other variables with in the two seasons. The soil moisture deficit is appeared following scarce in precipitation and it is responsible for decreasing evapotranspiration in winter season. During dry season, the water demand increases because crops and vegetations are need more water. Where as in summer season there is high duration, intensity and amount of precipitation distribution, high soil moisture, health vegetation and other land covers which accelerated evapotranspiration.

In terms of spatial distribution, the central to the eastern and northern part of the study area is relatively high evapotranspiration. Topographically lower part of the watershed has low evapotranspiration value which is low precipitation and vice versa. This is also due to land use land cover changes.

Table 7: Annual mean evapotranspiration value across different land cover types

| Land cover types | Evapotranspiration (mm) | | | | |
|---|---|---|---|---|---|
| Land cover | Area $km^2$ | Min | Max | Mean | STD |
| Natural forest | 76.4 | 279.7 | 2848.3 | 324.9 | 75.8 |
| Cropland | 283.6 | 278.0 | 2852.2 | 435.2 | 50.0 |
| Grassland | 17.8 | 283.6 | 2834.4 | 424.8 | 115.3 |
| Bare land | 28.5 | 283.0 | 2849.4 | 480.3 | 161.1 |
| Shrubs | 73.5 | 279.7 | 2854.5 | 449.0 | 95.8 |
| Plantation | 24.2 | 280.9 | 555.8 | 408.7 | 32.5 |
| Riverine vegetation | 10.0 | 284.1 | 2857.2 | 1179.1 | 1160.6 |
| Swamp | 0.0 | 1228.5 | 1228.5 | 1228.5 | 0.0 |
| Urban & rural Settlement | 0.9 | 354.1 | 2849.1 | 397.9 | 264.7 |

Meanwhile, the simulated map shows that the evapotranspiration value in riverine vegetation area in the river course is very high. this is because the consistent flow of water through perennial rivers (Figure 37). As shown in Table 7**.** Swamp area also has high evapotranspiration value. According to WetSpass model result, land use/land cover and precipitation are found to be the main input variables to control evapotranspiration in the watershed and evapotranspiration is the main hydrological process of water loss in the watershed which is a major water balance component that affects the recharge.

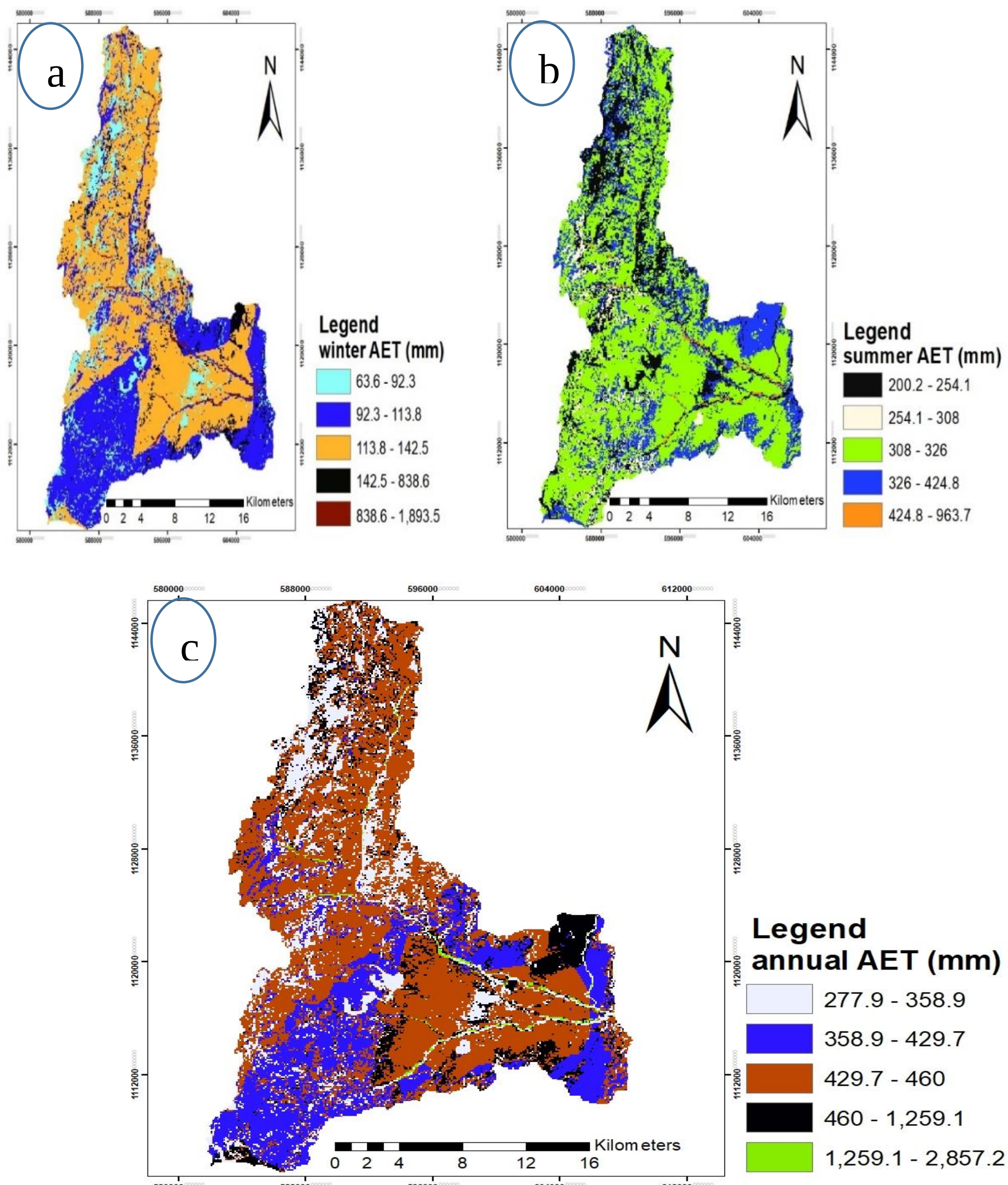



Figure 4.5: Figure: Simulated actual evapotranspiration map a) winter evapotranspiration b) summer evapotranspiration c) annual evapotranspiration map of Jewha watershed.

In addition, Interception value of the area is taken in account by the WetSpass model. Depending on the type of vegetation, the interception fraction represents a constant percentage of the annual precipitation value. Thus, the fraction decreases with an increase in an annual total rainfall amount (since the vegetation cover is assumed to be constant throughout the simulation period) (Batelaan & woldeamlak, 2007). The interception value in Jewha watershed is 30mm and 107mm in winter and summer seasons respectively. The total mean annual average value is 138mm with a standard deviation of 50.

### 4.3.2. Surface runoff

Different input variables and parameters are used by WetSpass-M model to calculate monthly surface runoff ($S_V$). It is a function of vegetation type, soil texture, slope and other meteorological characteristics of the watershed. The amount of runoff is highly variable depending on the above input variables in Jewha watershed.

The surface runoff $S_V$ value in Jewha watershed is highly variable spatially from place to place as well as seasonally in summer and winter. The model result shows that the annual value of runoff in Jewha watershed is vary in range from 79.75mm to 831.5mm as a minimum and maximum value respectively, with a mean of 299.5mm. The mean value accounts about 35% of the total annual rainfall of the watershed. The seasonal variation of runoff value in the watershed is 176.9mm and 122mm in summer (Jun to September) and winter (October to May) seasons respectively. From the total annual runoff 59% to be occurred in summer (wet) and the rest 41 % is flow in winter (dry) seasons.

The runoff value is highly depending on runoff coefficients. The runoff coefficient also highly influenced by the change in soil moisture, infiltration capacity, land use/land cover and the amount and intensity of rainfall. the seasonal variation in Jewha watershed is mostly due to amount of rainfall. during the wet season the rainfall exceeds the infiltration capacity of soil which leads to high surface runoff.

The Jewha watershed is located in the western margin of Rift system in Awash river basin. The western part of the watershed's boundary is a surface water divide between Abay and Awash basins. This leads to the area has high elevated and steep slopes. The simulated map shown that surface runoff in the watershed starts from the North west and South west part of the area (high cliff) to the Eastern part (lowland).

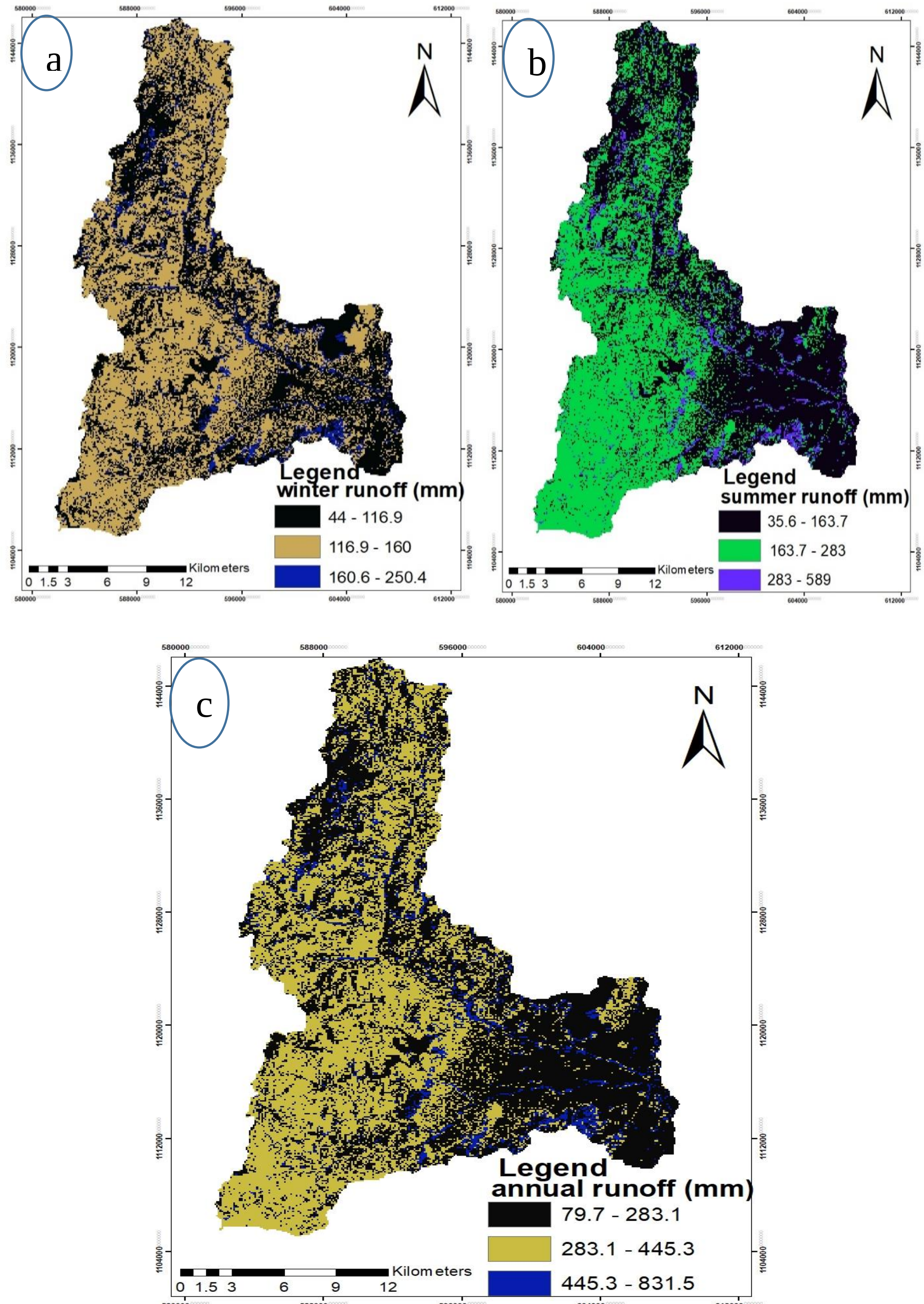



Figure 4.6: Runoff maps of Jewha watershed; a) winter runoff b) summer runoff c) annual runoff

The spatial variation of surface runoff value in the watershed is highly depending on different biophysical factors such as slope. The sensitivity analysis shows that the variation in slope has a significant effect on surface runoff (Figure 35). The slope of Jewha watershed is very high, about 62 % of the total area is between $15^{o}$ and $74^{o}$ .in terms of topography. in addition,54% of the area is between 2000m and 3554 m elevation above m.s.l. due to this, the runoff value is highly deviate from place to place. As shown on the map (Figure 38) high runoff value is occurred on south west and north west part of the elevated areas, and the lowest runoff hosted in the east part of the watershed. Which means the outlet of the watershed's river is located in the eastern part and the runoff flow is from mountainous area to this outlet. Following the river course, the runoff value is very high in both seasons this is due to perennial characteristics of the river.

Table 8: Annual mean Runoff value in different land use types

| Land cover | Surface runoff | | | | |
|---|---|---|---|---|---|
| Land cover | Area km2 | Min | Max | Mean | STD |
| natural forest | 76.4 | 124.2 | 826.4 | 260.7 | 51.1 |
| Cropland | 283.6 | 79.7 | 809.9 | 299.4 | 46.6 |
| Grassland | 17.8 | 142.6 | 815.5 | 286.0 | 64.7 |
| Bar land | 28.5 | 133.6 | 817.5 | 450.2 | 128.2 |
| shrubs | 73.5 | 110.8 | 826.6 | 264.8 | 62.2 |
| Plantation | 24.2 | 209.0 | 611.1 | 318.1 | 37.7 |
| Riverine vegetation | 10.0 | 93.0 | 831.5 | 404.1 | 282.6 |
| Swamp | 0.0 | 366.1 | 366.1 | 366.1 | 0.0 |
| settlement | 0.9 | 196.0 | 768.9 | 332.4 | 64.0 |

The land cover types which are Bare land and riverine vegetation are hosted high runoff rate annually in Jewha watershed (Table 8), In contrary, natural forest crop land, grassland and plantation have low runoff. This is due to low runoff coefficient value of the listed land cover types. the slope value of the topography also significantly affects the runoff, it has a direct relationship with rate of surface runoff;

The WetSpass model also simulates the monthly surface runoff and base flows in volumetric ratio from the watershed. The sum of this value is equivalent with the observed stream flow data obtained from river gage stations in Jewha watershed. This value has been used to calibrate model results (model performance).

### 4.3.3. Groundwater recharge

The amount of infiltration-percolation into groundwater recharge depends on different factors such as slope, land use soil texture and groundwater level (Al Kuisi & El-Naqa, 2013). There are different models to estimate recharge in a given area depending on actual areal conditions. In this case the WetSpass model estimates monthly long-term spatiotemporal distribution of groundwater recharge of Jewha watershed by subtracting surface runoff and evapotranspiration from precipitation. The model determines the monthly groundwater recharge depending on different input variables. Recharge is estimated as the residual of the water balance components from precipitation. Due to this, it is responds to variations and sensitive with varying in different input variables and model parameters.

$$P\text{-}ET\text{-}Sy\text{-}R=0 \qquad \textit{Eq 4.1}$$

Where P is precipitation, ET evapotranspiration, Sy surface runoff and R recharge. According to the WetSpass result, the annal recharge of the Jewha watershed is between 0 and 404mm as a minimum and maximum value respectively, with a mean of 124mm and standard deviation of 72. The estimated mean annual groundwater recharge is proportional to 64,450,240m$^3$/year. This represents 15% of the total annual rainfall. About 87% (107.7mm) of the total annual groundwater recharge of the watershed is occurred in the summer (Jun to September) season, and the remaining 13% (16.5mm) groundwater recharge is percolate in dry (October to May) season. This temporal variation is made due to the variation of different climatological and biophysical input parameters, mainly rainfall. There is high duration, intensity and amount of precipitation distribution and high soil moisture in the summer season which accelerated groundwater recharge.

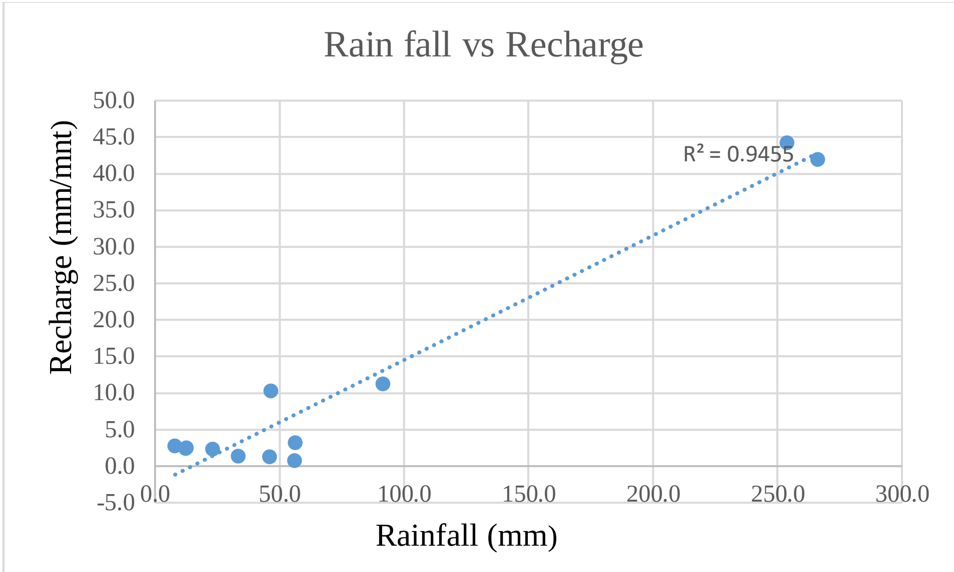



Figure 4.7: The relationship between rainfall and monthly recharge

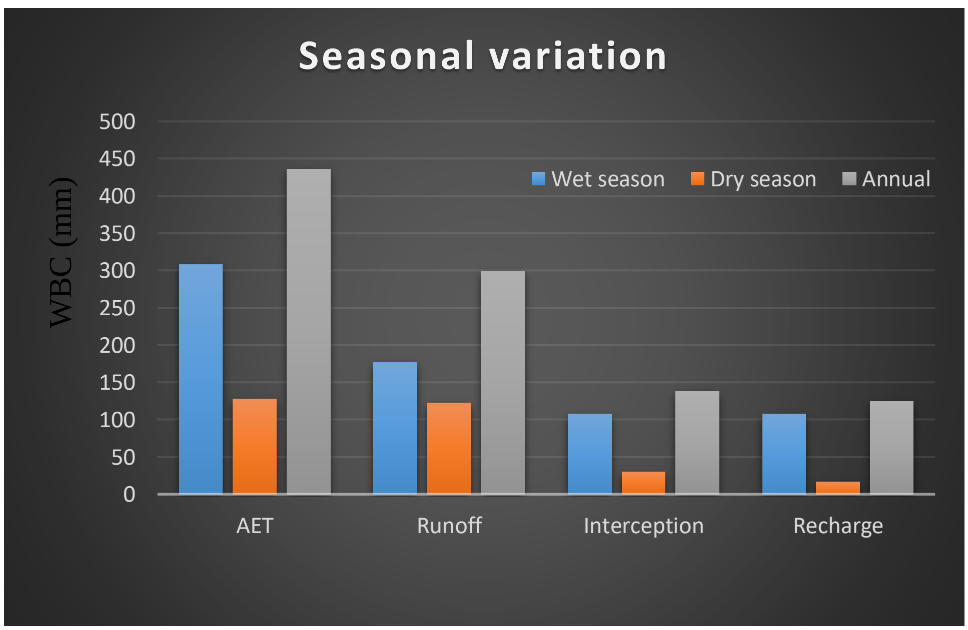



Figure 4.8: Temporal variation of water balance components in Jewha watershed

As discussed above in Figure 35. groundwater recharge is highly sensitive to variation in rainfall, potential evapotranspiration and other biophysical elements. Groundwater recharge can be negative or zero values in a given watershed. The negative value indicates that evapotranspiration exceeds to precipitation. In the case Jewha watershed, the minimum value is zero (0).

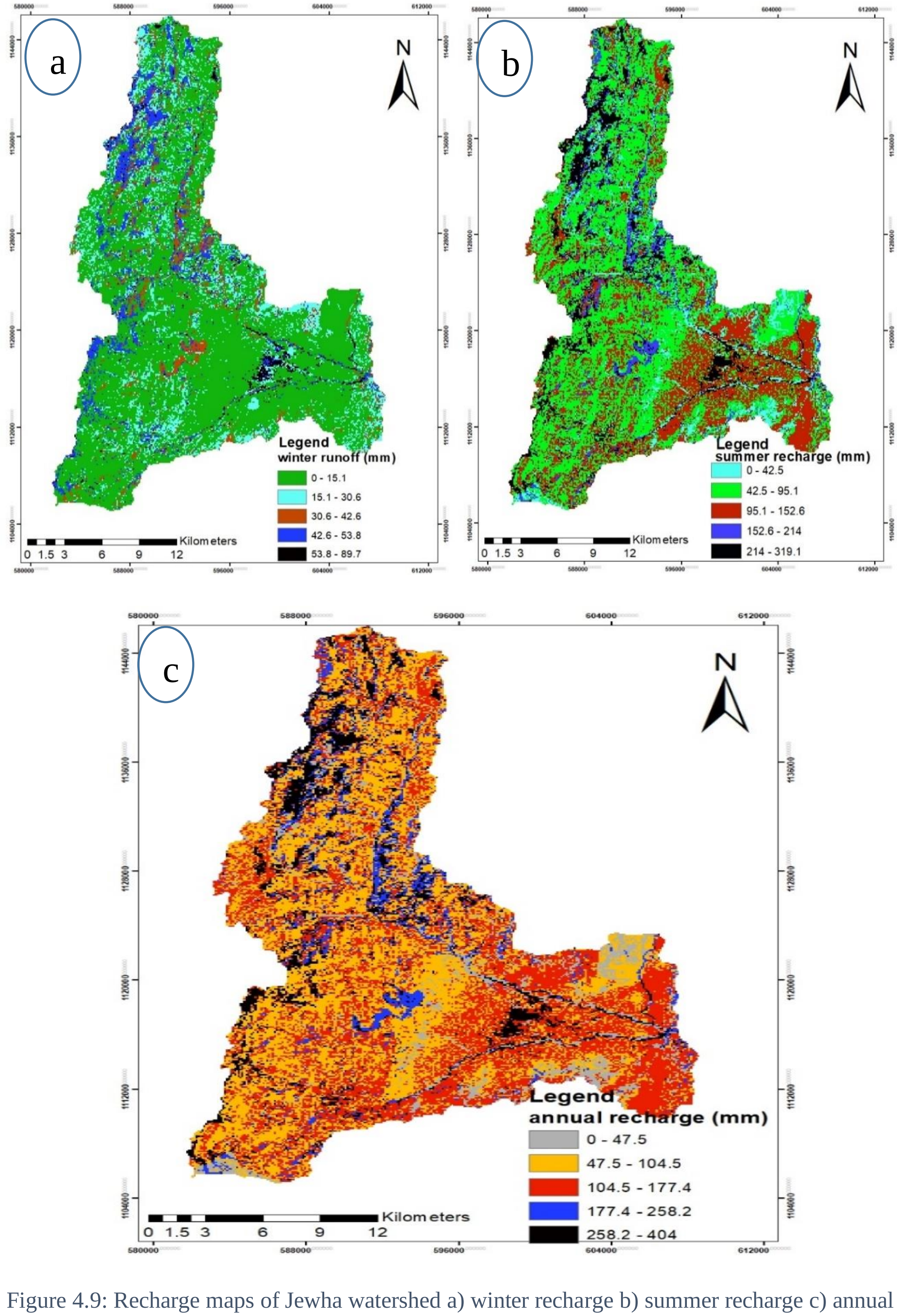



Figure 4.9: Recharge maps of Jewha watershed a) winter recharge b) summer recharge c) annual recharge

The groundwater recharge distribution in Jewha watershed also vary spatially from place to place. The north western and eastern part of the watershed is receiving more recharge. This is due to good permeability of these soils, mixed forest and crop coverage of land uses and gentle slope topography. the south western part of the area receives relatively low groundwater recharge. This is caused by the high gentle slope.

The geological characteristics of the area is also affecting the rate and amount of recharge over the area. Recharge in geological formation depends on the permeability of the rock. The rock permeability governed by the degree of weathering, fracture, availability of joints and other structural features. In Jewha watershed, different rock types are available. the local geology of the area discussed in 3.1.6, the mountainous part is moderately to highly weathered and fractured aphanitic basalt, rhyolite and volcanic tuff. In the lowland area of the watershed alluvial deposit is the main geological unit. The geological map shows that there are different regional and local structural features over the area, these features are highly significant for the infiltration-percolation-recharge processes. In addition, they are important by giving information about direction of flows.

Table 9: Distribution of groundwater recharge in different land use types

| Land cover types | | | Recharge (mm) | | | |
|---|---|---|---|---|---|---|
| Land cover | Area $km^2$ | Area % | Min | Max | Mean | STD |
| Natural forest | 76.37 | 14.8 | 0 | 404.1 | 244.8 | 66.1 |
| Cropland | 283.61 | 55.1 | 0 | 358.6 | 101.7 | 32.8 |
| Grassland | 17.76 | 3.5 | 0 | 362.1 | 134.4 | 54.1 |
| Bare land | 28.51 | 5.5 | 0 | 351.1 | 39.4 | 71.0 |
| Shrubs | 73.46 | 14.3 | 0 | 362.3 | 112.5 | 46.7 |
| Plantation | 24.16 | 4.7 | 0 | 330.7 | 121.8 | 44.6 |
| Riverine vegetation | 10 | 1.9 | 0 | 349.8 | 157.4 | 127.4 |
| Swamp | 0.01 | 0.0 | 67.7 | 67.7 | 67.7 | 0.0 |
| Settlements | 0.88 | 0.2 | 0 | 168.5 | 109.4 | 27.6 |

In Jewha watershed, there is high evapotranspiration and runoff value than groundwater recharge because the highland (mountainous) part of the watershed is covered by shrubs and bare land which is suitable for evapotranspiration and as well as more than half part of the area is steep slopes, in which this facilitates surface runoff by reducing ground water recharge. As shown in Table 9 above, the highest recharge rate in Jewha watershed is occurred in natural forest, riverine vegetation, grassland land cover types. While, the low rate of recharge occurred in bare land and swamp areas. In bare areas, rate of runoff is higher than rate of recharge. Because bare areas don't have a capability of holding water for sufficient time for infiltration-percolation process. In addition to this, the high slop characteristics of Jewha watershed is great significance for runoff process. In the same manner, in swamp areas, rate of evapotranspiration is much higher than rate of recharge and runoff. the recharge rate in swamp area is low. this is because, no difference in distance(depth) between the depth of groundwater table and surface elevation. That means the groundwater table is near to the earth's surface.

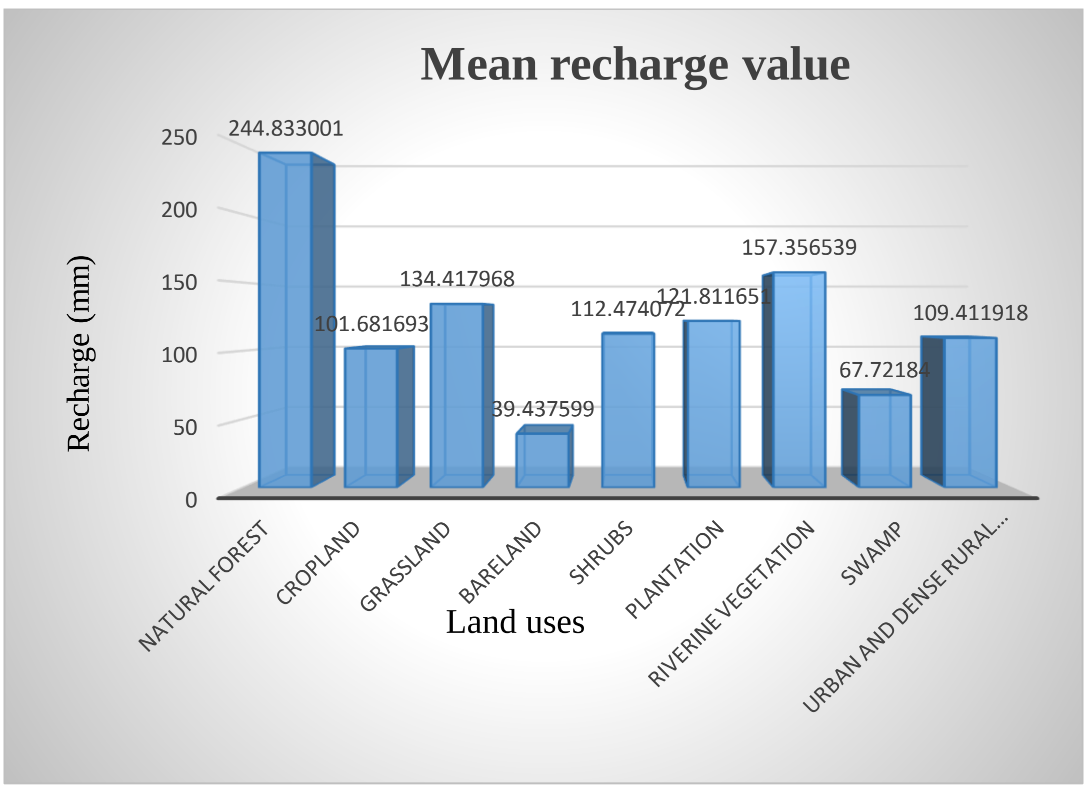



Figure 4.10: Spatial variation of recharge in Jewha watershed

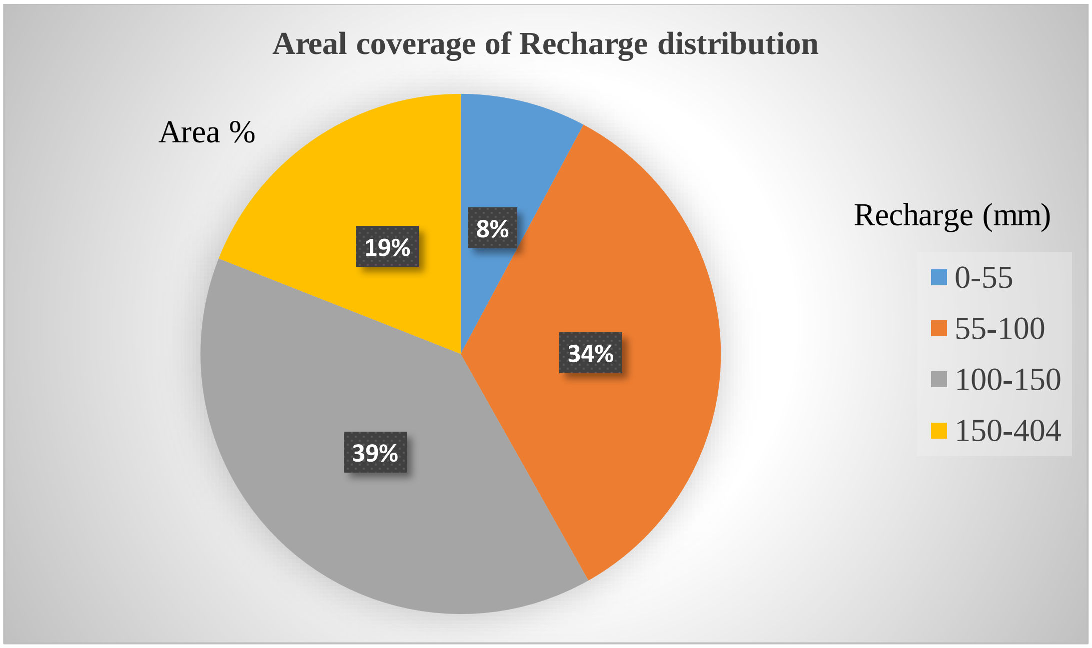



Figure 4.11: Areal coverage distribution of groundwater recharge in Jewha watershed

The result of the WetSpass model has been calibrated with the observed steam flow data, and resulted in good agreement. This leads to say that the result of the ground water recharge and other water balance components are represent the Jewha watershed.

## 4.4. Sustainable yield of Jewha watershed

Under natural or equilibrium conditions, recharge is balanced. In the long term, by discharge from the aquifer in to a stream, spring, or seep. Consequently, if pumping equals recharge eventually streams, marshes, and springs dry up. Continued pumping in excess of recharge also eventually also depletes the aquifer (Sophocleas, 1997). The annual abstraction of groundwater in Jewha watershed from annual recharge through wells is 8111059.2m3/year, which is 13% of the total mean annual ground water recharge (64,450,240m3/year). This value is obtained from the daily abstraction rate of ground water through wells. the discharge through stream, marsh, springs are not taken in to account in this value.

According to (Sophocleas, 1997) the sustainable yield of a certain watershed is range from 10 to 70 % of the total groundwater recharge. In doing so, the Jewha watershed has an efficient groundwater resource and the current withdrawal is only 13% of the total annual ground water recharge.

### 4.5. Groundwater recharge and discharge areas

A recharge zone can be defined as that a part of watershed or a drainage basin in which the net saturated flow of water is directly away from land surface to water table which is lies immediately below the surface or after deep unsaturated zone. whereas discharge zone can be defined as the movement of the net saturated flow of groundwater is directed toward the surface and the water table usually lies at or very close to the surface (Freeze & Cherry, 1979) topographically elevated part of a given watershed is mostly considered as recharge areas and topographically lowland areas are considered as a discharge zone. Indeed, groundwater is discharged as spring from highlands.

As showed in (Figure 39) elevated (mountainous) part of the watershed which located in north west have high recharge, whereas the lowland area located in eastern part of the watershed is relatively low recharge and considered as discharge area. Indeed, there are different biophysical factors in combination with elevation to govern groundwater recharges. Such as land use, soil texture and elevation if the area have sufficient precipitation.

# CHAPTER FIVE

## 5. Conclusion and Recommendation

### 5.1 conclusion

Water resource is a critical element to sustain life and it should be investigating and understand the hydrological environment for planning, managing and proper utilization of water resource. Now a days. Surface water use is decreasing due to different reasons like contamination and pollution and the water resource concentration is leading to groundwater. So as the available resource should be investigated. There are different physical and empirical models to understand the water balance components of a given watershed. One of the spatially distributed physical models is WetSpass model. the model considers all meteorological, hydrological and biophysical factors of the area. In order to evaluate groundwater recharge and other water balance component of the watershed hydro-meteorology, land use, soil texture, topography and slope of the area has been in investigated.

The WetSpass-M model has been simulated the seasonal and annual water balance components of Jewha watershed successfully. The highly variable distribution of the climatic inputs (parameters) associated with variation of land use/land cover, soil texture, topography and slope are responsible for variations of the water balance element within the watershed. Based on the model, the annual ground water recharge in Jewha watershed is 0 and 404mm as a minimum and maximum value with a mean of 124mm, which is represent 15% of the total annual rainfall. 87% (107.7mm) of the recharge is occurred in summer (Jun to September) and the rest 13% (16.5mm) of recharge percolate in winter (October to May).

The sensitivity analysis of the different input variables was conducted and most of the variables are highly sensitive in Jewha watershed. The results of the analysis show that rainfall, potential evapotranspiration and slope are the most important hydrologic process in the study area in terms of affecting the amount and rate of the different water balance components. The sensitivity results show further that rainfall as input to the system is a critical variable, while, uncertainties in this quantity result in uncertainties in the simulations. Evapotranspiration also plays an important role. in the same manner the parameters sensitivity analysis has been performed. The alfa coefficients, interception coefficients and *Lp* coefficient is relatively sensitive.

The calibration was made between the simulated and observed water balance component value of the watershed. The result showed that the simulated results of the WetSpass -M model is in best fit (good agreement) with the observed long-term average values of the watershed. The calibration process has been made through coefficient of determination($R^2$) and the Nash- Shuttle efficiency (NSE). The result shows that, the observed and simulated value is in good fit by $R^2$ of 0.91 and NSE of 0.74.

The annual rainfall is distributed to different water balance components and in Jewha watershed. From this most of the rainfall amount is back to the hydrological cycle through evapotranspiration and the less remaining part is distributed to runoff and ground water recharge. Topographically high elevated areas which is located in the north west part of the watershed in combination with natural forests have high ground water recharges. According to (Sophocleas, 1997) the sustainable yield of a certain watershed is range from 10 to 70 % of the total groundwater recharge. In doing so, the Jewha watershed has an efficient groundwater resource and the current withdrawal is only 13% of the total annual ground water recharge

## 5.2 Recommendation

The results obtained from this study can be taken as an initial investigation in the groundwater recharge modeling of Jewha watershed. The groundwater recharge and other water balance components result can be improved further and reached to more accurate if more monitored seasonal groundwater depth data, new and sufficient borehole data, soil and land use data that is prepared in fine resolution and new meteorological stations become available at the watershed. Because the GIS based WetSpass model is highly sensitive to those in put data.

- This study will be an input for further investigation as well as for water resources planning purpose, design and developmental activities.
- Based on the WetSpass model result, the Jewha watershed has sufficient groundwater resources. and it is highly suitable for different agricultural activities. More water based developmental activities also can be made using the groundwater

resources by drill more boreholes based on the estimated annual groundwater recharge.

- Sufficient groundwater level monitoring wells should be placed in the whole watershed in order to understand the general seasonal fluctuations in ground water levels. This helps to estimate the ground water recharge in different methods and important for WetSpass model validation test.
- The future groundwater resources development and improvement should be based on the results of water balance components obtained from this modeling.
- The estimated result also great significance for rainfall-runoff modeling and hydro-meteorological change studies in a hydrological environment.

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# Appendix

**Annex I**: Monthly average PET value of Different stations around Jewha watershed

| Months | Alemketema | Ataye | Mezezo | Shewarobit |
|---|---|---|---|---|
| January | 118.9 | 105.9 | 90.1 | 107.9 |
| February | 124.5 | 107.8 | 91.1 | 110.3 |
| March | 134 | 130.9 | 109 | 125.1 |
| April | 129.9 | 127.4 | 104 | 136 |
| May | 143.7 | 156.7 | 120.3 | 145.6 |
| June | 109.7 | 159.1 | 111.8 | 151.4 |
| July | 88.2 | 134.5 | 92.4 | 153.7 |
| August | 84.7 | 122.5 | 97.3 | 137.9 |
| September | 95.4 | 113.5 | 99.9 | 140.1 |
| October | 130.4 | 117.8 | 104.9 | 145.5 |
| November | 126 | 105.8 | 98.6 | 120.7 |
| December | 121.4 | 99.7 | 89.9 | 108.1 |

**Annex II**: Monthly average rainfall value of Different stations around Jewha watershed

| Months | Alemketema | Ataye | Mezezo | Shewarobit |
|---|---|---|---|---|
| January | 13.58 | 23 | 6 | 7 |
| February | 30.81 | 41 | 18 | 44 |
| March | 54.29 | 79 | 55 | 37 |
| April | 53.76 | 94 | 43 | 34 |
| May | 53.9 | 62 | 34 | 35 |
| June | 70.79 | 33 | 68 | 15 |
| July | 258.32 | 238 | 320 | 249 |
| August | 226.29 | 245 | 293 | 251 |
| September | 105.76 | 114 | 98 | 49 |
| October | 26.1 | 34 | 28 | 5 |
| November | 12.56 | 21 | 13 | 4 |
| December | 5.22 | 17 | 4 | 6 |

**Annex III**: Monthly average temperature value of Different stations around Jewha watershed

| Months | Alemketema | Ataye | Mezezo | Shewarobit |
|---|---|---|---|---|
| January | 18.8 | 17.2 | 12.1 | 22 |
| February | 20 | 18.3 | 13.1 | 22.5 |
| March | 20.2 | 19.7 | 14.3 | 24.1 |
| April | 20.7 | 20.3 | 15.3 | 25.7 |
| May | 20.6 | 21.7 | 17 | 26.5 |
| June | 19.5 | 23.2 | 16.8 | 28.7 |
| July | 16.5 | 21.5 | 14.5 | 27.2 |
| August | 16.5 | 20.6 | 15.6 | 25.7 |
| September | 17.7 | 19.8 | 15.3 | 26 |
| October | 18.7 | 18.2 | 13.3 | 24.5 |
| November | 18.2 | 17 | 13.1 | 21.7 |
| December | 18.3 | 16.6 | 11.8 | 20.6 |

**Annex IV**: Monthly average wind speed value of Different stations around Jewha watershed

| Months | Alemketema | Ataye | Debre Birhan | Shewarobit |
|---|---|---|---|---|
| January | 6.48 | 5.76 | 2.88 | 4.32 |
| February | 7.2 | 6.48 | 2.88 | 4.32 |
| March | 7.2 | 6.48 | 3.6 | 4.68 |
| April | 6.48 | 5.76 | 3.6 | 4.68 |
| May | 7.2 | 7.2 | 4.32 | 5.4 |
| June | 4.32 | 7.92 | 5.4 | 6.12 |
| July | 4.32 | 7.2 | 4.32 | 7.92 |
| August | 4.32 | 5.76 | 3.6 | 7.92 |
| September | 4.68 | 4.32 | 2.88 | 6.48 |
| October | 7.92 | 4.32 | 2.88 | 7.2 |
| November | 7.92 | 4.32 | 2.88 | 4.32 |
| December | 7.2 | 6.12 | 3.6 | 4.32 |

**Annex V**: Boreholes with hydrological characteristics

| Well id | x | Y | Depth | SWL | Q | T | T class |
|---|---|---|---|---|---|---|---|
| JWTW1 | 602800 | 1117220 | 195 | 0 | 68 | 229 | Moderate |
| JWTW2 | 604659 | 1117744 | 220 | 5.6 | 40 | 60 | Moderate |
| Mutifecha1 | 604286 | 1117981 | 200 | 5.9 | 32 | 95 | Moderate |
| Mutifecha2 | 605981 | 1119894 | 151 | 20 | 3.5 | 44.8 | Low |
| Bete | 606586 | 1123564 | 84 | 48 | 3.5 | | |
| Jewuha1 | 606303 | 1116779 | 119.3 | 1 | 6.2 | 98.83 | Moderate |
| Jewuha2 | 606269 | 1116617 | 162 | 5.2 | 22 | 35.3 | Low |
| Balchi/Tikure | 601593 | 1114778 | 196 | 5.5 | 30 | 410 | Moderate |
| Balchi | 603637 | 1114883 | 203.3 | 11.1 | 28 | 475 | Moderate |
| Gimb | 596488 | 1122774 | 150.5 | 13.3 | 24 | 50.5 | Moderate |

**Annex VI**: Four months rainy days in Jewha watershed

| Code | Rainy Days | Code | Rainy Days |
|---|---|---|---|
| 1 | 1 | 25 | 1 |
| 2 | 3 | 26 | 3 |
| 3 | 2 | 27 | 1 |
| 4 | 1 | 28 | 4 |
| 5 | 1 | 29 | 1 |
| 6 | 5 | 30 | 6 |
| 7 | 17 | 31 | 11 |
| 8 | 15 | 32 | 16 |
| 9 | 11 | 33 | 12 |
| 10 | 3 | 34 | 3 |
| 11 | 1 | 35 | 1 |
| 12 | 2 | 36 | 1 |
| 13 | 1 | 37 | 4 |
| 14 | 2 | 38 | 1 |
| 15 | 3 | 39 | 3 |
| 16 | 4 | 40 | 2 |
| 17 | 3 | 41 | 1 |
| 18 | 7 | 42 | 7 |
| 19 | 15 | 43 | 14 |
| 20 | 14 | 44 | 13 |
| 21 | 21 | 45 | 9 |
| 22 | 2 | 46 | 2 |
| 23 | 1 | 47 | 1 |
| 24 | 2 | 48 | 1 |

**Annex VII**: Observed monthly average stream flow data

| Month | Year | | | | | | | | Flow |
|---|---|---|---|---|---|---|---|---|---|
| year | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | (MCM) |
| Jan | 7.326 | 16.911 | 4.177 | 10.651 | 4.915 | 4.516 | 1.411 | 7.407 | (MCM) |
| Feb | 5.747 | 12.059 | 2.249 | 25.894 | 1.62 | 3.315 | 2.103 | 2.059 | (MCM) |
| Mar | 6.132 | 19.398 | 3.644 | 14.101 | 3.134 | 2.881 | 14.865 | 2.593 | (MCM) |
| April | 4.106 | 6.357 | 6.593 | 2.414 | 1.366 | 2.605 | 7.725 | 3.876 | (MCM) |
| May | 1.825 | 30.998 | 1.49 | 2.525 | 1.404 | 1.915 | 5.993 | 0.743 | (MCM) |
| Jun | 1.967 | 16.048 | 3.496 | 1.827 | 1.309 | 0.823 | 5.608 | 1.475 | (MCM) |
| July | 14.104 | 20.56 | 20.921 | 23.685 | 47.782 | 23.054 | 22.59 | 6.816 | (MCM) |
| Aug | 51.604 | 28.439 | 57.663 | 90.976 | 61.353 | 56.003 | 47.955 | 26.952 | (MCM) |
| Sept | 47.089 | 11.379 | 3.561 | 26.541 | 21.295 | 29.689 | 21.607 | 15.796 | (MCM) |
| Oct | 22.402 | 7.41 | 39.61 | 9 | 25.973 | 28.578 | 4.224 | 4.297 | (MCM) |
| Nov | 19.433 | 2.1 | 17.914 | 6.091 | 7.905 | 15.616 | 3.321 | 0.318 | (MCM) |
| Dec | 9.232 | 1.802 | 11.941 | 4.827 | 5.595 | 5.668 | 3.805 | 3.146 | (MCM) |

**Annex VIII**: Simulated monthly stream flow data ($m^3$/month)

| Months | Simulated Q Surf[$m^3$/mnt] | Simulated Q base[$m^3$/mnt]) | Simulated Q surf + Q base [$m^3$/mnt] |
|---|---|---|---|
| Jan | 1116707.207 | 156523.192 | 1273230.4 |
| Feb | 5366468.573 | 203148.649 | 5569617.22 |
| Mar | 8677469.173 | 359358.766 | 9036827.94 |
| April | 12893834.67 | 317764.271 | 13211598.9 |
| May | 13692241.07 | 320615.411 | 14012856.5 |
| June | 9041032.006 | 905453.276 | 9946485.28 |
| July | 24381420.56 | 3397890.47 | 27779311 |
| Aug | 33228387.42 | 5418680 | 38647067.4 |
| Sept | 19435397.45 | 4794146.41 | 24229543.9 |
| Oct | 12471202.19 | 3745368.89 | 16216571.1 |
| Nov | 7357920.083 | 2971950.68 | 10329870.8 |
| Dec | 3911655.501 | 2408687.23 | 6320342.73 |

**Annex IX**: Land use parameter table of Jewha watershed.

| Code | LUSE_ TYPE | RUNOFF_ VEG | VEG_ AREA | BARE_ AREA | IMP_ AREA | OPENW_ AREA | ROOT_ DEPTH | LAI | MIN_ STOM | VEG_ HEIGHT | N Manning | Land Factor | Aerodyn Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | build up | grass | 0.5 | 0 | 0.5 | 0 | 0.3 | 2 | 100 | 0.12 | 0.04 | 0.5 | 212 |
| 7 | excavation | bare soil | 0 | 1 | 0 | 0 | 0.05 | 0 | 110 | 0.001 | 0.09 | 0.222 | 426.7 |
| 10 | Open build up | grass | 0.6 | 0.1 | 0.3 | 0 | 0.3 | 2 | 100 | 0.12 | 0.045 | 0.444 | 212 |
| 21 | agriculture | crop | 0.8 | 0.2 | 0 | 0 | 0.4 | 4 | 180 | 0.6 | 0.037 | 0.541 | 115 |
| 27 | maize and tuberous p | crop | 0.8 | 0.2 | 0 | 0 | 0.3 | 4 | 180 | 1.5 | 0.05 | 0.4 | 76.02 |
| 28 | wet meadow | grass | 1 | 0 | 0 | 0 | 0.3 | 2 | 100 | 0.3 | 0.055 | 0.364 | 152.5 |
| 31 | deciduous forest | forest | 1 | 0 | 0 | 0 | 2 | 5 | 250 | 18 | 0.1 | 0.2 | 27.2 |
| 33 | mixed forest | forest | 1 | 0 | 0 | 0 | 2 | 5 | 375 | 16 | 0.1 | 0.2 | 28.1 |
| 35 | heather | grass | 1 | 0 | 0 | 0 | 0.2 | 6 | 110 | 0.75 | 0.05 | 0.4 | 104.4 |
| 36 | shrub | grass | 1 | 0 | 0 | 0 | 0.6 | 6 | 110 | 2 | 0.05 | 0.4 | 66.33 |
| 44 | mud flat/salt marsh | open water | 0.4 | 0.2 | 0 | 0.4 | 0.3 | 2 | 110 | 0.5 | 0.035 | 0.571 | 124.2 |
| 51 | navigable river | open water | 0 | 0 | 0 | 1 | 0.05 | 0 | 110 | 0.001 | 0.02 | 1 | 426.7 |
| 303 | beech | forest | 1 | 0 | 0 | 0 | 2 | 6 | 320 | 20 | 0.4 | 0.05 | 26.46 |

**Land-use table attributes**

Luse_type = Land Use Type; Runoff_veg = Runoff Vegetation; Num_veg_Ro = Runoff class for vegetation type; Num_imp_Ro = Impervious Runoff class for impervious area types; Veg_area = Vegetated Area; Bare_area = Bare Area; Imp_area = Impervious Area; Openw_area = Open water Area; Root_depth = Root depth; LAI = Leaf Area Index; Min_stom= Minimum Stomatal Opening; Interc_per = Interception Percentage; Veg_height = Vegetation Height

**Annex X**: Soil parameter table of Jewha watershed.

| Code | SOIL | FIELD_ CAPAC | WILTING_ PNT | PAW | RESIDUAL_ WC | A1 | EVAPO_ DEPTH | TENSION HHT | P_FRAC_ SUM | P_FRAC _WIN | Teta |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Sand | 0.12 | 0.05 | 0.07 | 0.02 | 0.5 | 0.05 | 0.07 | 0.09 | 0.01 | 0.136 |
| 2 | loamy sand | 0.15 | 0.07 | 0.08 | 0.035 | 0.5 | 0.05 | 0.09 | 0.09 | 0.01 | 0.176 |
| 3 | sandy loam | 0.21 | 0.09 | 0.12 | 0.041 | 0.4 | 0.05 | 0.15 | 0.09 | 0.01 | 0.266 |
| 4 | silty loam | 0.29 | 0.1 | 0.19 | 0.015 | 0.4 | 0.05 | 0.21 | 0.26 | 0.07 | 0.408 |
| 5 | loam | 0.25 | 0.12 | 0.13 | 0.027 | 0.4 | 0.05 | 0.11 | 0.15 | 0.02 | 0.333 |
| 6 | silt | 0.3 | 0.1 | 0.2 | 0.04 | 0.4 | 0.05 | 0.61 | 0.09 | 0.01 | 0.429 |
| 7 | sandy clay | 0.26 | 0.16 | 0.1 | 0.068 | 0.3 | 0.05 | 0.28 | 0.54 | 0.3 | 0.351 |
| 8 | silty clay | 0.36 | 0.19 | 0.17 | 0.04 | 0.3 | 0.05 | 0.33 | 0.62 | 0.41 | 0.563 |
| 9 | Clay loam | 0.33 | 0.19 | 0.14 | 0.075 | 0.3 | 0.05 | 0.26 | 0.62 | 0.41 | 0.493 |
| 10 | sandy clay | 0.32 | 0.23 | 0.09 | 0.109 | 0.3 | 0.05 | 0.29 | 0.8 | 0.68 | 0.471 |
| 11 | silty clay | 0.43 | 0.27 | 0.16 | 0.056 | 0.2 | 0.05 | 0.34 | 0.84 | 0.75 | 0.754 |
| 12 | clay | 0.46 | 0.33 | 0.13 | 0.09 | 0.2 | 0.05 | 0.37 | 0.95 | 0.85 | 0.852 |

**Soil table attributes**

Number = Soil type number; Soil = Soil type (texture); Fieldcapac = Field capacity; Wiltingpnt = Wilting Point; PAW = Plant available water content; Residual = Residual water content; A1 = Calibration parameter dependent on the sand content of the soil; Evapodepth = Bare soil evaporation depth; Tensionsh = Tension saturated height; P_frac_sum = Fraction of summer precipitation contributing to Hortonian runoff; P_frac_win = Fraction of winter precipitation contributing to Hortonian runoff