# GROUND WATER POTENTIAL AND LAND SUITABILITY MAPPING FOR SURFACE IRREGATION USING GEOSPATIAL TECHNOLOGY: THE CASE OF KATAR WATERSHED, RIFT VALLEY BASIN, ETHIOPIA

Mohammed Gena Edao

A Thesis Submitted to the department of Geomatics Engineering,

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Geoinformatics Engineering

Office of Graduate Studies

Adama Science and Technology University

September, 2022

Adama, Ethiopia

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# Declaration

I hereby declare that this Master Thesis entitled "Ground Water Potential and Land Suitability Mapping for Surface Irrigation Using Geospatial Technology: The case of Katar Watershed, Rift valley Basin, Ethiopia" is my own work and has not been submitted to any university for similar purpose. The references used in this proposal are duly recognized by proper citations.

| Name of the student | Signature | Date |
|---|---|---|

## Recommendation

we, the advisor(s) of this thesis, hereby certify that we have read the revised version of the thesis entitled "Ground Water Potential and Land Suitability Mapping for Surface Irrigation Using Geospatial Technology: The case of Katar Watershed, Rift valley Basin, Ethiopia" prepared under our guidance by Mohammed Gena Edao submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Geoinformatics Engineering Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

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| Co-advisor | Signature | Date |

# Approval Page

we, the advisors of the thesis entitled "Ground Water Potential and Land Suitability Mapping for Surface Irrigation Using Geospatial Technology: The case of Katar Watershed, Rift valley Basin, Ethiopia" and developed by Mohammed Gena Edao hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Mohammed Gena Edao have read and evaluated the thesis entitled "Ground Water Potential and Land Suitability Mapping for Surface Irrigation Using Geospatial Technology: The case of Katar Watershed, Rift valley Basin, 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

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Final approval and acceptance of the thesis 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).

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| CI | Consistency Index |
| CR | Consistency Ratio |
| DEM | Digital Elevation Model |
| NMA | National Meteorological Agency |
| ERDAS | Earth Resources Data Analysis System |
| AHP | Analytical Hierarchy Process |
| FAO | Food and Agricultural Organization |
| MCDM | Multi-Criteria Decision Making |
| GIS | Geographical Information System |
| GWPZ | Ground Water Potential Zone |
| ILS | Irrigation land suitability |
| IDW | Inverse Distance Weighting |
| LULC | Land Use Land Cover |
| NASA | National Aeronautics and Space Administration |
| PCM | Pair-wise Comparison Matrix |
| RI | Random Index |
| SRTM | Shuttle Radar Topography Mission |
| UTM | Universal Transverse Mercator |

## Abstract

*In Ethiopia, surface water is the primary source of agricultural production while groundwater is mainly used for domestic water use. Many irrigation systems that use surface water for irrigation get their water from river diversions, which only helps farmers that own the land along the river. But as rivers dry up due to climate change and increased irrigation use, there will be less water available, which will lead to new societal issues. Utilizing ground water potential is more crucial in order to increase irrigation potential and the possibility of acquiring reliable water resources for irrigation in the area that is far from the river because it is more reliable, less sensitive to droughts, and easily accessible for individual users. To overcome these challenges the aim of this study was to delineate Ground Water Potential and Land suitability for surface irrigation using Geospatial Technology in Katar Watershed, Rift Valley Basin, Ethiopia. The methodology under taken was considering nine parameters (lithology, geomorphology, slope, lineament density, land cover, rainfall, drainage density, Elevation and soil) that affect groundwater potential while soil, slope, GWPZ, equidistance to road, and land use/cover were taken into consideration for the potential land suitability zone (PLSZ). The weights of each thematic layer were assigned (weighted), normalized and ranked based on their Suitability to groundwater occurrence and land suitability for irrigation by AHP method through Pairwise Comparison Matrix (PCM). All reclassified thematic maps were integrated into the weighted overly analysis tool to create the GWPZ and PLSZ. The findings shows that the area could be divided into four classes: very low potential 39.92km2 (1.12%), low potential 1382.68km2 (40.73%), moderate potential 1852.28km2 (54.56%), and high potential 121.75km2(3.59%) for GWPZ, and not suitable 1.30km2 (0.04%), low suitable 437.06km2 (12.90%), moderate suitable 2143.59km2 (63.29%), and high suitable 805.05km for PLSZ. This shows that, relative to its overall area coverage, the study area has better groundwater potential and land suitable for irrigation. The delineated GWPZ was verified using the existing water yield point data and 86% of the total were matched with their respective zones. Thus, the identified Results are reliable. The study offers helpful information for upcoming irrigation projects that are intended to be foreseen, and it serves as a tool for policymakers' higher-level cognitive processes about irrigation development projects within the watershed.*

**Keywords:** *Analytical Hierarchy process, Ground Water Potential Zone, Pairwise Comparison Method, Potential land suitability zone*

# CHAPTER 1: INTRODUCTION

## 1.1 Background

Groundwater (GW) is the most preferred and vital natural resources for the reliable and economic providing of water supply for agriculture and domestic use. Utilizing ground water potential is more important in order to raise irrigation potential and the possibility of acquiring reliable water resources for irrigation in the area that is remote from the river. Groundwater irrigation is more reliable, less sensitive to droughts, and easily accessible for individual users when compared to conventional surface water irrigation systems (Garrido et al., 2006). Therefore, the aim of this study to identify the ground water potential zone and land suitability for surface irrigation utilizing this water resources.

The majority of African countries' economies are heavily dependent on agriculture (Abeyou W. Worqlul a,  Jaehak Jeong a, Yihun T. Dile b, Javier Osorio a, Petra Schmitter c, Thomas Gerik a, R. Srinivasan b 2017). The agricultural economy of Ethiopia is largely based on rain-fed agriculture, which employs 85% of the people and produces nearly 50% of the gross domestic product. Therefore, with limited usage of irrigation, the majority of the population depends on rain-fed agriculture. The high degree of rainfall fluctuation and unreliability is the main issue with the country's rain-dependent agriculture. Lower agricultural yields are a result of insufficient soil fertility management combined with rainfall variability. For instance, the country receives 70–90% of its annual precipitation during a brief period, primarily from June to September. Furthermore, during the rainy season, the country produces 90-95 percent of its annual food supply (Abeyou W. Worqlul a, Jaehak Jeong a, Yihun T. Dile b, Javier Osorio a, Petra Schmitter c, Thomas Gerik a, R. Srinivasan b 2017). Droughts and crop failures are prevalent as a result of this fluctuation. As a result, food insecurity often turns into famine with the smallest unfavorable climatic incident, especially harming the rural poor's means of subsistence. Thus, in order to attain food security on a national and family level, irrigated agriculture must be improved and expanded. The wise use of limited physical resources, such as land and water, requires appropriate management and irrigation system selection. A well-developed and appropriate database is crucial to ensure proper maintenance and design of a specific irrigation system. As a result, it should be able to handle factors that affect the system in different ways both spatially and temporally.

In Ethiopia, surface water is the primary source of agricultural production while groundwater is mainly used for domestic use. Many irrigation systems that use surface water for irrigation get their water from river diversions, which only helps farmers that own the land along the river. The population in the majority of Ethiopian watersheds grows gradually and uses water from the rivers and their tributaries for irrigation and drinking (Nigussie, Hailu, and Azagegn 2019). But as rivers dry up due to climate change and increased irrigation use, there will be less water available, which will lead to new societal issues. Through groundwater development research, groundwater irrigation could be practical solution to the nation's food needs. Over the past 50 years, groundwater irrigation has expanded quickly and currently provides more than one-third of the world's irrigated area. It significantly contributes to the water and food security of many millions of underprivileged people worldwide(Dawit.Y 2021). This shows that groundwater supply growth for irrigation is now rising throughout the region, and it is used in many nations and in all climate zones. Use of groundwater for irrigation is significant and growing because it gives farmers a reliable source of water that can be used in a flexible manner (Siebert et al. 1956). The twelve main river basins in Ethiopia have a substantial surface water potential, yet there is a lot of regional and temporal variability. The nation is referred to as the "water-tower" of Africa despite the lack of a full study on the potential of its groundwater resources (Abeyou W. Worqlul a, *, Jaehak Jeong a, Yihun T. Dile b, Javier Osorio a, Petra Schmitter c, Thomas Gerik a, R. Srinivasan b 2017).

The Central Rift Valley of Ethiopia is an example of an environmentally fragile region, where natural vegetation is quickly being turned into agricultural land as a result of the rapidly expanding population and inappropriate land management(Nigussie, Hailu, and Azagegn 2019). Rapid population growth accelerates deforestation and land degradation, leading to fierce competition for water and land resources. Sustainable groundwater management depends on accurate mapping and monitoring of groundwater resource quantities and yearly extraction rates. Field surveys, which are expensive, time-consuming, and labor-intensive, have been the main approach for mapping groundwater. These surveys were done with the aid of geomorphic interpretation, knowledge, and ancillary data analysis. Given the urgent need for information regarding the condition of this resource, remote sensing and geospatial data analysis are preferred alternatives for mapping groundwater resources (Nigussie, Hailu, and Azagegn 2019). Right now, groundwater resource potential detection is made simpler, more precise, and quicker by GIS and RS approaches

(Zeinolabedini and Esmaeily 2015). Groundwater potential has been located and mapped using a combination of these techniques. The Geographic Information System is a very valuable and influential tool for defining groundwater potential and shortage zones, as well as for assessing and quantifying multivariate groundwater incidence aspects(Groundwater Potential Assessment Using GIS and Remote Sensing Techniques: Case Study of West Arsi Zone, Ethiopia 2022).

The purpose of this study to find out the groundwater potential availability zone and land suitability for surface irrigation in the Katar watershed by the integration of GIS and Remote sensing based on multicriteria decision approach. This increases the accuracy and efficiency, save time, and the economy during groundwater resources management, planning, and developing by governmental and non-governmental organizations. In the watershed the existing irrigation system utilized only surface water potential for irrigation. But this is the limited water resources that can be reached everywhere across the watershed to optimize irrigation potential to the area and also affected by climate change. irrigable areas using ground water potential to the watershed have not been identified. Therefore, this study is necessary to overcome this uncertainty. Furthermore, the study has been supported by development of a suitability database that would help for further investigation on the area. The soil, terrain feature (DEM and its derivatives), Geology, lineament density, drainage density, Forms of the land feature and land use classification criteria were the basis used to define the suitability for GWP while Land Use/cover, Slop, Soil type, drainage density, Rain fall and the like data have been considered for Land potential for Surface Irrigation Analysis. For those criteria the preparation of thematic layers (LULC, soil, geology/lithology, rainfall, drainage density, lineament density, elevation, and slope) and reclassifying them for multicriteria overlay analysis have been conducted and weighted overlay analysis performed in ArcGIS to decide a suitable site for groundwater potential zone in the katar watershed. Finally, the ground water potential and irrigation suitability zone map were prepared and the result validation was conducted.

## 1.2 Statement of the Problem

In the world, agriculture plays a significant role in maintaining human life. Additionally, it dominates the Ethiopian economy. However, the agricultural sector of the nation is very reliant on the rains. Climate change reduces the area's productivity. Additionally, the need for more food due to population growth and limited land resources is another issue. Therefore, irrigation has been essential in ensuring food security and supplying food for the expanding population. Ethiopia has a significant chance to benefit from water-led development, but it must address serious issues with the planning and construction of irrigation systems in accordance with the appropriateness of the land and the availability of water. The impacts of unwise use of land resources and the failure to utilize land according to its potential suitability remain a serious issue. Agriculture is the main source of income in the Katar watershed, where the population is growing. Farmers mainly depend on rain-fed agricultural techniques. Changes in rainfall have a significant impact on agricultural production and result in low yields of crops. To satisfy expanding demand, agricultural land cannot be increased. In the area, the practice of using groundwater for surface irrigation is less common. The majority of farmers in the watershed only cultivate crop each year during the wet season. Existing resources produce and provide very little in the way of benefits. People living in the region become nervous because they constantly see people reaching out to help. In particular, Zuway Dugda Woreda is one of the primary locations in this watershed that frequently has this issue. There is a small surface water irrigation system that is only used in a small portion of the watershed. Adugna Gurara (2020) conducted study in watershed on irrigation land suitability using surface water. Nigussie, Hailu, and Azagegn (2019) attempted to delineate groundwater potential zones in study area. In this study the use of groundwater potential for agricultural activities has not focused in the study area. In order to respond to this, a study was conducted to evaluate the potential groundwater zone and land for surface irrigation development.

### 1.3 Objectives of the study

To identify Ground Water potential zone and land suitability for surface irrigation in katar watershed using GIS and RS

#### 1.3.1 Specific objectives

This study carried out to:

i. Identify factors that affecting ground water potential Zone and land suitability for surface
ii. Map the ground water potential and land suitability for surface irrigation through integration of their different thematic layers
iii. Identify areas potentially suitable for surface irrigation by ground water potential

### 1.3.2 Research questions

a. What factors influence the occurrence of groundwater potential and the suitability of land for surface irrigation?
b. How to identify groundwater potential zone and land suitability sites using geospatial data analysis?
c. Which land is suitable for surface irrigation development and groundwater potential zone?

## 1.4 Significance of the study

The study offers helpful information for upcoming irrigation projects that are intended to be foreseen, and it serves as a tool for policymakers' higher-level cognitive processes about irrigation development projects within the watershed. Additionally, any organization or person interested in conducting future research elsewhere will be able to use the methodology and procedures used in this study as a reference guide.

## 1.5 Scope of the study

The spatial scope of this study is restricted to Oromia Regional State, Arsi Zone, and the Katar Watershed, whereas the contextual scope is site suitability analysis for potential surface irrigation and defining potential ground water zones in the study area using geospatial technology and multi-criteria analysis methods based on the analytical hierarchy process (AHP). The goal of the study was to determine the underground water potential that could be used for domestic or agricultural purposes while taking into account the constraints that could affect its availability, such as slope, liner density, drainage density, soil type, land form, lithology, elevation, land use/cover, and rainfall. The slope, land use/cover, groundwater potential zone, equidistance to the road, and physical characteristics of the soil were taken into account when determining the best locations for surface irrigation using groundwater. These factors' thematic layers are reclassified and weighted in accordance with their influences. After integrating all the thematic layers using weight overlay analysis, the validity of the outcome was assessed using water inventor points.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Irrigation Potential

Irrigation development is important to improve smallholder livelihood through rise their crop production, increase crop variety and lengthen their agricultural seasons. The area that can be potentially irrigated depends on the physical resources of land, soil and water combined with the irrigation water requirements. Sustainable management of land and water resources is essential for the alleviation of poverty, economic development and the enhancement of the well-being of the Ethiopian people (Genole 2020). Hence, Irrigation expansion for potentially suitable lands and optimally using the available water is the most crucial. Irrigation potential is an important indicator of the extent of land suitable for irrigation development, this implies that its chances for irrigation development. The potential irrigable area depends on the physical soil and water resources in combination with the irrigation water demand, which is determined by cultivation patterns and climate (Genole 2020). So, this study considered on the availability of potential land for irrigation and the water potential found including (surface and ground water potential) to determine the maximum utilization of this resources to improve the productivity of the area.

## 2.2 Concepts of groundwater potential

Ground Water is the occurrence or water stored beneath the earth surface when a piece of precipitation that falls on the earth surface and surface water infiltrates through the soil and enters to subsurface to rise up ground water level. Different Authors and Researchers also defines Ground water in different ways. According to (Genole 2020) Ground water is a piece of hydrological cycle which is beginning when piece of the precipitation that falls on the earth's surface sinks through the soil and enters to the subsurface to rise up Ground water level. (Solomon. T, 2020) also define that Ground water is the one of the hydrological cycles which is formed when rain fall and surface water percolates into a crack and opening in beds of rock. Groundwater is the most important natural resource found beneath the earth's surface stored in a void space of geological stratum used in economic development, domestic life, and any ecological diversity (Dawit.Y 2021).

### 2.3 Geospatial Technology application for GW and land suitability studies

#### 2.3.1 Geospatial Technology application in groundwater Resources

The most powerful technologies used by so many researchers today for identifying ground water are geospatial ones, like remote sensing and GIS. In the current study, the geographic information system (GIS), multi-criteria decision analysis (MCDA), and remote sensing techniques were used to define the groundwater potential zone. Thematic maps for lithology, elevation, drainage density, lineament density, rainfall, soil type, slope, and land use/land cover are created using integrated remote sensing and GIS. The weight of each theme is determined using Saaty's analytical hierarchy technique based on the relative contribution of each of these maps towards groundwater potential. To create a composite weighted map, these weights are applied to each theme map. Finally, a groundwater potential map of the study area was created utilizing the weighted overlay analysis approach in GIS software by integrating the theme layers.

Remote sensing (RS) method offers systematic, comprehensive, quick, and repeating coverage of the physical characteristics of the earth in several electromagnetic range windows. As a result, it provides a special and potent instrument for quickly gathering spatiotemporal data about vast areas. When compared to traditional methods of hydrological surveys, remotely sensed data is typically more affordable, and it is especially important for remote and data-limited places. Satellite data provides immediate and relevant baseline information about a variety of parameters, such as geomorphology, soil types, land slope, land use, land cover, drainage patterns, and lineament density are directly or indirectly impact the occurrence and movement of groundwater(Machiwal, Jha, and Mal 2011). Consequently, a combined strategy using GIS and remote sensing techniques can be employed to effectively identify possible groundwater zones in the study area. Several researchers have successfully delineated groundwater potential zones using RS and GIS methodologies (Eliyas, A. 2018, Solomon, T. 2020, Demeke, S., Kumera, S., 2017, Dawit, Y. 2021, S.Arya et al. 2020, Shaibu, A., and Kpiebaya.p. 2020, Tarun, K. et al. 2016, Anshu, K., and Ajai, 2021).

#### 2.3.2 Remote sensing and GIS integration in land suitability study

Remote sensing in combination with GIS will be a powerful tool to integrate and interpret real-world situations most realistically and transparently. So, an integrated technology of GIS and remote sensing is the most broadly applicable technique to evaluate the irrigation land suitability for crop production using surface water as well as groundwater resources.

Many studies were taken out using this integrated technology (GIS-RS) to examine land suitability on a global and country scale. The assessment of potential land suitability for surface irrigation using groundwater(Dawit.Y 2021) and using surface water (Rekiya.M 2021) and (Yifru 2020) by considering physical land characteristics (land use/cover and slope), climate (rainfall and evapotranspiration) and the physical and chemical properties of the soil. They selected and applied the different land suitability influencing factors in different places based on the characteristics of the land.

### 2.4 Analytical hierarchy process (AHP) in groundwater identification

AHP is one of the most effective multi-criteria decisions making (MCDM) techniques which helps a decision-maker facing complex problems and conflict and internal multiple criteria. AHP method was first presented by(Saaty 1980) and is widely used for MCDM, and has successfully been applied to many practical decision-making problems. (Saaty 1980)Analytic Hierarchy Process (AHP) is a widely used MCDM technique in the field of water resources engineering. The method was first developed by Professor Thomas L. Saaty in the 1977s. Since then, the method has received numerous applications in natural resources, and environmental planning and management (Saaty 1980);(Pereira and Duckstein 1993); Chen et al. 2001; Eastman 2003; Thirumalaivasan et al. 2003; Kolat et al. 2006; Mendoza and Martins 2006; Madrucci et al. 2008; Chowdhury et al. 2009; Jha et al. 2010).

### 2.5 Multi-Criteria Decision Analysis

Multi-criteria decision-making is the concepts, approaches, models and methods that aid in evaluation expressing by weights, values or intensities of preference which ultimately lead to better decisions. The main purpose of the Multi-Criteria Evaluation (MCE) techniques is to investigate a number of alternatives in the light of multiple criteria and conflicting objectives(Fentahun Bezie 2017). Multi-Criteria Decision Making (MCDM) provides the foundation for selecting, sorting, and prioritizing criteria/factors and helps in overall assessment to make a better decision. To obtain an optimum/appropriate solution for a problem, the weighted overlay analysis is the best method. Weighted Overlay Analysis (WOA) is a simple method for a combined analysis of multiclass maps. The efficiency of this method lies in that human judgment can be incorporated into the analysis. This method takes into consideration the relative importance of the parameters and the classes belonging to each parameter. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis should be defined and each parameter should be assigned as importance. The Integrating of MCDM with Geographical Information System (GIS) has been used in site selection assessment to ensure proper decision making thus increasing the potential of environmental resources in arid and semi-arid regions(Neissi, Albaji, and Nasab 2019).

### 2.6 Factors Influence Groundwater Potential

In numerous earlier studies, various elements have been considered while examining the control of ground water occurrence and potential. Aquifer properties including hydraulic conductivity, aquifer thickness, storability, aerial expanse, groundwater levels, readily available drawdown, and recharge affect the yield of groundwater development. This suggests that the main elements governing the transportation and storing of groundwater in any region of the world are the kind of soil, the geology, the climate, and the characteristics of an aquifer (Ofomola 2015).

Groundwater is a result of the interaction of climatic, geological, hydrological, biological, and physiographic elements rather than any occurrence by chances( Arkoprovo, Prakash, Shashi, Adarsa and Sharma 2012). Numerous research on determining the ground potential zone has been conducted and debated, taking into account the most crucial governing factors, including geomorphology, lithology, slope, soil, LULC, lineament density, drainage density, and rainfall (Dawit.Y 2021, Eliyas.A 2018, Solomon 2020,Zeinolabedini and Esmaeily 2015). Finally, they concluded that all of the parameters are crucial in mapping the ground water potential zone. Based on these findings and the review, all of the key parameters were chosen for this investigation. Additionally, the effects of these elements are properly and efficiently taken into account to support any possible groundwater development in the region.

**Rainfall: -**Rainfall is one of the primary sources of groundwater and is expressed as the depth of precipitated water in inches, measured by rain gauge for selected periods. The relationship of rainfall to groundwater occurrence is modified by factors like topography, vegetation, and surface geology; all these factors affect the quantity of water that gets underground. The high rainfall amounts imply the possibility of high groundwater recharge thus high groundwater potential zones while low rainfall indicates low groundwater recharge thus low groundwater potential zones (Eliyas.A 2018).

**Land use/cover: -**Land use land cover is also affecting groundwater potential recharging. The land cover is the natural features like water bodies, vegetation, mountain, and rock or bares while land use is the modified natural environment by human operation and comprising parameters like croplands, industry, plantations, built-up lands, and so on. The effect of land use/cover is demonstrated either by reducing runoff and facilitating or by trapping water on their leaf and go down to recharge groundwater. The area covered with vegetation, water body, agriculture will produce high groundwater potential while covered with settlement and bare land produce low groundwater potential due to having less infiltration rate from the natural rainfall(Dawit.Y 2021).

**Soil Type: -**Soil texture has a valuable role in groundwater potential. The infiltration rate of water to the water tables is influenced by soil permeability. The permeability of the soil is directly related to the effective porosity of the soil and is greatly influenced by grains shape, size grains, adsorbed water, the degree of saturation, and impurities present. High permeability levels are observed in gravels and coarse sand; fine sand and loamy soils exhibit moderate permeability whereas the lowest permeability is shown by clay and silt soils. Thus, the soil has high permeability and low water holding capacity should have yielded a high percolation to the groundwater. According to Eliyas.A (2018) High permeability levels are observed in gravels and coarse sand; fine sand and loamy soils exhibit moderate permeability whereas lowest permeability is shown by clay and silt soils.

**Elevation: -**Elevation of any study area has a major role in occurrence of groundwater Potential and recharge zone. A plainer area, having lower elevation gives time for water to infiltrate and increase groundwater level. The higher elevation with steeply elevated area has large amount of runoff and small amount of infiltration. Consequently, those areas have low groundwater potential and low recharge zone; because rainfall has no time to infiltrate to ground. So that water tends to store at lower topography rather than at higher topography. The higher the elevation lesser the ground water potential and vice versa (Eliyas.A 2018).

**Geomorphology: -**Geomorphology is the highly influencing parameter of groundwater occurrence. So that Geomorphology and its features are essential components for understanding landforms evolutions, controlling the movement and occurrence of groundwater. The hydro-geomorphologic units like flood plains, valley fills, buried channels and lineaments are very good sources for groundwater. On other hand, structural hills, pediment zone and gullied lands are poor potential zones(Eliyas.A 2018).

**Slope: -**Slope is an important factor for the identification of groundwater potential zones. Slope of any terrain is one of the factors allowing the infiltration of groundwater into subsurface or in other words groundwater recharge. In the gentle slope area, the surface runoff is slow allowing more time for rainwater to percolate, whereas, steep slope area facilitates high runoff allowing less residence time for rainwater to percolate and hence comparatively less infiltration (Kumera 2017). So that as the slope steepness of an area increases the groundwater potential would be decreased.

**Lineament Density:-**Lineaments are structural lines such as faults, which often represent zones of fracturing and increased secondary porosity and permeability, and therefore of enhanced groundwater occurrence and movement(Kumera 2017). Lineaments are the structural discontinuity of the earth's surface such as faults, foliations, joints, bedding planes, and a map of linear features present on the surfaces. It may be a curve, linear, and slightly curve which is the most essential for the infiltration and movement of water to the ground. The characteristic of lines features may represent deep seated faults, fractures and joints sets, drainage lines and boundary lines of different rock formations. The lineament data was provided important information on subsurface fractures that may control the movement and storage of the groundwater in the study area. It is the ratio of total length of all the lineaments defined to the total study area and expressed in km/km2. High lineament density areas are good for ground water recharge and low lineament density are less suitable for groundwater recharge and discharges. The higher fault and lineament density can be used to speculate secondary porosity as most of the faults or fracture system serves as conduits for movement and storage of groundwater(Dawit.Y 2021).

**Drainage density: -**Drainage density is the natural flowing of water runoff to lowland/common points. It indicates the behavior of surface and subsurface formation, the information of rock, soil permeability, infiltration of water, and surface runoff. The drainage density is a degree of the length of stream channel per unit area of the drainage watershed. It is determined by the ratio of total length of the stream network to total area of the watershed and expressed in km/km2. According to (Solomon. T 2020); high drainage density values have high runoff and indicate a low possibility of groundwater availability and hence higher weights are assigning to the low drainage density area and vice versa.

**Lithology: -**Geology is one of main factors controlling the quantity and quality of groundwater occurrence in a given area. It has influences on both the porosity and permeability of aquifer rocks. Lithology plays a vital role in determining the groundwater potential of an area and it influences both the porosity and permeability of aquifer rocks for groundwater recharge. The porosity of rocks determines the storage capacity of rock formations, which means the sedimentary rocks were considered as high potential for groundwater occurrence due to high porosity and permeability than igneous and metamorphic rocks(Dawit.Y 2021). Thus, the area of rock having high permeability and porosity should have the ability to produce high groundwater occurrence.

## 2.7 Irrigation land suitability evaluation

Land suitability is the fitness of a given type of land for a defined use. In agriculturally based community, land Suitability refers to the ability of a portion of land to tolerate the production of crops sustainably(Rekiya.M 2021). The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976). Land evaluation is primarily the analysis of data about the land and its soils, climate, vegetation, and so on, in terms of realistic alternatives for improving the use of that land. For irrigation land suitability analysis, particular attention is given to the physical properties of the soil, to the land use land cover of an area, and the terrain conditions concerning methods of irrigation considered for the study.

### 2.7.1 Land Suitability Orders

Land Suitability orders indicate whether land assessed as sui

table or not suitable for the use under consideration. There are two orders Suitable and not suitable represented in maps, tables, etc. by the symbols S and N respectively. Order S suitable: Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources. Order N not suitable: Land which has qualities that appear to preclude (prevent) sustained use of the kind under consideration (FAO, 1976).

Table 2.1 Structure of land suitability order and classes. (Source: FAO, 1976)

| Order | Class | Description |
|---|---|---|
| Suitable (S) | S1 (Highly suitable) | Land having no or insignificant limitations to the given type of use |
| | S2 (Moderately suitable) | Land with minor limitations to the given type of use |
| | S3 (Marginally suitable) | Having moderate limitations to the given type of use |
| Unsuitable (N) | N (unsuitable) | Land with severe limitations that preclude the given type of use |

### 2.7.2 Land suitability evaluation factors

As extensively discussed in FAO land evaluation guidelines the land suitability factors for surface irrigation method and the given land utilization types can be expressed corresponding to suitability classes. In this study, the factors considered for land suitability evaluation described separately in the following sub-sections Depending on FAO land evaluation guidelines.

**Land use land cover: -**Land use land cover is one of the factors used to assess the land suitability for surface irrigation. Land use land cover provides a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation. Therefore, matching of existing land cover/use with topographic and soil characteristics to evaluate land suitability for surface irrigation with land suitability classes, present possible lands for new agricultural production(Rekiya.M 2021). Land use/land cover of the study area is one of the most important factors for surface irrigation land suitability assessment in terms of land use/land cover when the main theme is to give water for agriculturally able land by surface irrigation for better performance, so the identified cropland is command area which to be irrigated and the other class of land use/land cover was restricted from surface irrigation.

**Slope: -**The slope is the inclination of a surface and is often expressed as a percent. It affects the suitability of an area in terms of land preparation for irrigation and irrigation operation (Husen and Abate 2020). According to FAO standard guidelines for the evaluation of the slope gradient, mostly slopes, which are less than 2%, are very suitable for surface irrigation.

However, slopes that are greater than 8% are not widely recommended (FAO, 1999). Slope can able to indicate if an area is workable at all or not, if it's steeply and above the standard its erosion hazard is too. Thus, the study of slope is an important factor for the land suitability assessment for surface irrigation. A relatively flat slope may pose drainage problems in areas of high rainfall intensity. For borders, the most suitable slopes are usually less than 0.5 percent. For furrows, suitable slopes vary between 0.05 and 1percent. Slopes up to 2 percent can work for small furrows and corrugation irrigation type (Brehanu .A 2018).

**Soil drainage: -**The evaluation of soil drainage characteristics during irrigation land suitability assessment should be highly considered because it affects soil quality and nutrients as well as the water holding capacity of the soil that influences the soil moisture and crop water(Husen and Abate 2020). The soil drainage condition is important as it controls the continuous movement of water and salt through the soil profiles. Salt may be built up to a level that may be harmful to the landscape and vegetation unless it isn't continuously leached. In land suitability evaluation, well-drained soil in nature is highly suitable because it has a sufficient amount of nutrients and is good in nutrient retain capacity, and water penetration. In contrast, the poorly, imperfectly, and somewhat excessively drained soil is marginally suitable in causes a sufficient amount of water may not be stored in the soil particles(Dawit.Y 2021).

**Soil depth: -**The depth of soil also affects water holding capacity and nutrients of the soil and it should be highly considered for evaluating the land suitability for surface irrigation(Yifru 2020)**.** Thus, the shallow depth soil is marginally suitable, and very shallow depth soil is unsuitable for surface irrigation because they are poor to very poor water holding capacity and moisture content. However, deep and very deep soils are good for surface irrigation.

### 2.8 Empirical Literature Review

The different empirical studies related to groundwater potential and Land suitability mapping for surface irrigation was retrieved from unpublished and published research literature and some of them discussed below by classifying at global scale and local scale or country level.

### 2.8.1 Empirical Literature Review at Global or international scale

Large number of studies were published in worldwide recently by applying many methods to identify potential site for groundwater potential and on land suitability mapping for surface irrigation. Some of them are listed a table 2.2 below

Table 2.2 Related studies used GIS, RS and MCDA for irrigation Land suitability mapping

| Author | Method | Criteria | Country |
|---|---|---|---|
| (Neissi, Albaji,& Nasab 2019) | Analytical Hierarchy Process Integrated with GIS | climate, topography, Soil, skilled labor and system costs | Iran |
| (Mandal et al .2018) | Using GIS | soil type, slope, land cover/use, and distance from water supply | India |
| Albaji, and Nasab 2019) | AHP integrated GIS | Soil, Topography, slope etc | Iran |
| (Hagos et al. 2022) | GIS and RS | Soil drainage, soil depth, soil texture, slope, | Ethiopia |

Source (Author 2022)

Table 2.3 Number of studies used GIS, RS and MCDA for mapping GWP

| Author | Method | Criteria | Country |
|---|---|---|---|
| (Romanelli et al. 2012) | GIS-based integrating multiparametric data | Aquifer Thickness, Hydraulic gradient, Slop, electrical conductivity, Sodium Absorption ratio and Residual sodium carbonate | Argentina |
| (Mahato and Pal 2019) | GIS based MCAM | RF, Soil texture, Geology, Stream link, Slope, Watershed junction, Metrics score, LULC, Relief status, Ground water level, NDVI, | India |

| | | | |
|---|---|---|---|
| (Machiwal, Jha, and Mal 2011) | RS, GIS and MCDM method | RF, Geology, Soil, Slope, Surface Water body, Net Recharge and Geomorphology | India |
| (Kumari and Singh 2021) | RS, GIS and MCDM method | lithology, soil, geomorphology, lineament, LD, slope, relief, aspects, DD, LULC and groundwater depth maps were created | India |
| (Shabani, Masoumi, and Rezaei 2022) | multi-criteria decision analysis and geoelectrical surveying | slope, land-use, drainage density, spring density, lithology, lineament density, and rainfall are considered | Iran |

Where: LULC, DD, LD and RF are land use land cover, drainage density, lineament density and Rainfall respectively. Source (Author 2022)

### 2.8.2. Related previous (empirical) studies in Ethiopia

Relating to this area, many studies and research have been done previously based on different factors in different method. Teshome and Halefom (2020) had tried to identify possible areas suitable for irrigation in Gumara watershed, Blue Nile basin by analyzing parameters considered to be important in the fulfillment of the study by using the environment of the Geospatial Information System integrated with multi-criteria decision techniques. They selected six important factors like proximity, topography, land use, soil texture class, soil depth, and soil drainage classes to complete the study. The result of the study shows that, of the entire watershed area, 19.98% is highly appropriate, 30.98% is moderately appropriate, 47.18% is marginally appropriate, and 1.91% is not appropriate for the aforementioned purposes Therefore, the combination of primary data collected from the field and remote sensing data that were analyzed in the geospatial information system environment help the outcome of this study. cross-tabulation of each parameter considered was calculated to assess the impact of each parameter on the final result. This indicates that the integration of remote sense and GIS is the most effective techniques in studies of surface irrigation land suitability analysis. Girma, Gebre, and Tadesse (2020) had attempted to evaluate the suitability of the land for surface irrigation in Omo-Gibe River Basin, Southern Ethiopia, using GIS based weighted overlay analysis of individual parameters for better utilization of land resources.

Factors considered included physical land features (land use/land cover, soil and slope), and proximity to water sources. Based on soil depth, 82.4% of the study area is potential suitable for the intended uses; the drainage class scores 70% suitability; 80% the soil texture was clay dominant hence it was moderately suitable for surface irrigation. Considering the terrain, 11.75% of the basin is suited for irrigation practice. The LULC classification revealed that, 54.42% was found to be highly suitable and 16.7% is found to be unsuitable. In reference to river proximity, around 81% of the area could be highly recommended for the intended use. Excluding the national parks, 71% (7% is S1 and 64% is S2) is suitable for the intended use. Wagesho (2004)Had made study on GIS based irrigation suitability analysis Abaya-Chamo Basin, Southern Rift Valley of Ethiopia. The investigation includes factors like topography, climate, soil, land use pattern, water availability, agricultural practices, investment costs and socio-economic practices. Furthermore, the irrigation suitability criteria are defined based on these variables. Integrating all the aggregate suitability variables, the potential capacity of irrigable land is identified and mapped as well. The capacity of low flow as well as 80%, 90% and 95% time of exceedance flow of the available surface water in the respective sub basins is estimated. The area that can be irrigated with this flow is computed for the selected cropping pattern. To maximize the extent of irrigable land storage requirement with respect to different flow reliability level is estimated.

Thesis and Ganole( 2010) had done his M.Sc. Thesis on the Assessment the water and land resources potential of river catchments in Dale Woreda of Sidama Zone for irrigation development by using Geographic Information System. To identify potential irrigable land, He had considered irrigation suitability factors such as soil type, slope, land cover/use, and distance from water supply. The irrigation suitability analysis of these factors indicates that 86 % of soil and 58 .5 % slope in the study area are in the range of highly suitable to marginally suitable for surface irrigation system. In terms of land cover/use, 87.1% of land cover/use are highly suitable where as 12.9% were restricted from irrigation development. Overall, the weighted overlay analysis of these factors gave potential irrigable land among river catchments as Bilate (3,621.6 ha), Dama (552.7 ha), Gidawo (7,265.6 ha), Raro (693.35 ha), Wamole (1,511.3 ha) and Woyima (805.66 ha).

Eliyas.A (2018)conducted study in Sude district, Oromia Regional State, to delineate groundwater potential zone and recharge zone using Geographical information system and Remote sensing techniques through analytical hierarchy process. Ten parameters were considered that affecting the occurrence of groundwater potential zone and groundwater recharge zone such as; geology, geomorphology, lineament, drainage density, Rainfall, slope, land use/cover, runoff depth, soil, and elevation were considered. Nine thematic maps were used for delineation of groundwater potential zones and ten thematic maps were used for delineation of groundwater recharge zones. Analytic hierarchy process, weighted overlay by linear combination method in geographical information system to generate groundwater potential zone and recharge zone maps were used. The generated groundwater potential and recharge maps were classified in to high, moderate, low and very low zones.

Brehanu .A (2018) had done on Land suitability Assessment for Surface Irrigation by using GIS in Upper Awash Basin Of holeta River Sub basin West Shewa, Oromia. The methodology under taken was consider, relevant soil, DEM and land use land cover data which providing geo referenced map of the site using Geographic information System software. After evaluating each factor of land suitability for surface irrigation map was developed by weighting suitability factor of the catchment site and overlaying the factors to obtain the final suitable land map. Solomon. T (2020)Had tried to map groundwater potential and recharge zone using integrated approach of Geographical Information System (GIS) and Remote Sensing (RS) Technologies with Analytic Hierarchy Process in the Melka Kunture Watershed of Upper Awash River Basin in Oromia. Eight parameters (lithology, geomorphology, slope, lineament density, land cover, rainfall, drainage density, and soil) that affect groundwater potential and recharge were identified first based three theoretical selection criteria setting which derived using Saaty’s Analytic Hierarchy Process (AHP) approach are considered in this study. The weights of each thematic layer were assigned (weighted), normalized and ranked based on their Suitability, characteristic and relationship with the potentiality to groundwater and recharge zone occurrences and movements by AHP method through Pairwise Comparison Matrix (PCM).

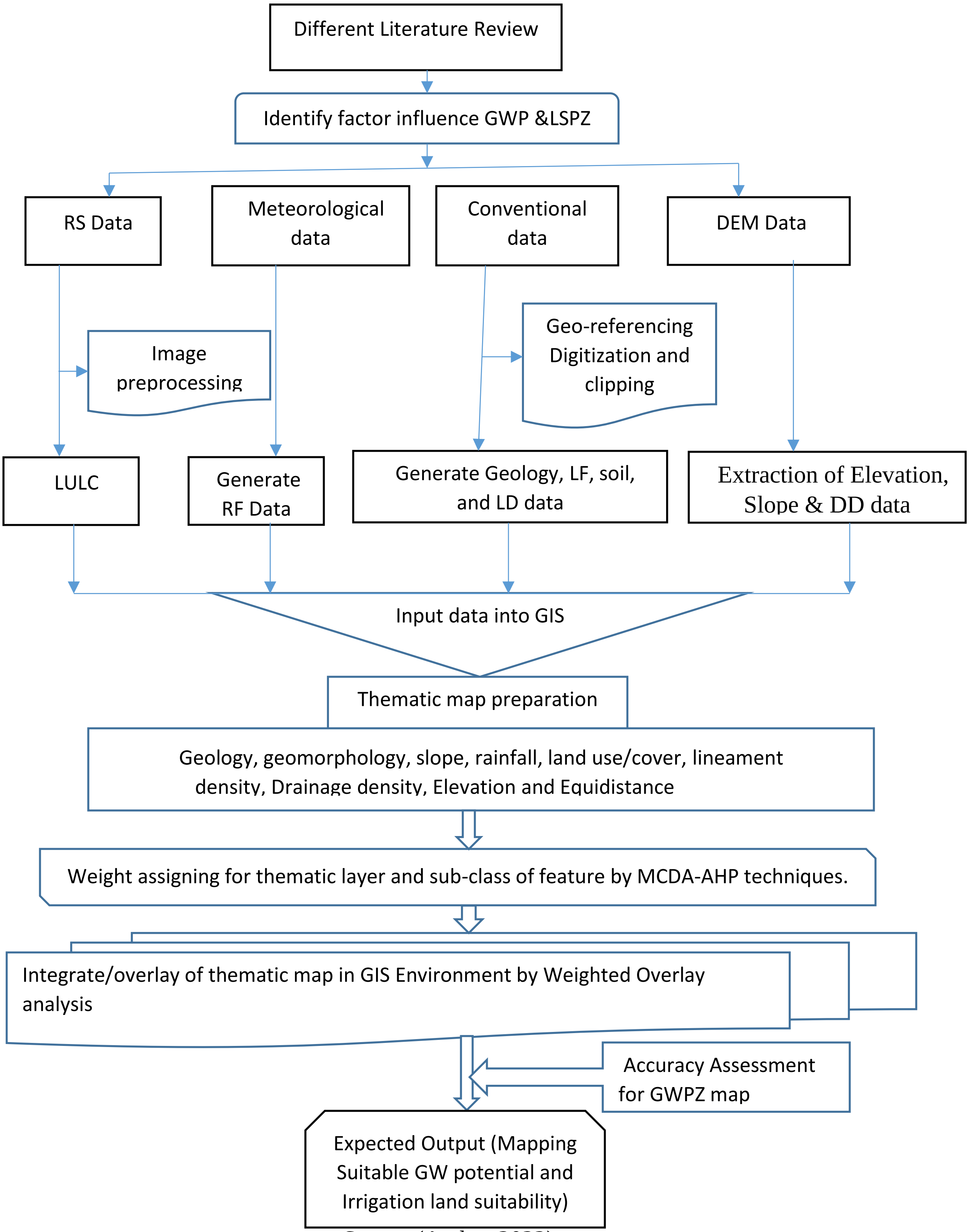
### 2.9 Research Gap

Despite so many studies carried out in the country and in study area, the use of Ground water in the analysis of irrigation land suitability as a water resource is less common rather than identifying its potential zone for multipurpose. The revised above study had done land suitability and ground water potential zone separately. Dawit Yohannes (2021) had delineate the groundwater potential zone and potential land suitability zone for surface irrigation using GIS-based Multi-Criteria Decision Analysis (MCDA) techniques in the Keleta watershed. He attempts to indicate irrigation land suitability utilizing ground water using Fuzzy-AHP methods. After identify GWP and irrigation land suitability separately then compare and interlink the results. What unique for this study is that Ground water potential was used as water source and taken as main factor to determine irrigation land suitability after ground water potential zone identified. And also, the accessibility of the area to road was considered as the market accessibility is significant for production. So, in this study the land suitability for surface irrigation had done using ground water as water source for irrigation rather than considering surface water as a previous study.

### 2.10 Conceptual Framework of GW Potential

This study summarizes groundwater potential and land suitability mapping using GIS and RS approaches by identifying factors that affect the occurrence of groundwater based on the analysis of related literature review. Numerous studies that sought to identify groundwater potential zones showed that slope, drainage density, land use/cover, soil texture, lithology, landform, lineament density, elevation, and rainfall had an impact on the occurrence and movement of groundwater. So, the primary factors or any relevant parameters have been picked and weighed by AHP to generate groundwater potential and have been based on the suitability and the nature of the study area. Developing a connection between RS data, GIS processing, and hydrologic phenomena maximizes the effectiveness of identifying possible development zones for groundwater sources. The layers must be integrated into the GIS environment by assigning different weightages to the respective layers depending on their influence on ground water; this method is known as the Weighted Overlay Analysis method. For the same, all those are used to develop a composite map showing various classes of ground water potentialities.

However, the user has the freedom to assign whatever weights to the various parameter layers based on his or her own judgment. The decision-maker is crucial in this situation. As a result, using AHP enables multiple criteria to be assessed, compared to one another, ordered, and given weights based on rational quantitative criteria, assisting the decision-maker in making thoughtful choices. The groundwater potential surface can be accurately predicted using the map generated from weighted overlay in a GIS environment using the AHP approach. It can also be used to estimate the best locations for developing groundwater recharge facilities. In order to create a simplified approach for detecting and mapping groundwater, the overall summary conceptual framework of all the evaluated material within this chapter is contextualized to the current study and is shown in Figure 2.1 below.



Source (Author 2022)

Figure 2.1 Conceptual framework of GWP and ILSP mapping

# CHAPTET 3: MATERIALS AND METHODS

## 3.1 Description of study area

### 3.1.1 Location

The Katar watershed is part of the Ziway-Shala Sub-basin and the Rift Valley Basin, which is located in the Arsi Zone of the Oromia region. The watershed is about 225 km south of Addis Ababa, the capital city of Ethiopia. It includes the major towns of Ogolcho, Asela, Etaya, Sagure, and Bekoji. The watershed covers an area of 3386 km2 and, geographically, it is located between 7.36o and 8.18o N latitudes and 38.89o to 39.41o E longitudes. According to the Ethiopian Central Statistical Agency's (CSA) census projection in 2018, the total population in the study area is approximately 1 million (Nuguse). The Katar River originates in Kaka Mountain, Rift Valley Basin Ethiopia, and Ziway Lake receives approximately 60% of its inflow water from the Katar River (Sime et al., 2020).

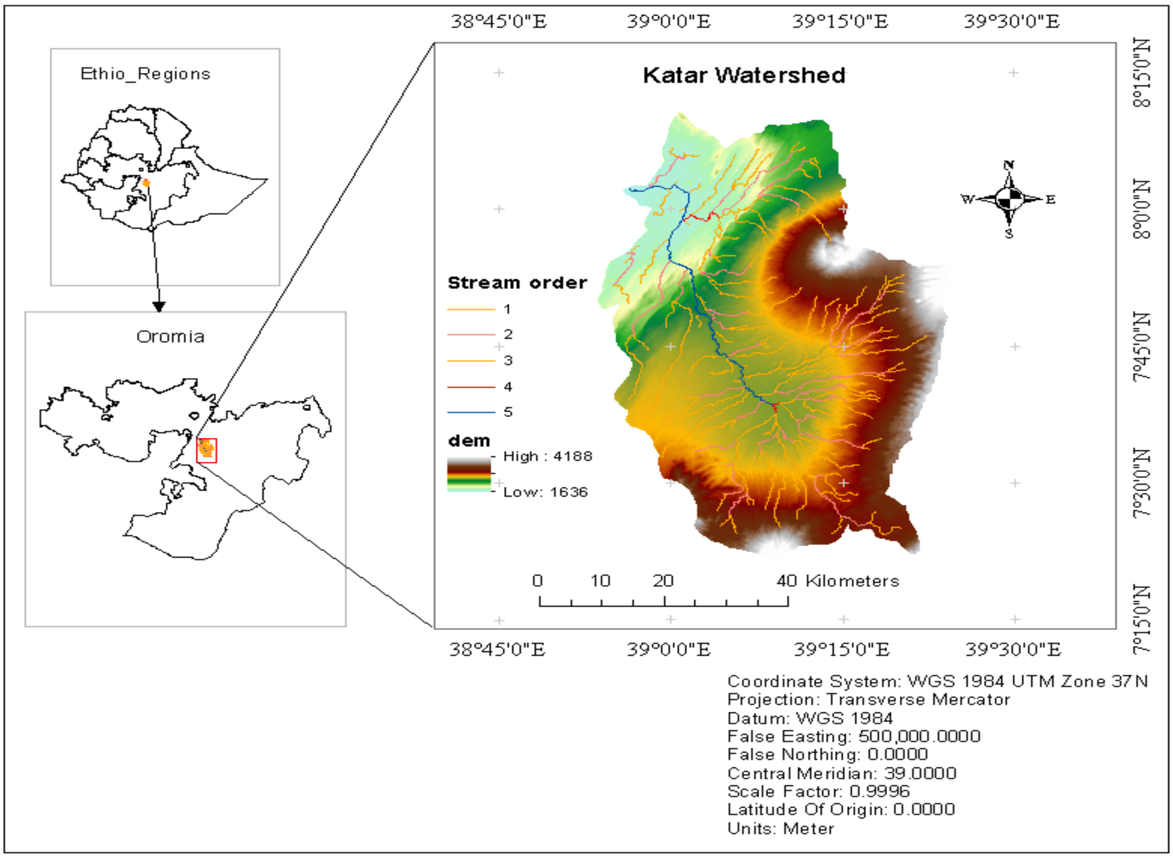



Figure 3.1 Study area location map

### 3.1.2 Topography and slope

The topography of the Katar Watershed as a whole is characterized by its physical variation, especially the difference between the eastern and western parts. Most of the eastern and Southern part is mountainous like Kaka, chilalo and Galama Ridge while the western at the entrance of Lake Ziway is a nearly flat area. Katar River is a perennial river that contributes high water for Lake Ziway.

### 3.1.3 Climate

The Watershed has annual precipitation that varies between 743 and 1148 mm. Lower annual precipitation is observed in lowlands area. Relatively high rainfall is recorded in the highlands of the Watershed. The Highest rainfall was recorded From Jun to September which locally known as Kiremt Season in the Watershed. The annual maximum and minimum temperatures in the basin vary between 16-31.5 ℃ and 3-16.5 ℃, respectively. The temperature along the river is relatively high, the highest is 28-31.5 ° C and the lowest is 13-16.5 ° C. The monthly rainfall of the various station is given in the figure 3.2.

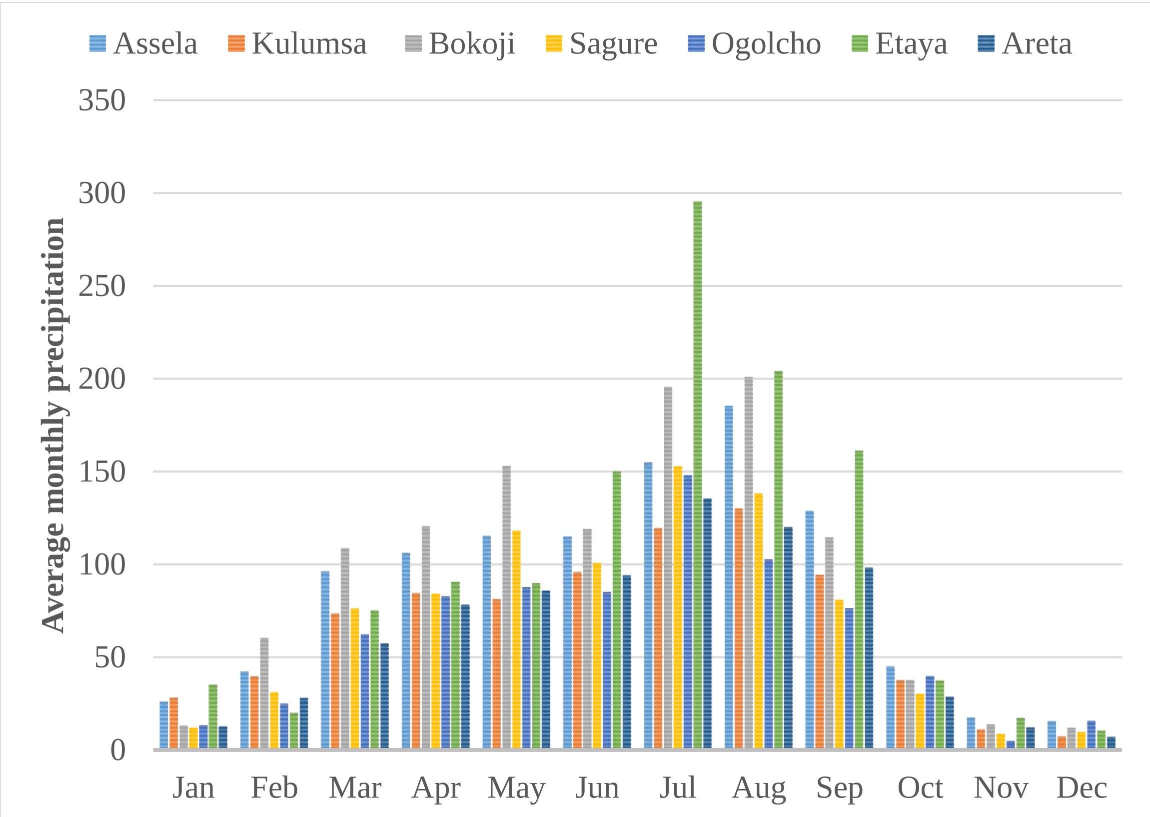



Figure 3.2 Average monthly precipitation of different station in study area (source NMA)

### 3.1.4 Soil type and land use land cover

According to the MoA soil classification system, Chromic Luvisols, Eutric Cambisols, Eutric Vertisols, Haplic Luvisols, Lithic Leptosols, Mollic Andosols, Vertic Cambisols, and Vitric Andosols are among the prevalent soil groups in the watershed, according to the MoA soil classification system. There are five different forms of land use or cover in the watershed, including farmland, vegetation, barren land, built-up area, and waterbodies. The majority of this land use is covered of agricultural land, with the most important crops in the watershed being wheat, buckwheat, maize, teff, onion, and potatoes.

## 3.2 Data sources and materials

By gathering all relevant and important data from various sources, research objectives were met. For this study, the National Meteorological Agency provided long-term daily meteorological data of rainfall at existing stations for 20 years (2001–2020). (NMA). Slope, drainage density from DEM, and landform were among the physiographic data that was downloaded from the open topography of the National Aeronautics and Space Administration, Shuttle Radar Topography Mission (NASA-SRTM). Land use and cover data were downloaded from Landsat8 Operational Land Image (OLI) at 30 m resolution from the United States Geological Survey (USGS) website. Also, 1:25,000 scale soil data from MoA and geological data from the Ethiopian Geological Survey were collected. The identified groundwater potential zones of the study area were confirmed using groundwater inventory points. ArcGIS 10.8, ERDAS Imagine 2015, Google Earth Pro 2020, and Handheld GPS are software and materials used.

Table 3.1 lists of Data used and its sources

| Data Used | Data Source | Purpose |
|---|---|---|
| Landsat 8 | USGS | To generate LULC map |
| DEM | SRTM DEM | To generate slope, DD, and Elevation |
| Soil data | MoA | To determine suitability of the area |
| GPS & GW yield data | Field Survey and GSE | To Validate the reality of the study |
| Rainfall Data | NMA | To Generate study area Rainfall Map |
| Geological data | GSE | To evaluate lithology map |

Source (Author 2022)

Table 3.2 Software Used

| Software and instrument Name | Version | Purpose |
|---|---|---|
| ArcGIS | 10.8 | For storing, managing, processing, analyzing spatial information and thematic map preparation. |
| ERDAS Imagine | 2015 | For processing and analyzing satellite images (To layer stack, mosaic, and classification of images) |
| Google Earth pro | - | Ground verification |
| Mobile GPS | - | Collect Ground control Point (GCP‟s) |

Source (Author 2022)

### 3.3 Thematic map preparation

The methods which helped to achieve the objectives of this study were data collection, selection of materials used, thematic map preparation for each factor, resample and reclassify input thematic maps, pair wise comparison by AHP, weighted overlay analysis in ArcGIS tools, develop groundwater potential zone and irrigation land suitability zone maps. Hence the major steps in generating the map: selection factors, assessment of the suitability levels of factors for GWP and ILSP, assignment of weight to these criteria, development of GIS-based suitability map by integration of thematic layers and generation of suitable GW potential and Land suitability map.

#### 3.3.1 Thematic map Preparation for groundwater potential

Thematic maps were the input information which represent the layers that indicate characteristics of different topographical feature, hydrological and geological of a given geographical location of the study area for delineation of groundwater potential and irrigation land suitability zones. After the Study area identified and the boundary of study area was extracted and the necessary data collected, the preparation of different thematic maps for each factor that influences the occurrence of groundwater potential carried out from collected data in the Arc map. Appropriate layers of factor influencing groundwater potential and irrigation land suitability zone used for this study area were; slope, drainage density, geomorphology, lithology, lineament, land use/cover, soil, elevation, road equidistance and rainfall. They were prepared from remote sensing data, DEM, meteorological data and conventionally exist map that firstly projected into the WGS_84 datum of UTM zone 37N using ArcGIS 10.8 software and different thematic maps were prepared and reclassified using a spatial analysis tool. The specific procedures of thematic layers preparation of factors influence groundwater and irrigation land suitability zone were described below.

#### 3.3.1.1 Drainage density map

DEM of the study area was downloaded from SRTM of USGS Earth Explorer and used to derive the slope, drainage density, and geomorphology maps of the study area. Then, this file was first imported into Arc map and projected to WGS_84 datum of UTM zone 37N. The study area DEM was extracted using the study area boundary shapefile. The Extraction of drainage density includes filling sinks, flow direction, flow accumulation, and stream network extraction. Lastly, a drainage density map was produced and calculated using a line density analysis tool through dividing the total length of the stream channel in watershed to total area of the watershed and reclassified using spatial analysis tools.

#### 3.3.1.2 Slope map

A slope map of the area was prepared from projected DEM with 30 m spatial resolution as input for slope extraction in ArcGIS spatial analysis tools. Finally, a slope maps of the study area were prepared using the surface tool in the spatial analysis tools and reclassified using the reclassify tool in spatial analysis tools based on their importance's.

#### 3.3.1.3 LULC map

The Landsat 8 image from a satellite data source was used to generate the LULC map of the area. A cloud-free Landsat 8 image of 2022 at 30 m resolution was downloaded from United State Geological Survey (USGS) website and imported to ERDAS Imagine 2015 software to stack the layers, preparing the composite band and classifying LULC of the study area using ERDAS imagine with the help of Google earth pro. Landsat 8 image has produced the land use/cover types for the study area in 30m resolution and served as bases from which land use/cover types were extracted. As result, the LULC map of the study area was developed from supervised maximum likelihood image classification in the ERDAS Imagine 2015 to categorize land use/cover types based on the site knowledge and spectral properties of features presented Finally, the image classification accuracy assessment was done by taking random points for each class.

$$\text{Kappacoefficient} = \frac{(\text{TS} * \text{TcS}) - \sum(\text{columnTot} * \text{rowTot}) * 100}{\text{TS}^2 - \sum \text{columntot} * \text{rowtot}} \qquad 3.1$$

Where TS: total number of samples; TcS: total correctly classified samples.

#### 3.3.1.4 Lineament density map

Lineament of the study area was also digitizing from Geological map of study area which gained from Ethiopian Geological survey. This data was imported to ArcMap and lineament of study area was prepared by digitizing method. The resulted lineament raster was called a lineament map, and it was used to generate lineament density which was calculated by the ratio of total length of all the lineaments demarcated to total study area. Finally, the Lineament density map of the study area was generated using the line density tool and then reclassified using the spatial analysis tool.

#### 3.3.1.5 Soil Texture map

Soil is the most important factor that can affect the ground water potential. Soil texture estimates the amounts of sand, silt and clay present in a soil, which regulates how much surface water penetrates into shallow aquifer system (Nigussie, Hailu, and Azagegn 2019). The percolation of water from surface to subsurface depend on the hydrological properties of soil. The rate of infiltration largely depends on the grain size and related hydraulic characteristics of the soils (Jhariya et al. 2016). Soil data was collected from Ethiopia minister of Agriculture and imported into ArcMap and projected to WGS_84 datum of UTM Zone 37N. After projection, the soil map of the Katar watershed was clipped from the Ethiopia soil map shapefile using the clip option found in the geo-processing menu bar. The description and classification of the soil physical properties were done based on the FAO guidelines, and three different soil texture groups were identified which were found in the study area, such as Clay, Loam and Sandy Loam.

#### 3.3.1.6 Lithology map

According to Arya, Subramani, and Karunanidhi (2020), groundwater flow and occurrence have a significant impact on the hydrogeological zone, which is porous and permeable and can easily store and transport water. Due to the study area's location at the intersection of these four indexes, the lithology map was also constructed using the Asela, Nazreth, Akaki, and Hosena geological map indexes. Those four indexes were georeferenced, combined together by ArcGIS tools and digitized then the study area extracted by study area boundary in ArcGIS using the spatial analysis tool. The different lithological units are found in the study area, such as:- Pliocene Trachyte (Tv7), Pliocene basalts (Tv6), Lacustrine Sediments (Q2us), pumice & Unwelded tuffs (Qwpu), Chafe Donsa Pyroclastic Deposits (Ncp), Unwelded rhyolitic pumice & tuffs, Porphyritic feldspar basalts of Tullu Moye, Nazireth Group, Chafe Donsa Pyroclastic Deposits, Highland Basaltic volcanic rock (Tv4), Ignimbrites, tuffs, water lain pyroclastic (Qdi), Porphyritic feldspar basalts of Tullu Moye (Qwb2), Quaternary Scoria cones (Qv2), Nazireth Group (Nn) and Quaternary Alluvial Deposit (Qal) were found in the study area. This lithological units of the study area also classified depending on their porosity and permeability by referring so many literatures.

#### 3.3.1.7 Topographic map

Topography of study area is also one of important factor to delineate Ground water potential zone. Eliyas. A (2018) Used Topography and classified it according to its elevation (Hight from m.s.l) and assumed that higher the elevations the lower the probability of high ground water potential and recharge zone existence and vice versa. DEM of study area was Downloaded from USGS STRM of 30m spatial resolution and classified according to its elevation difference.

#### 3.3.1.8 Geomorphology

The Geomorphology of study area was Digitized from the Asela, Hosana, Nazireth and Akaki Geomorphological map indexes by georeferencing and combining them due to the study area found in the adjacent of these separate sheets of images (indexes) that found from Ethiopian Geological survey. Then the digitized Geomorphology was clipped to study area using watershed boundary shapefile by clip option found in geoprocessing in ArcGIS. The clipped geomorphology map was in polygon format which need to convert to raster. The clipped feature geomorphology map was converted to raster by using polygon to raster window by selecting from conversion tools. The raster geomorphology map was reclassified by using reclass command in spatial analysis tools.

#### 3.3.1.9 Rainfall

For the occurrence of Ground water potential rainfall is significance, because Rainfall the primary sources of underground water. Ground water to be occur the rain water should be percolate from the surface of the Earth to the subsurface (Ground). The high rainfall amounts imply the possibility of high groundwater recharge (Eliyas.A 2018). The rainfall of study area collected from different metrological station within the area. The rainfall map was created in ArcGIS by using the Inverse Distance Weighting (IDW) interpolation method on data from eight rain gauge stations. Using deterministic methods of the algorithm, IDW estimates cell values by averaging the values of nearby sample data points.

### 3.3.2 Thematic map preparation for Land suitability for surface irrigation

#### 3.3.2.1 Slope map

Slope affects the land suitability of an area in terms of land preparation for irrigation. The slope gradient of the land has great impact on choice of the irrigation methods (Rekiya.M 2021). The slope of study area prepared from DEM and classified into different classes Depending on the variety of degree of inclination and then reclassified according to its suitability for surface irrigation. First Rating factors were given for each slope gradient of the study area based on literature review and FAO guidelines. The classes include very highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N).

#### 3.3.2.2 Soil map

Soil is a key factor in determining the suitability of an area for agriculture in general and irrigation in particular(Solomon. T 2020). The soil data (physical property; texture, drainage class and soil depth) covering the study area was accessed from the FAO website Harmonized World Soil Database, in Environmental System Research Institute (ESRI) shape file format. The soil texture refers to the relative proportion of different sized soil particles with their diameter. It is the most important soil characteristic which plays a major role in determining many other compounds land characteristics like drainage, erodibility and crack formation. In general, a sandier soil texture indicates better drainage, higher permeability, lower available water capacity and nutrient availability, better workability, higher bearing capacity, lower erodibility and no or fewer cracks (Brehanu .A 2018). Soil texture data Extracted from Ethiopia soil map shape file and classified According soil textural property. Soil Depth is the dimension from the soil surface to bedrock, hardpan, and water table; to a specified soil depth. If a soil and plant roots have deeper depth, there exist more soil water storage is available for plant use (Brehanu .A 2018).

Table 3.3 Soil suitability factor rating

| Soil texture Class | Soil Depth Range(cm) | Soil Drainage | Factor Rating |
|---|---|---|---|
| C, SiC, SC | >120 | Well | S1 |
| Si-CL, CL-C | 100 – 120 | Imperfectly | S2 |
| SL, SCL Course | 50 – 100 | Poor | S3 |
| Coarse Sand | >50 | Very poor | N |

C = Clay, SC = Sandy Clay, SiC = Silty Clay, Si = Silt, L = Loam, CL = Clay Loam, Si-CL= Silty Clay Loam, SCL = Sandy Clay Loam, SL = Sandy Loam, Source (FAO 1996)

#### 3.3.2.3 Land use land cover

Land use land cover also the significant factor to determine the land suitability for surface irrigation. The land use land cover of the study Area prepared for ground water identification in the above techniques reused for this land suitability evolution techniques.

#### 3.3.2.4 Equidistance to road

The proximity to road considered as a factor that used to determine the suitability of land for surface irrigation. For the area nearest to road, there is accessible of market for the product of irrigation. So, the main road network of study area was clipped from Ethiopian road network shapefile and projected using GIS spatial analysis tools. The distance to road calculated by spatial analysis tools in ArcGIS for the study area then reclassified according to its suitability depending on the related previous study. In this case the nearest area to the main road classified as most suitability as a result of its accessibility to the market, while the farther area from the road classified as less or not suitable because it's not access to market.

#### 3.3.2.5 Ground water potential Zone

The output ground water potential resulted from the above ground water potential analysis in this study was used as the input factor to determine the land suitability for surface irrigation using ground water resource. In this study the aim of delineation ground water potential zone was to use the ground water as additional water supply for surface irrigation. To do this the location overlay of ground water potential zone and land suitability for surface irrigation is necessary. So, the resulted ground water potential zone was reclassified as the high ground water potential zone high suitable for surface irrigation while poor ground water potential zone was less suitable for surface irrigation.

## 3.4 Data Analysis

After the collection of relevant data for groundwater potential assessment and land suitability evaluation based on different previous literature, the successful analysis of information in the spatially and temporally is significantly required to identify the suitable zone.

### 3.4.1 Theoretical selection of factors

The identification criteria are useful for indicating the main governing and the degree to which suitable to map groundwater potential and Land suitability zone of the study. These factors were so selected based on past studies or literature review of different scholars and their review were combined by setting criteria of Selection based on: 1) Frequency of usage

2) Criticalness of the factor 3) Ease of data access, which is summarized as matrix form as shown Table 3.4.

Table 3.4 Selection criteria matrices for factor influence GW potential

| Factor | Criteria | | | | |
|---|---|---|---|---|---|
| | C | C | C | Score | Rank |
| F1 | W11 | W12 | W13 | | |
| F2 | . | . | . | | |
| F3 | . | . | . | | |
| . | . | . | . | | |
| F9 | W91 | W92 | W93 | | |

Where, C-Criteria, F= factor affecting GWP and Recharge and C1= Frequency of Usage, C2= Criticalness of the Factor, C3= Ease/difficult of data access and W11= weight of factor one by criteria one.

### 3.4.2 Analytical Hierarchy Process (AHP) to Assign Weight

The analytical hierarchy process (AHP) is a comprehensive, logical and systematic mathematical framework that makes it possible to better understand and analyze difficult issues by breaking down the issue into a hierarchy. It was proposed by [Santy], and regularly used approach for groundwater potential mapping. It is based on the creation of a paired comparison matrix, which is put together for each thematic map using a nine-point rating scale or scale of relevance. Each weight is allocated to the values or ranges of each thematic map once the matrix has been resolved, creating a hierarchy for the variables that determine the presence of groundwater (Figure 3.3). The main goal is at the top of the decision hierarchy structure for groundwater potential and land suitability, which is composed of four levels of hierarchy. The two main groups of the nine factors employed in this study to determine the prevalence of groundwater potential are environmental factor and hydrological factor. These two elements were once more separated into many factors. Theoretical selection criteria based on relevant studies for a certain major study area problem were used to choose the examined factors. In a full hierarchy, each layer at a lower level has an impact on each element at a higher level. As a result, the elements at lower hierarchical levels were compared with one another according to how they affected the important layer above. nine criteria have been selected to calculate the potential groundwater zone. Each criterion has its own alternatives where the lowest value indicates poor status and the highest value indicates the good one. Saaty (1980) introduced the method in four steps: problem modeling and making hierarchical structure; pairwise comparison; evaluating weight and combining weights.

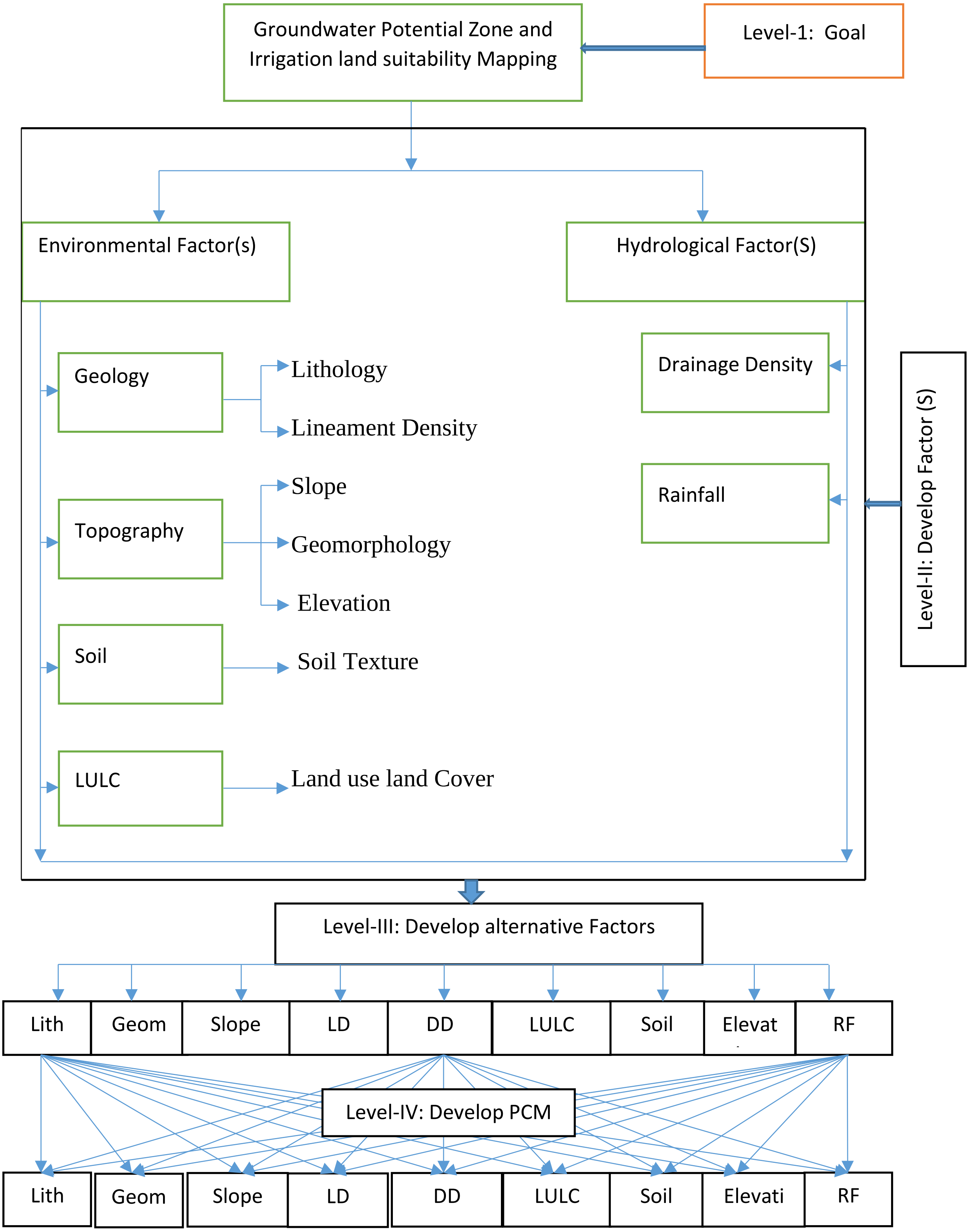


Figure 3.3 Hierarchical structure of AHP techniques. Source (Author 2022)

**Formation of pairwise comparison matrix:** It represents the relative importance of various attributes with respect to the fulfillment of goal. The matrix has been created using scale of relative importance on the basis of Saaty's 1–9 scale (Saaty 1980). Here, 1 represents equally important, whereas 9 represents extremely important. Considering the groundwater prospect, poor to very good linear ranking has been assigned where 1 represents poor status, while 5 represents very good potential.

Table 3.5 Scale of relative importance (9-poin rating scale) (Saaty's, 1980)

| Less Importance ← | | | | Equal Importance | | | → More Importance | |
|---|---|---|---|---|---|---|---|---|
| Extremely | Very Strong | Strong | Moderate | Equal | Moderate | Strong | Very Strong | Extremely |
| 1/9 | 1/7 | 1/5 | 1/3 | 1 | 3 | 5 | 7 | 9 |

Source (Saaty's, 1980)

Note: 2, 4, 6 and 8 - are intermediate values representing compromise and Reciprocal no (1/9, 1/7, 1/5 and 1/3) - indicate Values for inverse comparison.

The PCMs constructed within the relative importance for each element shown in table 3.6

Table 3.6 Pair-wise comparison Matrix

| Factors | F1 | F2 | F3 | … | Fn |
|---|---|---|---|---|---|
| F1 | a11 | a12 | a13 | | a1n |
| F2 | a21 | a22 | a23 | | a2n |
| F3 | a31 | a32 | a33 | | a3n |
| .. | .. | .. | .. | .. | .. |
| Fn | an1 | an2 | an3 | | Ann |

Source (Author2022)

Where, F = factor influence GWP and PLS and aij = relative importance weight value given for each element by pair-wise comparison.

**Normalized pairwise matrix:** It has been used to calculate the criteria weight. All the elements of the column are divided by the sum of the column to create the normalized pairwise matrix. Thereafter by averaging all the elements of the row and dividing it with the number of criteria. The PCMs in (table 3.5) was normalized, by divided each number in the column by the sum of each column.

$$a = \frac{a_{ij}}{\sum_{i=1}^{N} a_{ij}} \quad (3.1)$$

Where, a is the value of matrix, j is the row number, i is theme and N is the total number of themes. Thematic (criteria) weight (Wj) is calculated from normalized values according to (Equation). The normalized weight was then ranked in descending order

$$Wj = \frac{aij}{N} \quad (3.2)$$

**Consistency index**: To check how far the calculated value represents the reality, consistency ratio has been calculated. Pairwise comparison matrix has been multiplied by the criteria value. Thereafter, sum of the row represents weighted sum value. Eigen value or the priority vector (λmax) has been calculated by making the ratio between these two and averaging it with the number of criteria (Jha et al. 2010; Adiat et al. 2012).

$$\lambda max = (C1 + C2 + C3 + .. + Cn) \quad (3.3)$$

where, C1 to Cn substitutes weighted sum value, n is the number of criteria and λmax substitutes Principal Eigen Value (which measure the degree of consistency).

Then, consistency index (CI) has been calculated by the following formula:

$$CI = \frac{\lambda max - n}{N} \quad (3.4)$$

Finally, consistency ratio (CR) calculated by the following formula:

$$CR = CI/RI \quad (3.5)$$

RI is the consistency index of randomly generated pairwise matrix which was simply obtained from Saatt's ratio index for n matrix order (satty, 1980). It depends on the number of the factor being compared as shown (Table 3.7).

Table 3.7 Saatt's ratio index for n matrix order (satty, 1980)

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.89 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

Source (satty, 1980) If CR < 0.10, the weighting of each criterion was consistent, and the relative weights were appropriate and acceptable for decision-making. However, if CR > 0.10, the value of the ratio indicates inconsistent judgments. As a result, it is necessary to examine the components' relative importance or to adjust the pairwise weight in the CR assessment.

### 3.4.3 Groundwater potential Mapping

To generate the final potential zone, map the Selected raster layers had been overlaid by recognizing their cell values to the same scale, giving a weight value to individual criterion and integrating the weight cell values together (Pramanik, 2016). following formula indicates the weight overlay analysis.

GWP =LithwLithwi + LFwLFwi + SLwSLwi + LDwLDwi + DDwDDwi + LUwLUwi + SwSwi + RFwRFwi + ElwElwi where W represents normalized weight of each thematic layer and Wi stands for normalized weight of the features. Lith = lithology or geological unity of the area; Sl = slope; Lu= land use/land cover; LD = lineament density; RF = rainfall; El = elevation of the study area; S = soil texture and DD represents Drainage density.

### 3.4.4 Validation of the potential map

The Output result was validated with an existing water inventory point data to verify the study. In order to cross-check the resultant groundwater potential zone, 45 actual borehole-yield data which obtained from Ethiopian Geological survey have been overlaid with the ground water potential map and the results have been cross-checked. For verification the location of the overlaid observation site and groundwater potential level must coincide with each other. The obtained data was entered into excel and then imported into the ArcMap platform to generate the data. It shows the actual yield and the availability of groundwater in the study area for result validation of the delineated groundwater potential zone map.

### 3.5 Land suitability Overlay analysis

The land suitability for surface irrigation map was Prepared using the weighted overlay technique based on the percentage influence of five reclassified thematic maps (land use/ cover, equidistance to road, equidistance to water resources, soil suitability, and slope) in the GIS model. The prospective irrigation land suitability value for a particular area would be get by multiplying each scale value of every parameter by its weight or percent influence.
$PLSZ = (SLw * SLr) + (Sw * Sr) + (\text{Ro'}w' * \text{Ro'}r') + (\text{Ws'}w' * \text{Ws'}r') + (LULCw * LULCr)$
Where; PLSZ denotes Potential land suitability zone, SL denotes Slope map, LULC denotes

Land use/cover map, Ro denotes Equidistance to Road, Ws denotes water source and S denotes soil suitablity. And the subscript “w” and “r” refers to normalize criteria of the weight of the theme and normalized weight of the individual feature of rank respectively.

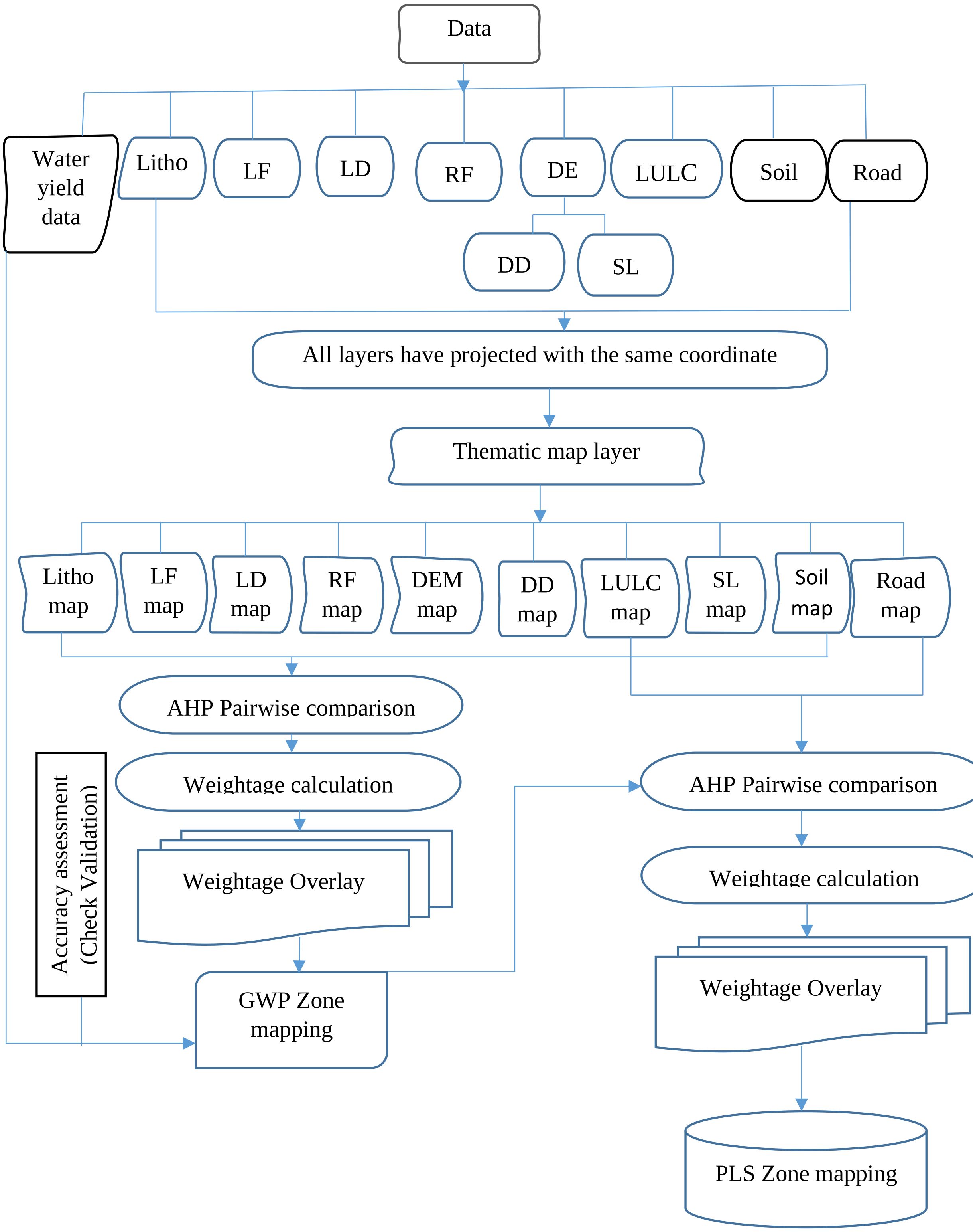



Figure: 3.4 methodology flow chart Source (Author2022)

# CHAPTER 4: RESULTS AND DISCUSSION

## 4.1 Identifying Factors Influence Groundwater Potential and Land suitability

When mapping groundwater potential and land suitability sites, choosing the best factor for groundwater occurrence and land suitability is crucial. Theoretical selection criteria were used to identify and pick the factors that affect the occurrence of groundwater potential and land suitability from a variety of prior research. According to their significance in groundwater occurrences, the detected factors were merged as a pair-wise comparison using theoretical selection criteria such as: frequency of usage (C1), criticality of the factor (C2), and ease/difficulty of data access (C3).

These criteria were identified as:

**Frequency of usage (C1):** 25 different past studies in Ethiopia and worldwide were selected and reviewed. The frequency value of their usage is given in Percent (%) n-times, out of 25% (Table 28). For example, Geology was taken 22-times which get 22% out of 25%.

**Criticalness of the factor (C2):** based on past scholar studies and basic scientific concept, the most significant role for the influence the groundwater occurrence is given in the range of (1-5) %, where, 1= very low importance, 2= low importance, 3= medium importance, 4= high importance and 5= very high importance (Table 4.1).

**Ease/difficult of data access (C3):** based data availability or ease of data access their pair comparison value is given in the range of (1-5) %, where, 1= very difficult, 2= difficult, 3= medium, 4= ease and 5= very ease (Table 4.1).

According to this analysis, nine (9) factor that have score in the range of (20-40) % were selected (Table 4.1). Therefore, these nine factors are the most significant factor affect groundwater occurrence and considered as the main factor responsible for groundwater resource development and identifying optimal site that prospect groundwater potential for this study area.

Table 4.1 Theoretical Selection criteria weight for factor identification

| Criteria (%) | | | | | |
|---|---|---|---|---|---|
| **Factors** | **C1(25%)** | **C2(5%)** | **C3(5%)** | **Score** | **Rank** |
| **Lithology** | 23 | 5 | 4 | 32 | 1 |
| **Landform** | 21 | 5 | 2 | 28 | 3 |
| **Slope** | 22 | 4 | 3 | 29 | 2 |
| **Lineament** | 20 | 4 | 3 | 27 | 4 |
| **Drainage** | 18 | 3 | 3 | 24 | 6 |
| **Rainfall** | 17 | 3 | 5 | 25 | 5 |
| **LULC** | 19 | 2 | 2 | 23 | 7 |
| **Soil** | 16 | 2 | 4 | 22 | 8 |
| **Topography** | 15 | 2 | 3 | 20 | 9 |

Where, C= Criteria, C1= Frequency of Usage, C2= Criticalness of the Factor and C3= Ease/difficult of data access.

### 4.2 Analysis of different input thematic layers for groundwater potential

For the analysis of the potential groundwater zone, a total of nine parameters were considered for the study, such as lineaments density, lithology, DEM, soil, slope, drainage density, landform, land use/land cover, and rainfall. The classification and suitability level of each thematic map were agreed upon and in the acceptable condition with other related studies.

#### 4.2.1 Slope

The slope is significant factor for the identification of groundwater potential zones in any region. The gentile slope zones have moderate surface runoff which permits more opportunity for water to penetrate the ground while zones with steep slopes work with high runoff along these lines allowing less time for water and thus sensibly less infiltration (Dawit.Y 2021). The slope of the study area varied from nearly gentile to steep slope and reclassified into five classes which was agreed with the different scholars. The highest rank was given to flat slope 0-2 (%) because it holds water to infiltrate into the ground whereas the lowest rank was assigned for very steep slope >8 (%) because they result in high runoff and low infiltration which cause low groundwater recharge. The slope of the study area was reclassified into four classes: 0-2%, 2-5%, 5-8%, and >8%, which cover 12.94%, 58.56%, 28.13%, and 0.37% of the watershed, respectively (Table 4.2). Therefore, the majority of this study area was dominated by slopes of 2-5%, covering 58.56% of the regions that were assigned as moderately suitable, which is moderately favorable for the occurrence of groundwater. This is illustrated in Figure 4.1. The suitability classification result of this study was acceptable in classification of slope for mapping groundwater potential according to various research findings such as (Nigussie, Hailu, and Azagegn 2019, Eliyas.A 2018, Dawit.Y 202), because the result falls in the range of those findings as compared to them.

Table: 4.2 The assigned weights and classes for the Slope gradient

| **No** | **Slope (%)** | **Suitability** | **Description** | **Area (skm)** | **Area (%)** |
|---|---|---|---|---|---|
| **1** | 0 – 2 | S1 | Highly suitable | 438.19 | 12.94 |
| **2** | 2 – 5 | S2 | Moderately suitable | 1982.81 | 58.56 |
| **3** | 5 – 8 | S3 | Less suitable | 952.45 | 28.13 |
| **4** | > 8 | N | Not suitable | 12.39 | 0.37 |

Source (Author2022)

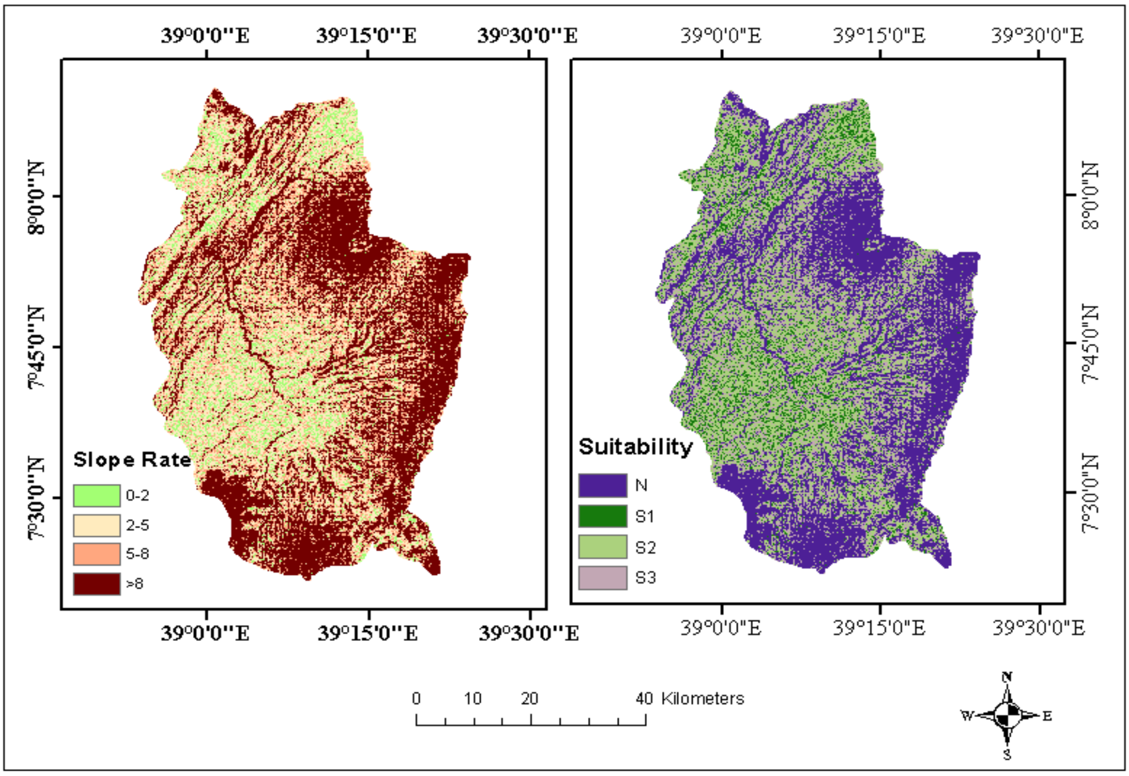



Figure 4.1 Slope and Reclassified Slope map

### 4.2.2 Land use land cover

The thematic map of land use/cover of study area was generated from layer stacked satellite data by clip the area of interest. This Clipped image was used for supervised classifications. Supervised image classification was conducted by ERDAS 2015 software and Google earth pro to classify and to identify the type of LULC on ground respectively then the overall accuracy and kappa coefficient were calculated and were 93.6 % and 92% respectively. So, the classified land use land cover consistency to use.

Land use/cover has been considered as one of the parameters for potential land suitability for surface irrigation and Ground water potential zone identification. (Figure 4.3). 80.94% of the Katar watershed covered by farm land, while 3.82% of the total area being occupied by built-up land. The highest rate given to farm land next to the water body, while Built-up land received a very low rating (Table 4.3). Because regions with roads and housing tend to have greater runoff than infiltration into the groundwater system.

Table: 4.3 land use land cover Suitability analysis

| Factor | Class name | Area (skm) | Area (%) | Rank | Influence |
|---|---|---|---|---|---|
| Land use land cover | Water body | 3.56 | 0.10 | 5 | Very high |
| | Farm land | 2758.75 | 80.94 | 4 | High |
| | Vegetation | 336.95 | 9.89 | 3 | Moderate |
| | Barren land | 178.94 | 5.25 | 2 | Low |
| | Built-up | 129.99 | 3.82 | 1 | Very low |

Source (Author 2022)

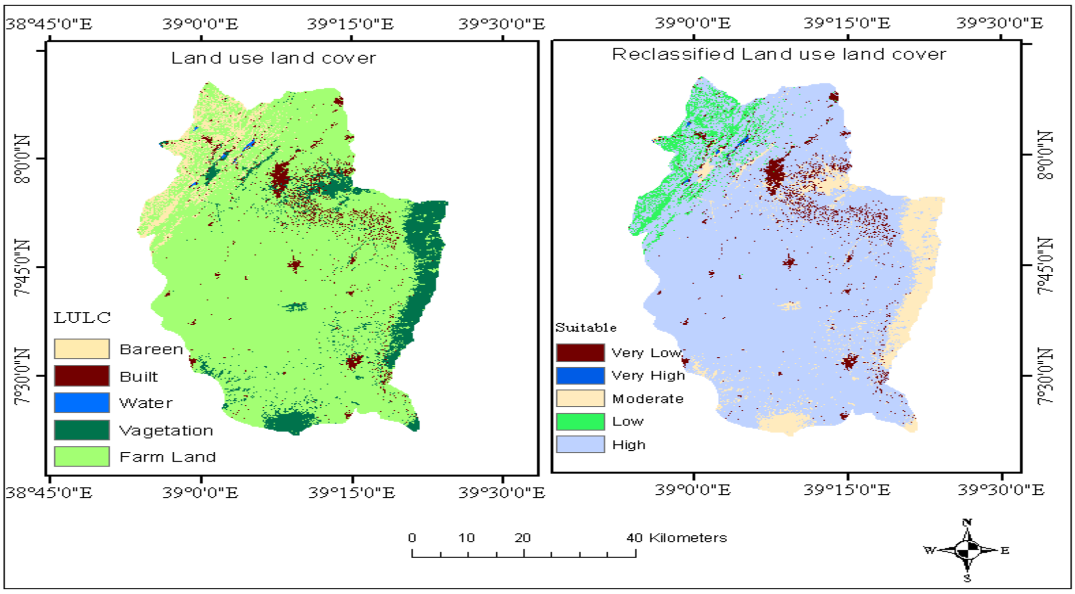



Figure 4.2 LULC and Reclassified LULC. Source (Author2022)

### 4.2.3 Topographic Map

To delineate groundwater potential zone the topographic elevation of study area is also used as one the factors that affect the occurrence of Ground water. Higher elevation has a lower chance to the occurrence of ground water potential and vice versa. Eliyas. A (2018) Used Topography and classified it according to its elevation (Hight from m.s.l) and assumed that higher the elevations the lower the probability of high ground water potential and vice versa. The elevation of this study area is between 1636 - 4188 above mean sea level. The detail presented in table 4.4 and spatial presentation was indicated in figure 4.3.

Table: 4.4 Elevation suitability analysis. Source (Author2022)

| **Factor** | **Class interval** | **Area (skm)** | **Area (%)** | **Rank** | **Influence** |
|---|---|---|---|---|---|
| | 1636 – 1998 | 510.66 | 14.99 | 5 | Very high |
| | 1998 – 2379 | 449.90 | 13.20 | 4 | High |
| Elevation | 2379 – 2783 | 1343.31 | 39.42 | 3 | Moderate |
| | 2783 – 3284 | 753.23 | 22.11 | 2 | Low |
| | 3284 – 4188 | 350.27 | 10.28 | 1 | Very low |

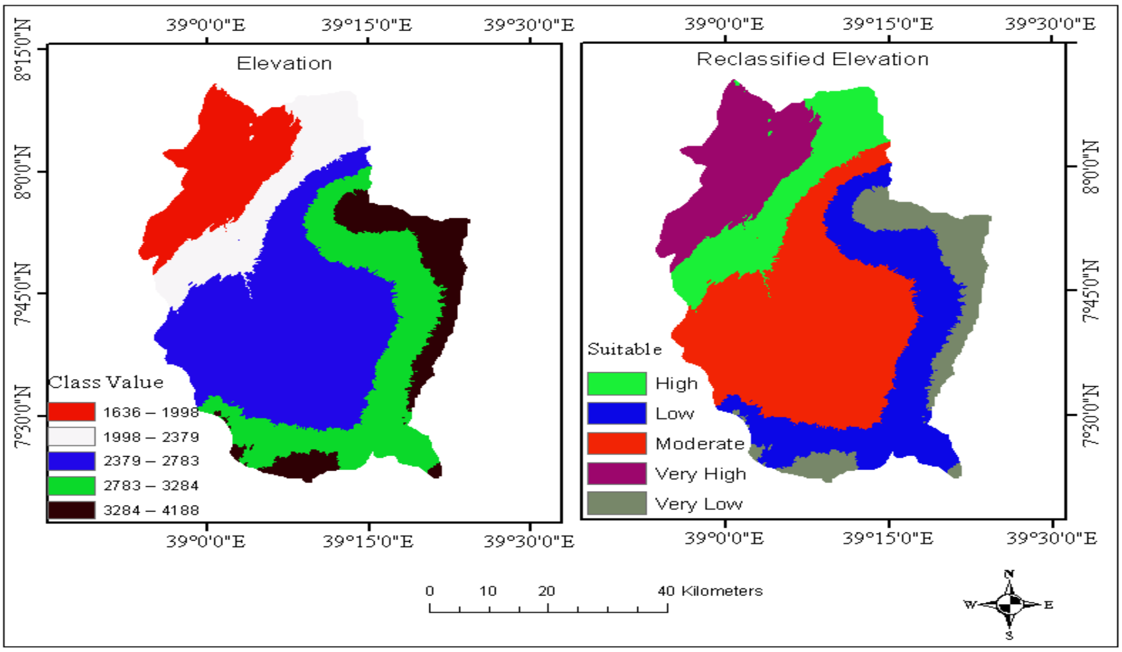



Figure 4.3 Elevation and reclassified Elevation map. source (Generated from SRTM DEM)

### 4.2.4 Lineament Density Map

Lineaments are the physical break of the earth surface such as faults, foliations, joints, bedding planes and map able linear features present on the surfaces. It may be curve, linear and slightly curve which is the most essential for the infiltration and movement of water to the ground. Lineament density was very important in groundwater potential identification because those lineament structure are served as a channel for groundwater movement (increase infiltration capacity and have high water holding capacity). According to Solomon Tullu et al. (2020) high lineament density value indicates high weight value or suitability for GWP whereas the low weight value for groundwater potential area is low lineament density area. So, in case of this study, the highest lineament density Indicate the highest groundwater potential since it has more joints and faults that infiltrate water to groundwater table and the lowest lineament density indicates the lowest groundwater potential as a result of those area has very low joints and faults for permeability of water to groundwater table. Consequently, the suitability classification) of the study is acceptable because the result under the range of finding stated above. The lineament density map was reclassified into five classes as per suitability rank for groundwater occurrences as illustrated on table 4.5 spatial distribution of lineament density was shown in figure 4.4

Table: 4.5 lineament density Suitability analysis

| Factor | LD (km/skm) | Area (skm) | Area (%) | Rank | Suitability |
|---|---|---|---|---|---|
| | 0-0.28 | 768.16 | 22.54 | 1 | Very Low |
| | 0.28-0.53 | 1044.05 | 30.63 | 2 | Low |
| **Lineament density** | 0.53-0.82 | 857.49 | 25.16 | 3 | Moderate |
| | 0.82-1.19 | 510.91 | 14.99 | 4 | High |
| | 1.19-2.08 | 227.88 | 6.68 | 5 | Very high |

LD = denoted lineament density Source (Autor 2022)

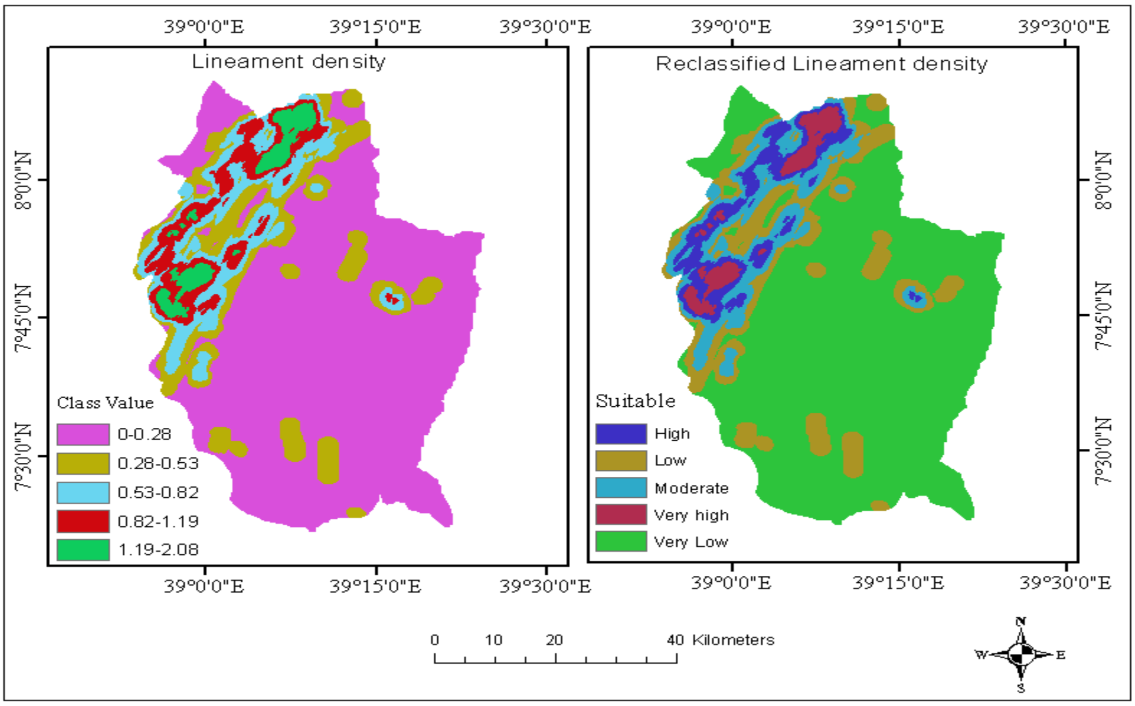



Figure 4.4 lineament density and reclassified lineament density map

### 4.2.5 Drainage density Map

Drainage density is expressed as the total length of all streams per unit drainage. In an area where higher drainage density has generally poor groundwater potential due to an occurrence of larger surface runoff whereas areas of low drainage density allow more infiltration and less surface runoff to recharge the groundwater system. High drainage density was found at the Eastern part of the watershed around the mountains area Such as Chilalo and Galama Ridge and some area in Nort and west. As it is known that an area that has a curved ridge or steep slope causes the larger runoff rather than the infiltration of water to the ground system. Hence the delineated drainage density of the study area was categorized into five classes based on appropriateness rank for potential groundwater zone, as shown on Table 4.6. These were 0.03 - 0.74 km/km2 covered 7.99% of the study area, 0.74 - 1.09km/km2 covered 19.69%, 1.08 - 1.35km/km2 covered 31.50%, 1.35 - 1.63km/km2 covered 29.85%, and 1.63 -2.50 km/km2 covered 10.97%. These drainage densities were categorized as very low, low, moderate, high, and very high, respectively, based on the suitability of groundwater (Figure 4.5). This suitability classification of the drainage density of the study was acceptable as compared with other finding done by (ABUBAKAR 2019) which conducted on groundwater potential mapping of Bosso and environs. Niger state, in Nigeria

Table: 4.6 drainage density analysis

| Factor | DD (km/skm) | Area (skm) | Area (%) | Rank | Suitability |
|---|---|---|---|---|---|
| | 0.03 - 0.73 | 272.22 | 7.99 | 5 | Very high |
| **Drainage Density** | 0.74 - 1.09 | 671.16 | 19.69 | 4 | High |
| | 1.08 - 1.35 | 1073.76 | 31.50 | 3 | Moderate |
| | 1.35 - 1.63 | 1017.36 | 29.85 | 2 | Low |
| | 1.63 - 2.50 | 374.00 | 10.97 | 1 | Very Low |

Source (Autor 2022)

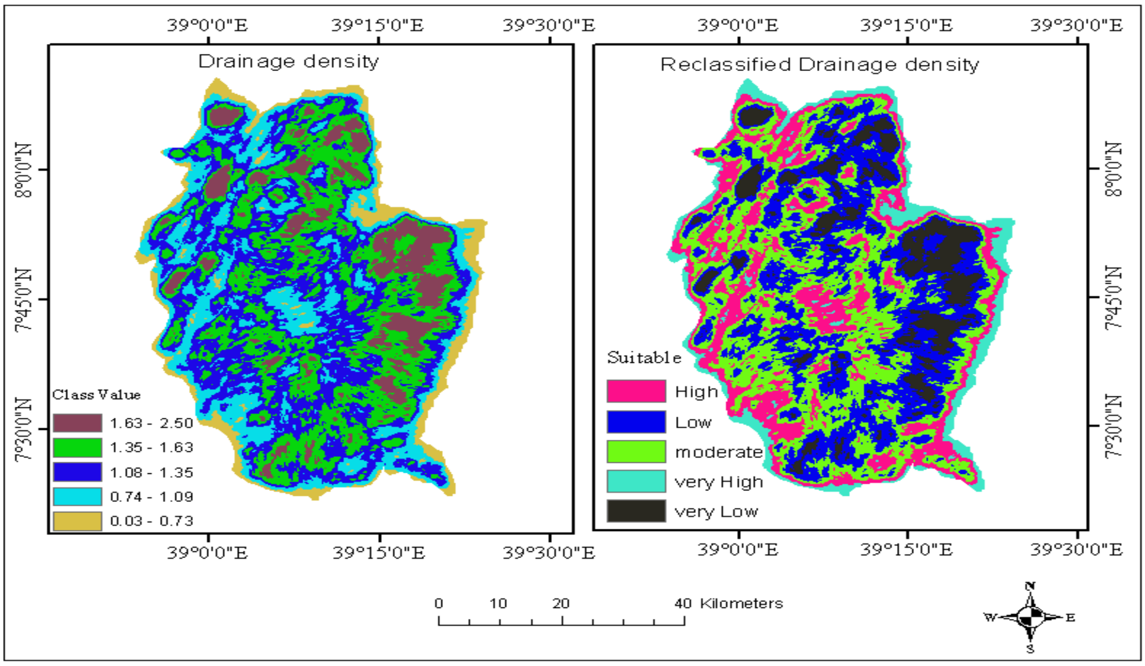



Figure 4.5 Drainage density and reclassified Drainage density

### 4.2.6 Geology

According to the Geological Survey of Ethiopia, geological units are a major factor that controls the quantity and quality of groundwater occurrence in the area. According to Nigussie, Hailu, and Azagegn (2019), sedimentary rocks have great potential for groundwater due to their high porosity and permeability relative to other rocks. Large spatial variation in rock permeability is a common feature of fractured volcanic terrain due to differences in the degree of fracturing. Ayenew (1998) observed variable groundwater potentials across the study area – some massive pumiceous pyroclastic have poor yields, while well-jointed or fractured ignimbrites have good yields. Thus the geological unit of study area categorized as:- Pliocene Trachyte (Tv7), Pliocene basalts (Tv6), Lacustrine Sediments (Q2us), pumice & Unwelded tuffs (Qwpu), Chafe Donsa Pyroclastic Deposits (Ncp), Unwelded rhyolitic pumice & tuffs, Porphyritic feldspar basalts of Tullu Moye, Nazireth Group, Chafe Donsa Pyroclastic Deposits, Highland Basaltic volcanic rock (Tv4), Ignimbrites, tuffs, water lain pyroclastic (Qdi), Porphyritic feldspar basalts of Tullu Moye (Qwb2), Quaternary Scoria cones (Qv2), Nazireth Group (Nn) and Quaternary Alluvial Deposit (Qal). The comparison of geologic unit was done in terms of their importance with respect to groundwater occurrences by considering their characteristic such as rock type and thickness, fracture density, compactness, the type and degree of cementation and the weightage were assigned based on their influence in groundwater. Rhyolitic and Tranchites have massive nature and very low permeability(Kumera 2017).

**Chefe Donsa Pyroclastic Deposits (Ncp): -**Exposure of this unit is found to North western of watershed. It is light to dark-grey in fresh samples and reddish to yellow to pink in weathered ones. It is fine grained, poorly welded rock containing vitrophyric fiamme and lithic fragments with associated rhyolitic lava flows interleaved with ash and and unwelded tuffs. Microscopically, it consists of crystals of 35 % K-feldspar (sanidine), 40% quartz, 20% plagioclase and 5% hornblend having vitrphyric texture.

**Lacustrine Sediments (Q2us): -**Exposure of this unit is found to north and north western occupying the rift floor of the area. It forms flat-lying topography and marshy areas. It consists of loose, brown to grey color sand, silt and calcrete.

**The highland basalt flows (TV4): -** These are central eruptions and exposed on top of upper pyroclasts. They are exposed around Bekoji and Sagure. These lava flows form large plateau areas and are younger fresh basalts. The basalts are separated with thin paleosoils.

**Pliocene basalt flows (TV6): -** The Pliocene basalts are exposed on the highland areas, restricted to the foot slopes of mountain peaks. They are exposed below Chilalo, Kaka. The basalts are fresh, compact, massive, and dense, usually grey to dark grey in color. The Pliocene basalt flows are immediately overlain by PlioPleistocene trachyte flows. They are younger post-rift flows.

**Pliocene trachyte flows (TV7): -** These trachyte flow form the summit of Chilalo, Kaka and Galema Mountain of the watershed. The Plio-Peistocene trachyte flows, are younger post-rift central type flows. They are light grey, slightly weathered, fine to medium grained and locally porphyritic, showing sanidine phenocrysts.

**Quaternary basalt flows (QV1): -** It is exposed in the MER to the NW part of the area. They are relatively fresh, lessely decomposed rocky surface which are hard and compact, fine to medium grained and dark grey colored. The basalts are often vesicular but mainly form coarse grained basalts and rich in opaque minerals.

**Quaternary alluvial deposits (Qal): -** The Quaternary alluvial deposits also occur on both the plateau and within the MER. On the plateau they form minor subdued topography, filled with silty-clayey sediments. Within the MER, they occur in grabens formed as rift-in-rift within main rift and often grades to lacustrine sediments, which are marshy to bogy silty-clays.

Depending on different related previous literature done in the area and other places in the country, the geological unity of study area was classified based on its hydrological properties (permeability and porosity). Nigussie, Hailu, and Azagegn (2019) perform study in the watershed and they classified the geology of study depending on its permeability property. So according to them; Pliocene trachyte and Pliocene basalt (UPB) were classified as very poor, Pumice and unwelded tuffs (PUT) classified as poor, Chefe Donsa pyroclastic flows, rhyolitic and trachytic lava domes and flows, high land basalt (CDPB) classified as moderate, Lacustrine sediment and alluvial (LSA) classified as good and Ignimbrites, recent and sub-recent basalts, Pleistocene basalt and basaltic pyroclastics (IBP) classified as very good.

According to Kabeto et al. (2022); pumice & Unwelded tuffs (Qwpu) was assigned as low ground water productivity , Ignimbrites, tuffs, water lain pyroclastic (Qdi) classified as moderate and Nathiret group (Nn) and Pleistocene basalts (Qwbp) were classified as high potential. So, depending on this literature the geological unity of study area was classified as shown on the table 4.7

Table 4. 7 Geological unity of study area

| Factor | Name of Lithology | Symbol | Rank | Suitability |
|---|---|---|---|---|
| Lithology | Pliocene Trachyte | Tv7 | 1 | Very low |
| | Pliocene basalts | Tv6 | 2 | Low |
| | pumice & Unwelded tuffs | Qwpu | 2 | Low |
| | Chafe Donsa Pyroclastic Deposits | Ncp | 3 | Moderate |
| | Highland Basaltic volcanic rock | Tv4 | 3 | Moderate |
| | Ignimbrites, tuffs, water lain pyroclastic | Qdi | 3 | Moderate |
| | Porphyritic feldspar basalts of Tullu Moye | Qwb2 | 3 | Moderate |
| | Lacustrine Sediments | Q2us | 4 | high |
| | Quaternary Alluvial Deposit | Qal | 4 | High |
| | Quaternary Scoria cones | Qv2 | 4 | High |
| | Pleistocene basalts | Qwbp | 4 | High |
| | Nazireth Group | Nn | 4 | High |

Source (Autor 2022)

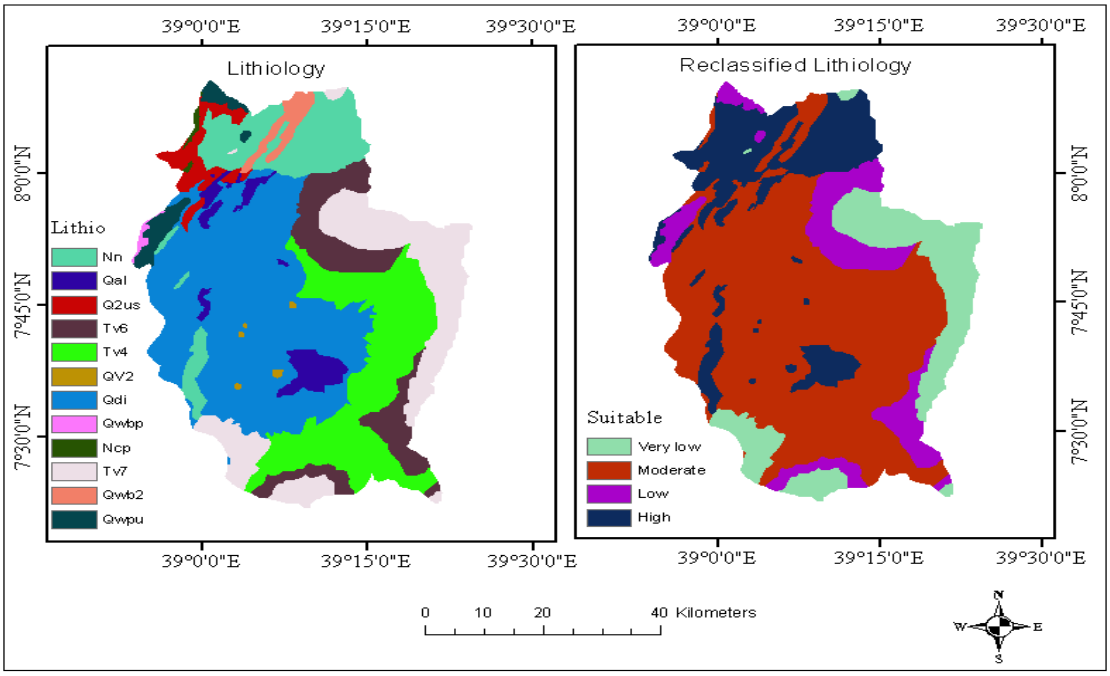



Figure 4.6 Lithology and Reclassified Lithology map

### 4.2.7 Land form Map

Land form is a Geomorphologic map that depicts the important geomorphic units, landforms and underlying geology so as to provide an understanding of the processes, lithology, structures, and geologic controls relating to groundwater occurrence as well as to groundwater prospects. In groundwater exploration geomorphology plays an important role in identification of favorable zone for groundwater. The land form of study area was digitized from The Geological map of study area that obtained from Ethiopia Geological survey and Geomorphologically classified as Rift Valley Lowland, Plateau, Steeped slope, Rift Valley Escarpment and Mount Peak/Galama Ridge. The mountain peaks and Galama ridge occur around Chilalo and Kaka mountains. They form high rising surface with steep slopes. The steep slopes are rather difficult to climb and these regions are inaccessible. Most of the high rising mountains are built of Pliocene trachytes, underlain by basalts of central eruption (Workineh Haro, Daba Bulto Mekonen Bekele, Desalegn Debelo and Edris 2020). So, because of its high rising surface with steep slopes, the probability of ground water occurrence in this region is very low. In the other hand the Rift Valley lowland occur to the northwestern part of the study area. This area is vegetated with acacia Senegal scattered with spiny euphorbia and rare tall grasses. The surface of these areas is relatively low flat land ornamented with remnant volcanic hills which show steep sided walls (Workineh Haro, Daba Bulto Mekonen Bekele, Desalegn Debelo and Edris 2020). So as a result of relatively flat land the occurrence of ground water potential is high.

Figure 4.7 shows the reclassified Landform map of the study area according to the suitability rank of groundwater potential. It demonstrates that the study area is dominated by a plateau, which is categorized as an area with high groundwater potential and covers 45.35% (Table 4.8) of the study area. It located in northeastern, southern, and central regions. High rank (4) and (5) was given for plateau and Rift Valley Lowland respectively which covers 45.35% and 15.29% of the study area. The north, north-east, north-west and central parts of the region classified as high and very groundwater potential zone, because of low runoff and high infiltration. Mountain peak and Galama Ridge sections, which make up 11.74% of the study area were classed as a very low GWP zone due to their steep terrain and high slopes that result in heavy runoff and limited infiltration, received a lower rank. The detail was shown in the table 4.8 and its spatial distribution was indicated by figure 4.7

This suitability classification was therefore acceptable because it was consistent with findings from other researchers, including those who evaluated groundwater potential and recharge zones using RS and GIS techniques in various areas of their research (Nigussie, Hailu, and Azagegn 2019, Solomon. T. 2020, Eliyas.A. 2018). Therefore, when compared to those and other findings, this study's classification and ranking of the study's groundwater potential zone are acceptable.

Table: 4.8 Geomorphology suitability classification for GWP zone identification

| Factor | Land form type | Area km2 | Area (%) | Rank | Suitability |
|---|---|---|---|---|---|
| | Mount Peak/Galama Redge | 400.05 | 11.74 | 1 | Very low |
| | Rift Valley Escarpment | 196.63 | 5.77 | 2 | Low |
| LF | Steeped slope | 744.37 | 21.85 | 3 | Moderate |
| | Plateau | 1545.01 | 45.35 | 4 | High |
| | Rift Valley Lowland | 521.00 | 15.29 | 5 | Very high |

LF = land form Source (Autor 2022)

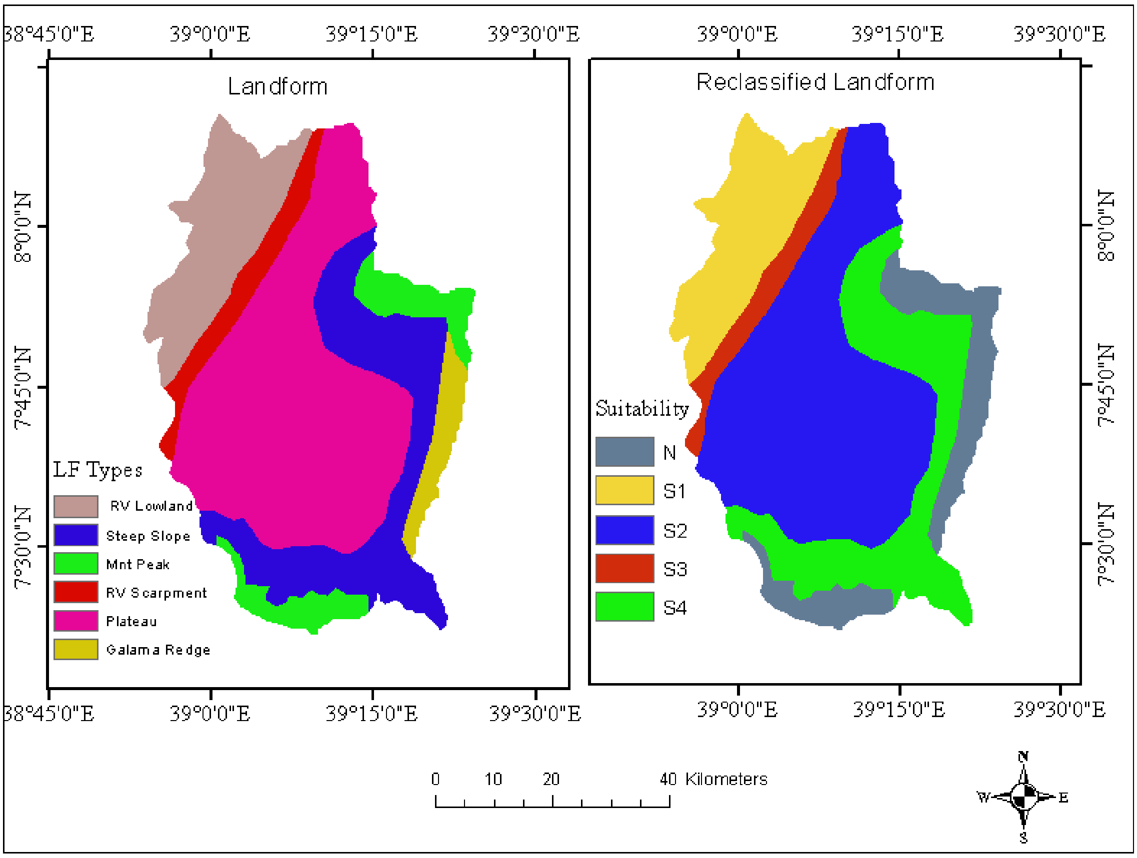



Figure 4.7 Landform and reclassified landform map

### 4.2.8 Soil Texture

The rate of infiltration largely depends on the grain size and related hydraulic characteristics of the soils (Jhariya et al. 2016). The soil for the study area reveals that three soil texture categories namely clay, Sandy loam and loam are found in the area. Rank of soil has been assigned on the basis of their infiltration rate. Sandy Loam has high infiltration rate, hence given higher priority, while, the clay soil has least infiltration rate hence assigned low priority it was shown in table 4.9 and Soil texture map of the study area is shown blow in Fig 4.8. Therefore, when compared to those and other findings (Nigussie, Hailu, and Azagegn 2019), the classified soil texture for this study's and ranking of the study's groundwater potential zone are acceptable.

Table: 4.9 Soil texture analysis

| Factor | Soil Texture | Area (skm) | Area (%) | Rank | Suitability |
|---|---|---|---|---|---|
| | Clay | 1762.841 | 51.72 | 1 | S3 |
| Soil | Loam | 1589.535 | 46.63 | 3 | S2 |
| | Sandy loam | 56.1258 | 1.65 | 5 | S1 |

Source (Autor 2022)

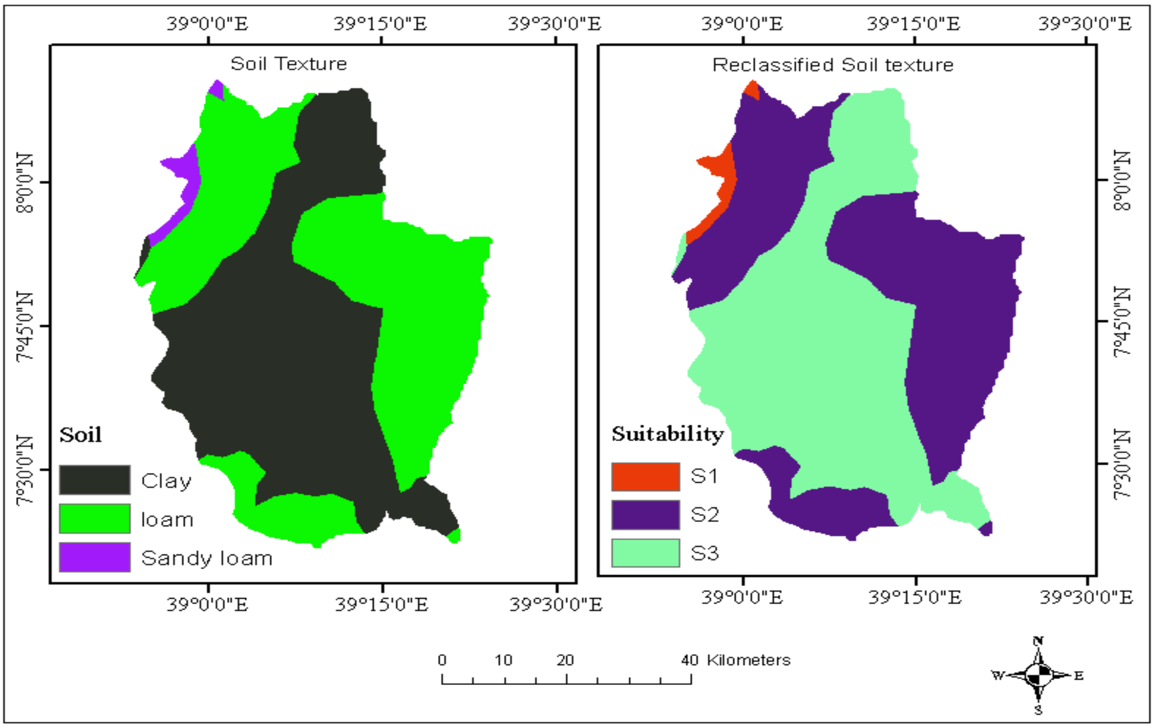



Figure 4.8 soil texture and reclassified soil texture

### 4.2.9 Rainfall

Another factor that affects how much water can infiltrate and join groundwater zones is rainfall. The amount of water that gets underground is affected by characteristics including terrain, vegetation, and surface geology, which all alter the relationship between rainfall and groundwater occurrence (Libasse, 2007).

The study area's long-term mean annual rainfall map was created using IDW interpolation from seven meteorological station data that recorded for ten years period of times (2001-2010). The relative weights for each rainfall class are shown in Table 4.10 and its map indicated in figure 4.9, based on the mean annual rainfall and its impact on groundwater occurrence. Due to strong infiltration rates, a location with a high mean annual rainfall is more probable than an area with a low mean annual rainfall to have a high groundwater potential.

Table 4.10 Rainfall suitability analysis

| Factor | Rainfall(mm) | Area (skm) | Area (%) | Rank | Suitability |
|---|---|---|---|---|---|
| | 1114-1200 | 537.63 | 15.81 | 5 | Very High |
| **Rainfall** | 1014-1114 | 626.84 | 18.44 | 4 | High |
| | 914-1014 | 1497.00 | 44.03 | 3 | Moderate |
| | 814 – 914 | 469.73 | 13.82 | 2 | Low |
| | 714-814 | 268.92 | 7.90 | 1 | Very Low |

Source (Autor 2022)

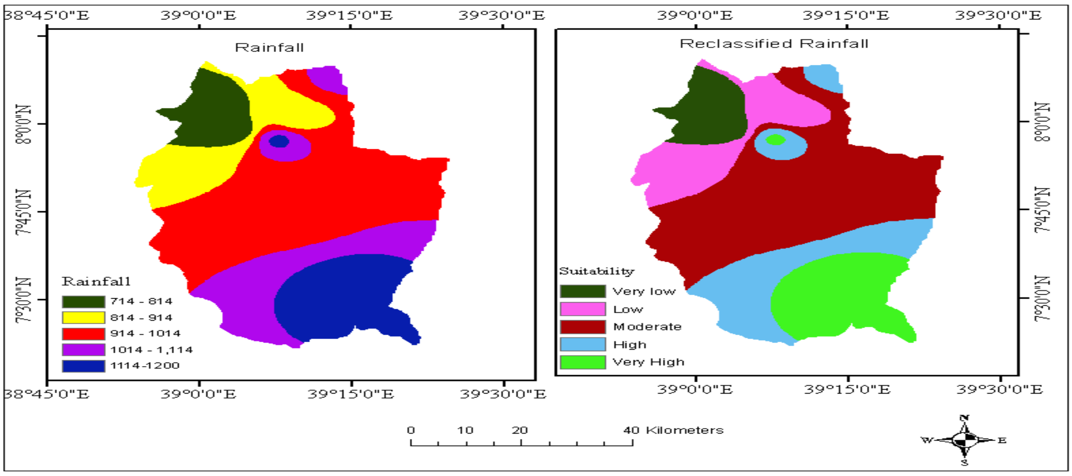



Figure 4.9 rainfall and reclassified rainfall map Source (Autor 2022)

## 4.3 Weight analysis by AHP

Relative weights of thematic layers such as; elevation, slope, soil, land use/cover, drainage density, lineament density, geomorphology, geology and rainfall were assigned according to their relative importance for occurrence of groundwater potential based on the judgment different literatures of similar work. This was done to compare the importance of two layers as one of them has more influence to the groundwater occurrence than the others. So, in this case, geology, and Landform were taken as more influencing parameters of groundwater potential zones as shown in Table 4.11

Table:4.11 Paired wise compression matrix

| | Lith | LF | Slope | LD | DD | LULC | Soil | RF | EL | Wt.% |
|---|---|---|---|---|---|---|---|---|---|---|
| **Lith** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 31 |
| **LF** | 1/2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 22 |
| **Slope** | 1/3 | ½ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 16 |
| **LD** | 1/4 | 1/3 | ½ | 1 | 2 | 3 | 4 | 5 | 6 | 11 |
| **DD** | 1/5 | ¼ | 1/3 | ½ | 1 | 2 | 3 | 4 | 5 | 7 |
| **LULC** | 1/6 | 1/5 | ¼ | 1/3 | 1/2 | 1 | 2 | 3 | 4 | 5 |
| **Soil** | 1/7 | 1/6 | 1/5 | ¼ | 1/3 | 1/2 | 1 | 2 | 3 | 4 |
| **RF** | 1/8 | 1/7 | 1/6 | 1/5 | 1/4 | 1/3 | 1/2 | 1 | 2 | 2 |
| **EL** | 1/9 | 1/8 | 1/7 | 1/6 | 1/5 | 1/4 | 1/3 | 1/2 | 1 | 2 |

Where LD: Lineament density; GEO: Geology; SP: Slope; RF: Rainfall; GM: Geomorphology; DD: Drainage density; LULC: Land use land cover; EL: Elevation, Source (Autor 2022)

## 4.4 Weight normalization

Normalized matrix was used to calculate Eigen vector of each parameter which shows the priority of parameters on delineation of groundwater potential zones. The higher the value of Eigen vector shows the more influencing parameters for delineation of groundwater potential zones. For instance, the Eigen vector of Lithology and Landform was 0.31 and 0.22 respectively. This shows prior parameters affecting the occurrence of groundwater potential zones were Lithology and Landform. Finally, the Eigen vectors calculated and summarized in Table 4.12 was used to calculate principal Eigen value shown in table 4.13 and consistency ratio of pair wise comparison matrix and weight analyzed by AHP was checked to be accept if CR is less than or equal to 0.1 and to be re analysis if CR is greater than 0.1. For this research case CR value was less than 0.1 which is acceptable.

Table: 4.12 Normalized matrix

| | **Lith** | **LF** | **Slope** | **LD** | **DD** | **LULC** | **Soil** | **RF** | **EL** | **Weight** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Lith** | 0.353 | 0.423 | 0.395 | 0.349 | 0.307 | 0.271 | 0.242 | 0.219 | 0.2 | 0.306 |
| **LF** | 0.176 | 0.211 | 0.263 | 0.262 | 0.245 | 0.226 | 0.208 | 0.191 | 0.177 | 0.218 |
| **Slope** | 0.117 | 0.105 | 0.131 | 0.174 | 0.184 | 0.181 | 0.173 | 0.164 | 0.155 | 0.154 |
| **LD** | 0.088 | 0.070 | 0.065 | 0.087 | 0.122 | 0.135 | 0.138 | 0.136 | 0.133 | 0.108 |
| **DD** | 0.070 | 0.052 | 0.043 | 0.043 | 0.061 | 0.090 | 0.104 | 0.109 | 0.111 | 0.076 |
| **LULC** | 0.058 | 0.042 | 0.032 | 0.029 | 0.030 | 0.045 | 0.069 | 0.082 | 0.088 | 0.053 |
| **Soil** | 0.050 | 0.035 | 0.026 | 0.021 | 0.020 | 0.022 | 0.034 | 0.054 | 0.066 | 0.037 |
| **RF** | 0.044 | 0.030 | 0.021 | 0.017 | 0.015 | 0.015 | 0.017 | 0.027 | 0.044 | 0.025 |
| **EL** | 0.039 | 0.026 | 0.018 | 0.014 | 0.012 | 0.011 | 0.011 | 0.013 | 0.022 | 0.018 |
| **Sum** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Source (Autor 2022)

Table: 4.13 Principal Eigen value calculation

| **Parameter** | **Weighted Sum Value (1)** | **Weight (2)** | **λ (1x2)** |
|---|---|---|---|
| Lith | 2.98 | 0.31 | 9.71 |
| LF | 2.13 | 0.22 | 9.78 |
| Slope | 1.50 | 0.15 | 9.76 |
| LD | 1.04 | 0.11 | 9.55 |
| DD | 0.71 | 0.08 | 9.34 |
| LULC | 0.49 | 0.05 | 9.16 |
| Soil | 0.34 | 0.04 | 9.08 |
| RF | 0.24 | 0.02 | 9.10 |
| EL | 0.17 | 0.02 | 9.22 |
| Λmax = 9.407994 | | | |

Source (Autor 2022)

The measure of consistency, called Consistency Index (CI) was calculated and given below as: $CI = \frac{\lambda max-n}{n-1} = \frac{9.407994-9}{8} = 0.050999$ Where, λmax is Principal Eigen value and n was the numbers of criteria used for analysis.

Table 1.14 Saatt's ratio index for n matrix order (satty, 1980)

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **RI** | 0 | 0 | 0.58 | 0.89 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

Consistency Ratio which denoted by CR = $\frac{CI}{RI}$. The RI value obtained from Saatt's ratio index for n matrix order that shown in the above table which RI=1.45 for n = 9. Thus CR = $\frac{CI}{RI}$ = $\frac{0.050999}{1.45}$, CR = 0.035 < 0.1 So that the Weighted analyzed by AHP were acceptable.

**4.5 Groundwater Potential zone mapping**

The groundwater potential zonation map was generated by integrating all the thematic layers through the weighted overlay method. The ranking assigned for each theme is based on its influence on groundwater occurrence. After integrating all the thematic layers with proper weightages and ranks, the groundwater potential zonation map of Katar Watershed was delineated using GIS.

Table: 4.15 Ranks and weightages assigned for various themes maps of parameters

| **Factors** | **Parameters** | **Area (skm)** | **Area (%)** | **Rank** | **Weight** |
|---|---|---|---|---|---|
| RF | 1114-1200 | 537.63 | 15.81 | 5 | |
| | 1014-1114 | 626.84 | 18.44 | 4 | 2 |
| | 914-1014 | 1497.00 | 44.03 | 3 | |
| | 814 – 914 | 469.73 | 13.82 | 2 | |
| | 714-814 | 268.92 | 7.90 | 1 | |
| Landform | Mountain Peak/Galama Ridge | 400.05 | 11.74 | 1 | 22 |
| | Steeped Slope | 744.37 | 21.85 | 2 | |
| | Rift Valley Escarpment | 196.63 | 5.77 | 3 | |
| | Plateau | 1545.01 | 45.35 | 4 | |
| | Rift Valley Lowland | 520.96 | 15.29 | 5 | |
| LULC | Built up Area | 129.9933 | 3.81 | 1 | 5 |
| | Bare Land | 178.9443 | 5.25 | 2 | |
| | Vegetation | 336.9546 | 9.89 | 3 | |
| | Farm Land | 2758.748 | 80.94 | 4 | |

| | | | | | |
|---|---|---|---|---|---|
| | Water body | 3.5595 | 0.11 | 5 | |
| Lithology | Tv7 | 505.67 | 14.84 | 1 | 31 |
| | Tv6/Qwpu | 397.94 | 11.67 | 2 | |
| | Tv4/Qdi/Ncp/Qwb2 | 1907.34 | 55.96 | 3 | |
| | Nn/Qal/Q2us/Qv2/Qwbp | 597.46 | 17.53 | 4 | |
| Lineament density | 0 - 0.1276 | 2293.14 | 67.28 | 1 | 11 |
| | 0.1276 - 0.3828 | 480.92 | 14.11 | 2 | |
| | 0.3827 - 0.6512 | 314.08 | 9.21 | 3 | |
| | 0.6512 - 0.9802 | 215.72 | 6.33 | 4 | |
| | 0.9802 - 1.7121 | 104.63 | 3.07 | 5 | |
| Soil Texture | Sandy Loam | 56.12 | 51.72 | 1 | 4 |
| | Loam | 1589.53 | 46.63 | 2 | |
| | Clay | 1762.84 | 1.65 | 3 | |
| Slope (%) | 0-2 | 708.95 | 20.86 | 4 | 16 |
| | 2-5 | 1253.05 | 36.86 | 3 | |
| | 5-8 | 615.52 | 18.11 | 2 | |
| | >8 | 821.70 | 24.17 | 1 | |
| Drainage Density | 0.0319-0.7394 | 272.22 | 10.97 | 5 | 7 |
| | 0.7394-1.0883 | 671.16 | 29.85 | 4 | |
| | 1.0883-1.3500 | 1073.76 | 31.50 | 3 | |
| | 1.3500-1.6311 | 1017.36 | 19.69 | 2 | |
| | 1.6311-2.5034 | 374.00 | 7.99 | 1 | |
| Elevation | 1636-1998 | 510.66 | 14.99 | 5 | 2 |
| | 1998-2379 | 449.90 | 13.20 | 4 | |
| | 2379-2783 | 1343.31 | 39.42 | 3 | |
| | 2783-3284 | 753.23 | 22.11 | 2 | |
| | 3284-4188 | 350.27 | 10.28 | 1 | |

Source (Autor 2022)

To identify the overall Ground water potential zone suitability of the area, the spatial analysis tool was used to overlay all theme layers using Arc map based on rates for the classes in each layer and the weight of thematic layers (percent of influences) resulting from pairwise comparison. The percentage influences of thematic layers and the rank for their parameters were assigned based on expert assessment of work carried out through a similar groundwater potential zone mapping study (Nigussie, Hailu, and Azagegn 2019). This is because none of those factors have the same effect on groundwater occurrence and movement (Saaty, 1980). The groundwater potential map of the study area generated was categorized into four zones such as ‘Poor’, ‘moderate’, ‘high’ and ‘very high’. Very high groundwater potential zones are found in Rift valley lowlands and in the area where there are high lineament densities occurs. About 1.12% of the basin area falls under Poor potential zone category; 40.73% area falls under moderate category; 54.56% area falls under high potential category; and 3.59% area represents very high potential category. The detail was shown in table 4.16.

Table 4.16 Spatial variation map of Ground potential in katar Watershed

| Zones | Weight Classes | Area (skm) | Percent (%) |
|---|---|---|---|
| Very low Potential | 1 | 37.92 | 1.12 |
| Low potential | 2 | 1382.68 | 40.73 |
| Moderate | 3 | 1852.28 | 54.56 |
| High Potential | 4 | 121.75 | 3.59 |

Source (Autor 2022)

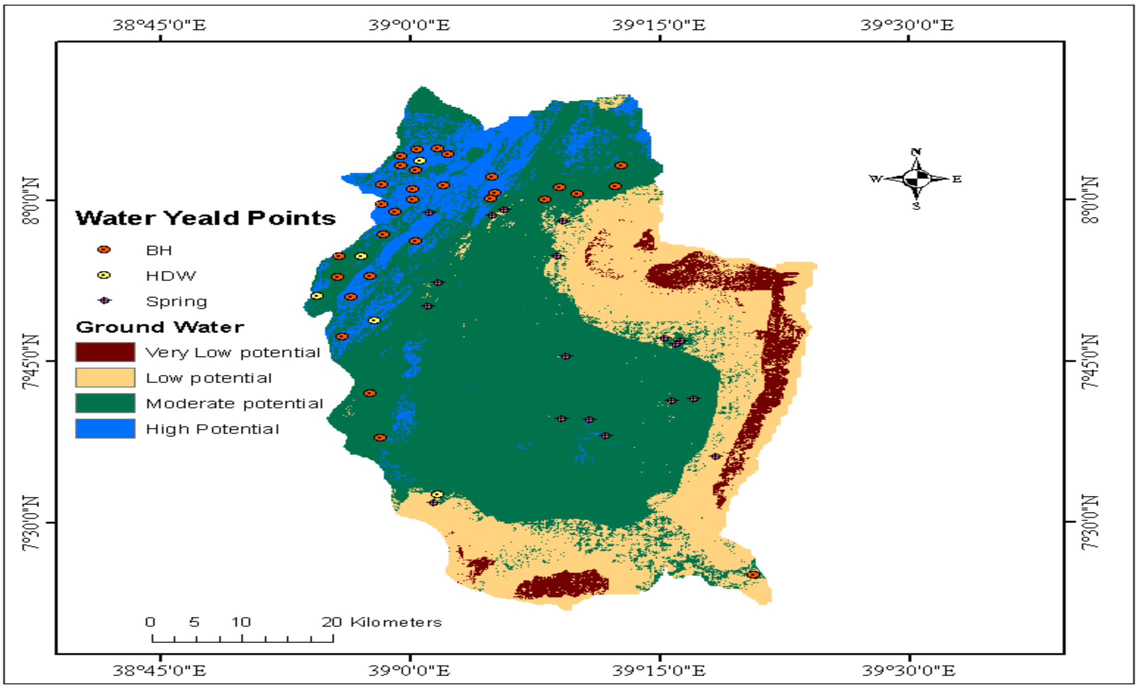


Figure 4.15GWPZ and water inventory points

Very low groundwater potential Found in same Eastern, southern, and southeastern Parts of the regions and it is 1.12% of the total area with a land area of 37.97 km2. Geologically, this region is mostly made up of Badda Trachyte formations like Pliocene Trachyte which have poor ground water productivity. The geomorphology of this area is mountainous like chilalo, Kaka and Galama Ridge. In this region there is high runoff surface water due to its steepest slope. Therefore, geomorphology and slope effect the area next to Geological unit for its poor water potential. The second classification of groundwater potential was "Low Potential", and it is also located in the Eastern to Southern Parts of the region. geological unity of this area was Pliocene basalts which its massive and poor to moderate permeability. It shares the same geomorphological characteristics (mountainous and escarpment) with poor potential category. So, geomorphology has greater effect for ground water potential occurrence in the area. This category is second largest among the four classes, with a share of 40.73%, spread over 1382.68km2 in the Area. Moderate potential zones are dominant among all classes, with an area of 1852.28 Km2, 54.56% of the total land area of the Katar watershed. Moderate potential located in same parts of northern, western and the north eastern to the whole central parts of the watershed. The major geology in this region were Tv4, Qdi, Ncp, Qwb2 while other geological units like, Tv6 and Qwpu were also exist. The region geomorphologically plateau or rounded plain and its slope nearly 2-5(%) which suitable for ground water due to there is less runoff surface water. High ground water potential zone which covers 121.75skm or 3.59% of study area located in NE, SW, N and W. the major geological unity in this area: Nn, Qal, Q2us, QV2 and Qwbp which have high water permeability property in the area. The geomorphologically categorized as rift valley low land that expected as high ground water potential and also has slope 0-2 (%) that nearly plain. Hence geology, geomorphology, Lulc and slope plays a great role for the occurrence of ground water potential.

### 4.6 Validation of the result for Groundwater Potential Zone

A total of 45 Borehole data was used to validate the GWPZ map. The groundwater potential map Prepared which is divided into Four sub-classes namely High potential zone, Moderate Potential zone, Low Potential zone, and Very low Potential Zone was overlayed with this point data for validation of the potential map generated in this study. From 45 points 29 points of Borehole and springs which the amounts of its water yield known were used to calculate the percentage of accuracy while 16 left points were undetermined. Thus, out of 29 water data in which 16 of 15 falls under high to very high potential, 13 of 10 falls under moderate potential, and all low-yield points are found under the low potential area (Table 4.17). This shows, that out of the total, 86% were consistent with their corresponding classes of groundwater prospective zones. So, it demonstrates that groundwater potential zones are relative to water inventory point data that were found in the watershed (Figure 4.15)

Table 4.17 Validity check using water yield points for ground water potential zone map

| **Expected GW perspective** | **GW perspective zone** | | | |
|---|---|---|---|---|
| | **Very low** | **Low** | **High to Moderate** | **Total** |
| Total number of validation under different GWP zone | No | 13 | 16 | 29 |
| No. of valid under agree | 0 | 10 | 15 | 25 |
| No. of valid under disagree | | 3 | 1 | 6 |
| Average yield data (l/s) | | 6.5 | 8 | |
| **Prediction accuracy (%) =25/29*100 = 86.21%** | | | | |

Source (Autor 2022)

### 4.7 Irrigation Land Suitability analysis

Land suitability analysis is the evaluation of potential suitable of land and its limitations for the surface irrigation development. The concept of limitation indicates the quality of the land. To find suitable land for irrigation; the individual suitability factors consisting of the slope, soil, land use and land cover, Proximity to Road and water resource were used as inputs for the identification of suitable areas for potential surface irrigation development and they are mapped separately. Using GIS based multi-criteria analysis; The factors were prepared for a weighted overlay with Arc GIS Map 10.8 spatial analysis tool. The analysis results of surface irrigation suitability evaluation factors are presented in the following sections.

#### 4.7.1 Soil suitability

The Soil suitability for surface irrigation of watershed has been established by evaluating the soil suitability parameters; soil texture, soil depth and soil drainage suitability through overlay analysis.

##### 4.7.1.1 Soil texture suitability

Soil Texture was considered as one of the major factors that determine the selection of land for surface irrigation potential in the study area. According to FAO guidelines for soil evaluation, the soil texture of the study area was evaluated and classified into clay (C), loam (L) and sandy loam (SL). The soil texture suitability of study area reclassified according to its suitability level depending on previous literature review. Soil textural class suitability analysis for surface irrigation development of the area revealed that 51.72 % of the soils in the area were under highly suitable, 46.63 % of the soil were categorized under moderately suitable class and 1.65 % of the soil textural class in the area were categorized under less suitable class. Table 4.18 clearly revealed that 1762.84 skm of the total area was highly suitable for irrigation in the study area and 1645.67 skm of the total area where ranges from moderately suitable to marginally suitable classes for surface irrigation. From the result found observed that most of the study area was suitable for potential surface irrigation in terms of soil texture. Clay texture soils which have a good characteristic for irrigation was categorized as highly suitable class whereas, loam and sandy loam soils were categorized as moderately and marginally suitable soil texture classes respectively.

Table 4.18 soil suitability analysis

| Soil texture | Suitability factors | Description | Area (skm) | Area (%) |
|---|---|---|---|---|
| Sandy loam | S3 | Less suitable | 56.13 | 1.65 |
| Loam | S2 | Moderately suitable | 1589.54 | 46.63 |
| Clay | S1 | Highly suitable | 1762.84 | 51.72 |

Source (Autor 2022)

#### 4.7.1.2 Soil depth suitability

Soil depth was considered as one of the major factors that determine the selection of land for surface irrigation potential in the study area. Soil depth determines the roots' growth as well as the presence of a volume of water and air in the soil. The depth of the soil layer in the study area was divided into four: >120, 90-120 and 70-90cm with a suitability class S1, S2, S3, respectively. The soil depth suitability analysis result indicated in the table 4.19 below, that about 95.3% of the total area of the watershed was categorized under highly suitable, the area which is about 4.6% of the watershed was moderately suitable and 0.1% of the total study area was less suitable for surface irrigation development. Generally, about 99.9% of the soil in the study area is in the range of high to moderate suitable and the remaining 0.1% of the area is grouped as less suitable in terms of soil depth suitability analysis.

Table 4.19 Analyzed soil depth

| Soil Depth(cm) | Suitability | Description | Area (skm) | Area (%) |
|---|---|---|---|---|
| >120 | S1 | Highly suitable | 3.6135 | 95.3 |
| 90-120 | S2 | Moderately suitable | 156.1905 | 4.6 |
| 70-90 | S3 | Less suitable | 3248.767 | 0.1 |

Source (Autor 2022)

#### 4.7.1.3 Soil drains suitability

FAO (1997) suggested that the soil drainage condition of a specific area be classified into; well-drained, moderately drained, imperfectly drained, poorly drained, and excessively drained. The well-drained soils are classified as a highly suitable class, moderately drained soils are classified as a moderately suitable class, imperfectly drained soils are categorized under less suitable and somewhat excessive and poor drained soil classed as not suitable for surface irrigation according to FAO guidelines. This shown in table 4.20 below

Table 4.20 Soil drain analysis

| Soil drainage | Suitability | Description | Area (skm) | Area (%) |
|---|---|---|---|---|
| Well drained | S1 | Highly suitable | 2507.74 | 73.59 |
| Moderate | S2 | Moderately suitable | 690.51 | 20.26 |
| Imperfect | S3 | Less suitable | 44.13 | 1.30 |
| Excessive and poor drained | N | Not suitable | 165.20 | 4.85 |

Source (Autor 2022)

The analyzed drainage suitability of the study area shows that, the well-drained area covers 73.59 % indicates a highly suitable class, 20.26 % of the area covered by moderately drained classified as moderately suitable and imperfectly drained which covers 1.3% of the study area classified as less suitable. The remaining classes somewhat excessive and poorly drained which occupy 4.85 % was not suitable for surface irrigation. The soil drainage result analyzed as, highly suitable drainage classes cover 2507.74 skm, moderately suitable drainage classes have an area coverage of 690.51 skm, the less suitable drainage suitability classes have 44.13 skm and not suitable drainage classes have an area coverage of 165.20skm of areal coverage.

### 4.7.2 Overall soil suitability

In the suitability analysis of each parameter, Soil drainage has Four suitability classes (highly suitable, moderately suitable, less suitable classes and not suitable), soil texture also has three suitability classes in the watershed (highly suitable, moderately suitable and less suitable classes) and soil depth has three suitability classes (highly suitable, moderately suitable and less suitable classes) for surface irrigation. From the table 4.21 The soil suitability classes indicate 91.09 % of the area of the watershed was highly suitable, 8.83% of the total area classified as less suitable and 0.08% of the watershed was categorized under not suitable class with respect to the combined effect of soil texture, depth and drainage classes. Most of the study area was categorized under highly suitable which covers the area 3093.49 skm (91.09%) and the area 299.95 skm (8.83%) is less suitable. There is only 2.7162 skm (0.08%) area under not suitable based on overall soil suitability for surface irrigation.

Table 4.21 overall soil suitability analysis

| Suitability factors | Description | Area (skm) | Area (%) |
|---|---|---|---|
| **S1** | Highly suitable | 3093.49 | 91.09 |
| **S3** | Less suitable | 299.95 | 8.83 |
| **N** | not suitable | 2.7162 | 0.08 |

Source (Autor 2022)

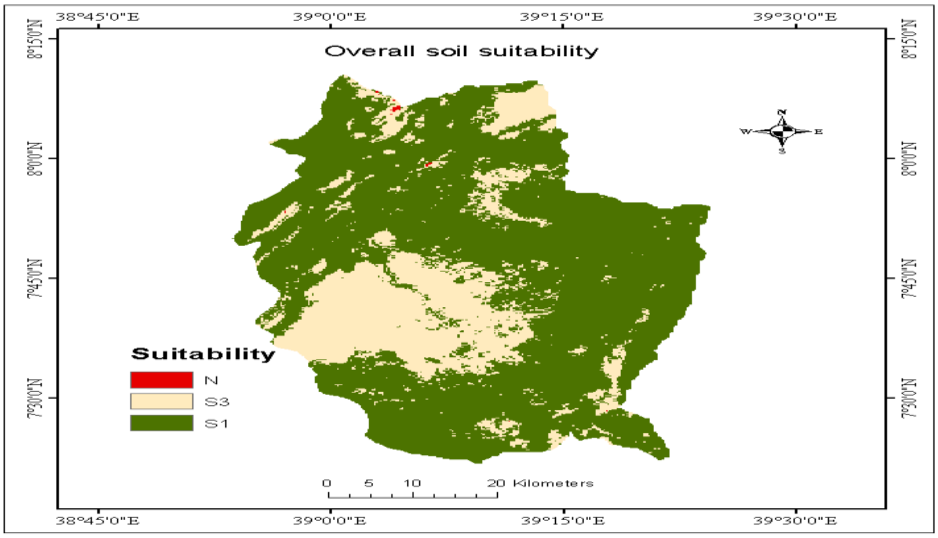



Figure 4.20 Overall soil suitability map

### 4.7.3 Slope

The slope is an important factor for land suitability study of surface irrigation. The slope map of the study area was derived from the digital elevation model (DEM) in ArcGIS and divided into four classes for suitability for surface irrigation, such as 0-2 degree as highly suitable (S1) which covers 708.95skm or 20.86% of study area, 2-5 degree as moderately suitable (S2) which cover1253.05skm or 36.86% of the watershed, 5-8 degree as less suitable (S3) which cover 615.52skm or 18.11% of total area of watershed and >8 degree as not suitable (N) that cover 821.70skm or 24.17% of the watershed.

Table :4.22 slope suitability analysis

| Factor | Slope (%) | Area (skm) | Area (%) | Rank | Suitability |
|---|---|---|---|---|---|
| | 0-2 | 708.95 | 20.86 | 4 | S1 |
| | 2-5 | 1253.05 | 36.86 | 3 | S2 |
| **Slope** | 5-8 | 615.52 | 18.11 | 2 | S3 |
| | >8 | 821.7036 | 24.17 | 1 | N |

Source (Autor 2022)

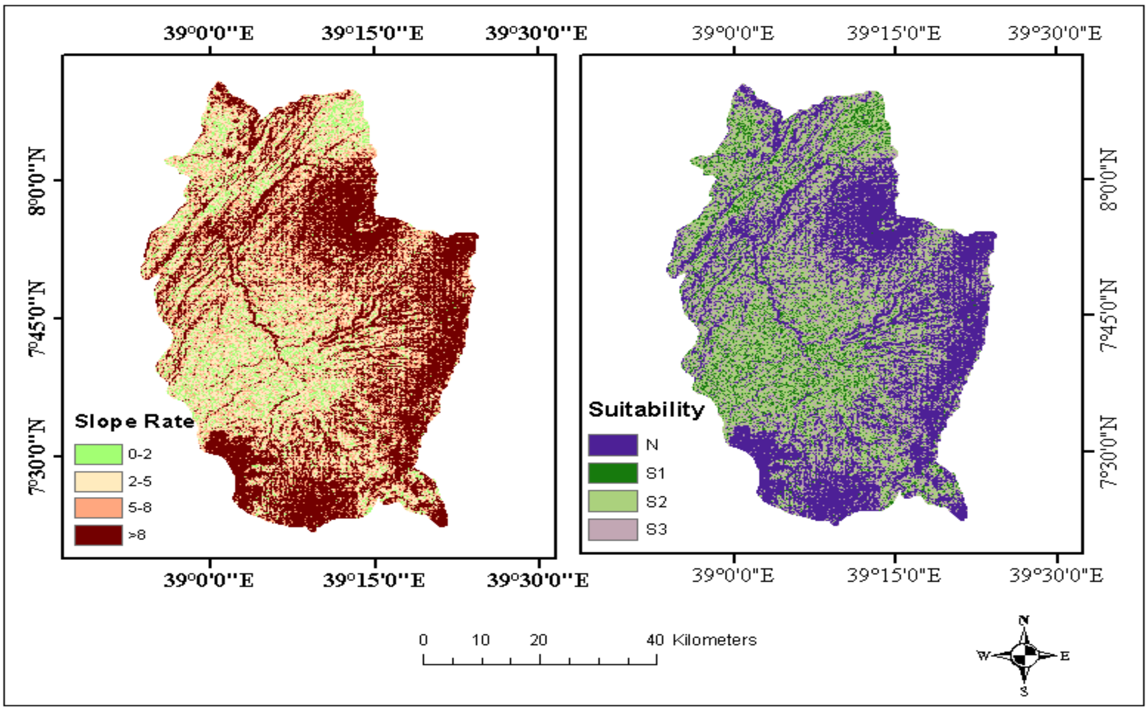



Figure 4.21 slope suitability map for PLSZ

### 4.7.4 Land Use and Land Cover Suitability

In land use/land cover suitability classification, most of the watershed area was categorized as highly suitable for surface irrigation as a result of agricultural area occupies large area of the watershed. In this study, farm land use types were classified as highly suitable (S1) which covers 80.94 % of the watershed area. Vegetation classified as moderately suitable (S2) and covers 9.89 % of the total area. Bare and shrub land, which requires higher initial investment for land preparation, were reclassified as less suitable (S3) with 5.25 % of area coverage. Built up and water body were reclassified as not suitable (N) with area coverage of 3.92 % of the watershed. This shown in table 4.23.

Table 4.23 Land use land cover suitability analysis

| Lulc | Suitability | Description | Area km2 | Area (%) |
|---|---|---|---|---|
| Farm land | S1 | Highly suitable | 2758.75 | 80.94 |
| Vegetation | S2 | Moderately suitable | 336.95 | 9.89 |
| Bare land | S3 | Less suitable | 178.94 | 5.25 |
| Built-up/ waterbody | N | Not suitable | 133.55 | 3.92 |

Source (Autor 2022)

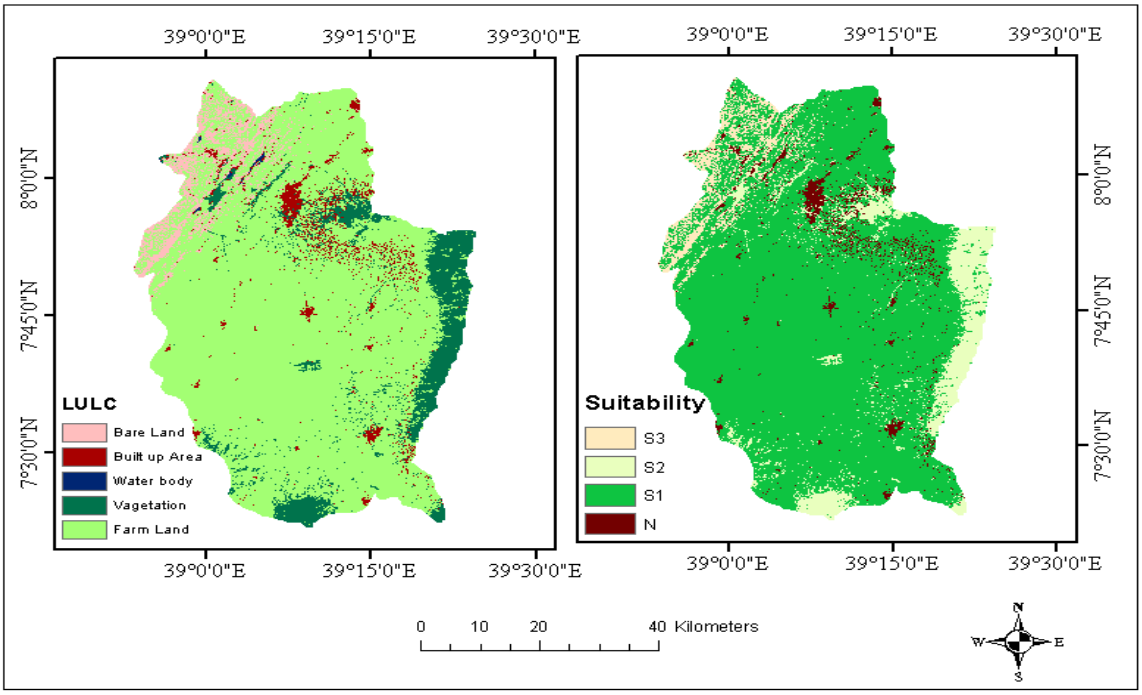



Figure 4.22 Land use land cover and reclassified Land use land cover map

### 4.7.5 Proximity to Road Network

The proximity to road considered as a factor that used to determine the suitability of land for surface irrigation. For the area nearest to road, there is accessible of market for the product of irrigation. So, the main road network of study area was clipped from Ethiopian road network shapefile and projected using GIS spatial analysis tools. The distance to road calculated by spatial analysis tools in ArcGIS for the study area then reclassified according to its suitability depending on the related previous study. In this case the nearest area to the main road classified as most suitability as a result of its accessibility to the market, while the farther area from the road classified as less or not suitable because it's not access to market. The analyzed result was indicated that: about 16.40% of the total area of the study was covered by highly suitable, 25.82% of the area covered by moderately suitable and 16.60% of the area covered by less suitable, while 41.18 % area of the study was covered by not suitable. Based on the distance from the Main Road, Proximity to road network Suitability for surface irrigation was shown in Figure 4.23 and Table 4.24.

Table 4.24 Road proximity suitability analysis

| **Road Proximity** | Rank | **Suitability** | **Description** | **Area(km2)** | **Area%** |
|---|---|---|---|---|---|
| < 1.5 km | 4 | S1 | Highly suitable | 557.64 | 16.40 |
| 1.5-3km | 3 | S2 | Moderate | 878.13 | 25.82 |
| 3-5km | 2 | S3 | Less suitable | 564.34 | 16.60 |
| >5km | 1 | N | Not suitable | 1400.22 | 41.18 |

Source (Autor 2022)

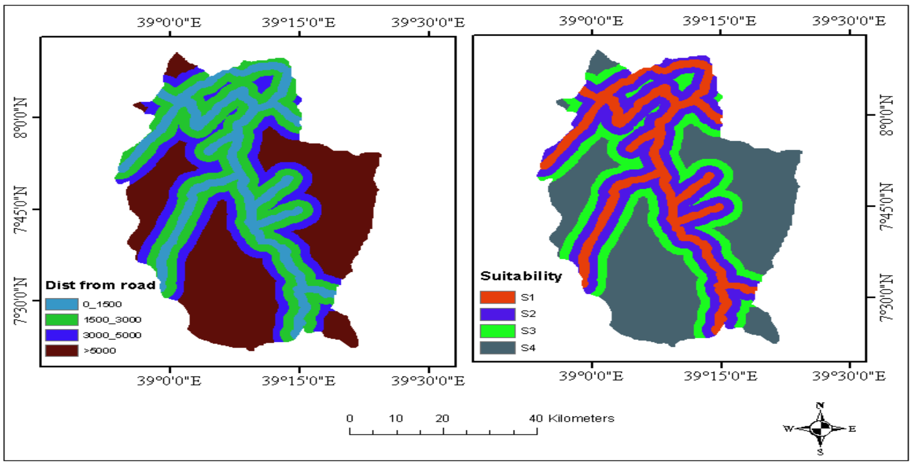



Figure 4.23 Proximity to Road map

### 4.7.6 Ground water potential Zone

The output ground water potential resulted from the above ground water potential analysis in this study was used as the input factor to determine the land suitability for surface irrigation using ground water resource. In this study the aim of delineation ground water potential zone was to use the ground water as additional water supply for surface irrigation. To do this the location overlay of ground water potential zone and land suitability for surface irrigation is necessary. So, the resulted ground water potential zone was reclassified as the high ground water potential zone was high suitable while poor ground water potential zone was less suitable for surface irrigation. From the result the High ground water potential cover 121.75skm or 3.59% of the total watershed classified as high suitable, Moderate ground water potential which cover around 1852.28skm or 54.56% of the watershed classified as Suitable, Low ground water potential zone which cover 1382.68skm or 40.73% the area of watershed classified as less suitable and very low potential zone that cover 37.92skm or 1.12% of the watershed was classed as Not Suitable for surface irrigation. Depending on the ground water potential content the ground water potential suitability of the study area was demonstrated in the table 4.25.

Table 4.25 Overall ground water potential suitability analysis

| **Factor** | **GWPZ_Type** | **Area (skm)** | **Area (%)** | **Rank** | **Suitability** |
|---|---|---|---|---|---|
| | High | 121.75 | 3.59 | 4 | S1 |
| | Moderate | 1852.28 | 54.56 | 3 | S2 |
| **GWPZ** | Low | 1382.68 | 40.73 | 2 | S3 |
| | Very low | 37.92 | 1.12 | 1 | N |

Source (Autor 2022)

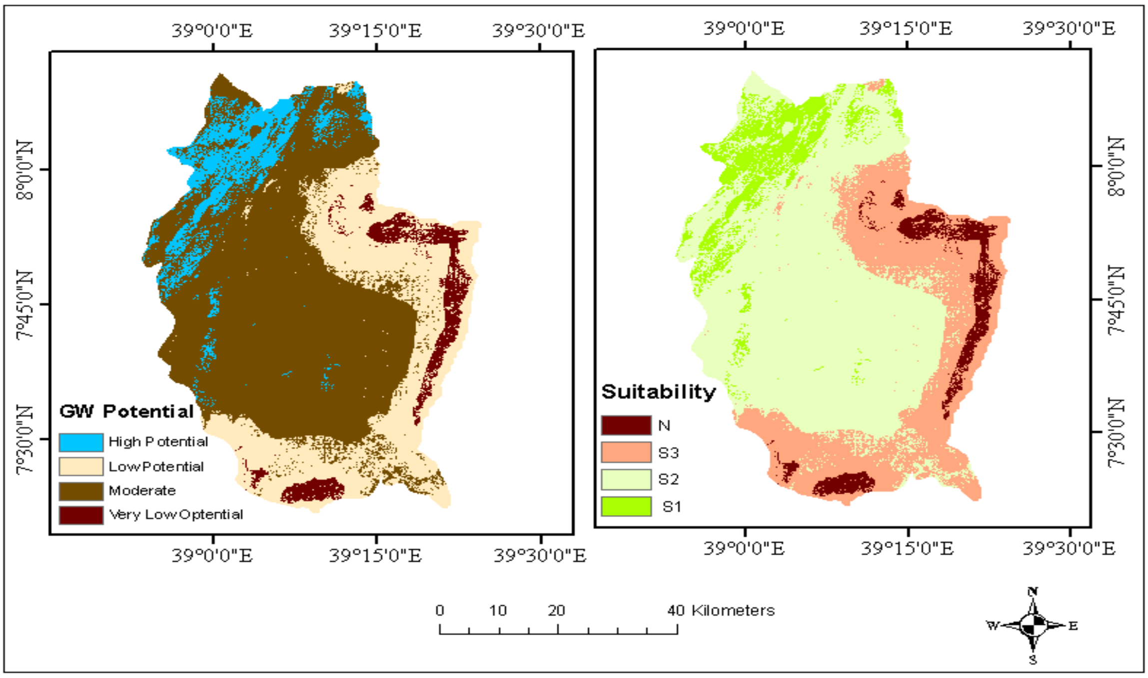



Figure 4.24 Ground water potential zone map

### 4.8 Location of suitable Land for Irrigation

Potential irrigable sites were obtained using soil suitability, slope suitability, land use land cover suitability, GWPZ suitability, proximity to Road and River suitability on Arc GIS 10.8 employing weight overlay analysis. Potentially irrigable land for surface irrigation in the watershed was identified based on their area coverage and geographic location.

#### 4.8.1 Weighted suitability Analysis

Land suitability was determined by assigning weights to the factors that likely affect the irrigation potential of a certain land area. Based on critical analysis of all the factors that affect land Suitability for irrigation, the priority of each of them for importance of final suitable land selection was done after literature investigation (Meron, 2007, FAO, 1977). The determined relative importance values were used in the weighted overlay analysis. Factors derived have different degrees of influence on suitability evaluation. The factors considered in this study are Slope, soil suitability, land use land cover, GWPZ, proximity to Road and proximity to River. The relative importance of each parameter has been determined. Therefore, the higher the weight, the more influence a particular factor would have on suitability evaluation. The final criteria weight in percentage analyzes of LULC, Soil and slope Suitability Factor Analysis was shown in Table 4.26 below.

Table 4.26 Pairwise comparison for soil suitability factors

| Factors | Slope | Soil | LULC | GWPZ | Road | River | Weight |
|---|---|---|---|---|---|---|---|
| Slope | 1 | 2 | 3 | 4 | 5 | 6 | 42 |
| GWPZ | 0.5 | 1 | 2 | 3 | 4 | 5 | 26 |
| LULC | 0.33 | 0.5 | 1 | 2 | 3 | 4 | 16 |
| Soil | 0.25 | 0.33 | 0.5 | 1 | 2 | 3 | 10 |
| Road | 0.2 | 0.25 | 0.33 | 0.5 | 1 | 2 | 6 |

CR = 0.015 Source (Autor 2022)

The value of the pairwise comparison matrix showed that the main Factors were analyzed and scored utilizing a scale created by saaty (1991). In the weighted overlay investigation, high weight of rate impact was given for slop, since it is the principal determinant Factor in the assessment of the given area for surface irrigation advancement. The validity of the pairwise matrix consistency was evaluated using a consistency ratio. In the weighted overlay analysis, the consistency Ratio (CR) is under 0.1; which infers, the Consistency was acceptable. Essentially, Getenet et al. (2019), viewed as the consistency apportion of 0.067 which was OK for weighting the elements to assess the actual land in Jabitenan area to foster water system reasonableness maps.

### 4. 9 Potential Suitable Land for Irrigation

The Final result of suitable area for surface irrigation was explained in a percentage layout where; S1, S2, S3 and N stands for highly, moderately, Less and not suitable class for surface irrigation development respectively.

Table 4.27 overall land suitability analysis

| Suitability | Description | Area (skm) | Area (%) |
|---|---|---|---|
| **S1** | Highly suitable | 805.06 | 23.77 |
| **S2** | Moderately suitable | 2143.59 | 63.29 |
| **S3** | Less suitable | 437.06 | 12.90 |
| **N** | Not suitable | 1.30 | 0.04 |

Source (Autor 2022)

Four potential classes of suitability map for irrigation were produced using weighted overlay which are very high, moderate, low and not suitability class with 23.77%, 63.29%, 12.90% and 0.0.4 % of area coverage for irrigation (Table 4.27). Based on visual Analysis of potentially suitable irrigable map result (Figure 4.26). This indicates that the area has productive soil types (Deep soil, well drained and Clay soil texture), Farm land use type, flat areas, High ground water potential zone and shorter distance from road.

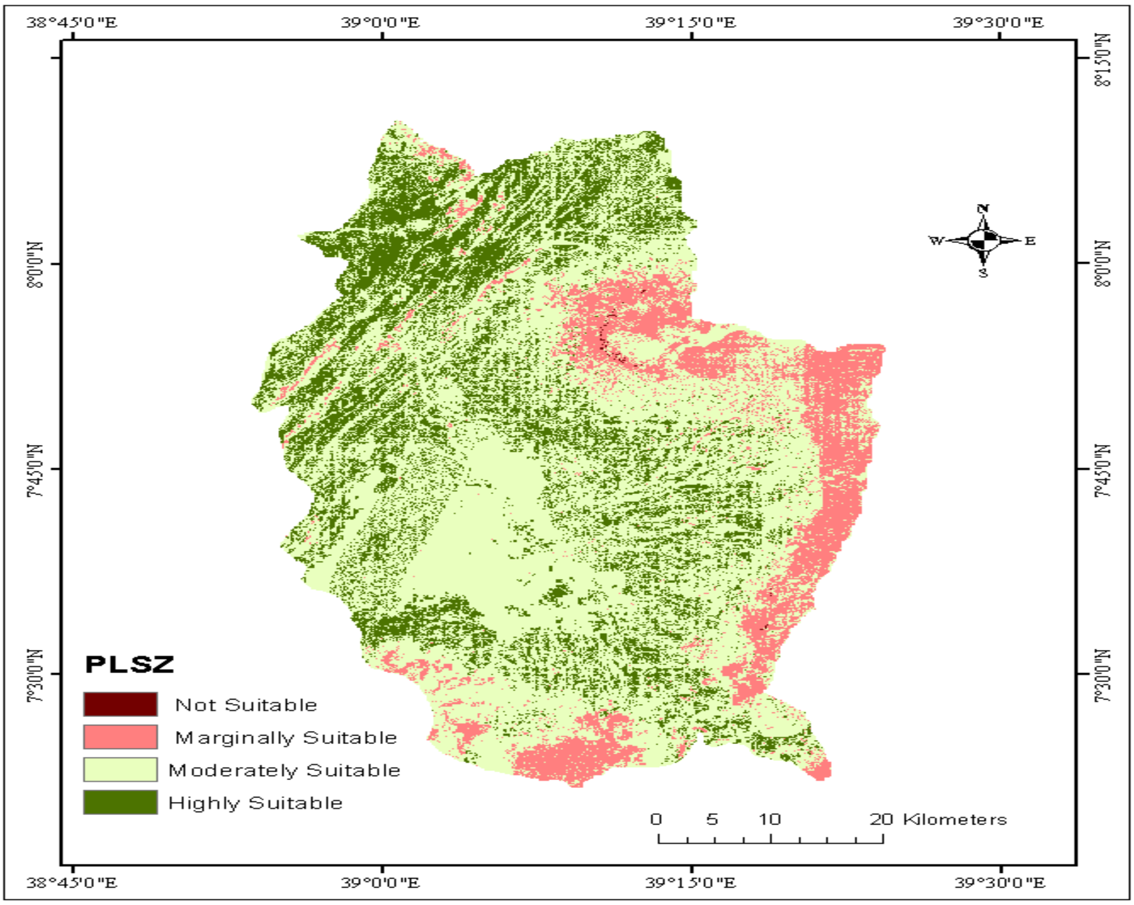



Figure 4.26 Potential land suitability zone map

**4.10 Groundwater potential and irrigation land suitability**

Integration of all the thematic maps was carried out to get the suitability classes for both works, and which are classified and identified into the four suitability classes such as highly, moderately, marginally suitable and not suitable. In both studies, the majority of a portion (11852.28km2 for GWP and 2143.59 km2 for PLS) are covered by moderately suitable as shown in (Table 4.28 and Figure 4.27.).

Table 4.28 Groundwater potential versus irrigation land suitability

| Rank | Suitability Classes | GWP Area (Km2) | PLS Area (Km2) |
|---|---|---|---|
| 1 | Not suitable | 37.92 | 1.3032 |
| 2 | Marginally suitable | 1382.68 | 437.0589 |
| 3 | Moderately suitable | 1852.28 | 2143.59 |
| 4 | Highly suitable | 121.75 | 805.0455 |

Source (Autor 2022)

As presented in the figure 4.27, high groundwater potential and Potential land suitability are mainly distributed within the same location in Zuway Dugda woreda which found in Nort western parts of the watershed and also distributed in small extent at the same location around north parts in Hetosa woreda, Southwestern parts in Munesa, western parts in Tiyo woreda and southern parts around bokeji and Digaluna_Tijo woreda. Hence, on-land surface irrigation development could be applied in this area with low investment on conveyance/distribution system. While moderate groundwater potential is highly distributed in southern, northwestern, and center to northeastern part, whereas moderate land suitability is a southern edge, southwestern to northern, and in the whole area to a small extent. And, low groundwater potential is located at southern, northern, and northeastern whereas marginal land suitability is highly distributed in the central part, and center to north part in small extent of the watershed. Therefore, the northeastern and northwestern parts of the area having high suitable land for surface irrigation also has high GWP in the same area. Hence, on-land surface irrigation development could be applied in this area with low investment on conveyance/distribution system. On the other hand, it can be possible to irrigate the crop in a moderately land suitable area by pumping and distributing water from a high groundwater potential area where they aren't located in the same region. Generally, most areas of the watershed are covered by moderate to high GW potential and irrigation land suitability zone. Hence, this helps to produce the agricultural crop in the area using groundwater source irrigation as optional during the dry season without investing high initial cost.

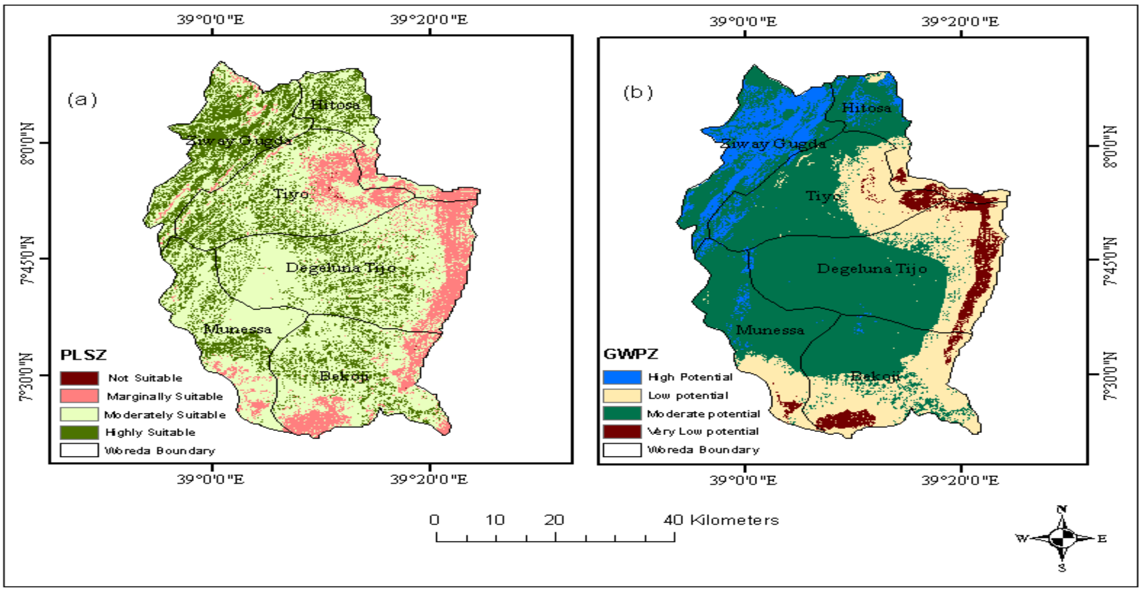



Figure 4.27 Groundwater potential versus irrigation land suitability

## 4.11 Discussions

### 4.11.1 Thematic map preparation for Layers affecting GWP and ILS

The occurrence and movement of groundwater and irrigation land suitability controlled by various factor, and each factor has its own weight depending on their influencing on the groundwater storage and movement. The influence of these factors was identified depend on the past studies and knowledge. According to this study nine factors (lithology, Landform, slope, lineament density, rainfall, land use/cover, drainage density, soil and DEM) were selected by considering as the main factor influence GWP and five factors (Slope, Soil, Land use land cover, GWPZ and Equidistance to main road network) were selected as the main influence factors that affect irrigation land suitability of the study area. Those Factors have projected with the same coordinate system and its thematic map layer produced Separately for both Ground water potential delineation and Land suitability for surface irrigation. The prepared thematic maps were the input information for delineation of groundwater potential and land suitability for surface irrigation. All those factors do not have equal importance in governing groundwater occurrence and irrigation land suitability. Hence the weight of each Factors calculates using AHP Pairwise comparison method and suitability map prepared for each factors separately for both Procedure (Nigussie, Hailu, and Azagegn 2019). The weight of each criterion was derived using AHP techniques, e.g., Fashae et al. (2014), Kumera (2017), and Vellaikannu et all (2021). In this study, lithology, geomorphology, slope and Lineament density are the main influence for groundwater occurrences while slope, GWPZ and land use land cover are the main important factor for land suitability site selection according to percentage of influence (weight). Their assigned weights are 31%, 22%, 16% and 11% for GW potential zone respectively and 42%, 26% and 16% for irrigation land suitability assessment. According to Satty (1980) the consistency of weighted comparison analysis (in pair-wise comparison) of those factors are checked, which should be less than 0.1. While deriving the weight of each factor for the present study, the CR value was 0.035 for GWP and 0.015 for irrigation land suitability which is less than 0.1 and it's acceptable for further analysis of those factor influence groundwater.

### 4.11.2 Delineated GWPZ and irrigation land suitability map

The groundwater potential zonation map was generated by integrating all the thematic layers through the weighted overlay method. The ranking assigned for each theme is based on its influence on groundwater occurrence. The delineated suitable groundwater potential zone map shows that the study area was classified into four suitability class such as high (4), moderate (3), low (2), very low (1) which covers 3.59%, 54.56%, 40.73% and 1.12% of total study areas respectively. The result compared with previous study done in the area by Nigussie, Hailu, and Azagegn (2019). According to their study they had classified the output into five suitability class such as Very high (5), High (4), moderate (3), low (2), very low (1). The distribution of ground water potential categories for both those studies was locationally consistent with each other, having a slight difference in area coverage. This may be due to the difference in some factors and categorized class differences.

Low and very low groundwater potential Found in Eastern, southern, and southeastern Parts of the regions and it is 41.85% of the total area with a land area of 1420.60km2. Geologically, this region is mostly made up of Badda Trachyte formations like Pliocene Trachyte. According to Nigussie, Hailu, and Azagegn (2019), Badda Trachyte formations like Pliocene basalts have low ground water potential as its massive and poor to moderate permeability. The geomorphology of this area is escarpment and mountainous like chilalo, Kaka and Galama Ridge. Groundwater occurrence is greatly influenced by topography, which is a result of slope and geomorphology. Groundwater is significantly influenced by slope since steeper slopes cause rainwater to runoff and level to gentle slopes allow rainwater to penetrate the soil (Ibrahim-Bathis and Ahmed, 2016). Therefore, in this region there is high runoff surface water due to its steepest slope. The area has also low linement density and high drainage density. In low lineament density area, the groundwater occurrence is low and in high drainage density there is low groundwater occurrence due to excessive surface water runoff. Therefore, geomorphology, slope and lineament density affect the area next to

Geological unit for its low water potential. Moderate potential zones are dominant among all classes, with an area of 1852.28 Km2, 54.56% of the total land area of the Katar watershed. Moderate potential zone covered most area of central parts and in small extent northern, southern and western parts of the watershed. The major geology in this region were Tv4, Qdi, Ncp, Qwb2 while other geological units like, Tv6 and Qwpu were also exist. The region geomorphologically plateau or rounded plain and its slope nearly 2-5(%) which suitable for ground water due to there is less runoff surface water. In this region elevation and lineament density may influence for the moderate ground water potential occurrence. High ground water potential zone which covers 121.75skm or 3.59% of study area located in NE, SW, N and W. the major geological unity in this area: Nn, Qal, Q2us, QV2 and Qwbp which have high water permeability property in the area. Geomorphologically this region found in rift valley low land that expected as there is high ground water potential. Areas with the highest potential for groundwater are in alluvial plains and valleys, with smooth and irregular plain geomorphological classes (Hussein, Govindu, and Nigusse 2017). And also, area has slope 0-2 (%) that nearly plain. Hence geology, geomorphology, Lulc, high lineament density and slope plays a great role for the occurrence of high ground water potential in this region. Many previous studies on groundwater potential zones were validated using existing boreholes, hand-dug wells and springs (e.g. Tessema, (2014); Jhariya et al. 2016; Kumera 2017; Dawit.Y 2021; Nigussie, Hailu, and Azagegn 2019. So, validity checked also for this study with the existing water yield point data, 86% matched with its corresponding groundwater potential zones, in which there is very good agreement. The delineated potential land suitability zone map was similarly another map which shows potential land suitability for surface irrigation of the study areas. According to land suitability for surface irrigation, this map was also classified as high suitable (S1), moderate suitable(S2), low suitable (S3) and not suitable (N) which covers 12.94%, 58.56, % 28.13% and 0.37% of total study areas respectively. High suitability zone was characterized by gentle slope, farmland areas, well drained and higher soil depth, high and moderate GWPZ and nearest to main road network. It is located in northern, western, southern and central parts of the watershed by covering 438.19skm or 12.94% of study area.

Moderate land suitability zone areas were distributed in northern, western, southern the most central part of the study areas and in small extent around eastern part which cover 58.56% of the total study areas at moderate to low sloped, semi-plain (plateau) and cultivated/agricultural areas. Less land suitability zone was also characterized by highly slope (sharp land) which have high runoff, poor drained and low soil depth. Hence this causes for less land suitability results. Not suitable zone, found around highland (hilly/mountain and steep slope), which unsuitable for agriculture due to topographic effect and inaccessibility to road network. So, this is the reason why gave not suitable results. Potentially usable physical resources like ground water potential and potential irrigable land identified for study area. High and moderate ground potential which cover 58.15% of watershed is suitable for surface irrigation at minimum cost as a result of no need water transport from place to place as it directly applied on its top surface. The usable potential land in study area analyzed as, the high suitable zone which cover 438.19skm or 12.94% of watershed on-land surface irrigation development could be applied with low investment. On the other hand, it can be possible to irrigate the crop in a moderately land suitable area by improving its accessibility to road, soil conservation and land use land cover modification. Generally, most areas of the watershed are covered by moderate to high GW potential and high to moderate irrigation land suitability zone. Therefore, this helps to produce the agricultural crop in the area using groundwater source irrigation as optional during the dry season without investing high initial cost.

# CHAPTER 5: CONCLUSION AND RECOMANDATION

## 5.1 Conclusion

The study delineates the ground water potential zone and assessed the potential irrigable land for surface irrigation of Katar watershed through the combined use of geospatial technologies like GIS and Remote sensing. GIS and remote sensing play a significant role in the water resources development in the field of hydrogeology by providing and collecting different data. So that the present study has tried to applied GIS-based multi-criteria analysis through the application of various spatial analysis tools to delineate groundwater potential and irrigation land suitability zone map of the Katar watershed. From the DEM, slope, Elevation and drainage density in the study area were identified.

The thematic map of the factors was prepared after identifying the main factors influence groundwater potential and Land suitability zone based on appropriate selection criteria set. The identified factors for this study area were includes drainage density, land use/cover, soil, lineament density, landform, slope, lithology, Elevation and rainfall for groundwater potential and five main influencing factors such as land use/land cover, soil factors (Texture, depth, and drainage), ground water potential, slope and Equidistance to Main Road network for irrigation land suitability were considered to generate the thematic maps. Since each factor affects the groundwater differently, determining the weights is very important after all thematic maps were prepared. Hence AHP method was used in a pair-wise comparison matrix to give the value of each factor based on their influences and the weighted comparison analysis was accepted after the consistency ratio was checked that was less than 0.1. The consistency ratio for the factors used to identify groundwater potential and irrigation land suitability zone in this study were 0.035 and 0.015, respectively. For the study, Geology, landform, slope, and lineament density were highly influencing factors for groundwater potential zone whereas slope, GWPZ and land use land cover were considered as the most influencing factors for irrigation land suitability zone.

After overlaying these all factors, the result of the study exposed that the delineated zone was classified into four namely, very low, Low, Moderate and High suitable for groundwater potential and less, moderate, high and very high suitable for irrigation land suitability. The result indicates that from the total area, not suitable was 0.04%, less suitable was 12.90%, moderate suitable was 63.29% and highly suitable was 23.77% for irrigation land suitability; very low potential was 1.12%, Low potential was 40.73%, Moderate was 54.56% and high potential was 3.59% for GW potential. Finally, the validity checked for groundwater potential with the existing water yield point data 86% were matched with its corresponding groundwater potential zones in which it is very good agreement.

High groundwater potential was found in Northwestern, northeastern, and western parts, this was because of the characterization by plain landform, nearly flat slope, lineament density and Geological unity of the area. According to Nigussie, Hailu, and Azagegn (2019), In the rift floor part of the study area, more fractures and lineaments cause the recent basalts and ignimbrites, which provides vast storage of groundwater. These areas were identified as having very high groundwater potential zones. Lacustrine sediments and alluvial deposits geological areas were also identified as high groundwater potential due to their primary porosity. The geomorphology and elevation also have a great influence in this area while the geomorphologically classified as Rift valley lowland and lower elevation which assigned as very high probability of ground water occurrence, and also since water flows from higher elevation area to the lower one there is high chance of ground water potential to the lower elevation area. So, the study consistence with Nigussie, Hailu, and Azagegn (2019) which carried out study in the same area and the result of both studies indicate that high ground water potential was found in the same location around rift valley lowland, high lineament density, lower elevation and level to gentle slope. High land suitability was located in Northern, northwestern and the central parts of the watershed to due to medium soil particles, nearly flat slope, and moderately well-drained soil in the areas. Whereas, less land not suitability was mainly distributed in the Eastern, Southern, western and the small extent in the central part which coincides with fine soil particles, poor soil drainage, shallow depth soil, and steep slope areas.

Generally, Ground water utilization for surface Irrigation plays an important role to maintain sustainable food security by improving agricultural production that is the core foundation for Ethiopia's economy, growth and long-term food security. The study develops an irrigation potential map for surface irrigation using ground water potential of the watershed for future planning and development possibilities and it can help decision-makers, donors and experts in sound surface irrigation development in the watershed. The study also contributes to shift the current rainfed agriculture to irrigated agriculture.

## 5.2 Recommendation

- Using the most recent and detailed conventional existing data with high resolution for groundwater potential mapping is necessary to get farther accuracy of the result as Geology and lineament are mainly control the occurrence and movement of groundwater on this study.
- Soil and water conservation methods, as well as integrated watershed management should be used in area on the way to promote groundwater recharge to valance the discharged water from the ground for agricultural and for other purpose uses.
- The analyses of land for irrigation did not consider the chemical characteristics of soil and quality of water, Hence, it would be better to include to increase the productivity nature of the land using GIS based multi-criteria Analysis.

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