



**AFRICA CENTER OF EXCELLENCE FOR WATER MANAGEMENT  
ADDIS ABABA UNIVERSITY**



**GROUNDWATER RECHARGE ESTIMATION AND WATER  
SUITABILITY EVALUATION: CASE STUDY OF UPPER FAFEM  
SUB CATCHMENT IN SOMALI REGIONAL STATE OF  
EASTERN ETHIOPIA**

By: MOHAMUD AHMED

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ADDIS ABABA UNIVERSITY



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Thesis submitted to:

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partial fulfillment of the requirement for the degree of Master of Science in  
water Management (**Hydrology and Water Resources Track**)

**May, 2021**

**Addis Ababa, Ethiopia**

AFRICA CENTER OF EXCELLENCE FOR WATER MANAGEMENT  
ADDIS ABABA UNIVERSITY

Thesis Approval form

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This is to certify that,we read this MSc thesis entitled “**Groundwater recharge estimation and water suitability evaluation at upper Fafem sub catchment**, in Somali region” that our understanding; it is fully adequate, in scope and quality, as aMSc thesis for the Degree of Master of Science in Water Management (**Hydrology and water resources track**).

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## Declaration

I, Mohamud Ahmed, hereby declaring that this study is my own work towards the MSc degree and that to the best of my knowledge, it contains no materials previously published by another person nor material which had been accepted for the award of any other university degree.

Mohamud Ahmed

signature.....

A handwritten signature in blue ink, appearing to read 'Mohamud', written over a dotted line.

## **Dedication**

I dedicate this thesis to:  
The sake of Allah, my Creator and my Master,  
My beloved parents  
My wife  
My children  
All my friends.

## **Acknowledgement**

First and foremost, praise be to Allah, the almighty, who has granted me countless blessings, knowledge and opportunity for completing my MSc thesis. Secondly, I would like to thank all those who have assisted me in doing this research. I am gratefully acknowledging my deepest gratitude to my supervisor professor Tenalem Ayenew, who have generously spent his time in giving the encouragement, guidance and comments until the completion of this thesis report. I am grateful to the Ethiopian Ministry of water, National meteorological agency, Somali region water works and supervision and geological survey of Ethiopia for providing me the necessary data in conducting this study.

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Finally, I would like to give my special thanks to my family, particularly my mother, Amina Mohamed and my wife Muna Yusuf, for their encouragement, support and prayers which were enabled me to conduct my MSc study and I am saying thank you for being my greatest inspirations and my deepest love goes to my children Mumtaz, Munazar and Mucad.

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## Acronyms

<b>AET</b>	Actual evapotranspiration
<b>AHP</b>	Analytical Hierarchy process
<b>DEM</b>	Digital elevation model
<b>GIS</b>	Geographic information system
<b>GWD</b>	Groundwater depth
<b>GWR</b>	Groundwater recharge
<b>Meq/l</b>	Milli equivalent per litter
<b>Mg/l</b>	Milligram per litter
<b>MoW&amp;I</b>	Ministry of water and Irrigation
<b>NMA</b>	National meteorological agency
<b>PET</b>	Potential evapotranspiration
<b>SRTM</b>	Shuttle radar topographic mission
<b>SRWW&amp;S</b>	Somali region water works and supervision
<b>SWBM</b>	Soil water balance method
<b>SWL</b>	Static water level
<b>USDA&amp;SCS</b>	United states department of agriculture and soil conservation service
<b>USGS</b>	United states geological survey
<b>Wetpass</b>	Water and energy transfer between soil, plants and atmosphere under Under quasi steady state

### **Abstract**

This study was conducted in upper Fafem sub catchment in Somali region which has an area of 1,300km<sup>2</sup>. Estimation of groundwater recharge and water quality for domestic and irrigation purposes of an area is very important for groundwater planning and management. There are number of methods used to estimate groundwater recharge. Wetspass model is one of the recharge estimation methods, this model simulates the recharge, run off and evapotranspiration in an annual and season bases. For estimating the recharge using wetspass, inputs of the model should be prepared in the form of digital maps using ArcGIS.

The inputs of the model are long term meteorological data (precipitation, temperature, wind and potential evapotranspiration) and physical characteristics of the catchment such as soil type, slope, land use/land cover, elevation and groundwater depth. For this study, long term average annual rainfall of 660.46 mm was distributed as 616 mm (93%) of actual evapotranspiration, 23 mm (4%) of groundwater recharge and 20 mm (3%) of surface run off.

Groundwater potential zones of upper Fafem sub basin were also identified using Remote sensing and GIS, the groundwater potential zones were classified as; low groundwater potential zone, moderate groundwater potential zone, high groundwater potential zone and very high groundwater potential zone. Most of the area is characterized by moderate groundwater potential, almost 52% of the area is characterized as moderate groundwater potential.

For evaluating groundwater suitability for drinking and irrigation purposes, eight water samples were collected from the boreholes in the study area. The laboratory result of the water samples was compared to the WHO and MoW&I standards. As a result, the groundwater of this catchment is suitable for drinking and irrigation purposes according to the laboratory results.

**Key phrases:** Upper Fafem sub catchment, groundwater recharge estimation, wetspass model, water suitability evaluation, groundwater potential zones, Soil water balance.

## CHAPTER ONE

### 1. INTRODUCTION

#### 1.1 Background

Groundwater, which is beneath the earth's surface, is one of the most important resources in the world, groundwater can be found almost everywhere. The water table may lie deep or shallow depending on a number of factors such as physical characteristics of the region, weather conditions and levels of recovery and exploitation. Heavy rains increase recharge and cause the water table to rise, but on the other hand, dry weather can cause water table to fall, groundwater is very important as it provides water to our wetlands, lakes, rivers and streams. So, it is very important to learn about groundwater, how the groundwater is part of the water cycle and the importance of protecting and maintaining the quantity and quality of this water resource.

Quantifying the rate of natural ground water recharge (Eilers et al., 2017) is a basic prerequisite for efficient groundwater resource management. The depth of groundwater depends on the type of local topography and springs available in the area directly related to geological structures constructed by various natural and artificial activities. All the groundwater flow systems of an area directly or indirectly related to the geological structures and lithological formations. The demand for water resources is growing exponentially, because water is the backbone for any development activities, the usage for water is becoming more complex due to industrialization, population growth, increasing technology and living standard of human and we know that any development is related either directly or indirectly with water utilization.

The purpose of this study was to estimate ground water recharge, to evaluate water suitability for drinking and Irrigation and to map the groundwater potential zones of Upper Fafem catchment in Somali Regional State of Eastern Ethiopia. Although there have been a number of studies conducted in the area, these studies have focused on exploration and modeling of groundwater, therefore there is still a gap for groundwater recharge estimation, groundwater suitability evaluation and groundwater potential zoning. So, studying or understanding the recharge or the amount of groundwater of this catchment is very essential.

Although water is needed for any activity, the water available is scarce and this shortage will cause ecosystem damage which has led to slow economic development and ultimately loss of

human life. Water shortages are caused by lack of rainfall, in a drought-stricken country like Ethiopia, groundwater recharge estimation is critically important for wise utilization and proper management of groundwater resources to bring about significant social and economic development. Groundwater is a valuable and widely distributed resource in the world and unlike any other mineral resource it receives its annual renewal from rainfall. Currently about one-fifth of all water used in the world is found from groundwater sources (Raghunath, 1987). In areas where there is a shortage of surface water, groundwater is the second source of domestic water supply, irrigation and industrial use.

## **1.2 Statement of the problem**

Due to the increasing demand for water resources and limited availability of surface water in the study area, groundwater is used for urban and rural water supply, livestock watering and Irrigation, this growing demand for water use will lead to excessive use of groundwater resources available and therefore better management of available groundwater is important by estimating and characterizing the groundwater of this catchment. Although there have been a number of studies conducted in the area, these studies have focused on exploration and modeling of groundwater, therefore there has been a gap for estimating groundwater recharge, mapping of groundwater potential zones and evaluating the water quality.

So, studying or understanding the recharge or the amount of groundwater and its suitability for Drinking and irrigation of this catchment is very essential. Though water is needed for any activity, available water is scarce and this shortage will lead to environmental degradation and delayed the economic development of the area.

## **1.3 Objectives**

### **1.3.1 General objective**

The general objective of this study was to estimate long term average ground water recharge and to evaluate the water suitability of upper Fafem Sub catchment of Somali Regional State in Eastern Ethiopia.

### **1.3.2 Specific objectives**

The specific objectives of this research were;

- ✓ To Estimate ground water recharge of upper Fafem sub catchment using Wetspass model.
- ✓ To determine ground water quality of upper Fafem sub catchment using laboratory analysis.

- ✓ To identify ground water potential zones of the basin using GIS and RS.

#### **1.4 Significance of the study**

In this study, the Groundwater Recharge of upper Fafem sub catchment was estimated using Wetspass model and the simulated result was compared to a calculated result using another recharge estimation method, called soil water balance method, the hydro chemistry of the water in the study area was analyzed in Addis Ababa University Laboratory, Department of chemistry for the purpose of knowing the water suitability for drinking and Irrigation, at same time the groundwater potential zones of the catchment was identified using Geographic information system and Remote sensing. Since the main source of water for the community in the study area is ground water, quantifying groundwater amount of this area will help and support the management of the water resource in this catchment. In broader sense the output of this research will help the planners, managers and decision makers to know about the groundwater quantity available and the quality of water in this area in order to manage the water resource efficiently at the same time, this will be a base or reference for further groundwater exploration.

#### **1.5 Scope and Limitation of the Study**

The study was focused only upper Fafem sub catchment, situated approximately 40 kms south west of Jigjiga, the Capital city of Somali National regional state of Ethiopia and 590 kms far from Addis Ababa, the capital city of the country which has an area of 1,300 km<sup>2</sup>. The long term spatially and temporarily distributed groundwater recharge, surface runoff and actual evapotranspiration were estimated, whether the water in this catchment is suitable for drinking and irrigation were determined and the potential groundwater zones were also determined using GIS and RS. Softwares used during this study were WetSpass and ArcGIS.

#### **1.6 Structure of the study**

The study is organized into six chapters. In the first chapter, an introductory section of the concepts that includes research issues related to groundwater recharge and water quality, statement of the problem, objectives, significance and scope of the work is presented. In the second chapter, a review of the literatures relating to groundwater recharge, factors affecting groundwater recharge, similar studies conducted in the past, groundwater chemistry, groundwater potential zoning and groundwater management are discussed.

The third chapter contains description of the study area. It includes the economic activities of the population, study area geology and hydrogeology. The fourth chapter focuses on

materials and methods. Hydro-meteorological data required for WetSpass modeling, GIS and RS raster maps for groundwater mapping and hydrochemistry data for groundwater quality are described. Chapter five is the result and discussion of WetSpass output, groundwater potential zones and groundwater quality. Finally, the final chapter is a conclusion and a recommendation.

## CHAPTER TWO

### 2 LITERATURE REVIEW

#### 2.1 Definition of Ground water recharge

Groundwater recharge could be defined as ‘the downward flow of water reaching the water table, forming an addition to the groundwater reservoir’ (Lerner et al. 1990). Balek (1988) has categorized groundwater recharge into four, as historical, perennial, seasonal, short-term, recharge based on time factor. (Scanlon et al., 2002) noted that two modes of recharge by which water move downward across the water table and named to diffuse and focused recharge. Diffuse recharge refers to uniform recharge from precipitation or irrigation in which fairly distributed over large areas, whereas focused recharge refers to concentrated recharge over topographic depressions such as rivers and lakes.

Athavale et al. (1988) classified sources of recharge as primary and secondary recharge sources, primary source of recharge is the deep percolation of part of the precipitation to water table after saturation of soil profile above, while secondary sources of recharge are percolation through beds of surface water bodies, return flow from irrigation and artificial recharge through spreading over favorable site or injection wells.

#### 2.2 Factors influencing ground water recharge

There are a number of factors affecting ground water recharge, some of these are.

- Topography of the location
- Rainfall (volume, intensity, duration)
- Plant or vegetation (cropping pattern, rooting depth) and evapotranspiration
- Soil type of the area
- Geology of the area

#### 2.3 Groundwater recharge estimation

Amount of groundwater in an area cannot be accurately measured and it is difficult to estimate accurately. Estimation of groundwater recharge is critical to the effective and sustainable management of groundwater system. There are number of methods that can be used to estimate groundwater recharge. Groundwater recharge estimation methods are divided into applied techniques, tracers and modeling.

## **2.4 Groundwater recharge estimation models**

Hydrological models are simplified real world systems to represent hydrologic cycle of a whole river basin or part of it. It is based on a set of related equations that try to convert the physical law, which control extremely complex natural objects. In addition, different types of models can be used, depending on the targeted output, the existing database, the input variables and the required analysis. Representation of the physical processes described by the rainfall-runoff models can be based on a simple mathematical link between the input and output variables of the basin or includes a description of the basic processes involved the generation of runoff.

Different models have been developed recently to estimate groundwater. These groundwater recharge estimation models can broadly be classified based on process description such as physically based distributed models, conceptual models and data-driven models (Beven, 2001). Two types of modeling methods have been proposed by Klemes (1983): bottom up and top-down approaches. Physically distributed models are examples of bottom-up modeling approach. Those models are mainly depending on the principles of physical processes based on conservation of energy and continuity, mass and momentum. In this modeling method, hydrological processes are simulated by presenting a large number of model parameters to be measured in a building or small water scale, representing different variations in the catchment. In top-down modeling method, the equations used to describe physical processes usually have (indirect) physical meaning but the parameters are obtained by calibration. In this way, the modeling process usually begins with a very simple model and progressively increase complexity through the step wise incorporation of process description (Sivapalan, 2003; Montanari et al., 2006).

In recent time, progress have been made for understanding of hydrological processes and modeling, using data driven, flexible, conceptual and semi distributed model structures (Gharari et al., 2013; Gao et al., 2014). The groundwater models used to analyze groundwater systems are usually quasi steady state and require long term average recharge input. Therefore, wetspass model which yields spatially varying groundwater recharge using soil, land use, slope, meteorological data, groundwater depth and elevation as an input can be used for the purpose of understanding the characteristics of groundwater recharge (Batelaan and Woldeamlak, 2003). Data driven models are based on extracting data that is fully contained in hydrological data. These models imply mathematical equation that does not rely

on physical principles such as mass or energy balance equation (Solomatine, 2011).

## **2.5 Related studies**

From the previous geological and geomorphological study conducted by Ministry of Agriculture of the federal government of Ethiopia (2013). In Fafem sub-basin and Adjacent Eastern Areas, shows that the area is dominated by basement rocks with some other rock types that make up the catchment area include Mesozoic sandstone, Hamanale limestone, basalt and alluvial sediments.

The general Hydrogeological Map of Ethiopia (Ethiopia Geological Survey, 1988) shows that the Ogaden basin and upper fafem have localized and low to moderately productive aquifer with fractures and/or karstic permeability (Consolidated sediments and Metamorphosed carbonates: Limestone, Sandstone, Shale, Marl and Evaporites) with moderate to large quantities of ground water specifically along the valleys. Generally, this sub-basin area receives less ground water recharge from rainfall ( $\approx 50\text{mm/year}$ ); low to moderate surface runoff and have a high potential evapotranspiration ( $\approx 1450\text{-}1500\text{mm/y}$ ).

The information related to previous studies such as reports, maps and professional works done in ogaden basin and Fafem in particular and other researches related ground water recharge estimation using Wetspass model, at the same time researches related to Groundwater potential evaluation using GIS and RS technique and water quality characterization conducted by different researchers in different locations, some of these researches that had been reviewed are: to had reviewed as follows.

Shaac Consulting co. (2011). Conducted hydrological investigation in 19 different locations throughout the Somali regional state of Ethiopia, the areas been emphasized were Liban, Godey, Dhagahbur, korahey and afdheer of the Somali regional state.

The ministry of Agriculture of Ethiopia (2013). Conducted geological and geomorphological study in Fafem and Jarar basins for the purpose of Groundwater Potential Assessment and Supervision of Test and Pilot Production Wells Drilling Project.

Sintayehu Mulu (2017) carried out a research in upper Fafem sub catchment with the objective of formulating and implementing numerical groundwater flow model for upper Fafem sub catchment, entitled on Groundwater Flow Modeling of Upper Fafem Sub Basin for Managed Groundwater System.

United States Geological Survey (2017), carried out groundwater Exploration and Assessment in the Highlands and Eastern Lowlands of the Ogaden Basin Area, Eastern

Ethiopia.

Study on werii watershed entitled on 'Estimation of groundwater recharge and potential under changing climate in werii watershed', tekeze river basin' conducted by Gebremedhin gebremeskel haile (2015), with the objective of estimating groundwater potential, groundwater recharge and the impact of climate change on water resources in Werii watershed , his result showed that the validated groundwater balance as calculated by wetspass gave an average long term annual recharge of 30mm/year where by about only 4.2 % of the precipitation is accounted for the recharge component.

Bahredin Ahmed Hassan (2018) carried out study entitled on 'GIS based Groundwater Recharge Estimation: The Case of Shinile Sub-Basin', Ethiopia, with the objective of estimating seasonal and annual runoff, potential evapotranspiration and ground water recharge of Shinile basin, using wetspass model. Ground water contribution and recharge estimation in the upper Blue Nile flows Ethiopia' done by Getachew Hadush Asmerom (2008), while the aim of his study was to quantify ground water contribution and recharge estimation in upper Blue Nile flows.

Bitsiet Dereje and Dr. Dessie Nedaw (2016) conducted research in upper Bilate catchment, their research was entitled as 'Groundwater Recharge Estimation using WetSpa Model in Upper Bilate Catchment, Southern Ethiopia.' According to their results in wetspass model the mean annual recharge of the catchment was found to be 9.4 % of the precipitation whereas the direct runoff was found to be 20% of the precipitation. Teklebirhan Arefaine, Dr. Dessie Nedaw and Tesfamichael Gebreyohannes (2012) conducted research on Groundwater Recharge, estimation of runoff and Evapotranspiration using WetSpa Model in Illala Catchment, Northern Ethiopia. The main objective of their study was to estimate the distributed groundwater recharge, surface runoff and evapotranspiration amount of Illala sub basin using Wetspass model. Long term hydro meteorological data and physical characteristics of the catchment such as land use/land cover, soil type, topography, groundwater level and slope were used as an input to the model. The mean annual groundwater recharge, evapotranspiration and runoff were found to be 66, 440 and 40mm respectively. Accordingly, recharge accounts for 12% of the precipitation while the rest 81% and 7% becomes evapotranspiration and surface runoff respectively.

Estimation of groundwater recharge using GIS-based WetSpass model for Birki watershed, Eastern zone of Tigray region, Northern Ethiopia, Esayas Meresa and Gebeyehu Taye (2017). Their research was aimed to use WetSpass model to estimate long-term average annual and seasonal groundwater recharge for Birki watershed (45 km<sup>2</sup>) in northern Ethiopia. The result showed that, summer (rainy season) recharge ranges from 0 to 41.09 mm/year with mean value of 24.1 mm/year (96.5%), winter (dry season) recharge ranges from 0 to 1.9 mm/year with mean value of 0.8 mm/year (3.5%) and yearly recharge ranges from 0 to 42.6 mm/year with mean value of 24.9 mm/year. Distributed recharge estimation for groundwater modelling using WetSpass model, in Gaza strip, Palestine, (Adnan, O Batelaan, et al., 2002). (Ali Salem, et al., 2016) conducted an assessment of Groundwater Recharge, Evapotranspiration and Runoff in the Drava Basin, Hungary using WetSpass Model with the objective of assessing monthly, seasonal and the annual averages of groundwater recharge, surface runoff and actual evapotranspiration in the Drava basin. The long-term temporal and spatial average monthly precipitation (58 mm) were distributed as 29% (17 mm) surface runoff, 27% (16 mm) actual evapotranspiration and 44% (25 mm) groundwater recharge. The analysis of simulated results showed that WetSpass-Model works properly to simulate hydrological water budget components of a basin.

Tesfa Gebrie Andualem and Girum Getachew Demeke (2019) conducted ground water potential assessment using remote sensing and GIS in Guna tana landscape, upper Blue Nile Ethiopia, their study was entitled as ‘Groundwater potential assessment using GIS and remote sensing’, case study of Guna tana landscape, upper Blue Nile Basin, Ethiopia. Tesfaye Tessema (2019) was carried out a research entitled as Ground Water Potential Evaluation Based on Integrated GIS and Remote Sensing Techniques, in Bilate River Catchment, South Rift Valley of Ethiopia. Bane Lamessa (2017); conducted a research in middle Awash River basin entitled on Groundwater potential and Recharge zone mapping using GIS and Remote sensing Techniques in the case of Middle Awash River Basins, Ethiopia.

Abdalla, F (2012) conducted study for groundwater potential zone mapping in Central Eastern Desert, Egypt, entitled on ‘Mapping of groundwater prospective zones using remote sensing and GIS techniques’: Case study from the Central Eastern Desert, Egypt. The final output map of his study shows that different zones of groundwater prospective potential such as very good (12.79%), good (26.95%), moderate (33.05%) and low (27.21%).

Nag, S. K. and Ghosh, P (2013), were also done research in West Bengal, India for delineating groundwater potential zones using RS and GIS, which was entitle as 'Delineation of groundwater potential zones in Chhatna Block, Bankura District, West Bengal, India using remote sensing and GIS techniques.

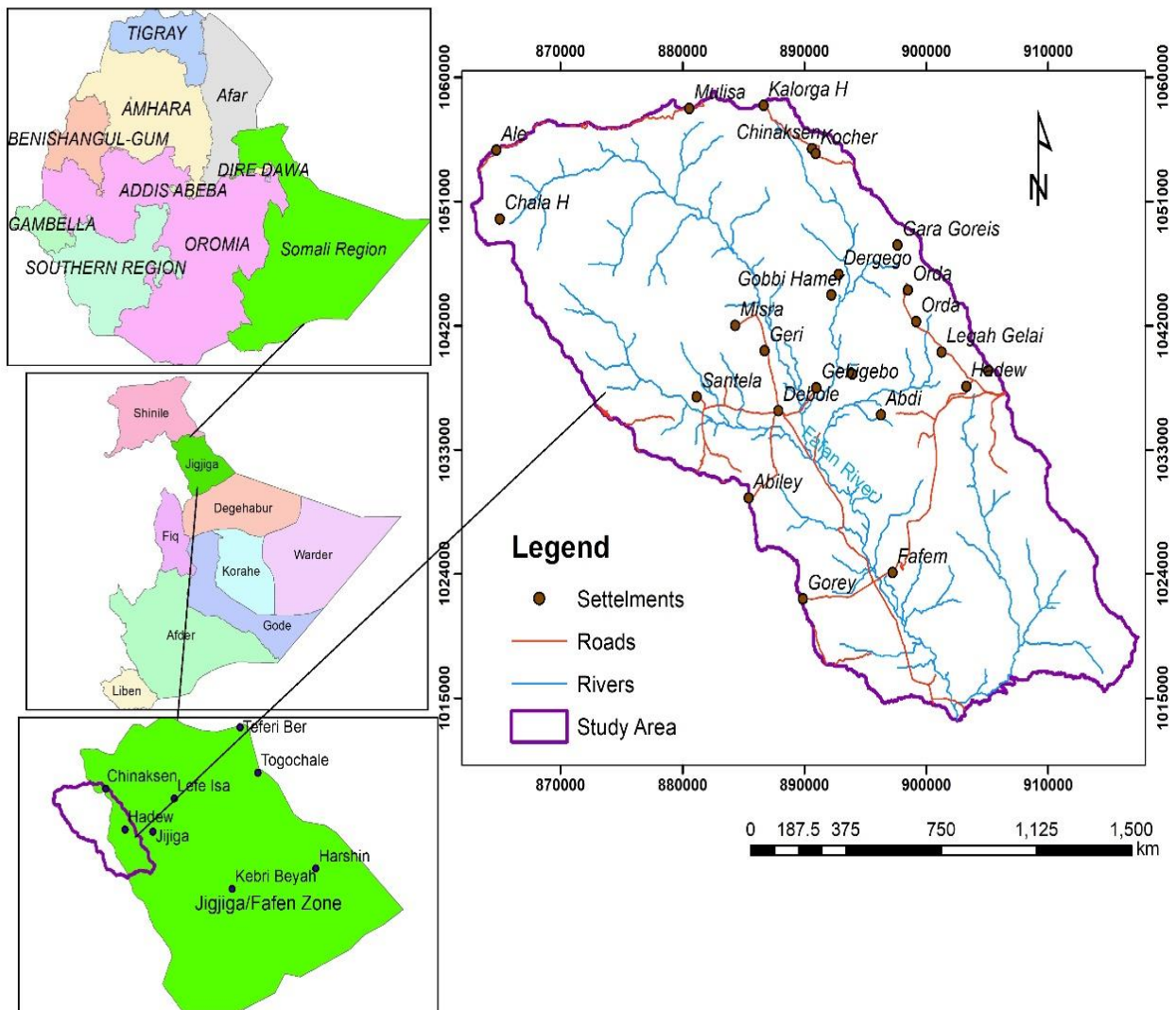
Narsimha et al., (2013); conducted a study related to the suitability of groundwater for drinking purpose in rural areas of Gunthakal, based on various water quality parameters, entitled on Evaluation of groundwater quality and its suitability for drinking purposes in Gunthakal Area, Ananthapur District, India. Diana Sharma and et al., (2016); conducted a research entitled on Evaluation of groundwater quality and its suitability for irrigation and drinking purposes in southwest Punjab, India using hydro chemical approach. Seyni Ndoye, and et al., (2018); conduct study related to groundwater quality which was entitled Groundwater Quality and its suitability for different uses in the Saloum Area of Senegal. Muhammad Hasan and et al., (2017); were also conducted a research entitled on Evaluation of Groundwater Suitability for Drinking and Irrigation Purposes in Toba Tek Singh District, Pakistan.

## CHAPTER THREE

### 3 DESCRIPTION OF THE STUDY AREA

#### 3.1 Location and Accessibility

Study area is located in the Fafem zone of the Somali State of Ethiopia. Fafem River Catchment is situated in eastern Ethiopia, almost all the study area falls under Somali Regional State, upper Fafem is about 40 kilometers southwest of Jigjiga, the capital city of Somali region and 590 km from Addis Ababa the capital city of the country and most of the villages in the study areas is been accessed by the asphalt road from Jigjiga to Harar, while the other miner sites in the study area were accessed using weathered gravel roads towards west and north east for Tulliguled and Galalshe respectively.



## **Figure 1: Location map of the study area**

### **3.2 Population and Economic Activity**

Dominant ethnic group living in Upper Fafem sub catchment is Somali and their economic activities are mainly depending on agriculture, pastoralists and the livelihood of the nomadic. They normally depend on their farms and livestock by selling the agricultural crops and milk from their livestock.

### **3.3 Physiography and Drainage**

Geographically, the area is bounded between the longitude range of 42°18'18.730'' E to 42°42'20.601'' E and latitude range of 9°9'18.730''N to 9°33'42.879'' with an average elevation of 1788m above sea level. Fafem river catchment is extends towards NW-SE direction and has more than 250km length and the whole study area has an area of about 1,300-kilometer square. The major drainage system is associated with valley plains. The rivers in the valley originate from the mountains of Guressa and Funnya and streams drain in to the Fafem valley. The Fafem valley can be classified in to eight minor watersheds namely, Godene, Chineksen, Gursum, Shebelley, Thikdeme, Hado, Fafem and Gorei.

### **3.4 Geology and geomorphic features of the study area**

#### **3.4.1 Geomorphology**

Mapping of regional geomorphic features and understanding of their formation has an influence and great role for the occurrence of groundwater. Geomorphic features control and participate the Interaction of different processes such as geologic structure, underlying lithologies and surface feature processes. Landforms develop on various types of rock formations such as igneous rocks (intrusive and extrusive rocks), metamorphic rocks (gneisses, granitites) and alluvial deposits (gravel, sand and clay). Furthermore, the primary and tectonic structures present in the rocks combined with surface processes such as climatic condition, erosion, rock weathering and fluvial action processes have an impact to the geomorphic features.

Understanding of landforms (geomorphic features) are very essential and useful for making reasonable deduction about the processes governing their formation. The geomorphic of the study area is mainly dominated by underlying lithologies, fluvial actions, tectonic structures

(fractures and faults). These are mainly associated with the uplift of horn of Africa, the formation of main Ethiopian rifts, Gulf of Aden and volcanic landscapes. In addition, the

Lithostratigraphic units	Description	Hydrogeologic Unit classification	comments
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presence of upper Paleozoic, grabens and horsts may also contribute the geomorphic features of upper Fafem catchment.

### 3.4.2 Geology

#### 3.4.2.1 Geological Map of Ethiopia (Kazmin, 1972; Tefera et al. 1996):

The geological map of Ethiopia (scale 1:2,000,000), first compiled by Kazmin (1972) and then revised by Tefera et al. (1996), constitutes an excellent reference material to have general lithological distributions and structural setup of the country. As large parts of the map were covered by interpretations of aerial photographs and satellite imageries, modifications and updates based on recent geological mappings being carried out by the GSE and research findings are very essential.

#### 3.4.2.2 Regional Geologic Setting

Upper Fafem sub catchment is located in ogaden basin where Mesozoic sedimentary rocks, Precambrian crystalline rocks and tertiary volcanic rock successions occur. Geochronological studies on Precambrian basement rocks in eastern Ethiopia near Harar and Hirna, not far from upper Fafem, conducted by (Teklay et al. 1998) revealed that Paleoproterozoic age. As a result, eastern Ethiopia's Precambrian basement rocks are divided into three groups: Upper complexes, Middle and lower and thought to contain rock components older than all other Precambrian basement rocks occur in western, south, northern and southwestern parts of the country. The Precambrian basement exposures are found near the rift margin in the upper reaches of the Fafem and Jerer sub-basins, implying significant uplift.

These rocks are similar to Precambrian basement rocks found in Awdal region of northern Somalia. Mesozoic sedimentary successions, primarily the Adigrat sandstone and limestone formations, are unconformably distributed.

**Table 1:Description of major hydrogeologic units in the study area (taken from USAID Final Approved Report,2013)**

Alluvial deposits and volcanic units	Unconsolidated basin, filling deposits and surface volcanic flows	Aquifer	Volcanic may serve as aquifers where fractured or scoriaceous; where dense and unfractured as confined units
Karamara volcanic	Tertiary-aged basalts	Barrier in north, leaky in the south	Where unfractured in the north of the study area, they act as confining units or barriers to flow, where they extend above the land surface
Jessoma Formation	Cretaceous-Tertiary sand stone	Aquifer	May contain a lower confining unit; serves as a major recharge area on the eastern edge of the study area
Mustahil Limestone	Cretaceous carbonate, rocks and alternating sandstone	Aquifer	-
Korahe Formation	Cretaceous gypsum and shales	Confining unit/barrier	-
Urandab formation	Jurassic shales and mudstone	Confining units	Main confining unit above the Hamanlei Formation aquifers
Hamanlei Formation	Jurassic carbonated rocks	Aquifer	High-quality aquifers due to karstification; surface exposures act as recharge zones
Adigrat Formation	Triassic-Jurassic sandstone	Aquifer	Good-quality aquifers; surface exposures act as recharge zones in the northern part of the survey area
Basement	Crystalline Metamorphic rocks	Impermeable basement	Base of probable aquifers

### 3.4.2.3 Tectonic Setting

Upper Fafem is situated Ogaden basin, where sedimentary basin is located in Eastern Africa. The Proterozoic East African Orogen (EAO), Paleozoic to Mesozoic sedimentary basins and

Tertiary rifting tectonic history were recorded in Precambrian basement, Paleozoic to Mesozoic sedimentary succession, Tertiary volcanic and sedimentary rocks are found. The basement rocks were formed during the EAO, at the end of Proterozoic time as a result of collision between East and West Gondwana to form the supercontinent Greater Gondwana (Stern, 1994). In the Study area generally the Marda fault separates the Mesozoic sedimentary sequence from the Jessoma sandstone formation.

#### **3.4.2.4 Lithology and stratigraphy**

##### **3.4.2.4.1 Precambrian basement rocks**

Precambrian basement rocks are exposed in the northwest part of the study area mainly in the upper reach of Fafem river, except some hilly areas capped by Mesozoic rocks and tertiary basaltic rocks and northeast to northwest of Jijjiga city. The basement rocks exposed in the area includes the granodiorites with associated gabbroic bodies, granitic gneisses, granodiorites and different generation of granites.

##### **3.4.2.4.2 Mesozoic Sedimentary Successions**

The Mesozoic sedimentary rock successions unconformably overlie the Precambrian basement rocks in the northwestern part of the study area in the valleys of Fafem and its major tributaries. These rocks comprise mainly the lower Sandstone and Hamanlei Limestone. The younger successions, mainly Urandab and Gabredarre formations are found to occur on flanks of mountain range of Karamara and towards the downstream on ridges separating tributary rivers entering in Fafem valley itself.

##### **3.4.2.4.3 Sedimentary Rocks and Tertiary Volcanic**

The Tertiary volcanic and sedimentary rocks in the study area are dominated mainly by basaltic rocks exposed along the prominent Karamara mountain range and Jessoma sandstone underlying the flat lying plain areas situated to the east of the Jerer valley (Sintayehu Mulu 2017).

##### **3.4.2.4.4 Karamara Basaltic Volcanic Rocks**

The top part of Karamara mountain range is occupied by Karamara basaltic volcanic rock, which occurs between the upper to middle reaches of the Fafem River. The linearly arranged outcrops of Karamara basalt trends in NW – SE direction paralleling the Marda fault zone. It

is presumed to be channeled and erupted through the Marda faults capping the Mesozoic sedimentary succession. Similar basalt is present in the southwest central part of the study area close to Degah medo locality and further northwest to the west of Fafem River. TsedekeKidane (2016).

#### **3.4.2.4.5 Adigrat stone**

Adigrat stone is mainly exposed in the northwestern part of the study area in upper part of Fafem catchment and at the foot of Karamara mountain range. This sandstone formation is the oldest Mesozoic sedimentary succession in the study area and is found to occur unconformably overlying the Precambrian basement rocks. The sandstone is generally massive with inter-layering of horizontally bedded shale and mudstone. The prominent ridges and hills at and around Funyan Bira & Buchmen are underlain by Adigrat sandstone and sandy limestone that is bottom part of Hamanlei Formation. The sandstones exposed at these areas are fine to medium grained.

The lithological contact between the Lower/Adigrat sandstone and the underlying Precambrian high-grade gneissic and plutonic basement rocks, wherever exposed is marked by unconformable relationship. At lithologic contact zones the underlying basement rocks are represented by deeply weathered, decomposed and friable basement rock materials. On the contrary the lithological contact between the Adigrat and overlying limestone is gradational as marked by gradation from sandstone – calcareous sandstone – sandy limestone – limestone; such relationship is observed not far from Jijiga at Sheik Algure area. This actually signify changes of sedimentary depositional environment, i.e., gradual deepening of the basin.

#### **3.4.2.4.6 Hamanlei Limestone**

This Formation represents fossiliferous limestone of Jurassic age exposed in southeastern Ethiopia mainly Ogaden region (e.g., Tefera et al. 1996 and references therein). The formation gets its name from Hamanlei locality situated between lower reaches of Fafem valley. therefore, on upper Fafem, Hamanlei formation is found to occur as its type of locality; upper Fafem valley, around Karamara mountain range. As observed in the Karamara mountain range, upper Fafem valley southwest of Jijiga town, the Hamanlei formation conformably overlies the Adigrat/Lower sandstone formation.

The nature of the lithological contact between Hamanlei and Adigrat formation is gradational

from sandstone – calcareous sandstone/fine sandstone or siltstone – shale and to sandy limestone – fossiliferous limestone. The thickness of the Hamanlei limestone is thin at places, particularly in the upper reaches of Fafem rivers where interplay of tectonic upliftment, mass-wasting, weathering and erosional activities removed the overlying succession and upper portion of the unit.

#### **3.4.2.4.7 Urandab Formation**

Urandab formation, is a succession consisting of black shale and marly and gypsiferous limestone, Urandab Formation, formerly described as Urandab Series (Kazmin, 1975; Raaben et al., 1979), similar in age to the Antalo Formation that occurs in the southern and eastern parts of Ethiopia. The unit consists of abundant microfossils on the basis of which the formation was assigned an age of Oxfordian-Kimmeridgian. The Urandab Formation rests on the washed-out surface of the upper part of the Hamanlei formation over most of the area, Urandab Formation is represented mainly by greenish gray to black, poorly carbonaceous organogenic shales. Gray to black argillaceous limestones is often found within the lower part of the sequence and are usually minor than the shales. The section lies a member of limestones which is dark gray with greenish shades, often changing to calcareous argillites, this grades upward into light gray to green.

#### **3.4.2.4.8 Gabardarre Formation**

This sequence consists of marly limestone and shaly limestone (Lower unit and upper unit) formerly named as the Gabredarre Series (Kazmin, 1972 & 1975), represents the upper most part of the Jurassic sedimentary succession in the western and eastern Ogaden. The Gabredarre Formation is exposed in the Wabi Shebele and Fafem River and consists mainly of light-colored limestone and marl, becoming gypsiferous and shaly eastward (Kazmin V., 1972). The Gabredarre Formation rests on the Urandab Formation and is conformably overlain by the Korahe Formation. The transition from the underlying Urandab Formation is sharp in eastern Ogaden and more gradual in western Ogaden. there is a lateral transition in the western part of Ogaden from limestones to sandstones with subordinate intercalations of limestones." In the age of Tithonian has 'been postulated for the Gabredarre Formation on the basis of foraminifera identified in the formation (Raaber et al., 1979).

#### **3.4.2.4.9 Jessoma Formation**

This formation, formerly known as Jessoma Sandstone (Kazmin 1972 & 1975) covers a wide

area in the eastern most part of the Tertiary sedimentary basin in eastern Ethiopia (Ogaden). The Jessoma Formation is a transgressive unit which rests unconformably on older formations but is conformably overlain by the Auradu Formation of Late Paleocene to Early Eocene age (Kllzmln,1975; Merla.1979). The Jessoma Formation consists of gray and variegated sandstones with Intercalations of variegated shales and horizons of laterites.

#### **3.4.2.4.10 Superficial Deposits**

##### **3.4.2.4.10.1 Alluvial Deposits**

On the valley of upper Fafem, particularly along its main course, deposits considerable alluvial deposits, which range from silty clay overbank floodplain sediments and fine-coarse sand channel deposits. The thickness of the alluvial deposits varies from place to place. Results of previous and current well drilling in the valley indicated the maximum thickness of the alluvial deposits range from ~40 m to ~70 m. As the major source of the alluvial deposits are the basement rocks in the upper Fafem, the size distributions of the alluvial sediments gradually decrease downstream suggesting dominance of silty clay or clayey silt in middle and lower Fafem valley.

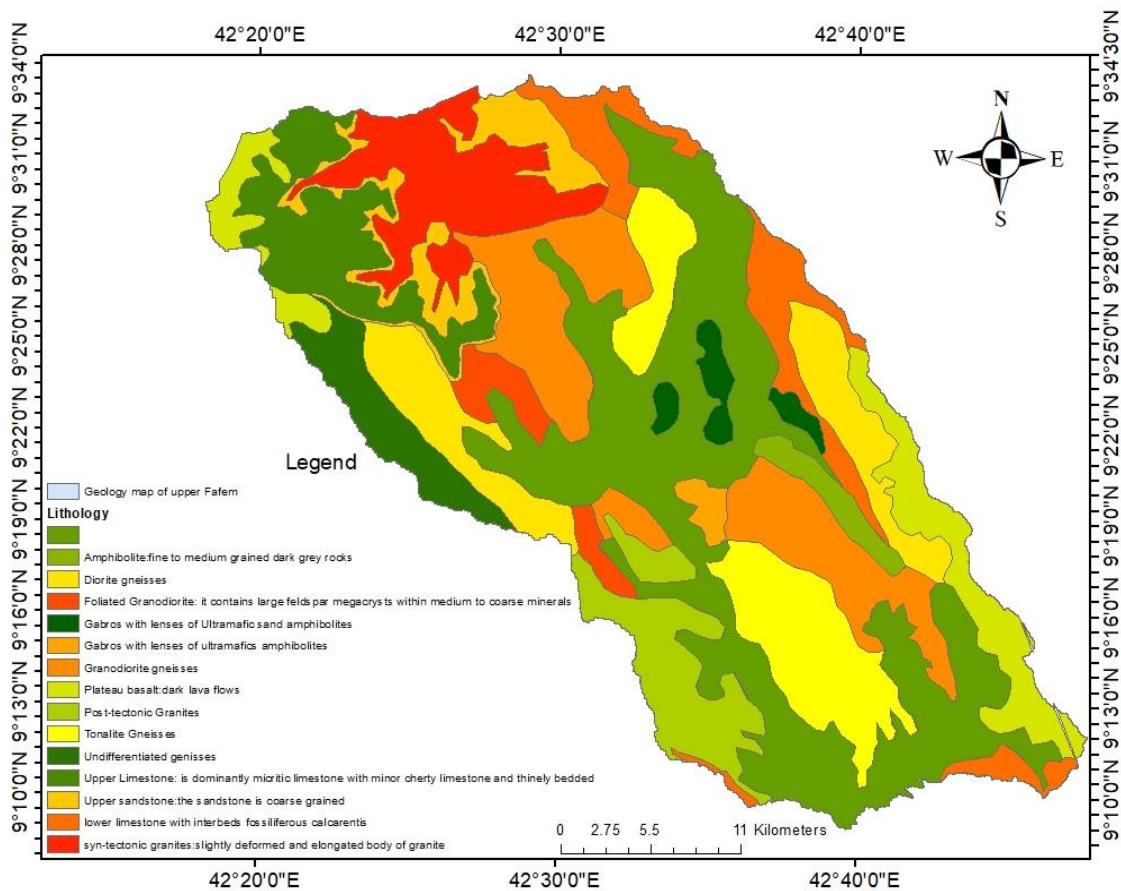
### **3.5 Geological Structures**

The geologic structure of the study area is described in (Gachet & Crémieux, 2012). The following sections provide a summary description of the geologic structure.

#### **3.5.1.1.1.1 General Setting**

Beginning in the late Cretaceous, uplift and fracturing occurred in northeast Africa resulting in the regression of the Mesozoic sea and deposition of Cretaceous to Tertiary aged sedimentary rocks in the eastern Ogaden Basin (sandstones of the Jessoma Formation and limestones of the Auradu Formation), the eruption of flood basalts and subsequent volcanism forming the Ethiopian highland plateaus (such as the Jima basaltic magmas injected along the Karamara Range in early Eocene time) and development of the East African rift systems including the Main Ethiopian rift, the Gulf of Aden and the Red Sea rift. These events, accompanied by intense fracturing along the shear-distensive corridor of the Marda Fault system and tectonic uplift, caused major effects on erosion and sedimentation dynamics. The Marda Fault system is a major continental structure that affects the area along a northwest to southeast oriented trend that extends from the northeastern Ogaden for about 900 km across the Hiran region in Somalia. The formation of the Marda Fault system down warped the

eastern Ogaden Basin in coastal Somalia and thus changed the pattern of sedimentation, it is also the apparent boundary between Mesozoic and Tertiary sedimentary deposits in the Ogaden Basin. The Marda Fault System is presumed to be a Precambrian structure later reactivated during Tertiary time. The Marda Fault System played a major role in the development of surface water drainages and the recharge of deeper aquifers. It has received little attention because it is too shallow for oil exploration and too deep for traditional hydrogeologic surveys.



**Figure 2: Geological Map of upper Fafem**

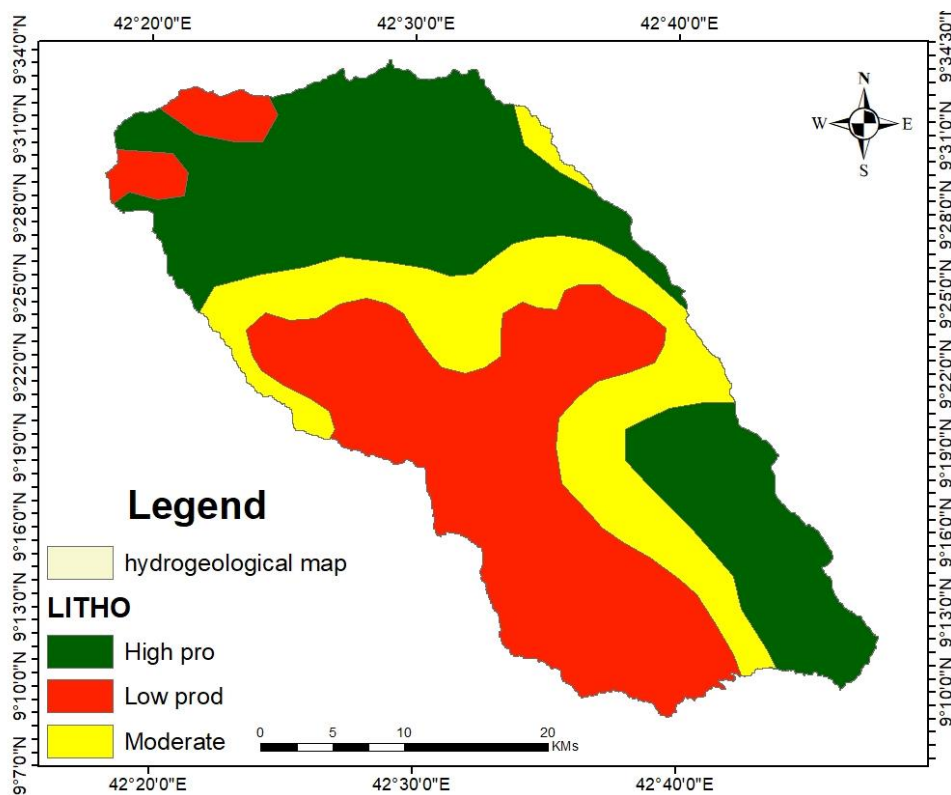
### 3.6 Hydrogeological Considerations

The geology of an area has an influence on how groundwater enters, flows through and is stored within the aquifer. The potential for alluvial sediments to be aquifers depends on the properties of the sediments that comprise the aquifer; these properties include grain size and distribution, lithology and stratigraphy (singhal 2010). An example of geologic properties influencing groundwater flow and recharge is weathering of basaltic rock, basaltic rock typically weathers to clay and colloids, reducing reservoir porosity and permeability.

Similarly, granitic rocks, quartzite and sandstones can themselves store or produce gravels that can store large volumes of water.

### 3.6.1 Hydrogeologic units

Hydrogeologic unit is any rock or soil which by virtue of its hydraulic properties has a distinct influence on the storage and movement of groundwater. Hydrogeologic unit has considerable lateral extent and has reasonably distinct hydrologic properties because of its physical (geological and structural) characteristics. An aquifer is a hydro geologic unit that can stores and transmit water at rates fast enough to supply reasonable amounts to wells (fetter, 2001). The water yielding materials in the study area is Fafem Valley and consists primarily of unconsolidated alluvial deposits. Consolidated (bedrock) carbonate rocks and sandstones that underlie the unconsolidated alluvium or exposed directly at the surface can be a source of water if the consolidated rocks are sufficiently fractured or have solution openings. Hydrogeological/productivity map of the study area was extracted from the hydrogeological map of Ethiopia and it shows that the upper part and south east part of the catchment has higher groundwater productivity compared to the lower part, the reason may be due to their high lineament density, its proximity to the main Ethiopian rift and their favorable lithology.



**Figure 3: Hydrogeological map of upper Fafem**

## CHAPTER FOUR

### 4 MATERIALS AND METHODS

#### 4.1 Groundwater recharge estimation methods

Groundwater recharge is the base for hydrologic processes in which groundwater occurs below the earth's surface by filling the aquifer system. Measuring groundwater recharge directly in the field is a daunting task and also involves uncertainty. However, data on groundwater recharge is very useful in assessing groundwater resources and the risk of groundwater depletion. In general, there are several methods used to estimate the amount of groundwater for particular location these methods include, Water Table Fluctuation, Soil water balance method, chloride mass balance, groundwater model and so on. Selection of the proper technique depends on available data, local geography and topographic conditions, temporal and spatial scale required and reliability of results (Islam et al., 2016).

The groundwater recharge estimation model, is considered to be an effective tool for estimating groundwater replenishment as it can measure spatial and temporal groundwater recharge. The WetSpass model (Water and Energy Transfer between soil, Plants and Atmosphere under quasi-Steady State), was selected for this study. WetSpass is one-dimension steady state spatially distributed water balance model which has been widely used for groundwater recharge estimation. WetSpass integrates the Geographic Information System (GIS) with the water balance equation to determine potential groundwater recharge (Batelaan & Smedt, 2007). This model is applicable for studying groundwater recharge of a particular area. Groundwater in upper Fafem is used for urban and rural water supply, livestock watering and Irrigation. Groundwater has been withdrawn by pumping from boreholes for agricultural and domestic uses.

The use of groundwater in upper Fafem is expecting to increase due to the economic expansion and increasing number of people and agricultural activities. Therefore, understanding the groundwater systems and potential groundwater recharge in regard to the current groundwater uses in Fafem basin is considerably important to develop appropriate groundwater management or to avoid the excessive uses and unsustainable withdrawal of groundwater in the future.

## **4.2 Basic concept of wetspass model**

Wetspass is an abbreviation and stands for water and energy transfer between soil, plants and atmosphere under quasi steady state (Batelaan and DeSmedt 2001; Batelaan and De Smedt 2007). It uses both physical and hydro-meteorological input files for simulation of long-term average spatial patterns of, actual evapotranspiration, surface runoff and groundwater recharge which is suitable for studying long-term effects of land use changes on the water resources in a watershed region (Batelaan and DeSmedt 2001, 2007; Aish et al. 2010).

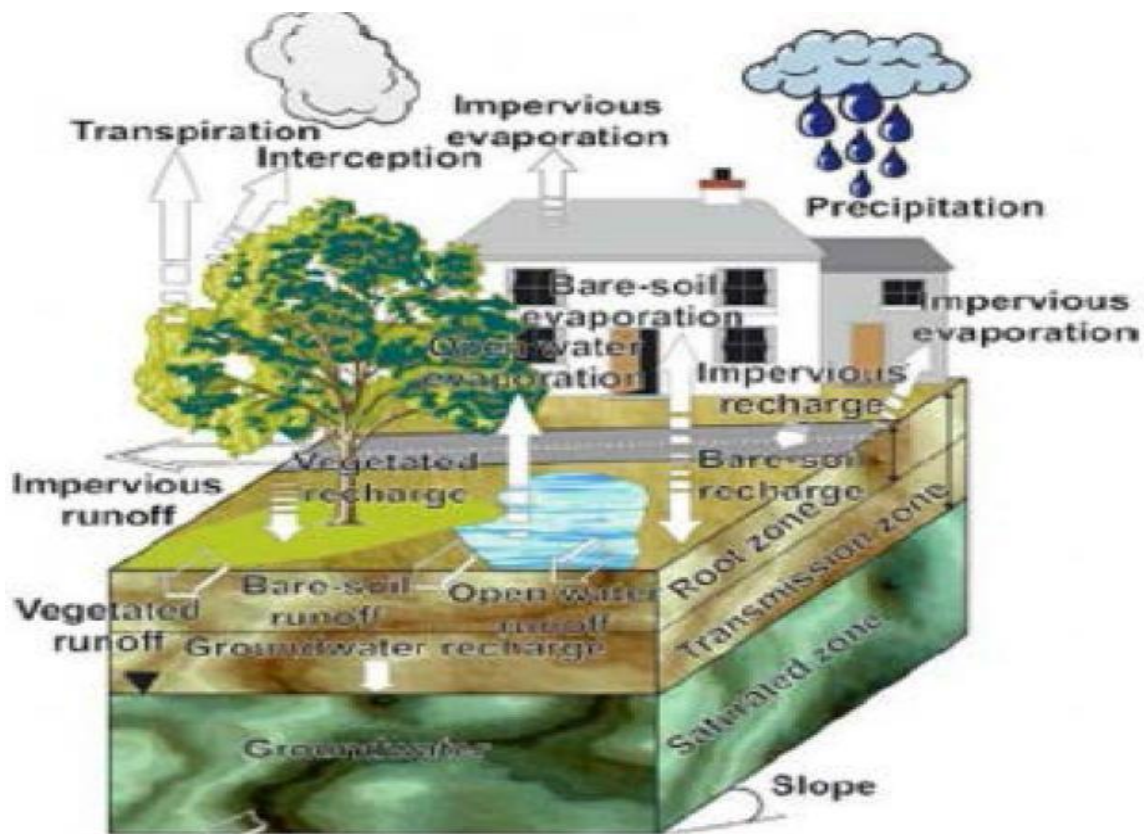
The use of this model is compatible and integrate with GIS ArcView software. During the simulation process, it estimates the variability of the groundwater recharge at seasonal and annual bases and has been used successfully in different countries by different authors, as a result, the findings of those authors have shown that groundwater recharge rates are successfully estimated with good result (Al Kuisi and El-Naqa 2013).

### **4.2.1 Model description**

In this model, the water balance of the raster cell is split into independent water balances for the vegetated, bare soil, open water body and impervious parts of each cell. This considers the uniformity of the land use per cell in regard to the cell resolution. The procedure in every part of a cell is set in a cascading way. Meaning that an order of occurrence of the processes, after the precipitation event, is assumed. arranging such an order is a prerequisite for the seasonal timescale with which the processes will be quantified. A combination of empirical and physical relationships is used to describe the process. Amount determined for each step is consequently limited by a number of hydro-meteorological and bio physical constraints of the given area under investigation (Batelaan and DeSmedt 2001).

The model was developed and used to study the impact of the long-term land cover changes on the water resource or basin (Batelaan et al., 2003; De Smedt). By using standard long-term average hydrometeorological parameters as inputs, the model simulates the temporal average and spatial information of surface run off, actual evapotranspiration and groundwater recharge. The inputs of this software are grid maps of precipitation, wind speed, temperature, potential evapotranspiration, groundwater depth, land use, soil, elevation and slope and parameter tables, like soil type and land use are connected to the model as an attribute table according to their respective grids, then the software makes use of grid GIS software and digital data to divide the precipitation into evapotranspiration, surface run off

and groundwater recharge as indicated in figure 4. This software was originally used for temperate regions, particularly in Europe, in recent time it has been used widely and has been successfully applied in different areas of the world (Batelaan & De Smedt, 2001).



**Figure 4: Schematic water balance raster cell (O. Betelaan and D. Smelt 2007)**

### Water balance calculations

The total water balance of a raster cell is calculated using the water balances of vegetated, bare-soil, open-water, and impervious surfaces as follows:

$$S_{\text{raster}} = a_s S_v + a_s S_s + a_o S_o + a_i S_i$$

$$R_{\text{raster}} = a_v R_v + a_s R_s + a_o R_o + a_i R_i$$

$$ET_{\text{raster}} = a_v ET_v + a_s ET_s + a_o ET_o + a_i ET_i$$

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

#### 4.2.2 Wetspass inputs

To estimate ground water recharge, evapotranspiration and surface runoff, wetspass model basically requires meteorological data (precipitation, wind speed, air temperature and potential evapotranspiration) and physical characteristics of the study area such as groundwater depth, Land use land cover and soil type, elevation and slope. Using Geographical Information Systems (GIS), these input data were prepared as grid maps, for the years 2002 to 2014. The climate data for five stations around and near the study area were collected from National Meteorological Agency.

Soil, Land use and borehole data were collected from the Ministry of water and irrigation and Somali region water works and supervision, the elevation 'DEM' of the study area with 30m x30 m were downloaded from USGS earth explorer, the slope of the study area was calculated from the 'DEM' using ArcGIS 10.4 with its spatial analysis extension. All of these data were resembled into same size of 50x50 grid cells and 1087 rows and 197 columns. The model works with two sets of seasonal data. for this particular study, the data were divided into two seasons with summer (April to September) and winter (October to March) with respect to their input data (precipitation, temperature, wind, potential evapotranspiration and land use). In Fafem basin and Somali region as a whole the major raining season is about June to September while another small rainy season occur mainly in March to May, that is the reason for dividing the data in to this way and prepared in these forms. August has a higher amount of rainfall than the rest of the months.

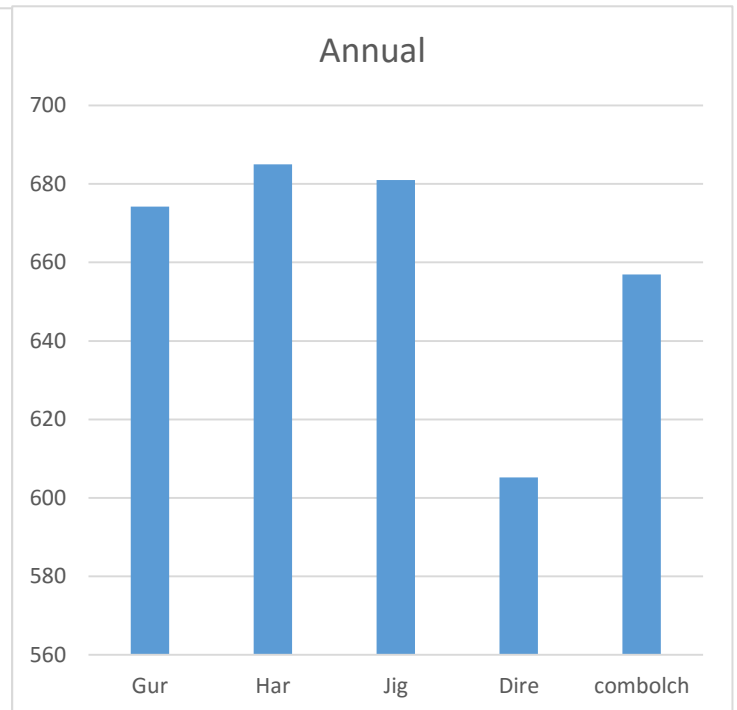
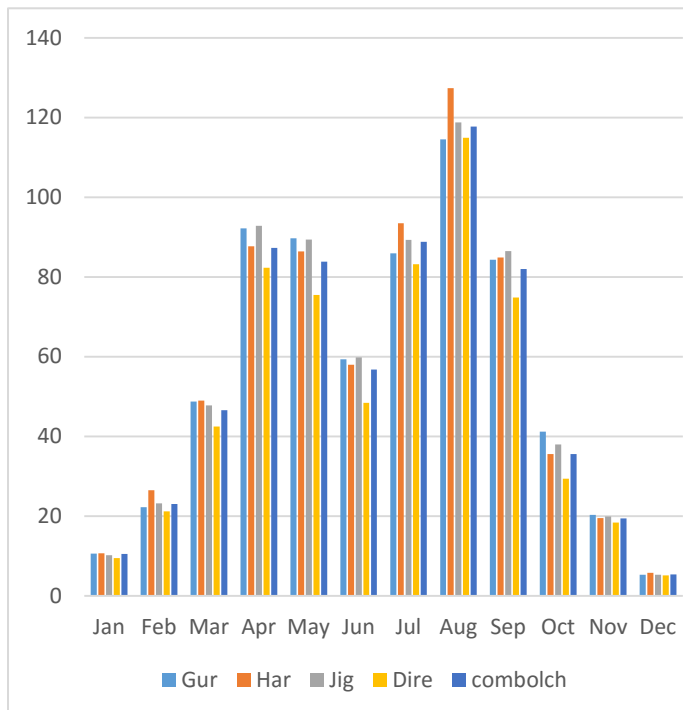
In March, farmers begin cultivating their land. As a result, it was presumed that, precipitation in March initiates vegetation development with maximum vegetation cover occurs in April. To run the model, two types of inputs were required: Parameter tables (dbf data), including inputs for land use, soil and runoff characteristics parameter tables. The tables were then applied to the map as an attribute. The runoff characteristics parameter tables include the runoff coefficient and soil type for each corresponding land use, the grid maps of the elevation, slope, land use, groundwater depth, soil, precipitation, wind, temperature and potential evapotranspiration were prepared using ArcMap 10.4 with its spatial analysis extension tool. These raster maps were converted to ascii format, using ArcMap 10.4 with its conversion tool, since Wetspass works in Ascii format. The preparation of input maps is indicated the following paragraphs.

## Precipitation

The rainfall data of thirteen years (2002-2014) for five stations around and near the study area were collected from the National meteorological agency, these data were interpolated using ArcGIS to produce the precipitation map of the area. Accordingly, the area gets long term average annual rainfall of 660.46 mm. For summer period it receives long term annual of 519 mm and in winter it gets 141 mm.

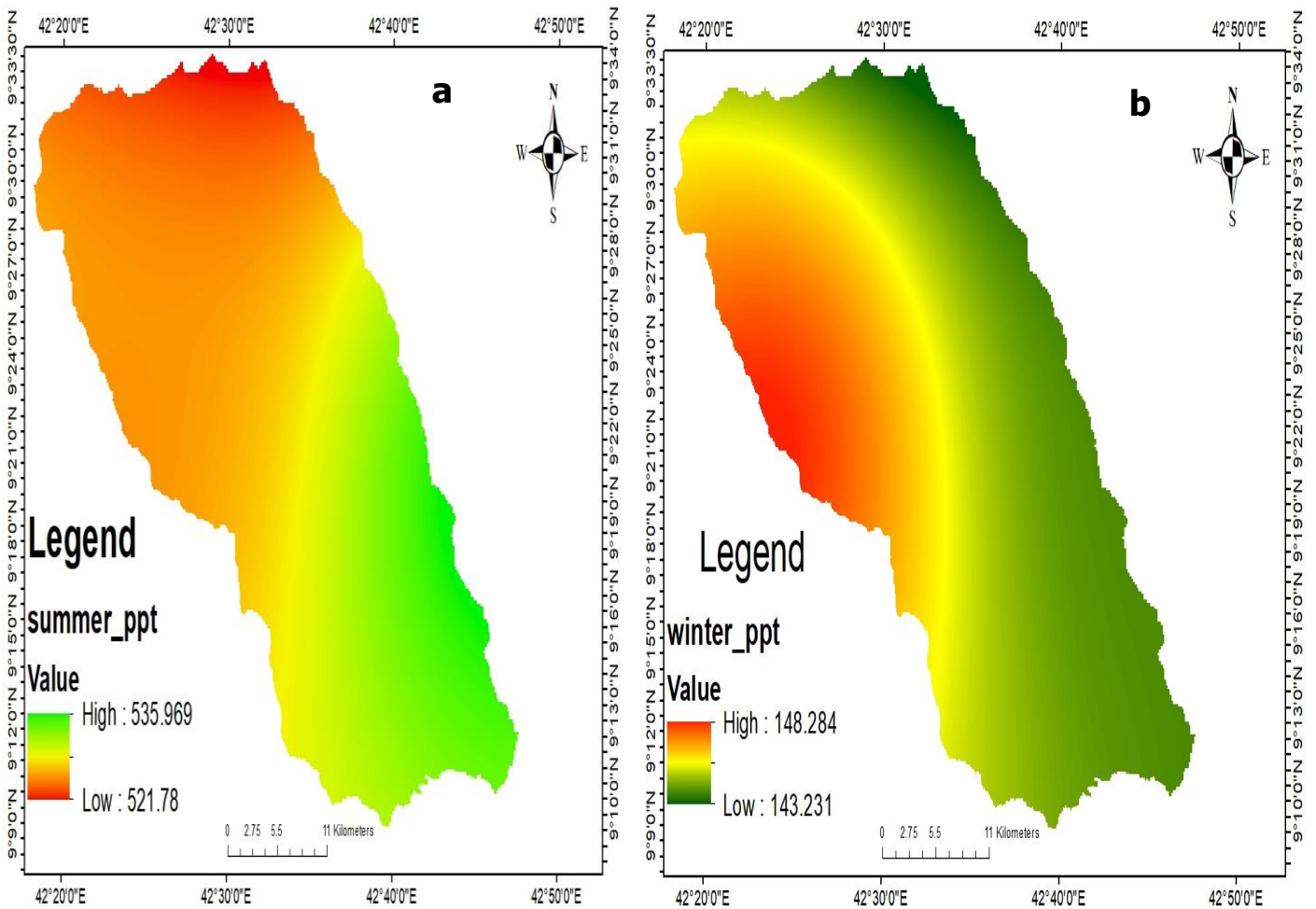
**Table 2: precipitation data of the study area**

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Gur	10.6	22.2	48.7	92.2	89.7	59.3	85.9	114.5	84.3	41.2	20.3	5.3	674.2
Har	10.7	26.5	49	87.7	86.4	58	93.5	127.4	84.9	35.6	19.5	5.8	685
Jig	10.2	23.2	47.8	92.8	89.4	59.8	89.3	118.8	86.5	38	19.9	5.3	681
Dire	9.5	21.2	42.5	82.3	75.5	48.4	83.2	114.9	74.8	29.4	18.4	5.1	605.2
Combolcha	10.5	23	46.6	87.3	83.8	56.8	88.8	117.7	82	35.6	19.4	5.4	656.9
Aver rain	10.3	23.22	46.92	88.46	84.96	56.46	88.14	118.66	82.5	35.96	19.5	5.38	660.46



**Figure 5:a) Mean monthly rainfall of study area**

**b) long term annual rainfall**



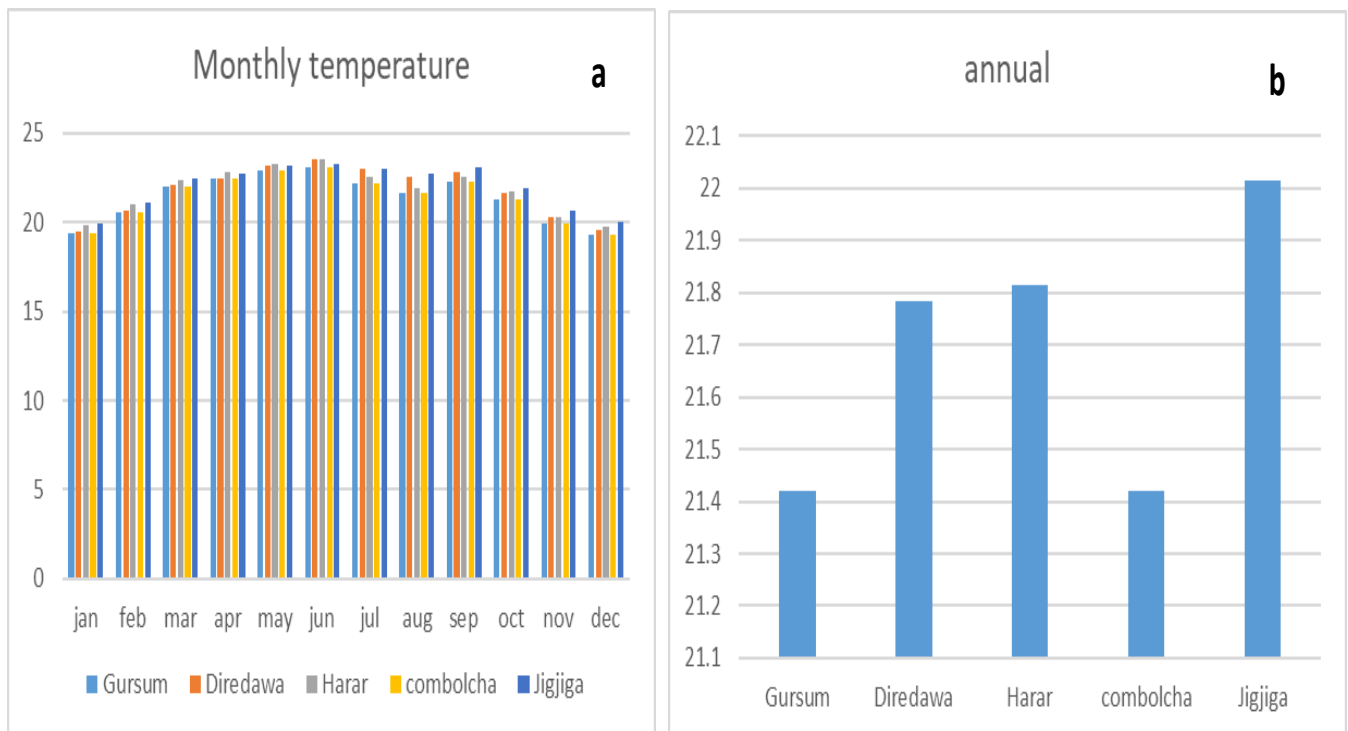
**Figure 6: Summer precipitation map (a), Winter precipitation map (b)**

### Temperature

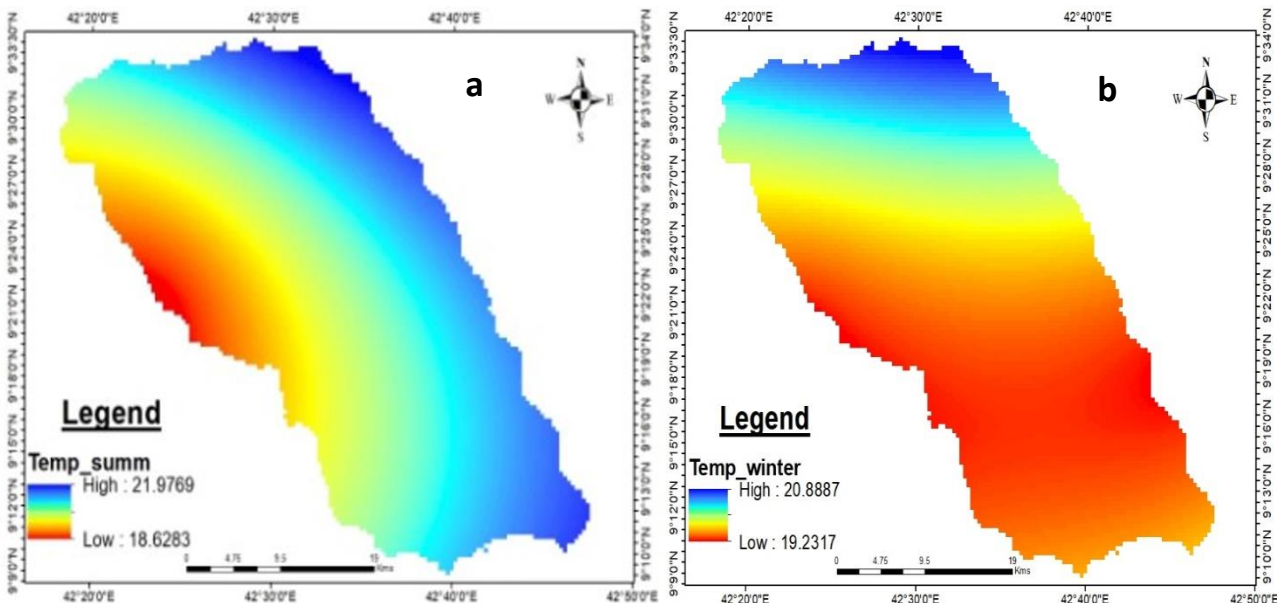
Temperature is another meteorological parameter which has an influence to the evapotranspiration. Temperature of an area is mainly depending on geomorphological set up, geographical location and altitude. Temperature of five stations in and around the study area were collected from the National meteorological agency, same as the rainfall data; the area is mainly characterized by high temperature. The summer and winter season temperature of the study area is indicated in (figure 8).

**Table 3: Temperature data of the study area**

Station	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gur	Max	27	28.1	29.3	29.2	29.7	29.5	28.1	27.4	28.4	28.4	27.5	26.8
	Min	11.7	13.1	14.8	15.7	16.2	16.8	16.3	15.9	16.2	14.2	12.32	11.8
	Aver	19.4	20.8	22	22.4	23	23.1	22.2	21.7	22.3	21.3	19.9	19.3
Diretawa	Max	26.7	27.7	28.9	28.8	29.6	29.6	28.8	28.2	28.6	28.2	27.3	26.6
	Min	12.3	13.7	15.9	16.2	16.8	17.4	17.2	16.9	17.1	15.1	13.2	12.6
	Aver	19.5	20.7	22.1	22.5	23.2	23.5	23	22.6	22.8	21.7	20.3	19.6
Harar	Max	27.7	28.6	29.7	29.7	30.2	30	28.5	27.7	28.7	28.9	28.1	27.5
	Min	12.1	13.4	15.1	15.9	16.2	17.2	16.5	16.1	16.6	14.6	12.5	12.0
	Aver	19.9	21	22.4	22.8	23.3	23.6	22.5	21.9	22.6	21.8	20.3	19.8
Combolcha	Max	27	28.1	29.3	29.2	29.7	29.5	28.1	27.4	28.4	28.4	27.5	26.8
	Min	11.7	13.1	14.8	15.7	16.2	16.8	16.3	15.9	16.2	14.2	12.3	11.8
	Aver	19.4	20.6	22	22.4	22.9	23.1	22.2	21.7	22.3	21.3	19.9	19.3
Jigjiga	Max	27	28	29.1	28.7	29.1	29	28.3	28.1	28.8	28.3	27.5	26.9
	Min	12.8	14.2	15.9	16.7	17.3	17.6	17.7	17.3	17.34	15.5	13.8	13.2
	Aver	19.9	21.1	22.5	22.7	23.2	23.3	23	22.7	23.1	21.9	20.7	20.1



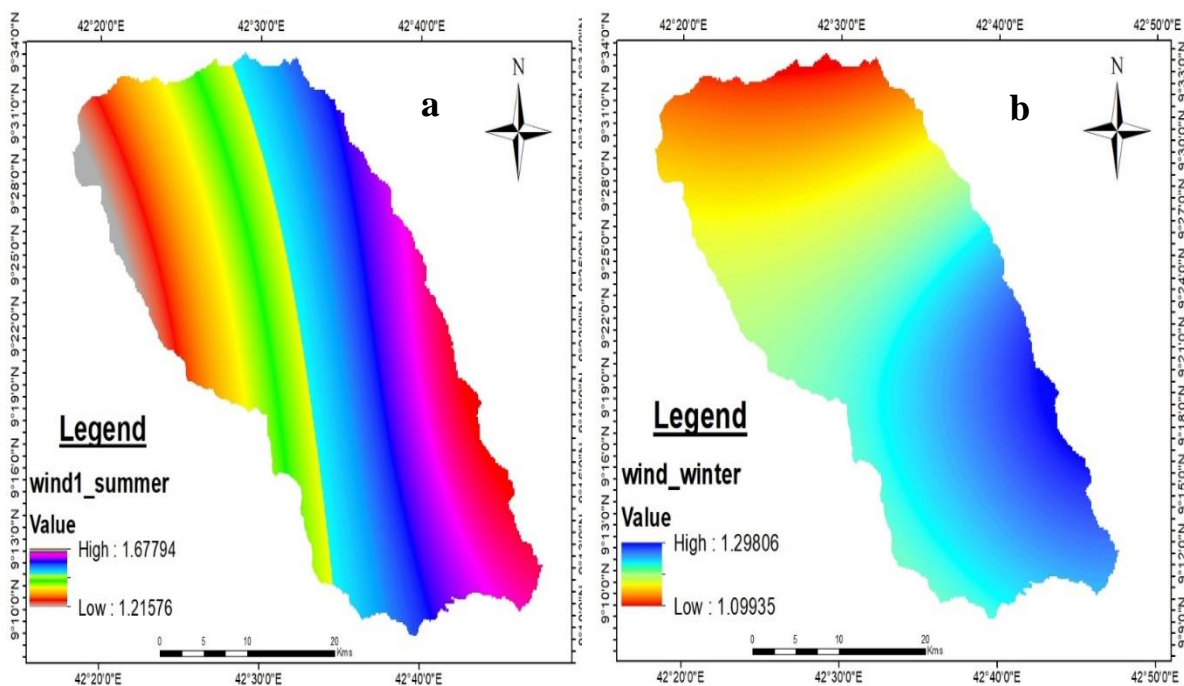
**Figure 7: Long term mean monthly temperature (a), Annual temperature of each station (b)**



**Figure 8: a) Summer temperature map (a), Winter temperature map (b)**

### Wind speed

Wind speed is one of the determining factors for evapotranspiration. The wind data of four stations near and around the study area were also collected from Meteorological agency. These four stations wind data were used to produce wind map of the study area. Average wind speed for summer is 1.7 m/s while winter average wind speed is 1.4 m/s. The maximum annual wind speed is 3.7 m/s



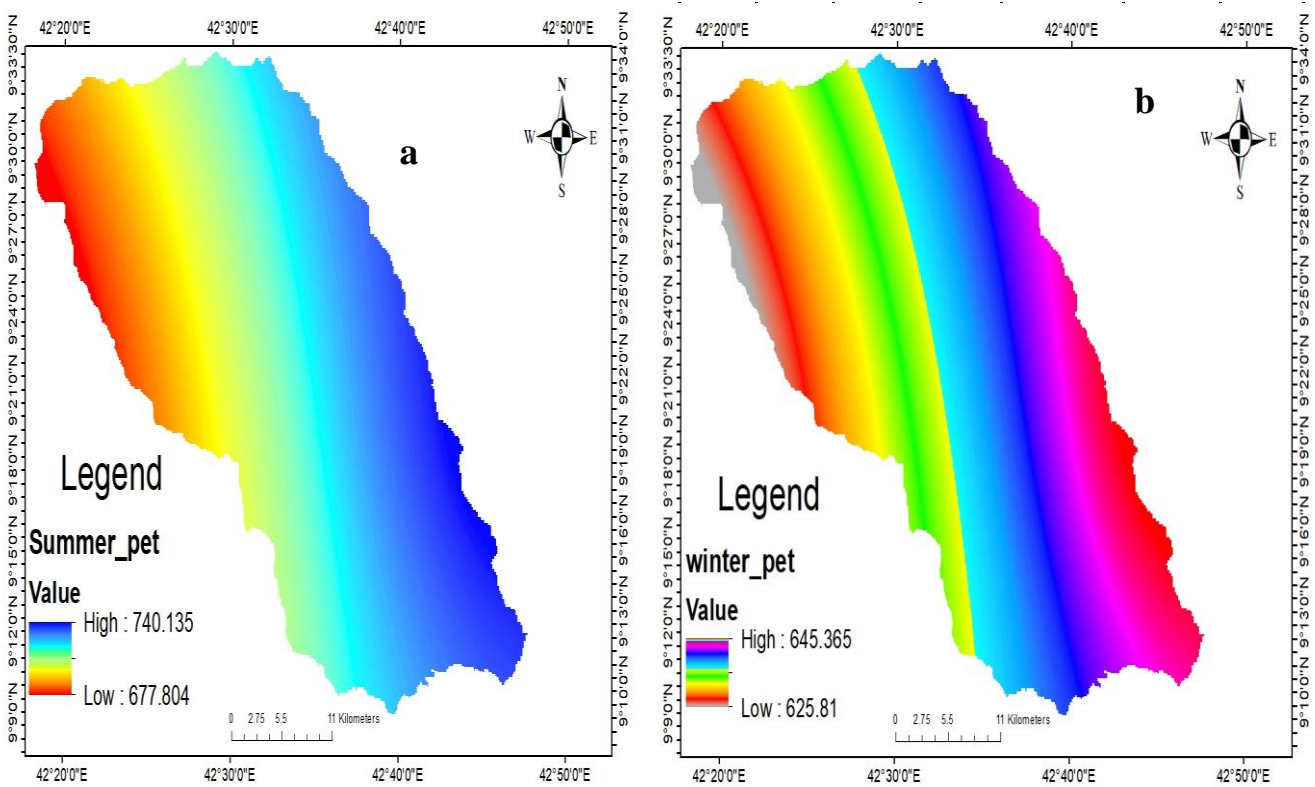
**Figure 9: Summer wind speed of upper Fafem (a), Winter wind speed of upper Fafem (b)**

## Potential evapotranspiration

Potential evapotranspiration is the maximum amount of water that can be removed from the earth's surface, through evapotranspiration (ET), it's the totality of both evaporation and transpiration provided that abundant supply of soil moisture (Amatya et.al, 2014). The potential evapotranspiration of Upper Fafem catchment was calculated using five meteorological stations with minimum and maximum Temperature. Thornthwaite (1948) has developed an empirical formula for calculating potential evapotranspiration as a function of climatic average monthly temperature and day length. This formula used to calculate, potential evapotranspiration with assumption that an exponential relationship existed between mean monthly temperature and mean monthly consumptive use. The mean monthly air temperature is being used for the calculation of potential evapotranspiration. Thornthwaite proposed the following formula:  $ET = 1.6b[10Ta/I]^a$ . ET = monthly pet in cm/ month, Ta is the mean monthly air temperature ( $^{\circ}C$ ), I annual heat index calculate as  $I = \sum (Tai/5)^{1.514}$  and b latitude correction. Since the data was monthly, the calculated result was divided into two main seasons similar to other data. Finally, the PET was converted to spatially distributed grid maps using interpolation. Then the grid maps of PET for the two seasons were used together with other input data for wetpass model to estimate the groundwater recharge, surface runoff and actual evapotranspiration. The mean potential evapotranspiration in summer is 761.3 mm and winter is 630.8, while the average annual potential evapotranspiration is 984.1mm.

**Table 4: Long term potential evapotranspiration of the study area**

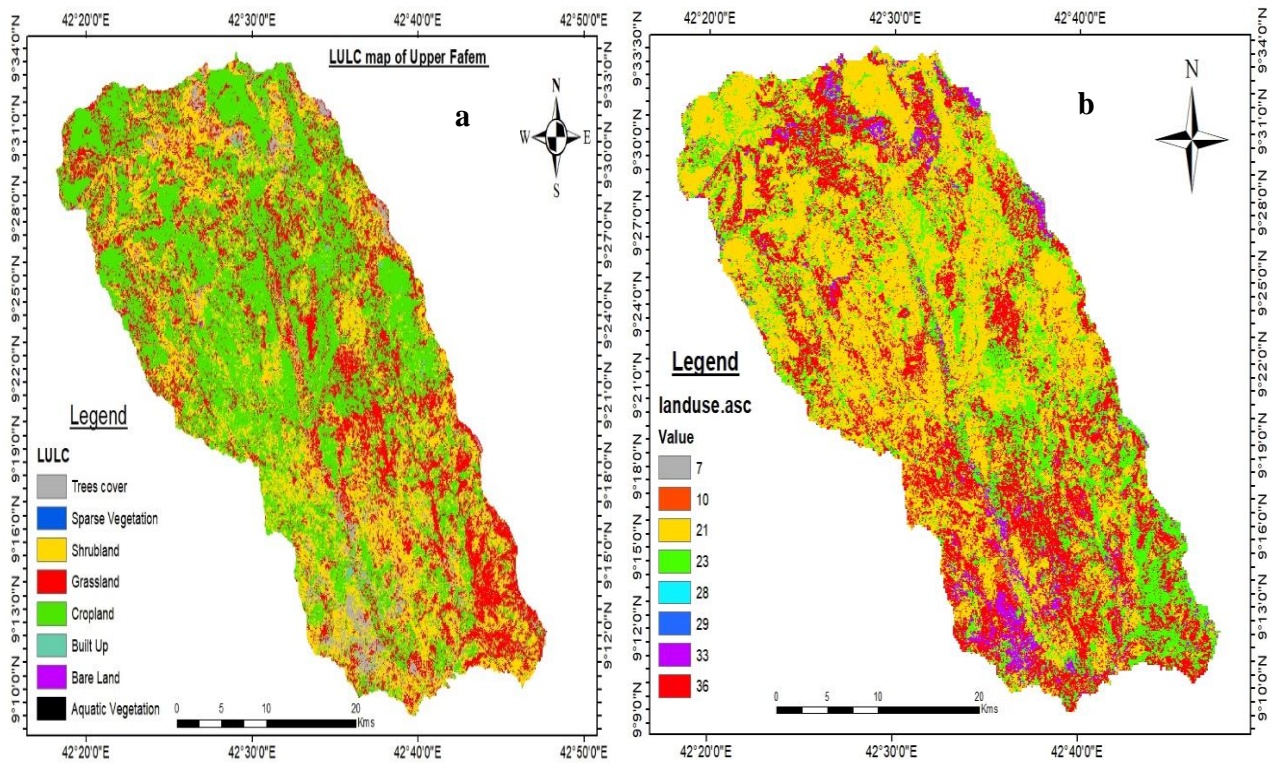
Station	Jan	Febr	March	April	May	June	July	Aug	Sept	Octob	Novem	Decem	
Gursum	19.5	20.56	22.02	22.42	22.92	23.12	22.18	21.66	22.29	21.3	19.91	19.32	21.42
Diredawa	19.5	20.68	22.07	22.5	23.17	23.52	23.01	22.59	22.84	21.67	20.25	19.61	21.78
Harar	19.9	21.01	22.41	22.79	23.32	23.58	22.52	21.91	22.58	21.76	20.3	19.76	21.81
Combolcha	19.4	20.58	22.02	22.42	22.92	23.12	22.18	21.66	22.29	21.3	19.91	19.32	21.42
Jigjiga	19.9	21.14	22.47	22.71	23.21	23.29	23.01	22.71	23.1	21.93	20.67	20.06	22.01
Average T <sup>o</sup>	19.6	20.8	22.2	22.57	23.11	23.32	22.58	22.1	22.62	21.59	20.21	19.61	21.69
B	0.97	0.98	1	1.03	1.05	1.06	1.05	1.04	1.02	0.99	0.97	0.96	
Ta/5	3.92	4.2	4.44	4.513	4.621	4.665	4.516	4.42	4.524	4.318	4.041	3.922	
Power <sup>1.514</sup>	7.91	8.65	9.55	9.794	10.15	10.29	9.8	9.489	9.827	9.158	8.284	7.918	110.8
A	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	
1.6b	1.55	1.57	1.6	1.65	1.68	1.7	1.7	1.7	1.6	1.6	1.6	1.5	
10Ta	193.7	205.8	220.2	224.2	229.2	231.2	221.8	216.6	222.9	213	199.1	193.2	
I	111.3	111.3	111.3	111.3	111.3	111.3	111.3	111.3	111.3	111.3	111.3	111.3	
10Ta/I	3.88	4.55	5.374	5.62	5.93	6.059	5.473	5.16	5.5403	4.954	4.192	3.893	
PET (Cm)	6.012	7.132	8.598	9.262	9.969	10.28	9.195	8.59	9.0418	7.847	6.506	5.979	



**Figure 10: Summer potential evapotranspiration (a), winter potential evapotranspiration (b)**

### Land use land cover

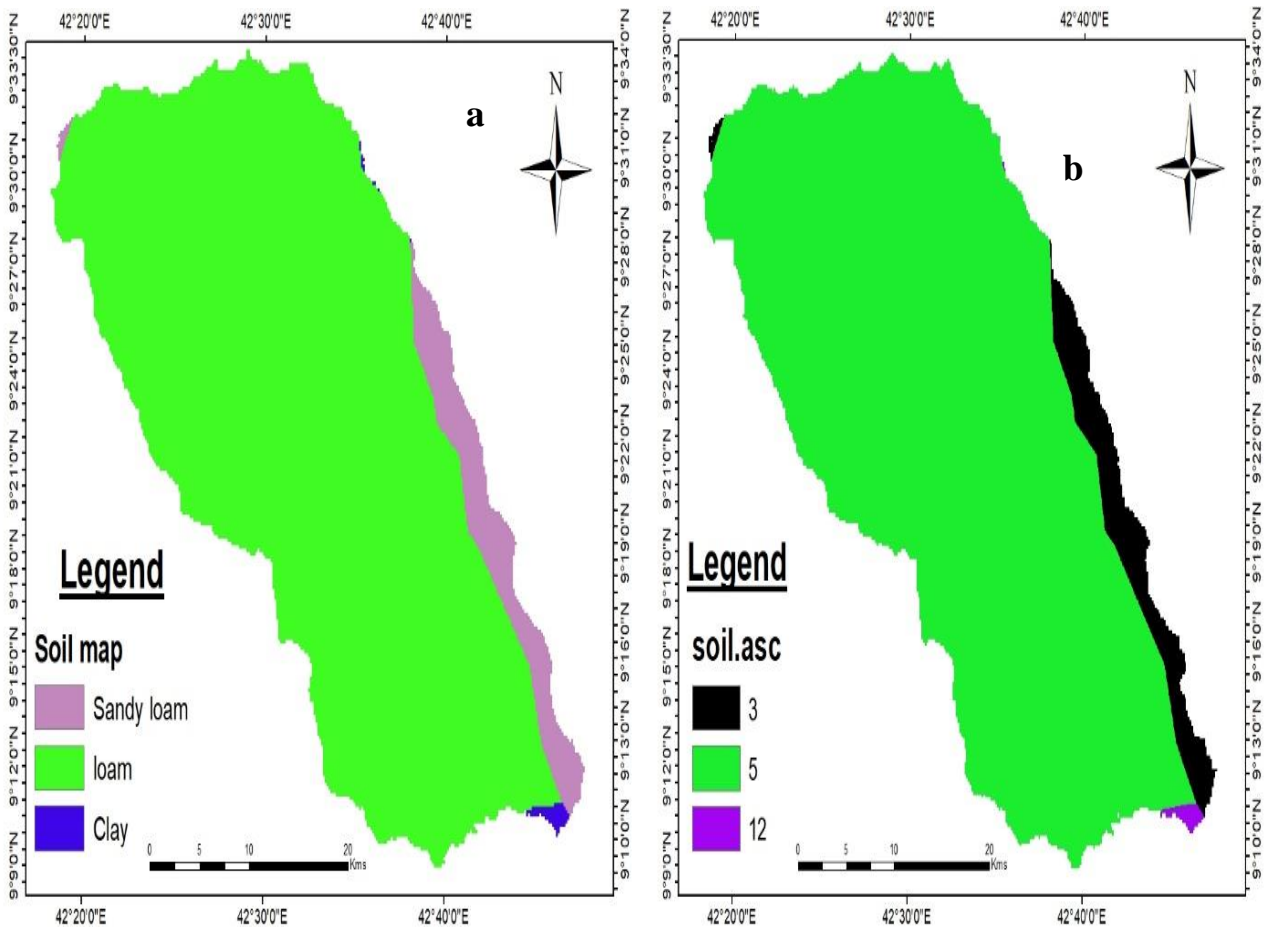
Land use of a region explains the activities practiced by people on a certain defined area in order to gain some economic, cultural and social benefits. On the other hand, the land cover deals with the existing bio-physical cover on the earth's surface. Under this perspective, land use and land cover map of an area should be prepared to give sufficient emphasis since a single area may fall into different land use and land cover categories. Land use, land cover of the study area was taken from the Ministry of water and irrigation. Land use and land cover distribution in the study area depends on variation in altitude, climatic conditions, population density, land use practice and agricultural activities. The land use, land cover types in upper Fafem include bare land, crop land, shrub land, vegetation, grass land, forest and built up. Vegetated land includes sparse and aquatic vegetation. Crop land, Grass land and shrubland are dominant land uses in this area.



**Figure 11: Land use map of upper Fafem (a), land use map of upper Fafem with codes(b)**

### Soil Map

The soil map of Ethiopia which has scale of (1: 250,000), were obtained from the Ministry of Water and Irrigation, the Soil map of Upper Fafem was extracted from this soil map. The main textural system, that wetpass uses is based on the soil texture developed by FAO which is based on the percent of Clay, Silt and Sand. According to this classification the major soil class in Upper Fafem is Loam soil which is about 93% of the area. The remaining soil classes are sandy loam and minor clay soil. The soil map of the study area was converted raster and then ascii format.



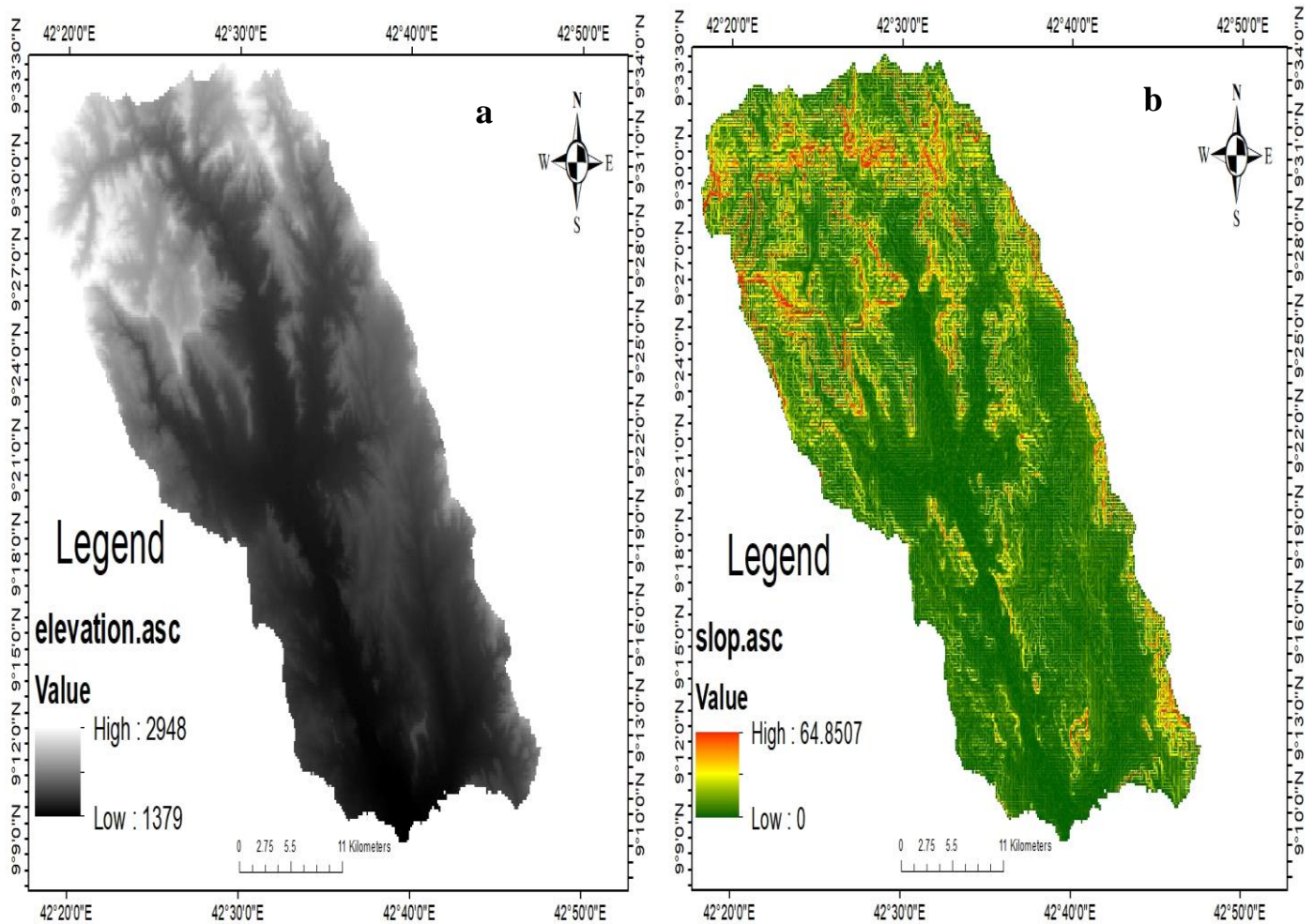
**Figure 12: Soil map of upper Fafem (a), Soil map of upper Fafem with codes(b)**

**Table 5: Areal coverage of soil texture of the study area**

Soil type	Code	Area coverage	Area %
Sandy loam	3	82.58184	6.67
Loam	5	1150.464	93
Clay	12	4.175474	0.33

### **Elevation and Slope**

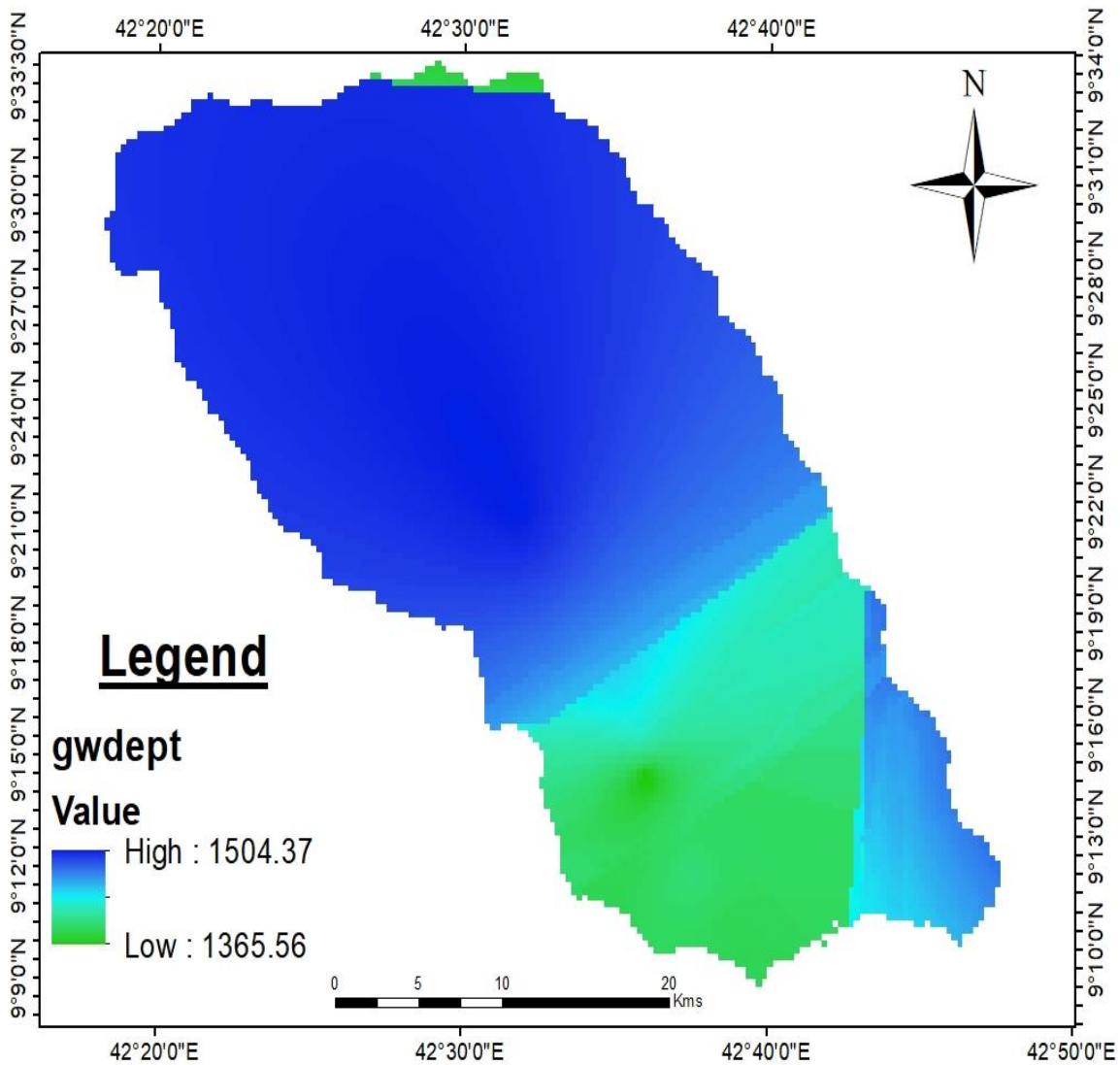
Digital elevation model (DEM) was downloaded from USGS earth explorer, the highest elevation of the catchment is about 2,948 m in the upstream area and the lowest is 1,379 m in the downstream, the mean elevation is 1,788 m. The slope of the study area was processed using ArcGIS with spatial analysis extension.



**Figure 13: Elevation map of the study area (a), Slope map of the study area (b)**

### **Groundwater depth**

The borehole data of the study area were collected from Somali regional water works and supervision, then the measured static water level was subtracted from the surface elevation to obtain the groundwater depth and its raster map was prepared using ArcGIS with its spatial extension kriging interpolation



**Figure 14: Groundwater depth of upper Fafem**

### **Input data with their sources**

Wetpass model, is a user-friendly software used to estimate groundwater recharge, surface run off and evapotranspiration, using long term hydro meteorological and bio physical data as main input. The model needs parameters in seasonal basis, due to this, six months from April to September were used as summer, rainy season and rest of the month as a dry season. The input data with their sources are shown the table below.

**Table 6: Input data of the Model with their sources**

<b>Input</b>	<b>Sources</b>	<b>Resolution</b>	<b>Method used to process</b>
Digital elevation model (DEM)	SRTM (USGS)	30x30	ArcGIS 10.4.1
Groundwater depth	SRWW&S	30x30	ArcGIS 10.4.1 with Kriging interpolation
Precipitation	National meteorological agency	30x30	ArcGIS 10.4.1 with Kriging interpolation
Wind speed	National meteorological agency	30x30	ArcGIS 10.4.1 with Kriging interpolation
Temperature	National meteorological agency	30x30	ArcGIS 10.4.1 with Kriging interpolation
Potential evapotranspiration	Calculated from the Meteorological data	30x30	Thornthwaite method and ArcGIS, Kriging interpolation
Slope map	From DEM	30x30	ArcGIS 10.4.1
Soil map	MoW&I	30x30	ArcGIS 10.4.1
LuLc map	MoW&I	30x30	ArcGIS 10.4.1

### **Data preparation**

WetSpas model is a spatial distribution model based on GIS, with all inputs in the form of spatial data (ASCII format). Because of the various sources of data collected and the various formats of data, the data must be transformed using a spatial analysis approach based on particular data type. Rainfall, wind speed, temperature and groundwater level data were collected from National meteorological agency and Somali region water works and supervision. For the spatial analysis of rainfall, wind speed, temperature, potential evapotranspiration and groundwater level, ArcGIS, kriging interpolation were used. The simulated result was compared with the calculated result using soil water balance method.

### **Preparation of parameter tables**

three types of parameter tables were prepared in an appropriate format in order to run the

model. The summer (rainy season) and winter (dry season) land use tables (table 7 and table 8), soil parameter table (table 9) and the run off coefficient was done as an attribute look up tables for the inputs of the software. These look up tables were reviewed from different literature published by different researchers. In regard to the local situation of the study area the seasonal land use parameters were adjusted. The parameter tables were added to the input files with the grid maps of Precipitation, wind, temperature, potential evapotranspiration, groundwater depth, land use, soil, slope and elevation to run the model for simulation of surface run off, actual evapotranspiration and groundwater recharge.

**Table 7: Land use parameter table for summer in upper Fafem**

C o d e	LUSE _TYP E	RUNO FF_V EG	NUM_ VEG_ RO	NUM_ IMP_ RO	VEG _AR EA	BARE _AR EA	IMP _AR EA	OPEN W_AR EA	ROOT _DEP TH	L A I	MIN _ST OM	INTE RC_P ER	VEG_ HEIG HT
21	Agriculture	Crop	1	0	0.9	0	0.2	0	0.4	0	180	35	0.7
23	Grassland	Grass	2	0	0.7	0.2	0.2	0	0.3	2	100	10	0.2
33	mixed forest	Forest	3	0	0.8	0	0.2	0	2.5	7.5	375	50	10
7	Bareland	bare soil	4	0	0.7	0.2	0	0	0.05	0.1	110	27	0.001
29	Orchard	Forest	3	0	0.2	0.8	0	0	0.8	0	200	10	3
10	open build up	Grass	2	3	0.6	0.1	0.3	0	0.3	2	100	10	0.12
36	Shrub	Grass	2	0	0.8	0	0.2	0	0.6	6	110	42	2.5
28	wet meadow	Grass	2	0	1	0	0	0	0.3	2	100	10	0.3

NUM BER	LUS E_T YPE	RUNO FF_V EG	NUM_ VEG_ RO	NUM_ IMP_ RO	VEG _AR EA	BAR E_AR EA	IMP _AR EA	OPEN W_AR EA	ROOT _DEP TH	L A I	MIN _ST OM	INTE RC_P ER	VEG_ HEIG HT
21	agric ulture	Crop	1	0	0.2	0.04	0.4	0	0.35	2	180	20	0.6
23	grassl and	Grass	2	0	0.3	0.2	0.05	0	0.3	2	170	20	0.2
33	mixe d forest	forest	3	0	0.8	0.1	0.1	0	2	4.5	350	38	10
7	Bare- land	bare soil	4	0	0.2	0.4	0	0	0.05	0	110	1	0.001
29	orcha rd	forest	3	0	0.2	0.8	0	0	0.8	0	200	10	3
10	open build up	Grass	2	3	0.6	0.1	0.3	0	0.3	2	100	10	0.12
36	shrub	Grass	2	0	0.2	0.8	0	0	0.6	0	110	30	2
28	wet mead ow	Grass	2	0	1	0	0	0	0.3	2	100	10	0.3

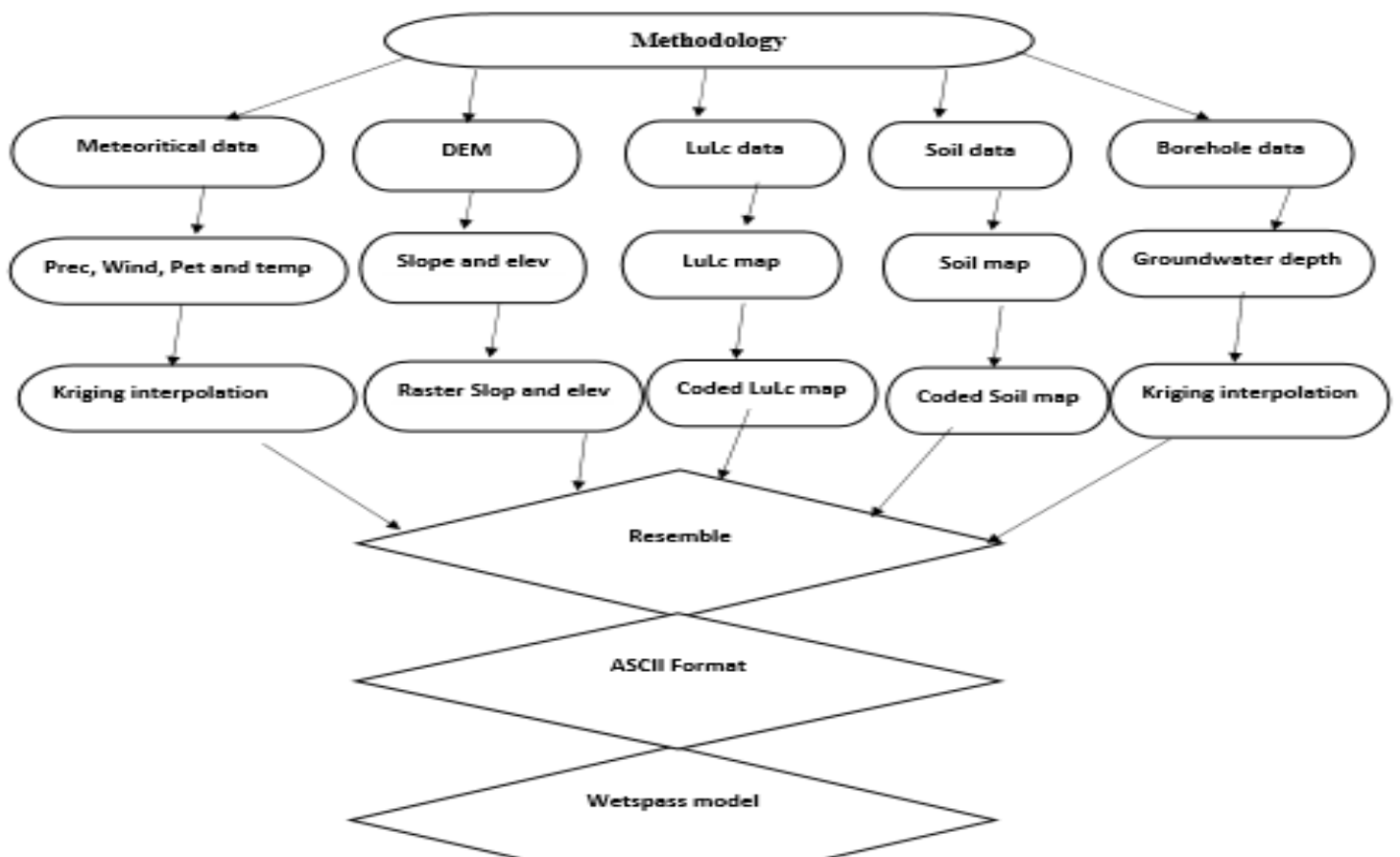
**Table 8: Land use parameter table for winter in upper Fafem**

**Table 9: Soil parameters attribute table of upper Fafem**

Code	Soil	FIELDCA PAC	WILTINGP NT	PAW	RESIDUA LWC	A1	EVAPODEPT H	TENSIONHH T	P_FRAC_SUM	P_FRAC _WIN
3	sandy loam	0.21	0.09	0.12	0.041	0.44	0.05	0.15	0.09	0.01
5	Loam	0.25	0.12	0.13	0.027	0.37	0.05	0.11	0.15	0.02
12	Clay	0.46	0.33	0.13	0.09	0.21	0.05	0.37	0.95	0.85

**Soil parameter attributes**

Code = Soil type number; Soil = Soil type (texture); Fieldcapac = Field capacity; Wiltingpnt = Wilting Point; PAW = Plant available water content; Residualwc = Residual water content; A1 = Calibration parameter dependent on the sand content of the soil; Evapodepth = Bare soil evaporation depth; Tensionhht = 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.



### **Figure 15: Conceptual framework used to estimate GW-recharge**

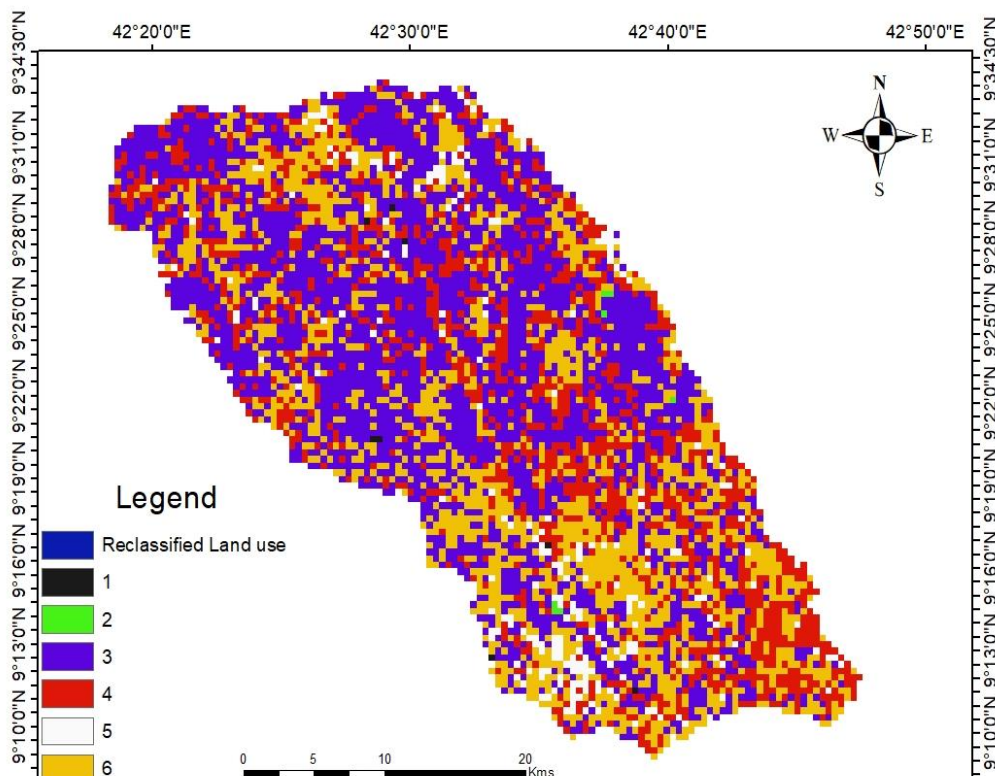
#### **4.3 Groundwater potential evaluation**

Groundwater is a precious and vital natural resource in the world and it is the most fundamental for the growth and development of every nation. Though groundwater potential estimation and identification of its recharge zone has still uncertainty due to the nature of groundwater. The groundwater potential zones of upper Fafem were determined using timely and cost-effective remote sensing and geographical information system (GIS) method for delineating and classifying groundwater potential zones of the catchment. The thematic maps used in this study were precipitation, slope, drainage density, geology, lineament density, LuLc, groundwater recharge and groundwater depth. All these thematic layers were reclassified using knowledge-based analysis that was reviewed from different kinds of literatures.

Each layer was assigned weight factor regarding to their relative importance as per suitable based on Saatty's scale of AHP. The highest weights were given to rainfall, recharge and geology, while drainage density has given to the lowest weight for identifying the groundwater potential zones of the study area. Analytical Hierarchical Process (AHP) is a multi-criteria decision-making procedure developed by Thomas L Satty in (1980) and this method was used in this study. It is a strategy to get proportion scales from paired difference. One of its advantage is its ease of use and it allows a pairwise comparisons for decision makers to weight coefficients and compare alternatives with relative ease. Thematic maps were generated and integrated for groundwater potential zoning. Groundwater potential zoning is the identification and mapping of the prospective zones omf ground in an area by qualitative assessment of the controlling and indicative parameters. Thematic map of each parameter was prepared as follows:

## Land use, land cover

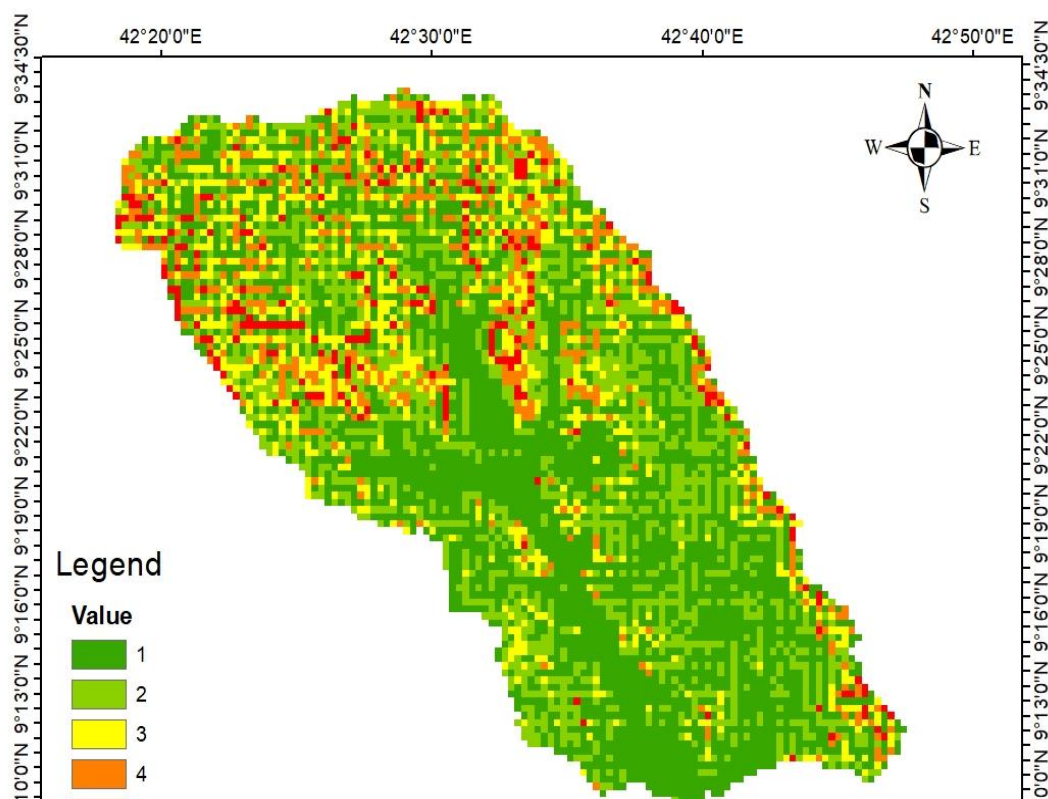
Land use of a region explains the activities practiced by people on a certain defined area in order to gain some economic, cultural and social benefits. On the other hand, the land cover deals with the existing bio-physical cover on the earth's surface. Under this perspective, land use and land cover map of a single area should be prepared to give sufficient emphasis since a single area may fall into different land use and land cover categories. Land use land cover of Ethiopia as a whole was taken from the Ministry of water and irrigation, then the land use, land cover of the study area was extracted. Land use and land cover distribution in the study area depends on variation in altitude, climatic conditions, population density, land use practices and agricultural activities. Land use is one of the major controlling factors for groundwater occurrence, it has influence for infiltration of water to the ground, evapotranspiration and run off. Both surface and ground water are influenced by the land use and land cover of an area of interest. For instance, the presence of trees and intensively cultivated land significantly decreases the surface runoff through interception and increased infiltration of the total precipitation that could otherwise flow to rivers and lakes. Reclassified maps including the land use map of the catchment was used to evaluate the groundwater potential of the catchment.



**Figure 16: Reclassified land use Map of the study area**

### Slope

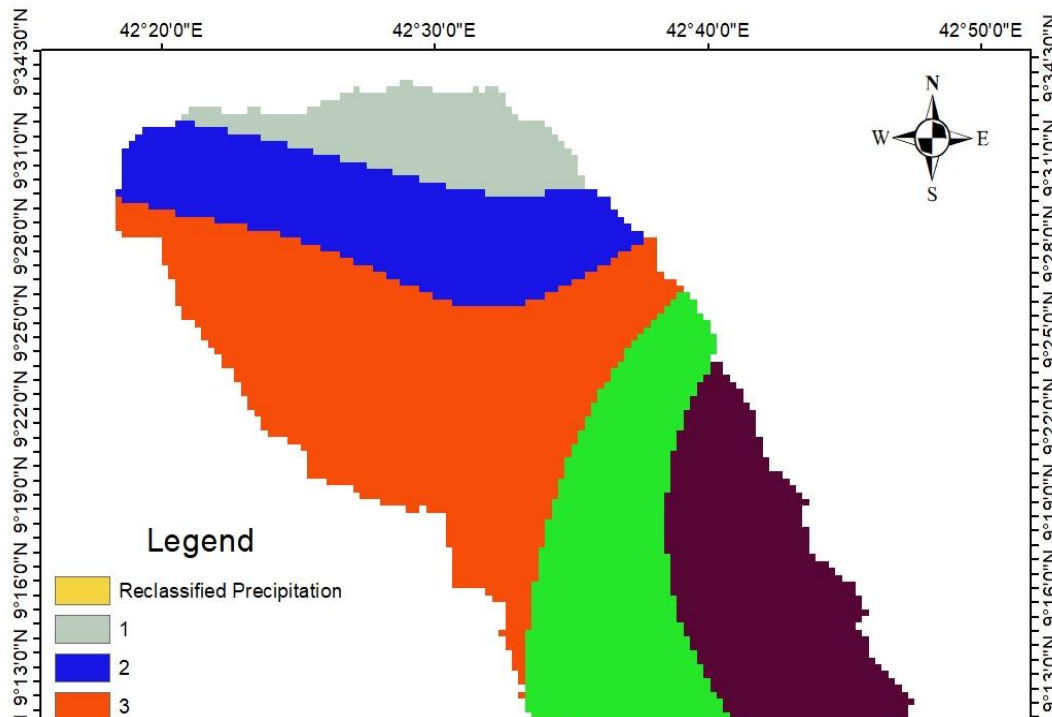
Slope is very important in identifying the groundwater potential zones of a watershed. Because it impacts the runoff speed, runoff retention on the soil surface as well as infiltration capacity. Flat areas are very good for groundwater recharge capability since such areas influence high infiltration rates and less generation of surface runoff. However, areas with steep slopes have low groundwater level since less time is allowed for storm water to infiltrate, thus rainfall is easily turned into runoff and rapidly flow down the slope. Generally, gentle slopes are prospects of high groundwater potential, more rainfall can percolate into the subsurface. Rainfall is the main source of groundwater; slope gradient directly affects the infiltration of rainfall into the ground. The slope of the study area was processed from DEM of the study area, using ArcGIS with spatial analysis extension. The slope of the watershed was grouped into five classes such as; very high slope ( $26^{\circ}$ - $65^{\circ}$ ), high slope ( $17^{\circ}$ - $26^{\circ}$ ), moderate slope, ( $10^{\circ}$ - $17^{\circ}$ ), gentle slope ( $5^{\circ}$ - $10^{\circ}$ ) and very low slope ( $0^{\circ}$ - $5^{\circ}$ ). Generally, areas that indicated from 0 to 5 degree indicated flat or plain areas which is really good for surface water settlement which leads to infiltration. Therefore, this area could be one of the possible groundwater potential region.



**Figure 17: Reclassified slope Map of upper Fafem**

**Precipitation**

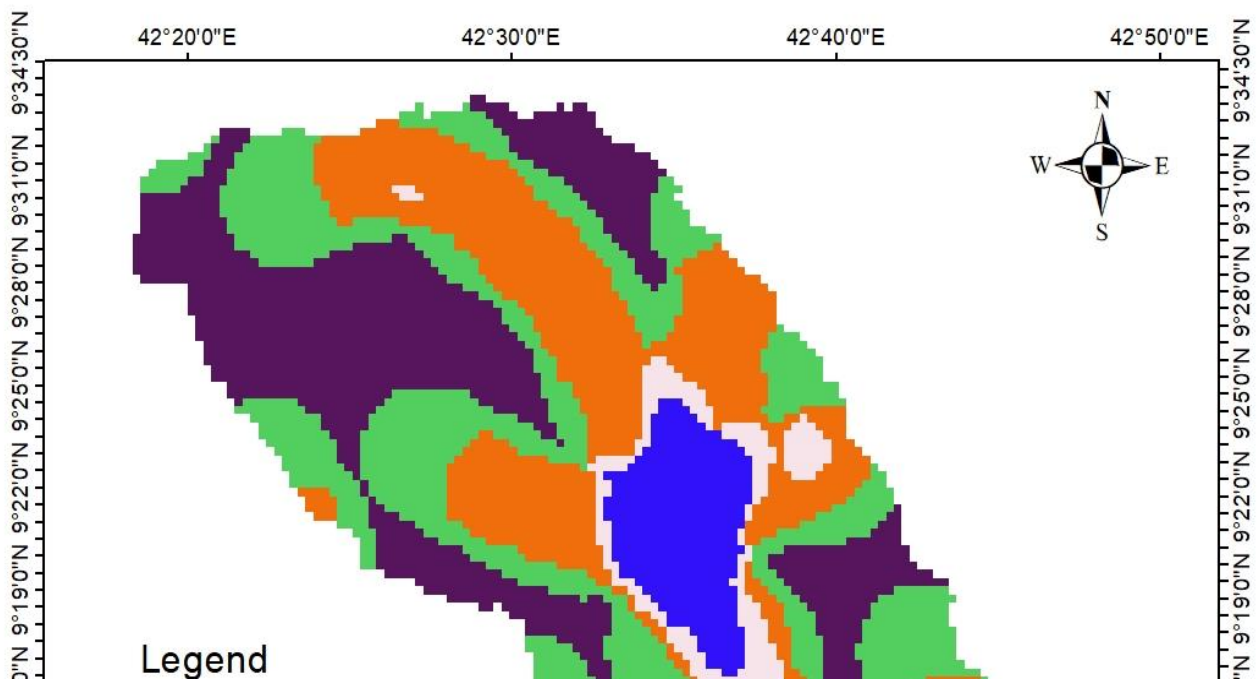
Precipitation directly affects the recharge and it's the main source of groundwater. However, the amount of infiltration highly depends of the land cover, slope, soil type and the geological nature of the area. So, based on these the overall annual precipitation distribution in five stations collected from national meteorological agency was used. Then kriging interpolations was used to estimate areal rainfall distribution of the study area and the result shows that the south eastern part of the study area gets heavy rain and areas in the north tip has less amount of annual precipitation. Therefore, a siding other factors, the south eastern part of the catchment has good groundwater potential and the most suitable areas for groundwater recharge.



**Figure 18: Reclassified Precipitation Map of upper Fafem**

**Drainage density**

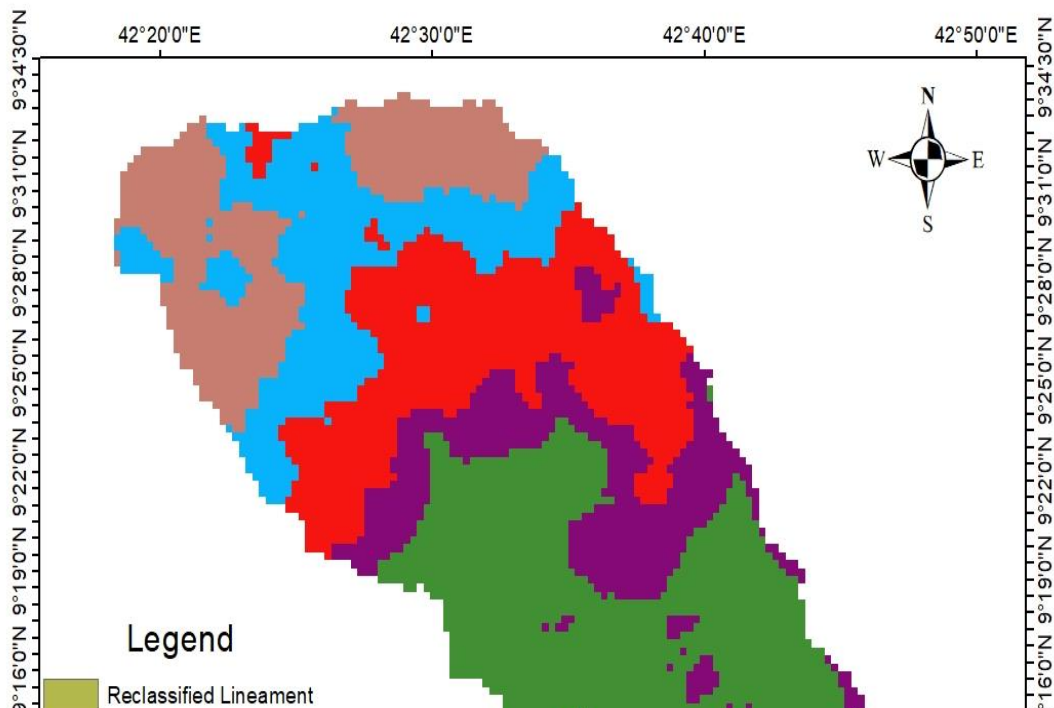
Drainage pattern in the study area is mainly characterized as a dendritic pattern and is controlled by geomorphology. normally drainage density depends on the slope, nature and attitude of bedrocks and in some places, it depends on the existing regional and local fracture patterns. Areas with higher drainage density shows that there is no much water that percolate rather there is high surface runoff, which leads to less infiltration and less recharge. Therefore, there is no possible groundwater potential in that area. In contrast to this, areas with low drainage density indicated higher infiltration, lower surface runoff, which favors good groundwater potential. Therefore, most of the areas shown with blue and white in the figure shows high dense areas, which may have lower groundwater potential possibly, but drainage density alone cannot be the determining factor for groundwater zones.



**Figure 19: Reclassified Drainage map of upper Fafem**

**Lineament density**

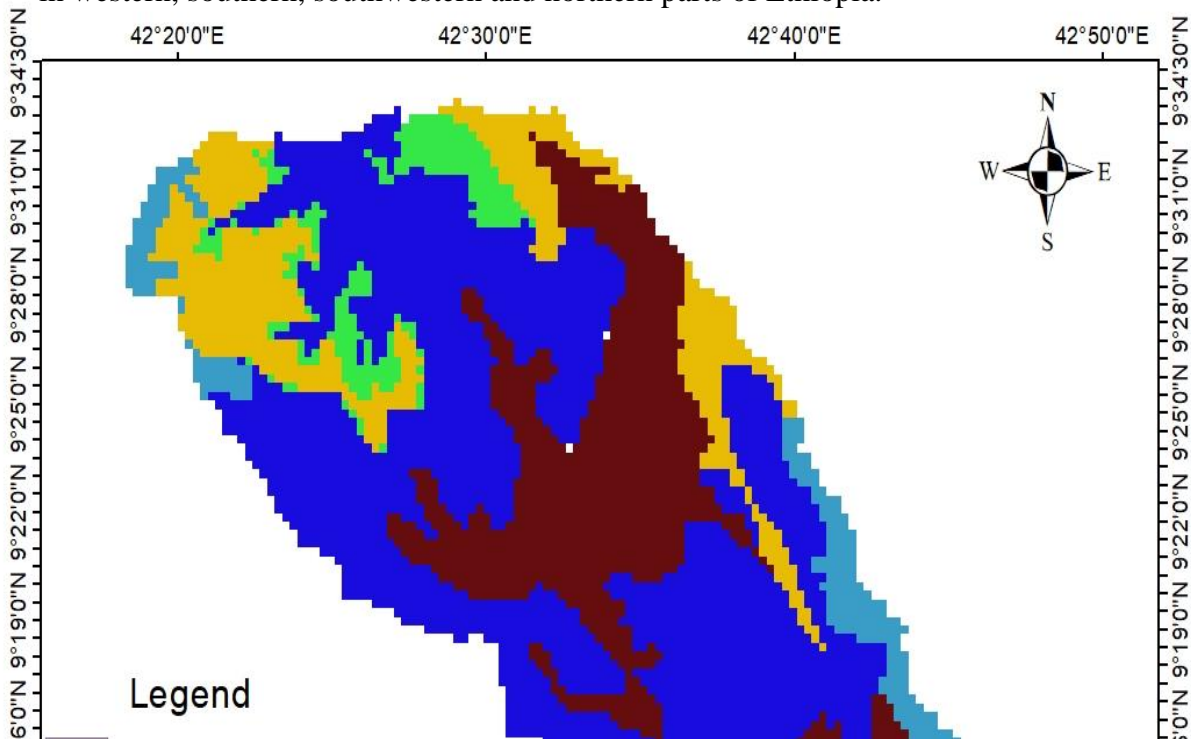
Lineament density generally shows the overall distribution of structures in the area. Based on this, most of the northern part of the study area have higher lineament density that is in favour of groundwater potential. Most of the central part of the study areas have lower lineament density, that does not mean area with high lineament density have higher groundwater potential, but lineament density is one of the main factors influence groundwater occurrence of an area.



**Figure 20: Reclassified lineament map**

**Geology**

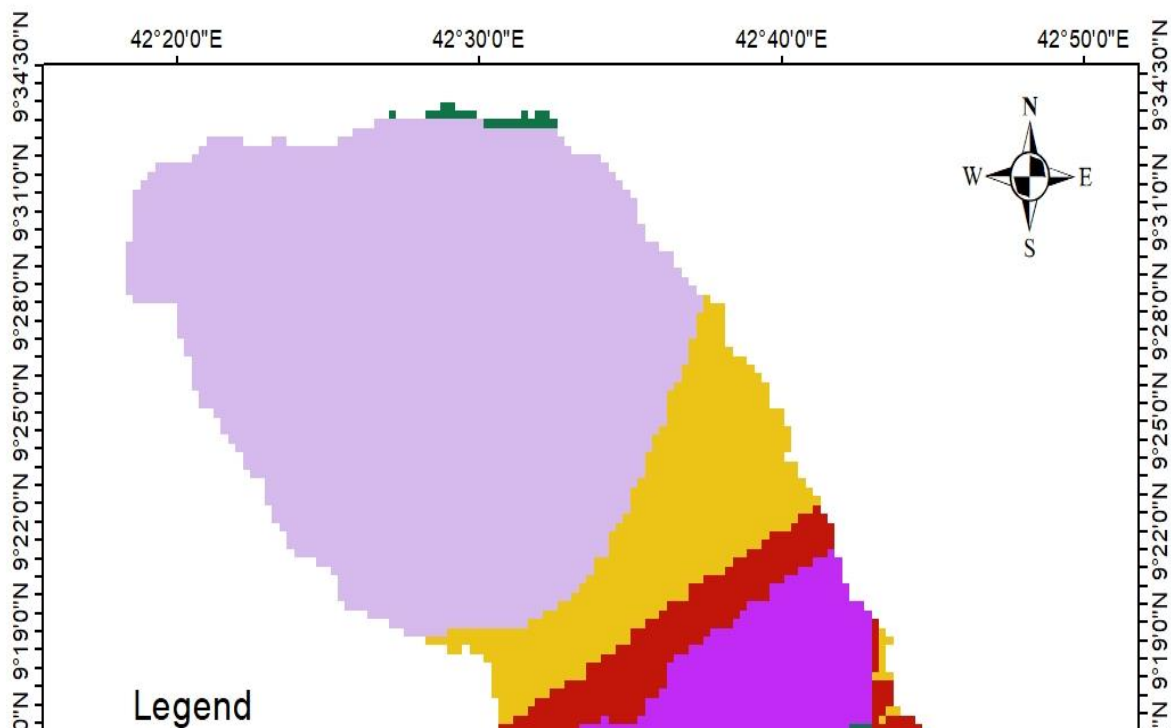
The availability of groundwater is largely affected by surface and subsurface geology. The porosity and permeability of a geologic formation controls its ability to hold and transmit water. Porosity is measured as a ratio of voids to the total volume of rock material and is usually described as a percentage. The geological map of the study area was obtained from Geological survey of Ethiopia, upper Fafem sub catchment is located in Ogaden basin in which Precambrian crystalline basement rocks, Mesozoic sedimentary rock succession and Tertiary volcanic and sedimentary rock successions occur. Geo chronological study conducted by Teklay et al. (1998) related to Precambrian basement rocks of eastern Ethiopia in Hirna and Herar which are near to upper Fafem sub catchment indicated that Paleoproterozoic and Archean ages. Accordingly, the Precambrian basement rocks of eastern Ethiopia are classified in to three groups which are upper, middle and lower complexes and assumed to contain rock components older than all other Precambrian basement occurrences in western, southern, southwestern and northern parts of Ethiopia.



**Figure 21: Reclassified Geology**

**Groundwater depth**

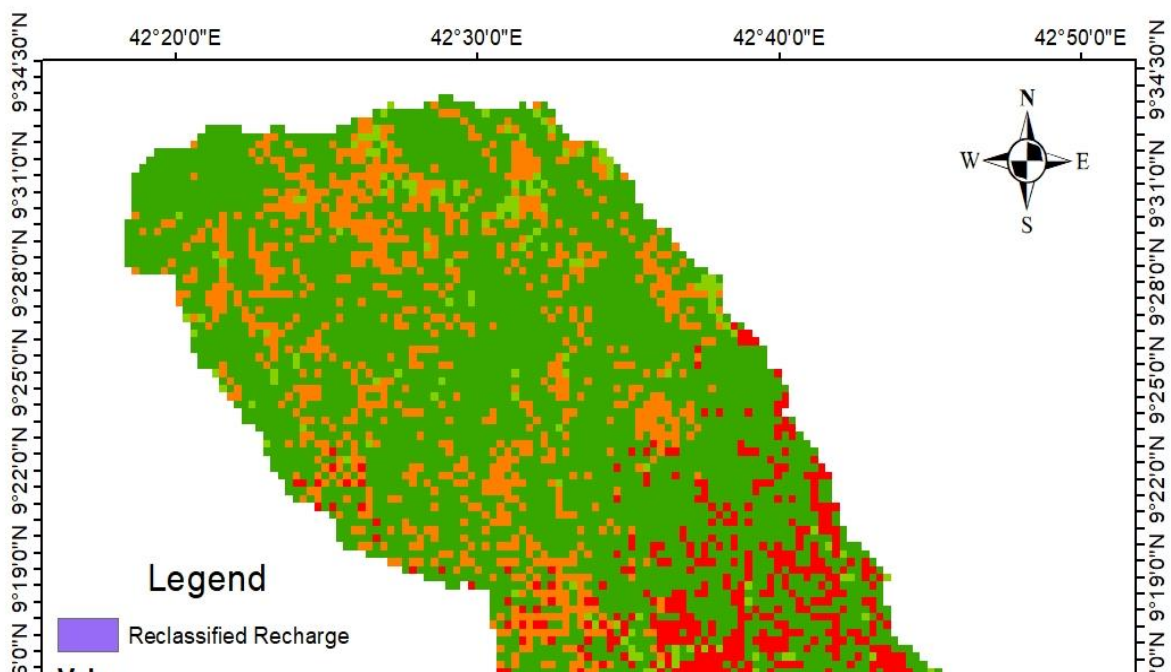
The borehole data of the study area was taken from Somali region, water works and supervision, then the measured static water level was subtracted from the surface elevation to obtain the groundwater depth and its raster map was prepared using ArcGIS with its spatial extension kriging interpolation, for using groundwater depth to evaluate groundwater potential zone, shallow groundwater table was given the higher scale and the deep ones were ranked as lower scale.



**Figure 22: Reclassified Groundwater depth**

**Groundwater recharge**

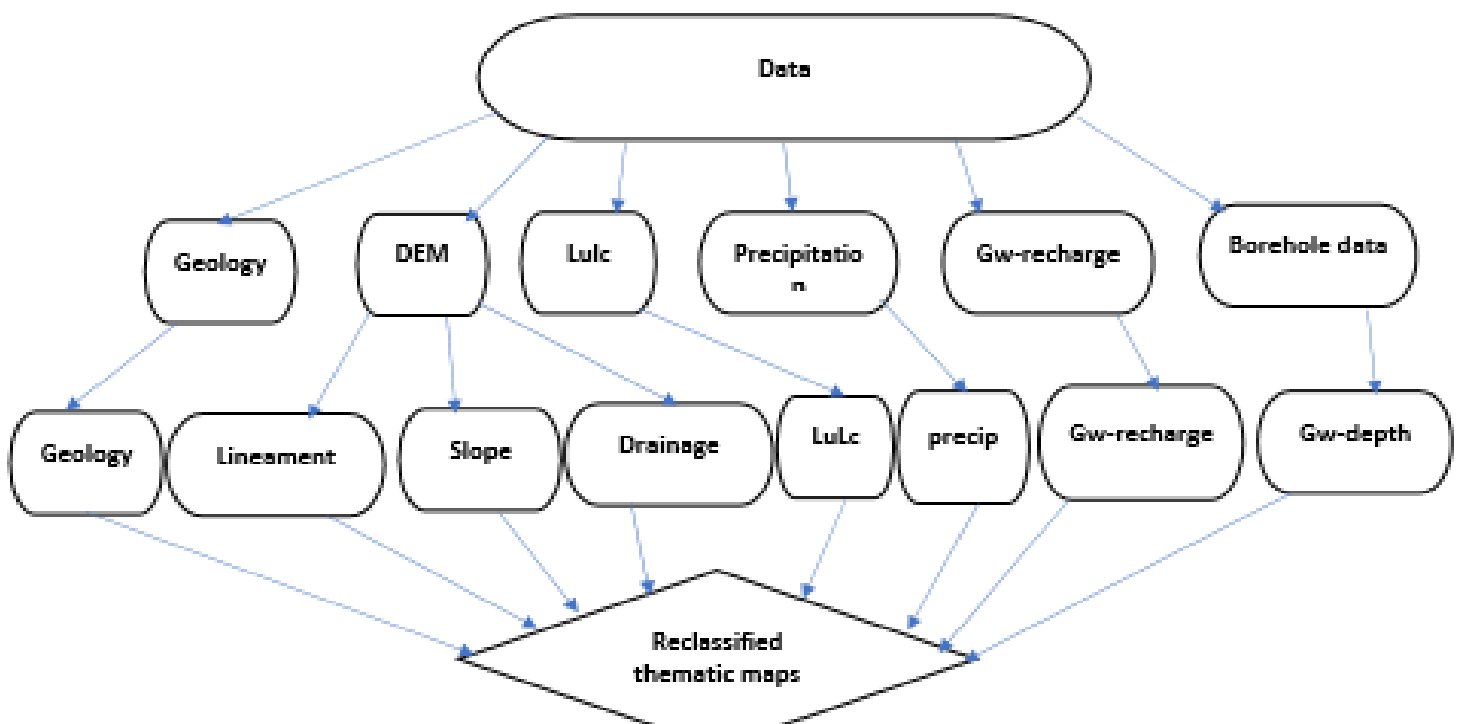
Groundwater recharge of the study area was used to evaluate groundwater potential zones, the annual groundwater recharge was the output of the wetpass model, areas of higher groundwater recharge was assigned to the higher values and vice versa. The lower part of the catchment has higher groundwater recharge.



**Figure 23: Reclassified Annual Groundwater recharge**

### 4.3.1 Weighted overlay

In this study, the reclassified layers were analyzed by giving scale value within each reclassified data sets according to their influence in the suitability mode and combines them to delineate ground water potential zones of the area. Each parameter was assigned a weightage regarding to the groundwater occurrence. By assigning percentage influence (%) for each parameter and comparing the relative importance of criteria. Finally, to produce groundwater potential map, all the thematic layers were overlaid using weightage overlay module in Arc GIS 10.4.1. In general, Remote sensing and GIS techniques were applied to delineate groundwater potential zones of the upper Fafem sub catchment through Analytical Hierarchy Process.



## **Figure 24: Conceptual framework methodology used for GW potential zoning**

### **4.4 Groundwater quality/ Hydro chemistry**

In several parts of the world, including Ethiopia, groundwater is an important source of freshwater for drinking, agricultural and domestic activities. The demand of groundwater for irrigation has been gradually growing as more land has been cultivated. In this study eight water samples were collected from boreholes in upper Fafem. The Groundwater in upper fafem basin is mainly used for drinking and Irrigation, therefore determining the water quality of this catchment has more important. The World Health Organization (WHO) reported that nearly half of the population in many countries around the world suffers from health problems associated with lack of good quality of drinking water (Nikolaos et al. 2004). The study was conducted to evaluate the degree of ionic toxicity of groundwater for drinking and irrigation.

The samples were analyzed to determine the dominant cations and anions such as K, Na, Ca, Mg, Fe, Mn, PH and Cl, F and HCO<sub>3</sub>. To determine water quality regarding to their suitability for drinking and irrigation purposes the laboratory results were compared to the WHO and MoW&I standard guidelines for clean drinking water. The soluble sodium percentage, Sodium adsorption ratio and permeability index were calculated to know whether this water is suitable for irrigation or not. In general, the quality of water is determined by the

total concentration of salts. In recent days various studies are available for evaluating groundwater suitability in domestic and agricultural use. hydro chemical analysis is very important in identifying a number of practical problems related to groundwater such as major ions and cations in the water. One of the objectives of this work was to evaluate, the water suitability of upper Fafem for drinking and agricultural use. The laboratory results of the samples were compared to the Ethiopian Ministry of water guidelines and World health organization (WHO) water quality guidelines for drinking and agricultural purposes. Knowing the degree of toxicity of water will help to minimize the risk, related to polluted water and to safeguard public health.

The samples were analyzed in the laboratory of Addis Ababa University, Chemistry department, all the eight samples were analyzed, the PH, Temperature, potassium (K), sodium (Na), calcium (Ca), Magnesium (Mg), Manganese (Mn), Chloride (Cl), fluoride (F), Hardness, bicarbonate ( $\text{HCO}_3$ ) and iron (Fe). Water quality suitability evaluation is basically based on physiochemical analysis. The required quality of water is based the purpose to be used, (Drinking, Agricultural or Industrial). For each purpose there are water quality standards which had been intended to monitor the water quality for that particular purpose. Standards are risk management plans developed at regional and nation level from scientific guidelines provided by WHO in 2001. The WHO developed a guideline for drinking water quality with the aim of protecting public health and this guideline clearly indicates the maximum reasonable required for safe use of water for the purpose of protecting the consumers. This guideline shows the reasonable concentration of each element that doesn't causes any risk to the health of the human being.

## **CHAPTER FIVE**

### **5 RESULT AND DISCUSSION**

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

In order to estimate the hydrologic balance of an area, each and every hydro-meteorological component must be quantified. Rainfall, temperature, wind speed and PET, are the most basic and necessary meteorological data. Rainfall, temperature, evapotranspiration and wind speed were interpolated using the ordinary kriging method, from readings obtained from meteorological agency during model simulation. WetSpas model, was used to estimate

hydrologic balance of the study area. As a result, actual evapotranspiration, surface runoff and groundwater recharge have been simulated and will be addressed in the following sections.

### **5.1.1 Rainfall**

Rainfall is one of the most important parameters in hydrologic cycle and is the fundamental element in climatic system and cannot be manipulated in an easy manner. Rainfall distribution analysis and transient variability were characterized by bimodal rainfall trend, based on rainfall data collected from meteorological agency, main rainfall occurs in the months of June, July, August and September and a minor rain occurs during the months of March, April and May. Rainfall is the most important element in a region's hydrologic cycle. During the rainy season rainfall ranges between 521 mm to 535 mm while in dry period it ranges 143 mm to 148 mm, for annual bases it ranges from 665 mm to 680 mm. About 80% of the rain occurs during the rainy season (April to September), the 20% of the rainfall occurs during dry period (figure 6).

### **5.1.2 Temperature**

thirteen years (2002 to 2014) meteorological data including the temperature data of five locations in and around the study area were collected from the Ethiopian national meteorological agency. The monthly temperature of the study area was divided into two seasons, summer months (April to September) and winter season as (October to March) after assigned to these ways, the average temperature values were converted to spatially distributed grid maps using ordinary kriging, then the grid maps of the two seasons were converted to ASCII format and used with the other parameters in the wetpass model. During rainy season the average temperature ranges between 18.6<sup>0</sup>C to 22<sup>0</sup>C with mean temperature of 21.7<sup>0</sup>C. for dry season it ranges between 19.2<sup>0</sup>C to 21<sup>0</sup>C with mean of 20.6<sup>0</sup>C, on annual bases the temperature of the study area ranges between 21.4<sup>0</sup>C to 22<sup>0</sup>C with mean of 21.69<sup>0</sup>C. (figure 8)

### **5.1.3 Potential evapotranspiration**

The term evapotranspiration is the totality of water that is lost due to the evaporation from soil and the transpiration of plants, this may further be classified into potential and

actual evapotranspiration. potential evapotranspiration (PET) is defined as the amount of evapotranspiration that would occur if a sufficient moisture is available. Evapotranspiration is an important factor for water budget which abstracts water from the system and controls the soil moisture content, Bitsiet Dereje and Dr. Dessie Nedaw (2018). Thornthwaite (1948) has developed an empirical formula for calculating potential evapotranspiration as a function of climatic average, monthly temperature and day length. This formula calculates potential evapotranspiration with assumption that an exponential relationship existed between mean monthly temperature and mean monthly consumptive use.

The average monthly temperature is being used for calculation of potential evapotranspiration. Thornthwaite proposed the following formula:  $ET = 1.6b[10Ta/I]^a$ . ET = monthly pet in cm/ month, Ta is the mean monthly air temperature ( $^{\circ}C$ ), I annual heat index calculated as  $I = \sum (Tai/5)^{15.14}$  and b latitude correction. Accordingly, the monthly PET of upper Fafem was divided into two seasons, six months of rainy season which is (April to September) and dry season (October to March). Finally, the PET value for each season was converted to spatially distributed grid maps using ordinary kriging interpolation, then these grid maps of both seasons were used with other input parameters in the model. The mean potential evapotranspiration in summer is 761.3 mm and winter is 630.8, while the average annual potential evapotranspiration of the catchment is 984.2mm. (figure 10)

#### **5.1.4 Wind speed**

Wind speed of four meteorological stations were obtained from the meteorological agency. These four stations wind data were used to produce wind map of the study area. As same to the other parameters, wind speed data was also divided to two seasons, on rainy season (April to September) and dry season (October to March). The average wind values of each season were interpolated and converted to grid maps using ordinary kriging interpolation. These grid maps of both seasons were converted to ASCII file and used as an input for the model. (Figure 9)

#### **5.2 Output of the wetspass**

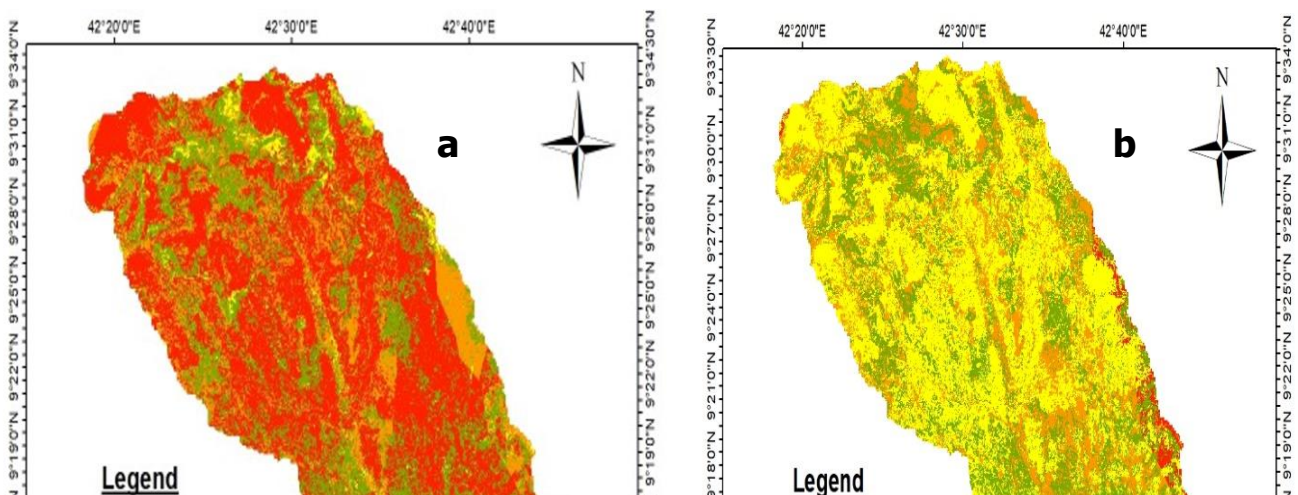
Raster maps of seasonal and annual groundwater recharge, surface runoff and actual evapotranspiration for the period 2002 to 2014. In this map each pixel represents the

magnitude of the water budgets. The outputs of the model were described as below

### 5.2.1 Actual evapotranspiration

Evapotranspiration is one of the hydrologic processes in which the water returns to the atmosphere and completes the hydrologic cycle. Evapotranspiration is the sum of evaporation from open water body, ground surface and transpiration from plants. Actual evapotranspiration is one the components of water balance for determining groundwater recharge of a catchment. Direct measurement of actual evapotranspiration is difficult and impractical therefore it is normally estimated using hydrologic models, empirical formulas or potential evapotranspiration.

Annual evapotranspiration simulated by the wetspass as a sum of evapotranspiration from bare soil, transpiration from vegetated cover, interception loss and evaporation from open water body. In this research the model simulated annual actual evapotranspiration of 180 mm to 680 mm as minimum and maximum respectively with mean actual evapotranspiration of 616 mm. the evapotranspiration of Upper Fafem accounts for 93.5% of the total annual rainfall. This indicates that evapotranspiration is the major process which causes water loss from the catchment, the reason may be due to the dry wind, high solar radiation and high plant cover. of the area nearly 80% of the evapotranspiration occur during summer while the remaining 20% occur in winter season, this disparity is caused by precipitation difference between these two seasons.



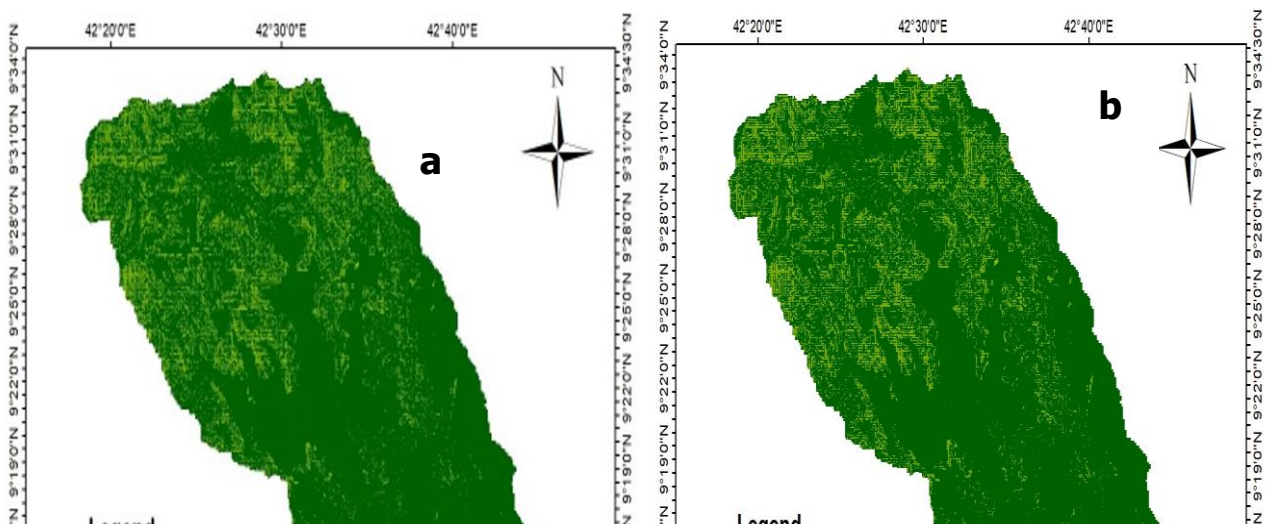
**Figure 25: Summer AET (a), Winter AET(b), Annual AET (c)**

### **5.2.2 Surface runoff**

To estimate the surface runoff of Upper Fafem sub catchment, wetspass uses runoff coefficient which varies its value with vegetation type, slope and soil type. The surface runoff of upper Fafem shows variation with precipitation, land use, slope and soil type, topography and other meteorological parameters.

The simulated annual runoff varies from 1.2 mm to 461 mm with mean of 20 mm which accounts 3% of the mean annual rainfall (660mm). surface runoff shows in summer and winter seasons, the mean surface runoff in summer is approximately 16 mm while in winter season the mean surface runoff is 3 mm, this shows that the surface runoff occurs mainly during the rainy season (April to September), The reason is that the rainfall exceeds the infiltration capacity of the soil during the wet season.

According to the annually simulated surface runoff of the catchment (Fig 26 c), the area is mainly characterized from low to medium surface runoff, this is because 93% of the area has a loam soil and 6.6% is sandy loam, only small portion of the area 0.4% has clay soil and this loam and sandy loam soils which has shrubs, crops and forest cover impede the surface runoff and this indicates that these soil types have great influence for the runoff in Upper Fafem.



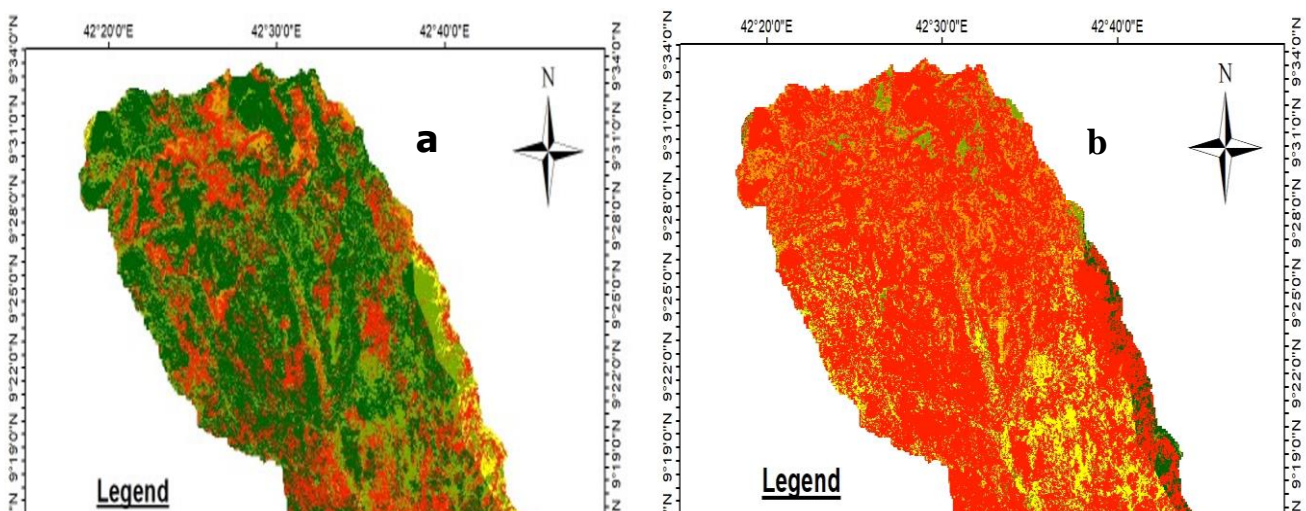
**Figure 26: Summer runoff (a), Winter runoff (b), Annual runoff (c)**

### **5.2.3 Groundwater recharge**

Recharge is an important parameter for evaluating groundwater resources but groundwater recharge cannot be accurately measured and it is difficult to estimate accurately. Wetspass model simulates seasonal and annual long-term distribution of recharge in upper Fafem, as spatial variable depending on land use, slope, soil texture and meteorological conditions by

subtracting the seasonal and annual surface runoff and actual evapotranspiration from seasonal and annual precipitation. In Upper Fafem the annual groundwater recharge varies from 0 to 129 mm with mean recharge of 23 mm. The average annual recharge of Upper Fafem accounts 3.5% of the average annual precipitation.

The simulated result of groundwater recharge of Upper Fafem is near to the groundwater recharge obtained by Ketema Tilahun and Broder J. Merkel (2009) in Diredawa which is 28 mm. Diredawa is very near to Fafem and has similar climate with Fafem. Generally, the recharge areas are areas which has higher topographic features while discharge area are lower in topography. The groundwater recharge value found using Soil water balance which is 26.19 mm, is more similar to the simulated result using the Wetspass model, thus to groundwater recharge estimation using Wetspass model is one of the best options for quantifying amount of recharge.



**Figure 27: Summer GW-recharge (a), Winter GW-recharge (b), annual GW-recharge (c)**

### **5.3 Soil water balance method**

For checking the result obtained using wetpass model, soil water balance method was used. In calculating the runoff, daily precipitation data for three stations for a period of 13 years from 2002 to 2014, collected from the National meteorological agency was used. Average rainfall for the whole watershed was computed using Thiessen polygon method by considering

the weighted influence of each station to the watershed.

### Run off

Estimation of runoff from rainfall, is mainly depend on time. Since there was no flow data in the study area, the run off volume was calculated using run off coefficient method by considering the value of runoff coefficients for different land uses, the curve number of each land use was used. The USDA-SCS runoff equation in (USDA-SCS, 1985):  $Q = \frac{(P-0.2S)^2}{P-0.8S}$ , Where: Q, runoff (mm), P, rainfall (mm), S, potential maximum retention after runoff begins (mm). The potential retention (S) can range from zero on smooth, impervious surface to infinity in deep gravel. Accordingly, the run off value was found to be 15.28 mm/year.

### Actual evapotranspiration

Actual evapotranspiration (AET) of Upper Fafem sub basin was obtained using an empirical formula developed by Turc (1961), which is  $AET = (p)/(\sqrt{[0.9+(P/L)^2]})$ . Where AET = actual annual evapotranspiration in mm, P is the mean annual rainfall in mm, T is the annual mean Temperature and  $L = 300+25T+0.05T^3$  in mm. this empirical formula is appropriate in semi-arid and hot areas and had been used widely for estimating Actual evapotranspiration, Shaw (1988).  $L=300+25T+0.05T^3=300+25*(21.69)+0.05(21.69)^3=1369.77$ .  $AET=(p)/(\sqrt{[0.9+(P/L)^2]})=618.99$  mm, therefore the AET was obtained to be 618.99.

### Water balance

Water balance of an area is the relation between the water entering the area through rainfall and water flowing out from the area through evapotranspiration, stream flow and recharge of groundwater. In this study soil water balance method has been used to estimate groundwater recharge for the purpose of comparing the simulated result of wetspass. The calculation was made on annual base therefore the change in soil moisture was assumed to be negligible. Therefore, the water balance equation of the catchment is simplified as  $P = AET+Q+R$ . according to (Yin et al., 2011), where P is stands for mean annual precipitation, AET is the mean annual actual evapotranspiration and Q stands for the mean annual runoff and R is the recharge. therefore, the groundwater recharge was calculated as residue,  $R = P-AET-Q$ .

**Table 10: Calculation: groundwater recharge**

Parameter	Amount in mm/year
P	660.46
Q (runoff)	15.28
AET	618.99
R(P-Q-AET)	26.19

## 5.4 Groundwater potential evaluation

Groundwater is a valuable and important natural resource in the world and it is the most fundamental for the growth and development of any country. though, estimating the groundwater recharge zones and its potential has still uncertainty due to the nature of groundwater. For evaluating groundwater potential zones of upper Fafem catchment all-important parameters were considered and used. The map of each parameter was prepared and converted to raster data with similar cell size and reclassified, then each map was assigned to a different weightage as per their influence to groundwater occurrence. Eventually the maps were integrated using GIS software for delineating the groundwater potential zones of the catchment.

### 5.4.1 Analytical Hierarchical Process (AHP)

Analytic Hierarchical Process (AHP) is a multi-criteria decision-making procedure developed by Thomas L Saty in (1980) and this method was used in this study for evaluation groundwater potential zones of upper fafem. It is a strategy to get proportion scales from paired difference. One of its advantage is that its ease of use and it allows a pairwise comparisons for decision makers to weight coefficients and compare alternatives with relative ease. Eight thematic maps were used in this study for evaluation and determining groundwater potential zones of Upper Fafem. The maps used were Rainfall, Geology, drainage, lineament, slope, Land use, groundwater recharge and groundwater depth. Since rainfall is the main contributing factor for groundwater recharge, it was given the highest values and assumed to have 24%, while the drainage was given the least value 3%.

**Table 11:scale of relative importance according to saaty (1980)**

Rating	Definition	Explanation
1	Equally important	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very Strong importance	One element is favored very strongly over another

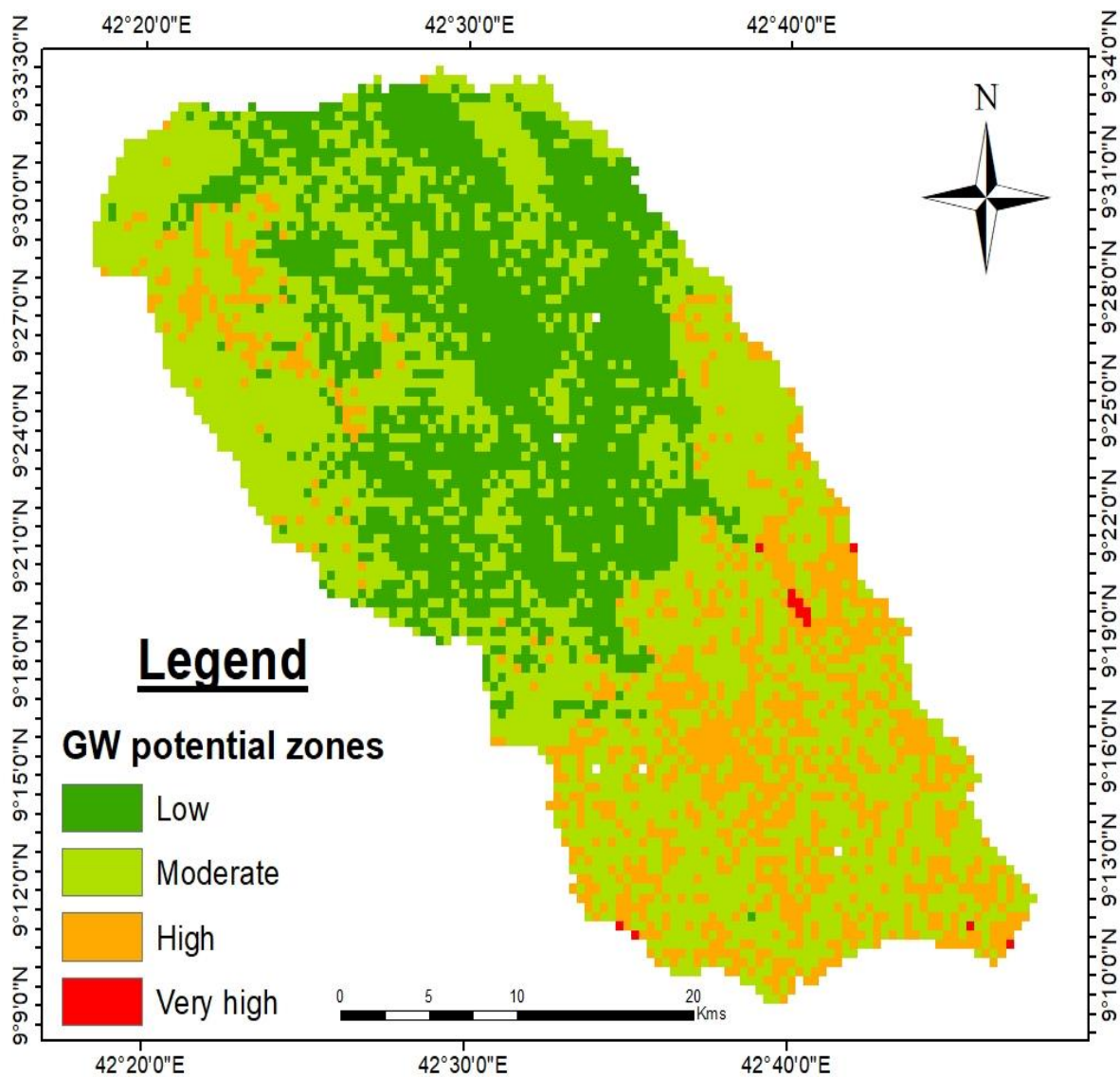
9	Extremely importance	Strong	The evidence favouring one element over another is of the highest possible order
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**Table 12:weightage of each map**

<b>Rank</b>	<b>Categories</b>	<b>Weightage (%)</b>
1	Rainfall	24%
2	Recharge	20%
3	Geology	16%
4	Lineament	14%
5	Lulc	13%
6	Gwdepth	6%
7	Slope	4%
8	Drainage	3%

#### **5.4.2 Groundwater potential zoning map**

Weighted overlay analysis in ArcMap was used for all thematic maps, the groundwater potential zones of Upper Fafem were delineated and classified as; low groundwater potential zone, moderate groundwater potential zone, high groundwater potential zone and very high groundwater potential zone. Most of the area is characterized by moderate groundwater potential, almost 52% of the area is characterized as moderate groundwater potential. Table (13) was indicated the area for each zone, 17.38% of upper Fafem catchment which is 215.0464 km<sup>2</sup> has high groundwater potential, 52%is characterized as moderate groundwater which an area of 640.146, small portion of the catchment which is 0.4325% has very high groundwater potential and 30.44% of the catchment has low groundwater.



**Figure 28: Groundwater potential zones map**

**Table 13: Areal coverage of groundwater potential zones**

No	Groundwater potential	Coverage (Km <sup>2</sup> )	Percentage
1	Low	379.6473	30.44%
2	Moderate	640.146	51.74%
3	High	215.0464	17.38%
4	Very high	2.411735	0.4325%

### 5.5 Groundwater quality

Water suitability evaluation for a particular purpose is an important factor and it

depends on its use for particular purpose, in Upper Fafem the groundwater is mainly used for domestic and Irrigation. For water to say, it is suitable for a particular purpose there should be water quality standards and guidelines to be used as a benchmark. Groundwater suitability evaluation for drinking and irrigation use of upper Fafem was one the objectives of this work, therefore eight samples of groundwater were collected from the boreholes in the study area for groundwater quality analyzes, the principle economic activities in upper Fafem are Agriculture and livestock. Groundwater in the study area is mainly used for all basic needs since there is no surface water, therefore it become an essential to assess the suitability of this water for domestic use and Irrigation as well.

### 5.5.1 Analytical results of groundwater

The analytical results were used to evaluate the groundwater suitability of upper Fafem for drinking and irrigation purposes. The analytical result from the laboratory for all the parameters in the study area are indicated the table below.

**Table 14: Laboratory results**

Ion in mg/l	pb	cu	Fe	Zn	ca	Mg	K	Ni	Mn	Ph	Temp	F-	Na	HCO3-
BH1	0.2085	0.1928	0.99	0.0225	8.344	102.5	10.45	0.0093	1.768	7.16	18.1	0.81	20.037	390.4
BH2	0.2168	0.1646	2.24	0.102	22.45	113.1	23.36	0.0085	2.639	7.8	18.1	0.6	20.094	488
BH3	0.1738	0.1522	2.39	0.52	17.44	105.3	19.42	0.0091	2.113	7.7	18.1	1.78	19.75	317.2
BH4	0.1771	0.1574	2.67	0.1353	20.29	107.1	19.59	0.0096	2.616	7.71	19.3	1.31	20.00	419.6
BH5	0.188	0.1629	4.48	0.04	15.14	113.9	20.85	0.0089	2.227	7.74	19.3	0.92	20.57	683.2
BH6	0.146	0.1502	4.07	0.0321	7.275	105	20.98	0.0098	3.053	7.75	18.3	0.12	19.94	244
BH7	0.1377	0.1519	4.42	0.1525	16.42	103.5	19.51	0.0093	4.588	7.34	18.1	0.14	18.84	244
BH8	0.1514	0.1495	4.87	0.1108	20.79	105.2	21.09	0.0092	4.79	7.65	18.3	0.6	20.14	390.4

**Table 15: WHO water quality standards (2001)**

Parameters or substances	WHO (1993)	MoWR (2002)
Temperature	High is not good	Non-objectionable
pH	6.5-8.5	6.5-8.5
Total Hardness (as CaCO <sub>3</sub> ), mg/l	300	392
Chloride, mg/l	250	533
Mg		
Zinc, mg/l	4	6
Ca		
Total iron, mg/l	0.3	0.4
Na		
Copper	2	5
K		
Nickel	0.02	
Fluoride	1.5	3.0
Lead	0.01	0.02
Manganese	0.5	0.8

## 5.5.2 Drinking water quality

### PH and Temperature

The PH values of the water samples collected from the study area ranges from 7.16 to 7.8. the lowest PH value was measured in Dhakato water while the highest PH value was measured at dhagaha. The PH of natural water is mainly determined by bicarbonate and carbonate content in that water. The PH values of the groundwater in Fafem valley is in the acceptable limits of WHO standards for drinking water. The overall inspection of the chemistry of groundwater of the Fafem Valley suggests that the groundwater of Fafem is good for drinking purpose. In regards to the temperature of the water in the study area, its characterized on similar temperature. According to the results found from the water samples all water in this area has a temperature range of 18.1 to 19.3<sup>0</sup>C.

**Table 16:PH for the water sample Vs WHO standard**

Site	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8
PH	7.16	7.8	7.7	7.71	7.74	7.75	7.34	7.65
WHO	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5

### Major cations and ions

The major cation found in this water is magnesium, for all water samples collected the magnesium content ranges from 102.5 to 113.9 mg/l. the highest magnesium value was found in dhakayo while the lowest found in dhakato. On the other hand, the major anion found for this water is bicarbonate and it varies from 244 mg/l to 683.2mg/l. in mostly the occurrence of bicarbonate in groundwater is causes by carbon dioxide, soil interaction and carbonate in the rocks.

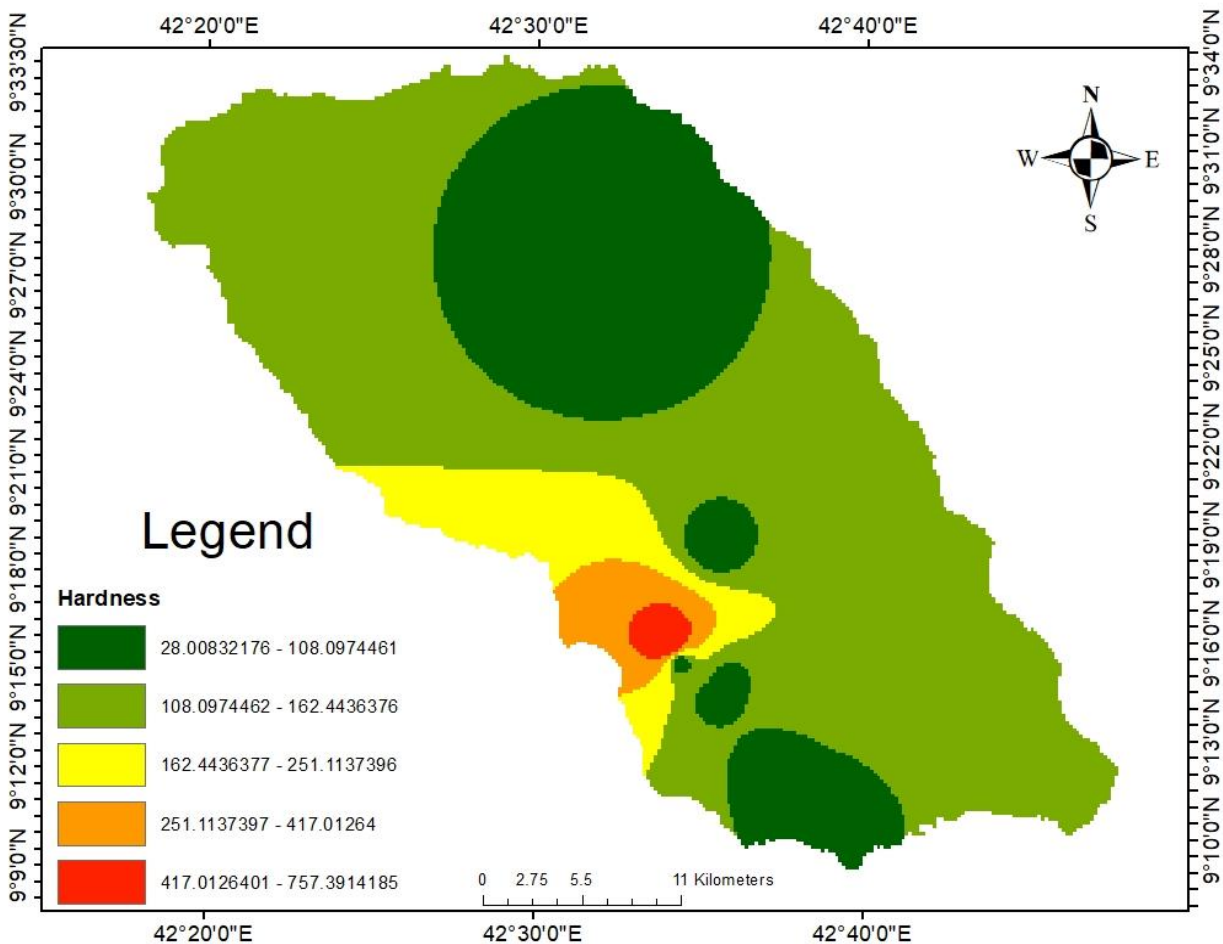
### Hardness

Water hardness is the amount of dissolved metallic ions to water particularly calcium and

magnesium, alkaline earth metals like manganese, iron etc. Water hardness is one of the water quality indicators. Hardness is normally expressed as the concentration of  $Mg^{2+}$  and  $Ca^{2+}$  in mg/l in water and total hardness is the totality of magnesium and calcium concentration in the water expresses mg/l. The permissible limit of water hardness for drinking according to the WHO is 300 mg/l and according to the MoW&I its 390mg/l. Therefore, Water hardness in upper Fafem is mostly occur in the permissible limit regarding to the samples collected, only dhufayska has hardness 760 mg/l which is very far greater than the permissible limit.

**Table 17: Sawyer and McCarty’s classification of groundwater based on hardness**

Hardness (mg/l)	Water type	Range (no of samples)	Percent %
<75	Soft	28-56 (3 samples)	37.5
75-150	Moderately hard	76-84 (4samples)	50
150-300	Hard	-	-
>300	Very hard	760 (1 sample)	12.5



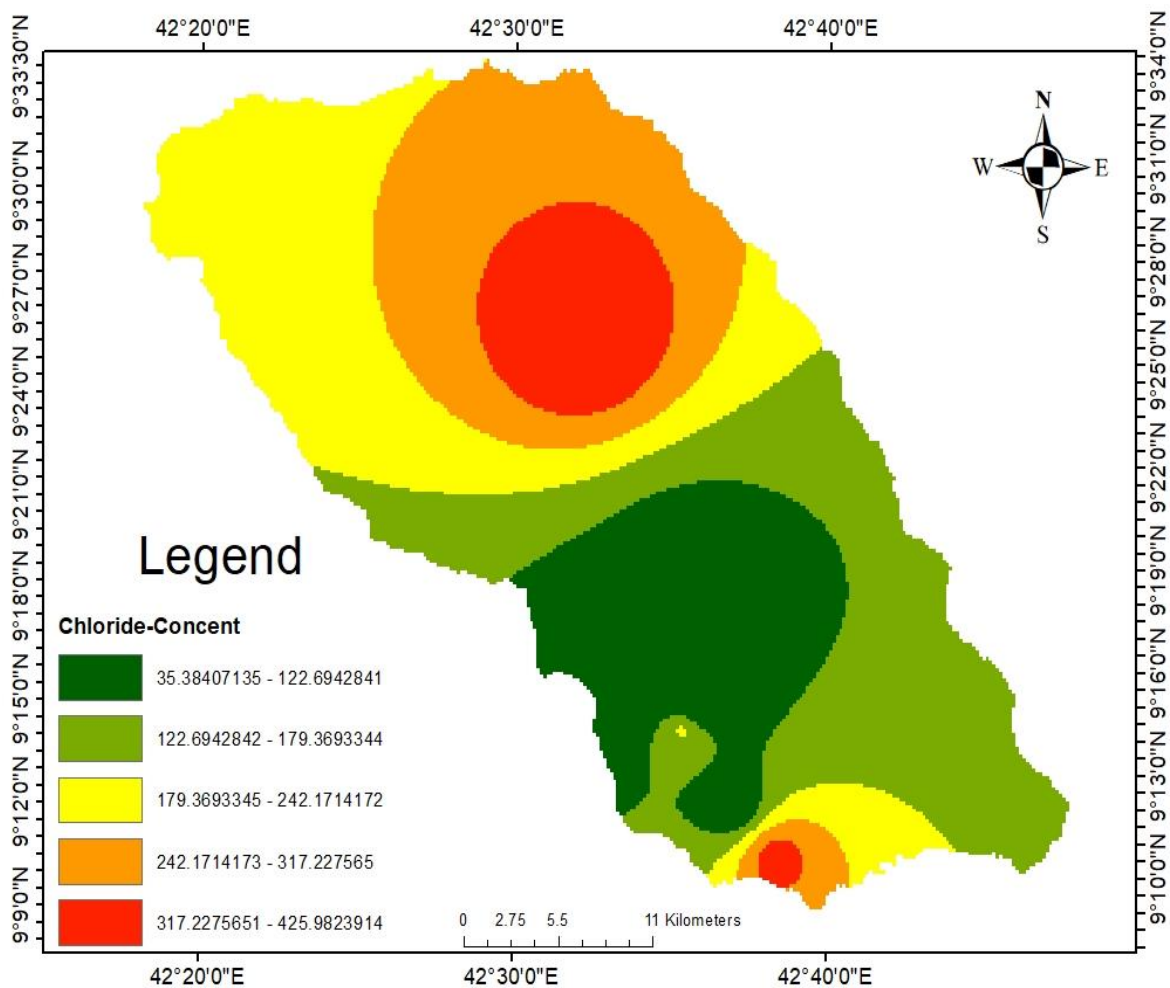
**Figure 29: water hardness of upper Fafem**

**Table 18: water hardness areal coverage**

No	Hadness level	Area	Percent (%)
1	28-108	343.417	27.75716
2	108-162	760.8638	61.49779
3	162-251	92.65515	7.488971
4	251-417	32.2712	2.608361
5	417-757	8.013653	0.647714

### **Chloride**

Chloride ion is a negatively charged and it's result of chlorine compound dissolve in water. Chloride ion is one of the most important ions that helps to control the fluid inside and outside of human cells in balance, chloride also participate in controlling blood pressure and PH of the body fluids. The permissible limit of chloride for drinking water according to WHO is 250mg/l and MoW&I the permissible limit is 533mg/l. In increased level of chloride can harm the body function and cause health problems as such as kidney disease. In upper Fafem the chloride concentration is still in the permissible limit, regarding to the results from the groundwater samples. Most of the samples occur under the recommended limit of WHO only two samples collected from dhakayo which is 355mg/l and Godane which 426 mg/l, fall higher than the WHO permissible limit but still they are under the recommended limit of MoW&I.



**Figure 30: Chloride content water in upper Fafem**

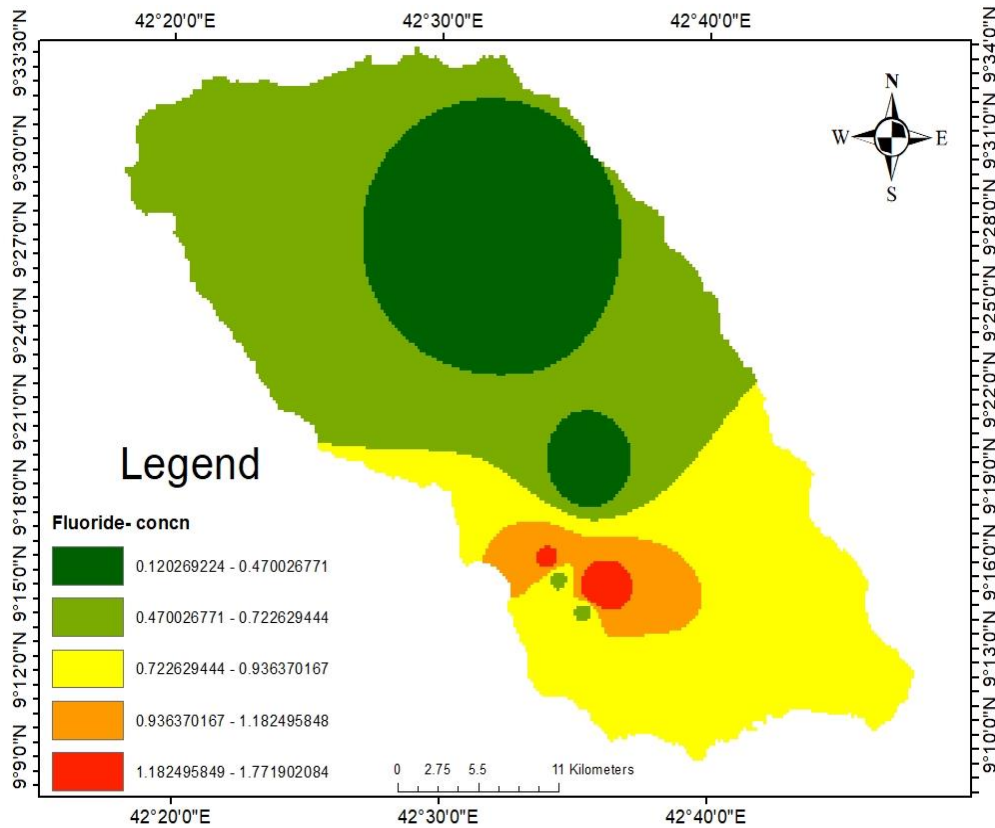
**Table 19: areal coverage of chloride**

No	Chloride level	Area	Percent (%)
1	35-122	225.4463	18.22199
2	122-179	328.8843	26.5825
3	179-242	325.3698	26.29844
4	242-317	248.312	20.07014
5	317-425	109.2087	8.826933

### Fluoride

Fluoride ion occurs rocks in earth, that can dissolve in water. Rock water interaction is the main and driving factor for occurrence of fluoride in water. The permissible limit of Fluoride in drinking water is 1.5 mg/liter. Fluoride concentration in drinking water higher than the WHO standard can cause health problems such as fluorosis, which affects the teeth and bones. In moderate rate it can lead to dental effect but long-term consumption of large amount of fluoride can result severe skeletal problems and even can cause cancer. Therefore,

it's very important to control the fluoride content in drinking water. The study area is mostly having normal fluoride concentration as we can see from the laboratory result most of the areas of the catchment have lower concentration regarding to the WHO limit, only small portion of the area around Goray village has higher fluoride concentration.



**Figure 31: Fluoride concentration of water in upper Fafem**

**Table 20: Areal coverage of fluoride**

No	Fluoride level	Area	Percent (%)
1	0.12-0.47	277.0819	22.3955
2	0.47-0.72	542.0827	43.81454
3	0.72-0.93	352.5232	28.49315
4	0.93-1.18	55.06003	4.450299
5	1.18-1.77	10.47314	0.846505

### 5.5.3 Irrigation water quality Sodium absorption ratio (SAR)

Salinity measures particularly sodium absorption ratio (SAR), sodium percentage (Na%) and permeability index (PI) are mainly used parameters to determine the groundwater suitability of irrigation. Sodium absorption ratio (SAR) is one of the parameters for measuring the suitability of water for irrigation, since the concentration of sodium for irrigation water can

minimize the permeability as well as the structure of the soil (Richards 1954). Sodium absorption ratio (SAR) is a measure of sodium hazard to crops, SAR of the water for the study area was calculated using the formula below:

$SAR = Na / [(Ca + Mg) / 2]^{0.5}$ . where Sodium, calcium and magnesium and meq/l. SAR value for irrigation water has a remarkable relation to the extent in which the soil can absorb the sodium. Irrigation water having high sodium absorption ratio can damage the soil since sodium can displace the magnesium and calcium in the soil. If an amendment is not made to the soil this can lead the soil to lose its ability to form aggregates and eventually loss of soil structure will occur. When the soil loses its structure the infiltration and permeability of the soil will decrease affecting the soil crop production. Calculated sodium absorption ratio in the study area ranges between 0.36 -0.4 (table 22). the SAR values of the samples occur in the range of excellent

**Table 21: Classification of groundwater based on SAR values (Richards 1954)**

Water quality	SAR values
Excellent	< 10
Good	10-18
Doubtful	18-26
Unsuitable	>26

**Table 22: SAR values of the water samples**

S/n	Sam1	Sam2	Sam3	Sam4	Sam5	Sam6	Sam7	Sam8
#	0.4	0.36	0.37	0.37	0.38	0.39	0.36	0.38

### Sodium percentage (Na%)

The sodium content in irrigation water is normally described as percentage of sodium. For all the natural water the percent in sodium is an ordinary parameter to evaluate the suitability of that water to irrigation purposes. The sodium percent in the samples were found by using the following formula.  $Na\% = Na \times 100 / [Ca + Mg + K + Na]$ . all these ionic concentrations are in meq/l. the result of the Na% found for all samples are less than 20% of Na which is in the excellent limit according to classification developed by (Wilcox 1955).

**Table 23: classification of water water suitability for irrigation according to (Wilcox 1955)**

Water quality	Na %
Excellent	< 20
Good	20-40
Permissible	40-60
Doubtful	60-80

Unsuitable	>80
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**Table 24: calculate Na% values of the water samples**

S/n	Sam1	Sam2	Sam3	Sam4	Sam5	Sam6	Sam7	Sam8
#	8.6	7.3	7.8	7.7	7.7	8.2	7.6	7.8

### **Permeability index (PI)**

The permeability of the soil is influenced by long term use of water for irrigation and has influence on the calcium, magnesium, sodium and bicarbonate contents in the soil. Doneen (1964) developed a criterion for evaluating the suitability of water for irrigation purposes based on PI. The permeability index of the samples was calculated using this formula;  $[Na+(HCO_3)^{0.5}] \times 100 / [Ma+Ca+Na]$ . The water which has a permeability index less than 60 is considered to be suitable for Irrigation, for Permeability index greater than this number is considered to be unsuitable for irrigation purposes. For all the samples collected, the result for PI found is under 60 and we can simply see that the water in upper Fafem is much suitable for Irrigation in regard to its permeability index.

**Table 25: calculate PI of the water samples**

s/n	Sam1	Sam2	Sam3	Sam4	Sam5	Sam6	Sam7	Sam8
#	34.6	32.4	29.9	32.3	38.1	28.7	27.5	31.9

## CHAPTER SIX

### 6 CONCLUSION AND RECOMMENDATIONS

#### 6.1 Conclusion

The overall objectives of this study were to estimate groundwater recharge, to evaluate the groundwater potential zones and to know the water quality of Upper Fafem basin. Wetspass model was applied to estimate groundwater recharge of the catchment, similarly soil water balance method was also used to check the simulated result of groundwater recharge. Water resources is the main driving factor for the existence of life on earth, therefore to safeguard this precious resource, proper planning and management should be put in place, in recent time GIS and RS has great support for modelling and estimation of groundwater recharge. Wetspass model is a simulation model for estimation of groundwater recharge based on biophysical and hydrometeorological data. Wetspass estimates long term seasonal and annual average recharge. In this study the long term seasonal and annual groundwater recharge of Upper Fafem was found to be 17 mm in summer, 5 mm in winter and 23 mm in annual. 74% of the groundwater recharge in study area occurs during summer season while the remaining portion of about 26% occur in winter season. The reason is that during summer the rainfall in the study area is much higher. Average annual precipitation of (660 mm) was divided into 23 mm groundwater recharge, 20 mm surface run off and 616 mm of actual evapotranspiration.

The area is mainly characterized from low to medium surface runoff, this is because 93% of the area has a loam soil and 6.6% is sandy loam, only small portion of the area 0.4% has clay soil and these loam and sandy loam soils which has shrubs, crops and forest cover impede the surface runoff and this indicates that these soil types have great influence for the runoff in Upper Fafem. The simulated results of ground recharge and surface runoff were compared to the calculated results surface runoff and groundwater recharge using soil water balance method and it's found that the calculated results are more similar to simulated result. Due to this reason, we can say that wetspass model is one of the best models for estimating groundwater recharge.

Remote sensing and GIS were used to evaluate and to delineation of groundwater potential zones in Upper Fafem catchment. To delineate groundwater potential zones of Upper Fafem

a combination of eight layers were used by giving each layer a weightage regarding to its influence for groundwater occurrence. The layers used in this study are precipitation, land use, Drainage map, lineament map, geology, slope, recharge and groundwater depth. Since precipitation is the main source and prime factor for groundwater occurrence it has been assigned the highest weightage for the delineation groundwater potential zones of the study area, followed by recharge and geology map. After integration of all these thematic layers the groundwater potential zones of upper Fafem have been delineated and the resulted map of the groundwater potential shows that the zone of moderate groundwater potential accounts nearly 52% of the catchment. RS and GIS are very useful tools in identification and mapping of groundwater potential zones of an area.

Knowing the amount of groundwater and its potential zones are not enough for groundwater management and exploration it's also an important to determine the suitability of this water to domestic and agricultural use. In this study the water suitability evaluation for drinking and irrigation purpose has been determined. In general manner the water quality of this catchment is met the water quality standards of WHO and MoW&I as well. Due to limited availability of meteorological stations in the catchment, the input data used in the wetpass model was only five meteorological stations, which are Gursum, Combolcha, Jiggiga, Harar and Diredawa, some of these stations particularly diredawa has limited influence less than 15% to the catchment since its somehow far from the study area. Therefore, the result of the recharge, runoff and actual evapotranspiration may experience little bit change in the future, if other meteorological stations stablish in and around the catchment.

The analytical parameters used in this study are limited to precisely tell the water quality of this catchment since some important ions nitrate, phosphate and sulphate are not included in the analysis. Due to the limited availability of chemical reagents for the chemistry department.

## **6.2 Recommendations**

Establishment of weather stations in and around Fafem catchment is more important for proper water management and planning. Detailed studies regarding to groundwater investigation and estimation should be made in order to provide abundant water supply to the residents of Upper Fafem and Jigjiga, the capital city of Somali region as well. Finally, groundwater recharge estimation, water quality evaluation and knowing groundwater potential zones of Upper Fafem is critically important for wise utilization and proper management of groundwater resources in this catchment since the community in this area rely on mainly the groundwater to bring about significant social and economic development for its residents.

## References

- Abdalla, F (2012). Mapping of groundwater prospective zones using remote sensing and GIS techniques': A case study from the Central Eastern Desert, Egypt.
- Aish AM, Batelaan O. De Smedt F (2009). Distributed recharge estimation for groundwater modelling using WetSpas model, case study Gaza strip, Palestine.
- Ali Salem, József Dezs and Mustafa El-Rawy (2016). Assessment of Groundwater Recharge, Evaporation and Runoff in the Drava Basin in Hungary.
- Bahredin Ahmed Hassan (2018). GIS based Groundwater Recharge Estimation: Case of Shinile Sub-Basin, Ethiopia.
- Bane Lamessa (2017). Groundwater potential and Recharge zone mapping using GIS and Remote sensing Techniques in the case of Middle Awash River Basins, Ethiopia.
- Bitsiet Dereje and Dr. Dessie Nedaw (2016). Groundwater Recharge Estimation Using WetSpas Modeling in Upper Bilate Catchment, Southern Ethiopia.
- Diana Sharma and et al., (2016). Evaluation of groundwater quality and suitability for irrigation and drinking purposes in southwest Punjab, India using hydro chemical approach.
- E. Obuobie, B. Diekkrüger and B. Reichert (2008). Estimation of groundwater recharge in the context of future climate change in the White Volta River Basin, West Africa.
- Esayas Meresa and Gebeyehu Taye (2017). Estimation of groundwater recharge using GIS-based WetSpas model for Birki watershed, the eastern zone of Tigray, Northern Ethiopia.
- Gebremedhin gebremeskel haile (2015). Estimation of groundwater recharge and potentials under changing climate in werii watershed, tekeze river basin.
- Getachew Hadush Asmerom (2008). Ground water contribution and recharge estimation in the upper Blue Nile flows.
- K. Tilahun and B. J. Merkel (2009). Estimation of groundwater recharge using a GIS-based distributed water balance model in Dire Dawa, Ethiopia, Hydrogeology Journal.
- Muhammad Hasan and et al., (2017). Evaluation of Groundwater Suitability for Drinking and Irrigation Purposes in Toba Tek Singh District, Pakistan.
- Nag, S. K. and Ghosh, P (2013). Delineation of groundwater potential zone in Chhatna Block, Bankura District, West Bengal, India using remote sensing and GIS techniques.
- Narsimha et al., (2013). Evaluation of groundwater quality and its suitability for drinking purposes in Gunthakal Area, Ananthapur District, India.
- Seyni Ndoye, and et al., (2018). Groundwater Quality and its Suitability for different uses in the Saloum Area of Senegal.

SHAAC, Engineering Consulting plc, Hydrogeological investigation of 19 sites in Gode, Afder, Liban Dhagahbur, Korahe, and Warder Zones, SRS of Ethiopia, UNICEF, Final draft report, October 2011.

Sintayehu Mulu (2017). Groundwater Flow Modeling of Upper Fafem Sub Basin for Managed Groundwater System.

Teklebirhan Arefaine, Dr. Dessie Nedaw and Tesfamichael Gebreyohannes (2012). Groundwater Recharge, Evapotranspiration and Surface Runoff Estimation Using WetSpas Modeling Method in Illala Catchment, Northern Ethiopia.

Tesfa Gebrie Andualem and Girum Getachew Demeke (2019). Ground water potential assessment using remote sensing and GIS in Guna tana landscape upper Blue Nile Ethiopia.

Tesfaye Tessema (2019). Ground Water Potential Evaluation Based on Integrated GIS and Remote Sensing Techniques, in Bilate River Catchment, South Rift Valley of Ethiopia.

United States Geological Survey (2017). Groundwater Exploration and Assessment in the Eastern Lowlands and Associated Highlands of the Ogaden Basin Area, Eastern Ethiopia. Water Works Construction Enterprise, Somali Regional State, Final drilling report of Hadow boreholes; Drilling Project Well No-1, August 2007.

WWDSE, (2013). Fafem-Jerer sub basins and the adjacent eastern areas groundwater potential assessment and supervision of test and pilot production wells drilling project, ANNEX-I GEOLOGICAL AND GEOMORPHOLOGICAL STUDY.

WWDSE, (2013). Wabi-Shebele Basin and the Adjacent Eastern Areas Groundwater Potential Assessment and Supervision of Test and Pilot Production Wells Drilling Project, ANNEX-III GEOPHYSICAL SURVEY.

## Appendices

### Annex 1: Borehole data

BHID	X	Y	Total_Dept	SWL	Elev	GW_depth	DWL	q(l/s)	Scheme	Village
FPW6	236688	1023656	62	3.0	1439.0	1436.0			BH	
BH 3	236344	1024752	53	8.8	1451.0	1442.2			BH	
HDW2	236006	1024863	0	1.5	1450.0	1448.5			HDW	Hadew
HDW 4	236013	1022983	15	5.4	1436.0	1430.6			HDW	Fafem Town
HDW 9	235061	1026848	8	5.0	1455.0	1450.0			HDW	Halla Hago
HDW 11	232894	1029268	10	7.7	1476.0	1468.3			HDW	Gormaji
HDW 12	236932	1021253	15	3.3	1427.0	1423.7			HDW	Gulmurad
HDW 14	238699	1018017	25	9.0	1411.0	1402.0			HDW	Dufeske
HDW 15	241111	1015597	15	6.8	1389.0	1382.2			HDW	Degeyu
HDW 16	241212	1015605	0	4.2	1386.0	1381.8			HDW	Degeyu
HDW 19	235942	1023216	0	4.3	1436.0	1431.7			HDW	
BH 5	230555	1033301	42	8.9	1506.0	1497.1		7.20	BH	Gola Ajo
BH 6	230570	1032917	42	7.3	1502.0	1494.8	26.00	7.20	BH	Gola Ajo
BH 7	228996	1033898	37	8.8	1515.0	1506.2	16.93	13.60	BH	Kobijaro Gunta
BH 8	229106	1035366	43	9.4	1527.0	1517.6	26.16	13.13	BH	Kobijaro Kaliga
HDW 26	240763	1016635	0	3.2	1397.0	1393.9	33.55		HDW	
Oxfam-HIDIS	240780	1087707	130	98.2	1272.0	1173.8		5.00	BH	
BH 11	265492	1017438	127	66.7	1537.0	1470.3	133.10	4.93	BH	Jijiga water supply
BH 12	263251	1019685	127	72.7	1555.0	1482.3	74.70	4.47	BH	Jijiga water supply
BH 13	262723	1020408	127	42.3	1560.0	1517.7	95.80	3.32	BH	Jijiga water supply
BH 14	262431	1020868	125	37.0	1565.0	1528.0	75.30	9.07	BH	Jijiga water supply
BH 15	262369	1021129	126	36.0	1566.0	1530.0	54.35	1.65	BH	Jijiga water supply
BH 16	262577	1021348	130	36.5	1568.0	1531.5	79.70		BH	Jijiga water supply
BH 17	264599	1017915	115	62.7	1540.0	1477.3	43.45		BH	Jijiga water supply
BH 18	264105	1018289	113	67.5	1544.0	1476.5	72.63		BH	Jijiga water supply
BH 19	263556	1019358	130	72.0	1554.0	1482.1	71.90		BH	Jijiga water supply
BH 20	263822	1019358	120	71.3	1559.0	1487.7	82.50		BH	Jijiga water supply
BH-21	273375	1007060	200	70.8	1469.0	1398.3	87.40	3.00	BH	
FPW-03	230859	1031666	65	4.68	1493	1488.32	13	25.84	BH	MCDWW
FPW-04	233964	1027059	99	18.31	1469	1450.69	4.9	34.64	BH	MCDWW
FPW-06	235430	1025082	75	5.51	1444	1438.49	19.6	7.98	BH	MCDWW
FPW-07	236396	1022638	72	1.37	1078	1076.63	33.7	3.54	BH	MCDWW
FPW-08	238613	1020135	59.7	2.6	1413	1410.4	15.1	7.4	BH	AQUA Boreholes

FPW-12'	235950	1023167	53	4.35	1417	1412.65	19.6	2.77	BH	AQUA Boreholes
FPW-18	239157	1017669	82.5	6.8	1434	1427.2	27.86	10.42	BH	MCDWW

### Annex 2: Chemical analysis results

Ion in mg/l	pb	cu	Fe	Zn	ca	Mg	K	Ni	Mn	Ph	Temp	F-	HCO3-	Cl-	Na	Hardness
BH1	0.2085	0.1928	0.99	0.0225	8.344	102.5	10.45	0.0093	1.768	7.16	18.1	0.81	390.4	71	20.037	84
BH2	0.2168	0.1646	2.24	0.102	22.45	113.1	23.36	0.0085	2.639	7.8	18.1	0.6	488	184.6	20.094	80
BH3	0.1738	0.1522	2.39	0.52	17.44	105.3	19.42	0.0091	2.113	7.7	18.1	1.78	317.2	71	19.75	84
BH4	0.1771	0.1574	2.67	0.1353	20.29	107.1	19.59	0.0096	2.616	7.71	19.3	1.31	419.6	35.2	20.00	760
BH5	0.188	0.1629	4.48	0.04	15.14	113.9	20.85	0.0089	2.227	7.74	19.3	0.92	683.2	355	20.57	76
BH6	0.146	0.1502	4.07	0.0321	7.275	105	20.98	0.0098	3.053	7.75	18.3	0.12	244	71	19.94	56
BH7	0.1377	0.1519	4.42	0.1525	16.42	103.5	19.51	0.0093	4.588	7.34	18.1	0.14	244	426	18.84	28
BH8	0.1514	0.1495	4.87	0.1108	20.79	105.2	21.09	0.0092	4.79	7.65	18.3	0.6	390.4	71	20.14	44

### Annex 3: Long term precipitation data

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Gur	10.6	22.2	48.7	92.2	89.7	59.3	85.9	114.5	84.3	41.2	20.3	5.3	674.2
Har	10.7	26.5	49	87.7	86.4	58	93.5	127.4	84.9	35.6	19.5	5.8	685
Jig	10.2	23.2	47.8	92.8	89.4	59.8	89.3	118.8	86.5	38	19.9	5.3	681
Dire	9.5	21.2	42.5	82.3	75.5	48.4	83.2	114.9	74.8	29.4	18.4	5.1	605.2
Combolcha	10.5	23	46.6	87.3	83.8	56.8	88.8	117.7	82	35.6	19.4	5.4	656.9
Aver rain	10.3	23.22	46.92	88.46	84.96	56.46	88.14	118.66	82.5	35.96	19.5	5.38	660.46

### Annex4: Soil parameter table

Cod e	Soil	FIELD CAP AC	WILTING P NT	PA W	RESIDUAL WC	A1	EVAPODEP TH	TENSIONH HT	P_FRAC_SU M	P_FRAC_W IN
3	sandy loam	0.21	0.09	0.12	0.041	0.44	0.05	0.15	0.09	0.01
5	Loam	0.25	0.12	0.13	0.027	0.37	0.05	0.11	0.15	0.02
12	Clay	0.46	0.33	0.13	0.09	0.21	0.05	0.37	0.95	0.85

Annex 5: Summer Land use parameter table

Code	LUSE_T YPE	RUNO FF_V EG	NUM_ VEG_ RO	NUM_ _IMP_ RO	VEG_ _AR EA	BAR E_AR EA	IMP _AR EA	OPEN W_AR EA	ROOT _DEP TH	L A I	MIN_ _ST OM	INTE RC_P ER	VEG_HEIG HT
21	Agriculture	crop	1	0	0.9	0	0.2	0	0.4	0	180	35	0.7
23	Grassland	grass	2	0	0.7	0.2	0.2	0	0.3	2	100	10	0.2
33	mixed forest	forest	3	0	0.8	0	0.2	0	2.5	7.5	375	50	10
7	Bareland	bare soil	4	0	0.7	0.2	0	0	0.05	0.1	110	27	0.001
29	Orchard	forest	3	0	0.2	0.8	0	0	0.8	0	200	10	3
10	open build up	grass	2	3	0.6	0.1	0.3	0	0.3	2	100	10	0.12
36	Shrub	grass	2	0	0.8	0	0.2	0	0.6	6	110	42	2.5
28	wet meadow	grass	2	0	1	0	0	0	0.3	2	100	10	0.3

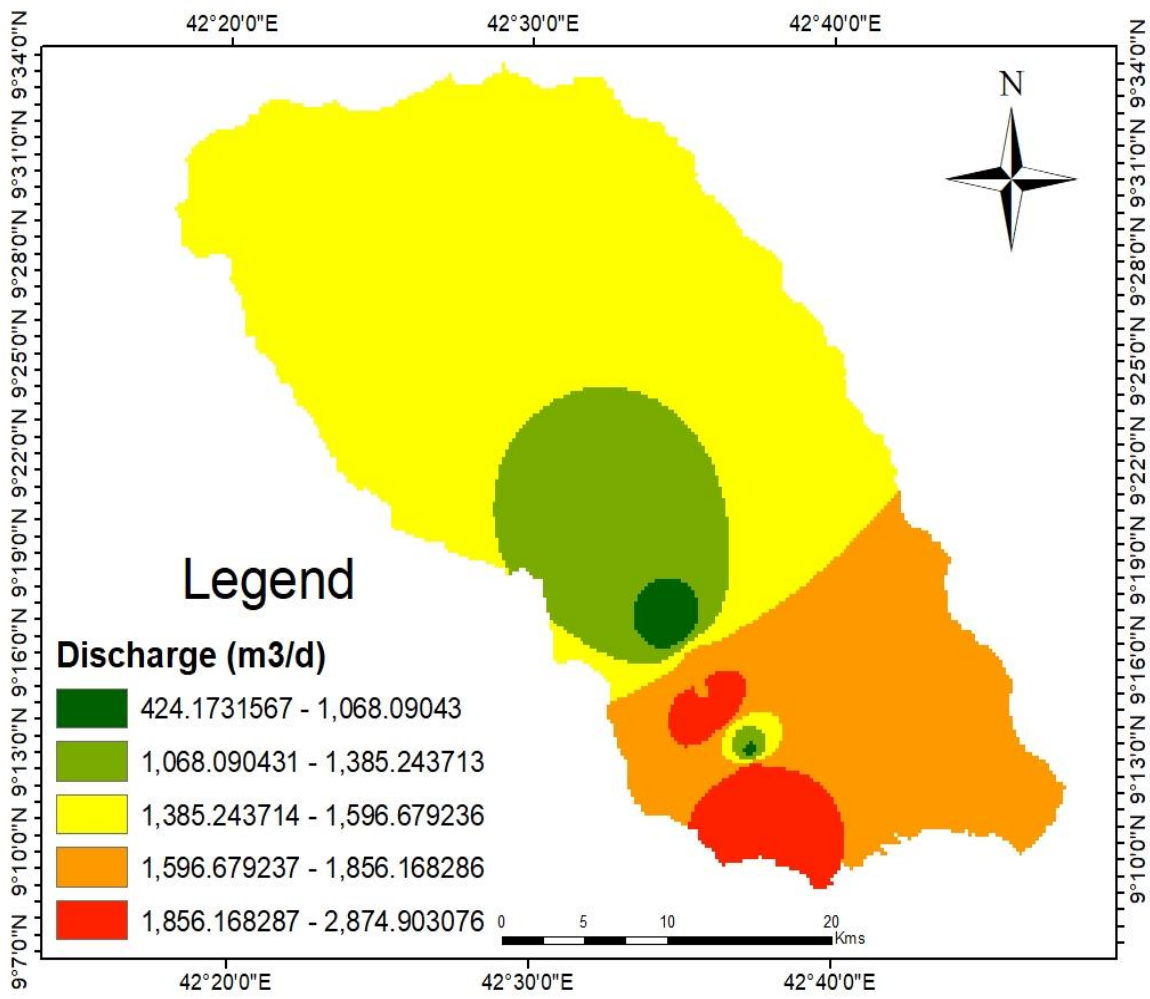
Annex 6: Winter land use parameter table

NUMB ER	LUSE_ _TYP E	RUNO FF_VE G	NUM_ VEG_R O	NUM_I MP_R O	VEG_ ARE A	BARE _ARE A	IMP_ ARE A	OPEN W_AR EA	ROOT_ DEPTH	L A I	MIN_ STO M	INTER C_PER	VEG_ HEIGH T
21	Agricu lture	crop	1	0	0.2	0.04	0.4	0	0.35	2	180	20	0.6
23	Grassl and	grass	2	0	0.3	0.2	0.05	0	0.3	2	170	20	0.2
33	mixed forest	forest	3	0	0.8	0.1	0.1	0	2	4.5	350	38	10
7	Bare- land	bare soil	4	0	0.2	0.4	0	0	0.05	0	110	1	0.001
29	Orchar d	forest	3	0	0.2	0.8	0	0	0.8	0	200	10	3
10	open build up	grass	2	3	0.6	0.1	0.3	0	0.3	2	100	10	0.12
36	Shrub	grass	2	0	0.2	0.8	0	0	0.6	0	110	30	2
28	wet meado w	grass	2	0	1	0	0	0	0.3	2	100	10	0.3

Annex7: Well data of upper fafem sub catchment

Well ID	Locality	X	Y	Z	Depth	SWL	Q (L/Sec)	D	Specific Cap	T	Q(m <sup>3</sup> /d)	GW E	K cons(m/day)	K Rec(m/day)	DDE
FB H-05	Degahale	236396	1022638	1432	72	1.37	33.7	3.54	9.52	1290	2911.68	1430.63	51.9	42.8	1427.09
FB H-09	Batey	238182	1020820	1418	58.5	2.89	15.5	10	1.55	304	1339.2	1415.11	22.9	13	1405.08
FB H-12	Batey	238613	1020135	1416	52.5	5.04	10	19.4	1.98	132	8646.03	1410.96	15.9	7.76	1391.56
FB H-13	Tohadakesis	238777	1018737	1409	76.5	5.45	25.88	2.74	9.45	1200	2236.03	1403.55	42.6	39.8	1400.81
FB H-17	Degahale	238613	1020135	1420	59.7	2.6	15.1	7.4	2.02	295	1304.64	1417.4	42.1	13.2	1410
FB H-19	Dufeyis	239157	1017669	1401	82.5	6.8	27.86	10.4	2.67	501	2407.1	1394.2	37.3	4.88	1383.78
FB H-20	Halhago	235430	1025082	1444	75	5.51	19.6	7.98	2.46	263	1693.44	1438.49	14.6	5.87	1430.51
FB H-24	Halhago	233964	1027059	1469	99	18.31	4.9	34.6	0.14	77.5	423.36	1450.69	0.189	0.534	1416.05
FB H-26	Halhago	230859	1031666	1493	65	4.68	13	25.8	0.5	36.3	1123.2	1488.32	1.56	2.07	1462.48
FB H-35	Degahale	235950	1023167	1433	53	4.35	19.6	2.77	7.08	2180	1693.44	1428.65	75.5	73.9	1425.88

Annex 8: Well discharge data



**Figure 32: Well, yield map of upper fafem**