Identifying and Mapping Ground Water Potential Zone Using Geospatial Technology: A Case of Adama city, Oromia, Ethioipa

Kiya Ayalew

Thesis Submitted to the Department of Architecture
School of Civil Engineering and Architecture (SOCEA)

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Geo-informatics Engineering

Office of Graduate Studies
Adama Science and Technology University

June, 2024
Adama, Ethiopia

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DECLARATION

I declare hereby this research thesis entitled "Assessment of ground water potential zone and mapping using Geospatial technology: case of Adama city " is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this proposal have been duly acknowledged through citation.

____

Student name Signature Date

RECOMMENDATIONS

I/we, hereby certify that the recommendation and suggestion given by the proposal review committee are appropriately incorporated into final thesis/dissertation proposal entitled "Assessment of ground water potential zone and mapping using Geospatial technology: case of Adama city " by Kia Ayalew.

Dr. Temesgen Abraham	____________________	______________
Major Advisor/Supervisor	Signature	Date

APPROVAL SHEET

We, the advisors of the thesis entitled "Assessment of ground water potential zone and mapping using Geospatial technology: case of Adama city "and developed by Kia Ayalew hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Temesgen Abraham	____________________	____________________
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We, the undersigned, members of the Board of Examiners of the thesis by Abdi Tena muleta have read and evaluated the thesis entitled "Assessing the future advancement of cadastral system using conceptual framework techniques: Adama city, Oromia, Ethiopia "and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geoinformatics Engineering.

Chairperson	Signature	Date
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Final approval and acceptance of the thesis proposal is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Post graduate office dean	Signature	Date

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LIST OF ABBREVIATIONS AND ACRONYMS

AHP	Analytical Hierarchy Process
BCM	Billion Cubic Meters
DEM	Digital Elevation Model
GIS	Geographic Information System
GPS	Global Positioning System
LULC	Land Use Land Cover
RS	Remote Sensing
UN	Unite Nations
UNDP	United Nations Development Programme
USGS	United States Geological Survey

Abstract

This study focuses on the assessment and mapping of groundwater potential zones in Adama City using geospatial technology. By integrating remote sensing data, Geographic Information Systems (GIS), and hydrogeological parameters, the research aims to identify and delineate areas with varying groundwater potentials. Key factors such as land use, soil type, slope, rainfall, and drainage density were analyzed to create a comprehensive groundwater potential map. The results reveal distinct zones with high, moderate, and low groundwater potential, providing valuable insights for urban planning and sustainable water resource management. This geospatial approach offers a systematic and efficient method for groundwater assessment, supporting informed decision-making and contributing to the long-term water security of Adama City.

Keywords: Groundwater, Potential Zones, Geospatial Approach

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Groundwater stands out as the safest and most dependable water source for domestic, irrigation, industrial, and municipal purposes. Opting for groundwater development for water supply is more favorable than relying on low discharge springs and dug wells, which are often insufficient, non-resistant to drought, and may remain permanently dry and unrecoverable after prolonged drought periods (Sunkari et al., 2019). This limited and precious resource requires thorough prospecting, management, and assessment to ensure its optimal utilization. The escalating global population and urbanization necessitate the exploration of alternative freshwater sources (Saha and Ray, 2019).

Groundwater plays a crucial role as a water source, serving as base flows for rivers and acting as an underground reservoir. It represents the purest form of water from natural sources, meeting the overall water demand of rural and semi-urban populations. In numerous regions worldwide, groundwater serves as the largest single freshwater source, offering a crucial buffer during extended dry periods (Nag and Kundu, 2016). The successful exploitation of groundwater necessitates a comprehensive understanding of the hydrological and geological characteristics of the area. The groundwater quantity, quality, and water table level are determined by the hydrological environment, influenced by topography, climate, and geology (Hiscock and Bense, 2014).

Groundwater remains a primary source for drinking, domestic, industrial, and agricultural purposes globally (Fienen and Arshad, 2016; Wagh et al., 2016). However, the increasing demand for groundwater, driven by rapid population growth, expanded irrigation, and industrialization, poses challenges. Urban expansion, inadequate waste disposal infrastructure, and the absence of well-developed sewer and drainage systems contribute to the depletion and contamination of groundwater resources (Kazi et al., 2009).

The rise in anthropogenic activities, such as industrial effluents, agricultural fertilizers, municipal wastewater, landfill, and animal waste, has led to a rapid increase in groundwater pollution worldwide (Farooq and Ustad, 2015). Studies point to untreated wastewater and leachate from waste disposal sites contaminating groundwater in specific regions, such as south India (Mohanakavitha et al., 2019a, 2019b). Anthropogenic activities significantly degrade groundwater quality, limiting the availability of freshwater resources.

Research studies conducted in the Ethiopian rift highlight variations in the chemical composition of groundwater in highland and rift valley aquifers (UNDP, 1973; Chernet, 1982; Wood and Talling, 1988; Halcrow, 1989; Gizaw, 1996, 2002; Kebede et al., 2005; Berhanu, 2007; Ayenew et al., 2008; Ayenew, 2008; Kebede et al., 2008; Demlie and Wohnlich, 2006; Demlie et al., 2007a, 2007b, 2008; Yitbarek et al., 2012; Amanial, 2015; Kawo and Shankar, 2018). The presence of high fluoride concentrations in rift valley groundwater is attributed to mica-based volcanic aquifers and the contribution of pyroxene and amphiboles (Furi et al., 2011). Additionally, liquid waste discharges from cities in the rift valley are identified as a source of groundwater pollution.

Various studies, such as those conducted by Taye (1988), Tamiru (2004), Haile (1999), Dinka (2015, 2017), and Eliku and Suleiman (2015), further emphasize the pollution of groundwater due to anthropogenic activities in specific regions, indicating the pressing need for sustainable water resource management and pollution control measures.

The amalgamation of GIS technology and remote sensing data holds the potential to enhance our understanding of hydrogeology. This can be achieved by creating a spatially referenced model that integrates physiographic, geological, hydrogeological, and geochemical data. Recently, there has been a growing emphasis on utilizing GIS in water resource evaluation, with an expanded focus on both surface and subsurface applications (Hamed et al., 2023). These tools prove highly effective in delineating groundwater potential zones and recharge areas. The contemporary application of GIS, remote sensing, and multicriteria analysis, including the use of Analytical Hierarchy Process (AHP) and ground truthing, offers an efficient method for identifying groundwater prospect zones within a given area. This approach facilitates the establishment of relationships between geological characteristics and yield data in the region (Allafta et al., 2020). Additionally, the combined use of remote sensing and GIS has demonstrated promising results in groundwater development in various African regions, including Ethiopia (Olarinoye, et al., 2023).

1.2 Statement of the Problem

The availability of water is crucial for survival and maintaining good health, yet a global challenge of water scarcity persists. According to Shan et al. (2020), approximately 700 million people across 43 countries are currently living with water scarcity, with a significant portion residing in sub-Saharan Africa. This region constitutes a quarter of the global population facing water scarcity, predominantly in developing countries. The scarcity of water has compelled people worldwide to resort to using unsafe water for drinking and other domestic purposes (Grönwall and Danert, 2020).

The issue of accessing clean water and basic sanitation is intricately linked to sustainable development. Examining the Millennium Development Goal 7, particularly target 7.C, underscores the critical role of water in sustainable development. Therefore, any country that fails to ensure access to clean water and basic sanitation is unable to achieve sustainable development goals (Martínez-Santos, 2017). Notably, it is primarily developing countries that grapple with the challenges of providing potable water and basic sanitation. Consequently, the availability of clean water serves both as a means to attain sustainable development and as an indicator of a country's level of development (Nhapi, 2015).

Ethiopia, categorized as a third-world country, is not immune to the adverse socio-economic consequences of a shortage of clean water. The availability of potable water is extremely limited, with a minimal percentage of the population having access to clear and safe water sources (Arega, 2022). Specifically, in Ethiopia, only 12 percent of the nation's population in rural areas and 70 percent in urban regions have access to a safe water supply. The use of unsafe water has led to a high prevalence of diarrhea diseases among children, resulting in elevated infant and child mortality rates, with pregnant women facing increased risks (Baye, 2021). The insufficient availability of clean water is attributed, in part, to the ineffective, unequal, and suboptimal utilization of the country's existing water resources for significant and sustainable socio-economic development (Birhanu, 2020).

Likewise, the study area is confronted with a potential risk of inadequate access to potable water. Additionally, there is a shortage of drinking water within an acceptable distance in the region. Some parts of the community resort to using untreated surface water for domestic and drinking purposes due to water scarcity, posing a potential health risk associated with the consumption of polluted water. The lack of understanding of groundwater potential stands out as a crucial factor in planning water supply from groundwater resources. Consequently, evaluating the groundwater potential in the catchment becomes essential to provide crucial information for sustainable groundwater development and management.

This paper focused on the delineation of Groundwater Potential Zones in Adama and the Surrounding Watershed, Ethiopia, utilizing Geospatial Techniques. The objective was to establish an additional or complementary tool for locating groundwater. Additionally, a thematic map illustrating potential zones for accessing drinking groundwater was presented. The assessment incorporated rainfall data, aquifer hydrogeological and hydraulic characteristics, hydro-morphological features, lithological data, and groundwater quality information. Moreover, the reliability of the groundwater potentiality mapping was evaluated.

Groundwater was a vital resource for sustaining agricultural, industrial, and domestic activities, particularly in regions facing water scarcity challenges. Adama and its surrounding watershed in Ethiopia were no exception, relying heavily on groundwater for various purposes. However, a comprehensive understanding of the groundwater potential zones in this area was lacking, hindering effective water resource management. Therefore, there was a need for research that employed Geographic Information Systems (GIS) and Remote Sensing (RS) techniques to delineate groundwater potential zones in Adama and its surrounding watershed, providing valuable insights for sustainable water resource development.

1.3. Objectives of the Study

1.3.1. General objective

The general objective of this study is to delineate the groundwater potential zone delineation using geospatial techniques in Adama Wereda, Oromia, Ethiopia.

1.3.2. Specific objectives

More specifically, the specific objectives of the study are:

- To identify the groundwater controlling factors using geospatial techniques.
- To identify groundwater potential zones through integration of various techniques.
- To map the potential Groundwater zone using geospatial techniques.

1.4. Research Questions

- What is the groundwater controlling factor?
- How to identify and delineate groundwater potential zones?
- How to map the groundwater potential zones?

1.5. Significance of the Study

Ethiopia is one of the countries in Africa known by abundant water resource but there is minimum utilization to ground water for irrigation, domestic life, and lively wood. The main part of Ethiopian rift valley is characterized by shortage rainfall. The population of Adama Wereda and its surrounding are used waters for drinking and other livestock consumptions from ponds, surface waters and the others by going long travel to fetch the waters from rivers. The decrease rainfall trend of dry zone and the increase of population size and demands of water for irrigation and other livelihood requirement's calls sustainable exploitation of the groundwater resources in the area. By considering the problem and the gap from the other studies in terms of cost and time, increasing number of population density and fluctuation of climate on water scarcity in Wereda. This research analyzes, design and map the spatial and temporal distribution of, groundwater availability, identify recharge areas and factors for ground water formation for the study area.

1.6 Scope of the Study

The study is limited to delineate ground water potential zones in Adama Wereda watershed. It focuses on some technical aspects of delineate groundwater potential zones. The issues under consideration in this study are only delineating ground water potential zones. The study not includes explore, engineering, supply and design part of the construction. Delineating criteria is limited to Geomorphology, Geology, Land use Land cover, Drainage Density, Lineament Density, Soils, Slope and Rainfall.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The principal aim of Hydro geological investigations is to provide general information on the ground water resource potential areas. It refers to the study of lithological and structural aspects of a territory using basic geologic methods and will be finalized in the understanding of the factors that regulate effective infiltration, groundwater reserve, the circulation and outflow of the ground water. Some water underlies the surface of the earth almost everywhere: beneath hills, mountains, plains and deserts. It is sometimes difficult to locate such water. For instance, in a marsh area it may lie close to the land surface while it may occur many hundreds of feet below the surface in some arid areas. Furthermore, water at very low, moderate and great depth might be few hours, hundred and several thousands of years old respectively (Chenini et al., 2015).

Groundwater is the subsurface water that fully saturates pores or cracks in soils and rocks (U.S. Geological survey, 1998). It is water that fills pores and fractures in the ground. It is stored in and moves slowly through moderately to highly permeable rocks-aquifers. The word aquifer comes from two Latin words: aqua-water and ferre-to bear or carry. Hence, literally aquifers carry water underground. Aquifer might be a layer of gravel or sand, a layer of sandstone or cavernous limestone, a rubble top or base of lava flows, or even a large body of massive rock, such as fractured granite, that has sizable openings. In terms of storage at any one instant in time, ground water is the largest single supply of fresh water available for use by humans (Baird and Low, 2022).

Within one-half mile of the land surface, an estimated one million cubic miles of the world's groundwater is stored. However, only a portion of this reservoir of the groundwater can be practicably utilized and made available on a permanent basis through wells and springs. The amount of ground water in storage is more than 30 times greater than the nearly 30,000 cubic miles volume in all the fresh-water lakes and more than the 300 cubic miles of water in all the world's streams at any given time. Groundwater is replenished by precipitation. When rain falls or snow melts, some of the water evaporates, transpired by plants, flow overland and collects in streams, and some infiltrates into the pores or cracks of the soil and rocks. The water that has been evaporated or used by plants during a preceding dry period is replaced by the first water that enters the soil. Hydrologists call the zone between the land surface and the aquifer water - unsaturated zone. In unsaturated zone, mostly in smaller openings of the soil and rock there is often at least a little water while the larger openings usually contain air instead of water. The unsaturated zone may be almost saturated after a significant rain while the zone may be dry after a long dry period. Molecular attraction held some water in the unsaturated zone and that water will not flow toward or enter a well. Any surplus water, after the water requirements for plant and soil are satisfied, will infiltrate to the water table-the top of the zone below which the openings in rocks are saturated. Beneath the water table, all the openings in the rocks are full of water that moves through the aquifer to streams, springs, or wells from which water is being withdrawn (Kresic, 2009).

Groundwater moves slowly through the unsaturated zone and the aquifer. Therefore, natural refilling of aquifers at depth is a slow process. On the contrary, in an area of substantial precipitation a shallow aquifer may be replenished almost immediately. Aquifer may be replenished artificially: by spreading water over the land in pits, furrows, or ditches, or to erect small dams in stream channels to detain and deflect surface runoff thereby allowing it to infiltrate to aquifer; by constructing recharge wells and inject water directly into an aquifer –a more expensive method but may be justified where the spreading method is not feasible (Kresic, 2009).

A groundwater is described as under water-table conditions if that ground water is not confined under pressure. Water-table aquifers generally are recharged locally, and water tables in shallow aquifers may fluctuate up and down directly in harmony with precipitation or stream flow. Furthermore, an aquifer may be filled to the point that the water overflows onto the land surface-spring. According to the geologic formation from which they obtain their water, springs may be classified as limestone springs or lava-rock springs; or according to the amount of water they discharge — large or small; or according to the temperature of the water — hot, warm, or cold; or by the forces causing the spring — gravity flow. Thermal springs are ordinary springs except that the water is warm and, in some places, hot. Many thermal springs occur in regions of recent volcanic activity and are fed by water heated by contact with hot rocks far below the surface.

Even where there has been no recent volcanic action, rocks become warmer with increasing depth. In some such areas water may migrate slowly to considerable depth, warming as it descends through rocks deep in the Earth. If it then reaches a large fracture that offers a path of less resistance, it may rise more quickly than it descended. Water that does not have time to cool before it emerges forms a thermal spring. Geysers are thermal springs that erupt intermittently and to differing heights above the land surface (Bachmat and Daniel, 2005).

2.2 Factor Determining Groundwater Occurrence

Groundwater occurrence is influenced by various factors, and understanding these factors is crucial for managing and utilizing groundwater resources effectively. Below are some key factors that determine groundwater occurrence, along with relevant citations:

Drainage System

The drainage system of any area usually plays crucial role in different aspects. They reflect the Lithology and structure of an area. Drainage pattern is indicative of the presence of structures that act as conduits or storage for sub-surface water. With respect to groundwater occurrences the higher drainage density is related to less infiltration of water to the ground, which in turn leads to higher run off and vice versa (Igwe et al., 2020).

Terrain slope

Terrain slope plays great role in characterizing the nature of the terrain, landforms and hydrological conditions. In relation to groundwater flat areas, where the slope amount is low, are capable of holding rainfall which in turn facilitates recharge whereas in elevated areas, where the slope amount is high, there are high run-off and low infiltration (Anbarasu et al., 2020).

Soil

Soils have different rates of infiltration. Hence, soil properties influence the relationship between runoff and rainfall. Permeability and infiltration are the principal factors required to classify into hydrologic groups (Fan et al., 2011).

Land Use/ Land Cover

Land use/ land cover influence the occurrence of groundwater. The effect of land use / land cover is evident either by reducing runoff and facilitating or by trapping water on their leaf. Trapped water droplets in this way go down to recharge groundwater. Land use/land cover may also affect groundwater negatively by evapotranspiration, assuming interception to be constant (Elmahdy et al., 2020).

Rainfall

In Ethiopia, rainfall has an uneven distribution both in time and in space. This is partly due to the presence of one major and one small rainy season, in large part of the country. A subsidiary effect is that a large amount of rainfall on the highlands is concentrated as runoff in river valleys, which drain into the low-lying areas where annual rainfall is low. In almost all river basins in Ethiopia, some 80% of the runoff results from annual precipitation falling in four months from June to October. The recharge to the groundwater system is also variable as the rainfall over Ethiopia is extremely variable in both space and time. The main source of recharge for the vast groundwater system is the rainfall on the highlands. The major recharge occurs in the northeastern and southwestern plateau where annual rainfall is high. Rapid infiltration occurs in areas covered by fractured volcanic and to a lesser extent in sedimentary rocks and thick permeable soils. The Ethiopian rift acts as a discharging zone, which contains numerous perennial rivers, fresh and salt lakes, cold and thermal springs (Berhanu and Hatiye, 2020). Rainfall is one of the primary sources of groundwater. It is expressed as the depth of precipitated water measured by rain gauge for selected periods of time. Intensity of rainfall is less important to groundwater (Hagos and Andualem, 2021). In Ethiopia, it may not be possible to correlate directly the presence of higher rainfall belts in certain areas with the size of the local groundwater storage. The Precambrian outcrops in the south eastern part of the country receive high rainfall (Hagos and Andualem, 2021). For instance, Adolla/Kibre Mengist, Shakisso and Negelle receive 1061mm, 1043mm and 632mm rainfall respectively. In these areas, the chance of obtaining water in the upper weathered part is very high. The main problems of arid areas are linked to groundwater resources. Since vertical permeability of soils is often higher in low rainfall regions than high rainfall areas (Alemayehu et al., 2006).

With respect to different surface condition which affect the amount of water that goes to the ground, annual rainfall should be taken in order to average the amount of water that percolates in to the ground regardless of surface condition. In general, high rainfall amounts imply the possibility of high groundwater potential zone (Haile et al., 2022).

Lineaments

Lineaments are linear features caused by the linear alignment of regional morphological features such as streams, escarpments, and mountain ranges, and tonal features that in many areas are the surface expressions of fractures or fault zones. Lineaments are the results of faults and fractures. Hence, in relation to groundwater exploration it infers zone of increased porosity and permeability which in turn has greater significance in groundwater occurrence and distribution (Sarikhani et al., 2014).

Geomorphology

Landforms are the most common structure of the earth. They throw light upon the geologic history, structure and Lithology of a region. In groundwater exploration, geomorphology plays an important role in identification of favorable zone for groundwater. More promising groundwater is in flood plains, alluvial fans and valley fills that are associated with thick alluvial and weathered materials to give high porosity and permeability. Sediments generally are not favorable for groundwater potential zones (Adji and Sejati, 2014). In Ethiopia, there is variable recharge, which is high on the plateau and low along the dry lands (Gebru et al., 2020).

Geology

The rock's porosity determines the quantity of water that a given type of rock holds. Porosity is a measure of pore space between the grains of the rock or of cracks in the rock that can fill with water. For instance, if the grains of a sand or gravel aquifer are all about the same size, or "well sorted," the water-filled spaces between the grains account for a large proportion of the volume of the aquifer. However, if the grains are poorly sorted, the spaces between larger grains may be filled with smaller grains instead of water. Sand and gravel aquifers having well-sorted grains, therefore, hold and transmit larger quantities of water than such aquifers with poorly sorted grains. The pores of a rock must be connected to one another in order to allow water through it (Golkarian and Rahmati, 2018).

A rock is permeable if the pore spaces are connected and large enough that water can move freely through them. If a rock has many interconnected pore spaces or cracks, it will yield large volumes of water to wells or springs. A compact rock, almost without pore spaces such as granite, may be permeable if it contains enough sizable and interconnected cracks or fractures. Nearly, all consolidated rock formations are broken by parallel systems of cracks-joints which are caused by stresses in the Earth's crust. At first many joints are hairline cracks, but they tend to enlarge through the action of many physical and chemical processes. Ice crystals formed by water that freezes in rock crevices near the land surface will cause the rocks to split open (Bernabé et al., 2016).

Heating by the Sun and cooling at night cause expansion and contraction that produce the same result. Water will enter the joints and may gradually dissolve the rock or erode weathered rock and thereby enlarge the openings. Correlation between the water-bearing capacity of rocks and the depth at which they are found does not necessarily exist. For instance, at the land surface, very dense granite that will yield little or no water to a well may be exposed. On the other hand, porous sandstone such as the Dakota Sandstone may be positioned hundreds or thousands of feet below the land surface and may yield hundreds of gallons per minute of water. Rocks that yield fresh water have been found at depths of more than 6,000 feet, and salty water has come from oil wells at depths of more than 30,000 feet. On the average, however, the porosity and permeability of rocks decrease as their depth below land surface increases; the pores and cracks in rocks at great depths are closed or greatly reduced in size because of the weight of overlying rocks (Joly, 2021).

Based on the geological cover the proportion of each of the formation out of the total surface area of Ethiopia is: Basement cover= 18%, Paleozoic and Mesozoic cover=25%, Tertiary volcanic=40% and Quaternary sediments and volcanic=17%. Geology plays an important role in the distribution and occurrence of groundwater. To estimate the volume of the groundwater reserve, it is assumed that basement rocks do not contribute to the reserve due to very low permeability and storage capacity. By excluding the unproductive basement rock which is 202,860 km^2 and the assuming the mean groundwater recharge for the entire country which is 200 mm, the total groundwater reserve will be 185 billion m3, which is distributed in an area of 924,140 km^2 made of Sedimentary rocks, volcanic rocks and Quaternary sediments, including the highland and the Rift valley. The igneous and metamorphic rocks of Ethiopia can be categorized as hard rocks, which are devoid of primary water bearing structures. However, from the hydrological point of view, they are rather homogeneous in two respects. They have virtually no primary porosity and they have secondary porosity due to fracturing and weathering, which permits the flow and storage of groundwater. Metamorphic rocks usually tend to have porosity less than 1 % and are frequently discontinuous or ineffective pore spaces. Their permeability is, therefore, low as well. Fracturing either associated with regional deformation or weathering may create significant porosity and permeability which is the most important feature for their groundwater potential (Moges, 2019). Degree of fracturing in crystalline rocks has generally been found to decrease with depth, because the rock becomes more massive and harder with depth under higher pressure and temperature conditions (Messene, 2015).

2.3. GIS and Remote Sensing in Groundwater Potential Zone delineation

Groundwater exhibits spatial and temporal variability, and given its paramount importance as a water source, there is a pressing need for in-depth examination of its assessment and potential. To ensure sustainable water resource development, it is imperative to pinpoint regions undergoing groundwater replenishment (Evaggelopoulos, 2005). The utilization of Remote Sensing (RS) and Geographic Information Systems (GIS) emerges as valuable tools for mapping groundwater exploration. Numerous studies have explored the applications of RS and GIS in Hydrogeology. Tweed et al. (2007) demonstrated the utilization of RS data and GIS to estimate recharge and discharge areas, as well as surface and groundwater interactions. Additionally, Entekhabi and Moghaddam (2007) showcased the estimation of groundwater recharge using RS observations of soil moisture.

In hard rock hydrogeology, Remote Sensing (RS) proves pivotal in delineating lineaments, enabling the identification of rock fractures crucial for groundwater localization (Abdalla, 2012). Furthermore, remote sensing not only aids in identifying potential zones for groundwater exploration but also contributes to estimating total groundwater resources and selecting suitable drilling or artificial recharge sites. RS becomes particularly useful in areas lacking detailed geological and hydrogeological maps and field data (Chakraborty, 2019). Sander (2007) provided a comprehensive overview of lineament mapping and interpretation using RS data for groundwater exploration, highlighting its limitations in semi-arid hard rock areas.

The integration of Geographic Information Systems (GIS) facilitates synergistic processing of multi-source spatial data. Although GIS application in hydrogeology is in its early stages, successful developments have begun to emerge (Oikonomidis et al., 2015). The use of GIS for mapping groundwater potentiality allows for the storage, manipulation, and analysis of data in diverse formats and at various scales (Khan et al., 2022). Once integrated into the database, all data can be registered as layers with a common coordinate system, enabling the creation of thematic maps, including vulnerability maps for the overall study area (Voudouris et al., 2010).

Recent years have witnessed the application of various techniques by researchers to map groundwater potentiality and select sites for drinking-water boreholes. Gupta and Srivastava (2010) employed RS and GIS to identify groundwater potential zones. Al Saud (2010) proposed a method using RS and GIS to map potential areas for groundwater storage, considering factors such as rainfall, lithology, rock fractures, slope, drainage, and land cover/use. Elewa and Qaddah (2011) devised a method for groundwater potentiality mapping in the Sinai Peninsula (Egypt) using RS and GIS, incorporating parameters like rainfall, net groundwater recharge, lithology or infiltration, lineament density, slope, drainage density, and depth to groundwater. Konkul et al. (2014) applied a similar method to map hydrogeological characteristics and groundwater potentiality in the Huay Sai area (Thailand), using potential surface analysis. Antonakos et al. (2014) employed multicriteria analysis within a GIS environment to produce a distribution map of site suitability for drilling new production boreholes in Korinthia Prefecture (Greece), considering criteria such as aquifer productivity, groundwater quality, and economic and technical factors.

2.4 Ground Water in Ethiopia

The occurrence of groundwater in Ethiopia is significantly influenced by factors such as geology, geomorphology, tectonics, and climate. The variability of these elements in Ethiopia has a profound impact on both the quantity and quality of groundwater across different regions of the country (Tibebu, 2022). The geological composition of Ethiopia plays a crucial role in providing accessible groundwater, facilitating the efficient percolation of precipitation to recharge aquifers, leading to the formation of springs and sustaining perennial streams. To harness and manage this groundwater resource effectively, it is essential to comprehend the dynamics of groundwater occurrence in terms of spatial and temporal distribution (Kebede, 2012).

Despite the significance of groundwater in Ethiopia, there is a scarcity of studies focusing on the country's groundwater infrastructure. The natural endowment of Ethiopia includes a substantial amount of groundwater resources, but precise quantification is hindered by the lack of adequate hydrogeological data. Estimates suggest that Ethiopia's groundwater potential is approximately 30 billion cubic meters (BCM). In comparison to surface water supplies,Ethiopia exhibits a lower groundwater capacity (Mengistu et al., 2021).

Groundwater serves as a primary source of domestic water in Ethiopia, constituting about 85% of the total supply. One notable advantage of groundwater resources is their natural protection from pollution, obviating the need for extensive treatment before distribution to users. The genesis of groundwater is primarily influenced by the geophysical and climatic conditions prevailing in the region. Ethiopia exhibits a distinctive hydrogeological structure characterized by extensive heterogeneity in geology, geomorphology, and environmental conditions (Tolera et al., 2020).

The aquifer systems in Ethiopia are diverse, varying across different river basins or regional states. The occurrence of groundwater displays significant temporal and spatial variability, and there is a considerable diversity in depths and yields among wells located in close proximity. Understanding these complexities is crucial for the sustainable management and utilization of Ethiopia's groundwater resources (Mechal et al., 2016)

2.5 Empirical Literature Review

This review highlights key findings from relevant studies, providing insights on groundwater potential zone delineation using geospatial techniques. Here is a literature review on the assessment of cadastral systems:

“Delineation of groundwater potential zones in lower Rihand River Basin, India using geospatial techniques and AHP” by Verma and Patel (2021).

Verma and Patel investigate the groundwater potential in semi-arid regions, employing geospatial analysis techniques. The study focuses on factors such as land cover, slope, and geological formations to map potential zones, providing valuable insights for water resource management in arid and semi-arid environments.

“Fuzzy AHP based GIS and remote sensing techniques for the groundwater potential zonation for Bundelkhand Craton Region, India” Kumar et al. (2022).

Kumar et al. compare various GIS-based models for groundwater potential zonation, evaluating the efficacy of each model in different geological and climatic conditions. The study highlights the importance of selecting appropriate models based on the specific characteristics of the study area.

“Application of convolutional neural network in predicting groundwater potential using remote sensing: a case study in southeastern Liaoning, China” by Xu et al. (2020).

Xu et al. explore the application of machine learning techniques in conjunction with geospatial data for groundwater potential mapping. The study evaluates the performance of machine learning algorithms in predicting potential zones and compares the results with traditional GIS-based approaches.

“A review of advances in the identification and characterization of groundwater dependent ecosystems using geospatial technologies” by Pérez Hoyos et al. (2016).

Pérez Hoyos et al. provide a comprehensive review of geospatial technologies applied to groundwater identification and characterization. The study covers advancements in remote sensing, GIS, and field-collected data, emphasizing their collective role in delineating groundwater potential zones. This integration of field-collected data and remote sensing is still a challenge in the delineation of Groundwater Exploration because of poor development of automated techniques for this integration, differing formats and scattered storage locations of field observational data, and scarcity of geospatial data with high spatial resolution.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Description of Study Area

Adama City, situated at approximately 8° 30′ 52.1172″N latitude and 39° 16′ 9.3252″ E longitude, emerges as a bustling urban center about 80 kilometers away from the Ethiopian capital, Addis Ababa. Its elevation, reaching 1712 meters above sea level, not only offers a picturesque landscape but also hints at its strategic significance. The city's proximity to the international port of Djibouti, merely 777 kilometers away, positions it as a pivotal hub for trade and industry in the region. This geographic advantage not only facilitates efficient logistical operations but also attracts businesses keen on leveraging its accessibility to global markets. Consequently, Adama emerges as a preferred destination for commercial endeavors, embodying the fusion of geographical advantage and economic opportunity.

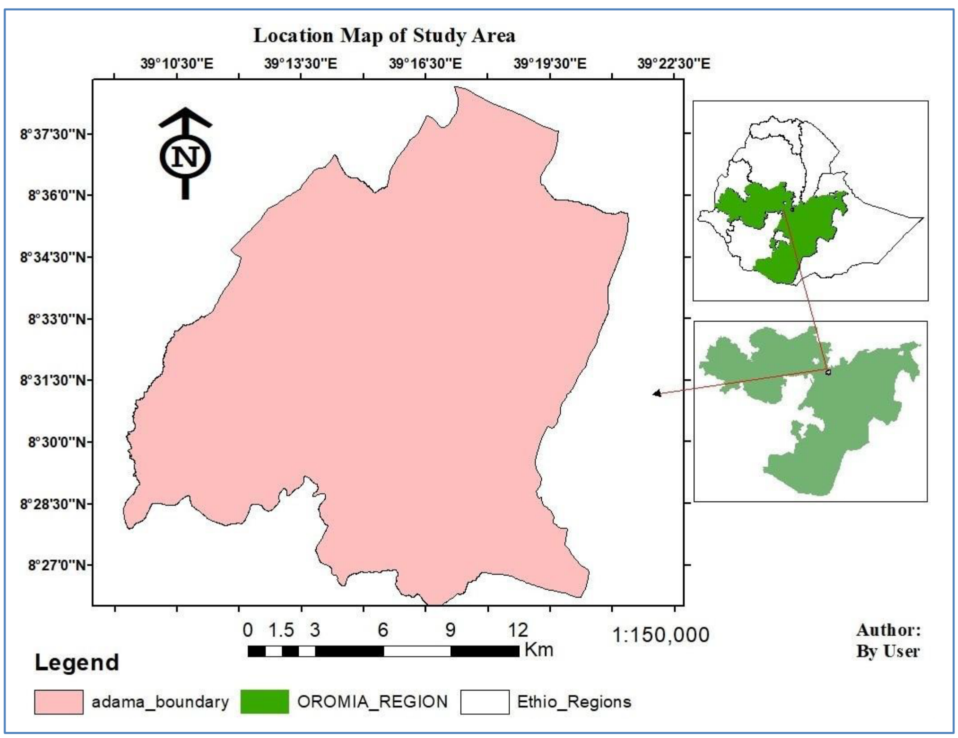

Figure 3-1: Location of study Area

3.2. Method of Data Collection

The data collected for the project was categorized into two: primary and secondary data.

3.2.1. Primary Data Collection

The primary data was gathered through unstructured interviews (or oral interviews) with a variety of people and observation. In addition, a reconnaissance survey was undertaken with the use of GPS, which was the primary tool for the study, to collect the current infrastructure components in the area.

3.2.2. Secondary Data Collection

Most of the data was collected from secondary sources (reviewing different maps that were obtained from different institutions, topographic map, satellite map, and attribute information) from the land administration of the study area and Ethiopian Geospatial Agency.

3.3. Data Source and Software Used

This part included gathering both spatial and non-spatial data from primary and secondary sources. The table below showed types of data used in the study, their sources, and data specifications.

Table 3.1: Data and their sources

No	Data	Source	Purpose
1	Orthophoto	Ethiopian Geospatial Agency	To use as a back ground
2	Landsat Satellite Imagery	USGS portal/ Ethiopian Geospatial Agency	Landsat Satellite Imagery Data (2000,2010 and 2022)
3	Policy & Operational Documents	Adama Land administration office	For evaluation
3	Parcel Data	Adama Land administration office	To prepare cadastre information in geodata base.

In this study, a combination of software tools was employed to effectively collect, organize, analyze, interpret, and present data for groundwater potential assessment. Firstly, ArcGIS 10.8 was utilized for raster clipping, GIS processing, and analysis. This powerful GIS software provided the tools necessary to manipulate spatial data, perform geoprocessing tasks, and generate thematic maps essential for understanding the spatial distribution of groundwater-related factors. Secondly, IDRISI 3.2 was employed for factor weight calculation, enabling the assessment of various parameters contributing to groundwater potential through geospatial analysis. Thirdly, GPS technology was utilized for point data collection, facilitating the georeferencing of different maps and ensuring accurate spatial representation of ground-truth data. Finally, the Arc Hydro extension for ArcGIS was utilized for catchment delineation, enabling the identification and delineation of watershed boundaries critical for understanding surface water-groundwater interactions. By leveraging these software tools in combination, the study was able to comprehensively assess groundwater potential, integrating various datasets and conducting sophisticated spatial analyses to support decision-making processes related to groundwater resource management.

Table 3-2: Software used and their purpose

S.N	Software Type	Anticipated use
1	Arc GIS 10.8	Raster Clip, GIS processing and analysis
2	IDRISI 3.2	Factor weight calculation
3	GPS	Point data collection for georeferencing different maps
4	ArcHydro extension	Catchments Delineation

3.4. Method of Data Analysis

Delineating groundwater potential zones in the Adama and surrounding watershed in Ethiopia involves a systematic analysis integrating GIS and remote sensing techniques. This process begins with compiling relevant spatial datasets such as geological maps, land use/land cover maps, and digital elevation models, followed by preprocessing to ensure data consistency and accuracy. Weighted overlay analysis is then conducted to integrate these layers, considering factors like lithology, land cover, soil type, and slope, to assign a composite groundwater potential index to each location. Hydrological modeling and terrain analysis further refine the assessment by simulating groundwater flow patterns and identifying potential recharge zones. Interpretation of remote sensing data aids in identifying surface features indicative of groundwater potential, while ground truthing validates the results through field surveys. The final step involves classification and zonation of the study area into different groundwater potential zones, culminating in the creation of thematic maps and visualizations to guide sustainable groundwater management and development efforts.

3.4.1. Catchment Delineation

To delineate the catchments of the study area, a Digital Elevation Model (DEM) will be utilized. The DEM for Adama woreda and its surrounding watershed will be extracted by masking using the woreda boundary feature class. This process ensures that only the elevation data within the study area are considered. Subsequently, the DEM and the network of drainage feature class of Adama woreda will be employed to delineate the catchments utilizing the Arc Hydro Tools extension within the ArcGIS 10.8 environment. The drainage network of the study area will be digitized from the Geologic map, ensuring its accuracy and relevance to the local terrain. This digitized drainage network will then be exported into a personal geodatabase to create a drainage network feature class, which will be used alongside the DEM for catchment delineation. Through this comprehensive approach, the catchments of the study area can be accurately delineated, providing essential insights into surface water flow patterns and hydrological processes within the watershed.

3.4.2. DEM Reconditioning

The DEM and stream network feature class (Hydro edge) of the area were presented on the ArcMap and saved before proceeding. A vector buffer was created around the linear feature class, specifying the number of cells for smoothing. The smooth drop/raise parameter determined the amount by which the river was dropped or the fence was extruded, aiding in interpolating the DEM into the buffered area. Additionally, a sharp drop/raise was applied to ensure the preservation of linear features used for burning or fencing, by adding an additional amount of drop or extrusion on top of the smooth buffer interpolation. These steps were undertaken to prepare the data for further analysis and catchment delineation within the ArcGIS environment.

3.4.3. Fill Sinks

The Fill Sinks function was employed to rectify elevation data inconsistencies by modifying the elevation values and eliminating sink-related issues. This process utilized the DEM reconditioning function output as input, ensuring that any depressions or sinks in the terrain were effectively filled. By smoothing out these irregularities in the elevation data, the Fill

Sinks function facilitated the creation of a more accurate and reliable representation of the terrain surface. This preprocessing step was crucial for subsequent hydrological analyses, ensuring that the DEM data used for catchment delineation and other watershed-related assessments were free from sink-related artifacts, thereby enhancing the overall quality and reliability of the results.

3.4.4. Flow Direction

The Flow Direction function computed the flow direction for a given grid, determining the direction of the steepest descent from each cell. This process utilized the output of the Fill Sinks function as input. By analyzing the changes in elevation values between cells and the distances between them, the function calculated the maximum drop, which represented the flow direction. Specifically, the maximum drop was determined by dividing the change in z-value between cells by the distance between them. This step was essential for understanding the natural drainage patterns and channel networks within the study area, laying the groundwork for further hydrological analyses such as flow accumulation and catchment delineation.

3.4.5. Flow Accumulation

The Flow Accumulation function computed the flow accumulation grid, which represented the accumulated number of cells upstream of each cell in the input grid. Utilizing the output from the Flow Direction calculation, this function determined the accumulated flow as the cumulative weight of all cells flowing into each downslope cell in the output raster. In cases where no weight raster was provided, a default weight of one was applied to each cell. Consequently, the values of cells in the output raster indicated the number of cells that contributed flow to each respective cell. Areas with high flow accumulation values denoted concentrated flow and were indicative of stream channels, while cells with a flow accumulation of zero identified local topographic highs, such as ridges. This analysis provided valuable insights into the drainage patterns and terrain characteristics of the study area, aiding in the identification and delineation of watersheds and stream networks.

3.4.6. Stream Definition

The Stream Definition function computed a stream grid, assigning a value of "1" to all cells in the input flow accumulation grid that surpassed a specified threshold. This threshold, typically set as a percentage of the maximum flow accumulation value, defined the minimum flow accumulation required for a cell to be classified as part of a stream. By default, the threshold was often set to 1% of the maximum flow accumulation value, serving as the recommended threshold for stream determination. A smaller threshold resulted in a denser stream network and typically led to the delineation of a greater number of catchments. Cells that did not meet the threshold criteria were assigned a no-data value in the Stream Grid. This process facilitated the identification and delineation of stream channels within the study area, providing crucial information for hydrological modeling and watershed management purposes.

3.4.7. Stream Segmentation

The Stream Segmentation function generated a grid of stream segments, each assigned a unique identification. These segments were categorized into head segments or segments between two segment junctions. In this process, cells within the same segment were assigned the same grid code specific to that segment. The input for this function included the output from the Flow Direction calculation and the Stream Definition, delineating the flow direction and identifying stream cells, respectively. By segmenting the stream network in this manner, the function facilitated the analysis and management of stream networks by providing a systematic breakdown of stream segments, aiding in the identification of stream reaches and their characteristics within the study area.

3.4.8. Catchment Grid Delineation

The Catchment Grid Delineation function generated a grid where each cell was assigned a value (grid code) indicating the catchment to which it belonged. This value corresponded to the value carried by the stream segment that drained that particular area, as defined in the stream segment link grid. The inputs for this function included the output from the Flow Direction calculation, which provided information on the direction of flow, and the Stream Segmentation, which segmented the stream network into distinct segments. By combining these inputs, the function facilitated the delineation of catchment boundaries within the study area, enabling the identification and analysis of hydrological units for further assessment and management purposes.

3.4.9. Catchment Polygon Processing

The Catchment Polygon Processing function converted a catchment grid into a catchment polygon feature, allowing for the representation of catchment boundaries as vector polygons.

The input for this function was the output of the catchment delineation process, which assigned each cell in the grid a value indicating the catchment to which it belonged. By converting the raster representation of catchments into vector polygons, this function facilitated the visualization, analysis, and further processing of catchment boundaries within a Geographic Information System (GIS) environment. These catchment polygons were valuable for various hydrological and environmental applications, including watershed management, land use planning, and water resources assessment.

3.5. Methodological Flow Chart of the study

The process begins with data collection, where various spatial datasets essential for groundwater potential assessment are gathered. These include Digital Elevation Models (DEMs), land use/land cover maps, soil maps, geological maps, and satellite imagery for remote sensing analysis. Once the data is collected, the next step involves preprocessing. This includes clipping DEM and other relevant datasets to the study area boundary and cleaning them to ensure consistency and accuracy in subsequent analyses.

Following preprocessing, terrain analysis is conducted to identify slope, aspect, and elevation characteristics of the study area. This helps in understanding surface water flow patterns through flow direction and flow accumulation analysis. Hydrological features such as streams and rivers are extracted from the DEM and flow accumulation results to delineate the existing surface water network. Subsequently, a detailed analysis of groundwater factors is undertaken. This involves studying factors such as lithology, soil type, and land use/land cover that influence groundwater occurrence. Weighted overlay analysis is then performed, where weights are assigned to each factor based on their significance. This leads to the generation of a groundwater potential index** through the integration of these factors.

Validation and calibration of the results are essential steps in the process. This involves ground truthing by conducting field surveys to validate the accuracy of the analysis. If discrepancies are identified, the model is calibrated accordingly based on ground-truth data. With the groundwater potential index established, the study area is classified into different groundwater potential zones. These zones delineate areas with high, moderate, and low potential for groundwater occurrence, aiding in decision-making for sustainable groundwater management.

Finally, the results are presented through thematic maps depicting groundwater potential zones. These maps, along with detailed reports and presentations, provide stakeholders with valuable insights for informed decision-making regarding groundwater management and development initiatives. Throughout the process, an iterative approach is adopted, allowing for continuous review and refinement based on feedback and new data, thus ensuring the accuracy and reliability of the groundwater potential assessment.

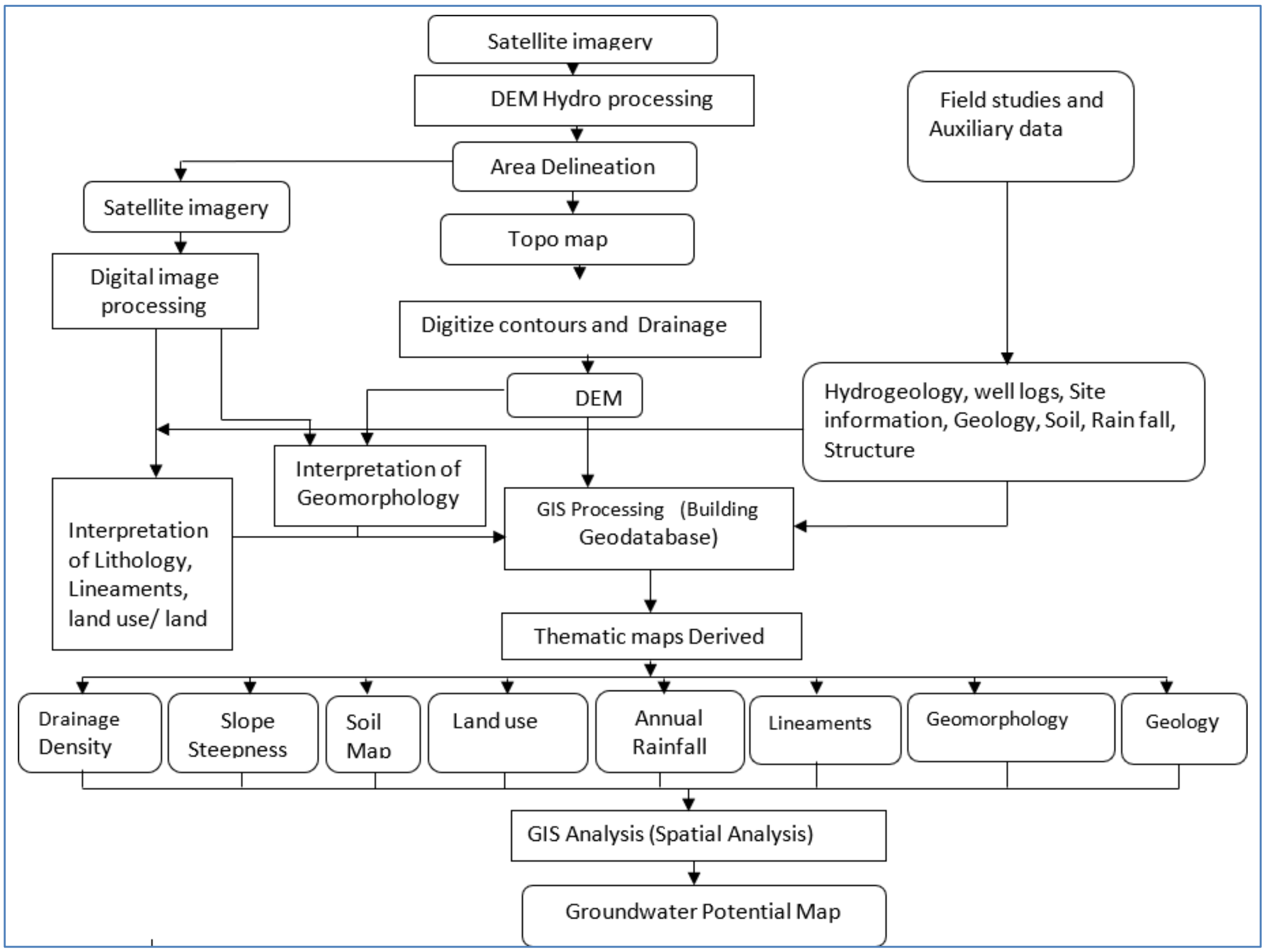

Figure 3.2: Methodological flowchart

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Catchment Area Delineation

Digital Elevation Models (DEMs) play a pivotal role in catchment area delineation and various hydrological analyses, making them indispensable for preserving our immediate environment. DEMs provide essential information about terrain relief, offering detailed representations of elevation variations across landscapes. This data is crucial for identifying drainage patterns, determining flow directions, and delineating catchment boundaries. In hydrological modeling, DEMs serve as foundational inputs for estimating water volumes in lakes and rivers, calculating soil erosion rates, and predicting flood risks (Figure 4-1). By leveraging DEMs, researchers and environmental practitioners can gain valuable insights into hydrological processes, enabling informed decision-making and effective management strategies aimed at mitigating environmental degradation and ensuring the sustainable use of water resources.

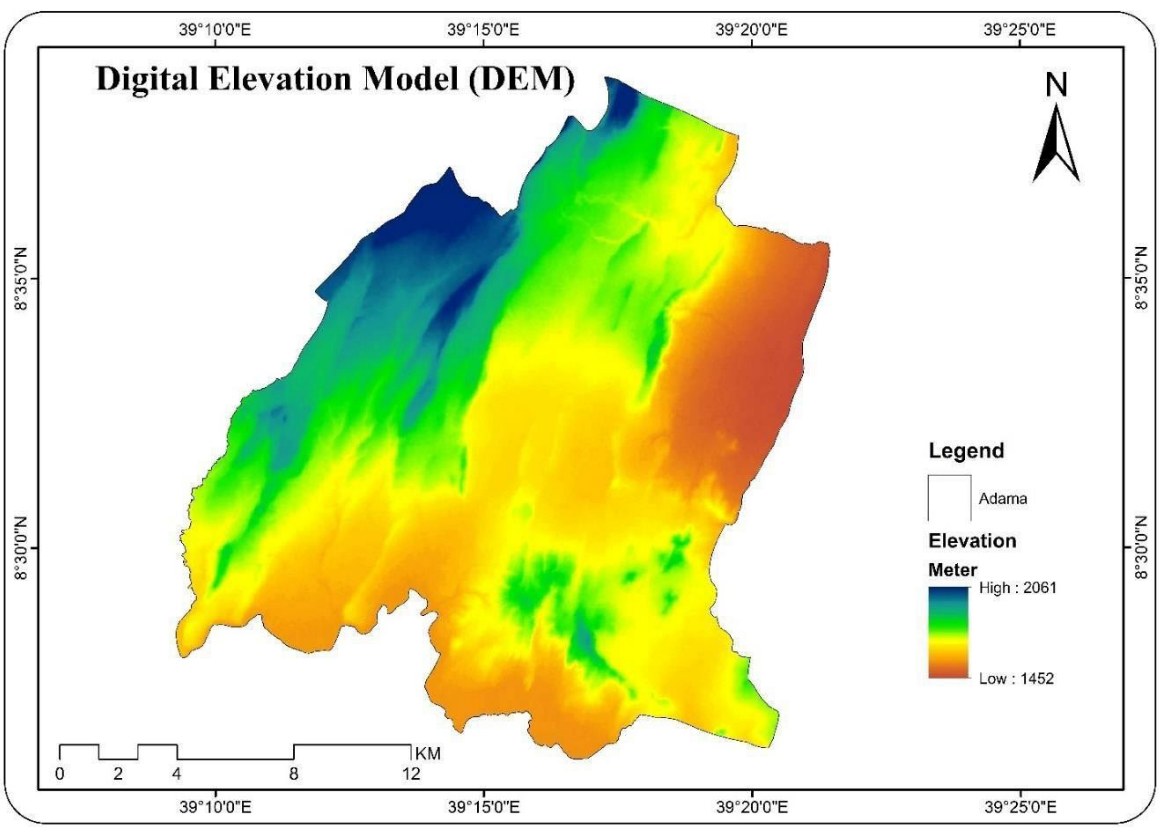

Figure 4-1: Digital Elevation Model

4.1.1 DEM Reconditioning

The DEM Reconditioning process modified the DEM by incorporating linear features onto it. Prior to execution, both the DEM and the stream network feature class (Hydro edge) of the area were presented on the ArcMap and saved. A vector buffer, specifying the number of cells around the linear feature class for smoothing, was applied. Additionally, parameters such as smooth drop/raise and sharp drop/raise were defined. Smooth drop/raise determined the vertical adjustment of the river or fence, facilitating DEM interpolation within the buffered area. Sharp drop or raise provided additional vertical adjustment to ensure the preservation of linear features during the interpolation process. These steps were crucial for integrating linear features into the DEM accurately, ensuring their representation within the terrain model for subsequent hydrological analyses.

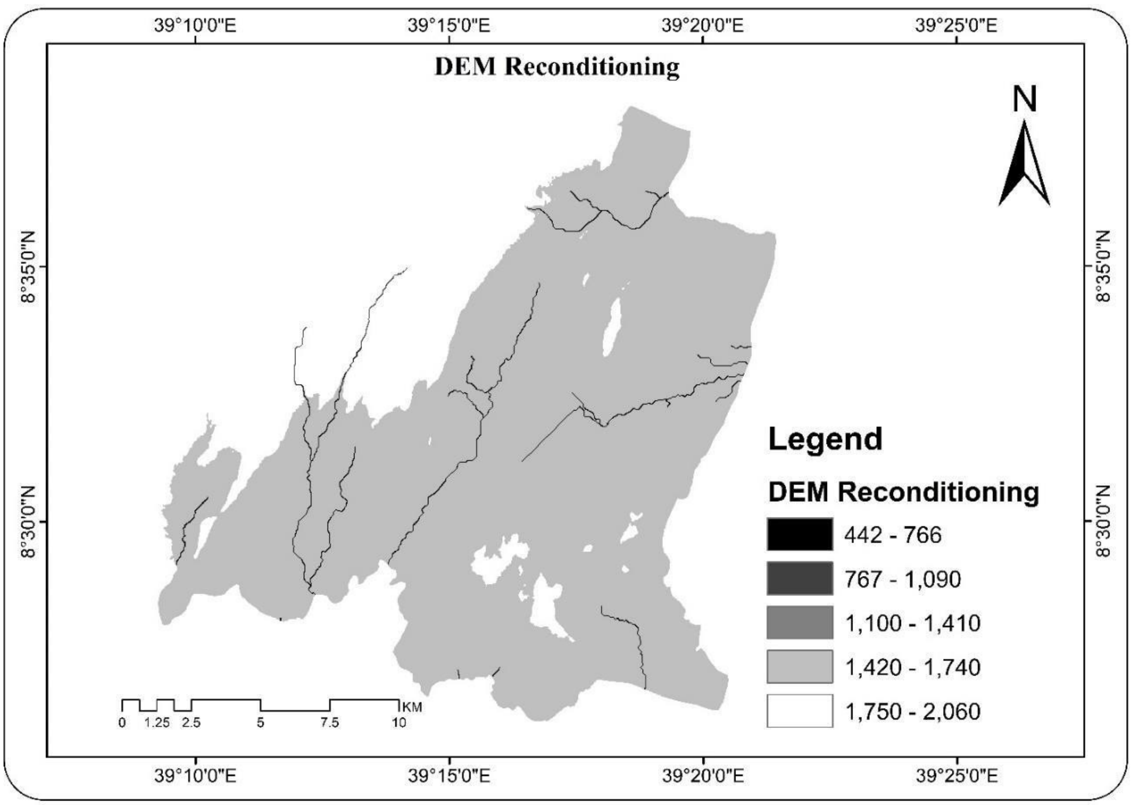

Figure 4-2: DEM Reconditioning

4.1.2 Fill Sinks

The Fill Sinks function was employed to address the issue of depressions or sinks in the terrain model. When a cell is surrounded by higher elevation cells, water can become trapped within it, hindering the natural flow of water. This function aimed to rectify such instances by modifying the elevation values within the DEM, effectively leveling out depressions and allowing water to flow unimpeded. The input for this function was the output from the DEM Reconditioning process, ensuring that any modifications made to the DEM during the reconditioning stage were taken into account. By eliminating depressions and ensuring a more realistic representation of the terrain surface, the Fill Sinks function contributed to the accuracy and reliability of subsequent hydrological analyses, such as flow direction and catchment delineation.

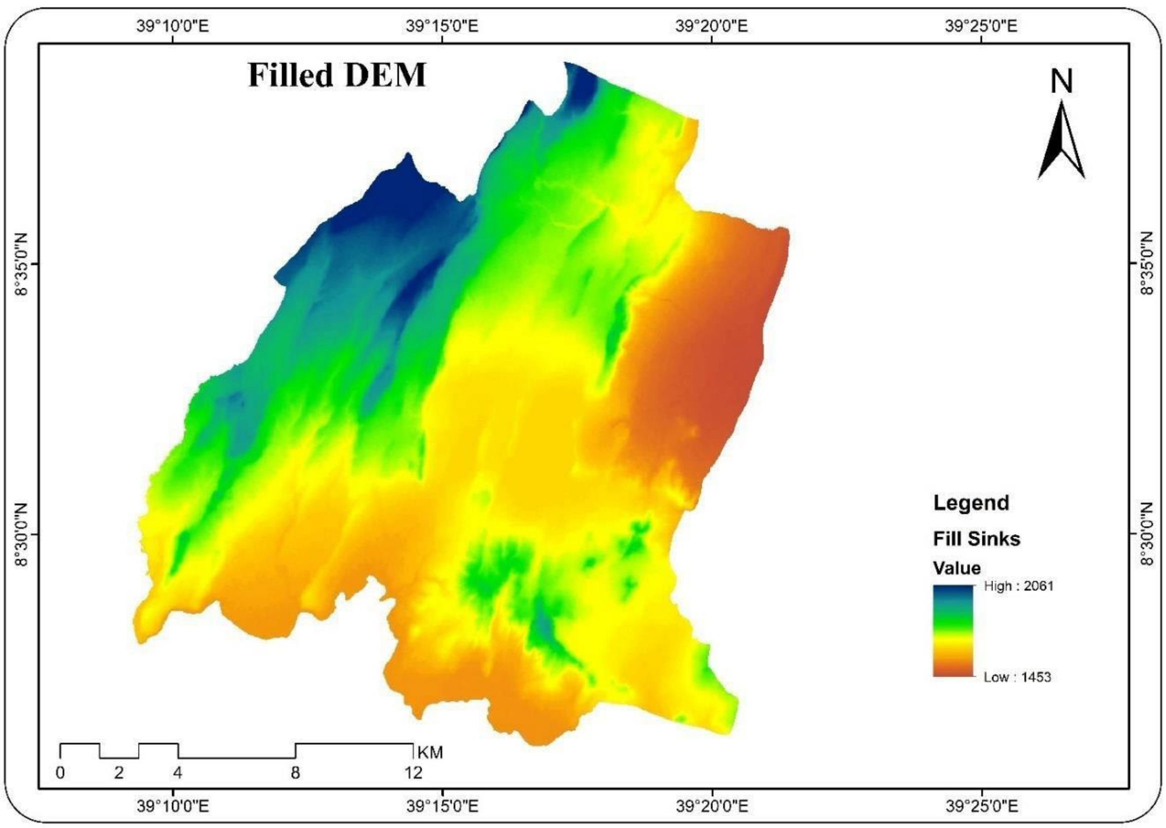

Figure 4-3: Fill sinks

4.1.3 Flow Direction

The Flow Direction function calculates the direction of water flow for each cell in a given grid, facilitating hydrological modeling and analysis. It determines the direction of the steepest descent from each cell, indicating where water would naturally flow downhill. This process is crucial for understanding surface water flow patterns and identifying drainage pathways within a watershed. The values in the cells of the flow direction grid represent the direction towards which water flows from each cell, typically denoted using cardinal directions (e.g., north, south, east, west) or using a numerical coding system. The calculation of flow direction involves considering the change in elevation (z-value) between cells and the distance between them, enabling the determination of the maximum drop or steepest descent. The input for this function is the output from the Fill Sinks process, ensuring that any modifications made to the DEM to address sinks or depressions are considered in the flow direction calculations. Overall, the Flow Direction function is essential for various hydrological analyses, including flow accumulation, watershed delineation, and flood risk assessment.

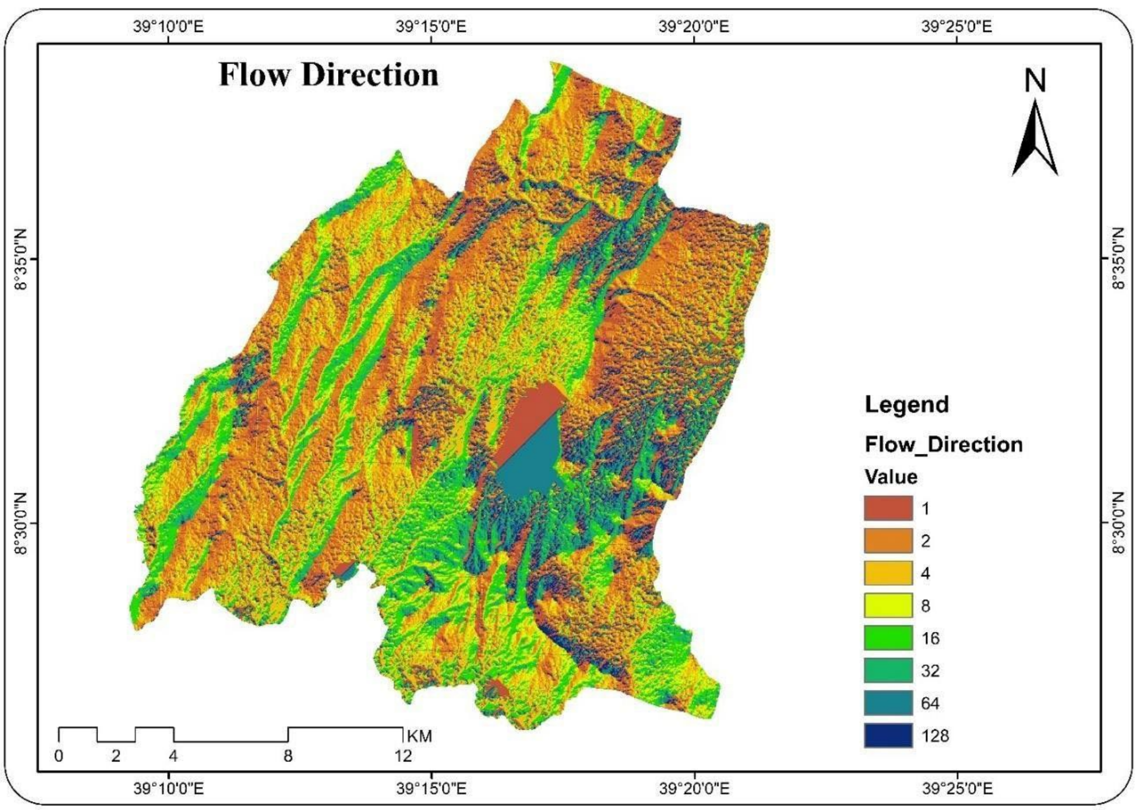

Figure 4-4: Flow Direction

4.1.4 Flow Accumulation

The Flow Accumulation function is a critical step in hydrological analysis, computing a grid that represents the accumulated flow upstream of each cell within the input grid. This accumulation is determined by summing the flow from all cells that contribute to the downstream flow of a particular cell. In instances where no weight raster is provided, each cell is assigned a weight of one, and the output raster values correspond to the number of cells that flow into each cell. High flow accumulation values indicate areas of concentrated flow, often associated with stream channels, while cells with a flow accumulation of zero represent local topographic highs such as ridges. Weight raster can be utilized to incorporate additional factors, such as rainfall intensity, into the calculation, allowing for more nuanced analysis. For example, a weight raster representing average rainfall during a storm event can be used to estimate the amount of runoff flowing into each cell. Overall, the Flow Accumulation function provides valuable insights into watershed dynamics and is instrumental in various hydrological assessments, including flood risk analysis and watershed management.

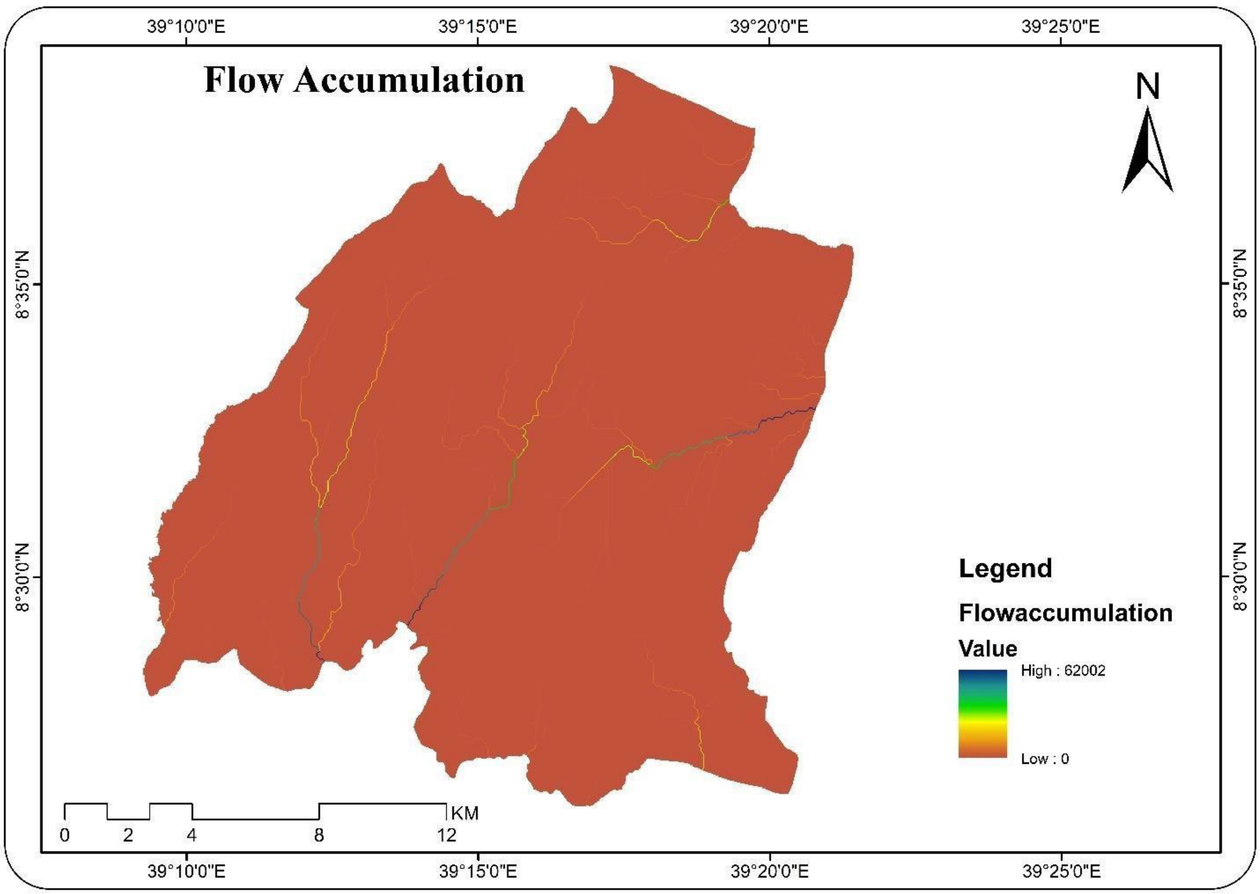

Figure 4-5: Flow Accumulation

4.1.5 Stream Definition

The Stream Definition function calculates a stream grid, where cells with flow accumulation values exceeding a specified threshold are assigned a value of "1," indicating the presence of streams. All other cells in the stream grid are designated as no data. The default threshold is typically set at 1% of the maximum flow accumulation value, serving as the recommended threshold for stream determination. This threshold can be adjusted to influence the density of the stream network and the number of delineated catchments. A smaller threshold results in a denser stream network and typically leads to the identification of a greater number of catchments. By utilizing the output of flow accumulation as input, the Stream Definition function helps identify stream channels within a watershed, facilitating the delineation of hydrological features and informing watershed management decisions.

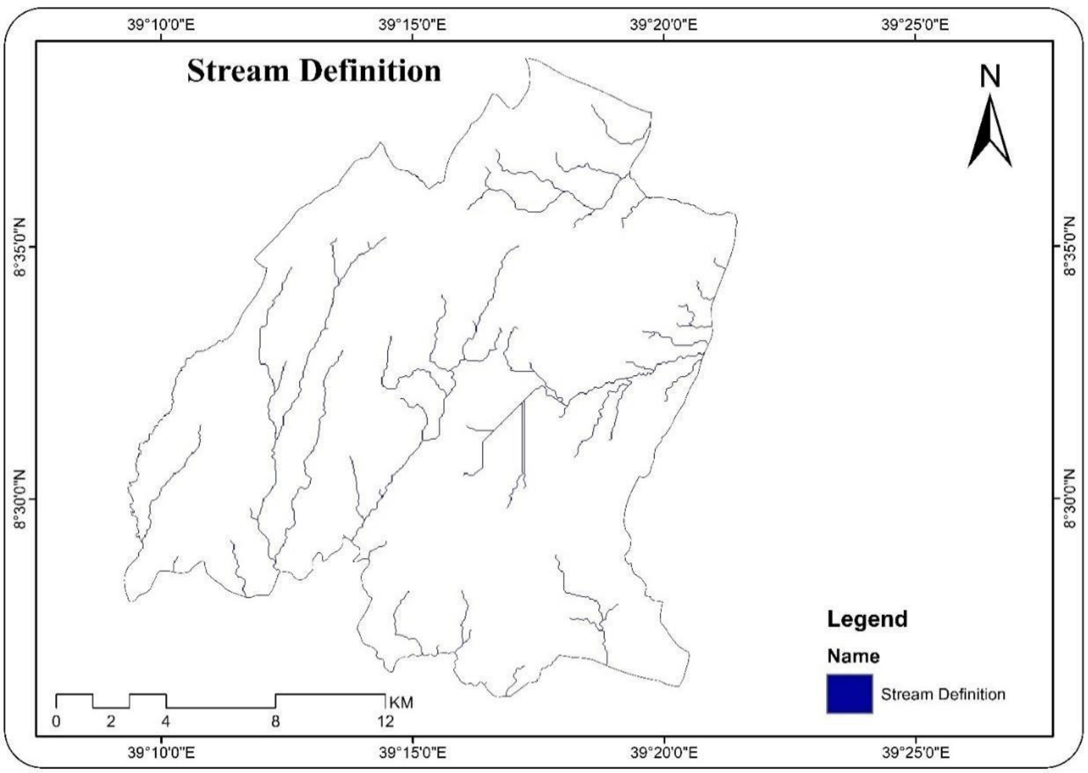

Figure 4-6: Stream Definition

4.1.6 Stream Segmentation

The Stream Segmentation function generates a grid of stream segments, each uniquely identified with a specific grid code. These segments can be categorized as either head segments or segments between two segment junctions. Within each segment, all cells share the same grid code, enabling differentiation and analysis of individual stream segments. This function requires the output from both the flow direction and stream definition processes as inputs. The flow direction data provides information on the direction of flow within the stream network, while the stream definition data identifies the cells representing streams. By combining these inputs, the Stream Segmentation function facilitates the systematic organization and identification of stream segments within the watershed, aiding in the analysis of stream characteristics and hydrological processes.

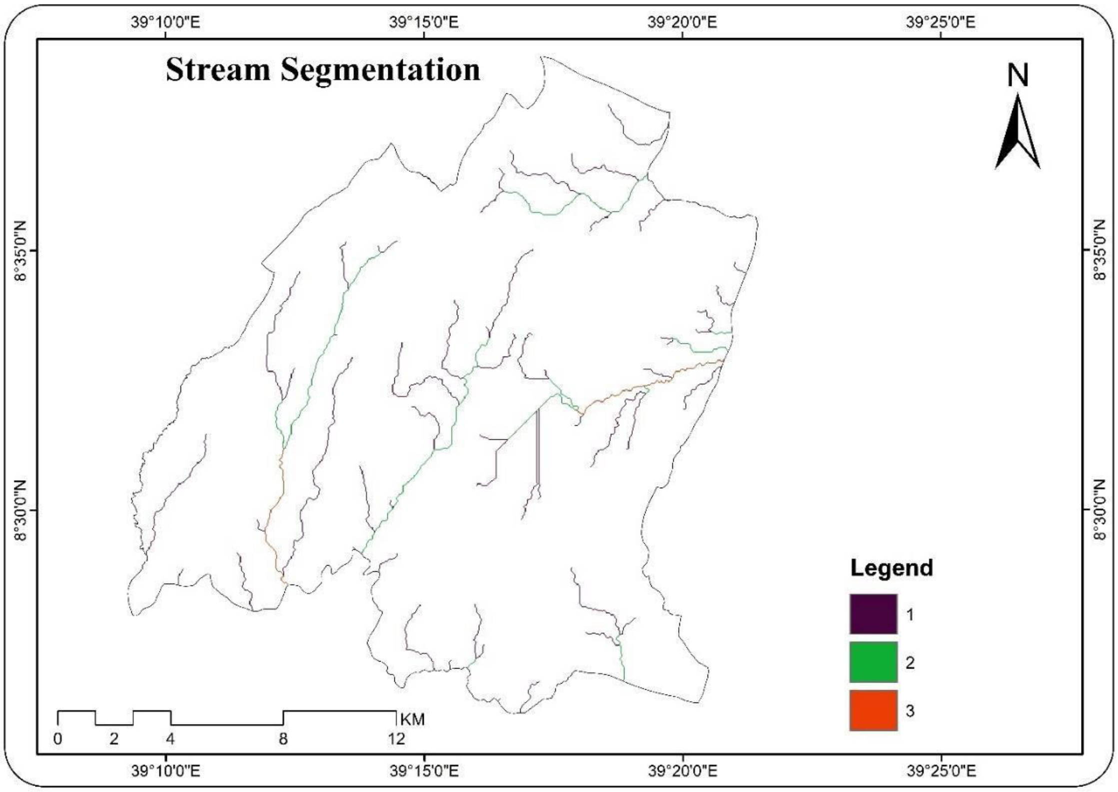

Figure 4-7: Stream segmentation

4.1.7 Catchment Grid Delineation

The Catchment Grid Delineation function generates a grid where each cell is assigned a value (grid code) indicating the catchment to which it belongs. This assignment is based on the stream segment that drains the area represented by each cell, as defined in the stream segment link grid. The input for this function includes the output from both the flow direction and Stream Segmentation processes. The flow direction data provides information on the direction of flow within the watershed, while the Stream Segmentation data identifies the individual stream segments. By combining these inputs, the Catchment Grid Delineation function systematically assigns catchment identifiers to each cell in the grid, facilitating the delineation and analysis of hydrological catchments within the study area. This process is essential for understanding the flow paths and drainage patterns within the watershed, enabling further analysis and modeling of water resources and hydrological processes.

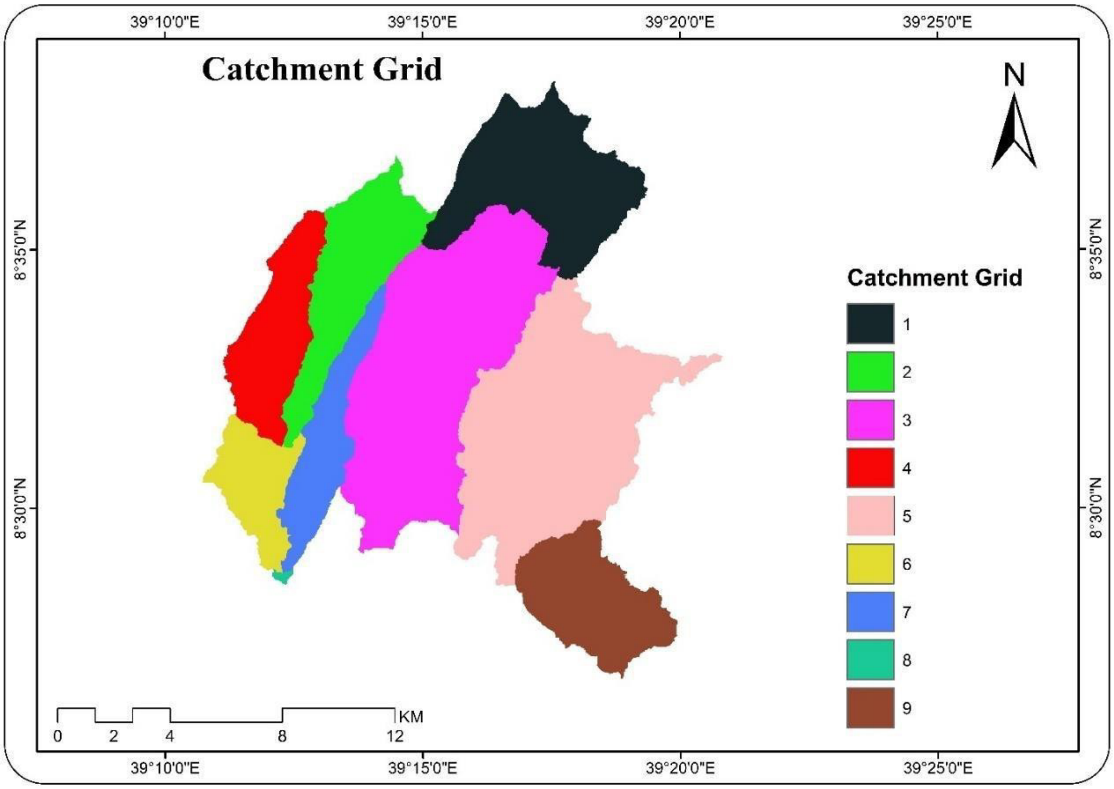

Figure 4-8: Catchment Grid delineation

4.1.8 Catchment Polygon Processing

The Catchment Polygon Processing function transforms a catchment grid into a catchment polygon feature, providing a vector representation of catchment boundaries. This process is essential for converting raster-based catchment delineation results into vector format, facilitating further analysis and visualization within a Geographic Information System (GIS) environment. The input for this function is the output of the catchment delineation process, which assigns each cell in the grid a value indicating the catchment to which it belongs. By converting the raster representation of catchments into vector polygons, this function enables the creation of detailed and accurate representations of catchment boundaries. These catchment polygons serve as valuable spatial datasets for various hydrological and environmental applications, including watershed management, land use planning, and water resources assessment.

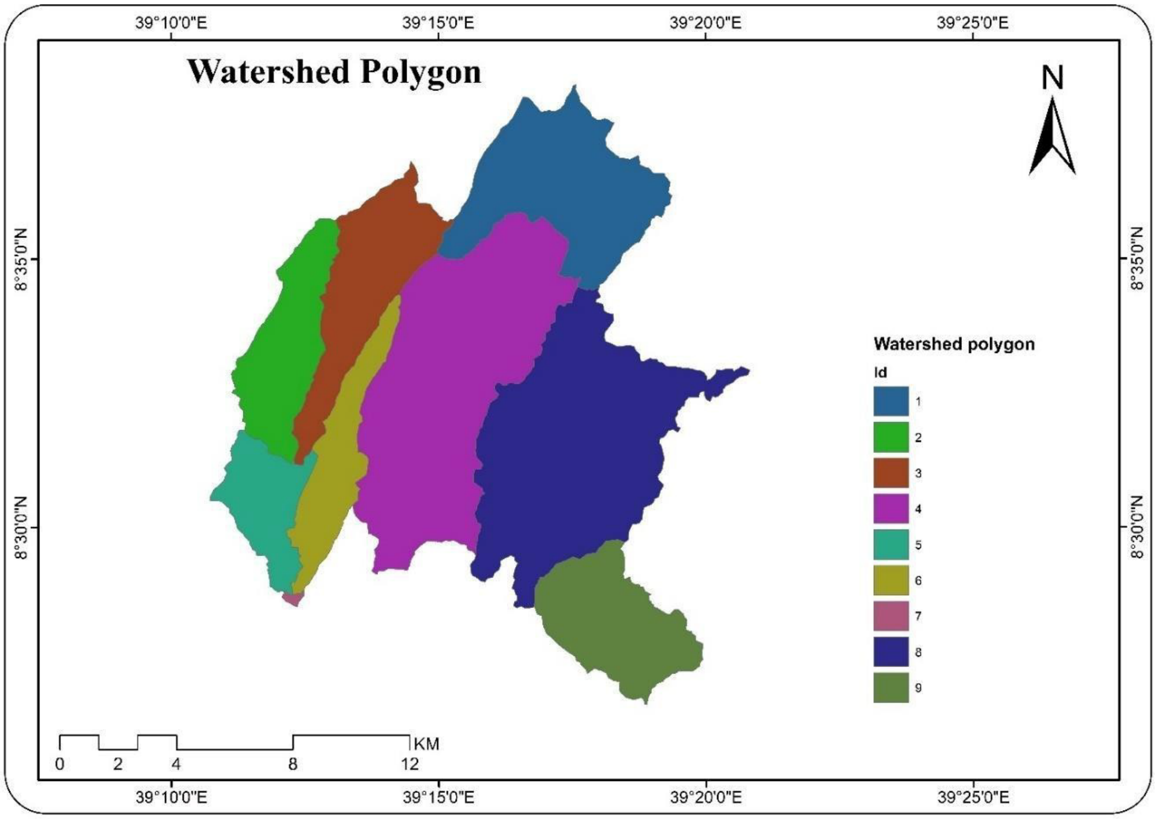

Figure 4-9: Catchment Polygon Processing

4.2 Setting criteria for potential ground water assessment

In assessing the potential for groundwater occurrence, various criteria are taken into account to gauge the likelihood of significant groundwater resources. These criteria encompass a range of factors, including drainage density, slope range, soil types, distances from lineaments, landforms, and geologic units. Drainage density, which measures the concentration of streams within a given area, serves as an indicator of potential groundwater occurrence. Areas with low drainage density, such as those falling within the range of 1.18 to 1.97, are deemed to have very low potential for groundwater, while higher density areas, falling below 0.39, are considered to have very high potential. Similarly, slope range plays a crucial role, with areas exhibiting low slopes, such as those between 0.00 to 1.00, classified as having very high potential for groundwater occurrence. Soil types further influence groundwater potential, with certain types, like Vertisols and Phaeozem, indicating higher potential due to their water retention properties. Additionally, the proximity to lineaments, or linear features such as faults or fractures, is considered, with closer distances indicating higher potential.

Landforms also provide insight, with level land indicating higher potential compared to steep land. Lastly, geologic units are evaluated, with recent basaltic flows and cinder cones, for example, suggesting very high potential due to their porous nature and potential for groundwater storage. By integrating these criteria, a comprehensive assessment of groundwater potential can be conducted, guiding decision-making processes related to groundwater resource management and development. This multidimensional approach enables stakeholders to prioritize areas for further exploration and investment, ensuring the sustainable utilization of groundwater resources to meet the needs of both present and future generations.

Table 4-1: Criteria to evaluate each parameter for ground water potential assessment

Variable	Criteria	Rank	Description
Drainage Density	0 – 0.39	5	Very High
	0.39 – 0.79	4	High
	0.79 – 1.18	3	Moderate
	1.18 – 1.58	2	Low
	1.58 – 1.97	1	Very low
Slope Range	0.00 -1.00	5	Very High
	2.00– 10.00	4	High
	10.00 – 30.00	3	Moderate
	>30	2	Low
	30.00 – 70.00	1	Very low
Soil Types	Vertisols	1	Very low
	Luvisols	2	Low
	Lithosol	3	Moderate
	Andosols	4	High
	Phaeozem	5	Very High
Distances from Lineaments	0 – 1800.31	5	Very High
	1800.31- 3684.94	4	High
	3684.94 – 6016.89	3	Moderate
	6016.89 – 9344.49	2	Low
	9344.49 – 15583.66	1	Very low
Landforms	Level Land	4	High
	Sloping Land	3	Moderate
	Steep land	2	Low
Geologic Units	Very recent Basaltic flow and cinder cones	5	Very High
	Bofa Fissurals	4	High
	Oversaturated Trachytic obsidian	3	Moderate
	Dacitic Lava flows	2	Low
	Lacustrine Sediment with subordinate alluvium	1	Very low

4.3 Development of Groundwater Potential Determining Factors

4.3.1 Drainage Density Factor

In assessing the Drainage Density Factor for groundwater occurrence, the study area's drainage network was initially digitized from the Geologic map. Subsequently, the drainage density was directly calculated within ArcMap utilizing spatial analyst tools. The analysis aimed to understand the relationship between drainage density and groundwateroccurrences, recognizing that higher drainage density typically correlates with reduced infiltration of water into the ground, resulting in increased runoff, and vice versa. To facilitate further analysis, the drainage density layer was ranked and reclassified into five distinct classes using the reclassify tool within the spatial analyst toolbox. This reclassification process involved assigning higher ranks to areas with lower drainage densityand vice versa, aligning with established principles in groundwater hydrology (Sisay Libase,2007). Ultimately, the reclassified map of drainage density was generated, providing a visualrepresentation of the spatial distribution of drainage density across the study area (refer to fig 4.10).

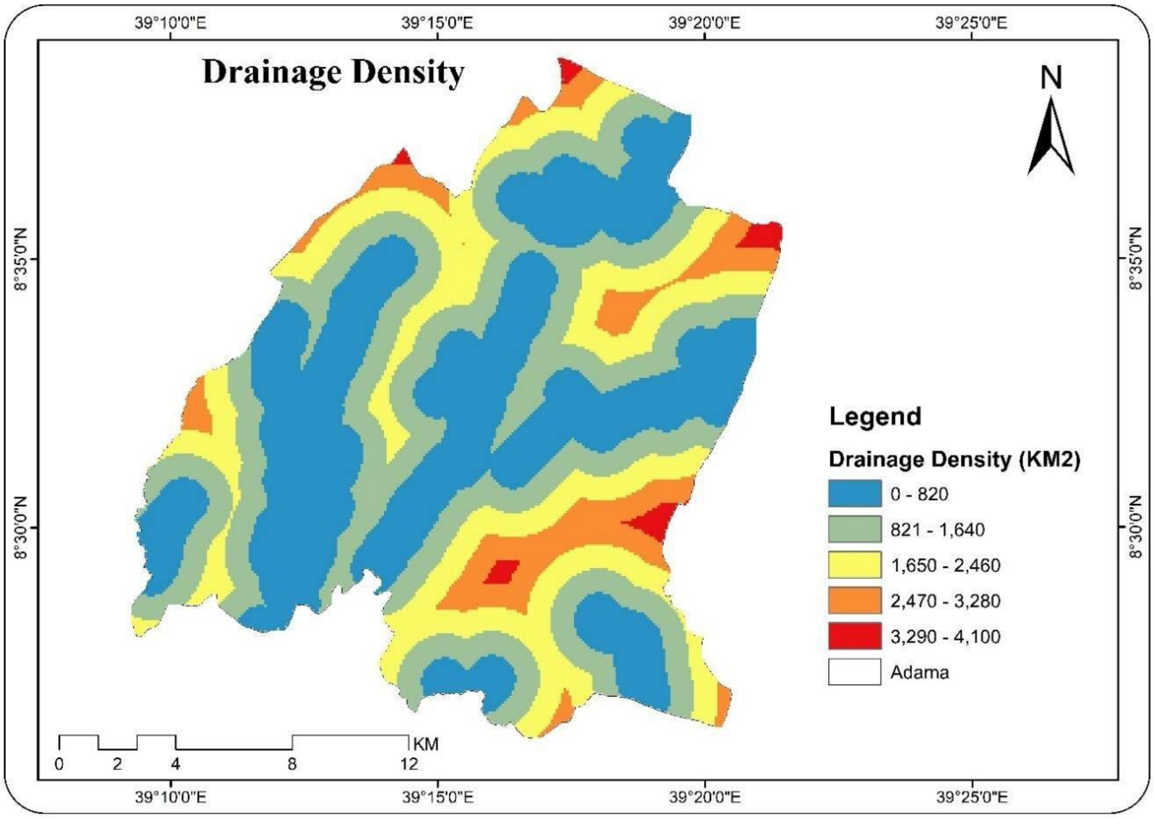

Figure 4-10: Drainage density map

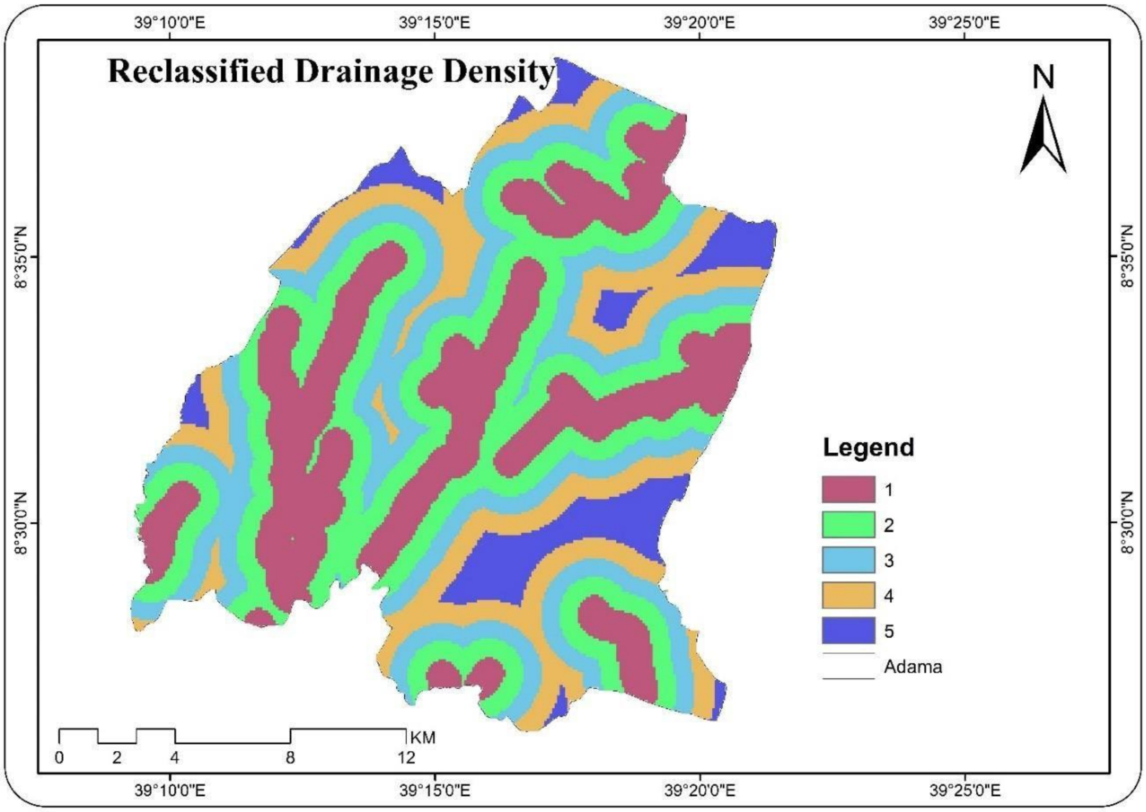

Figure 4-11: Reclassified drainage density

4.3.2 Slope Factor

In analyzing the Slope Factor for groundwater assessment, the slope of the study area was computed through spatial analysis within ArcGIS 10.8, utilizing the Triangulated Irregular Network surface derived from contours of the Adama District. These contours were initially digitized from a georeferenced geologic map of the area. Subsequently, the slope of the study area was categorized into four distinct classes using the reclassify tool within the spatial Analyst toolbox (refer to Table 4.1). Considering the implications for groundwater occurrence, areas characterized by flat or level terrain with low slope values are capable of retaining rainfall, facilitating recharge processes and thereby assigned the highest rank. Conversely, elevated areas with steep slopes experience higher runoff and lower infiltration rates (Nag S.K. & Anindita Lahiri, 2011). Consequently, they were assigned lower ranks in the classification scheme. The resulting reclassified slope map provides valuable insight into the spatial distribution of slope characteristics across the study area (see figure 4.12), aiding in the identification of areas with varying degrees of susceptibility to groundwater occurrence based on terrain slope.

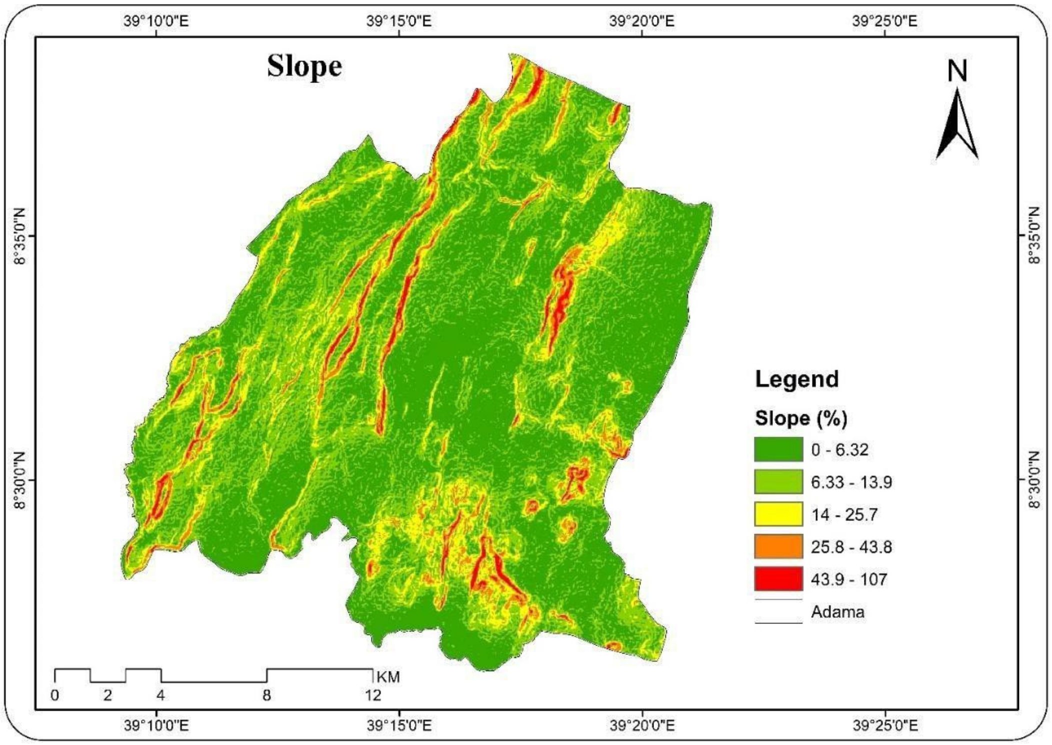

Figure 4-12: Slope

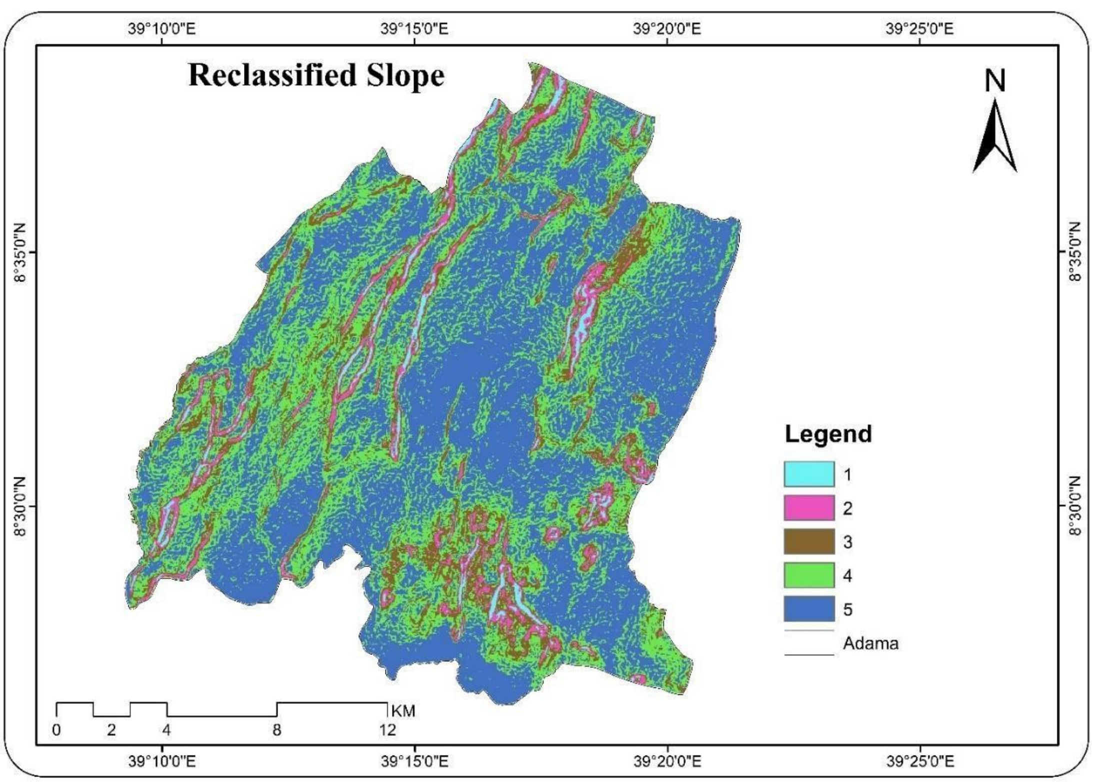

Figure 4-13: Reclassified slope

4.3.3 Soil Factor

In evaluating the Soil Factor for groundwater assessment, the permeability and infiltration characteristics of soil play crucial roles. Following the methodology outlined by Sisay Libase and referencing the Ethiopian Road Authority Drainage Density Manual (2002), soil reclassification into hydrologic groups is based on these fundamental factors. To begin, the soil layer was obtained from the FAO Soil and Database of East Africa (1997) and prepared for analysis. This involved clipping the soil layer to the study area extent and identifying five general soil types. Subsequently, the soil layer was converted into a raster format and reclassified into five distinct classes using the reclassify tool within the spatial Analyst toolbox. The classification scheme assigned the highest rank to soil types exhibiting very high permeability, in accordance with their potential for groundwater occurrence (refer to Table 4.1). Finally, the resulting reclassified soil map provides a spatial representation of soil types and their respective ranks in relation to groundwater potential across the study area (see figure 4.14).

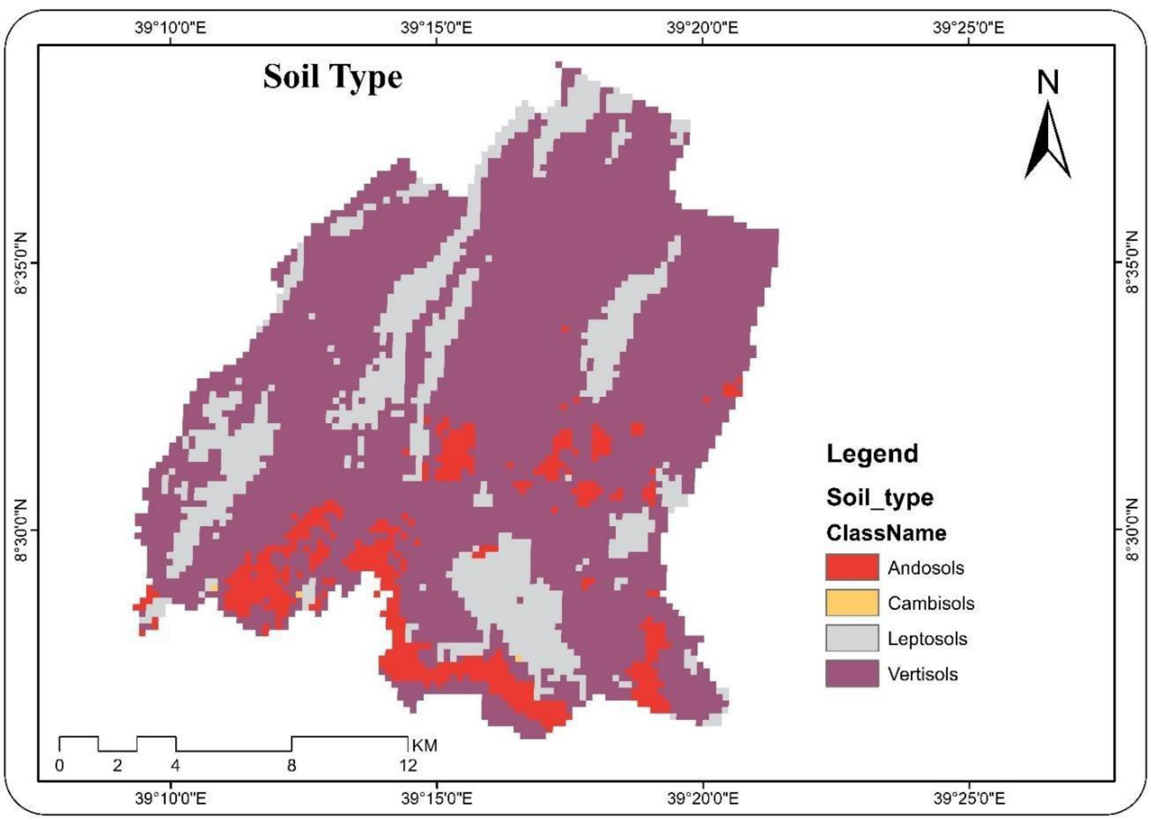

Figure 4-14: Soil Type

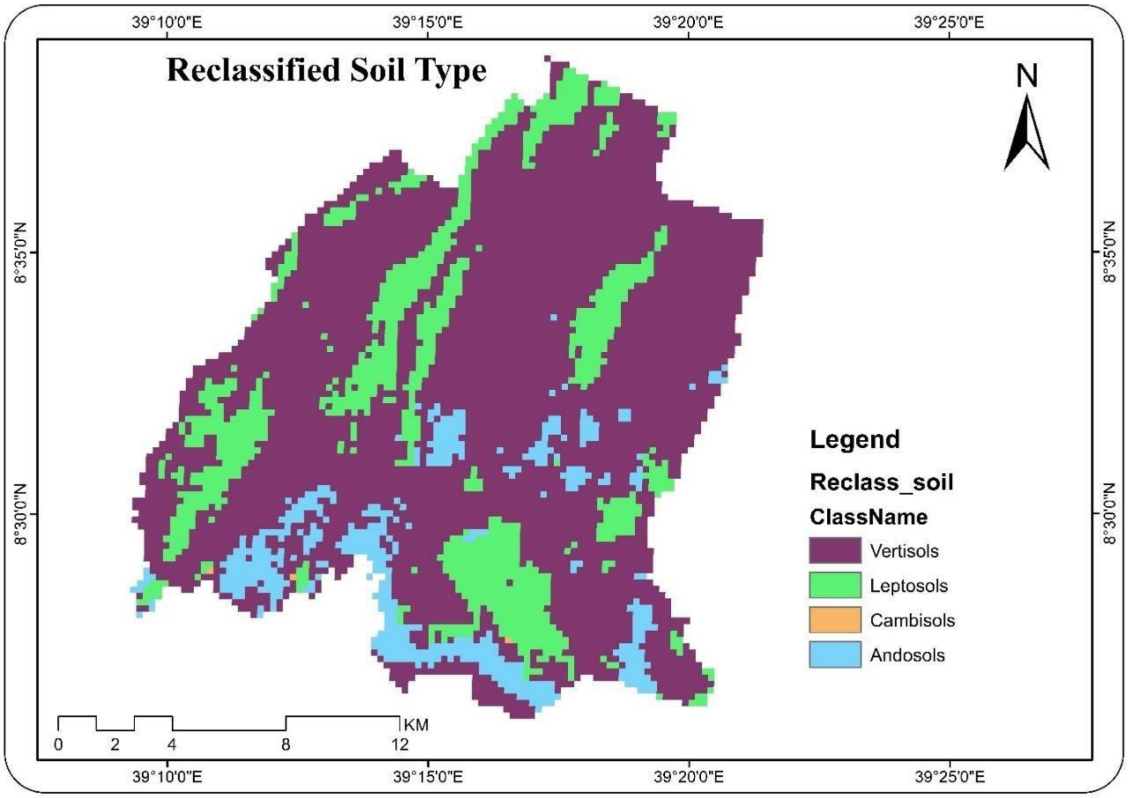

Figure 4-15: Reclassified soil types

4.3.4 Land Use Land Cover Factor

In assessing the Land Use Land Cover (LULC) Factor for groundwater occurrence, fifteen distinct land use types were identified across the study area. The data on LULC was sourced from the Copernicus Global Land Cover facility. Recognizing the significant influence of land use and land cover on groundwater behavior, the LULC classes were ranked based on their capacity to facilitate water penetration into the ground and retain water on the surface. The classification process involved reclassifying the LULC data into five classes using the reclassify tool within the spatial analyst toolbox. Specifically, areas covered by shrubs were assigned a higher rank due to their significant contribution to groundwater recharge, particularly in elevated areas where they are less susceptible to overgrazing by cattle. Notably, the dominant animals in the area, such as camels and goats, are browsing animals that do not consume shrubs, further enhancing their potential as groundwater recharge zones. Finally, the resulting reclassified LULC map provides valuable insights into the spatial distribution of land use types and their respective contributions to groundwater recharge across the study area.

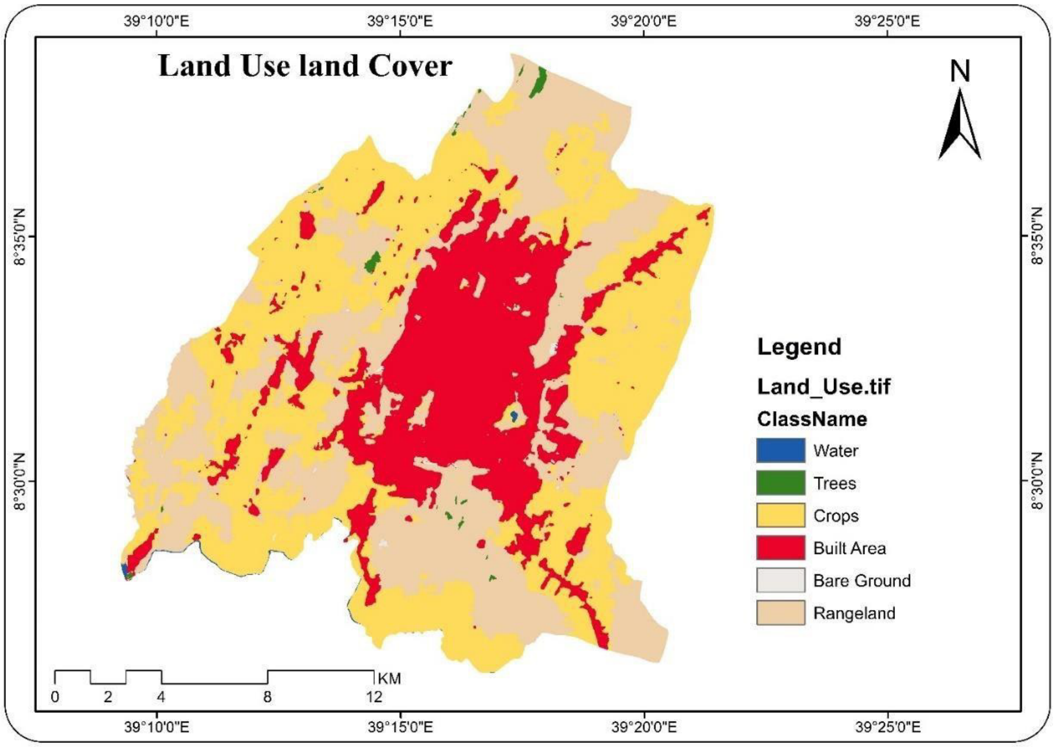

Figure 4-16: Land use land cover

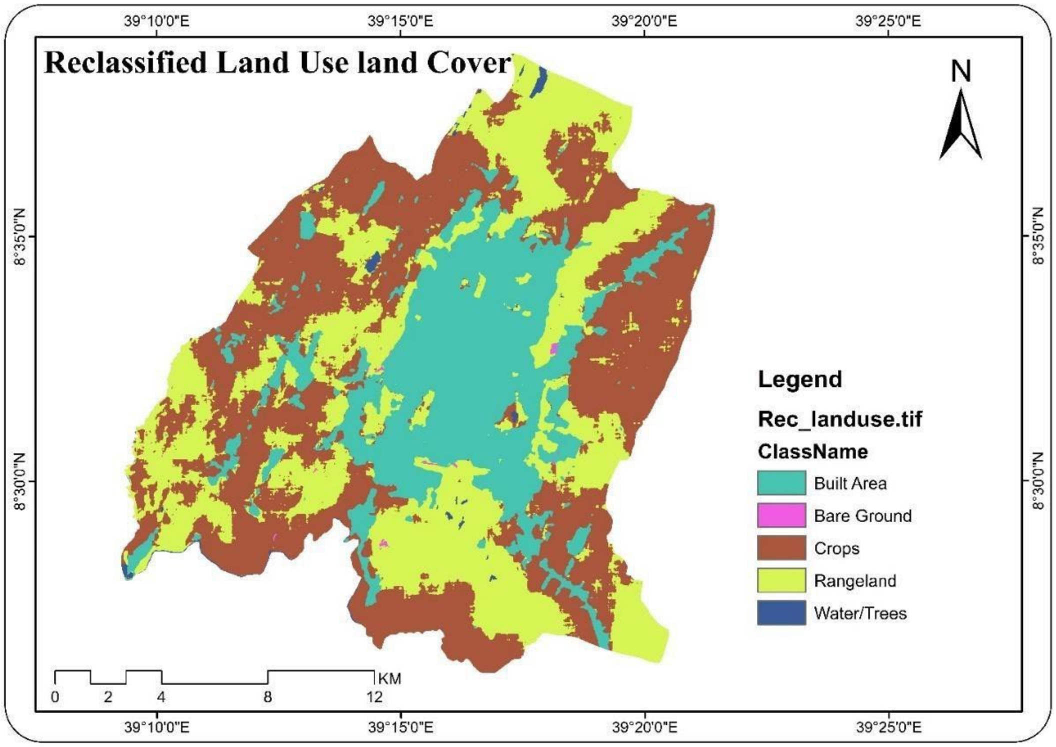

Figure 4-17: Reclassified land use land cover

4.3.5 Annual Rainfall Factor

In evaluating the Annual Rainfall Factor for groundwater potential, rainfall serves as a fundamental source of groundwater recharge. Higher amounts of rainfall typically indicate the potential for high groundwater occurrence zones. However, due to the uneven distribution of rainfall stations in and around the study area, interpolation techniques were employed to estimate rainfall across the entire study area. Specifically, the Inverse Distance Weight tool within the spatial analyst toolbox was utilized for this purpose. Following interpolation, the rainfall raster layer for the study area was clipped to focus on relevant data. Given the relatively low rainfall amounts and the absence of significant differences among rainfall data, the clipped rainfall raster layer was classified into two classes using the reclassify tool within the spatial analyst toolbox. Finally, the resulting reclassified rainfall map provides a simplified representation of rainfall distribution across the study area (see Figure 4.17), aiding in the identification of areas with potential groundwater recharge based on annual rainfall patterns.

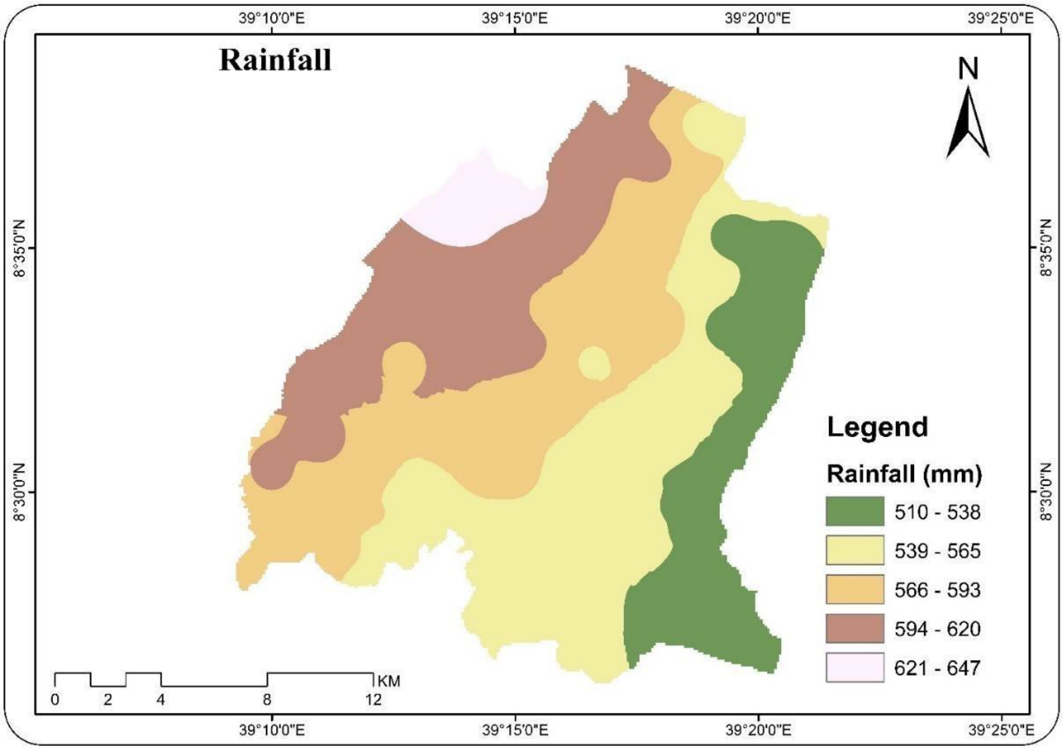

Figure 4-18: Rainfall

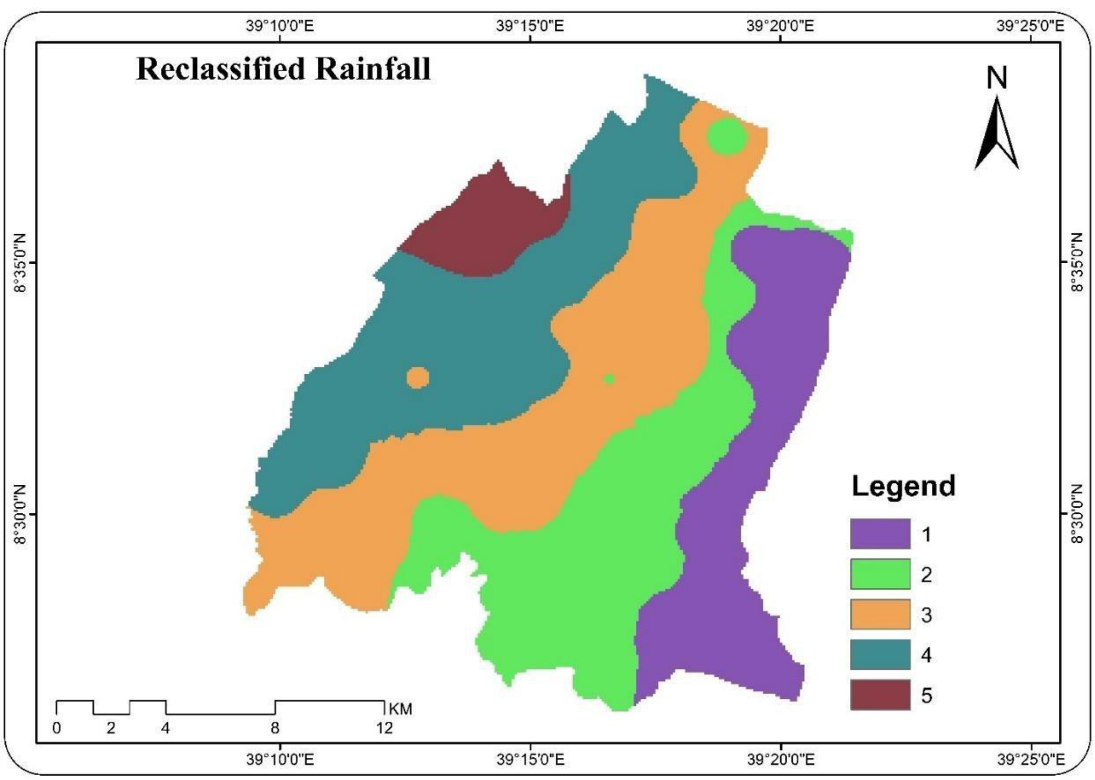

Figure 4-19: Reclassified rainfall

4.3.6 Lineament Factor

In assessing the Lineament Factor for groundwater potential, structural features were identified and digitized from the geologic map of the area. To analyze their relevance to groundwater occurrence, the digitized lineaments were rasterized, allowing for distance analysis. The resulting lineament distance layer was then classified into five classes based on the principle that areas in close proximity to lineaments exhibit increased porosity and permeability, thus enhancing the likelihood of groundwater accumulation (refer to Table 4.1). This classification scheme ranks areas according to their distance from lineaments, with closer distances indicating higher potential for groundwater occurrence. Finally, the reclassified map of lineament distance provides a visual representation of areas with varying degrees of susceptibility to groundwater accumulation based on their proximity to structural features (see Figure 4.19), facilitating the identification of potential groundwater recharge zones within the study area.

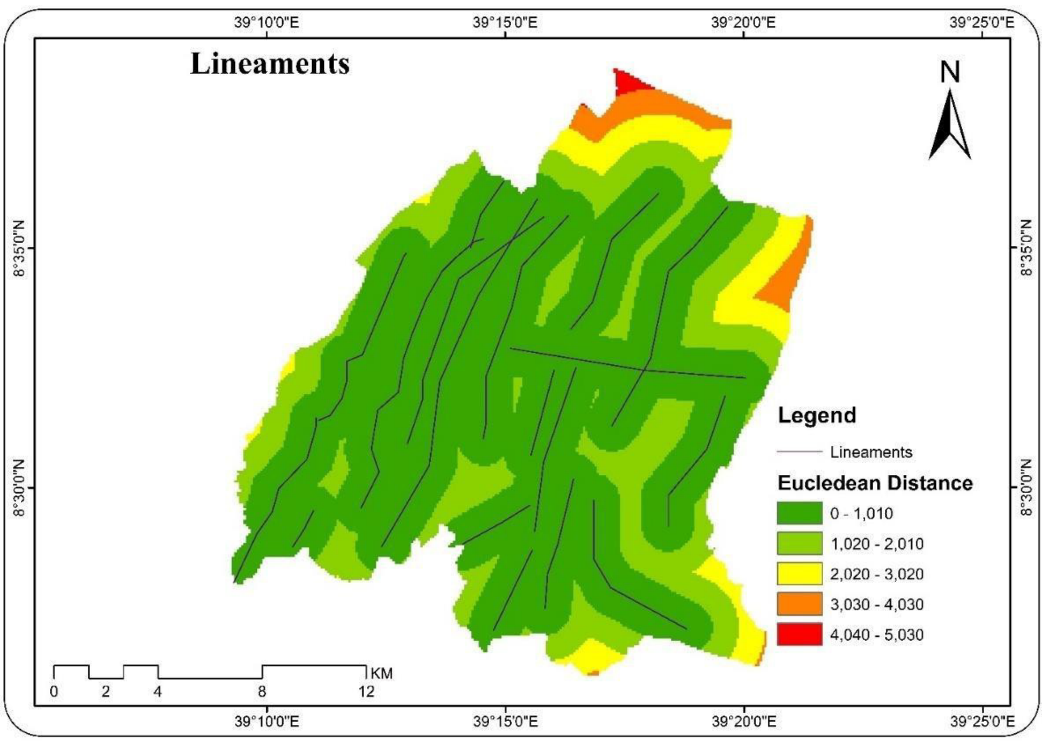

Figure 4-20: Distances from Lineaments

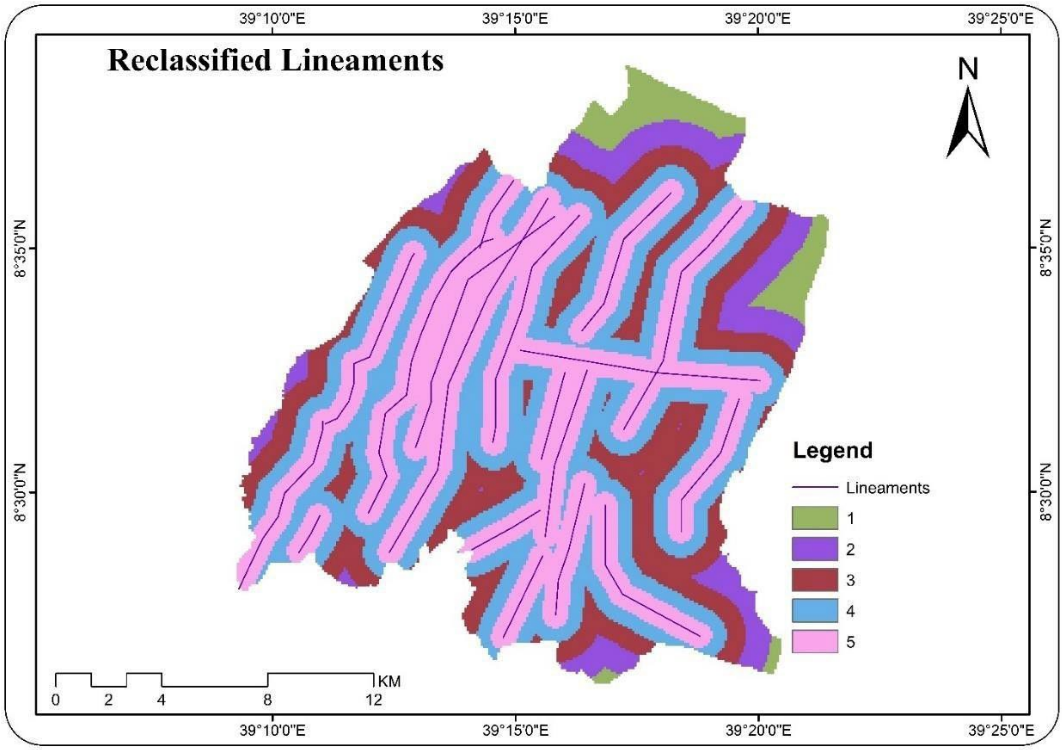

Figure 4-21: Reclassified lineaments

4.3.7 Geomorphologic Factor

In groundwater exploration, understanding the geomorphologic characteristics of an area is crucial for identifying favorable zones for groundwater occurrence. The landform type of the study area was derived from the Digital Elevation Model (DEM). Specifically, level landforms are considered to be the most conducive for groundwater occurrence due to their ability to facilitate recharge and promote the circulation of water through interflow at shallow depths, above the groundwater level. To assess the significance of geomorphology in relation to groundwater potential, the Landform layer was ranked and classified into three classes. This classification scheme prioritized level landforms, assigning them the highest rank based on their favorable characteristics for groundwater occurrence. Finally, the resulting reclassified map provides a visual representation of areas with varying geomorphologic characteristics and their respective potential for groundwater occurrence (see Figure 4.22), aiding in the identification of target zones for groundwater exploration within the study area.

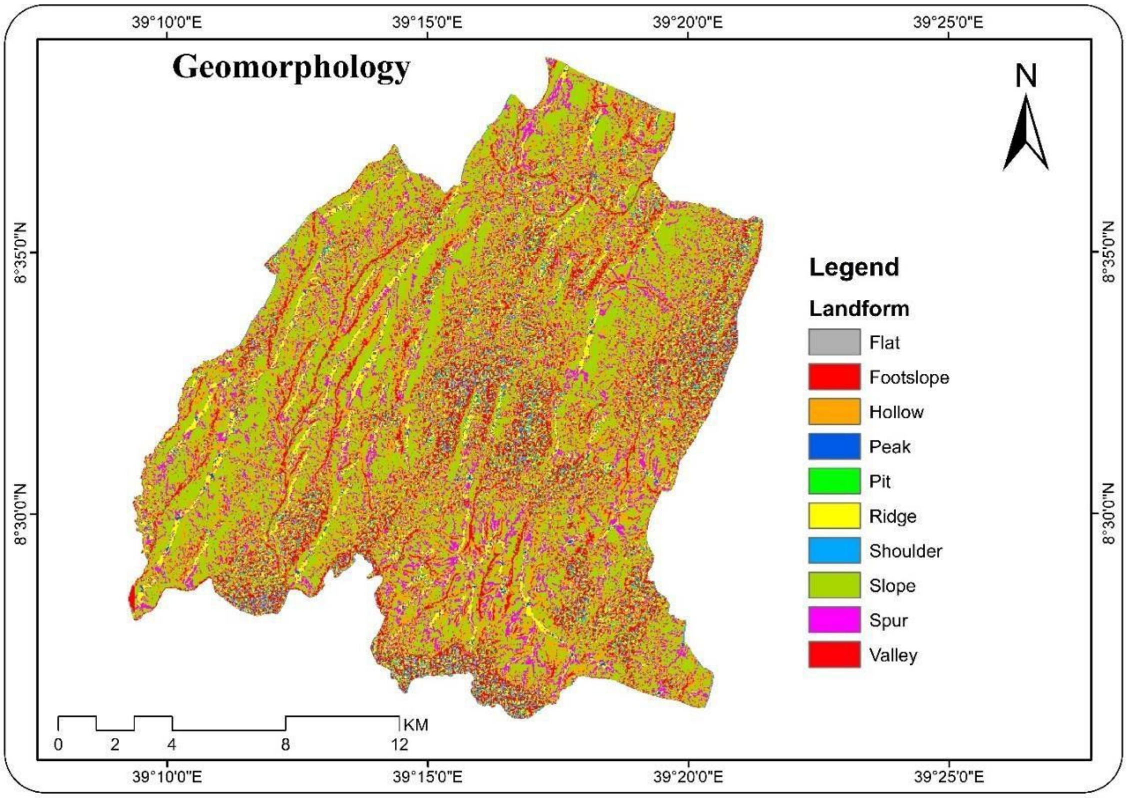

Figure 4-22: Landform

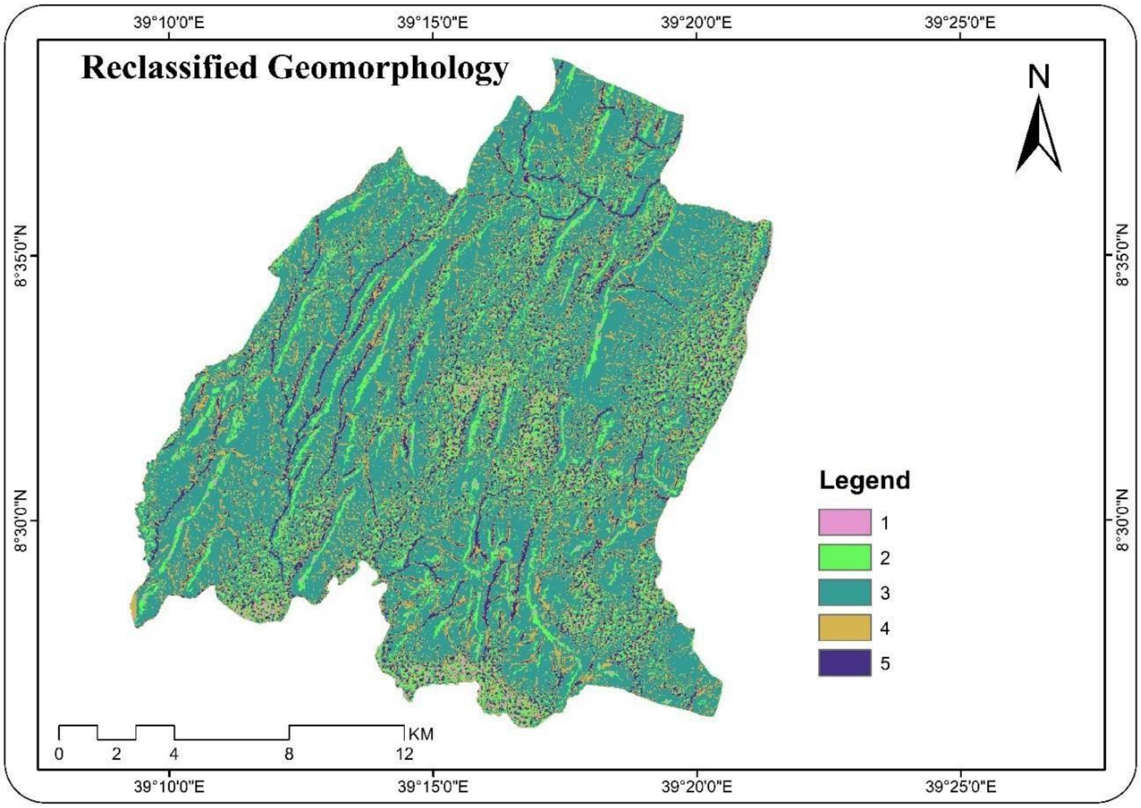

Figure 4-23: Reclassified landform

4.3.8 Geological Factors

Geological factors significantly influence the distribution and occurrence of groundwater within a given area. In the present study, five distinct geologic units were identified and digitized from the geologic map of the study area. To assess their relevance to groundwater recharge, the digitized geologic units were converted into raster format and subsequently ranked and classified into five classes based on their importance. The classification scheme, outlined in Table 4-1, highlights the varying degrees of significance of each geologic unit in relation to groundwater recharge. Finally, the resulting reclassified map provides a spatial representation of the distribution of geologic units and their respective importance for groundwater recharge within the study area (see Figure 4.24). This analysis aids in identifying areas with higher potential for groundwater occurrence based on the underlying geologic characteristics, thereby informing groundwater exploration and management strategies.

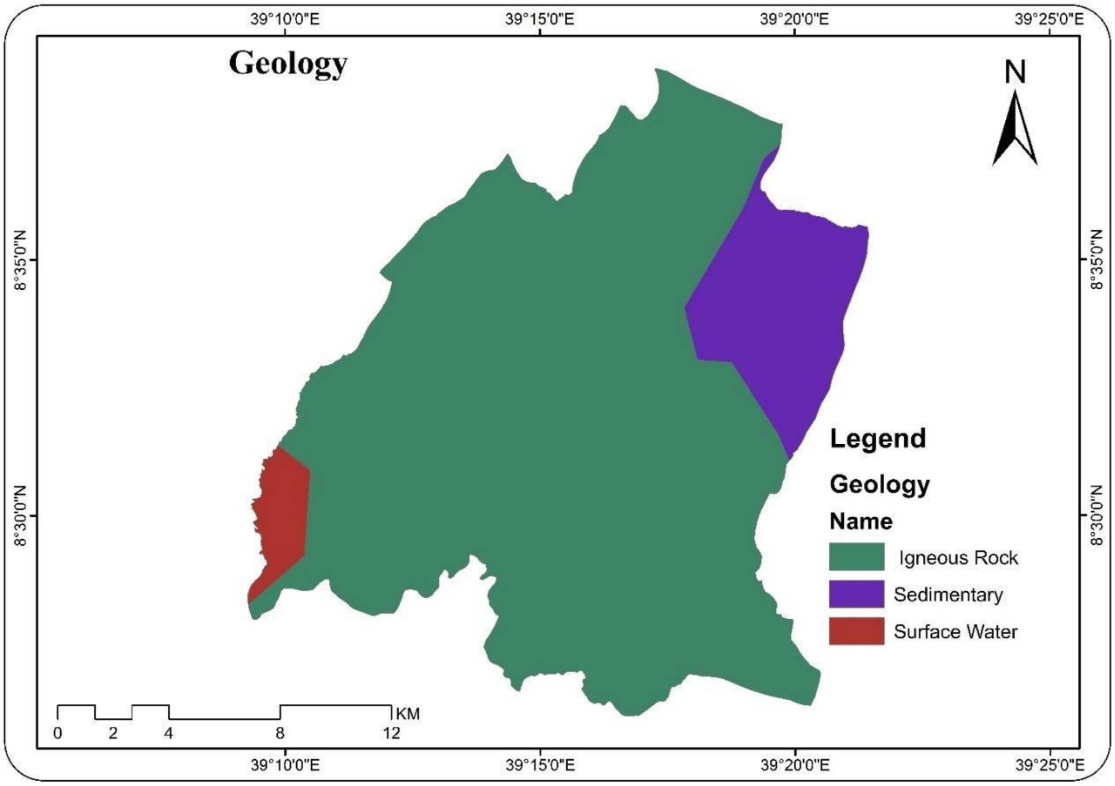

Figure 4-24: Geologic unit

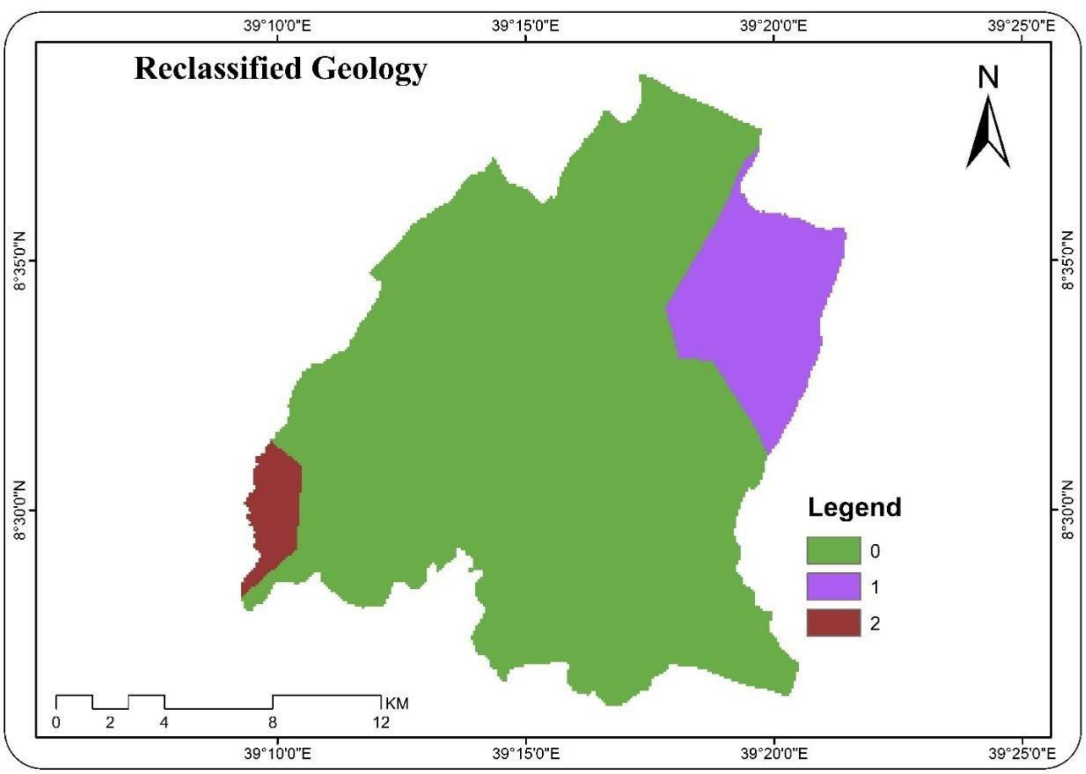

Figure 4-25: Reclassified geologic unit

4.4 Data Integration and Analysis

In the process of data integration and analysis, the eight layers representing groundwater occurrence determining factors were combined using the Weighted Overlay Tools available in the Spatial Analyst ArcToolbox of ArcGIS 10.8. The integration process involved assigning weights to each layer based on their relative importance, which were calculated using IDIRISI 3.2 software. These weights reflect the significance of each factor in contributing to groundwater potential within the study area. Subsequently, the weighted layers were overlaid to generate a composite map representing the overall groundwater potential zone. To streamline this process, the Model Builder tool within ArcGIS 10.8 was utilized. Model Builder facilitated the creation of a customized workflow, automating the integration and analysis steps to generate the groundwater potential zone map. By combining the weighted layers and applying the specified workflow, the model generated a comprehensive output representing the spatial distribution of groundwater potential across the study area. This integrated approach to data analysis allows for a holistic assessment of groundwater potential, taking into account multiple contributing factors and their respective influences. The resulting groundwater potential zone map provides valuable insights for decision-making in groundwater resource management, land use planning, and sustainable development initiatives within the study area.

4.4.1 GIS Modeling

GIS modeling involves the creation and execution of spatial processes using tools available in the ArcToolbox within ArcGIS software. Model Builder, a graphical interface within ArcGIS, facilitates the construction of complex workflows by linking together various geoprocessing tools and commands. These workflows automate tasks such as data processing, analysis, and visualization, streamlining the GIS modeling process. Once the model is created and configured to perform specific tasks, it is executed to generate outputs. These outputs may include maps, tables, or other spatial data representing the results of the modeling process. After the execution of the model, the outputs are visualized and explored within ArcMap, the main interface of ArcGIS. In ArcMap, users can interactively view, analyze, and interpret the generated data layers, allowing for further exploration and refinement of the modeling results. Overall, GIS modeling using Model Builder enables users to create sophisticated spatial analyses and workflows, automating repetitive tasks and facilitating efficient decision-making processes in various domains such as environmental management, urban planning, and natural resource assessment.

4.4.2 Weighted Overlay Analysis

In the groundwater potential zone assessment, a Weighted Overlay Analysis was conducted to integrate multiple factors influencing groundwater occurrence within the study area. This analysis was performed using the Weighted Overlay Tool available in the Spatial Analyst extension of ArcGIS 10.8, allowing for the combination of diverse input layers on a common measurement scale to create an integrated analysis. Eight factors were considered in this analysis: Geology, Landform (Geomorphology), Lineaments, Slope, Soil, Rainfall, Land Use/Land Cover (LULC), and Drainage. Each factor contributes differently to groundwater potential, with certain factors deemed more influential than others. To assign relative weights to these factors, pair-wise comparisons were conducted using IDRISI 3.2, resulting in the calculation of Eigen vector weights. These weights were then normalized and adjusted to ensure consistency, resulting in the final relative weights for each factor.

The relative weights were assigned based on their perceived importance in groundwater occurrence assessment, with Geology considered the most significant factor due to its direct influence on factors such as discharge magnitude, rock fracturing, and formation thickness. Geomorphology and Lineaments were assigned secondary and tertiary importance, respectively, given their roles in controlling infiltration rates and facilitating water percolation into the ground. To facilitate the Weighted Overlay Analysis, continuous raster layers were reclassified into integer values, with each value representing a specific range or category. The assigned weights for each factor were then multiplied by 100 to ensure compatibility with the integer-based Weighted Overlay Tool. The Weighted Overlay Tool was then employed to combine the raster layers using the assigned weights, resulting in the generation of groundwater potential zones. The assigned weights for each factor, as well as the resulting integrated model, are summarized in Table 4.2. These weights reflect the relative importance of each factor in determining groundwater potential zones, providing valuable insights for groundwater resource management and land use planning within the study area.

Table 4-2: Weight assignment to each factor that determine GW potential Zones

No		Geology	Landform	Lineaments	Slope	Soil	Rainfall	LULC	Drainage	Weight*100
1	Geology	1								35
2	Landform	1/3	1							23
3	Lineaments	1/3	1/3	1						16
4	Slope	1/5	1/3	1/3	1					9
5	Soil	1/5	1/7	1/5	1/3	1				7
6	Rainfall	1/7	1/5	1/5	1/3	1/3	1			5
7	LULC	1/7	1/5	1/5	1/3	1/3	1/3	1		3
8	Drainage	1/7	7-Jan	1/5	1/5	1/3	1/3	1/3	1	2
Total										100

4.4.3 Groundwater potential Zones

The assessment of groundwater potential zones using the Weighted Overlay Tool in ArcGIS 10.8 revealed distinct spatial patterns within the study area. High groundwater potential zones were predominantly situated along the southwestern margin, particularly around the sides of the Awash River. These areas are characterized by favorable geological and hydrological conditions, facilitating groundwater recharge and storage. Conversely, low groundwater potential zones were observed at elevated locations, such as the summits of Adama Guddo Mountain and Borchota Hill. These areas typically exhibit limited groundwater recharge and storage capacity due to geological constraints.

Medium groundwater potential zones encompassed the majority of the study area, extending from one extreme to the other in all directions. This indicates moderate suitability for groundwater occurrence across a wide expanse of the landscape. Statistically, the study area comprises 21.93% low groundwater potential zones, 49.89% medium groundwater potential zones, and 28.17% high groundwater potential zones. This distribution underscores the dominance of moderate potential zones, highlighting their significance in groundwater resource availability.

From an administrative perspective, high groundwater potential zones are concentrated in specific rural kebeles, notably Dire Degaga, Qachachule Guja, and Sara Areda in the southwestern part of the district. Moderate potential zones are prevalent in various kebeles throughout the study area, excluding elevated regions. Low potential zones are primarily situated in southern parts of Buta Wegere Mariyam, southeastern Dengore Ferda and Dengore

Tiyo, and elevated areas of Adama Guddo and Borchota Hills. This administrative delineation aids in identifying priority areas for groundwater management and resource allocation efforts.

Overall, the spatial distribution of groundwater potential zones provides valuable insights for sustainable groundwater resource management and informed decision-making regarding land use planning and development initiatives within the study area.

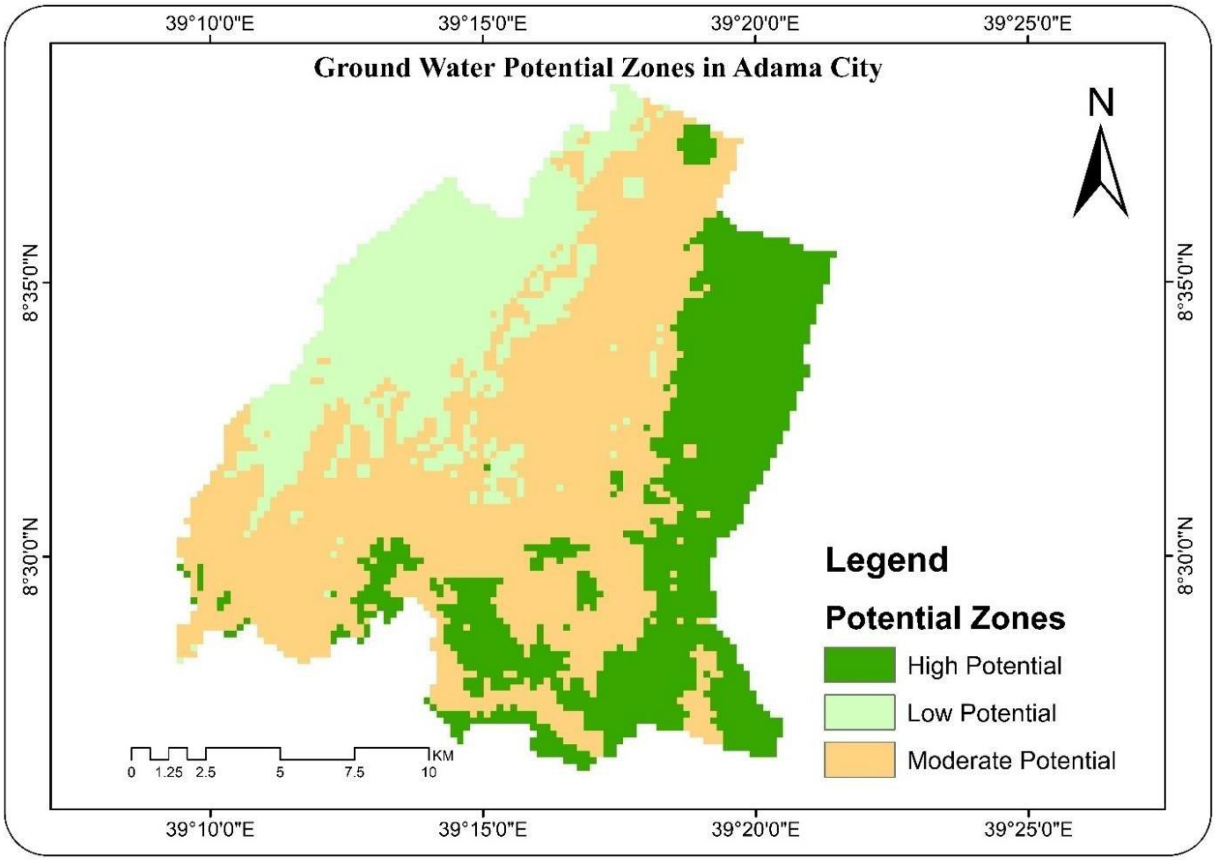

Figure 4-26: Ground water potential zone map of Adama City

Table 4-3: Classification of Groundwater Potential Zones (After integration of all thematic maps)

Class	Area Km^2	% of the area
Low Potential	6718.57	21.93
Moderate Potential	15283.61	49.89
High Potential	8630.27	28.17
Total	30632.45	100.00

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The assessment of groundwater potential zones in Adama City using geospatial technology has proven to be a valuable method for sustainable water resource management. The study successfully identified various zones with different groundwater potentials, providing critical data for urban planning and development. By integrating remote sensing, GIS, and various hydrogeological data, the research has established a comprehensive groundwater potential map for Adama City. This map serves as an essential tool for decision-makers to ensure efficient and sustainable use of groundwater resources, ultimately contributing to the city's long-term water security and resilience against water scarcity issues. GIS is an important tool for Groundwater Potential Zone assessment studies which is used to store, process, analyse and integrate different layers according to their relative importance in Spatial analysis tools of ArcGIS 10.8 and Arc Hydro extension in classifying layers into required number of classes and integrating different layers according to the weights calculated using Pair wise comparison of IDRISI 3.2 Software is critical in solving this problem. The use of GIS techniques is a very cost-effective approach in viewing and in preliminary survey, hydrological and geophysical prospecting are usually some conditions for groundwater mapping.

5.2 Recommendation

- The Regional Water Bureaus should use the result of this research as baseline information to make further study in the assessment of groundwater potential areas in the district for solving water supply problem of the study area.
- The approach of the current study should be adopted for groundwater study in the area for instance using GIS is a crucial and accurate system for investigation of geographical problems like delineation of GW potential zones.
- GW is the safest type of water resource next to ice; much attention should be given to potential areas identified in conserving the identified zones from different pollutants especially from planting factories around it, like textile manufacturing and tanneries since they use different chemicals that harm human being.

- GIS integrated with hydrological and geophysics could be solved for mapping GW shortage.
- International Donors, Non-Governmental Organizations and Governmental Organizations should give more attention to solve the availability of data problem through the development of special place where citizen can easily access the necessary data to solve societal problems in the areas of scientific research.
- The significance of public participation is great here because to conserve the GW Potential area.
- Implement continuous monitoring of groundwater levels and quality to detect any changes promptly and manage resources more effectively.
- Adopt sustainable groundwater management practices, including controlled extraction and recharge enhancement techniques, to prevent over-exploitation and depletion of the resource.
- Educate the community about the importance of groundwater conservation and the role they can play in sustainable water management.
- Encourage ongoing research and periodic updates of the groundwater potential map to incorporate new data and technological advancements, ensuring the information remains accurate and relevant.

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