UNIVERSITY OF NAIROBI

Using Remote Sensing and Geographic Information Systems to Determine Suitable Borehole Sites in Kitui County, Kenya

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A project report submitted to the Department of Geospatial and Space Technology in partial fulfillment of the requirements for the award of the degree of:
Master of Science in Geographic Information Systems

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Declaration

I, Nzau Grace Njeri hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

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This project report has been submitted with approval of university supervisor.

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Abstract

Water is considered a powerful natural resource in the world: a source of life, the backbone of growth and prosperity. The increasing demands for water against the limited natural sources and its increasing scarcity have a possibility of resulting in devastating conflicts and calamities. The economic and social developments anticipated by the vision 2030 blueprint will require much more resources in terms of quantity and quality than at present. The country, therefore, aims to manage water sources effectively and efficiently while starting new ways of harvesting rain and groundwater. Groundwater is harvested through digging up of wells in areas where the water table is very shallow and sinking boreholes where the water table is very deep.

The objective of this study was to determine the most suitable areas in Kitui County where boreholes can be drilled by incorporating different hydrogeological factors using GIS and Remote Sensing. This was done by identifying the different hydrogeological factors that determine potential borehole sites and applying the factors in a multi-criteria weighted overlay to determine the potential borehole sites and thereafter mapping the potential zones in the area of study.

Groundwater potential areas in Kitui County were effectively mapped through the integration of factors that affect the occurrence of groundwater. From the final suitability map, it’s clear that the western part of the county is unsuitable for borehole siting. The southern areas of the county are occupied by Tsavo national park which is a protected area hence no drilling can take place there. The central part of the county is the most suitable area for borehole drilling as they have a higher lineament density.

Geospatial technologies should be embraced in carrying out suitability studies due to their improved accuracy as they can delineate the appropriate areas for groundwater exploration and borehole sitting and time conscious thus facilitating studies over large areas. The county government of Kitui County should sink more boreholes in the central part of Kitui County that this study found to be suitable for borehole sinking.

Acknowledgment

I would like to thank Almighty God for His guidance, energy, good health, and sufficient grace through the two years of hard work.

I am grateful to my supervisor, Dr. Ing Sammy Mulei Musyoka for his guidance and encouragement as I worked on the project.

I wish to thank all the staff in the Department of Geospatial and Space Technology of the University of Nairobi for their continued support, contribution, and assistance in the course of my studies and during this project.

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ABBREVIATIONS

BCM - Billion Cubic Metre
DEM - Digital Elevation Model
ERDAS - Earth Resources Data Analysis
GBP - Great Britain Pound
GIS - Geographic Information Systems
ILRI – International Livestock Research Institute
KITWASCO - Kitui Water & Sanitation Co. Ltd
MDG - Millennium Development Goals
NWRMS - Natural Water Resource Management Strategy
SRTM - Shuttle Radar Topographic Mission
TAWWDA - TANATHI Water works Development Agency
UNDP - United Nations Development Programme
UNEP - United Nations Environmental Programme
US EPA - United States Environmental Protection Agency
WIOA - Weighted index overlay analysis
WRMA - Water Resources Management Authority

CHAPTER 1: INTRODUCTION

1.1 Background

Water is considered both a social and an economic right around the globe. Water is vital for health, human survival, and dignity and is classified as a basic resource for human development. Kenya is a water-scarce country, whose challenges have increased due to deforestation, wetlands encroachment, overgrazing, and the increase of human settlements into areas previously under forest cover. These activities have grossly contributed to the degradation of forest and vegetation cover with a corresponding decline in renewable water resources hence springs, aquifers, and rivers water levels are reducing alarmingly (Waters et al.1990).

The low-level development of water as a resource is approximated at less than 20% (1.6 BCM per annum) compared to the surface water estimated of 7.4 BCM and groundwater potential of 1.0 BCM per year. The dire situation requires expansive investment to get the highest possible harnessing of the rechargeable portion of the freshwater resources. Kenya is grouped as a water-scarce country of 647m^3 per capita compared to the global benchmark of 1000m^3 (Waters et al.1990).

Global climate change has seen a change of weather patterns in most parts of the world with a significant decrease in the amount of rainfall in most parts of the world. Coupled with other factors, this has led to gradual encroachment of arid-like characteristics to areas that were previously wetlands. In Africa, the condition has seen desertification become rampant, especially in the past decades with Kalahari and Sahara deserts advancing at the rate of one Kilometre per century.

Services related to water and sanitation are among the most basic services and infrastructure (UNDP, 2006). Freshwater accessibility is one of the greatest global problems whose effects are largely felt in third-world countries. Research by UNEP/Water program, 2007, that over 40% of the total population living without water is found in sub-Saharan Africa. A report regarding The Millennium Development Goals (MDG) released in 2013 indicated that 783 million people in the globe did not have access to water. It is projected that in the year 2015, 603 million people will still be lacking access to it. Among the sources of water that were referred to in the report were: -

protected dug wells and springs, rainwater, household connections, boreholes as well as public standpipes.

With a population of 55 million, about 32 percent of Kenyans use unimproved water sources, like shallow wells, ponds, and rivers. On the other hand, 48 percent of Kenyans do not have access to basic sanitation. These problems and predicaments are mostly evident in urban slums and rural areas where people are mostly not able to connect to piped water infrastructure. Therefore, to achieve the goals of vision 2030, it is important to resolve issues regarding water. In some areas, piped water connections do not guarantee a constant and reliable flow of water. Hence, sources like shallow wells, boreholes, and rainwater harvesting tanks are also used as solutions in urban and peri-urban areas (water.org 2021).

The source of water is an important facet of water resources. Water sources are classified into surface water and groundwater. Surface water is water that collects on the surface of the planet. Examples of surface water sources include: - streams, lakes, wetlands, rivers, and oceans. Surface runoff replenishes surface water through the hydrologic cycle. Groundwater, on the other hand, is water found underground in cracks and pores in soil and rocks. Groundwater is stored and slowly circulates through geologic formations known as aquifers. Nearly 2% of the earth's water occurs as groundwater and 0.1% occurs as rivers and lakes. Just 2.8% of all the globe's water is fresh whereby 2.2% is surface water while 0.6% is groundwater. Approximately 2.15% of surface freshwater is in form of ice caps and glaciers, 0.01% in lakes and reservoirs, 0.0001% in streams, and the remainder as soil moisture and atmospheric water vapor. These statistics show that groundwater is the biggest source of fresh water on earth (Waters et al. 1990).

Several aspects affect the occurrence, distribution, and quality of groundwater. Some of these aspects that affect the occurrence and distribution include geology, the amount of rainfall, slope, topographic elevation, lineament density, drainage density as well as the land use and land cover (Ndatuwong, &Yadav, 2014). In the determination of water table depth, Slope and elevation are significant. The rate at which precipitation infiltrates the ground is shown by the drainage pattern. Permeability of the rocks varies depending on the type of rocks and determines infiltration. Precipitation percolates into the ground to form groundwater and thus the amount of rainfall determines the occurrence and distribution of groundwater. Some land uses permit more infiltration than other land uses and thus affect the occurrence of groundwater. Lineaments provide information on the storage and permissibility of groundwater thus are a significant factor in groundwater exploration (Rahmati et al. 2015).

Kitui County faces serious water shortage issues. Many rivers have been rendered seasonal and others have dried up completely as a result of recurring droughts and thus the water supply has decreased. There is decreasing water catchment capacity as a result of high rates of deforestation which have severely worsened the water scarcity problem. As the County's population increases and climate changes, water availability is affected. Degradation of upstream catchment mainly due to agricultural growth as a result of population growth is already affecting water availability. Water demands in the County will continue to outstrip available freshwater supplies.

Poor waste disposal in Kitui County is also impacting heavily on the available water resources such as rivers near the urban areas. Some residential houses have been constructed on the river reserve so much that the domestic wastes are dumped in the river causing water pollution. Also due to the poor sewerage system that is some residential houses are not connected to the County sewerage system; some of the human wastes also find their waste in the river causing severe water pollution for the people downstream and animals.

This project, therefore, is aimed at assessing suitable sites in Kitui County using geospatial technologies such as Remote Sensing and GIS to determine suitable areas where boreholes can be drilled to provide sufficient clean water for the increasing population of the County. According to Covenant Life Foundation, a non-profit making organization; borehole drilling is an expensive exercise of approximately $12,500 and the machinery is around $400, 000 to $500,000 which is about 322,582 GBP. Therefore before it's carried out in an area, a thorough knowledge of the availability of water underground and its quality must be assessed to avoid incurring heavy losses in case after drilling there is no sufficient underground water.

The science of acquiring information about the Earth's surface without actually coming into contact with it is known as remote sensing. This is accomplished by sensing and recording reflected or emitted energy and then processing, analyzing, and applying the data (Canada Centre for Remote Sensing Tutorial).

A Geographic Information System (GIS) combines hardware, software, and data to capture, manage, analyze, and display all types of geographically referenced data. GIS enables us to view, comprehend, question, interpret and visualize data in a variety of ways (Burrough, 1985).

Geographic Information System and Remote sensing have been previously used in different studies by combining factors in a multi-criteria weighted overlay to come up with suitable areas for different things including boreholes or areas suitable for certain crops.

1.2 Problem Statement

Kitui County faces serious water shortage issues. Many rivers have been rendered seasonal and others have dried up completely as a result of recurring droughts and thus the water supply has decreased. As the County's population increases and climate changes, water availability is affected. Degradation of upstream catchment mainly due to agricultural growth as a result of population growth is already affecting water availability. Water demands in the County will continue to outstrip available freshwater supplies. There have been cases where boreholes were sited and no water was found, other cases where they dried up too soon or even take too long to fill up before pumping it out.

1.3 Objectives

The main objective is to determine the most suitable areas in Kitui County where boreholes can be drilled by incorporating different hydrogeological factors using GIS and Remote Sensing.

The specific objectives are:

i) To identify the different hydrogeological factors necessary to determine potential borehole sites.

ii) To apply the hydrogeological factors in a multi-criteria weighted overlay to determine potential borehole sites

iii) To validate the mapped groundwater potential zones in Kitui County.

1.4 Justification for the Study

Due to an acute shortage of clean water in Kitui County and the seasonality of rivers, there is a need to drill boreholes even though it's an expensive project so that more water can be available for the people of Kitui County. According to sustainable development goals, there is a need to provide clean water to people. TANATHI Water Works Development Agency (TAWWDA) and - Kitui Water & Sanitation Co. Ltd (KITWASCO) water is not sufficient enough to provide clean water for the people of Kitui County and hence other alternatives for water sources are needed.

The use of geospatial technologies such as geographical information systems and Remote Sensing can be used to delineate areas in Kitui County where boreholes can be drilled. This will help supplement the few existing water sources in the County hence meeting the high demand for water in the County due to population growth.

1.5 Area of Study

Kitui County Headquarters, about 150 kilometers east of Nairobi, is the area of interest and is depicted in Figure 1. According to the 2019 census, the county has a population of 1,136,187 people. It is located between latitudes 0° 10'S and 3° 10'S and longitudes 37° 40'E and 39° 10'E. It covers an area of 20,402 km^2, including 6,290.3 km^2 at the district's southern end, which is occupied by the Tsavo East National Park.

Kitui is a semi-arid county with highly erratic and unreliable rainy seasons. Rain-dependent agriculture is the county's main economic activity. Water availability is a limiting factor in irrigation agriculture, and as a result, it occurs only in small areas along river banks.

Elevation ranges from 400 to 1800 meters above sea level in the western and central parts of the county, which is characterized by hilly ridges separated by wide, low-lying areas, and has a slightly lower elevation range of 600 to 900 meters above sea level.

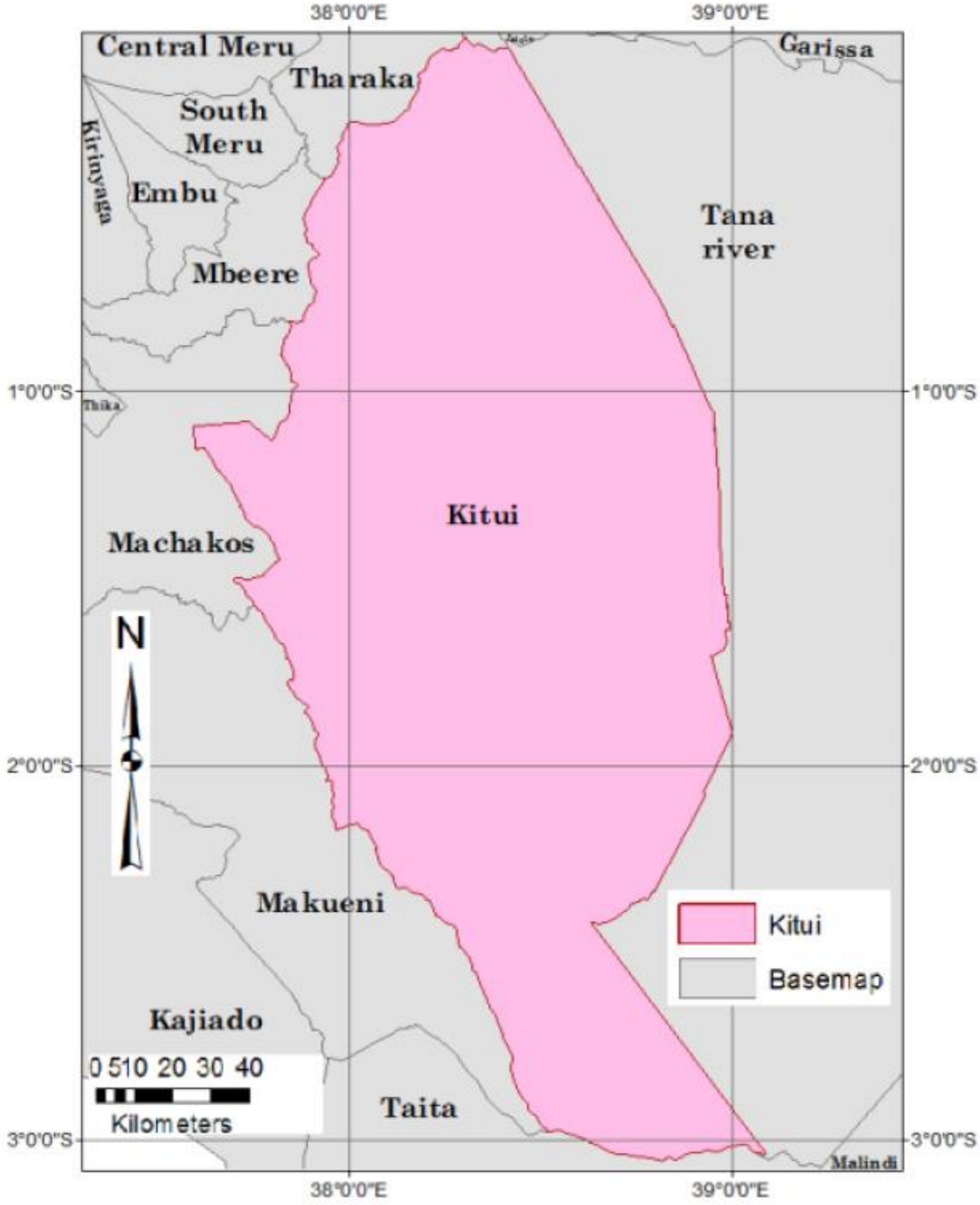


Figure 1: Map of the study area (Kitui County)

Source: www.ilri.com (Kenya County shapefiles)

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The science of acquiring information about the Earth's surface without actually coming into contact with it is known as remote sensing. This is accomplished by sensing and recording reflected or emitted energy and then processing, analyzing, and applying the data (Canada Centre for Remote Sensing Tutorial).

A Geographic Information System (GIS) combines hardware, software, and data to capture, manage, analyze, and display all types of geographically referenced data. GIS enables us to view, comprehend, question, interpret and visualize data in a variety of ways (Burrough, 1985).

Geographic Information System and Remote sensing have been previously used in different studies by combining factors in a multi-criteria weighted overlay to come up with suitable areas for different things including boreholes or areas suitable for certain crops.

Health and quality of life require easy access to basic human needs like safe and potable water. Due to the shortage of clean water sources across the world, the increasing human population is exerting pressure on the available resources hence the need for groundwater exploration to meet the high demand. Groundwater can be accessed through the drilling of boreholes once suitable sites have been located.

According to the International Committee of the Red Cross, when designed and maintained properly, drilled boreholes have the following advantages:

a) Boreholes are less prone to water level drops and drought when drilled into deep water-bearing aquifers.
b) Have the potential to produce high yields if properly positioned.
c) They can draw from more than one aquifer (when aquifers are vertically separated).
d) They are less susceptible to contamination than other water sources.
e) Boreholes are less likely to collapse than shallow wells.
f) They can be used to track groundwater levels for purposes such as waste disposal or environmental research.

g) They can be quantitatively monitored and tested, allowing for accurate aquifer modeling, optimal pump design, water supply efficiency, and storage/distribution systems.

The disadvantages of drilled boreholes include:

a) There is a need for a high initial cost of material and specialized expertise to be used.
b) They are prone to sabotage with minimal effort if not protected.
c) Boreholes are prone to irreversible natural degradation when not properly monitored and maintained.
d) Because of its nature, maintenance and repairs are difficult to handle and must be performed by experts.
e) Require a source of energy for water extraction.

2.2 Aquifers

Underground water is commonly drawn from aquifers. An aquifer is a porous and permeable subsurface rock or sediment unit that stores useful amounts of water. Aquifers are classified into several types, which include:

a) A confined aquifer

An aquifer that is surrounded by impermeable rock or sedimentary layers. When a borehole punctures a 'confined' aquifer under pressure, the static water level rises to a higher piezometric level. The piezometric surface is occasionally, but infrequently, above ground level, allowing water to flow from the borehole without the need for an energy source. This is referred to as ‘artesian water.'

b) Perched aquifer

This is an unconfined aquifer that sits on top of an impermeable layer of rock and is bounded by permeable formations or surmounts another unconfined aquifer to a limited extent. It is small in size and sits on an impervious layer that is normally higher than the general water table of the region.

c) An Unconfined aquifer

An aquifer that is not covered by impermeable rock. This aquifer is pressurized by atmospheric pressure. This type of aquifer is recharged by river infiltration or rainfall in the watershed area.

Figure 2 shows different possible sites where underground water may be drawn.

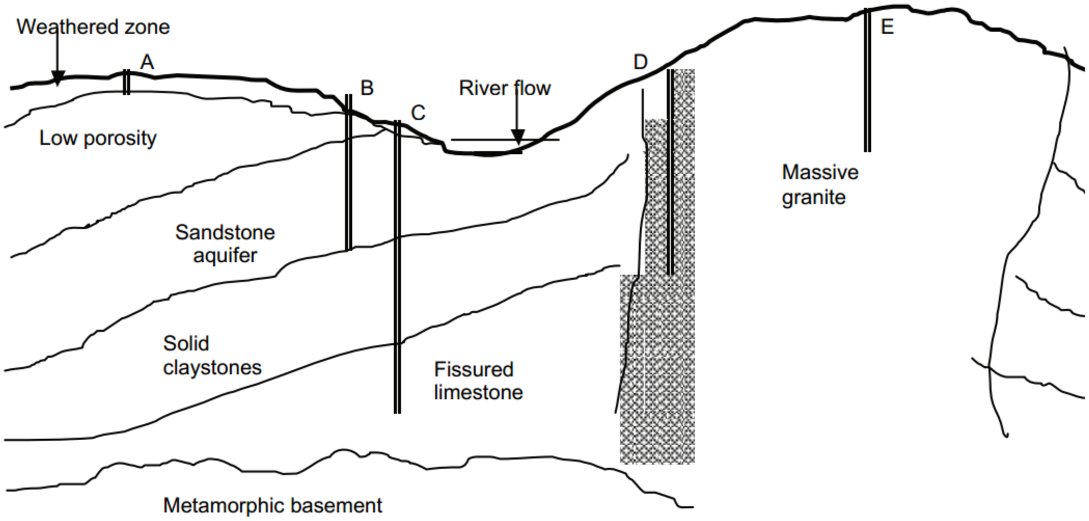


Figure 2: A hypothetical hydro geological scenario

Source: understanding groundwater and wells a manual by UNHCR

From Figure 2, there are five possible sites from where underground water may be drawn from i.e. sites A, B, C, D, and E.

A - Perched aquifers

Site A depicts a shallow well that draws water from a weathered zone aquifer. The amount of water in a perched aquifer is limited.

B - Shallow unconfined aquifers

An unconfined aquifer is one in which the water is exposed to atmospheric pressure. In this case, a static water level and a piezometric surface were used. This aquifer is recharged by the river.

C - Confined aquifers

The shallow unconfined aquifer and a deeper confined aquifer are intersected by deep borehole C. The static water level in C may be the same or higher elevation than in B due to overpressure in the deep confined aquifer. The deep confined aquifer may have no recharging source, and the water in this aquifer is ancient and can be overexploited and exhausted.

D -Fracture zone

Borehole D, drilled into fractured granite (shaded area), discovers water trapped in the fracture zone. These form as a result of mechanical stress applied to non-plastic formations as a result of tectonic movement during geological time.

E-Hydrogeological basement

A borehole at site E is dry, having been sunk into massive granite on top of a hill. Extending a borehole to the "bedrock," also known as the metamorphic basement or "hydrogeological basement," is a waste of time and money. It is unlikely that groundwater can be found beneath the bedrock.

Rainfall is the primary source of groundwater on land. Depending on the rock types, a portion of rain that falls on the ground usually percolates into an aquifer. A borehole is used to extract water from aquifers. This water can be pumped out, and more water will be drawn from the borehole to replenish it. This is the fundamental idea behind a water borehole.

Aquifers' three main characteristics are storage coefficient, transmissivity, and storativity. The rate at which water can flow through the aquifer material is expressed by transmissivity, whereas storage coefficient and storativity express the volume of water that an aquifer can store and release.

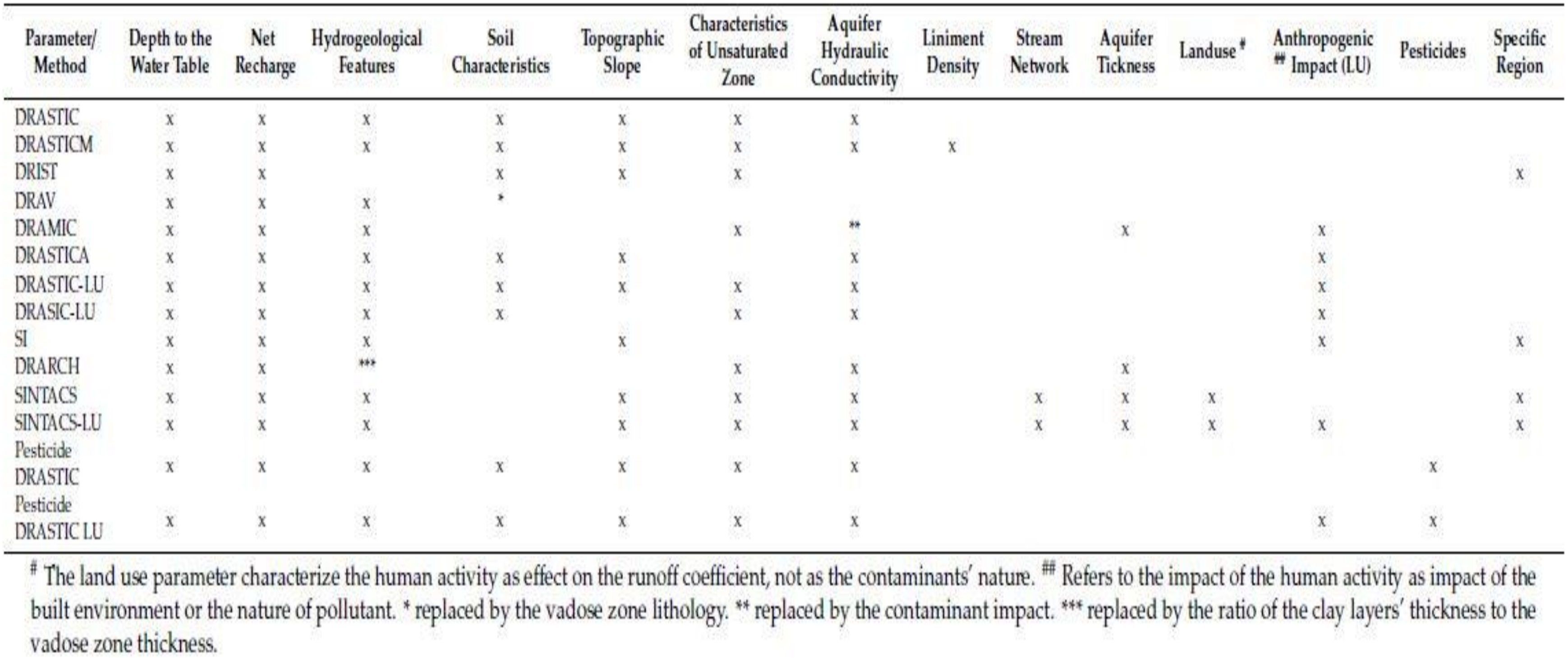
2.3 Models

Different models are used for estimating groundwater occurrence and subsequently vulnerability. They can be grouped into three categories:

1. Index-based methods, which take into consideration only the characteristics of soil and unsaturated zone.
2. Statistical approaches that assess the groundwater vulnerability through statistical analysis or regression models.
3. Simulation methods, which uses simulation techniques for forecasting the processes related to contaminant transport.

The index-based techniques have the advantage that they do not depend on data availability or similarities. The most used index models for studying the groundwater vulnerability are DRASTIC, GOD, AVI rating system, DIVERSITY, ISIS, PRAST, SEEPAGE, SINTACS. Introduced in 1985, DRASTIC is among the most popular approaches used in groundwater vulnerability estimation due to its capability and easy-to-use. Table 1 shows the different models that can be used to estimate groundwater occurrence and vulnerability.

Table 1: Groundwater vulnerability models



Parameter/ Method	Depth to the Water Table	Net Recharge	Hydrogeological Features	Soil Characteristics	Topographic Slope	Characteristics of Unsaturated Zone	Aquifer Hydraulic Conductivity	Liniment Density	Stream Network	Aquifer Tickness	Landuse #	Anthropogenic ## Impact (LU)	Pesticides	Specific Region
DRASTIC	x	x	x	x	x	x	x							
DRASTICM	x	x	x	x	x	x	x	x						
DRIST	x	x		x	x	x								x
DRAV	x	x	x	*										
DRAMIC	x	x	x			x	**			x		x		
DRASTICA	x	x	x	x	x		x					x		
DRASTIC-LU	x	x	x	x	x	x	x					x		
DRASIC-LU	x	x	x	x		x	x					x		
SI	x	x	x		x							x		x
DRARCH	x	x	***			x	x			x				
SINTACS	x	x	x		x	x	x		x	x	x			x
SINTACS-LU	x	x	x		x	x	x		x	x	x	x		x
Pesticide DRASTIC	x	x	x	x	x	x	x						x	
Pesticide DRASTIC LU	x	x	x	x	x	x	x					x	x	

The land use parameter characterize the human activity as effect on the runoff coefficient, not as the contaminants' nature. ## Refers to the impact of the human activity as impact of the built environment or the nature of pollutant. * replaced by the vadose zone lithology. ** replaced by the contaminant impact. *** replaced by the ratio of the clay layers' thickness to the vadose zone thickness.

The models can further be classified based on:-

- **Based on the extent of their use:**

i) With general applicability—DRASTIC, GOD
ii) For specific regions—SINTACS, DRAMIC, DRIST, DRAV
iii) That considers the land use—DRASTIC-LU, DRASIC-LU, SINTACS-LU
iv) For urban area—DRAMIC, DRASTICA

- **Based on the specific vulnerabilities assessed:**

i) Lithological-oriented—methods assessing the kart aquifer vulnerability and for the fractured environment (referred to in the following by Modified DRASTIC).
ii) Pollutants oriented—Pesticide-DRASTIC, Modified Pesticide–DRASTIC, and SIDRARCH.

The DRASTIC model employs numerous parameters, and its outputs are only sometimes compared with field-collected data and hence chosen for this study. The other reason that DRASTIC was chosen is that it has general applicability. Although the DRASTIC model was intended to be used in mapping applications, it was not expressly designed for use in a GIS, its initial applications employing a manual map overlay and computation procedure. It is however now used in GIS due to its capability of retrieving, storing, organizing, analyzing, and presenting geographically referenced spatial data

2.4 Factors

According to Saraf and Choudhury (1998), the following factors affect of occurrence of groundwater

- Land use
- Topography
- Rainfall
- Soil
- Lineament
- Slope
- Lithology

2.5 Previous Studies

The existing groundwater exploration methods, which are geophysical and geo-electrical techniques, are costly and time-consuming, particularly in large areas of study. In the exploration of groundwater, new technologies such as Geographical information system (GIS) and Remote Sensing are required (Sener et al., 2005). Various studies and investigations have been carried out using geospatial technologies in the delineation of the occurrence of groundwater.

A previous study incorporated GIS and Remote Sensing to investigate new water sources in the Burdur area which is located in the southwest of Turkey. They generated thematic maps of lineament density, topography, land use, surface drainage, slope, geology, and annual rainfall. GIS processing of the derived maps was done, through the use of the spatial analyst tool, to produce a groundwater potential map. They concluded that groundwater indicators are related to rainfall amounts, geology, land use, terrain conditions, lineaments, and the surface drainage of an area. They also concluded that satellite data is useful for surface study, and especially in surface features and attributes including geology, topography, and lineaments (Sener et al. 2005).

Another study used GIS to identify groundwater potential areas in Madhurawada, India, using hydrogeological investigations and hydrogeological mapping (Rao et al. 2009). Another study used a combination of GIS and Remote Sensing methods, as well as Multi-Criteria Analysis (MCA), to create thematic maps of the factors influencing the potential occurrence of groundwater. Their study concentrated on determining three major factors influencing groundwater potential zones: availability, accessibility, and exploitability. They were calculated using lineaments, existing borehole data, distance to water points, slope, and area drainage density (Doumouya et al. 2012).

In the Musi basin, groundwater potential zones were mapped using remote sensing data and GIS. Lineament density, soils, slope, geology, digital elevation model, land use land cover, and geomorphology of the area were all taken into account (Ganapuram et al. 2009). Umikaltuma I and Mutua F, 2014, applied Remote Sensing and GIS in investigating the groundwater potential of the Geddo region in Somalia. The factors considered were; lineament density, surface drainage, and geology. For lineament extraction, she combined automatic and manual methods. The automatic method involved the use of the LINE tool from Geomatica 2014 software.

In the evaluation of groundwater condition of a soft rock terrain in India's Midnapur District, GIS was used in the analysis of hydrogeological data acquired using Remote Sensing and surface geophysical techniques (Shahid et al. 2000). GIS, Remote Sensing, and spatial modeling were employed to map the occurrence of groundwater potential zones in Ghana. The factors considered included geomorphology, slope, digital elevation model, rainfall, land use, and drainage density. Thematic maps showing the factors in consideration of the study were produced and weighted overlay analysis was used to produce the final suitability map showing the suitable areas of groundwater occurrence in Ghana (Murali Krishna Gumma & Paul Pavelic 2011).

Remote sensing and geographic information system (GIS) techniques were used to map the presence of groundwater potential zones in the Salem chalk hills of Tamil Nadu, India. Geomorphology, drainage density, geology, soil, land use, and lineament density were all taken into account. The factors under consideration were combined using weighted index overlay analysis (WIOA). The groundwater potential index map of the study area was then created using ArcGIS software (N. Thilagavathi et al 2015).

From the above aforementioned studies, it’s therefore clear that factors such as geology, soil, slope, DEM, geomorphology of the area, lineament density, and rainfall determine the occurrence of groundwater and geospatial technologies are efficient tools to use in groundwater exploration.

CHAPTER 3: MATERIALS AND METHODS

3.1 Data

The datasets that were used in the study include Digital Elevation Model, LandSat 8 imagery, Rainfall, Soil, and Lithology. These datasets were arrived at after the factors that affect the existence of groundwater were determined from the literature review.

3.1.1 Digital Elevation Model (DEM)

Digital Elevation Models are a representation of the earth's surface in a three-dimensional format. DEM represents the height above sea level of an area. The digital elevation model of Kenya was downloaded from the ILRI (International Livestock Research Institute). The shuttle Radar Topography Mission (SRTM) satellite was used to extract digital elevation models (DEM) at an accuracy of 30m for the country Kenya. Using the extraction by mask tool in Arc GIS software the digital elevation model of the area of interest (Kitui County) was derived. From the digital elevation model, a slope map was generated. Figure 3 shows the Digital Elevation Model of Kitui County.

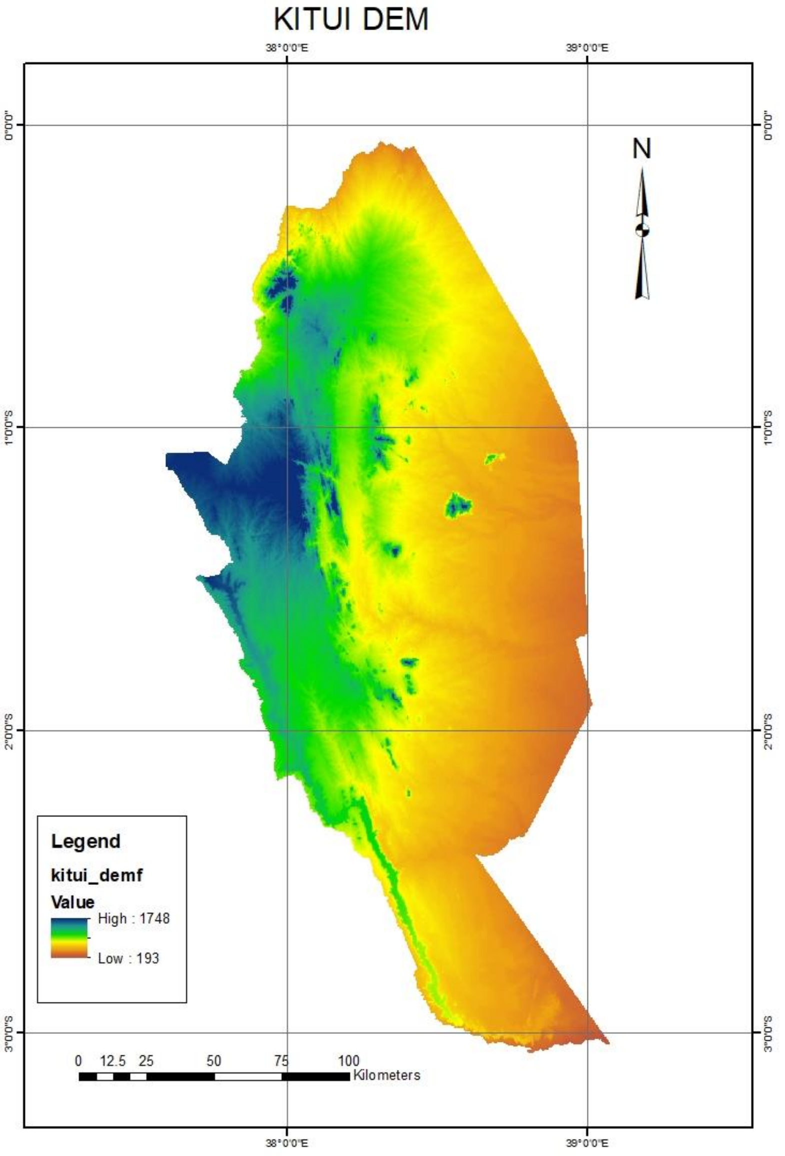


Figure 3: Kitui Digital Elevation Model

3.1.2 Landsat 8 Imagery

The LandSat imagery with a spatial resolution of 30m was downloaded from the United States Geological Survey (USGS) website. Image pre-processing was carried out using the ERDAS IMAGINE software. The process included layer stacking the imagery, mosaicking the imagery, and finally sub-setting the imagery with the area of interest Kitui County shapefile.

From the LandSat imagery land use/land cover was determined and lineaments extracted from the imagery. Figure 4 shows the mosaicked Landsat Imagery for Kitui County.

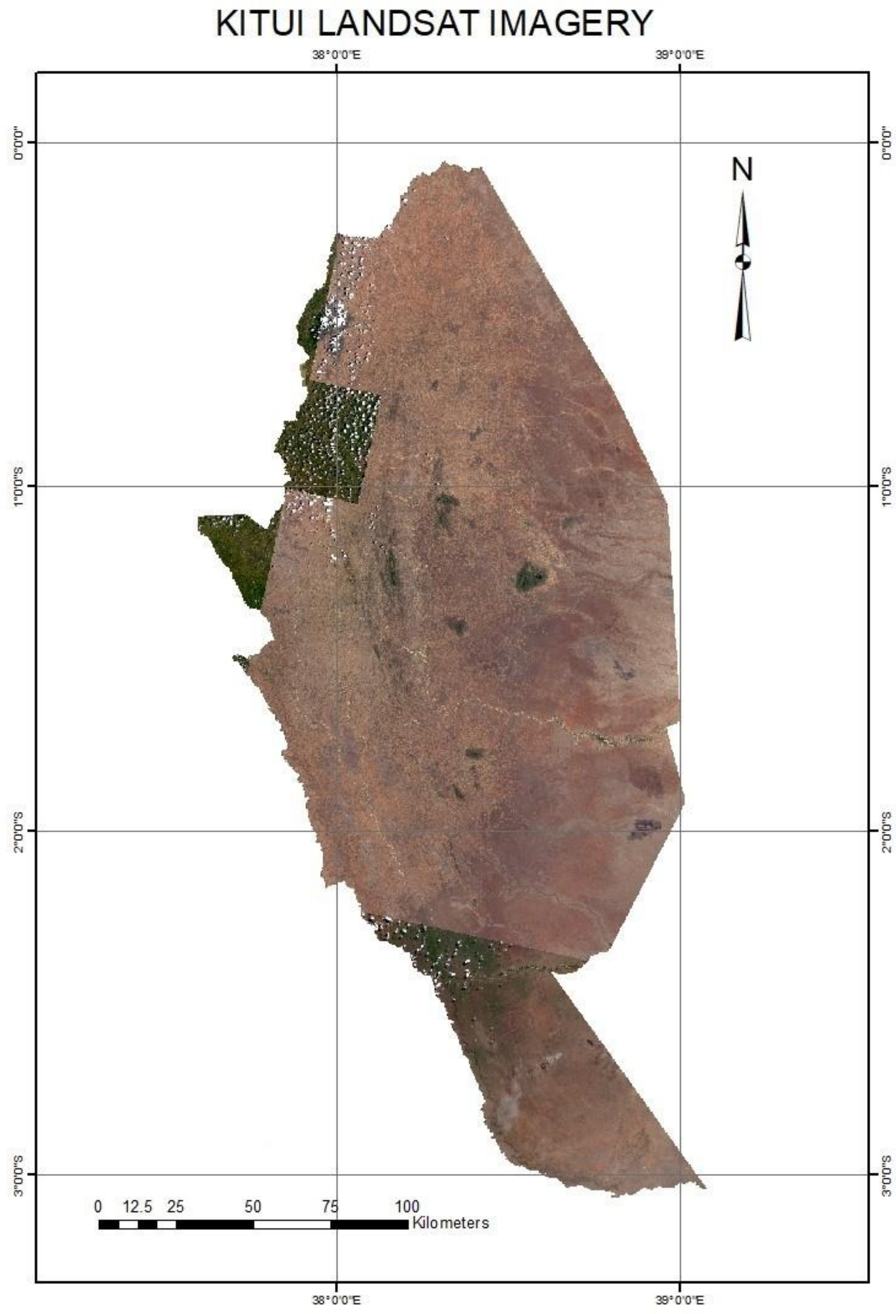


Figure 4: Kitui Landsat Imagery

3.1.3 Rainfall Data

Rainfall is considered to be the main source of groundwater replenish. Kitui being an arid and semi-arid area receives rainfall sparingly annually with some months having a record of zero mm while others have some significant amount of rainfall. The rainfall data used was from Kenya meteorological department. Areas that receive the lowest amount of rainfall are considered to be the poor area of groundwater exploration while areas that receive a high amount of rainfall are considered to be reliable areas of groundwater exploration (Rahmati et al. 2015). Figure 5 shows the Annual Rainfall distribution of Kitui County.

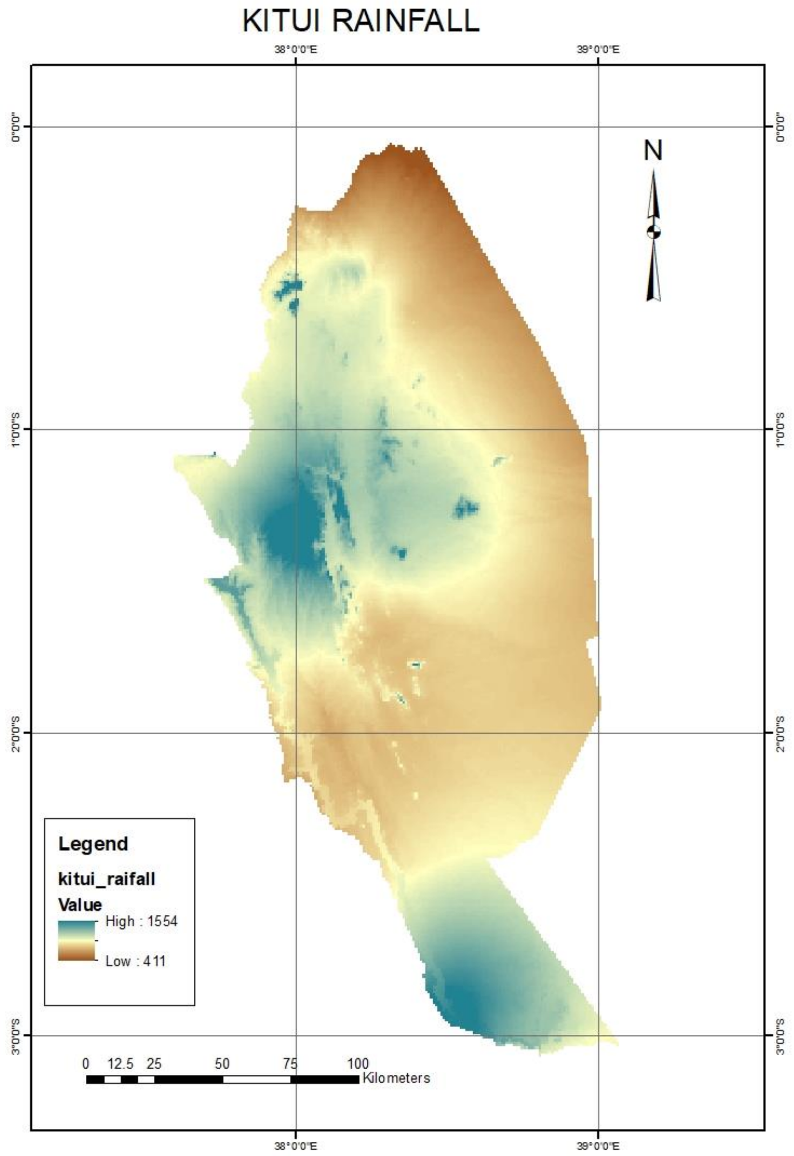


Figure 5: Kitui Annual Rainfall

3.1.4 Soil

Soil attributes have a significant role in groundwater quantity as well as quality. Soils are derived from rocks, due to weathering and erosion. Loamy soils are the best soils as they allow efficiently the infiltration of water into the ground and also the retention of the water. Loamy soils have an average drainage capacity. Sandy soils have the best drainage but have poor water retention capacity while clay soils have the best water retention capacity with poor drainage capacity (N. Thilagavathi et al 2015). Figure 6 shows the location distribution of Soils in Kitui County.

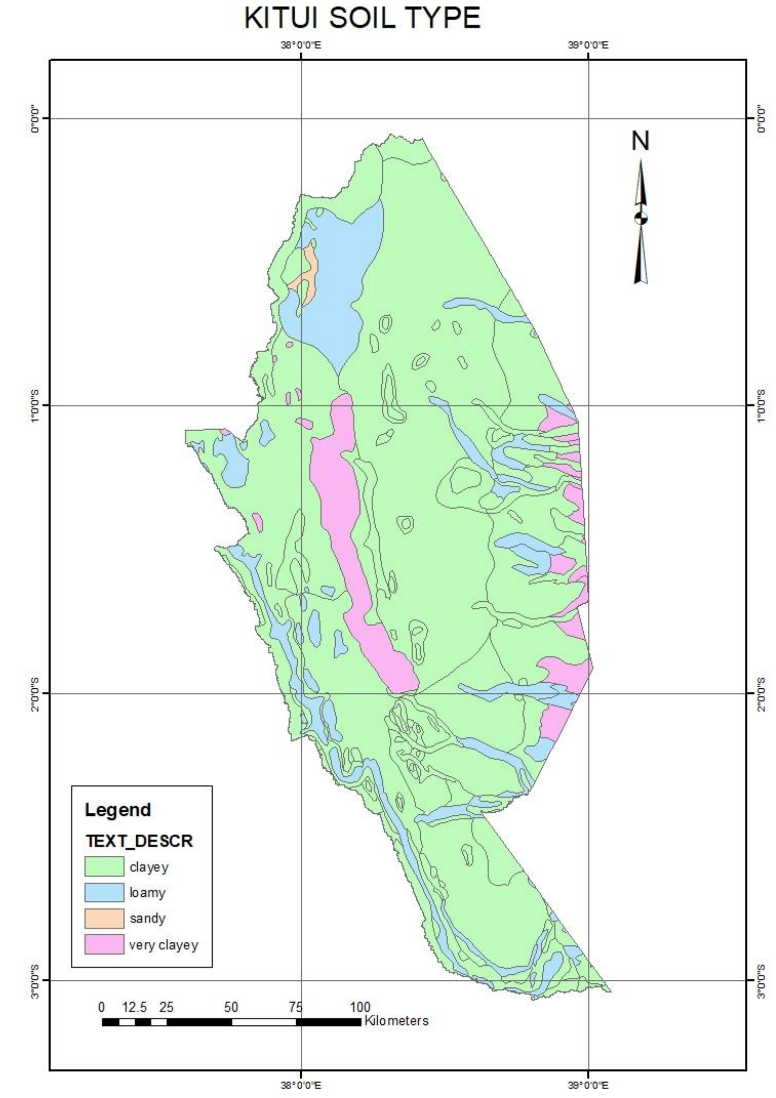


Figure 6: Location Distribution of Soils in Kitui County

3.1.5 Lithology

Geological data of the study area was downloaded from the ILRI website as a shapefile. The data is from the Kenya Geological Department. Figure 7 shows the Lithology of Kitui County.

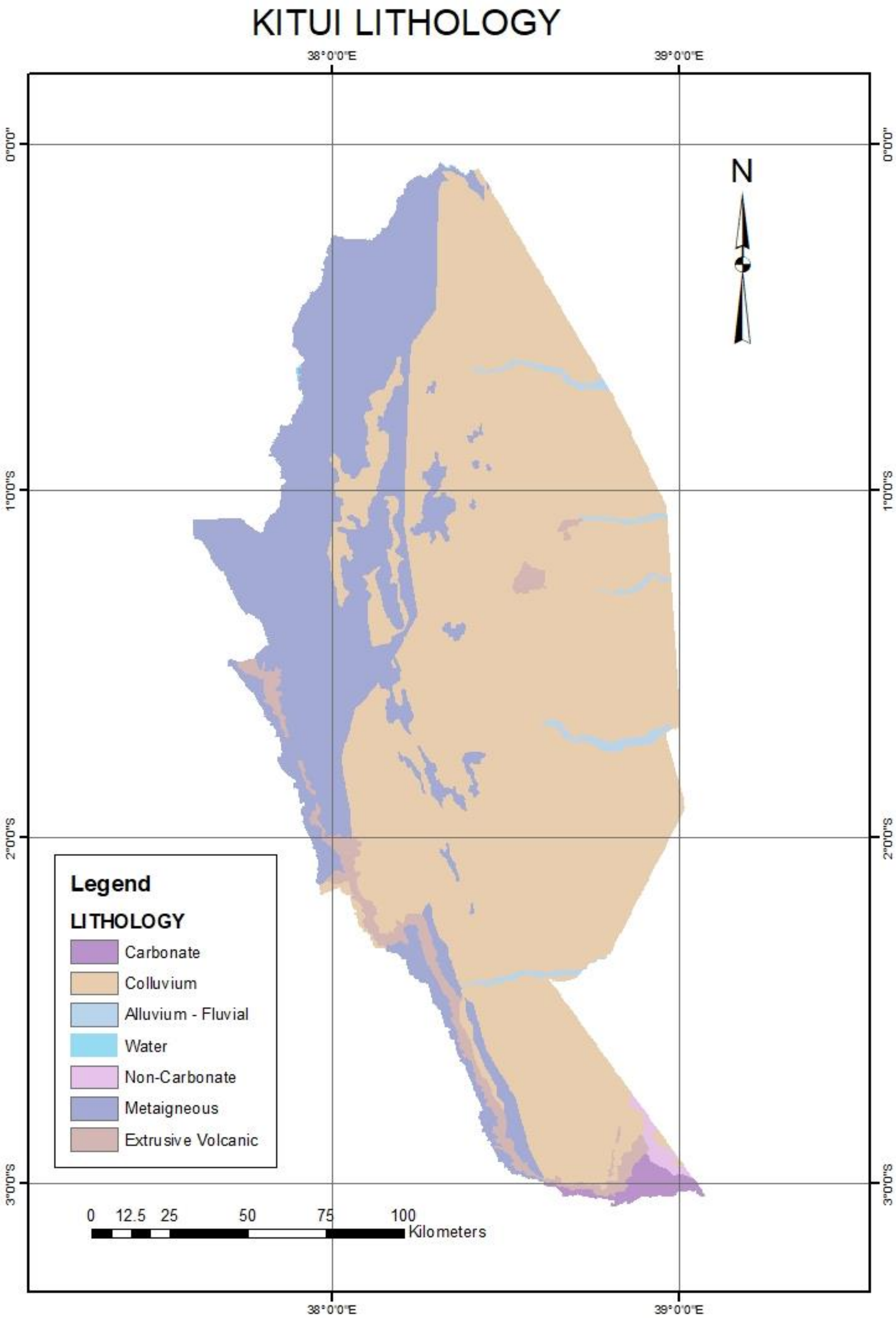


Figure 7: Lithology Data in Kitui County

3.2 Methodology

The methodology used in the study includes the use of GIS techniques and Remote Sensing techniques to analyze the data. Figure 8 shows the methodology workflow chart used in this study.

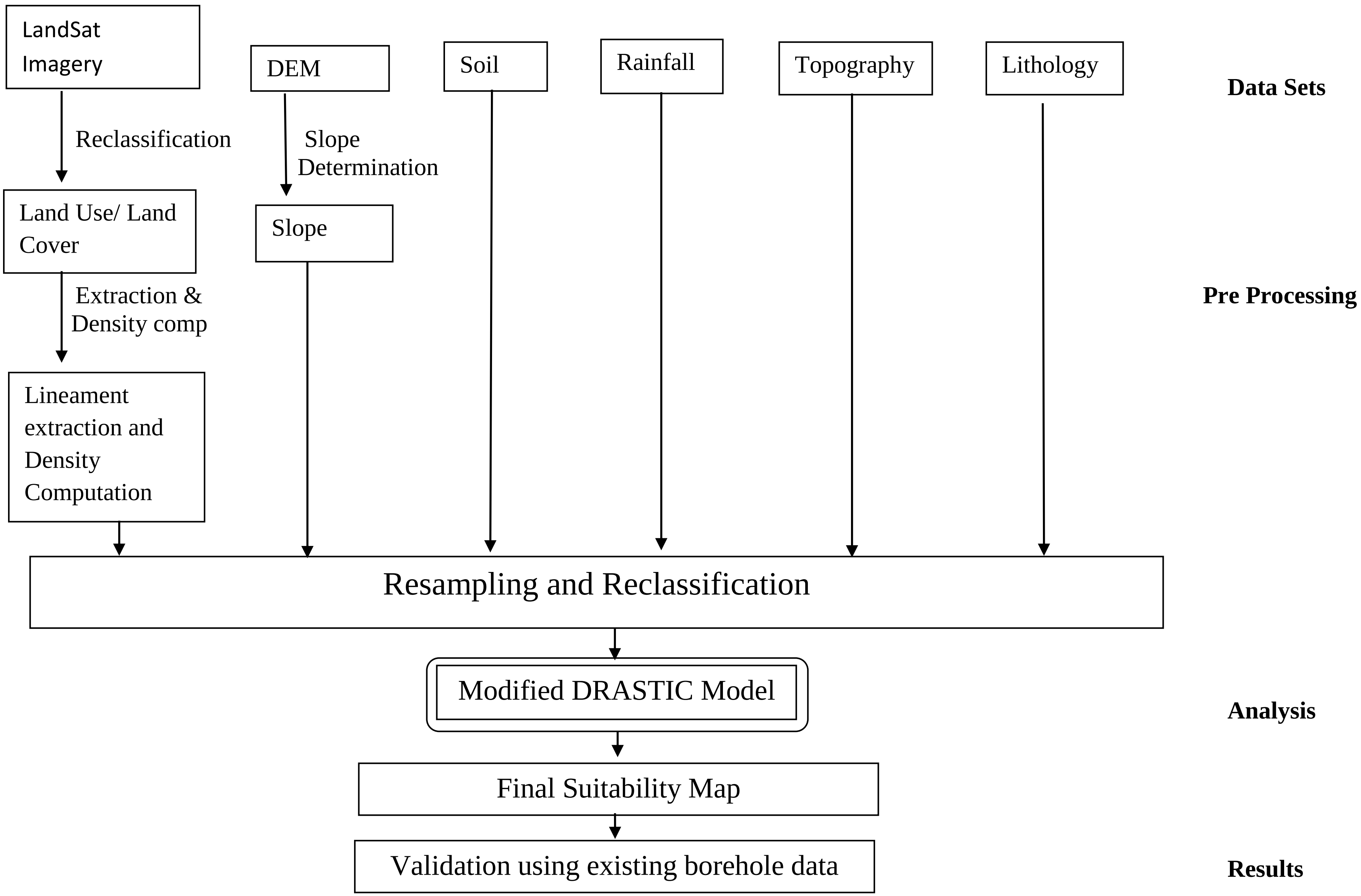


Figure 8: Methodology flow chart.

3.2.1 Pre-processing

Remote Sensing aspect entailed the pre-processing of the imagery using ERDAS IMAGINE software. The imagery downloaded was layer stacked and then mosaicked to form composite imagery. Image sub-setting will then be carried out using the Kitui County shapefile to come up with the LandSat imagery of the County. From the subset LandSat imagery, lineament extraction will be carried out, and land use/land cover classification done on the imagery.

Lineaments are the surface expressions of underlying structural features such as geological fractures such as faults or joints, and they indicate the presence of groundwater because they act as conduits for groundwater flow. They play an important role in the formation and spread of groundwater (Mohamed 2014).

Lineaments were extracted automatically using the Geomatica software's line extraction tool. The density of lines was then be calculated in ArcGIS software using the line density tool.

Land use is the activities that the land is used for while the land cover is the features that encompass the land surface. Land use/land cover classification will be done on the Landsat imagery of the study area using the supervised classification method utilizing the maximum likelihood method.

The slope of the area was generated from the DEM using ArcGIS software.

Reclassification is used to simplify raster data by changing an old value to a new value or grouping a range of values into a single value. Reclassification was carried out using ArcGIS software. It enables the process of carrying out weighted overlay analysis.

After reclassification, the input factors were assigned weights. From the expert-based information acquired in the field, the weights were arrived at. The input factors were weighed according to their order of importance on how they affect the occurrence of groundwater. The weighted overlay tool was used to produce the final suitability map of the location of boreholes.

3.2.2 DRASTIC Method of Overlay

The DRASTIC method was used to combine the factors influencing the occurrence of groundwater. The DRASTIC method was developed by the US EPA (the United States Environmental Protection Agency). It provides a low-cost method for identifying areas that require further investigation based on known conditions, without the need for extensive, site-specific pollution data.

3.2.2.1 Parameter used in the DRASTIC Model

D: Depth to Groundwater: The depth to the Aquifer

R: Net Recharge: The total amount of water that percolates into the aquifer.

A: Aquifer: material that forms the aquifer (such as sand, gravel, and limestone)

S: Soil Media: The topmost portion of the vadose zone which has significant biological activity

T: General Topography or Slope: The slope of the land surface

I: Vadose Zone: The unsaturated zone above the water table

C: Hydraulic Conductivity of the Aquifer: transitivity of aquifer material.

3.2.2.2 Governing Equation

Each parameter has a rate and a weight assigned to it. The governing equation for DRASTIC model is:-

$$DRASTIC\ INDEX = Dr*Dw + Rr*Rw + Ar*Aw + Sr*Sw + Tr*Tw + Ir*Iw + Cr*Cw$$

Where:

r = the rating for the parameter
w = an assigned weight for the parameter
D = Depth to Groundwater
R = Net Recharge
A = Aquifer
S = Soil Media
T = General Topography or Slope
I = Vadose Zone
C = Hydraulic Conductivity of the Aquifer

In the modified DRASTIC algebra method the factors that influence groundwater occurrence are used to replace those factors that determine the pollution of groundwater in the above equation.

CHAPTER 4: RESULTS AND DISCUSSION

Several map layers were produced after processing the input factors to determine the suitable areas.

Lineaments are linear features that are key indicators of the occurrence of groundwater. These lineaments were extracted using the line tool in GEOMATICA software LandSat imagery of Kitui County. The rivers were obtained from the shapefile of Kitui County from the whole map of Kenya as a country using the clip tool in ArcGIS software. Figure 9 shows the Lineaments map of Kitui County.

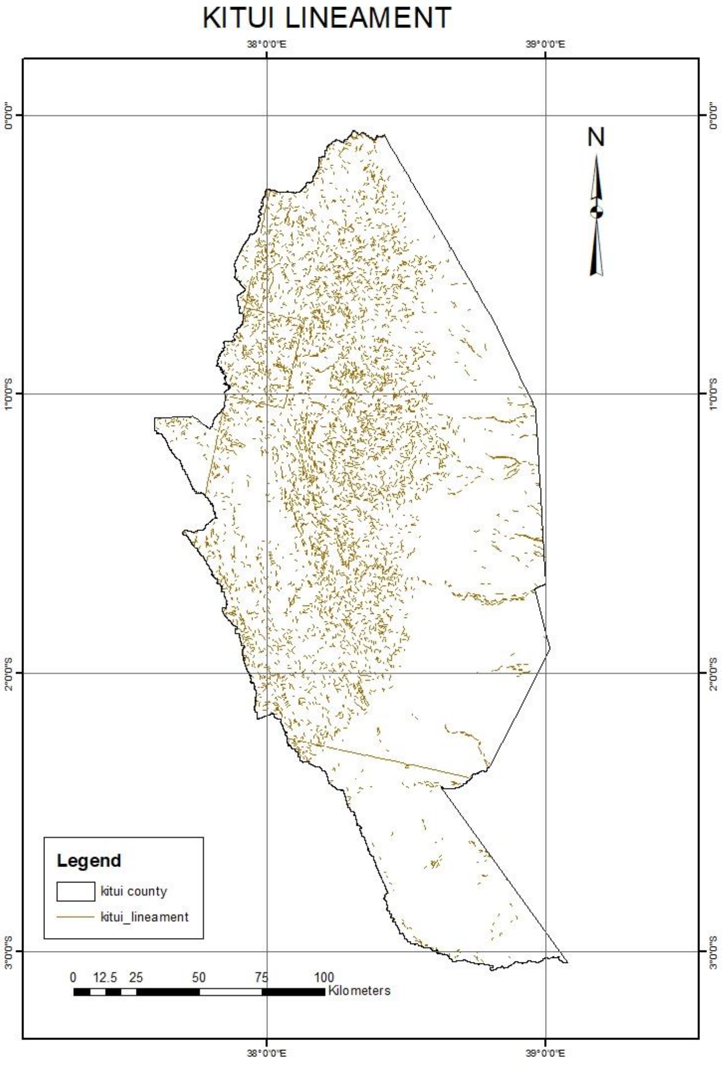


Figure 9: Kitui Lineaments map

Lineaments density shows how the lineaments are concentrated in a certain region of the map. The higher the lineament density the higher the potential of groundwater being found in a particular area. Lineaments density is computed using the line density tool in ArcGIS software. The area with dark brown color are the areas of high lineaments density hence have a higher potential of groundwater. Figure 10 shows the Lineament density map of Kitui County.

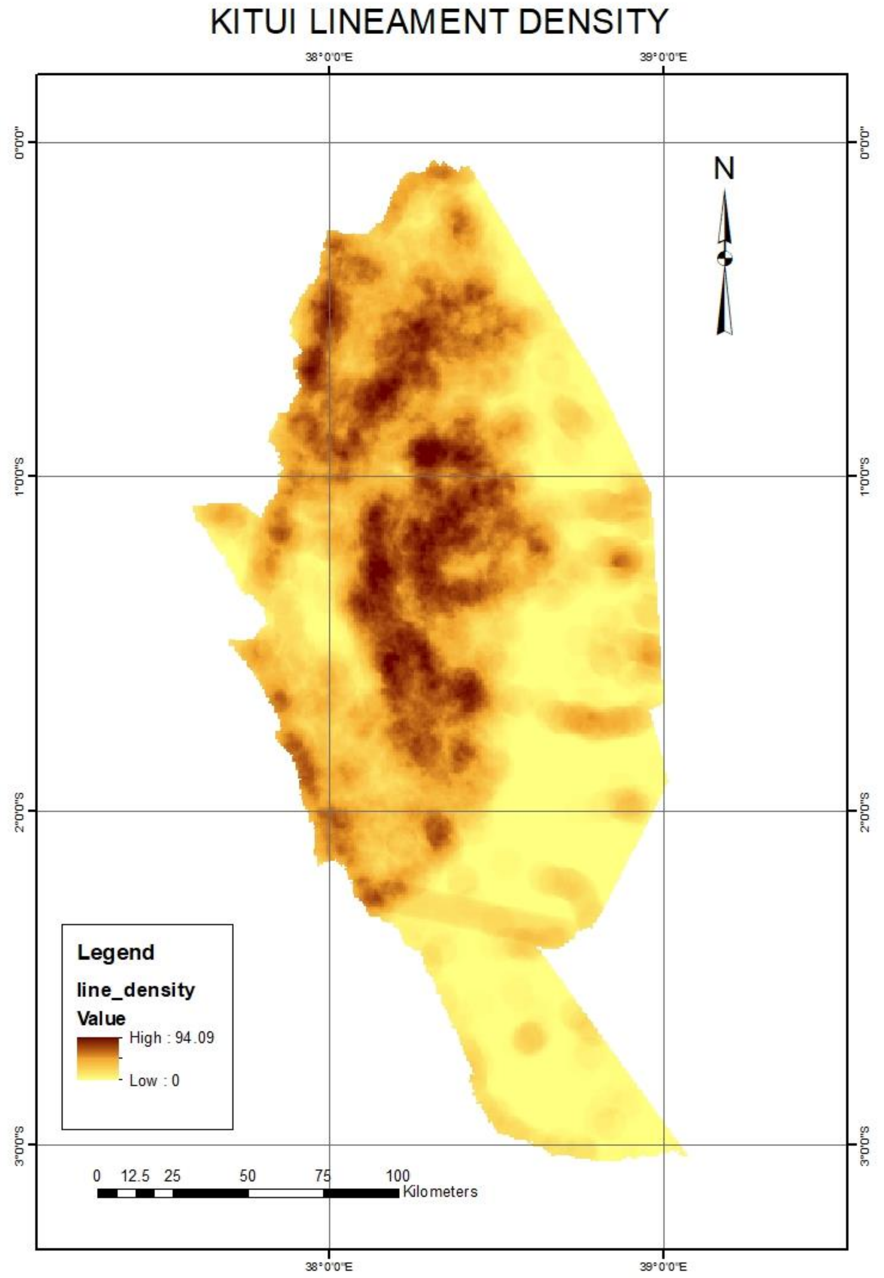


Figure 10: Kitui Lineament Density

Bushland comprises of small growth of shrubs, bushes, and small trees. This kind of vegetation can easily be cleared when there is a need to drill boreholes in an area without too much interference of the ecosystem as they easily re-grow. They also hold the soil intact minimizing erosion and also help in the preservation of soil moisture. Woodlands areas are covered with large trees. They act as water catchment and their clearance will bring about ecosystem interference to a great extend. Bare ground is the ground that has less cover of vegetation. In this area, the rate of soil erosion is very high and there is poor conservation of soil moisture. Figure 11 shows the Landuse map of Kitui County.

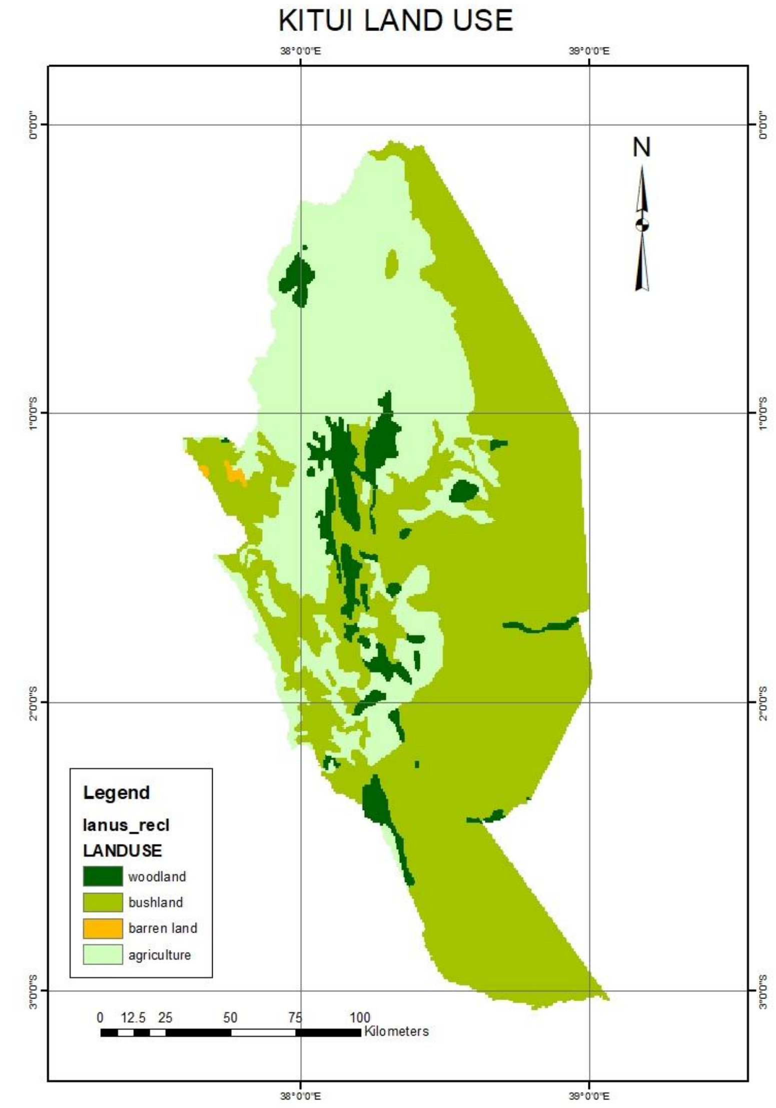


Figure 11: Kitui Land use map

Reclassification is used to simplify raster data by changing an old value to a new value or grouping a range of values into single values 1 – 4 with 1 being the situation less likely for groundwater occurrence and 4 being more likely. Reclassification was carried out using ArcGIS software. It enabled the process of carrying out weighted overlay analysis.

Lithology is reclassified to change the pixel values of the initial map to new pixels to enable the process of carrying out weighted overlay analysis in ArcGIS. Figure 12 shows reclassified Lithology map of Kitui County.

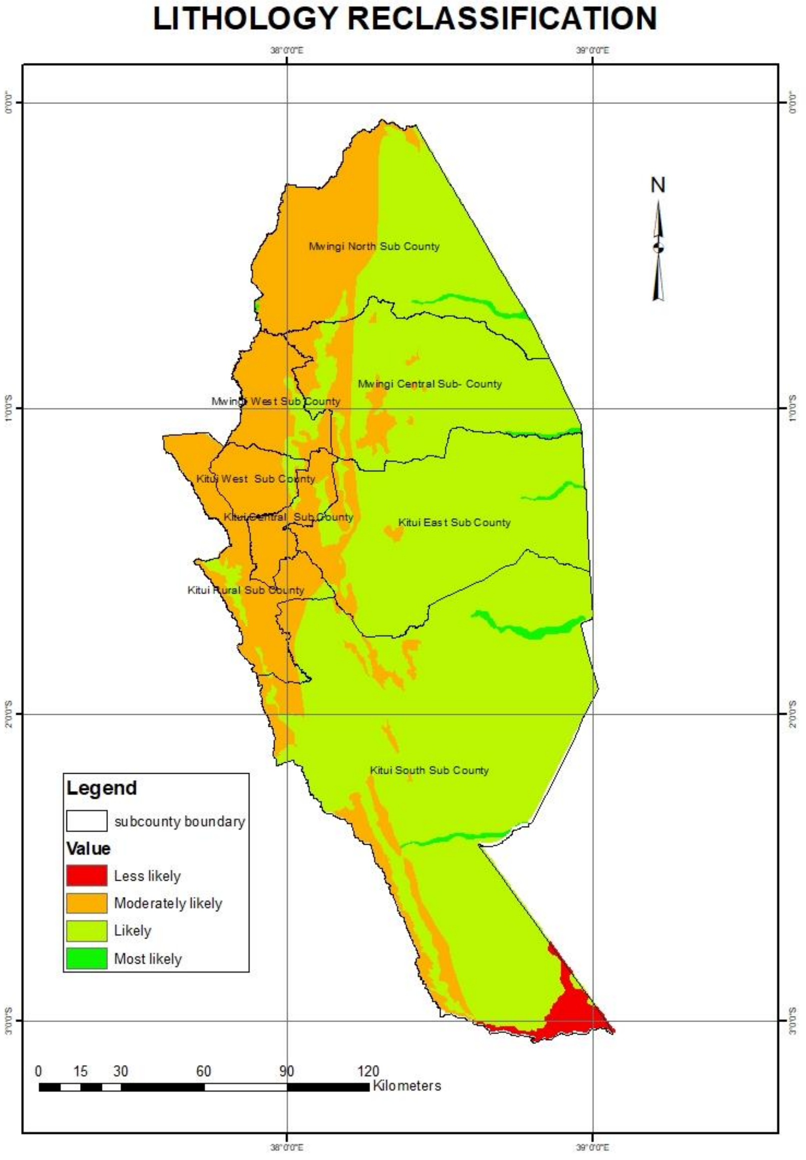


Figure 12: Lithology reclassification

The slope was generated from the digital elevation model of Kitui County. The slope determines the highest and lowest values of Kitui County. Areas of low slope act as discharge areas and areas of high slope act as recharge areas. Figure 13 shows reclassified slope map of Kitui County.

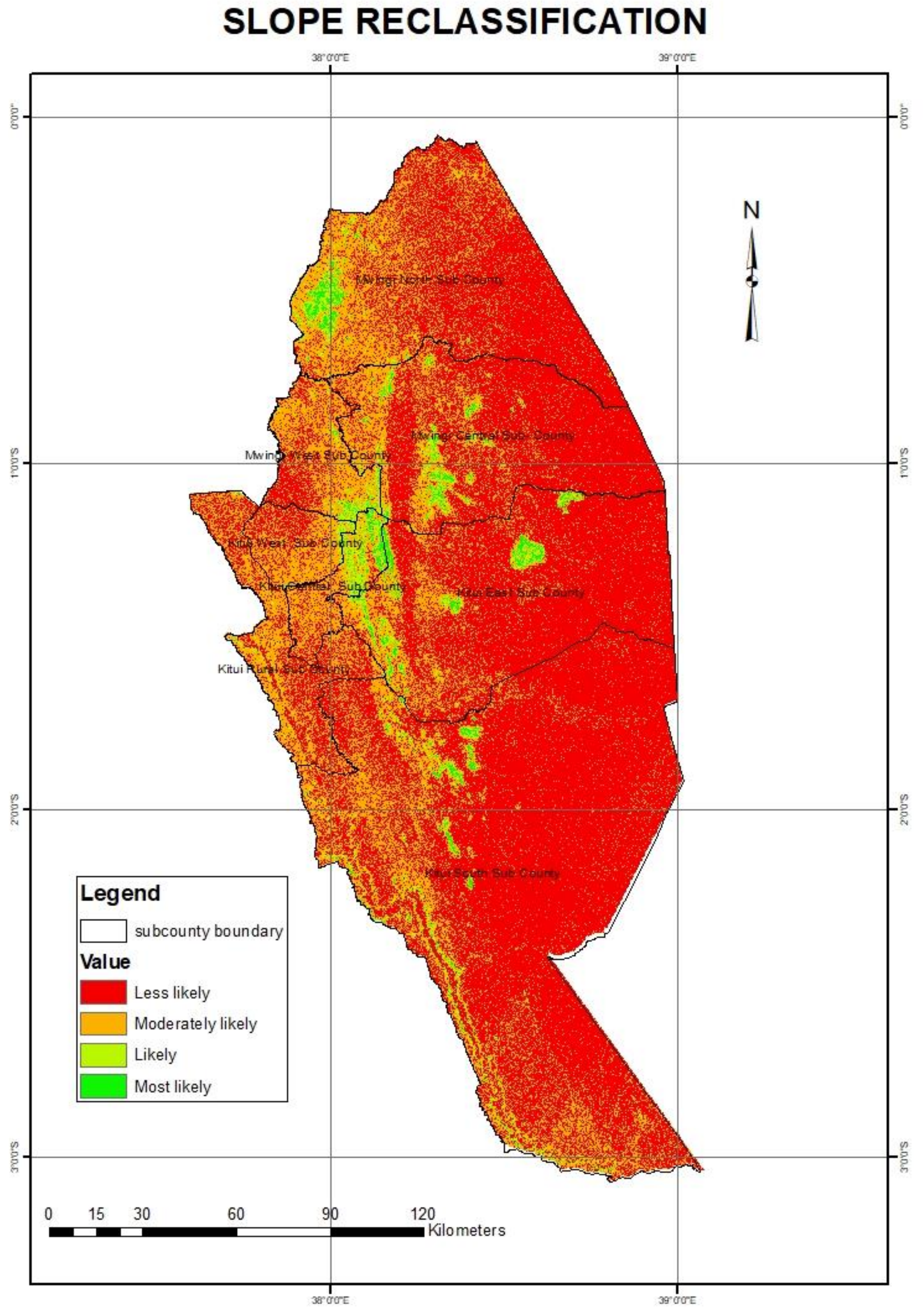


Figure 13: Reclassified slope Map

Rainfall acts as the main recharge of groundwater. After raining water percolates into the ground and it's stored as groundwater. Areas with a very low amount of rainfall tend to have a low rate of groundwater recharge comparable to areas that receive a tentatively high amount of rainfall. Reclassification was carried out to change the pixel values of the initial map to facilitate the process of weighted overlay analysis in ArcGIS software. Figure 14 shows the Reclassified Annual Rainfall map of Kitui County.

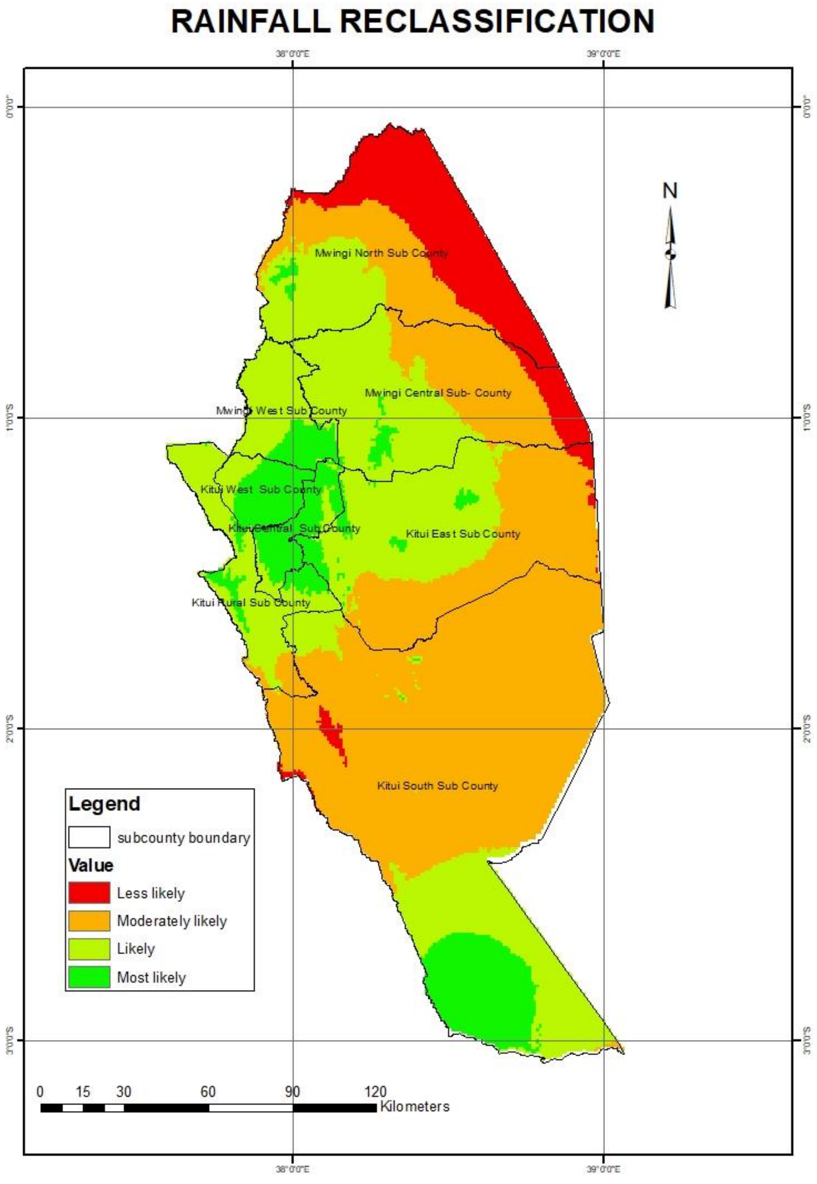


Figure 14: Reclassified Rainfall Map

Loamy soils are the best soils as they allow efficiently the infiltration of water into the ground and also the retention of the water. Loamy soils have an average drainage capacity. Sandy soils have the best drainage but have poor water retention capacity while clay soils have the best water retention capacity with poor drainage capacity. Figure 15 shows the Reclassified soil map of Kitui County.

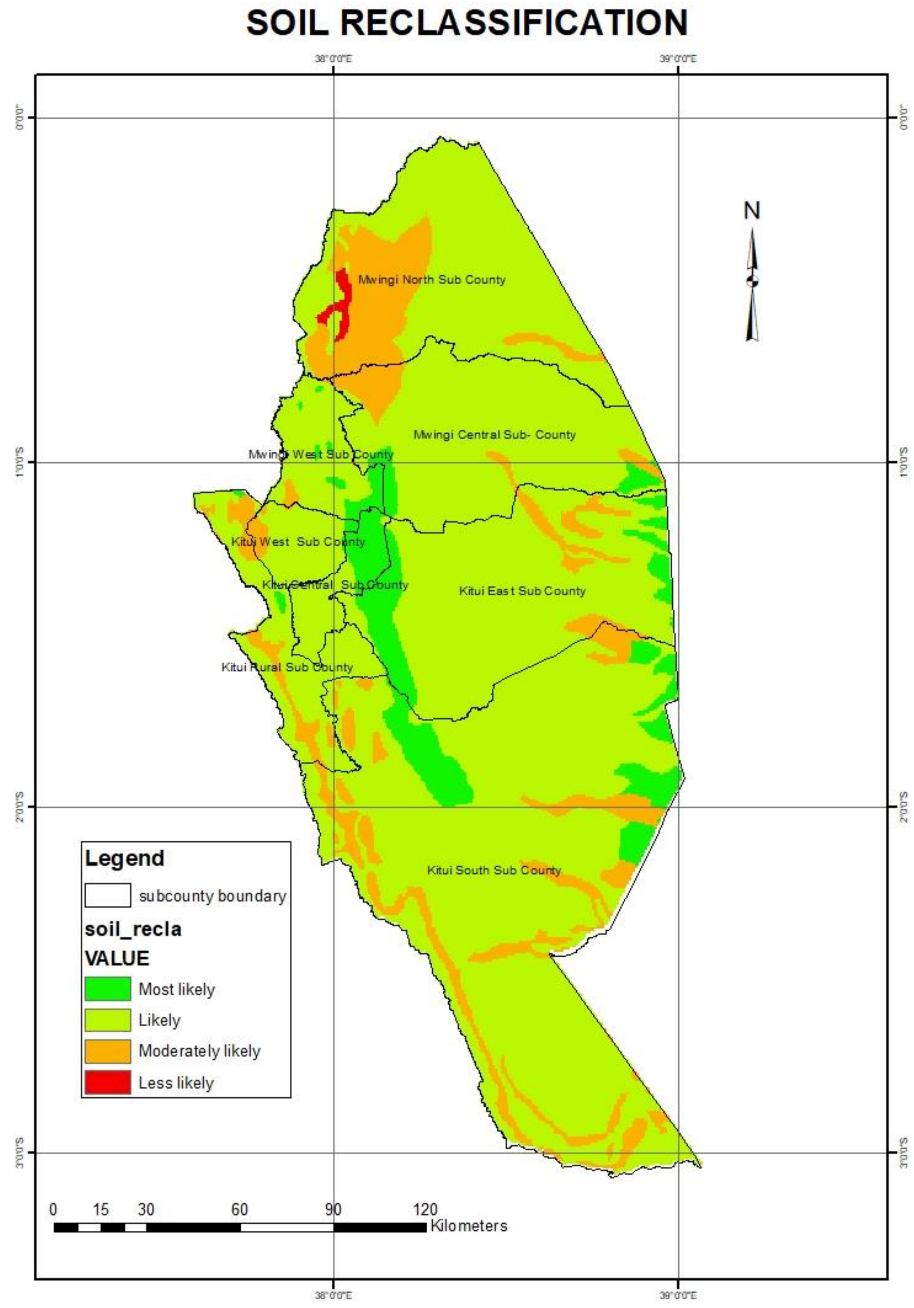


Figure 15: Reclassified Soil Map

Figure 16 shows reclassified lineament density map of Kitui County.

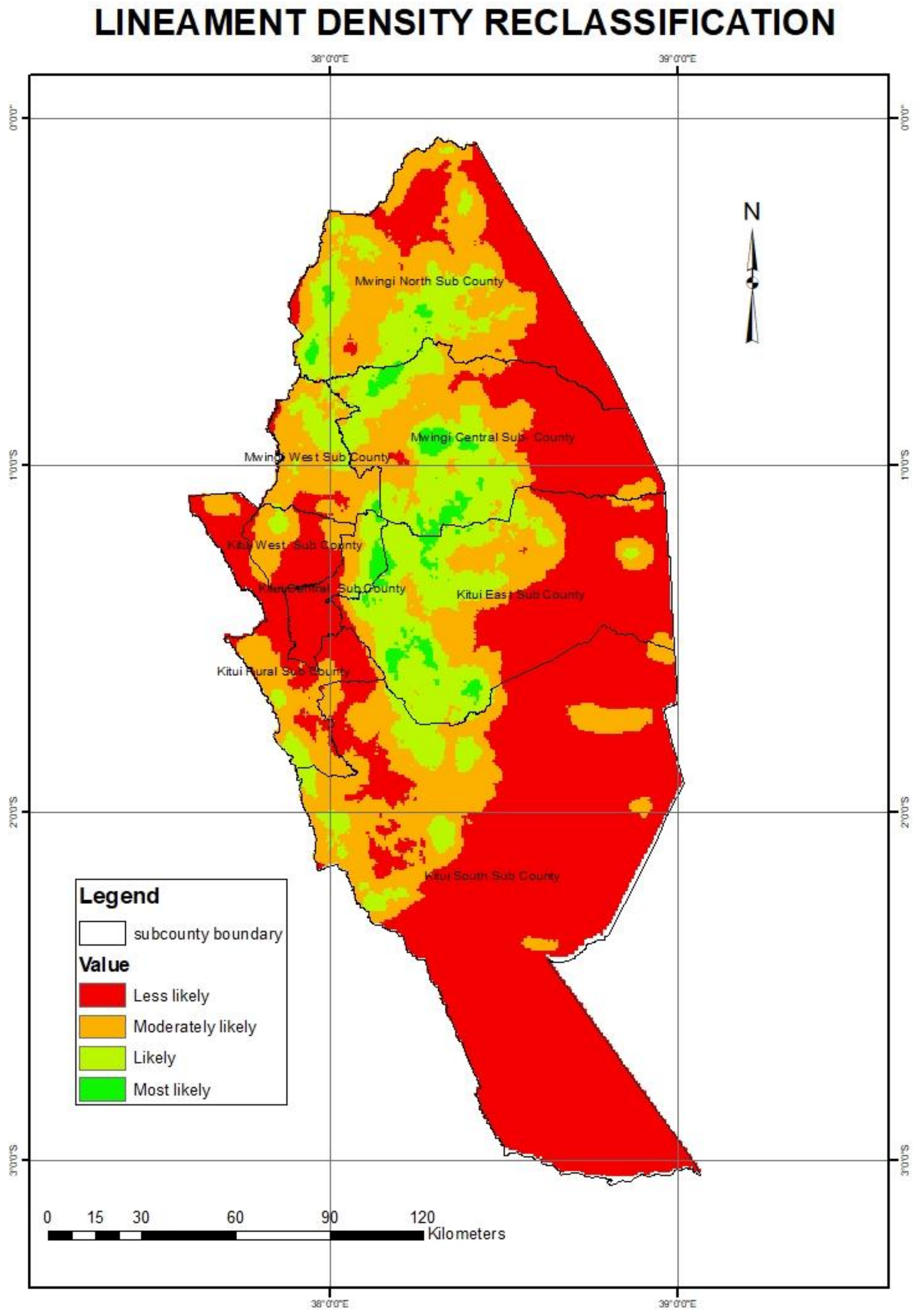


Figure 16: Reclassified Lineament Density Map

Figure 17 shows Reclassified Topography in Kitui County.

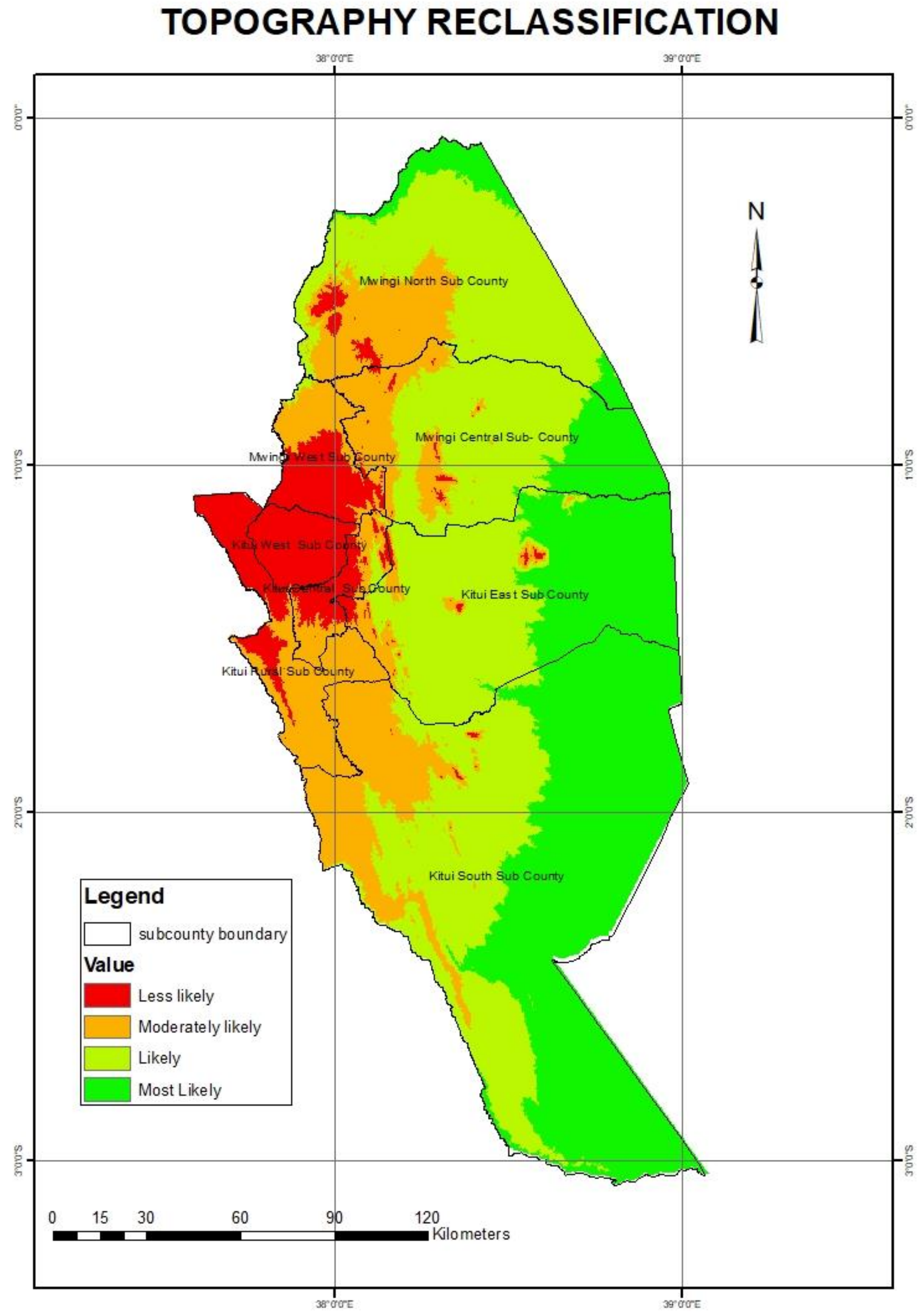


Figure 17: Reclassified Topography Map

Figure 18 shows Reclassified Landuse Map for Kitui County

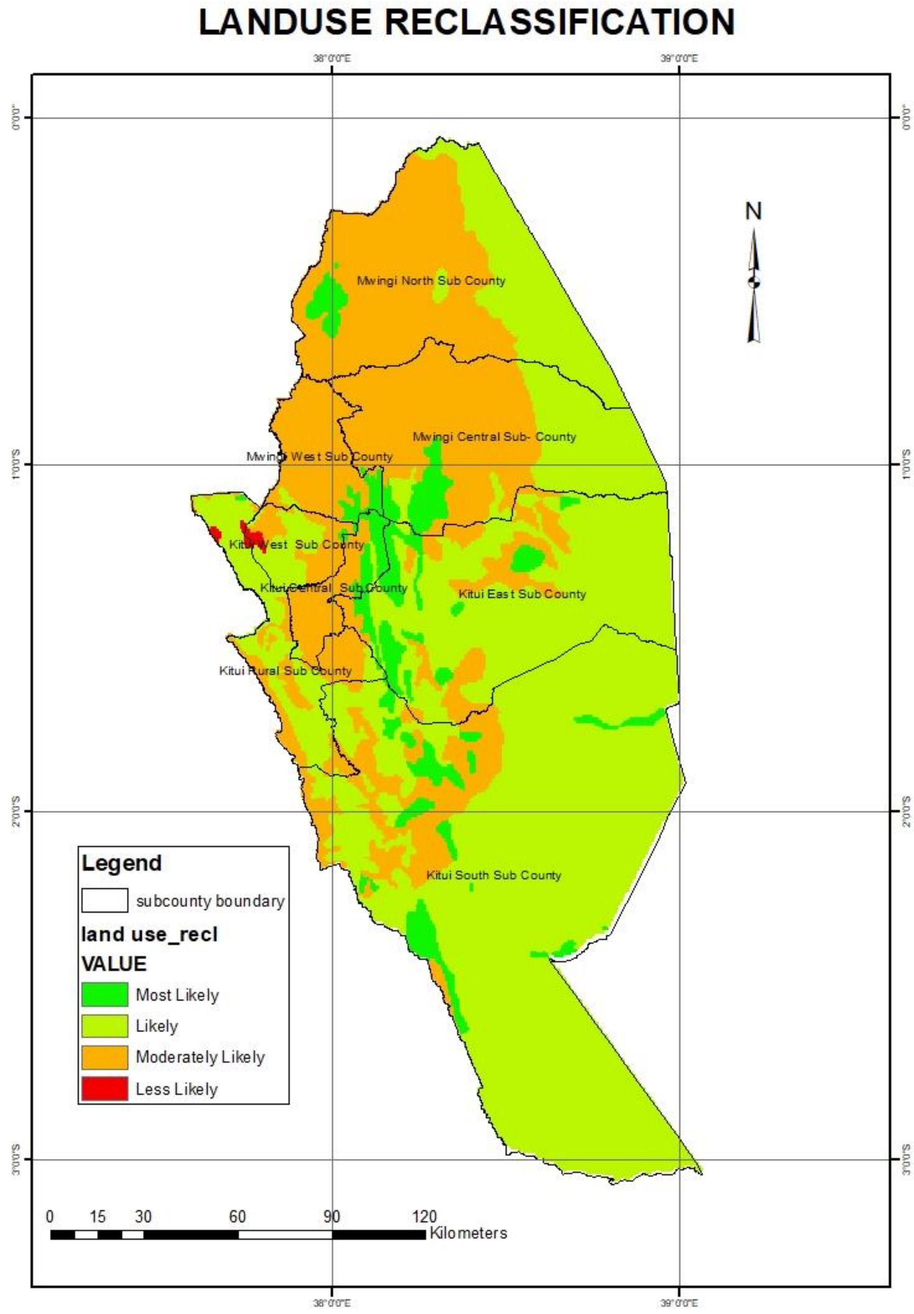


Figure 18: Reclassified Land-use Map

Table 2 shows how the weights applied in the weighted overlay were reached at.

Table 2: Weighting

	LD	TOP	SLOP	LU	LITH	RAIN	SOIL									
LD	1	0.33	0.5	0.14	7	9	7		LU*1/Total	0.061	0.034	0.069	0.075	0.211	0.176	0.22
TOP	3	1	0.33	0.2	7	9	7		TOP*1/total	0.183	0.103	0.046	0.107	0.211	0.176	0.22
SLO	5	3	1	0.2	7	9	7		SLO*1/total	0.305	0.309	0.139	0.107	0.211	0.176	0.22
LU	7	5	5	1	9	9	9		LD*1/total	0.427	0.514	0.693	0.535	0.272	0.176	0.28
LITH	0.14	0.14	0.14	0.11	1	7	0.5		LITH*1/total	0.009	0.014	0.019	0.059	0.03	0.137	0.02
RAIN	0.11	0.11	0.11	0.11	0.14	1	0.14		RAIIN*1/total	0.007	0.011	0.015	0.059	0.004	0.02	0
SOIL	0.14	0.14	0.14	0.11	2	7	1		SOIL*1/total	0.009	0.014	0.019	0.059	0.06	0.137	0.03
Total	16.4	9.72	7.22	1.87	33	51	31.64									
1/Total	0.06	0.1029	0.139	0.535	0.03	0.02	0.032									
									Factor	LU	TOP	SLOPE	LD	LITHO	RAIN	SOIL
									Total	0.848	1.048	1.468	2.901	0.284	0.12	0.33
									Total/7	0.121	0.15	0.21	0.414	0.041	0.017	0.05
									WEIGHTS	12.11	14.96	20.97	41.45	4.063	1.72	4.72
									Total weights=1.00							

Final Weights.

FACTOR	**WEIGHT (%)**
1. Land use	12.11
2. Topography	14.96
3. Soil	4.72
4. Lineament	41.45
5. Slope	20.97
6. Lithology	4.06
7. Rainfall	1.72

Figure 19 shows the areas that were found to be suitable for borehole siting.

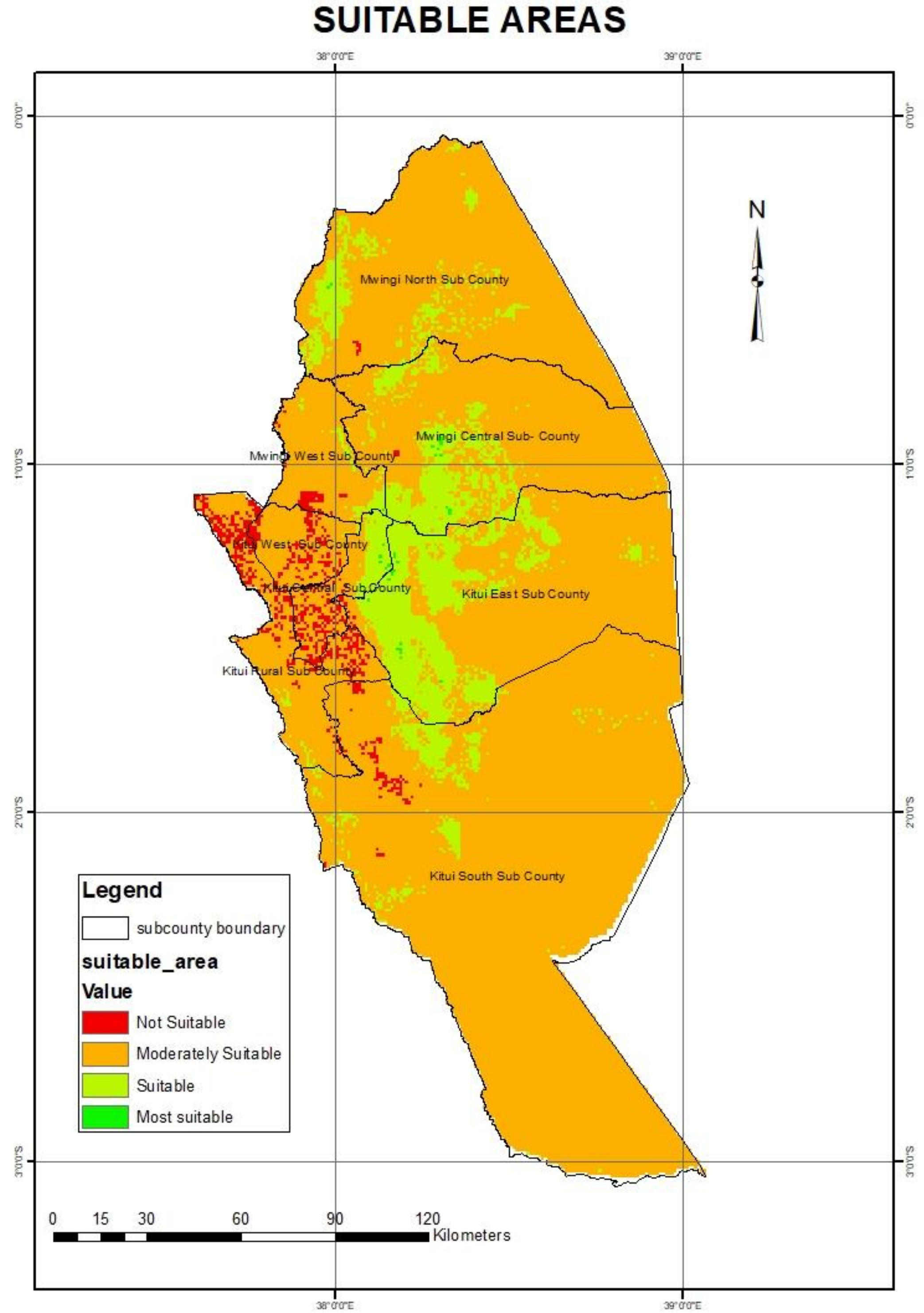


Figure 19: Suitable areas Map

From the final suitability map, it is clear that the western part of the county is unsuitable for borehole sitting. This is due to the fact that the area has very low lineaments and barren land which are the key factors to the occurrence of the groundwater. The southern areas of the county are occupied by Tsavo national park which is a protected area hence no drilling can take place there. The central part of the county is the most suitable area for borehole drilling as they have a higher lineament density.

Validation of the study was further done by doing an analysis on the existing boreholes and the area they were found that is most suitable, suitable, moderately suitable, and not suitable. Forty-four borehole sites were used to validate. This data was sourced from Kitui County Government, Ministry of Agriculture, Water and Livestock. The borehole data was intersected with the suitable areas and 10 boreholes (22.73%) were found to be in the suitable areas, 33 boreholes (75%) were in moderately suitable areas and 1 borehole (2.27%) was in the unsuitable area.

Figure 20 shows the existing borehole data (blue dots) overlaid on suitable areas for validation.

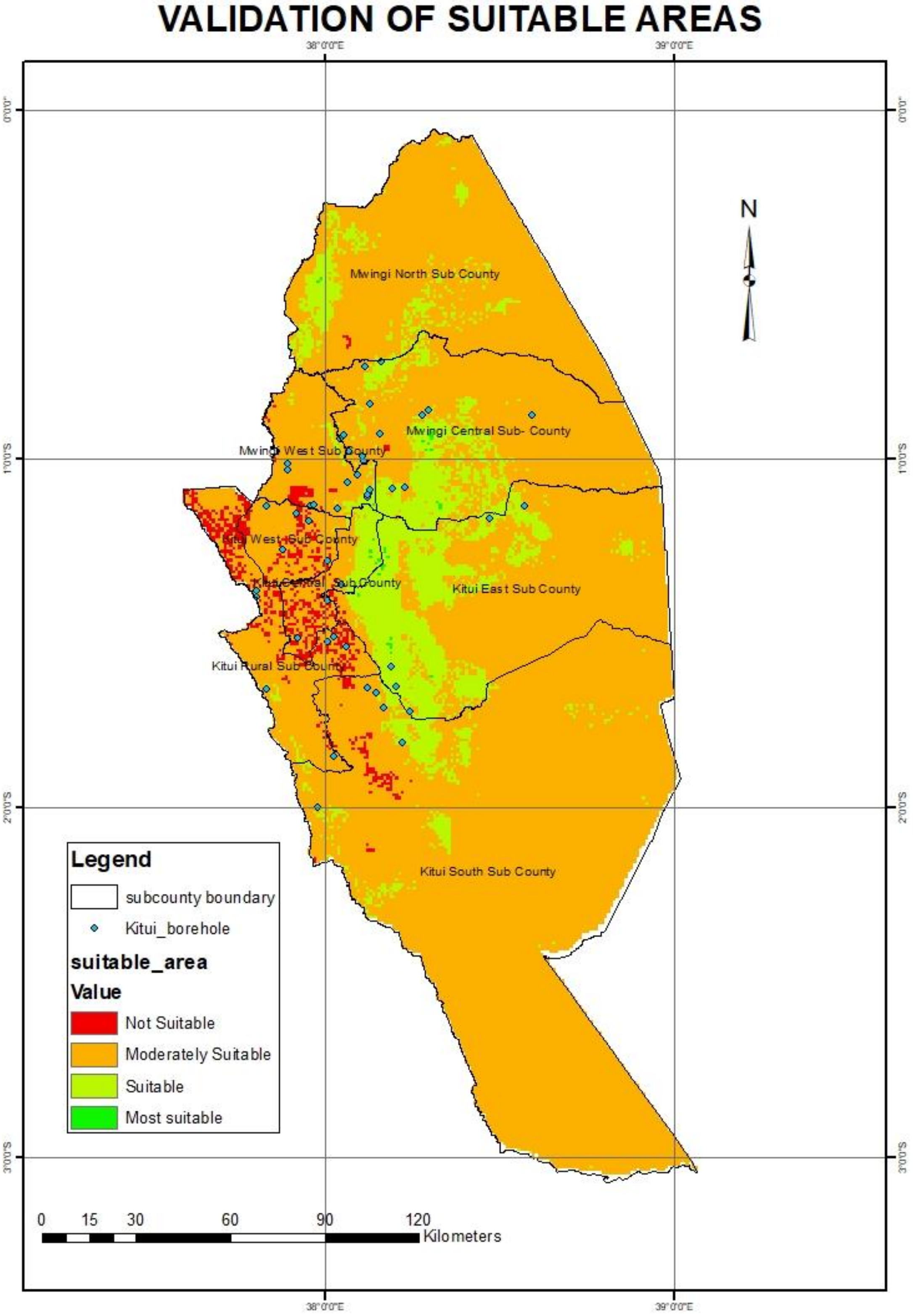


Figure 20: Suitable areas Validation

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Groundwater potential areas in Kitui County were effectively mapped through the integration of factors that affect the occurrence of groundwater. This was done using geospatial technologies that are remote sensing and Geographic Information Systems. The drastic method in conjunction with the weighted overlay method yields the desired results in comparison with other studies carried out in delineation of the occurrence of groundwater considering the same factors.

The areas found to be most suitable for borehole siting was 0.09%, suitable was 12.64%, moderately suitable was 85.01% and 2.26% was not suitable for borehole siting. Validation showed that 10 boreholes (22.73%) were found to be in the suitable areas, 33 boreholes (75%) were in moderately suitable areas and 1 borehole (2.27%) was in the unsuitable area.

5.2 RECOMMENDATION

Geospatial technologies should be embraced in carrying out suitability studies due to their improved accuracy as they are able to delineate the appropriate areas for groundwater exploration and borehole siting. Geospatial technologies are also time conscious thus facilitating studies over large areas such as the case of the whole Kitui County.

This study revealed that some areas in the Kitui East and Mwingi Central Sub-counties fall under the suitable areas and hence, these areas should be concentrated for groundwater management and developing activities. These areas of the sub-counties that this study found to be suitable for borehole sinking can further be investigated based on population to find out if these areas can have boreholes sited. Since, in these areas, the number of water harvesting structures is seen to be minimal.

The integrated map could be useful for various developmental activities likes, sustainable developments of groundwater in the study area, as well as identification of priority areas for implementation of water conservation projects and programs.

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