



**JIMMA UNIVERSITY**

**JIMMA INSTITUTE OF TECHNOLOGY**

**FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING**

**MASTER OF SCIENCE IN HYDRAULIC ENGINEERING**

**GIS –BASED GROUNDWATER POTENTIAL ZONE MAPING OF  
BURJIE WATERSHED, ABAY BASIN, ETHIOPIA**

**BY**

**MUHAMMED YIMER**

A thesis submitted to the chair of hydrology and hydraulic engineering of Jimma Institute of Technology in Partial fulfillment of the requirements for the degree of Masters of Science in hydraulic Engineering.

**February , 2023**

**Jimma, Ethiopia**

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Advisor: Dr. Dawud Temam (PhD)

Co-advisor: Mr. Bekan Chelkeba (MSc.)

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**February, 2023**

**Jimma, Ethiopia**

## **DECLARATION**

I hereby declare that the thesis entitled “GIS- Based Groundwater Potential Zone Mapping of Burje Watershed Abay Basin, Ethiopia” has been, carried out by me under the supervision of Dr. Dawud.T (PhD) & Mr. Bekan Chelkeba (MSc). At Jimma University during the year 2021-2022 as a part of Master of Science in hydraulic Engineering. I further declare that this work has not been, submitted to any other University or Institution for the award of any Degree or Diploma.

Muhammed Yimer

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Signature

Date

## APPROVAL SHEET

We certify that the thesis entitled “GIS- Based Groundwater Potential Zone Mapping of Burje Watershed, Abay Basin Ethiopia” is the work of Muhammed Yimer, and we here by recommend for the examination by Jimma Institute of Technology in partial fulfillment of the requirements for degree of Masters of Science in Hydraulics and Water Resources Engineering.

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As a member of the Board of Examiners of the MSc thesis open Defense Examination, we certify that we have read and evaluated the Thesis prepared by Muhammed Yimer, and examined the candidate. We recommended that the Thesis could be accepted as partial fulfilling the thesis requirements for the Degree of Masters of Science in Hydraulic Engineering.

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## ABSTRACT

*Groundwater is a hidden natural resource which plays a crucial role in all the environmental and biological processes with a greater significance on socio-economic activities. A case study with an aerial extent of 523.1 km<sup>2</sup> was carried out to determine the groundwater potential zones in the Burje watershed, Abay basin, Ethiopia. A total of seven thematic layers including geology, lineament density, slope, soil, Land use/Land cover, rainfall, and drainage density were used to map the groundwater potential zones of Burje catchment. The methods to assess the identification of groundwater potential zone mapping was using weight overlay analysis and Analytical Hierarchy Process (AHP) algorithm. Finally, groundwater potential zones are classified into three categories namely low, moderate, and high zone. It is observed that 32.7% (171.05 km<sup>2</sup>) of the study area falls under 'low' groundwater potential zone. Approximately 155.94 km<sup>2</sup> area accounting for 29.8% of the study area falls under 'moderate' category and 'high' groundwater potential zone encompasses an area of 196.11 km<sup>2</sup> accounting for 37.5 % of the total study area. The geographical information system method output results were validated by conducting field survey by randomly selecting wells in different places using Geographical positioning System (GPS) instruments. About 27 bore wells yield data had been collected to quantify the yield from groundwater potential zone map derived from geo-informatics. The produced result was verified by comparing with the existing groundwater borehole databases and the results show that there is good agreement between the predicted groundwater potential map and the existing groundwater borehole database. From the 7 wells 4 falls on high zone (57.14%). Out of 11 wells yields data ,7 wells (63.63%) of them were fallen on the moderate zone whereas out of the 9 wells yield data ,7 wells and springs data (77.77 %) was fallen on the zone classified as low.*

**Keywords:** *AHP, Ground water Potential Zone, Remote Sensing, Geographic Information Systems*

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## **LIST OF ABBREVIATIONS**

AHP	Analytical Hierarchy Process
ARC	Aeronautical Reconnaissance Coverage
DEM	Digital Elevation Model
EGS	Ethiopian Geological Surveys
ETM+	Enhanced Thematic Mapper plus
GIS	Geographic Information system
GwPZ	Groundwater Potential Zones
IWMI	International Water Management Institute
LANDSAT	Land Space Application Technology
LULC	Land Use Land Cover
MCDA	Multi-Criteria Decision Analysis
MOA	Ministry of Agriculture
NMA	National Meteorological Agency
RS	Remote Sensing
SRTM	Shuttle Radar Topographic Mission
USGS	United State Geological Survey
UTM	Universal Transverse Mercator
WOA	Weighted Overlay Analysis

# 1 INTRODUCTION

## 1.1 Background

Groundwater is one of the most important and valuable natural resources found in the subsurface geological formations of the earth's crust (Arulbalaji, Padmalal and Sreelash, 2019). It is a key natural resource on the globe and one of the most crucial for a country's growth and development. It's also known as "subsurface water," which is defined as water that occupies all of the pore space in soils and geologic formations beneath the water table. (Tamiru Tolcha, 2019). A geological stratum's spaces are filled by a type of water called groundwater. Earth's crustal structures that contain water serve as reservoirs and transmission channels for water (Berhanu and Hatiye, 2020). Groundwater moves slowly through the subsurface to discharge locations such as wells, springs, rivers, lakes, and the ocean (HsinFuYeh, 2018). The hydrological, lithological, atmospheric, soil, and topographic features of a region also affect groundwater movement (Yifru *et al.*, 2020). Numerous factors, including lithology, geological structures, soil, lineament characteristics, slope, drainage pattern, geomorphology, land use, and land cover, and the interactions between these elements, control the presence and movement of groundwater in a given area. (Gebrie and Getachew 2019).

One of the most valuable natural resources on Earth's surface is groundwater, which is found in subterranean aquifers that are located underground (Jothimani, Abebe and Duraisamy, 2021). In many regions of Ethiopia, particularly the arid areas where surface waters are in scarce supply and only available seasonally, groundwater is a significant source of water and the primary source for domestic supply. Nearly 80% of Ethiopia's water supply comes from groundwater; 90% of it is used for domestic use, 95% is used for industrial use, and only a small percentage, 1%, is used for irrigation (Tadesse 2018). The valuable thing about it is that sometimes it is in limited supply and other times it is abundant but unevenly distributed, both in space and time. It is the world's second-most abundant freshwater resource, responsible for nearly 30% of global freshwater resources (Tamiru Tolcha, 2019). In many parts of the world, groundwater is the primary supply of domestic, agricultural, and industrial water (Tolche, 2021). More than 1.5 billion people around the world utilize groundwater for drinking and domestic purposes. (Mengistu *et al.*, 2021). Precipitation and recharge from surface water are the most major sources. Water that has infiltrated into the earth directly from precipitation, recharge from streams and other natural water sources, and manmade recharge due to human activities are all forms of groundwater. It becomes an essential source of

water supply in both urban and rural areas of any country due to its constant availability and high natural quality (Lakshmi and Reddy, 2018). According to estimates, between a third and half a billion people in Sub-Saharan Africa depend heavily on both protected and unprotected groundwater for their daily water supply (Kassahun, 2015). Both rural and urban populations rely extensively on groundwater for drinking and domestic use, with over 90% and 30%, respectively (Kumar and Krishna, 2018). The majority of existing groundwater resources are primarily used to supply domestic and industrial water. Ethiopia is heavily dependent on groundwater for drinking, livestock production, and industries (Hussein, Govindu and Nigusse, 2017). Aquifers provide more than 80% of the country's water supply (Mengistu *et al.*, 2021). Groundwater potential in Ethiopia is shaped by complex geological formations and the diversity of topography, climate and soil. The event of groundwater is mainly influenced by the geophysical climate condition of the area (Gudeta, 2018). The amount and quality of groundwater in different sections of the country are heavily influenced by the variability of these elements. Numerous areas have usable groundwater, which allows for good rainfall transmission to recharge aquifers, the upkeep of springs, and the sustainability of perennial river flows. However, in other areas, groundwater is only found at depth (e.g., lowland regions like Somalia), in restricted amounts (with limited storage), or the quality poses a health risk (Mechal *et al.*, 2016).

There are various methods for identifying and mapping groundwater occurrence and distribution. Because groundwater cannot be seen directly from the surface of the earth, a variety of approaches can be used to determine its occurrence. Several studies since early 1960's have been attempted to explain spatial variability of groundwater occurrence in different terrain conditions using technologies like aerial photography and geographic information system (Kebede, 2015). Remote sensing and GIS techniques can be used to collect and integrate data on the input parameters in the above. The principle of integrated remote sensing and geographic information systems (GIS) has shown to be a useful tool in groundwater investigations, allowing for better data analysis and interpretation (Berhanu and Hatiye, 2020). One of the most important sources of surface feature information for groundwater, such as land use, land forms, and drainage density, is remote sensing. These data can readily be entered into a GIS to determine the groundwater zones (Mallick *et al.*, 2015).

Using integrated Remote Sensing and GIS techniques, the current study attempted on groundwater potential zone mapping of Burje Basin, Ethiopia. Geology, drainage density, lineament density,

land use land cover, soil, slope, and rainfall are the thematic layers addressed in this study. Using the Saaty's Analytical Hierarchy Process, weights were assigned to all the thematic layers based on their relative importance in groundwater occurrence. These weights were used in a linear summation equation to create a unified weight map that included all of the input variables' due weights. Finally, using ArcGIS Software, the thematic layers were combined to create a groundwater potential zone map. As a result, three groundwater potential zones were identified: high, moderate and low. The zones with the highest potential correspond to low slopes, low drainage density and high lineament densities. The structural hills, sloppy, intermediate drainage density, and intermediate lineament density areas all have moderate groundwater potential zones. This study was focused on GIS- based groundwater potential zone mapping of Burje catchment, Abay basin, Ethiopia by the integrated approach of GIS software and AHP modeling approach.

## **1.2 Statement of the problem**

In many regions of Ethiopia, the primary source of potable water is groundwater. However, the occurrence of groundwater is not uniform because it depends on various environmental and geological factors (Tarekegn, 2015). Groundwater is a fundamental element of national development. However, it is not well studied, and valuable information about recharge rates is unavailable due to data scarcity. For Ethiopia, which has an economy highly dependent on agriculture and high population growth, it is prudent to effectively manage its water resources. Fresh-water is a finite; naturally, renewable resources received by way of precipitation, but are significantly unevenly distributed in time and space and the hydro-climatologically conditions of a region set the limit for its availability. To improve such limitations, the use of remotely sensed data and geographic information systems is very important to analyze and manage the spatial and temporal data of ground water. At the end of the analysis, one can identify and delineate the spatial distribution of the groundwater resource potential zones and recharge area map of a given area of interest. However, very limited studies are available in Ethiopian context in general and there are no previous studies in the Burje Watershed in particular. Therefore, the aim of this study is to identify and map the groundwater potential zones of Burje Watershed by using GIS and RS techniques.

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

#### **1.3.1 General objective**

The general objective of this study is Assessment of Groundwater potential zone in Burje Sub-Watershed by using GIS and AHP algorithm.

#### **1.3.2 Specific objective**

The specific objectives of this project are

1. To estimate groundwater resources potential in the study area.
2. To identify and delineate ground water potential zones through integration of various thematic layers.
3. To identify the most rechargeable zone in the study area by using MCDA.

### **1.4 Research questions**

The research question on this study is as follows

1. How much volume of groundwater does exist in the study area?
2. Where are the best potential zones were found in the study area?
3. Which one is/or are the most rechargeable zone in the study area?

### **1.5 Significance of the study**

Water scarcity is a major issue in the area, which primarily relies on springs, rivers, hand-dug wells, and a few boreholes. The findings of this study could be useful in determining the groundwater potential zones in the Burje River Catchment. Groundwater would be the primary water source in the area due to its vast availability, especially during droughts, and relatively high quality. It may also serve as a springboard for future ambitions to create a new well-digging operation.

### **1.6 Limitations of the study**

The key problems with this study are the incompleteness of the groundwater inventory data and the unequal distribution of the data points. a poor understanding of the elements influencing the presence of groundwater.

## 2 LITERATURE REVIEW

### 2.1 Introduction

Groundwater is a subsurface water that found below the earth's saturated surface. In a hydraulic water cycle, surface waters (precipitation, lakes, reservoirs, seas, etc.) seep into the earth below the water table and become groundwater. Oceans, lakes, rivers, ponds, lagoons, and other bodies of water cover more than 70% of the earth's surface (Berihun, 2018). The most important and vital resource that sustains life on Earth's surface is water, and conserving and maintaining this resource has not always been considered or recognized (Tumsa, 2021). Groundwater is a part of the water on the planet that can be used by humans. Water is a component of both the physiological systems and the body temperature systems of animals and plants. Significant amounts of water are present in both food and beverages.

### 2.2 General overview of groundwater potential

Groundwater is a renewable and dynamic natural resource. However, it is only partially available in hard rock terrains. For the reliable and affordable provision of higher-quality water supplies in many parts of the world, groundwater is a valued natural resource. Only 2.8% of the water on Earth is classified as fresh water, with groundwater accounting for 97% of this amount (Mitiku, 2019). Groundwater is a component of the hydrologic cycle. A portion of the precipitation that falls on Earth's surface percolates through the soil and into the groundwater system, where it becomes groundwater. In many parts of the world, particularly in rural areas in dry and semi-arid regions, groundwater is the main supply of water, yet little research has been done on its potential. The effective management of this crucial resource has been and continues to be greatly hampered by the lack of understanding about it, its hidden character, and its occurrence in complex subsurface formations. Therefore, in order to manage these resources for sustainable use, it is essential to have a better understanding of the groundwater systems. There are two zones where groundwater is found. first zone, which is found right beneath the surface of the ground. It is known as the "unsaturated zone" and includes both air and water. The second zone, below the unsaturated zone, is full of water and is known as the saturated zone.

Previous research by many authors has discussed the groundwater potential zone at various times. As (Tolche, 2021), said Groundwater is the main source for domestic, agricultural, and industrial usage in many parts of the world. Since groundwater is less susceptible to pollution than surface water, it has been discovered to be a more preferable supply. And he also concludes that, the

potential of the groundwater resource is significantly impacted by groundwater recharge. Studies can also be conducted to determine the product's quality and suitability for various uses, including domestic, irrigation, and industrial ones. On the basis of the use of GIS and remote sensing technology, several studies were conducted to map out groundwater potential zones. Only a small portion of the relevant literatures evaluated and summarized are included here.

(Saranya and Saravanan 2020) had tried on Groundwater potential zone mapping using analytical hierarchy process (AHP) and GIS. The methodology is demonstrated by a case study in Kancheepuram District, Tamilnadu, India. Using ArcGIS software, all nine thematic layers are collected and prepared as part of the study's approach. Weights calculated by the analytical hierarchy procedure were applied to the georeferenced maps. Finally, a groundwater potential zone map was created for the research by integrating the chosen theme maps using the weighted linear combination method in a GIS environment.

(Gebrie and Getachew 2019) made a study, on Groundwater potential assessment, using GIS and remote sensing on Guna tana landscape, upper Blue Nile Basin, Ethiopia. He uses the following methodology, Soil (30×30 m resolution) and digital elevation model (30×30 m resolution) were collected from the ministry of water, irrigation, and electricity of Ethiopia, land cover image (30 x 30 m resolution) downloaded from USGS Earth Explorer website for January 2018.

The research work conducted by Yifru et al., (2020) on Groundwater Potential Mapping Using SWAT and GIS-Based Multi-Criteria Decision Analysis. In this work, a GIS-based AHP is used to integrate thematic layers, which influence the natural storage and movement of water.

(Mukherjee and Kumar, 2020) have also conducted the Delineation of groundwater potential zones in a drought-prone semi-arid region of east India using GIS and analytical hierarchical process techniques. In this study, an integrated remote sensing and GIS approach based on the AHP method was successfully applied to identify the groundwater potential zones of the Birbhum district.

### **2.3 Occurrence and Movement of Ground Water**

The presence of groundwater is more dependent on the interaction of climatic, geological, hydrological, biological, and physiographic elements than on random occurrences (Saranya and Saravanan 2020). The hydrological cycle includes groundwater, which is a dynamic system. It is created by the process of surface infiltration. Then it seeps into the earth, which is made up of various rock formations with various hydrogeological characteristics. The porosity of the rock affects how much space it can hold in rock formations. Depending on the hydraulic conductivity or

permeability, water in the rock formation travels from sites of recharge to areas of discharge under the effect of hydraulic gradients. To put it another way, the amount of storage space and the speed of transmission determine whether ground water is present at a certain site. Although the initial geometric shape of the rocks, which ranged from tabular to lenticular to cylindrical, was established at the time of their creation, the hydro-geological parameters of the aquifer underwent diverse alterations as- a) The structural and erosional modifications change the thickness and, lateral continuity of most major rock units, b) The hydrothermal alteration, contact metamorphism, diagenesis, and thermal mechanical effects modify rock-hydraulic properties to differing degrees locally, and c) The fracturing alters permeability along fault /fracture zones. These modifications result in major differences in the hydrological characteristics of the rock type, which alter the capacity of the earth to store and transfer water both horizontally and vertically (Berihun, 2018).

#### **2.4 Groundwater recharge**

The process of water percolating through the soil to the subterranean water system from precipitation, canals, rivers, lakes, and streams is known as groundwater recharge. It is the downward flow of water that is added to the groundwater reservoir and enters the regional groundwater system (Banti, 2017). Moreover, a variety of factors, such as the nature of the precipitation, vegetation, geography, soils, and geology, influence the percentage of precipitation that percolates to the water table. The amount of groundwater in the subsurface is thus determined by the number of open spaces in rocks and the spatial extent of these rocks (Kumar, 2014). Every body of subsurface freshwater must have had a source of recharge. Normal precipitation (rainfall and snowmelt) but also seepage from rivers, lakes, and canals might be considered here. The recharge normally moves downward through the unsaturated zone, filling the aquifer until water emerges from the earth as springs or seeps and supplies the surface with water.

#### **2.5 Factors Affecting Groundwater potential**

Groundwater potential and recharge zone affected by different factors that control. According to several prior investigations, many elements that influence or promote this process have an impact on the groundwater potential and recharge zone (Banti 2017). Lithology, geomorphology, lineament, soils' slopes and types, drainage patterns, land usage, and rainfall. The aforementioned variables are crucial ones for mapping the recharge zone and groundwater potential. In this study, geology, lineament, slope, soil, drainage density, land cover, rainfall, etc. are the primary determinants of groundwater potential zone development. it is possible to study the origin of

occurrence and movement location of groundwater by using remote sensing data based on indirect examination of immediately observable terrain elements such as geological formations, geomorphology, land-use/landcover, slope, rainfall, drainage density, and lineaments.

## **2.6 Role of GIS and Remote Sensing in Groundwater Potential Mapping**

Modern technologies such as remote sensing and geographic information systems (GIS) have proved to be useful for studying geological, structural and geomorphological conditions together with conventional surveys (Berihun, 2018). According to (Tolche, 2021) In the discipline of hydrogeological study, remote sensing and geographic information systems have emerged as key instruments for evaluating, monitoring, defining, and preserving groundwater resources. It is used to analyzing and modeling the interrelationship between the layers. It enables the manipulation and analysis of any individual spatial data theme layer. Exploration and satellite sensors' capacity to highlight the opening of new systematic and effective groundwater, landform, geological, mineral, and geohazard investigations. Additionally, it aids in understanding various landforms that are difficult to detect. The present study mainly deals with the integrated approach of Remote Sensing and Geographical Information System (GIS) to delineate groundwater potential zones in Burje Watershed. The application of GIS tools helps to increase the accuracy of results in delineation of groundwater potential zones. In order to analyze and quantify such multivariate elements of groundwater occurrence, the Geographic Information System has proven to be a powerful tool.

## **2.7 Ground water potential in Ethiopia**

Ethiopia is primarily reliant on groundwater. Aquifers provide more than 80% of the total water supply. Groundwater in Ethiopia is shaped by complex geological formations, diversified topography, and soil, and the demand lacks abilities to investigate, develop, and manage the resource, resulting in a lack of awareness of groundwater as a viable and strategic resource (Mengistu, Demlie and Abiye, 2019). For the vast majority of people in various places, groundwater provides a renewable and essential source of water. The lack of in situ soil and groundwater data utilized in hydrogeological applications, on the other hand, hinders the ability to assess water resources (Mengistu *et al.*, 2021). Groundwater, on the other hand, is a critical component of national development. However, it hasn't been thoroughly researched, and crucial information on recharge rates is lacking due to a lack of data. As a result, several development projects fail, resulting in financial losses. Furthermore, groundwater's critical function and contribution to the development of water infrastructure in Ethiopia has not been expected in the

past. As a result, it is critical to investigate the spatiotemporal extents of groundwater consumption using a variety of technical and institutional methodologies (Mengistu *et al.*, 2021). Groundwater is the only feasible means of meeting rural communities in Ethiopia's dry and semi-arid regions since it is a supply of domestic water in both urban and rural locations. The groundwater potential in Ethiopia was estimated to be around 28 BCM based on hydrogeological parameters (Tolche, 2021). In my study area, there is no documented data and yet done. But in simple observation the area has mostly moderate groundwater potential availability. Only a small portion of this enormous groundwater potential has been utilized for domestic purposes. In general, there is no shortage of groundwater in the study area, but there are gaps in the knowledge of that groundwater for those who should know by identifying the areas with and without groundwater and mapping the groundwater potential zones using GIS and remote sensing methods.

### 3 MATERIALS AND METHODS

#### 3.1 Description of the study area

##### 3.1.1 Geographic Location

Burje catchment is located in 11°20'0"N - 11°32'0"N and 36°6'0"E - 36°36'0"E latitude and longitude respectively with an approximate altitude ranging between 1200 and 2600 a.m.s.l. This watershed covers a total surface area of 523.1 km<sup>2</sup>. The main river in the Burje catchment is called the Burje River, which originates from the Belaya Mountains in Chamich Districts, flows generally in an eastern direction and terminates into the Abay Basin of the Beles River. The study area is in Ethiopia's Abay Basin, Beles Sub-basin. The Burje catchment is situated in the eastern part of Ethiopia, and the study area falls both in Benishangul Gumuz and Amhara regional states. But most of the study area falls under Benishangul Gumuz regional state and is located 18 km from Manbuk town, the administrative location of Dangur woreda.

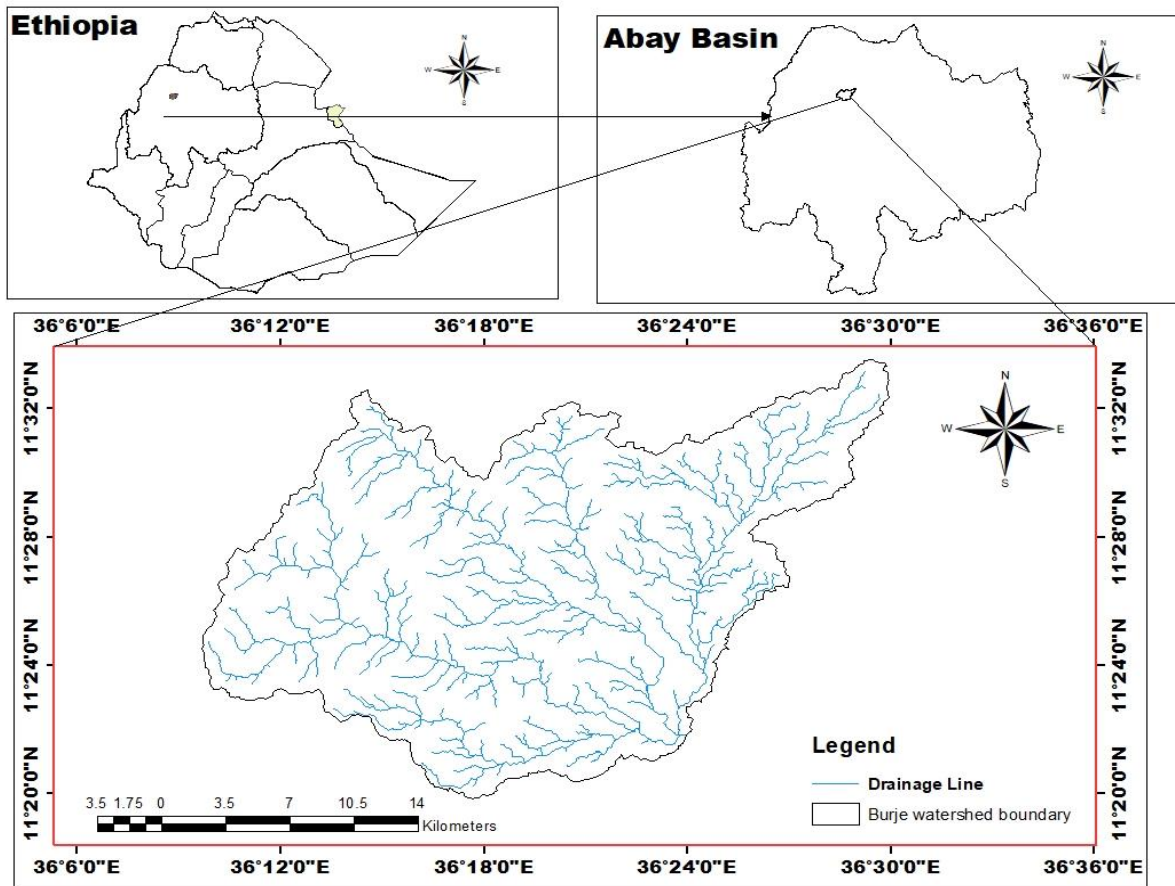


Figure 3-1 Study Area Map

### **3.1.2 Topography**

The area's topography ranges from mountains in the area of Niguse Dawit (Belaya mountain) to lowlands in the north-east and east. The catchment's average elevation is 1900 meters above sea level. The study area's altitude falls from 1200m to 2600m above mean sea level in a south-easterly direction.

### **3.1.3 Climate**

The study area's climate, known locally as "kolla," has the most yearly rainfall throughout the summer (August, and September). Based on long term observations made by the national metrological agency on three rain gauge stations (1996-2017), the monthly maximum temperature is ranging between 26 °C and 41.5 °C while the monthly minimum temperature is falling between 18 °C and 25 °C. The "kremt" (summer) season, which lasts from June through September, has the most rainfall. And during the off-season, the watershed has not received precipitation. According to the meteorological data from 1996 to 2017, the annual rainfall of the study area ranges between 801 mm and 1250.8 mm (NMA).

### **3.1.4 Soil**

Soil texture type is one of the significant parameters for agricultural production and recharge of groundwater. It controls the penetration of surface water into an aquifer system. The careful analysis of soil textures reveals that the study area is covered by fine, fine loamy, loamy and coarse loamy types of soils (Kumar and Krishna, 2018). Soils are the world's natural resource and a soil map is a spatial representation of these resources. Therefore, soil map is fundamental and should be the starting point when ground water potential zone delineation processed. The analysis of the soil type reveals that the study area is predominantly covered by Eutric Fluvisols, Eutric Cambisols, Eutric leptosols, Haplic Nitisols, Rhodic Nitisols.

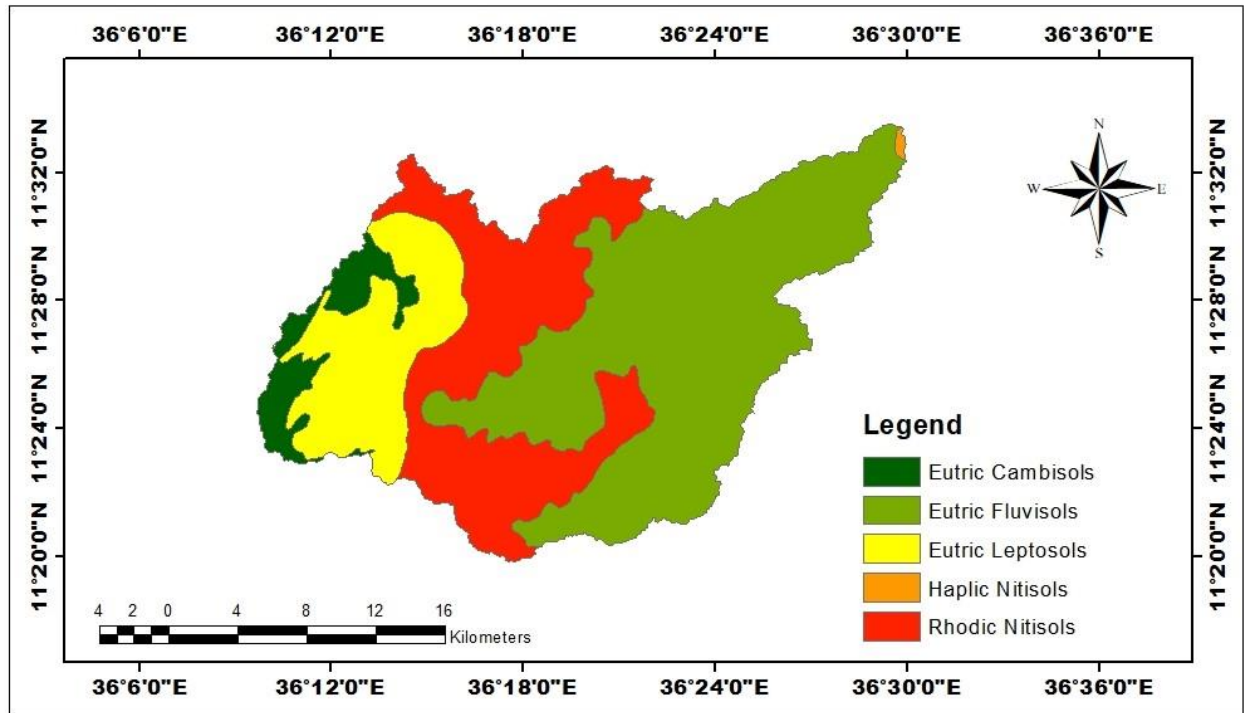


Figure 3-2 Soil Map of the Study Area

Table 3-1 Soil classes and their Area coverage

Soil classes	Area Coverage (KM <sup>2</sup> )	% of Area Coverage
Eutric Fluvisols	256.794	49.38
Eutric Cambisols	29.684	5.52
Eutric Leptosols	82.234	15.67
Haplic Nitisols	1.894	0.15
Rhodic Nitisols	152.494	29.24

### Fluvisols

Are young soils developed in recent alluvial deposits of river plains, deltas, former lakes and coastal areas. Soil conditions are highly variable. In arid regions many soils are saline. Fluvisols with having a base saturation of 50 per cent or more, are Eutric Fluvisols. It is found on exposed surface of unconsolidated sediment. They are very diverse and young soils that are often found on low-lying plains and near river stream courses. Fluvisols are generally good agricultural soils and often intensively used, although land use has to be adapted to floods, inundations or high groundwater (Abdilbasit, 2013).

### **Cambisols**

Cambisols are developed in medium and fine-textured materials derived from a wide range of rocks, mostly in alluvial, colluvial and aeolian deposits. Most of these soils make good agricultural land and are intensively used. Cambisols in temperate climates are among the most productive soils on earth. Cambisols are less common in the tropics and subtropics, but they are common in areas with active erosion where they may occur in association with mature tropical soils (Abdo, 2013).

### **Nitiosols**

Eutric Nitiosols are found on almost flat to sloping terrain in the highlands. It is among the best agricultural soils. The physical properties are similar to those of the Dystric Nitiosols. Chemically these soils are better, although available p contents are low (Abdo, 2013).

### **Leptosols**

Leptosols are very shallow soils over continuous rock and are extremely gravelly and/or stony with various kinds of continuous rock or of unconsolidated materials with less than 20 percent (by volume) fine earth. Leptosols have a resource potential for wet-season grazing and as forest land. Erosion is the greatest threat to Leptosols areas, particularly in mountain regions in the temperate zones. Steep slopes with shallow and stony soils can be transformed into cultivable land through terracing, the removal of stones by hand and their use as terrace fronts. The excessive internal drainage and the shallowness of many Leptosols can cause drought even in a humid environment (Abdilbasit, 2013).

### **3.1.5 Slope**

In the study area the slope is also another topographical aspect that influences the delineate ground water potential. Slope is one of the major factors that controlling infiltration of water to the ground and the indicator of groundwater potential suitability. Very high sloping region causes more runoff and less infiltration and have poor groundwater prospects when compared to the low slope region. Low slopping regions causes less runoff and high infiltration rate and has good groundwater potential (Rahmati *et al.*, 2020). It is an important factor in delineate, because slope determines the amount of runoff in the site. In this study, slope of the study area generates from DEM and analysis using Arc-GIS technology.

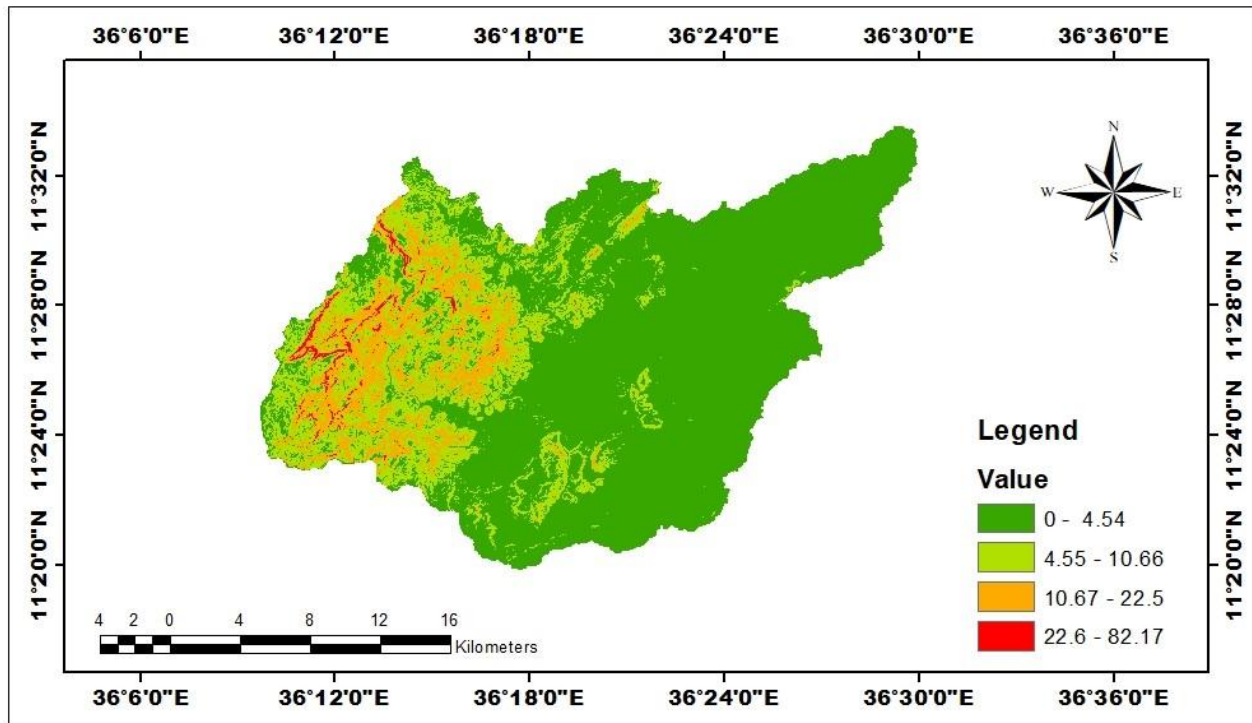


Figure 3-3 Slope map of the study area

Table 3-2 Slope Classifications (*Daliya et al., 2020*).

Factor	Classes	Classifications	Groundwater Prospect	Rank	Influence weight (%)
Slope	0-4.54	Gentle	High	2	27
	4.55-10.66	Moderate	Moderate	3	
	10.67-22.5	High	Low	4	
	22.6 – 82.17	Steep	Very low	5	

### 3.1.6 Lithology/Geology

The type of rock exposed to the surface significantly affects groundwater recharge. Lithology affects the groundwater recharge by controlling the percolation of water flow. Although some investigations have ignored this factor by regarding the lineaments and drainage characters as a function of primary and secondary porosity, this study includes lithology to reduce uncertainty in determining lineaments and drainage (*Yeh et al., 2009*). The geology of the study area is the result of the geological activities that took place in the part of the Eastern Africa and Ethiopia. The availability of groundwater depends primarily on the geology. Groundwater is stored within pore spaces and fractures in rocks (*Gaye and Tindimugaya, 2019*). Geology is a major factor controlling

the quality and quantity of groundwater occurrence in a given area. It is represented by the distribution of different rock units characterizing the area under study(Kumar and Krishna, 2018). The geological setting of the study area is generally classified in to four groups; namely, Undifferentiated lower Complex, Termaber basalt, Ashangi basalts, and Alluvium. These four groups of geological setting are influence on ground water occurrence potential zones.

Table 3-3 Geological type and their area coverage

Groups	Area of Coverage (KM <sup>2</sup> )	% of Area Coverage
<b>Undifferentiated lower complex</b>	245.345	47.14
<b>Termaber basalt</b>	53.595	10.09
<b>Ashangi basalts</b>	189.425	36.33
<b>Alluvium</b>	34.735	6.45

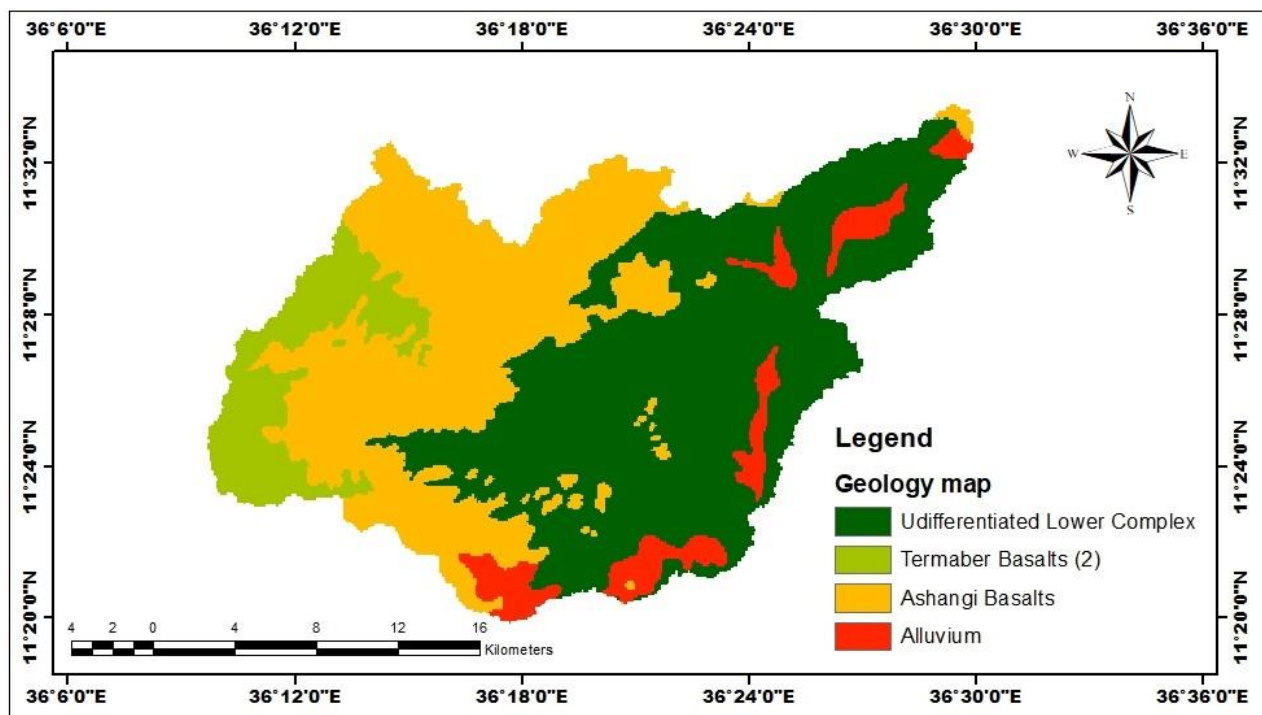


Figure 3-4 Geology map

### **Undifferentiated Lower Complex**

The Undifferentiated Lower Complex Formation is the dominant geological formation in Burje watershed covering the total area of 245.345 km<sup>2</sup>. Undifferentiated barren lands encompass cleared lands that have no apparent site preparation or any indication of past activities. Such areas vary in shape and size but generally possess little vegetation, exposing the soil or surface material only. Ancillary information also gives no indication of former uses (Landtschoote, 2017).

### **Termaber Basalt**

The basalt is aphanitic, black, and hard, outcrops with thin soil cover. Where as in Burje river valley, it is found at the deepest part of the valley overlain by rhyolite. The basalt is columnar jointed with spheroidal weathering at the surface. The Amba-Aiba Formation is unconformably layered under the Termaber Formation, which is the Upper Basalt series. Rhyolite- trachyte flows, coriaceous lava flows, and large amounts of tuff make up its composition. It prefers alkalis. The presence of red paleo soils makes this formation simple to identify in the field (Landtschoote, 2017).

### **Ashangi Basalts**

The Ashangi Basalts are the earliest Tertiary volcanic rocks in north Ethiopia, hence they are in the lowest position. The Ashangi formation is frequently injected by dolerite sill and dykes and is composed primarily of mildly alkaline basalt with interbedded pyroclastic. These dark porphyritic basalts are separated from the Mesozoic formations below it by basal conglomerates. The basalts hold phenocrysts that developed before the magma reached the earth surface. These basalts are weathered, partially eroded and have a sub-horizontal stratification, particularly at the lower part (Ayehu, 2010).

### **Alluvium**

Alluvium material deposited by rivers. It is usually most extensively developed in the lower part of the course of a river, forming floodplains and deltas, but may be deposited at any point where the river overflows its banks or where the velocity of a river is checked for example, where it runs into a lake. Alluvium consists of silt, sand, clay, and gravel and often contains a good deal of organic matter. It therefore yields very fertile soils such as those of the deltas of the Mississippi, the Nile, the Ganges and Brahmaputra, and the Huang Rivers (Melkie 2019). In some regions alluvial deposits contain gold, platinum, or gemstones and the greater part of the world's supply of tin ore (cassiterite).

### 3.1.7 Drainage Density

The drainage density is inversely related to permeability which influences runoff and quantity of infiltration (Saranya and Saravanan 2020). Stream network can be generated from an elevation model (DEM) and satellite image data. A drainage network density describes the way of streams that feed other larger streams and rivers branch off in different directions. Thus, major drainage pattern in the study area can be described as streams and rivers, in which the Streams tend to from about 2 major rivers in the area. Burje River and Derek wonze rivers, are the most areas of the catchment is slightly sloppy at the initial point of the catchment. Drainage network or drainage density is an indicator for the natural infiltration of a terrain. A higher drainage network density reflects a higher runoff, hence less infiltration; or as stated in the denser the drainage network, the lower the recharge rate.

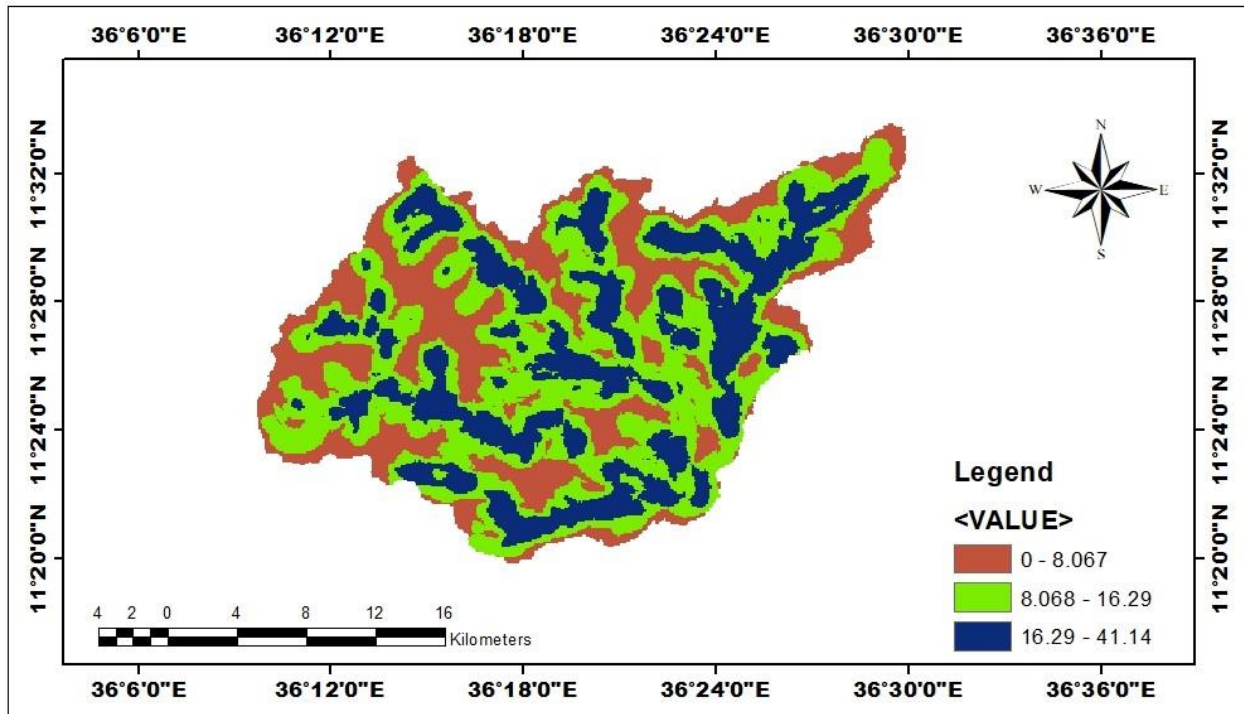


Figure 3-5 Drainage density map

### 3.1.8 Lineament Density

Lineaments are naturally occurring curvilinear or linear structurally controlled features in a landscape, which are an expression of an underlying geological structure, including faults (Yifru *et al.*, 2020). The lineament density is generated by extracting the lineament from the DEM using the ArcGIS 10.4.1 Software's. The study area is found to have a number of crisscrossed lineaments. The intersection of lineaments is considered as good occurrence of groundwater potential zones. Lineaments like joints, fractures and faults are hydro geologically very important and may provide the pathways for groundwater movement. The density of the lineament is generated using the lineament map by using line density methods using spatial analyst tool.

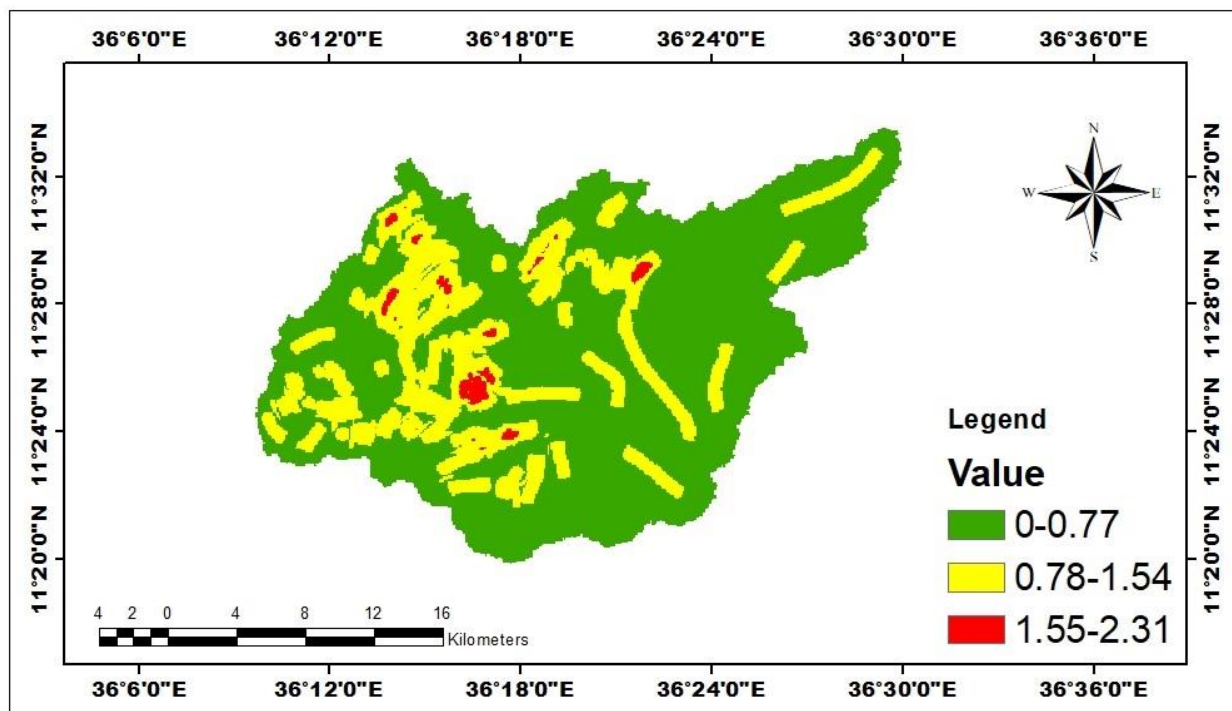


Figure 3-6 Lineament density map

### 3.1.9 Land Use/Cover Data

Land-use and land-cover changes are one of the main human induced activities altering the occurrence and development of groundwater resources (Patra, Mishra and Mahapatra, 2018). Land cover plays a significant role in the development of groundwater resources. It controls many hydro geological processes in the water cycle viz., infiltration, evapotranspiration, surface runoff (Tamiru Tolcha, 2019). Surface cover provides roughness to the surface, reduce discharge thereby increases the infiltration. In the forest areas, infiltration will be more and runoff will be less whereas in urban

areas rate of infiltration may decrease (Kattimani *et al.*, 2018). It is one of the aspects affecting groundwater occurrence and availability of aquifer identification (Pande *et al.*, 2018). Classification of land use/cover for analysis was done based on their character to infiltrate water in to the ground and to hold water on the ground. There is a various land use/ land cover classes in the study area which used to delineate groundwater potential zone. The various classes in the study area are: Bushland, Dominantly cultivated, Moderately cultivated, Grassland, Woodland dense, and Woodland open in the study area.

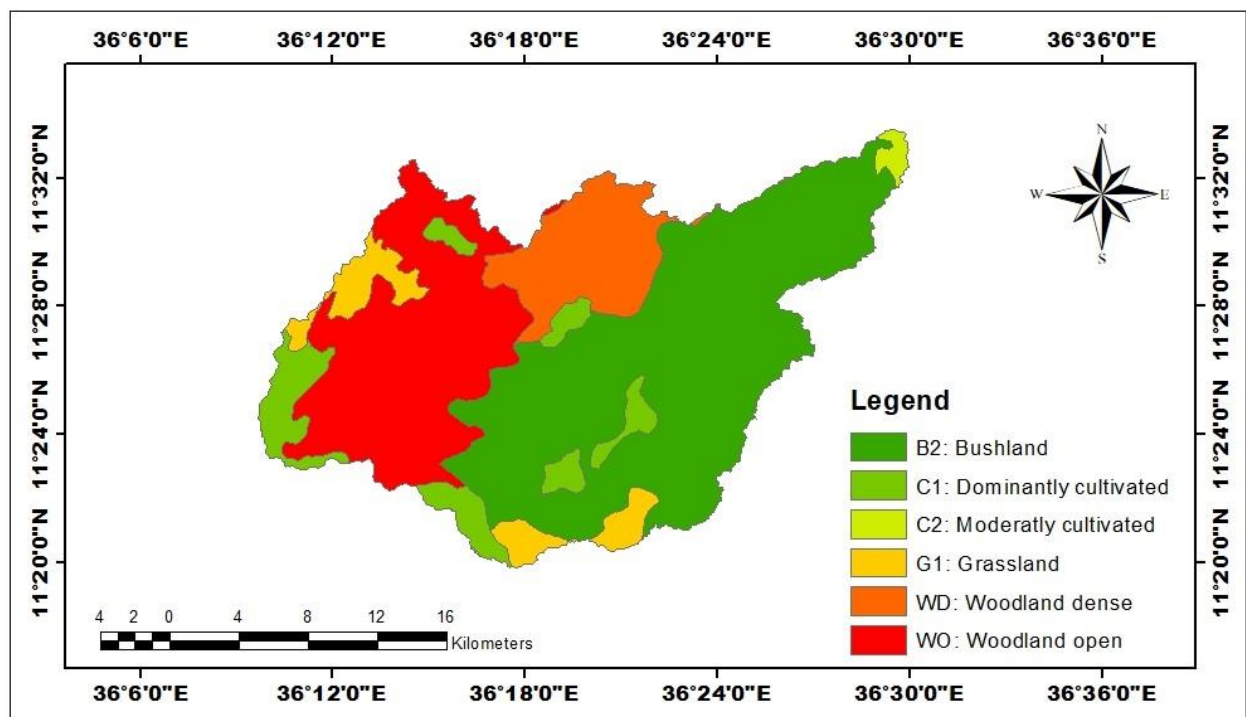


Figure 3-7 LULC map of the study area.

Table 3-4 The various classes of LULC (2020).

Classes	Area of Coverage (KM <sup>2</sup> )	% of Area Coverage
Bushland	252.21	48.53
Dominantly cultivated	44.51	8.42
Moderately cultivated	4.78	0.74
Grassland	29.17	5.458
Woodland dense	56.94	10.822
Woodland open	135.47	25.99

## 3.2 Data Sources, Materials and Methods

### 3.2.1 Data Sources

Various forms of data and software were used in this study. Using the ArcGIS tool, a digital elevation model (DEM) with a resolution of 30 meters was obtained from the Shuttle Radar Topography Mission (SRTM). Filling sinks, flow direction, flow accumulation, and stream network extraction are all part of the drainage density development process. After that, a line density analysis tool was used to create the drainage density map. The lineament density was calculated using a Landsat 8 Operational Land Imager (OLI) satellite image taken from the United States Geological Society (USGS) website (USGS, 2019). Soil data from Ethiopia's Ministry of Agriculture, Geological Map, LULC Map, Soil Map of Study Area from Geological Survey Ethiopia (GSE), and rainfall data from Ethiopia's National Meteorology Agency are among the key data sources used in this study. All pictures were downloaded in level 1 geo-tiff format, are from Landsat ETM+, and have a spatial resolution of 30 meters.

Table 3-5 Types of data and data source

S.no	Data	Scale/Resolution /Format	Source	Functions
1	DEM Data	SRTM (30m*30m) Resolution	United States Geological Survey (2019).	Used to generate Slope, Drainage and Lineament Density map of the study area.
2	LULC Map,	Shape File	Geological Survey Ethiopia (GSE) (2020).	Used to generate Land use Land cover map of the study area.
3	Rainfall data	Excel Format	National Metrological Agency (1996- 2017)	Used to generate Rainfall map of the study area.
4	Geology Map	Shape File	Geological Survey Ethiopia (GSE)	Used to generate Geological map of the study area.
5	Soil Map	Shape File	Geological Survey Ethiopia (GSE)	Used to generate Soil map of the study areas.
6	Borehole Data	Excel Format	Collected by Handled GPS	Used to validate the groundwater potential map.

### 3.2.2 Materials

The ground water potential zone site for the Burje river catchment was determined using a variety of sensors and technology. In this study, computer hardware and software are employed for data preparation and organization, data analysis, and output generation. A personal computer, a printer, and a digital camera are included with the hardware. Among the software programs used to collect and store data in materials are GPS, Excel, and Microsoft Word. Arc GIS 10.4.1 is the software used for data processing and preparation, data analysis, editing, and output generation.

Table 3-6 Types of Software's and their purpose

S.no	Software	Purpose	Remark/Version
1	ARC GIS Software	Clip image, merging polygon, Generating different Thematic map	10.4.1
2	MS word and MS excel	Write, chart preparing and statistical analysis.	2019
3	XLSTAT	To fill the missing rainfall data	2019

### 3.2.3 Methods

#### 3.2.3.1 Data Collection Methods

Data collection methods are determined by the information needed to answer each research topic. The most important aspect of any research is collecting correct and reliable data because it affects the research's quality. This study's data will be gathered by field observation, downloading, and digital imaging. As a result, the essential data will be gathered from the appropriate sources. Dangur Woreda water office was provide borehole data such as groundwater depth, borehole well sites, and borehole discharged/yields ( $m^3/h$ ). Geology Map of the study area is obtained from Geologic Survey of Ethiopia for mapping geologies. The lineament density of the study area is extracted using DEM data from the study area. The DEM is also used to extract the study area's slope, and drainage pattern. Borehole data such as groundwater depth and well position are collected using GPS. All of the following information was gathered, processed, and evaluated in a GIS environment in preparation for further investigation.

#### 3.2.3.2 Data Analysis Methods

Thematic map production and integration through GIS environments were part of the integrated approach methodology for estimating groundwater potential zone in the study area. The techniques are applied in every stages of analysis, starting from data organization to final out put modeling/generation. Individual class weights and map scores were assessed prior to the integration

of diverse information using Satty's Analytic Hierarchy Process, which involved creating a pair-wise comparison matrix for each map using a nine-point important scale and weighting it based on relative importance.

The result is a unified weight map that includes the appropriate weights for all input variables. The final map's weight values were then logically classified to arrive at a groundwater potential zone map. This gives a general understanding of the groundwater potential in the study area. To achieve the study's final goal of delineating groundwater potential zones, multiple thematic layers were integrated using GIS and remote sensing techniques including geology, lineament density, drainage density, slope, soil, land use/land cover, and rainfall. Methods like rectifying, digitizing, reclassifying, Analytical Hierarchy Process, and weighted overlay analysis are the major ones used in this study to delineate groundwater potential zone maps.

### **3.2.3.3 Consistency of rainfall data**

Records of rainfall data are crucial for hydrologic studies that involve trends. The double-mass curve methodology was used to test rainfall records before they are utilized in such studies to make sure that any trends found are attributable to meteorological factors and not adjustments to gage position, exposure, or observational techniques. The consistency of the rainfall data was adjusted using the double mass curve approach, as illustrated in the fig. below, in order to prepare them for further use. The outcome of the double mass curve analysis revealed significant correlation between all stations, with all correlation values between the cumulative rainfall recorded at each station and the cumulative rainfall of all stations being  $R^2 > 0.9$ . All stations were also determined to be consistent.

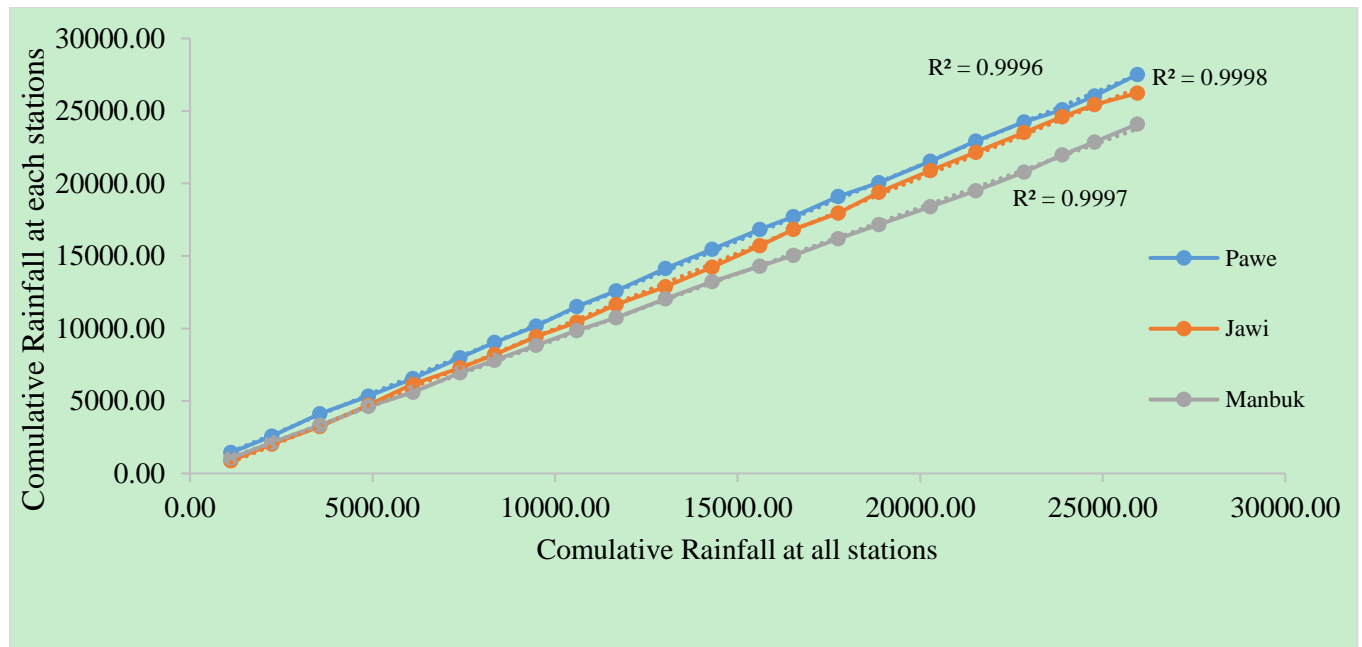


Figure 3-8 Rainfall consistency graph

### 3.3 Preparation of Thematic maps using GIS and Remote sensing technique

Thematic maps are a valuable resource for GIS data. These are all tools that were used to communicate geographic concepts using maps. Rainfall, land use, land cover, geology, slope, lineament, soil, and drainage density maps are created by digitizing and overlaying data with the required criteria.

#### 3.3.1 Geographic Information System (GIS)

Geographic Information System is a system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth (Ali, 2020). The groundwater potential zones were delineated using a geographic information system and remote sensing technology (Pande *et al.*, 2018). Geospatial technologies have evolved as useful tools for executing spatial data and making decisions in a variety of sectors, including engineering and the environment. RS and GIS are examples of geospatial tools that are useful for analyzing large amounts of hydrogeological data and simulating complicated features (Hussein, Govindu and Nigusse, 2017). GIS is used to organize, use, and classify remote sensing data, as well as to explore sites, combine groundwater recharge potential variables, and give appropriate weight relationships (Yeh *et al.*, 2009).

### 3.3.2 Analytical Hierarchical Process

To demarcate GWPZs, the Analytical Hierarchical Process (Saaty, 1987) is an effective multi-criteria decision-making tool. This method was used to combine the thematic layers, which are regarded influential variables that govern water storage and flow in a region. The impact of each layer, however, was not the same. As a result, each thematic layer was assigned a relative weight based on Saaty's scale of criticality and water holding capacity. The backbone of AHP is a knowledge-driven process for determining the criticality of one thematic layer over another. As a result, relative weights were assigned based on past research and field experience in various geographical regions. The methodology's detailed steps can be found elsewhere (Mukherjee and Kumar, 2020). A paired-comparison matrix was created via pairwise comparison using Saaty's importance scale to determine the relative value or weights of each theme map. Consistency ratios are the consistency properties of these matrices (CR). According to Saaty, the matrices having CR values larger than 0.1 should be re-evaluated. This method aids in analyzing the matrix and identifying inconsistencies in the definition of interrelationships. The consistency value in this situation was 0.05, which is acceptable. To reduce computation time, the weights were normalized by multiplying by 100. These weights were used in a linear summation equation to produce an integrated weight map that included the due weights of all input variables, which was then classed to produce a groundwater potential map.

The weights for the thematic layers and the rates for the classes in a layer were calculated using Saaty's AHP (Saaty 1980). The most commonly adopted method for scaling the rates/weights of factors whose entries show the strength with which one component dominates over the other in relation to the relative criteria is Saaty's AHP (Tamiru Tolcha, 2019). The decision maker in this approach must express his view on the value of one pairwise comparison at a time. The fundamental issue with pairwise comparisons is determining how to quantify the language choices made by the decision maker during the evaluation process. As a result, matrices were created in which each criterion was compared to the others in terms of relevance, using Saaty's scale of 1 to 9. A score of 1 shows that the two aspects are of equal importance, whereas a score of 9 indicates that one factor is far more essential than the other as shown in (Table 3-7) below.

Table 3-7 Saaty's (1980) Relative Weight Parameters and their explanation

Intensity of importance	Definition	Explanation
1	Equal	Two elements contribute equally to the objective importance
3	Moderate	Experience and judgment slightly favor one element over another
5	Strong	Experience and judgment strongly favor one element over another
7	Very strong	One element is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme	The evidence favoring one element over another is of the highest possible order of affirmation

2,4,6,8 can be used to express intermediate values

Table 3-8 Paired comparison matrix

Matrix	Rainfall	Drainage density	Geology	Soil	Slope	LULC	Lineament density	weight	Weight (%)
Rainfall	1	1/5	1/7	1	1/5	1/3	1	0.5	5
Drainage density	5	1	1	1	1/3	1	3	0.15	15
Geology	7	1	1	3	1	5	7	0.28	28
Soil	1	1	1/3	1	1/3	3	3	0.12	12
Slope	5	3	1	3	1	3	5	0.27	27
LULC	3	1	1/5	1/3	1/3	1	3	0.09	9
Lineament density	1	1/3	1/7	1/3	1/5	1/3	1	0.04	4

Table 3-9 Calculated of eigenvector and weights influence in percent

The eigenvector of weights	weight	Weight (%)
Rainfall	0.5	5 %
Drainage Density	0.15	15 %
Geology	0.28	28 %
Soil	0.12	12 %
Slope	0.27	27 %
Land Cover	0.09	9 %
Lineament Density	0.04	4 %
Total	1	100%

Consistency ratio = **0.05** which is acceptable

Consistency Ratio= 0.05, and the value of Consistency is acceptable.

The consistency ratio value < 0.05 for 3 x 3 matrix

0.09 for 4 x 4 matrix

0.1 for greater than 4 x 4 matrix.

For the complex regional and temporal distribution, rain fall and geology score the highest relative to the other characteristics in the table above, whereas soil scores the lowest.

Slope, drainage density, lineament density, geology, land use and land cover, soil, and rainfall pattern were all considered to delineate the ground water potential zones in this study. The drainage density map, lineament density map, and slope map were all created using DEM data. These parameters are generated in a GIS environment, and weights for each class are determined using an analytical method. The weight value of each parameter is estimated after the Analytical Hierarchical Process (AHP) matrix has been built using set criteria. According to Satty, the acceptable CR value should be less than 0.1. The consistency ratio (CR) of 0.05 is significantly less than 0.1, indicating that it is acceptable look at table 3-9 above.

### 3.4 Data Preparation Methods

The current study's methodology was to use GIS and remote sensing tools to delineate a groundwater potential zone for further hydrogeological exploration. Input of data sets, derivation of data sets, reclassification of data sets, weighting and merging datasets of thematic maps, and processing of all data are the four primary processes of the study.

The, steps required are discussed as follows: -

#### **3.4.1 Inputting dataset**

SRTM data and Landsat images of the area are identified and used as input data sets for further processing in this investigation. The SRTM (Shuttle Radar Topographic Mission) 30\*30m resolution data sets were used to generate the slope, drainage density, and lineament density of the Burje River Catchment.

#### **3.4.2 Stemming Data set**

Data analyses are used in this step to extract new information from current or input data in order to create a thematic map. The study to reveal the ground water potential zone delineation includes creating drainage network data, computing drainage density, extracting elevation, creating lineament data, computing lineament density, digitizing geology data, and generating land cover data.

#### **3.4.3 Reclassifying**

The extracted data is reclassified using a similar scale, with higher values indicating more acceptable features and lower values indicating less suitable attributes. Slope, soil, land use/cover, geology/rock type, drainage density, lineament density, and rainfall will all be reclassified.

#### **3.4.4 Weighting Overlay**

All thematic maps or layers were created in raster format and given a normalized weight in accordance with the groundwater potential controlling capabilities, as shown in the preceding sections. Similarly, the normalized rate or rank was assigned to each thematic layer type. After completing these steps, Arc GIS 10.4.1 was used to perform the overlay analysis. by assessing the relative relevance of each condition and giving a percentage impact (%) to each. Finally, all the thematic layers were overlaid using a weighting overlay in Arc GIS 10.4.1 to create the groundwater potential map, which was then checked with ground truth. In general, the Analytical Hierarchy Process was used to delineate the groundwater potential zone of the Burje River Catchment using remote sensing and GIS techniques. The DEM data is then utilized to generate a drainage density map, a lineament density map, and a slope map. The geological information that was used to construct the geological map. The study area's soil map was created using soil data. The study area's rainfall map was created using rainfall data. The study area's LULC map was created using LULC data. Thematic layers (rainfall, slope, lineament density, drainage density, soil texture, land-use/land-cover, and geology) were given relative weights based on their relative importance for

each analyzed based on the judgment of researchers or expert knowledge gained through similar groundwater potential zone mapping work (Tadesse 2018). Groundwater potential zones were identified for the study area by grouping the interpreted layers using Weighted Overlay Analysis and then assigning different potential zones. Each of the primary seven thematic layers (slope, geology, drainage density, lineament density, soil, land use/land cover, and rainfall) is essentially divided into three groups based on groundwater potential: 1. High, 2. Moderate, and 3. Low. Each class of a certain thematic layer has been assigned a suitable weighting on a scale of "1-to-9" based on their contribution to ground water potentiality. Table 3-9 shows the weights and percent of impact assigned to various classes across all the thematic layers. All of the thematic maps have been put together. The aforementioned technique is used to create a final groundwater potential map. The majority of the study area has a high level of groundwater potential, while the rest is designated as moderate, with a minor part having excellent groundwater potential. The weighting overlay analysis was used to merge all of the categorized thematic layers with GIS.

The groundwater potential zone map (GPZM) was created using the following equation:

$$GPZM = 5 * Rainfall\ map + 28 * Geology\ map + 9 * LULC + 12 * Soil\ map + 15 \\ * Drainage\ density\ map + 4 * Lineament\ density\ map + 27 * Slope\ map$$

Groundwater prospect zones were delineated from the composite layer by combining the polygons into three separate prospect zones: High, Moderate, and Low.

## **3.5 HYDROLOGY**

### **3.5.1 Rainfall**

The three meteorological stations that are nearest to the study area were constructed by Ethiopia's National Meteorological Agency (NMA). They are located in Pawe, Manbuk, and Jawi. There are various methods for estimating missing rainfall data that vary depending on how terrain affects the distance between rainfall stations and how much rainfall is actually recorded at each station. The Burje Watershed's missing rainfall data was estimated using the XLSTAT 2019 approach.

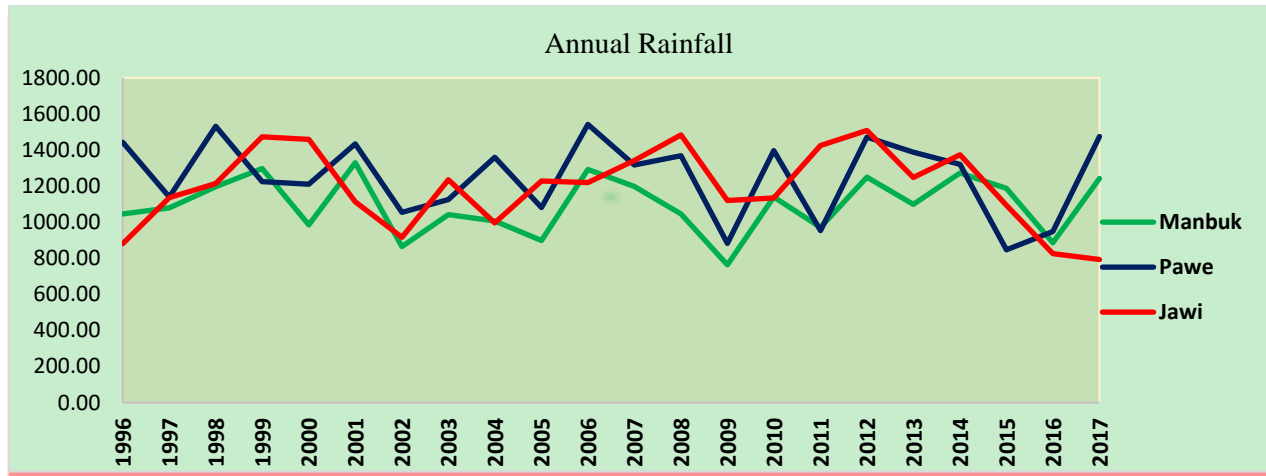


Figure 3-9 Annual Rainfall (1996-2017).

### 3.5.2 Determination of aerial depth of precipitation

A rainfall event recorded by a rain gauge was a point observation at a particular location and shouldn't be interpreted as a representation of the watershed as a whole. As a result, the catchment-wide average of the reported point precipitation must be calculated. There are numerous methodological methods for calculating the amount of precipitation that falls in the aerial depth over a given basin. Thiessen polygons, isohyet, and arithmetic averaging are the methods that are used most commonly. The factors for choosing the optimal approach include the densification of meteorological networks, the characteristics of the topography within the catchment, and the size of the watershed. The arithmetic mean method is usually applied for preliminary evaluation of precipitation depth. The Thiessen polygon method of calculating the average precipitation over an area is superior to the arithmetic average method as some weight is given to the various stations on a rational basis. Further, the rain gauge stations outside the catchment are also used effectively. Therefore, Thiessen polygon method is more applicable to determine areal rainfall for the study area.

Table 3-10 Areal Rainfall interpolated using Thiessen Polygon Method for Burje watershed

Station	Pi	Ai	Ai/At	Pi (Ai/At)
Manbuk	1095.33	235.17	0.450	492.42
Pawe	1250.80	151.21	0.289	361.55
Jawi	1192.21	136.73	0.261	311.62
Total	3538.34	523.10		1165.59

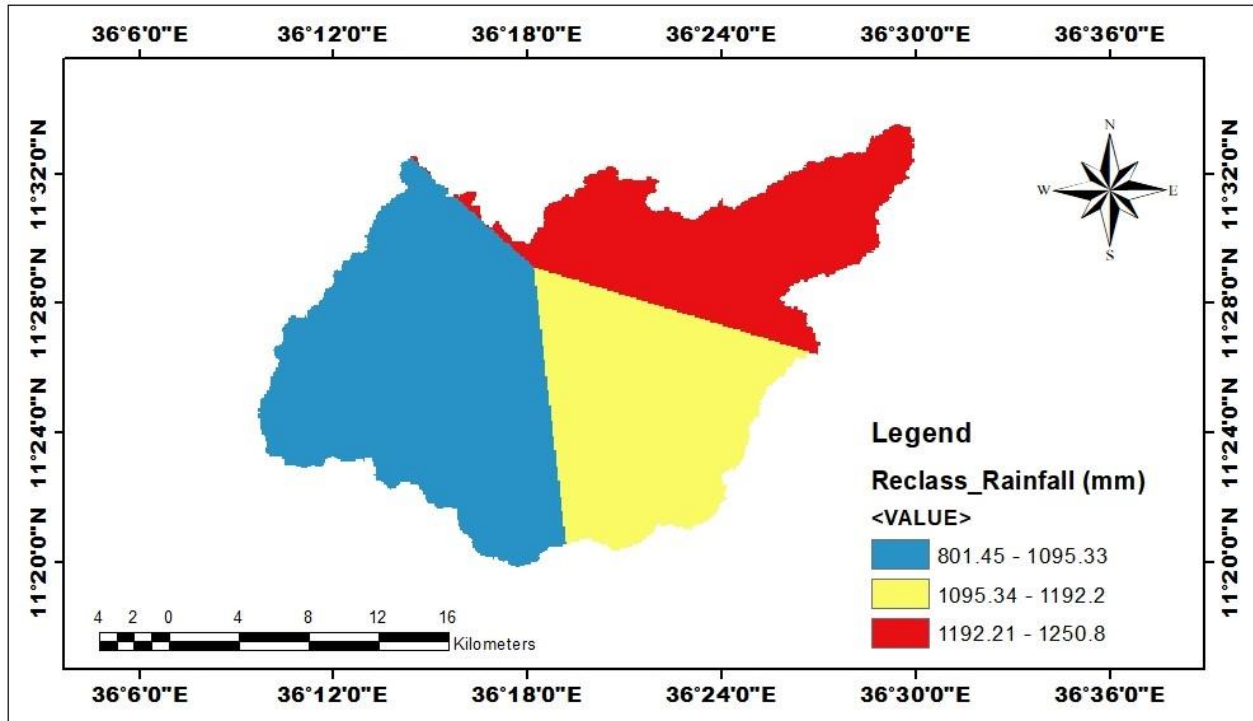


Figure 3-10 Rainfall map

### 3.5.3 Runoff

Runoff is the term for water that flows into surface water instead of percolating through the soil or soaking into the earth. The most important factors affecting runoff are the local geology, slope, and topography, while actual evapotranspiration, rainfall, and vegetation cover have the least impact. In general, less than average rainfall, high evapotranspiration, gentle slope, very permeable volcanic falls and disappearing drainage pattern can assure the lowest runoff. Direct runoff is that component of the precipitation, snow melt, or irrigation water that come in existence in uncontrolled surface streams, rivers, drains and sewers. It is composed of precipitation that neither evaporates, transpires nor goes into the surface to become groundwater. It happens whenever the rate of rainfall on a surface go beyond the rate at which water can percolate the ground and any depression storage has already been become full. This is more frequently takes place in arid and semi-arid area, to which rainfall intensities are far above and the soil infiltration ability is become smaller by reason of surface impervious, or in pavement region. From the 22-year rainfall data Runoff for Burje catchment is calculated using Excel Sheet by empirical formula.

Table 3-11 Long- term mean monthly surface runoff (mm) of Burje Watershed

<b>Month</b>	<b>Pawe</b>	<b>Manbuk</b>	<b>Jawi</b>	<b>Mean</b>
<b>Jan</b>	0.00	0.00	0.00	0.00
<b>Feb</b>	0.00	0.00	0.00	0.00
<b>Mar</b>	0.50	0.00	0.00	0.17
<b>Apr</b>	2.00	0.12	0.00	0.71
<b>May</b>	27.20	18.30	25.29	23.60
<b>Jun</b>	83.50	76.40	89.25	83.05
<b>Jul</b>	87.38	66.53	96.02	83.31
<b>Aug</b>	85.17	90.18	118.08	97.81
<b>Sep</b>	91.54	75.12	62.65	76.44
<b>Oct</b>	43.49	27.28	38.89	36.55
<b>Nov</b>	0.80	0.73	2.37	1.30
<b>Dec</b>	0.00	0.09	0.00	0.03

### **3.5.4 Evapotranspiration**

The total amount of water lost through evaporation and transpiration from a land surface and vegetation cover is defined as evapotranspiration. The type of vegetation and the amount of water in the soil affect its value. There are two types of evapotranspiration: potential evapotranspiration and actual evapotranspiration.

#### **3.5.4.1 Potential evapotranspiration**

Potential evapotranspiration is the total amount of water that evaporates and transpires from a vegetated surface when there is an unlimited supply of water. It constitutes the maximum possible loss rate under the prevailing meteorological conditions.

#### **3.5.4.2 Actual Evapotranspiration**

Actual evapotranspiration accounts for the field condition; it depends on the availability of water. It is the sum total of the evaporation of the water intercepted mainly by vegetation, direct evaporation from the soil surface, lake, seas, and all water bodies, and transpiration of plants. The evapotranspiration is highly affected by sunshine, wind and humidity. The highest evapotranspiration is observed on March and May when there is high sunshine hours and wind speed, implying that those meteorological parameters are important factors to evapotranspiration.

The Turc method is used to estimate the actual evapotranspiration of the study area

$$ETA = \frac{P}{\left[1.9 + \left(\frac{P}{J}\right)^2\right]^{0.5}} \dots\dots\dots \text{Equation 3.1.}$$

Where, P= is the annual precipitation

ETA= Annual actual evapotranspiration

$$J = 300 + 25 * T + 0.05 * T^3$$

T= Annual average temperature

Table 3-12 Actual evapotranspiration (AET) of Burje watershed.

Stations	Average annual precipitation (mm)	Average annual temperature (°C).	AET (mm/year).
Manbuk	1095.33	24.05	711.41
Pawe	1250.80	23.10	775.55
Jawi	1192.21	22.92	746.11
<b>Average AET</b>			<b>744.36</b>

### 3.6 Water balance and groundwater potential evaluation

#### 3.6.1 Recharge

Groundwater recharge can be defined as the amount of water that will eventually reach the water table. The amount of this recharge depends upon the rate and duration of rainfall, the surface conditions at the upper boundary, the soil moisture conditions, the water table depth and the geology. The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon the groundwater recharge. Quantification the natural groundwater recharge is a basic pre-requisite for efficient groundwater resource management. It is important in areas with large demands for groundwater supplies, where such resources are the key to economic development. Though there are several techniques to estimate the natural groundwater recharge, the soil water balance approach was used in this study.

##### 3.6.1.1 Soil water balance method

Soil water balance model was developed by Thornthwaite and later revised by Thornthwaite and Mather. It estimates the balance between the inflow and outflow of water in the soil. The soil water balance can be represented by:

$$Gr = P - AET + \Delta S_m - R_o \dots\dots\dots \text{Equation 3.2.}$$

Where, Gr = Groundwater recharge

P = Precipitation

AET = Actual evapotranspiration

$\Delta S_m$  = Change in soil moisture

R<sub>o</sub> = Runoff

The previous calculated values of aerial precipitation and actual evapotranspiration of the catchment are 1165.59 mm/year and 744.36 mm/year respectively and also the calculated value of runoff is 402 mm. The adjusted value of change in soil moisture is zero. Substituting the values in the above equation, the total recharge of the study area is 19.24 mm/year. Considering the total area of the catchment as 523.1 km<sup>2</sup>, the annual groundwater recharge of the Burje catchment is estimated to be 10.06 MCM.

This calculation's primary goal is to do a quantitative assessment of the volume of water that percolates into the ground in order to recharge the groundwater circulation that exists in the study area. The following is a summary of the assumptions used to develop the water balance equation for the research area:

- a) Since the computation is made annually, net change of the soil moisture and groundwater storage are assumed to be zero.
- b) The area is part of the regional groundwater flow system and groundwater is not in closed system. Therefore, groundwater inflow from adjacent basin or area is equal to groundwater outflow in to the adjacent basin or area.

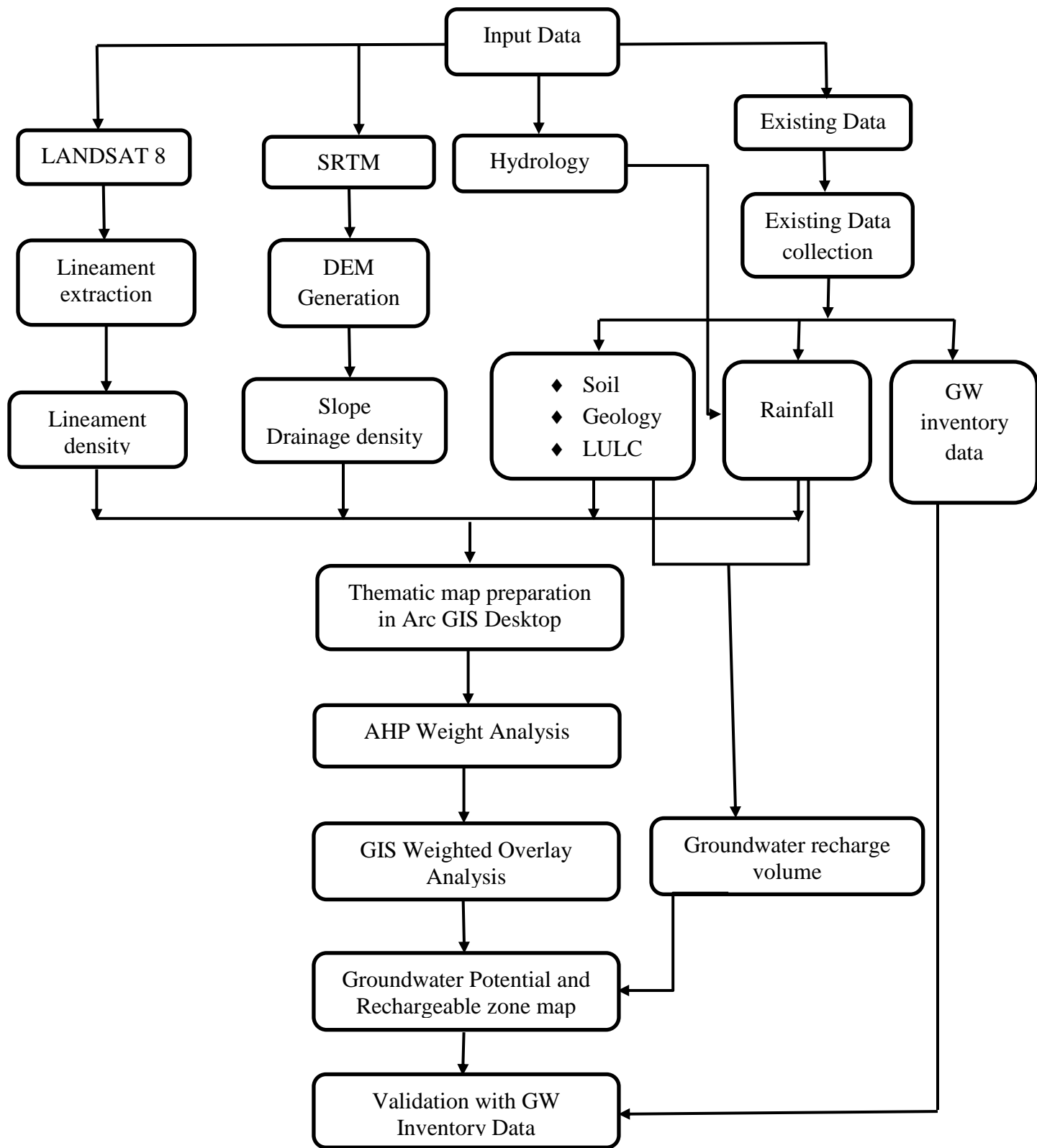


Figure 3-11 Flow Chart

## 4 RESULTS AND DISCUSSIONS

### 4.1 Recharge zone

When groundwater is recharged, water from the unsaturated zone enters the saturated zone below the water table's surface and flows away from the water table as a result (Yeh *et al.*, 2009). Because recharge is the result of numerous characteristics and is extremely variable depending on local variables, it is challenging to directly quantify groundwater recharge. Consequently, it should employ a different indirect technique. Recharge can be measured in millimeters per year on average or as a proportion of the yearly rainfall. The detailed mentioned above at 3.6, by multiplying the recharge rate by the area of the watershed under consideration, one can calculate the amount of recharge, represented as cubic meters per year. Considering the total area of the catchment as 523.1 km<sup>2</sup>, the annual groundwater recharge of the Burje watershed is estimated to be 10.06 MCM.

The result of present work on the groundwater potential zone mapping was done by the analysis of different thematic layers (rainfall, geology, LULC, drainage density, lineament density, soil, and slope) and the parameter values are given based on the Saaty's 1980 scale. The influence percentage of thematic layers and the rank for its parameters was assigned based on the judgment of works carried out by researchers or knowledge of expert gained through similar work on groundwater potential zone mapping (Tadesse 2018). Because of the increased demand for water, assessments of prospective groundwater zones have been more common in recent years. Groundwater occurrence indicators are linked to the area's land use, geology, slope, and drainage features. Different themed maps were created to demarcate the groundwater potential zones. Lithology and geology, soil type, drainage density, lineament density, land use, land cover, and slope are examples of these. Groundwater potential zones can be delineated using an integrated assessment of thematic maps utilizing a weighted overlay method created using GIS software.

### 4.2 Groundwater potential zoning map

Thematic map generation and integration through GIS and remote sensing techniques were used to evaluate the data and findings of this study, which involved the delineation of groundwater potential zones. Thematic maps with a spatial resolution of 30m x 30m pixels were created. The map was developed using a GIS tool and seven input parameters that indicate groundwater potential zone delineation. Groundwater potential zones were identified and classified as high potential, moderate potential and low potential zones based on the integration of all thematic maps. Rainfall, geology, land use/land cover, drainage density, slope, soil, and lineal density are the key elements that

influence groundwater resource development. The following are the thematic maps for each parameter: -

#### 4.2.1 Rainfall

Rainfall has a major role in groundwater recharge because it is the primary source of groundwater recharge (Allafta, Opp and Patra, 2021). The annual average rainfall of the study area calculated from Ethiopia National Meteorological Agency on three rain gauge stations namely Pawe, Jawi and Manbuk stations. A rainfall measurement is a one-time event that may or may not be representative of the area under investigation. As a result, in order to obtain more reliable and representative data, it is necessary to obtain an effective and consistent depth of rainfall across the study area (Hussein, Govindu and Nigusse, 2017). Rainfall is never evenly distributed throughout the basin or catchment; instead, it varies regionally in terms of both intensity and duration. As a result, each rain gauge station's rainfall data should be weighted based on the area it serves. Another method to determine the areal depth of precipitation for the catchment under consideration from a number of point rainfall data sets is the Thiessen polygon. On a base map, locate all rainfall stations that are accessible, together with their locations and amounts within and around the catchment. Next, determine the region of effect for each station. These 3 stations are located in a scale-drawn catchment region. These stations are connected to create a triangle network. The triangles have perpendicular bisectors painted on each of their sides. A polygon is created by these bisectors around each station. Catchment boundaries are used as the polygon's outer limits if they cut across the bisectors. Thiessen polygon are the defining polygon. Thiessen interpolation methods were used to estimate the areal depth of rainfall in the catchment using data from three metrological stations. By determining a weighted factor for each gauge, the Thiessen interpolation approach allows for non-uniform rain gauge distribution. The mean annual rainfall of the catchment was found 1095.33, 1250.8 and 1192.21 mm, respectively.

Table 4-1 Three Rain Gauge Station Mean Annual Precipitation

No	Station	Mean Annual Precipitation	Years
1	Manbuk Station	1095.33	1996-2017
2	Pawe Station	1250.80	1996-2017
3	Jawi Station	1192.21	1996-2017

The rainfall factor was calculated according to the equation given by Hurni (1985) which is derived from a spatial regression analysis (Hellden, 1987) for Ethiopian conditions. It was based on the available mean annual rainfall data

$$R = (0.55 * MAP) - 24.7 \dots\dots\dots \text{Eq. 4.1}$$

Where MAP is the mean annual Precipitation in mm

Rainfall data from three rain gauge stations around the study area was obtained from the National Meteorological Agency over a period of 22 years (1996–2017). Using the Thiessen’s Polygon method in Arc GIS 10.4.1, a rainfall map was created from the Mean Annual Precipitation of the three stations. The R-value was calculated using the raster calculator tool of ArcGIS and the above formula suggested by Hurni (1985) from a rainfall map with a cell size of 30m x 30m. The prepared rainfall map is classified into three categories based on their relationship to potential groundwater zones. These are (1092.21 – 1250.8 mm) High groundwater potential zone, (1095.34 – 1192.2 mm) Moderate groundwater potential zone, (801.45 – 1095.33 mm) Low groundwater potential zone.

#### 4.2.2 Geology

Groundwater availability is mostly determined by geology. Groundwater is held in pore spaces and rock fissures (Gaye and Tindimugaya, 2019). Geology plays a significant role in determining the quality and amount of groundwater in a given area. It is reflected by the distribution of several rock units that characterize the study area (Kumar and Krishna, 2018). The study area's geological setting can be divided into four categories: alluvium, Ashangi basalts, Termaber basalts, and undifferentiated lower complex. These four geological settings have an impact on the potential zones for groundwater occurrence.

Undifferentiated Lower Complex, Termaber basalts, Ashangi basalts and Alluvium are the four types of geological units that cover the area (Figure 4-1). Most of the study area is covered with Undifferentiated Lower Complex (245.345 km<sup>2</sup>; 47.14 %), Ashangi basalts (189.425 km<sup>2</sup>; 36.33 %), Termaber basalt (53.595 km<sup>2</sup>; 10.09 %), and Alluvium (34.735 km<sup>2</sup>; 6.45 %).

Table 4-2 Geology and its aquifer characteristics.

Factor	Classes	Groundwater Prospect	Rank in Number	Influence weight (%)
	Undifferentiated lower Complex	Moderate	3	
Geology	Termaber basalt	Low	4	28

Ashangi basalts	Low	4
Alluvium	High	2

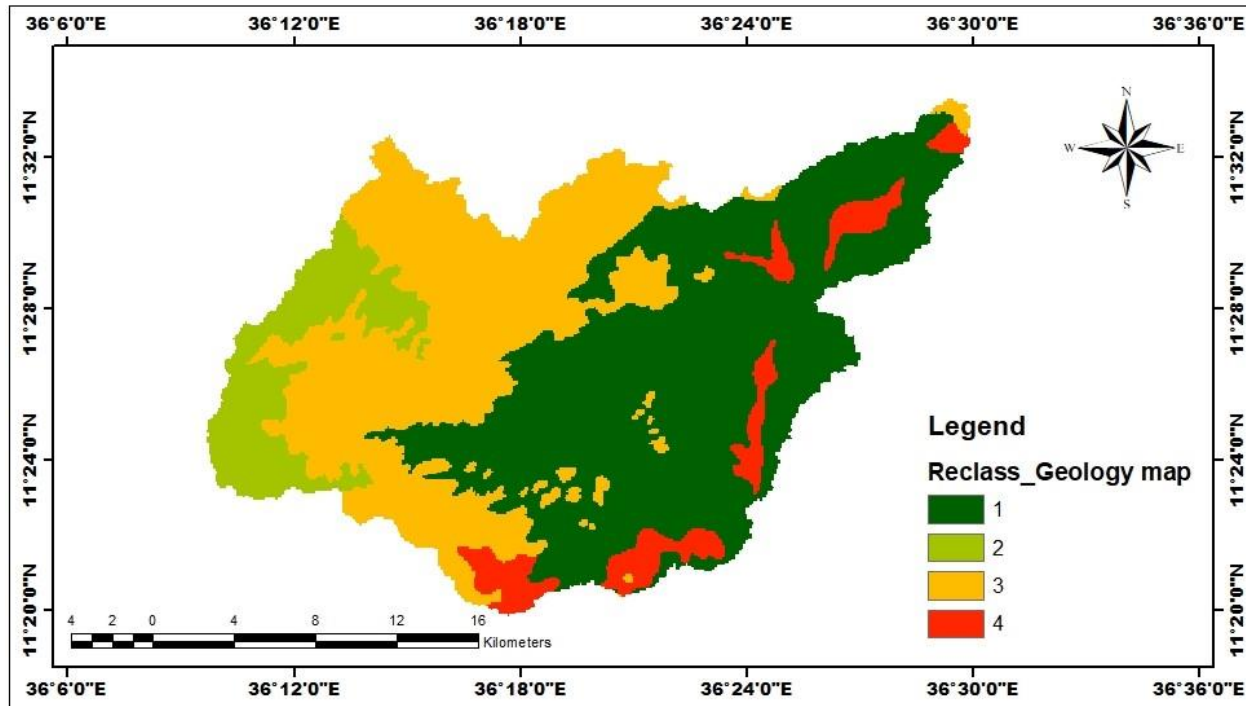


Figure 4-1 Reclassified Geology Map

#### 4.2.3 Land Use/cover

Changes in land use and land cover are one of the most common human-caused factors affecting the occurrence and development of groundwater resources (Patra, Mishra and Mahapatra, 2018). Land use/cover was classified for analysis based on its ability to infiltrate water into the ground and keep water on the ground. The study area has a variety of land use and land cover classes that are used to define the groundwater potential zone.

The various classes in the study area are: Bushland (252.21Km<sup>2</sup>; 48.53%), Dominantly cultivated (44.52Km<sup>2</sup>; 8.42%), Moderately cultivated (4.8Km<sup>2</sup>;0.747%), Grassland (29.17Km<sup>2</sup>;5.458%), Woodland dense (56.93 Km<sup>2</sup>; 10.822%), and Woodland open (135.476Km<sup>2</sup>;25.99%) area as shown in (Figure 4 - 2) below in the study area.

Table 4-3 LULC value and its rank as per suitable for ground water potential

Factor	Classes	Groundwater Prospect	Rank in number	Influence weight (%)
Land use/cover	Bushland	Moderate	3	9
	Dominantly cultivated	Low	4	
	Moderately cultivated	Low	4	
	Grassland	Moderate	3	
	Woodland dense	Moderate	3	
	Woodland open	Moderate	3	

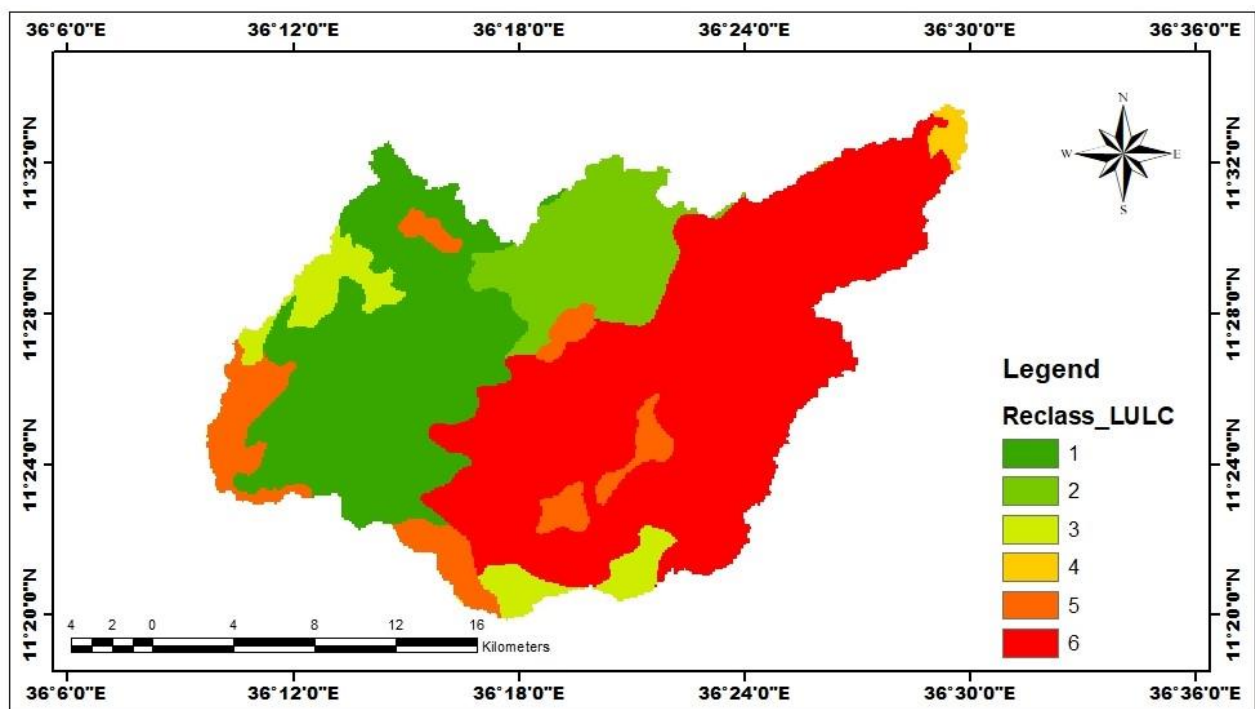


Figure 4-2 Reclassified LULC Map of the study area

#### 4.2.4 Drainage Density

The natural drainage of water runoff to the lowland surface is known as a drainage basin. The information on rock and soil permeability, water penetration, and surface runoff is directly related to drainage density and type (Tadesse 2018). One of the important factors in the delineation of groundwater potential zones is drainage (Tamiru Tolcha 2019). Drainage density is inversely proportional to permeability, which affects runoff and infiltration (Saranya and Saravanan 2020). The formation of surface and subsurface characteristics is referred to as a drainage

pattern. If the drainage density is higher, the runoff will be higher as well. As a result, there will be less water infiltration in that area. Infiltration will be greater if drainage density is low. As a result, there could be a groundwater potential zone (Reddy and Lakshmi, 2018). The density of surface and subsurface drainage in a given area is a key indicator for determining the hydrologic features that depict the characteristics of surface and subsurface formations. Drainage density is defined as the closeness of stream spacing, which is measured as the total length of all stream orders' drainage segments per unit area (Ponnusamy, 2020).

The stream order values were regrouped to produce a drainage density map that was reclassified into three categories which are 0 – 8.0671 km/km<sup>2</sup> (High), 8.0672 – 16.2956 km/km<sup>2</sup> (moderate) and 16.2957 – 41.1422 km/km<sup>2</sup> (low). That means the area under 0 – 8.0671 km/km<sup>2</sup> is high groundwater potential, the area 8.0672 – 16.2956 km/km<sup>2</sup> the groundwater potential is moderate, the area 16.2957 – 41.1422 km/km<sup>2</sup> the groundwater potential is low.

Table 4-4 Drainage density value and its rank as per suitable for ground water potential

Factor	Classes	Groundwater Prospect	Rank	Influence of weight (%)
Drainage density	0 – 8.0671	High	2	15
	8.0672-16.2956	Moderate	3	
	16.2957 – 41.1422	Low	4	

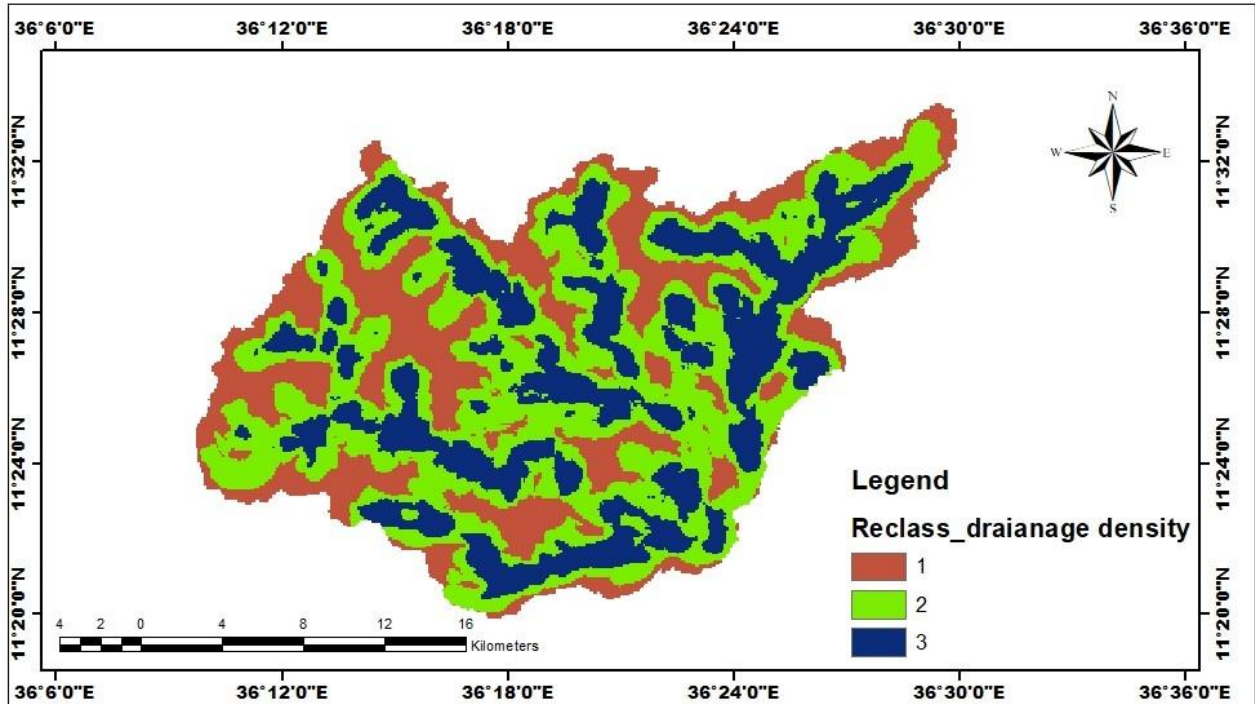


Figure 4-3 Reclassified Drainage density Map

#### 4.2.5 Lineament Density

As the lineament density increases, so does the groundwater potential (Yifru *et al.*, 2020). The lineament map was generated using ArcGIS 10.4.1 and a DEM with a resolution of 30m x 30m. A number of crisscrossed lineaments can be identified in the study area. Groundwater potential zones are estimated to result frequently at the intersection of lineaments. Hydro-geologically, joints, crisscross fractures, and faults are hydro-geologically significant and may provide groundwater movement pathways. Using line density methods, the density of the lineament is obtained from the lineament map. A lineament density map was created based on the concentration and length of lineaments. A lineal density map ( $\text{Km/Km}^2$ ) is a measure of the quantitative length of a linear feature.

Lineament density of an area has direct influence on groundwater prospective ness of that area. In present study area lineament density is observed with a value ranging from 1.55 - 2.31  $\text{km/km}^2$  having high groundwater potential, 0.78 – 1.54  $\text{km/km}^2$  have moderate groundwater potential, and from 0 – 0.77 have low groundwater potential. The entire map classified in three categories.

Table 4-5 Lineament density value and its rank as per suitable for ground water potential

Factor	Classes	Groundwater Prospect	Rank in number	Influence weight (%)
Lineament density	0 – 0.77	Low	4	4
	0.78 – 1.54	Moderate	3	
	1.55 – 2.31	High	2	

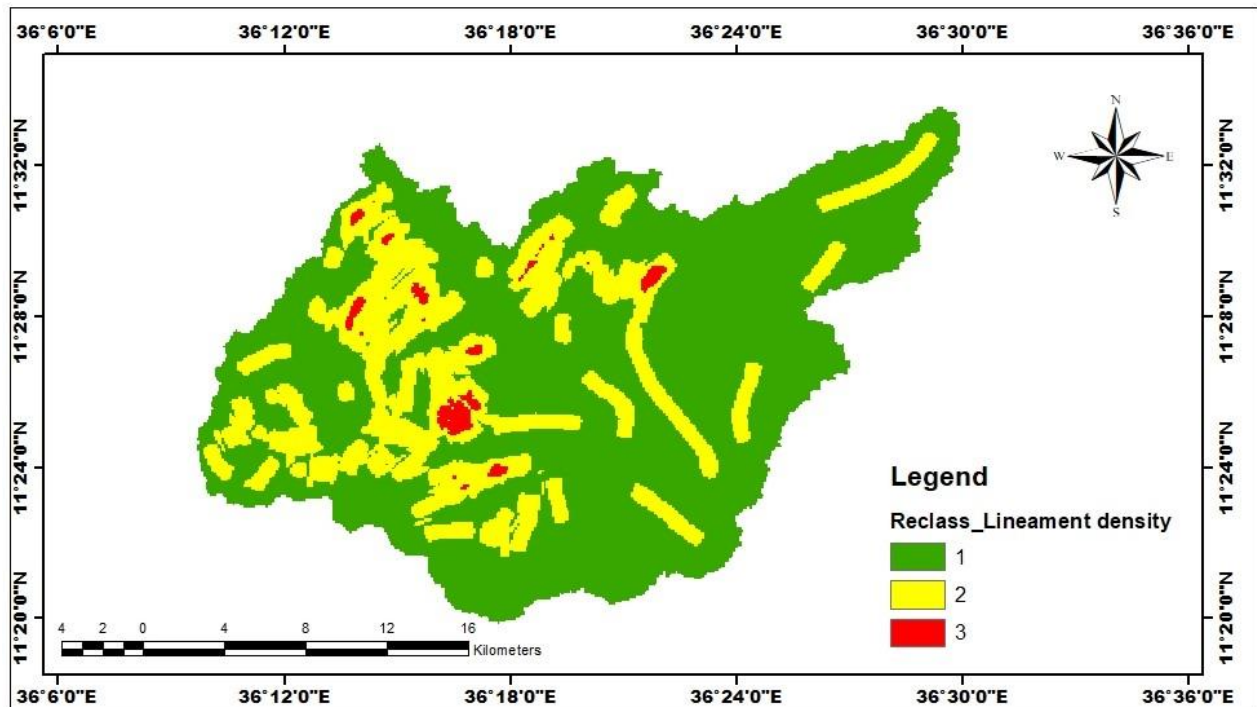


Figure 4-4 Reclassified Lineament Density Map

#### 4.2.6 Soil

The infiltration and recharge potential are determined by various soil characteristics such as porosity, texture, and coefficient of permeability (Paul *et al.*, 2020). Groundwater recharge zones are areas where water can infiltrate and percolate through the soil due to the ground surface (Hindeya Gebru, Tesfamichael Gebreyohannes, 2020). The movement and infiltration of ground water are greatly influenced by soils (Tamiru Tolcha, 2019). A soil map is a spatial representation of these resources. It is the world's natural resource. When delineating groundwater potential zones, a soil map is a crucial starting point.

The study area is mostly covered by Eutric Fluvisols, Eutric Cambisols, Eutric leptosols, Haplic Nitisols, and Rhodic Nitisols, according to the soil type analysis. The study area has a variety of soil types that are used to define the groundwater potential zone. The various classes in the study area are: Eutric Cambisols (29.684Km<sup>2</sup>; 5.52%) Eutric Fluvisols (256.794 Km<sup>2</sup>; 49.38%), Eutric Leptosols (82.234 Km<sup>2</sup>;15.67%), Haplic Nitisols (1.894Km<sup>2</sup>;0.15%), Rhodic Nitisols (152.494 Km<sup>2</sup>; 29.24%) Area as shown in (Figure 4- 5) below in the study area.

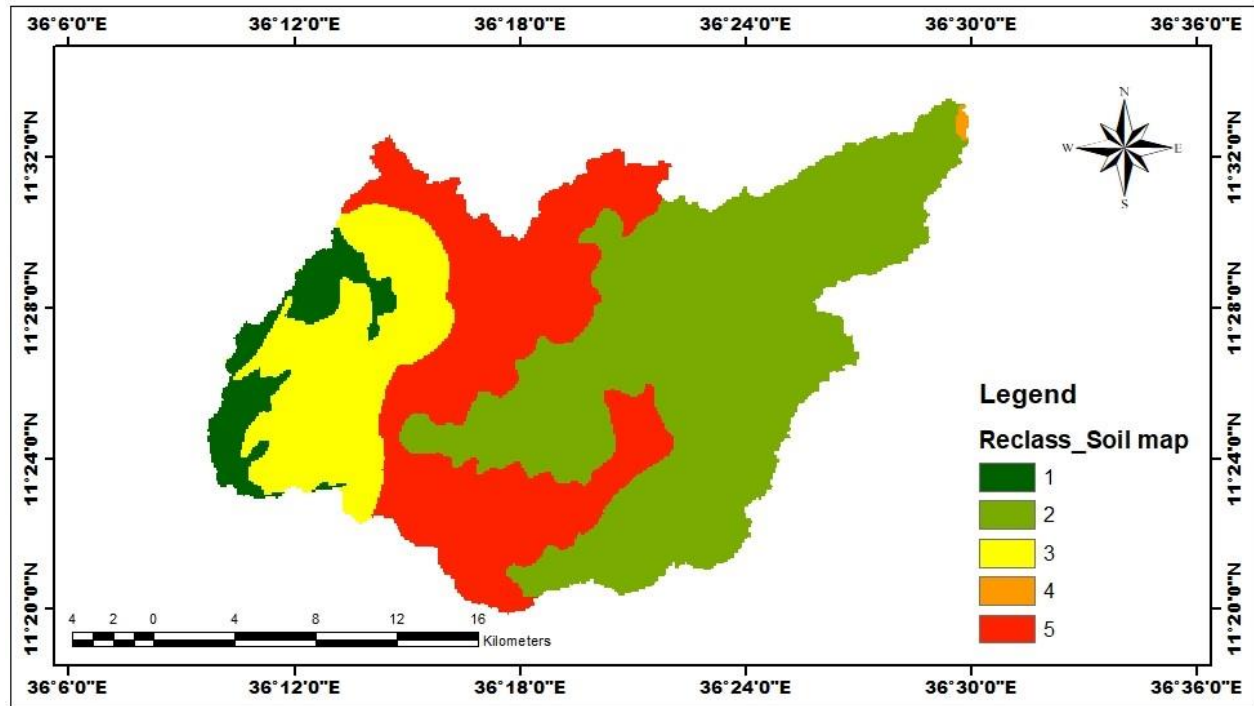


Figure 4-5 Reclassified Soil Map of the study area

Table 4-6 Soil value and its rank as per suitable for ground water potential

Factor	Classes	Groundwater Prospect	Rank	Influence weight (%)
Soil type	Eutric Cambisols	High	2	12
	Eutric Fluvisols	Moderate	3	
	Eutric Leptosols	Low	4	
	Haplic Nitisols	Moderate	3	
	Rhodic Nitisols	Moderate	3	

#### 4.2.7 Slope

The topography of an area shows the patterns of geographical characteristics. Slope is one factor that influences the delineation of ground water potential zones in this study. Because slope determines the quantity of runoff on the site, it is an important factor in delineation.

The slope of the study area was computed using DEM and Arc-GIS technology in this study. The identified slope category varies from (0 – 82.17%) in the study area and area classified into four classes like (0 – 4.54%) gentle, (4.55 – 10.66 %) moderate, (10.67-22.5 %) high, (22.6 - 82.17 %) steep. Because of the high slope, higher runoff, little infiltration, and low rainfall recharge zones, areas with a high slope are considered to have low groundwater potential. moderate sloping areas are considered as moderate groundwater potential zones, gentle slope areas are considered high groundwater potential zones. The details are shown in figure 4-6 below.

Table 4-7 Slope value and its rank as per suitable for ground water potential

Factor	Classes	Classifications	Groundwater Prospect	Rank	Influence weight (%)
Slope	0-4.54	Gentle	High	2	27
	4.55-10.66	Moderate	Moderate	3	
	10.67-22.5	High	Low	4	
	22.6 – 82.17	Steep	Very low	5	

Source (Daliya *et al.*, 2020).

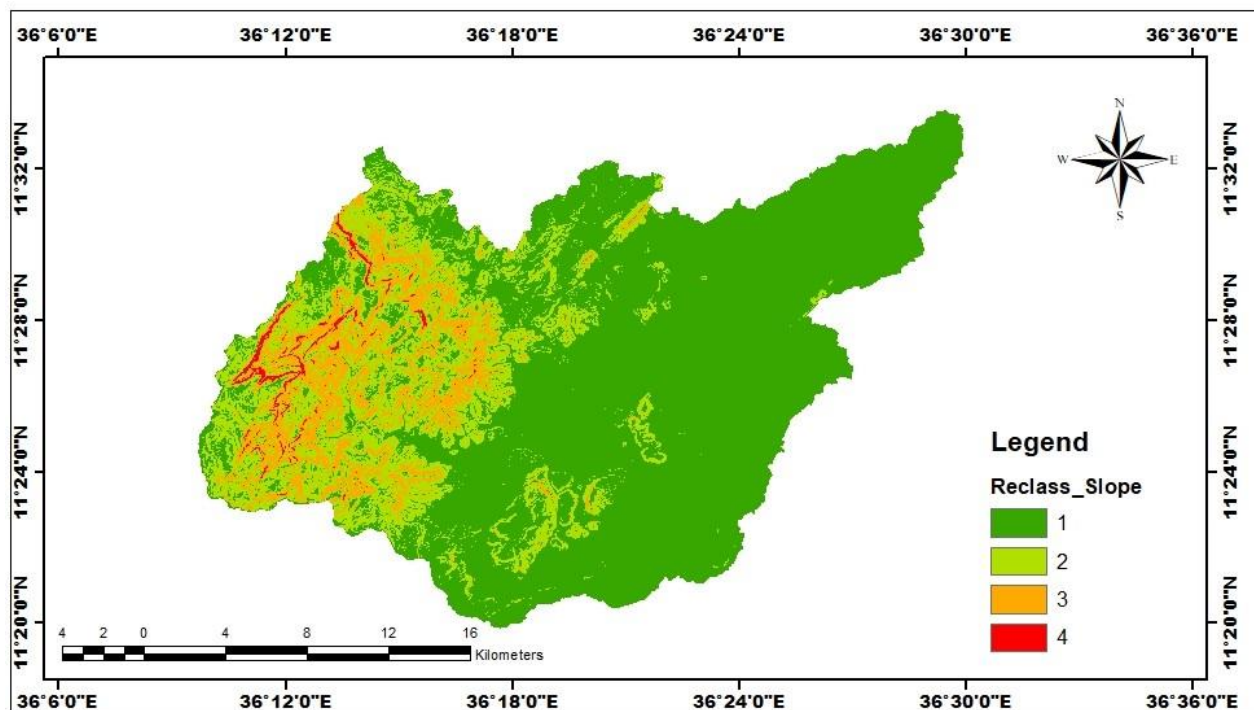


Figure 4-6 Reclassified slope map of the study area

#### 4.2.8 Data Integration Analysis in GIS Environment

The present study used important characteristics to identify different groundwater potential zones, and maps for each layer were prepared. These maps were transformed to raster data sets with the same pixel size, and different weightages were assigned based on their groundwater potential control capability within the study area, and each map was reclassified using the weight values.

All of the weighted thematic maps were combined, and criteria weights were defined using an AHP excel sheet and overlay analysis using Arc GIS 10.4.1 software, resulting in the identification of possible groundwater prospect zones (Figure 4-7). The final ranking and weighting for each theme are shown in (Table 4-8).

Table 4-8 Final ranking or scale value and Final weightage value for each class

Factors	Class	Ground water prospects	Rank in number	Influence weight (%)
Rainfall	1192.45 – 1250.8	High	2	5%
	1095.34 – 1192.2	Moderate	3	
	801.45 – 1095.33	Low	4	

Drainage Density	0 – 8.0671	High	2	15%
	8.0672-16.2956	Moderate	3	
	16.2957 – 41.1422	Low	4	
Slope	0-4.54 (Gentle)	High	2	27%
	4.55-10.66 (Moderate)	Moderate	3	
	10.67-22.5 (High)	Low	4	
	22.6 – 82.17 (Steep)	Very low	5	
Soil	Eutric Cambisols	High	2	12%
	Eutric Fluvisols	Moderate	3	
	Eutric Leptosols	Low	4	
	Haplic Nitisols	Moderate	3	
	Rhodic Nitisols	Moderate	3	
Geology	Undifferentiated lower Complex	Moderate	3	28 %
	Termaber basalt	Low	4	
	Ashangi basalts	Low	4	
	Alluvium	High	2	
Land use/ cover	Bushland	Moderate	3	9%
	Dominantly cultivated	Low	4	
	Moderately cultivated	Low	4	
	Grassland	Moderate	3	
	Woodland dense	Moderate	3	
	Woodland open	Moderate	3	
Lineament Density	0 – 0.77	Low	4	4%
	0.78 – 1.54	Moderate	3	
	1.55 – 2.31	High	2	

The groundwater potential zone model was created in this study using a weighted overlay analysis of seven thematic layers in Arc GIS. All of the thematic maps were converted to raster format and then superimposed using the weighted overlay method, which consists of rank and weightage-based thematic maps and GIS integration. These factors have different effects on groundwater potential

zonation. Each factor was given a weight based on its impact on groundwater movement and storage (Tolche, 2021).

#### 4.2.9 Criteria Weights and Map Scores

The study uses pair-wise comparison using Satty's importance scale to determine the relative relevance or weights of each thematic map. Consistency ratios are the consistency properties of these matrices (CR). According to Satty, the matrices having CR values larger than 0.1 should be re-evaluated. This method helps in analyzing the matrix and identifying inconsistencies in the definition of interrelationships. The consistency value in this case was 0.05, which is acceptable (Table 4-3). To reduce computation time, the weights were normalized by multiplying by 100. These weights were used in a linear summation equation to create a single weight map with the correct weights for all input variables, which was then classed to create a groundwater potential map. The importance matrices and their weights are mentioned as shown in (Table 3-9). The following equation was used for the generation of the groundwater potential zone map

$$\text{GPZM} = 5 * \text{Rainfall map} + 28 * \text{Geology map} + 9 * \text{LULC} + 12 * \text{Soil map} + 15 * \text{Drainage density map} + 4 * \text{Lineament density map} + 27 * \text{Slope map} \dots \text{Eq. 4.2}$$

Groundwater prospect zones were delineated from the composite layer by grouping the polygons into three different prospect potential zones: very high, high, and moderate.

#### 4.2.10 Groundwater Potential Zone

Groundwater potential zones were delineated/identified for the study area by grouping the interpreted layers through Weighted Overlay Analysis and then assigning different potential zones. Each of the seven primary theme layers (Geology, Land use, Land cover, drainage density, lineament density, soil, slope, and rainfall) is prepared based on the groundwater potentiality. Groundwater potential zones were identified and classified as high potential, moderate potential, and low potential zones based on the integration of all thematic maps. From this study Groundwater potential zones were categorized into three zones viz., Low (32.7%), Moderate (29.8%) and High (37.5%). The best suitable areas were found in the North and some parts of the North-East. The study suggested that the GWPZM generated will serve as useful guidelines for planners, engineers and decision makers providing quick decision- making in the management of groundwater resources, site selection for GW exploration and exploitation. In the study generally, the reason for High groundwater potential is area which has low drainage density, low slope, and very high

lineament density. The reason for Low ground water potential zone is area which has very high drainage density, very high slope, low lineament density.

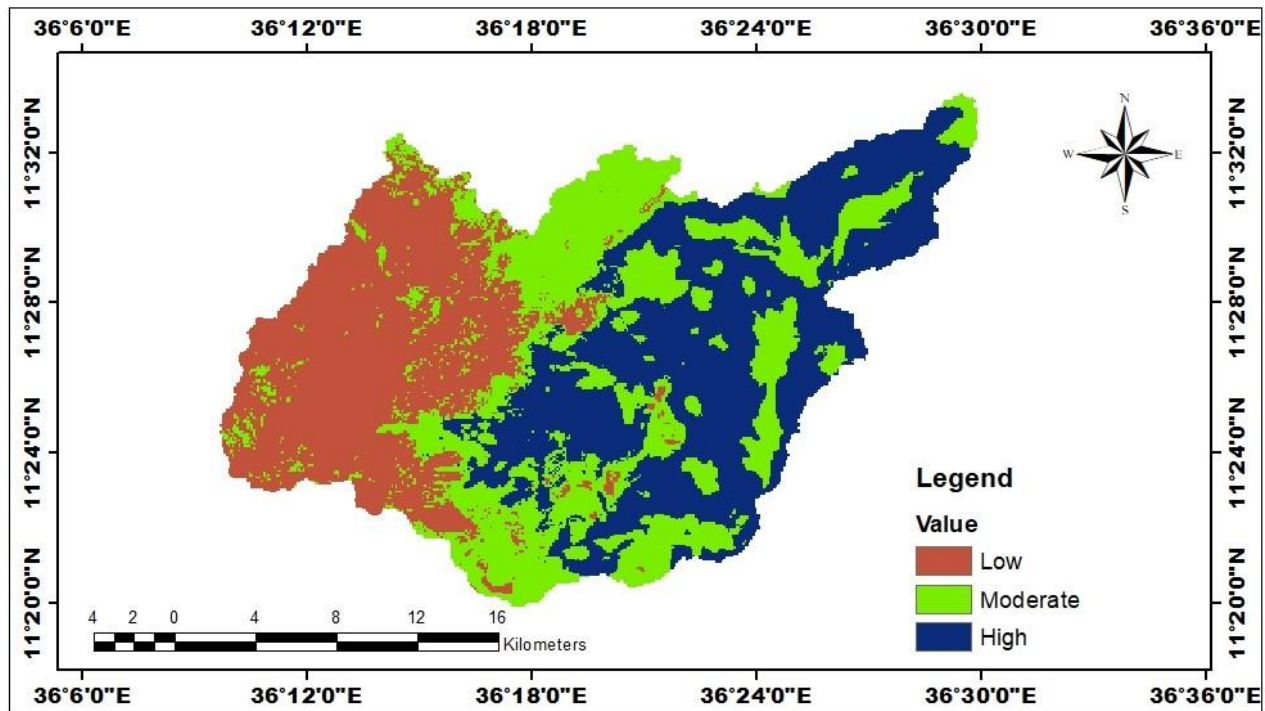


Figure 4-7 Groundwater potential zones

Table 4-9 Area in % and in KM<sup>2</sup> of groundwater potential zones map

S.no	Groundwater Potential zones	Area in (KM <sup>2</sup> )	Area in (%)
1	High	196.11	37
2	Moderate	155.94	30
3	Low	171.05	33
Total		523.1	100

According to the above table the area North -East and East of the catchment is classified as high potential zone or rechargeable zone. The area is covered by woodland dense that hold more trees cover that allows the infiltration of water to the earth surface. The area covers 196.11 km<sup>2</sup> of the catchment highly permeable water bearing bore holes, numerous springs are found in this part of the area. Burje river catchment receives quite significant amount of recharge. The area in North-west and west part lies on moderate groundwater potential zone. The source of the recharge is

limited in time and amount. The area covers 155.94 km<sup>2</sup>. The area is covered by woodland dense, woodland open, and grassland. And finally, the area of low groundwater potential zone lies on the south part of the catchment. The low groundwater potential zone covered by grassland, bushland and dominantly cultivated land. The area covers 171.05 km<sup>2</sup>.

### 4.3 Results Validation

A total of 27 groundwater sources of data from boreholes and hand dug wells were collected for validation purposes in the study area. The data to create a shape file for boreholes was obtained in a Microsoft Excel file and imported into ArcMap 10.4.1. As a result, the model-generated output map of the groundwater potential zone is further validated with data related to yield potentialities of different boreholes, hand-dug wells, and springs in the area; the pictorial representation of the yield data location points is overlaid upon the final groundwater potential zonation map; and a map prepared from actual well yield data for validation was categorized into three potential areas according to expert opinion for reclassification. Then, out of 27 wells with data, 7 are classified as high and 11 as moderate groundwater potential zones, while 9 are classified as low potential zones. Although there isn't a universal grading system, the site-specific characteristics allow for various classification schemes to be applied to the borehole yields. With some modifications from earlier investigations, the classification scheme of 0-1 l/s low, 1-1.66 l/s moderate, and > 1.66 l/s high was used in this study. Using this classification, it was determined that four of the seven boreholes with yield data (> 1.66 l/s) that were higher yielding were located in the zone with the highest groundwater potential (GwPZ). Out of 11 boreholes yields data (1-1.66l/s), 7 boreholes (63.63 %) of them were fallen on the moderate GwPZ whereas out of the 9 borehole yield data (0-1l/s), 7 boreholes and springs data, 77.77 % was fallen on the GwPZ classified as low.

Table 4-10 Agreement between the groundwater points and the GwPZ

Classes of GwPZ	Yield(l/s)	No wells/ springs	No of wells/ springs fall under GwPZ	Agreement (%)
Low	0-1	9	7	77.77
Moderate	1-1.66	11	7	63.63
High	>1.66	7	4	57.14

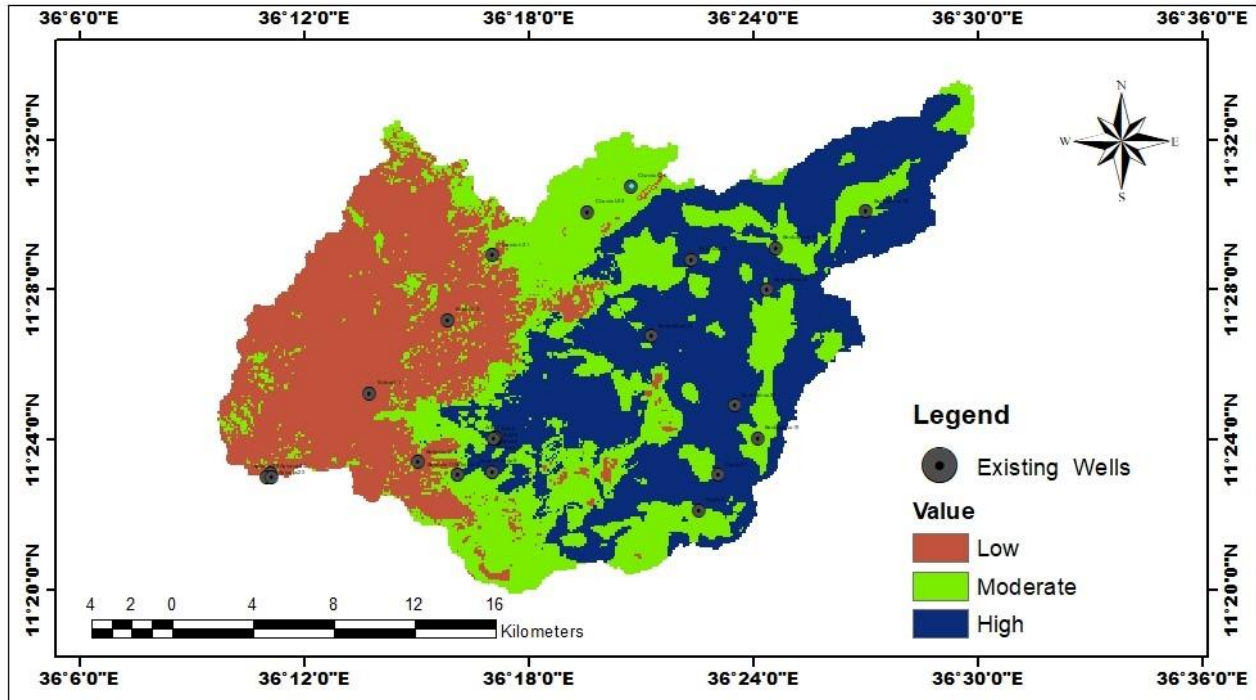


Figure 4-8 Groundwater potential zone map validation using borehole data

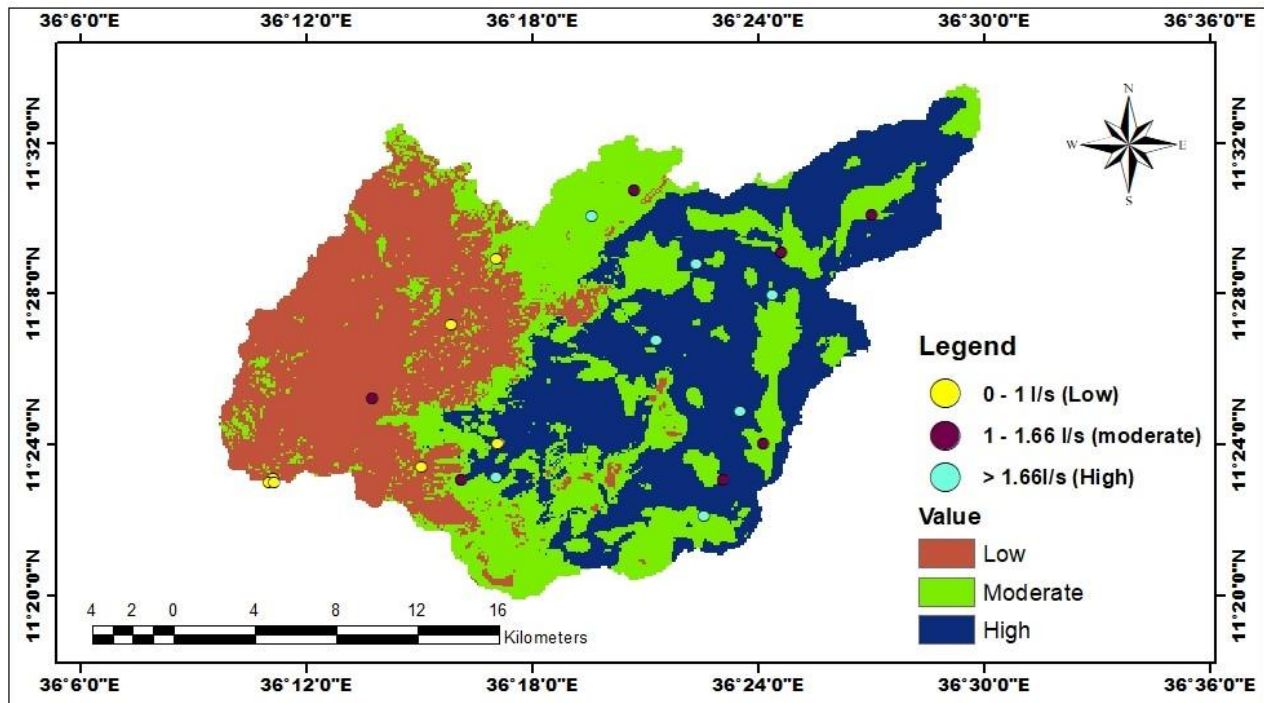


Figure 4-9 Groundwater potential zones with the corresponding existing groundwater yield classes

As shown this figure about two of the four high-potential wells are fitted to or superimposed on the value of the high-potential zone in the model, while the other two wells are matched to the moderate zone. Approximately 7 wells are fitted with the model low zone results from 9 low potential wells, and 2 low potential yield points are in the moderate zone. The model moderate zone findings are fitted to 7 of the 11 moderate potential wells, while the yield points of 3 moderate wells are in the low potential zone and 1 in high potential zone.

Table 4-11 Comparison of Derived GWPZ with actual wells yield.

No	Groundwater Prospect zones / Actual yield	High	Moderate	Low
1	Number of wells modeled PGWZ using a model.	7	11	9
2	Number of bore wells under agreement	4	7	7
3	Number of bore wells show excess yield	0	1	2
4	Number of bore wells show less yield	3	3	0

Table 4-12 Model validation using groundwater borehole wells

S.No	Name	Well Type	Easting	Northing	Well depth in meter	Well Yield		Class	GW potential model result
						Lit/sec	m3/h		
1	N.dawit	Spring	36.2292	11.4207		1.3	4.68	Moderate	High
2	N.dawit	Spring	36.2642	11.4532		0.4	1.44	Low	Moderate
3	Arbit	SW	36.2856	11.4008	38.5	1.7	6.12	High	High
4	Arbit	SW	36.2856	11.4009	42	1.6	5.76	Moderate	Low
5	Arbit	SW	36.2854	11.4006	35.6	0.95	3.42	low	Low
6	Arbit	SW	36.2851	11.401	48	1.71	6.156	Moderate	High
7	Arbit	SW	36.2845	11.4004	41.5	1	3.6	Low	Low
8	Burje	SW	36.2843	11.3859	44	1.4	5.04	Moderate	Moderate
9	Burje	SW	36.2843	11.3859	46	1.6	5.76	Moderate	Moderate
10	Bakusta	HDW	36.2688	11.3844	12	0.95	3.42	Low	Moderate
11	Bakusta	SW	36.2512	11.3901	45	1	3.6	Low	Low
12	Bakusta	SW	36.2688	11.3844	43	1.32	4.752	Moderate	Moderate
13	Banbajihua	SW	36.3548	11.446	41	1.81	6.516	High	Moderate
14	Ankasha	SW	36.3729	11.48	46	1.66	5.976	High	High
15	Banbajihua	SW	36.4061	11.4665	49	1.7	6.12	High	Moderate
16	Banbajihua	SW	36.4101	11.4851	42	1.5	5.4	Moderate	Moderate
17	Banbajihua	SW	36.4506	11.5014	45	1.48	5.328	Moderate	Moderate
18	Banbajihua	HDW	36.4021	11.4007	13.5	0.8	2.88	Low	Low
19	Banbajihua	SW	36.3922	11.4151	47.5	1.75	6.3	High	Moderate
20	Chamich	SW	36.2841	11.4822	40	1.4	5.04	Moderate	Moderate

21	Dupla	HDW	36.376	11.3687	12	0.75	2.7	Low	Low
22	Dupla	SW	36.3847	11.3845	48	1.4	5.04	Moderate	Low
23	Ayipopu	SW	36.1851	11.3854	44	0.85	3.06	Low	Moderate
24	Ayipopu	SW	36.1834	11.3834	49	1	3.6	low	Low
25	Ayipopu	SW	36.186	11.3836	41	1.65	5.94	Moderate	Moderate
26	Chamich	SW	36.3265	11.5013	40	1.8	6.48	High	High
27	Chamich	SW	36.3455	11.5126	42	2	7.2	High	High

Recharge occurs when water infiltrates into the saturated zone from above the groundwater level. The water cycle is a crucial part of nature's circulation system. Topography, lithology, geological structures, depth of weathering, extent of fractures, primary porosity, secondary porosity, slope, drainage patterns, landform, land use/land cover, and climate are only a few of the variables that influence the occurrence and flow of groundwater in a region. The region north and north-east of the catchment is classified as a high potential zone or rechargeable zone based on the aforementioned groundwater potentials of zones. The high-potential zone of the defined area was referred to as the most rechargeable zone. The region is covered in dense woodland with more tree cover, which allows water to infiltrate the earth's surface. This region of the area, which spans 196.11 km<sup>2</sup>, contains many springs and very permeable water-bearing bore holes. The recharge's source has a time and resource constraint. The findings show that the catchment's north and north-east regions have the most efficient groundwater recharge zones.

## 5 CONCLUSION AND RECOMMENDATION

### 5.1 Conclusion

The objective set out was accomplished. In this work the utility of hydrological data to estimate groundwater resources potential in the study area in Burje river catchment has been demonstrated. The result of present work on the groundwater potential zone mapping was done by the analysis of different thematic layers (rainfall, geology, LULC, drainage density, lineament density, soil, and slope) and the parameter values are given based on the Saaty's scale. This was achieved through preparation of different thematic maps. In this research, seven parameters were selected which have more affects the occurrence of groundwater potential zone prior to overlay analysis. By assigning quantitative weights, it is possible to make important criteria that have a greater influence on the result than other criteria. The AHP, methods were adapted and give the value for each factor. This approach allows decision makers to give the judgments in order to reduce complexity in decision making processes. During weighed overlay analysis, the ranking has been given for each individual parameter of each thematic map and weights and obtained three groundwater potential zones in terms of high, moderate and low groundwater potential zones.

Therefore, in this study Ground water potential zone map have been produced using seven thematic maps from satellites images, exiting data and field data. Produced ground water potential zone map were compared and validated by existing well yield data obtained from different localities of the study area. The result showed fairly significant correlation or agreement with the discharge data.

The study concludes that most of the high potential areas represented by, low drainage density, very high lineament density, coincide with the low slope and very high rainfall areas. The study has resulted the groundwater potential zone map for the Burje river catchment which identified and delineated in three categories namely high, moderate and low potential zones.

The study confirms that paired comparison matrix analysis indicates that all parameters are significant but the most effective parameters in the area are: rainfall, geology and slope. Most of the area, around 196.11 km<sup>2</sup> (37.5%) zoned under high potential and the next high coverage of the area 171.05km<sup>2</sup> (32.7%) is low potential zone where as 155.94 km<sup>2</sup> (29.8%) is high potential zone. This study generally demonstrates that GIS and Remote sensing techniques in combination with field data could be used for the assessments of ground water potential zonation in the study area. It can be considered as a time and cost-effective tool for delineations and identification of high ground water potential target area.

## 5.2 Recommendations

Based on the results obtained from the study the following recommendations are forwarded;

- ❖ The delineated groundwater potential zone information will be useful for effective identification of suitable locations for extraction of water which used to for different purpose. Further, it can be said that the present methodology can be used as a guideline for further research.
- ❖ As compared to other areas where the geology structures are less complex, good model outputs in these places require professional experience and knowledge of the hydrogeological condition and environment, variability, and their functions as parameters for better field calibration. For the resource to be used effectively and sustainably, field observation and measurement should be taken into consideration.
- ❖ Future research should, take in to account a range of modifications to the current models, which should include more data collection, a different conceptual model design, and other elements. It is recommended that a detailed investigation into the data availability in the area be conducted because one of the shortcomings of the current study is its reliance on the scant data obtained on the basin.
- ❖ The study only considers three gauging stations, yet it covers a fairly vast area (523.1sq.km). It is advised to use more gauging stations to ensure the accuracy of metrological data in the basin. Because of the meteorological setting's focus on the upper catchment, there is also a problem with an unequal distribution of data, which has an impact on the model's accuracy.

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## APENDIX

### Appendix 1: Pawe Mean Annual Precipitation

Name	Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	SUM
Pawe Station	1996	0.2	0	42.5	57.1	98.8	206.9	270.5	332.7	272.2	150.2	12.3	0	1443.4
	1997	0	0	2.1	31.2	147.4	180.4	230.8	183.3	175.7	170	16.9	1.4	1139.2
	1998	0	0	9.8	9.6	153.6	511.3	284.8	166.6	243	146.7	5.6	0	1531
	1999	2.2	0	0	35.5	180.7	280.9	185.7	159.2	223.6	134.6	19.2	4.3	1225.9
	2000	0	0	2.1	61.2	188.7	264.8	100.9	165.3	176.7	223.8	25.7	2	1211.2
	2001	0	0.7	0	0	100.3	290.3	317.4	303.5	247.6	167.5	0	6.4	1433.7
	2002	0	0	0	1.3	0	344.8	183.3	155.8	190	139.7	39.5	0	1054.4
	2003	15.5	0	0	0	3	287.2	302.3	104.3	310.3	97.3	5.9	0	1125.8
	2004	0	0.6	0.1	83	45	264.4	329.2	255.3	293.2	69.7	15.1	4	1359.6
	2005	0	0	18.1	3	43.8	166	269.2	161.5	250.7	165.9	3.2	0	1081.4
	2006	9.2	11.2	0	18	152.7	226.6	301.9	360.5	263.4	192.3	6.2	0	1542
	2007	0	0	1.9	36.5	99.8	317.7	248.7	200.7	314.4	69.9	27.3	0	1316.9
	2008	2.2	1	0	55.1	141.5	280.3	389.5	212	232.2	42.6	13	0	1369.4
	2009	0	0	3.2	22.9	42.1	305.1	270.3	18.3	155.1	58.9	6.2	0	882.1
	2010	5.2	0	0	24.1	71	270.3	335.1	238.1	242.4	203.9	6.4	0	1396.5
	2011	0	0	7.5	4.7	181.6	132.3	137.2	162	247.6	80.5	0	0	953.4
	2012	0	0	0	0.2	77.4	216.2	322.5	397	286.4	140.5	27.3	4.6	1472.1
	2013	0	0	0	0	184.8	214.9	206.6	332.8	308.1	91.6	48.6	0	1387.4
	2014	0	0	26.3	74.5	192.3	234.7	179.3	103	284.7	226.4	0	0	1321.2
2015	0	0	0	0	190.6	155.1	76.1	47.8	232.1	94.6	50.1	0.8	847.2	
2016	0	0	40.6	0	240.1	189.5	137.6	62.4	163.8	109.2	5.8	0	949	
2017	0	1.5	0	60.9	258.9	165.4	242.6	243.5	311.7	165.3	25	0	1474.8	
Mean Annual Precipitation														1250.8

## Appendix 2: Mambuk Mean Annual Precipitation

Name	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC	SUM
Mambuk Station	1996	0.3	0	0.2	22.9	22.5	165.39	204	266.5	230.7	133.3	0	0	1045.79
	1997	0	0	0	13.7	154.7	207.2	190.7	184.6	169	149.42	11	0	1080.32
	1998	0	0	23	6.5	140.6	209.7	173.4	306.6	195.8	137.8	3	0	1196.4
	1999	2.9	0	0	27.2	153.4	236.5	239.4	202.8	269.67	146.14	15	4	1297.01
	2000	0	0.4	3.3	33.4	155.8	105.8	272.8	192.9	155.1	60.4	6.2	0	986.1
	2001	0	0	0	1	71.6	270.3	325.8	239.6	242.4	179.06	0	0	1329.76
	2002	0	0	0	1	0.1	226.6	101.8	240.2	163.4	123	8.1	0	864.2
	2003	22	0	0	0	1	201.2	295.5	175.1	287.2	55.9	5.3	0	1043.2
	2004	0	0.1	0	33.3	42.1	208.8	211.2	196.8	255.2	49.5	9.1	0	1006.1
	2005	0	0	12	0	28.7	184.01	156.9	203.5	220.2	88.6	4.4	0	898.31
	2006	5.4	5.5	0	21.2	166	280.33	260	224.5	212	115	2.7	0	1292.63
	2007	0	0	0	34.5	113	204	266	249.6	260.75	46.7	22	1	1197.55
	2008	3.6	0	0	34.4	157.3	229.6	145.4	199	184.5	84.3	8.6	0	1046.7
	2009	0	0.1	4	18.7	22	234.4	217.3	78.6	119	62.18	5.47	2	763.75
	2010	6.6	0	0	31.3	54.6	211.8	209.5	293.2	221.4	109.9	1	0	1139.3
	2011	0	0	5.8	3.9	103.3	156.3	74.7	254.7	260.93	112	0	0	971.63
	2012	0	0	0	0.5	88.4	249.5	188.6	361	239	105	17.29	0	1249.29
	2013	0	0	0	0	129.3	115.38	123	345	259.96	77.9	48.9	0	1099.44
	2014	0	0	35.3	14.8	92.7	412.9	33.3	256.7	266.56	150.08	11	0	1273.34
2015	0	0	0	0	200.1	287.2	102.2	184.3	295.8	97.3	21.32	0	1188.22	
2016	0	0	17.1	0	182	206.3	85.9	56.8	197.75	135.8	4	0	885.65	
2017	0	2	0	65.1	218	149.8	184.3	261	239	105	18.28	0	1242.48	
Mean Annual Precipitation														1095.33

### Appendix 3: Jawi Mean Annual Precipitation

Name	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC	SUM
Jawi Station	1996	0	0	7.6	13.1	104	269.8	95.1	254.5	108.6	13.6	15.5	0	881.8
	1997	0.68	0.2	0	16.18	141.18	239	325	224	30.3	130.18	29.87	0	1136.59
	1998	0.29	0	0	0	153.4	232.5	239	205	220.88	132.43	31.37	0	1214.87
	1999	0.71	0.25	31.8	0	129.3	117.04	291.83	460.7	342.35	68.1	31.27	0	1473.35
	2000	0	0	15.6	34.4	175.5	129.43	234.5	323.12	231.8	284.7	28.6	1	1458.65
	2001	0.73	0.21	9.04	34.2	213.1	260.7	171	159.6	27.7	225.8	11	1.1	1114.18
	2002	0	0	0	0	148.1	165.3	166.3	160.9	96.3	127.5	52.4	0	916.8
	2003	0	0	9.3	6.5	235.9	185.6	123.7	157.2	130.1	215.7	171.4	0	1235.4
	2004	0	1.2	0	38.4	146.3	174.3	270.4	178.8	120.2	64.7	0	2.1	996.4
	2005	0.63	0.21	0	8	63	211	217	287	323.5	112	7	0	1229.34
	2006	0.6	0.23	0	16.55	123.5	132.3	334.2	280	183.2	129.7	19.4	0	1219.68
	2007	0	0	13	28	77	408	318	250	112	115	21	0	1342
	2008	2	0	0	34	113	403	298.2	290	321	23	0	0	1484.2
	2009	0	0	10	12	0	249.1	242	282	186	133	6	0	1120.1
	2010	0	0	0	4	126.91	315.78	322.09	254	35	77	0	0	1134.78
	2011	0	0	0	3	198	247	266	450	176	83	3	0	1426
	2012	0.56	0.22	9.03	0	142.41	312.68	330.49	326.33	224.4	131.59	28.67	2.32	1508.7
	2013	0.72	0.24	9.57	16.29	113.57	208	324.04	368.5	96.1	82.2	28.88	0	1248.11
	2014	0	0	23	63	140.6	209.7	273.5	326.6	95.8	241	0	0	1373.2
2015	0	0	0	0	237.2	108.8	193.8	272.9	155.2	118.7	7	0.75	1094.35	
2016	0	0	12	0	16.19	315.95	226.3	88.6	32.2	127.83	7.6	0	826.67	
2017	0	0	0	0	12.5	62.8	113.67	321.18	121.8	130.82	30.75	0	793.52	
Mean Annual Precipitation														1192.21

#### Appendix 4: Pawe Runoff in mm

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1996	0.0	0.0	2.5	2.3	34.3	71.1	95.72	115.54	106.3	61.3	0.0	0.0
1997	0.0	0.0	0.0	0.9	26.6	62.2	85.40	83.16	85.2	38.9	0.0	0.0
1998	0.0	0.0	0.0	0.0	57.4	167.8	115.46	72.89	93.7	53.1	0.0	0.0
1999	0.0	0.0	0.0	0.0	49.5	108.2	50.89	74.81	51.5	54.3	0.0	0.0
2000	0.0	0.0	2.1	8.4	30.6	97.5	34.40	76.07	49.1	96.2	0.0	0.0
2001	0.0	0.0	0.0	0.0	19.3	126.0	85.70	136.23	86.1	34.0	0.0	0.0
2002	0.0	0.0	0.0	0.0	0.0	143.4	44.06	61.92	57.9	31.3	0.0	0.0
2003	0.0	0.0	0.0	0.0	0.0	98.3	135.71	47.03	124.3	30.3	0.0	0.0
2004	0.0	0.0	0.0	11.0	0.5	86.3	131.24	120.16	134.2	23.2	0.0	0.0
2005	0.0	0.0	0.0	0.0	0.8	36.3	123.08	73.27	111.2	70.3	0.0	0.0
2006	0.0	0.0	0.0	0.0	31.5	97.7	94.50	171.68	117.1	53.0	0.0	0.0
2007	0.0	0.0	0.0	0.0	12.1	122.9	84.23	75.93	116.1	14.5	0.0	0.0
2008	0.0	0.0	0.0	3.1	35.9	99.3	127.71	89.43	69.4	8.2	0.0	0.0
2009	0.0	0.0	0.0	0.0	0.4	90.4	121.54	5.68	38.4	12.8	0.0	0.0
2010	0.0	0.0	0.0	0.0	3.7	75.4	130.00	79.46	86.7	74.4	0.0	0.0
2011	0.0	0.0	0.0	0.0	28.4	27.2	50.38	61.09	81.6	33.4	0.0	0.0
2012	0.0	0.0	0.0	0.0	13.2	70.9	115.95	181.21	134.0	26.7	0.0	0.0
2013	0.0	0.0	0.0	0.0	32.0	53.0	89.96	159.25	82.4	25.6	12.0	0.0
2014	0.0	0.0	0.0	13.7	48.3	49.2	64.07	44.87	71.5	121.6	0.0	0.0
2015	0.0	0.0	0.0	0.0	38.3	56.3	17.72	16.49	102.7	19.1	6.5	0.0
2016	0.0	0.0	5.9	0.0	51.6	56.1	49.60	24.33	67.0	20.0	0.0	0.0
2017	0.0	0.0	0.0	4.2	83.5	40.6	75.04	103.27	147.4	54.6	0.0	0.0
Mean	0.0	0.0	0.5	2.0	27.2	83.5	133.3	173.3	91.5	43.5	0.8	0.0

**Appendix 5: Manbuk Runoff in mm**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
1996	0.00	0.00	0.00	0.00	0.00	55.53	65.98	95.03	91.29	38.16	0.00	0.00
1997	0.00	0.00	0.00	0.00	28.50	65.62	72.15	74.10	66.24	30.79	0.00	0.00
1998	0.00	0.00	0.00	0.00	40.47	59.72	72.74	140.23	72.73	44.99	0.00	0.00
1999	0.00	0.00	0.00	0.00	42.70	93.22	75.93	88.63	64.07	53.76	0.00	0.00
2000	0.00	0.00	0.00	0.00	25.56	26.20	117.06	81.02	35.15	9.14	0.00	0.00
2001	0.00	0.00	0.00	0.00	10.07	120.42	90.25	99.22	82.18	41.31	0.00	0.00
2002	0.00	0.00	0.00	0.00	0.00	85.66	19.15	96.45	51.48	23.68	0.00	0.00
2003	0.00	0.00	0.00	0.00	0.00	69.98	130.00	73.87	105.70	12.28	0.00	0.00
2004	0.00	0.00	0.00	0.00	0.40	79.12	81.21	91.86	100.20	9.48	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	39.31	65.92	94.01	83.58	21.96	0.00	0.00
2006	0.00	0.00	0.00	0.00	31.52	128.26	70.74	101.74	81.00	22.72	0.00	0.00
2007	0.00	0.00	0.00	0.00	12.81	88.03	87.36	85.57	85.30	5.26	0.00	0.00
2008	0.00	0.00	0.00	0.00	37.00	67.11	43.74	84.70	39.75	31.95	0.00	0.00
2009	0.00	0.00	0.00	0.00	0.00	70.95	103.72	20.94	16.65	14.23	0.00	2.00
2010	0.00	0.00	0.00	0.00	5.07	62.29	70.29	89.62	72.64	30.04	0.00	0.00
2011	0.00	0.00	0.00	0.00	7.98	41.15	29.25	98.49	126.59	47.43	0.00	0.00
2012	0.00	0.00	0.00	0.00	13.67	91.05	65.60	143.42	90.55	5.58	0.00	0.00
2013	0.00	0.00	0.00	0.00	13.73	20.33	47.29	138.88	72.10	15.25	12.16	0.00
2014	0.00	0.00	0.00	0.00	28.69	166.97	9.62	112.10	60.69	56.91	0.00	0.00
2015	0.00	0.00	0.00	0.00	39.21	140.50	48.10	67.71	108.14	22.51	0.00	0.00
2016	0.00	0.00	0.00	0.00	32.31	64.69	31.73	18.34	88.61	34.25	4.00	0.00
2017	0.00	0.00	0.00	2.73	32.83	44.63	65.74	88.03	58.05	28.40	0.00	0.00
Mean	0.00	0.00	0.00	0.12	18.30	76.40	66.53	90.18	75.12	27.28	0.73	0.09

### Appendix 6: Jawi Runoff in mm

YEAR	Jan	Feb	March	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
1996	0.00	0.00	0.00	0.00	6.20	104.92	41.77	94.36	101.99	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00	20.54	98.80	136.87	109.79	5.53	45.68	0.00	0.00
1998	0.00	0.00	0.00	0.00	55.08	184.57	131.72	77.77	79.77	23.67	0.00	0.00
1999	0.00	0.00	0.00	0.00	14.22	49.23	155.99	175.99	99.57	20.51	0.00	0.00
2000	0.00	0.00	0.00	0.00	41.16	51.76	83.69	134.30	92.78	73.90	0.00	0.00
2001	0.00	0.00	0.00	0.00	47.65	78.86	74.01	97.04	10.63	91.19	0.00	0.00
2002	0.00	0.00	0.00	0.00	43.29	61.77	40.10	74.65	45.67	48.81	4.36	0.00
2003	0.00	0.00	0.00	0.00	36.85	45.12	49.64	107.94	36.16	45.93	47.76	0.00
2004	0.00	0.00	0.00	0.00	23.45	62.15	91.79	88.83	46.55	19.11	0.00	0.00
2005	0.00	0.00	0.00	0.00	7.34	62.40	68.28	169.02	132.96	37.72	0.00	0.00
2006	0.00	0.00	0.00	0.00	22.65	184.61	112.98	97.96	98.09	51.69	0.00	0.00
2007	0.00	0.00	0.00	0.00	6.00	163.51	151.66	89.28	44.77	31.26	0.00	0.00
2008	0.00	0.00	0.00	0.00	23.67	189.34	155.43	127.72	146.65	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00	0.00	72.69	88.53	115.48	78.93	20.92	0.00	0.00
2010	0.00	0.00	0.00	0.00	35.83	128.96	122.47	102.35	13.04	23.60	0.00	0.00
2011	0.00	0.00	0.00	0.00	34.11	57.56	94.83	192.41	96.45	23.12	0.00	0.00
2012	0.00	0.00	0.00	0.00	25.90	120.29	137.91	126.63	75.06	49.57	0.00	0.00
2013	0.00	0.00	0.00	0.00	19.63	56.74	120.20	200.33	34.76	25.97	0.00	0.00
2014	0.00	0.00	0.00	0.00	41.99	70.99	76.66	126.85	27.91	119.59	0.00	0.00
2015	0.00	0.00	0.00	0.00	50.83	21.24	49.27	112.45	50.72	16.86	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00	85.50	85.76	23.06	0.00	40.45	0.00	0.00
2017	0.00	0.00	0.00	0.00	0.00	12.41	42.86	153.57	60.25	46.14	0.00	0.00
Mean	0.00	0.00	0.00	0.00	25.29	89.25	96.02	118.08	62.65	38.89	2.37	0.00

### Appendix 7: Analytical Hierarchy

		Criteria		more important ?	Scale
i	j	A	B	A or B	(1-9)
1	2	Rainfall	Drainage Density	B	5
1	3		Geology	B	7
1	4		Soil	B	1
1	5		Slope	B	5
1	6		LULC	B	3
1	7		Lineament Density	B	1
1	8				
2	3	Drainage Density	Geology	A	1
2	4		Soil	A	1
2	5		Slope	B	3
2	6		LULC	A	1
2	7		Lineament Density	A	3
2	8				
3	4	Geology	Soil	A	3
3	5		Slope	B	1
3	6		LULC	A	5
3	7		Lineament Density	A	7
3	8				
4	5	Soil	Slope	B	3
4	6		LULC	A	3
4	7		Lineament Density	A	3
4	8				
5	6	Slope	LULC	A	3
5	7		Lineament Density	A	5
5	8				
6	7	LULC	Lineament Density	A	3
6	8				
7	8				

## Appendix 8: Matrix

Matrix		Rainfall	Drainage Density	Geology	Soil	Slope	LULC	Lineament Density	0	0	0	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
Rainfall	1	1	1/5	1/7	1	1/5	1/3	1	-	-	-	4.80%
Drainage Density	2	5	1	1	1	1/3	1	3	-	-	-	14.48%
Geology	3	7	1	1	3	1	5	7	-	-	-	28.32%
Soil	4	1	1	1/3	1	1/3	3	3	-	-	-	11.85%
Slope	5	5	3	1	3	1	3	5	-	-	-	27.40%
LULC	6	3	1	1/5	1/3	1/3	1	3	-	-	-	9.14%
Lineament Density	7	1	1/3	1/7	1/3	1/5	1/3	1	-	-	-	4.01%
0	8	-	-	-	-	-	-	-	1	-	-	0.00%
0	9	-	-	-	-	-	-	-	-	1	-	0.00%
0	10	-	-	-	-	-	-	-	-	-	1	0.00%