DELINEATION OF DISTRIBUTION OF GROUNDWATER RESOURCES IN PARKS

A Case Study of Ruaha National Park

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A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Science in Geoinformatics (BSc. GI) of Ardhi University

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University dissertation titled **"Delineation of Distribution of Groundwater Resources in Parks, a case study of Ruaha national park"** in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics at Ardhi University.

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Date ……………………….	Date ……………………….

DECLARATION AND COPYRIGHT

I, MLAGARA FRANK hereby declare that, the contents of this dissertation are the results of my own findings through my study and investigation, and to the best of my knowledge they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

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DEDICATION

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ABSTRACT

Groundwater is an important resource that contributes significantly to the total annual water supply.. Inadequate surface water supply is being a serious problem for the wildlife in parks due to climate changes and population growth. The present study has been undertaken with an objective to delineate the groundwater potential of Ruaha national parks. A combination of geographical information system and analytical hierarchical process techniques (AHP) was used in the present study. A total of 11 thematic layers such as Geology, Land Use/Land Cover, Lineament density, Drainage density, Rainfall, Soil, Slope, Roughness, Topographic Wetness Index, Topographic Position Index and Curvature were prepared and studied for groundwater potential zone demarcation. Weights assigned to each class in all the thematic maps are based on their characteristics and water potential capacity through AHP method. All thematic layers are integrated with a multicriteria evaluation technique. The reliability of the output is checked by the calculated consistency index and consistency ratio which is reasonably acceptable (0.005< 0.1). The accuracy of the output was cross-validated with information on groundwater prospects of the area. The groundwater potential zone map thus obtained was categorized into five classes-very good, good, moderate, poor and very poor. The study reveals that about 30.6% of the park is covered under moderate groundwater potential zone. The good and very good groundwater potential zones are observed in 25.9% and 12.3% respectively. The remain portion consists poor and very poor groundwater potential which covers 31.2%.

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ACRONYMS AND ABBREVIATIONS

RS	Remote Sensing
GIS	Geographic Information System
AHP	Analytical Hierarchy Process
SAW	Simple Additive Weight
MDA	Multi-criteria Decision Analysis
LULC	Land Use/Land Cover
IPCC	Intergovernmental Panel on Climate Change
DEM	Digital Elevation Model
SRTM	Shuttle Radar Topographic Mission
GST	Geological Survey of Tanzania
GPZ	Groundwater Potential Zones
GPI	Groundwater Potential Index
CR	Consistency Ratio
CI	Consistency Index
RI	Random Index
TWI	Topographic Wetness Index
TPI	Topographic Position Index
DD	Drainage Density
CW	Criteria Weight
LD	Lineament Density

CHAPTER ONE
INTRODUCTION

1.1 Background

The distribution of groundwater resources in parks plays crucial role on supporting various ecological system, sustaining biodiversity, and providing water resources for recreational activities and human use. Parks which encompass national parks, nature reserve, and protected areas, often contain unique landscape and habitats that rely on groundwater for their functioning and survival.

It is undeniable that water has been the most essential natural resource for the substance of life on planet earth. Groundwater is considered as one of the vital elements of nature which is found in voices of the earth and packs the pore space of soil beneath the water table. Groundwater is proven as tone of the most significant natural resources which is dependent as a sources of water supply in all climatic regions of the world. Almost 30%of the world's fresh water is supplied by groundwater while only 0.3%is furnished by surface water including lakes, rivers, and reservoirs (Shemsanga et al., 2018). The main sources of groundwater are rainwater and snowmelt which are leaching down through the soil pores into the aquifer.

Uncontaminated and groundwater is a crucial to sustain life on earth, particularly at the present time when water scarcity is becoming central issue in many nations across the globe. At present time due to rapid growth of industrialization and population, demands on freshwater directly affected on groundwater has been increasing which is a worldwide concern, therefore exploitation of groundwater is considered as an essential art of water management and planning. The tropical and sub tropical regions are severely affected with the problems related to groundwater. The scarcity of water in Tanzania is more observable in arid and semiarid regions such as Dodoma, Manyara, Iringa, because these regions are associated with a limited availability of surface water sources, which to a large extent are subjected to the effects of natural processes, pollution and climate change (Herrera-Pantoja & Hiscock, 2015). And 25% of Tanzanians depend on groundwater for their daily domestic and economic activities (Elisante & Muzuka, 2017), but a very small percentage of water is used for irrigation, which mostly generate from surface water.

More people require more food, which requires more water and thus more abstraction of water from rivers, which is often done unsustainably. This leads to a freshwater crisis and associated conflicts between people in upstream and downstream areas, and between people and nature in much of semi-arid East Africa (Crisman et al., 2003). In general, unsustainably practiced human activities increase low-flow periods in rivers and modify or destroy flow pathways. A sustainable supply of water requires healthy watersheds (Nugroho et al.,2013; Welde and Gebremariam 2017; Guzha et al., 2018; Jacobs et al.,2018; Lee et al., 2018), and this is directly impacted by human activities (Seeteram et al., 2019; Elisa et al., 2021; Kihwele et al., 2021). Furthermore, the IPCC predicted that climate change in East Africa will affect rainfall and river flows with consequences for livelihoods and wildlife. For the last twenty years, TANAPA (Tanzania National Parks) has taken proactive actions to address the water crisis in its National Parks, which support Tanzania's tourism industry. The parks are scattered throughout the country covering all environments.

Inadequate surface water supply is being a serious problem for the wildlife in parks due to population growth. The practical development of the groundwater resources will have a significant effect on the improvement of the community's livelihood. Generating a groundwater potential map has a significant effect to enhance the sustainable management of groundwater resources in the study area. Thus, the present study is critical for quick identification of groundwater potential for better utility in the study watershed.

Geographic Information System (GIS) is a computer-based system that can be used capture, store, manipulate, analyse and present geospatial data to solve several complex and complicated problem in the environment (Prasad & Loveson, 2020). Recently, the application of GIS is being powerful and applied to deciphering the potential areas of groundwater occurrence with cost effective manner. GIS has great role for effectively addressing groundwater exploration and delineating potential areas in a certain region of study. Extensive use of remote sensing satellite images along with ground truth data has made it easier to provide the baseline information for delineating groundwater potential zones. Literatures reveal that several researchers have been using GIS to delineate groundwater potential zones with the integration of statistical approach such as simple additive weight (SAW) and analytic hierarchy process (AHP) and, machine learning. The combination of GIS and remote sensing technologies reduce the ambiguity of hydrogeological data various aspect.

1.2 Justification

Various studies based on groundwater distribution discovered that, distribution has a considerable impact on water resources. During the dry season, water resources become scarce, and surface water bodies such as rivers and ponds may dry up. Groundwater plays a vital role in supporting the ecosystems within parks. Many plants, animals and aquatic species rely on groundwater for their survival, especially during dry season or in arid regions. By distributing groundwater resources strategically, parks can maintain a suitable habitat for these species and promote biodiversity conservation. It is crucial to identify water problems for specific areas within the parks rather than highlighting them as a global case of the parks. This resolves the challenges in the uncertainty of responsive measures that can be implemented in certain areas where there is an ignorance of local water problems. Knowing exact water challenges for local areas, within the parks improves the adequacy of resource allocation as a responsive measure.

Therefore, identifying groundwater potentiality zones helps in preserving the ecosystem by ensuring an adequate water supply. Protecting and managing groundwater resources in parks promote biodiversity, sustains wetland and support the overall ecological balance.

1.3 Research problem

Large part of the reserves in Tanzania is covered by seasonal rivers and streams that become dry during the dry season. Climate change is pronounced to be the primary factor of prolonged drought in the parks. These parks are famous for their large number of mammals that migrate seasonally to and from the parks; these migrations are driven by the variability of surface water quantity and quality during dry season. Some of their seasonal migration routes bring them outside the parks to unprotected areas for searching enough water.

On other hand, water scarcity is one of the factors causing death to the wild animals. Furthermore, many parts in parks groundwater potential zones are not recognized yet, so these potential zones are needed to be assessed and delineated for understanding the distribution and availability of groundwater resources in parks. The national parks administration should have a strong, localised management system that can identify drought-stricken areas in order to anticipate water stress in specific areas within the parks.

1.4 Objectives

1.4.1 Main objective

The main objective of the study is to identify groundwater potentiality zones areas for understanding distribution and the availability of groundwater resources in national parks.

1.4.2 Specific objectives

The following are the specific objectives to attain the main objective:

- To assessing groundwater resources in the study area.
- To identify and weighting all criteria that influencing availability of groundwater resources.

1.5 Research questions

- What are main sources of water in the parks?
- What are weigths for all criteria that influence water resources?

1.6 Significance of the study

The study helps the national park management to plan sustainable groundwater exploitation and management for brought groundwater to the surface either through wells drilled or by pumping groundwater up the surface after all zones being identified. The output of this research will provide valuable information to develop sustainable groundwater management and suitable location for borehole drilling that can be used by decision-makers, government agencies, and TANAPA management. Furthermore, the results of this study important to have proper administration, management, and sustainable use of groundwater resources in Ruaha national park. Also, the study will improve the availability of water in the park for wild animals even during the dry season after recognizing all groundwater potential zones. The availability of water throughout the year different human activities for example agricultural activities are conducted without depending only on surface water.

1.7 Scope of the study

The scope of the study of this research of groundwater distribution resources using the AHP technique includes assessing groundwater resources, developing an AHP model, selecting and weighting criteria, collecting and analyzing data, conducting spatial analysis and validating results.

1.8 Thesis Layout

The thesis is organized into five chapters. After this brief introductory chapter. Chapter 2 provides a literature review with an overview of related studies conducted in other parts of the world together with previous works in the area. The different data sets used and the methods utilized are described in Chapter 3. The data sets include digital data such as remote sensing images and digital elevation models as well as lithological and soil type data. In addition, the techniques the methods used in the generation of the various thematic maps from remote sensing data as well as digital elevation models are described in detail. Methods to integrate and analyse the various thematic layers using a geographic information system (GIS) are given. Moreover, the steps to generate groundwater potential zones using GIS are presented in detail. The results are presented in Chapter 4. Finally, the conclusions drawn together with recommendations are presented in Chapter 5.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Groundwater exploration is the study of underground formations to better understand the hydrogeological cycle, determine the quality and quantity of groundwater and determine the nature and type of aquifers (Shishaye & Abdi, 2016). The groundwater condition at any location in a subsurface depends on the distribution of permeable layers (gravel, sand and fractured rocks) and impermeable or low-permeability layers (e.g., till, clay and solid rocks; Ernstson, 2006; Kirsch, 2006). Tanzania, and in particular the Iringa region, lacks adequate data and information available for the major aquifers (Sangana et al., 2019). Even the available data and information are scattered, fragmented and incomplete. Keeping in mind that the hydrogeological setting of the aquifers varies according to their location and variations in geology, there is a need to understand the exact nature of the hydrogeological conditions. The study explains the favourable geological environments for groundwater potentiality, the geology of Tanzania and that of the Iringa region in particular with groundwater potential and the implication of the geology and geomorphology to groundwater potential.

2.2 Remote Sensing Techniques

Groundwater availability in any terrain is largely controlled by the prevalence and orientation of primary and secondary porosity. Groundwater exploration entails delineation and mapping of different lithological, structural and geomorphological units. Satellite based remote sensing data facilitate the preparation of lithological, structural, and geomorphological maps, especially at a regional scale. These data show major rock groups, structural features, such as folds, faults, lineaments and fractures, and different landforms, due to their synoptic coverage and multispectral capability (Siegal and Gillespie 1980, Drury 1987). Visual interpretation of remote sensing images is achieved in an efficient and effective way using basic interpretation keys or elements (Sabins 1987). An interpretation key comprises combinations of characteristic features to identify objects in an image. Typical key features are size, shape, tone, texture, pattern and color. Similarly, many procedures are available for image data manipulation (Jensen 1986, Lillesand and Kiefer 1994, Drury 1987, Hord 1982, Mather 1987, Schowengerdt 1983). Studies of the spectral reflectance of rock-forming minerals provide the physical basis for the remote determination of earth materials (e.g., Hunt and Salisbury 1970, Hunt 1977, Hunt 1979, Hunt and Ashley 1979, and Goetz et al. 1983). The use of spectral reflectance to improve understanding of the characteristics of rock formations in an image has been practiced in many studies (e.g., Kaufmann 1988, Amos and Greenbaum 1989, Abrams and Hook 1994, Nalbant and Alptekin 1995, Younis et al. 1997).

Lineament analysis of remote sensing data constitutes an important part of studies related to tectonics, engineering, geomorphology and in the exploration of natural resources such as groundwater, petroleum and minerals (e.g., Koopmans 1986, Kar 1994, and Philip 1996). Mapping of lineaments from various remote sensing imagery is a commonly used step in groundwater exploration in hard rock areas. The term hard rock commonly applies to hard and dense rocks that the main part of the groundwater exists and flows in secondary structures, mainly fractures. Crystalline rock types such as meta-volcano-sedimentary, gneiss, meta-igneous and igneous predominate but volcanic rocks are also included in the concept hard rock from a hydrogeological point of view (Olofsson et al. 2001). Lineaments were introduced in a groundwater context by Lattman (1958) and Lattman and Parizek (1964). Since then, many workers followed their example and tried to quantify groundwater resources in hard rocks, based on linear features in various types of maps and remote sensing imagery (e.g., Greenbaum 1987 and 1992, Waters 1990, Mabee et al. 1994, Sander 1996, Koch and Mather 1997). The surface expression of geological structures such as fractures (faults, joints, dykes and veins), shear zones and foliations are often displayed or represented in the form of lineaments in aerial photographs or remote sensing data.

The routine procedure for geological lineament extraction from digital remote sensing data usually involves initial digital image enhancement followed by manual interpretation. There have been significant approaches for the evaluation and automatic detection of lineaments and curvilinear features from satellite images (Cross 1988, Cross and Wadge 1988, Taud and Parrot 1992, Karnieli et al. 1996), but the human expert is still an asset for lineament detection and interpretation with its subjective perception (Suzen and Toprak 1998). The availability of multispectral and multi-sensor data and image enhancement techniques provide an opportunity to prepare more reliable and comprehensive lineament maps. The extensive ground coverage and high resolution of satellite images enables regional and local lineament analysis.

2.3 Hydrogeology of Tanzania

The geology of Tanzania comprises rocks of mainly Precambrian and Phanerozoic formations. The oldest known formations in the country are of Archean age and form predominant granite-greenstone terrains (Borg & Shackleton, 1997; Manya et al., 2006). The central portion of

Tanzania is covered by the Tanzanian Craton (2.5 Ga), which extends to the southern and eastern parts of Lake Victoria (Schlüter, 2008). The main aquifer systems in Tanzania are unconsolidated and consolidated sedimentary rocks and fractured basement rock complexes (Bakari et al., 2012a, 2012b).

The main components of the unconsolidated sedimentary aquifers in Tanzania are the unconsolidated sediments of the alluvial deposits, fluvial deposits, and volcano-pyroclastic sediments (Kashaigili, 2010). The alluvial deposits are largely restricted to the coastal delta areas and along river valleys. Unconsolidated sediments are found close to coastal plain areas and are made up of beach sands, dunes and salt marshes. The occurrence of some consolidated limestone deposits is uncommon (Mjemah & Walraevens, 2015; Van Camp et al., 2013; Walraevens, 2008). Volcano-pyroclastic sediments occur in proximity to previously active volcanoes (Brown & Sparks, 2010).

Due to the varying lithologies in this form of the aquifer system, the borehole yields differ greatly (Kashaigili, 2010). However, the most prospective aspect of the unconsolidated sedimentary aquifer system is found within the volcano-pyroclastic and alluvium deposits of the Kahe Basin and Sanya Plain near Kilimanjaro (Lwimbo et al., 2019a, 2019b). Recorded yields range between 0.2 and 2 L/s (Mlangi & Mulibo, 2018). Although the thickness of unconsolidated aquifers is poorly defined, the depth to the water table falls between 10–20 m. The average depth of boreholes in this system is between 100–200 m (Kashaigili, 2010), and groundwater quality around coastal plain deposits is vulnerable to seawater intrusion (Sappa et al., 2017).

The aquifer thickness varies from 5–30 m, with the surface to water table depth recorded between 10–35 m. The average depth of boreholes in this system generally does not exceed a depth of 80 m (Kashaigili, 2010). The main material components of the Karoo sedimentary aquifer system are sandstones and conglomerates. These materials are characterized by intergranular flow and storage, which are locally improved by secondary fracture permeability. Karoo sedimentary aquifer systems are predominantly unconfined, with recorded borehole yields between 0.1–5 L/s, although yields as high as 15 L/s have been encountered. The thickness of aquifers within this system is similar to that of the coastal aquifer system.

The average aquifer thickness within the basement aquifers is 50 m. There are no significant recorded water quality or quantity issues, although the reported values of fluoride have been as high as 180 mg/L (Kilham & Hecky, 1973). These anomalous zones of fluoride are often found in boreholes situated in proximity to the rift zone as well as the crystalline bedrock and have been interpreted by Davies (2010) as a result of mixing with fluids from hot springs and volcanic gases, which can contain concentrations of fluoride of several tens to hundreds of milligrams per litre. Recharge generally occurs through fracture zones, faults or lineaments

2.4 Geomorphological environmental for groundwater potential

Geomorphology is the study of landforms, their origin and evolution, and the processes that shape them. Geomorphic units are critical in determining the relative groundwater potential of different areas (Rani et al., 2015). The geomorphology of the area influences the quality and availability of groundwater (Ballukraya & Kalimuthu, 2010). It determines the surface flow direction and controls the amount and rate of infiltration (Alsharhan & Rizk, 2020). The geomorphological features that play a great role in groundwater availability and quality include slope, elevation, drainage density, lineament density, soil, land use and land cover (LULC).

Elevation is an important factor in the occurrence of groundwater because weather and climatic conditions vary greatly at different elevations, resulting in differences in soil and vegetation. Slope is defined as the rise or fall of land surface (Al-Abadi et al., 2016) delivered from elevation (Ettazarini & El Jakani, 2020). The slope has a significant impact on the amount of water to be recharged to the aquifer (Rajaveni et al., 2017; Yeh et al., 2009). It controls the amount of water accumulated on the surface, and low slope land has the potential for groundwater availability because precipitation will have more time to stay on the ground and finally percolate into the ground and recharge the saturated zone compared to high slope areas (Yeh et al., 2009). The rate of change of slope is called curvature, or sometimes referred to as slope of the slope (Kimerling et al., 2016) and represents the morphology of the topography.

The curvature is interpreted into three types: total curvature, profile curvature and plan curvature. All these factors have a significant impact on the availability of groundwater. The profile curvature is parallel to the maximum slope direction and primarily affects the acceleration and deceleration of flow across the surface (Al-Abadi et al., 2016). The calculated value of the profile curvature is negative, positive or zero. A negative profile curvature indicates that the surface is upwardly convex. A positive curvature implies that the surface is upwardly concave at that cell. A value of zero indicates that the surface is linear (Lee & Evangelista, 2005; Staley et al., 2006). The plan curvature primarily determines the divergence and convergence of the flow across the surface.

It is always perpendicular to the direction of the maximum slope. During the calculation, a cell is assigned a negative, positive or zero value, which implies that the surface is sideward concave, convex and linear, respectively (Kimerling et al., 2016). The combination of the profile curvature and the plan curvature is called the total curvature and enables us to understand the accurate flow of water on the surface (Al-Abadi et al., 2016; Yeh et al., 2009). Aspect is the orientation of the slope, measured clockwise in degrees from 0° to 360° and indicates where the slope faces at that location. It identifies the downslope direction of the maximum rate of change in value from one raster cell to its neighbours. Aspect has a strong influence on hydrologic processes through evapotranspiration and the direction of frontal precipitation and thus on weathering, vegetation, and root development, particularly in drier environments (Al-Abadi et al., 2016; Dai et al., 2001; Golkarian & Rahmati, 2018).

Drainage density is defined as the total length of the stream per unit area occupied (Dragičević et al., 2018; Yeh et al., 2009). It is an important factor in the identification of suitable areas for groundwater potentiality. Areas with high drainage densities are not suitable for groundwater potentiality. High-level drainage density areas reduce infiltration and increase runoff (Khodaei & Nassery, 2013; Yeh et al., 2009). Drainage density is influenced by geology, soil-water absorption capacity, canopy cover and climate (Khodaei & Nassery, 2013).

Land use/land cover (LULC) generally refers to the categorization or classification of human activities and natural elements on the landscape within a specific time frame based on established scientific and statistical methods of analysis of appropriate source material. These include urban or built-up land, forestland, barren land, and agricultural land. LULC is a significant factor affecting groundwater availability and quality (Rajaveni et al., 2017; Scanlon et al., 2005). It affects groundwater recharge processes, surface runoff, and the infiltration rate (Ghosh & Jana, 2018; Rajaveni et al., 2017; Yeh et al., 2009) and modifies the groundwater chemistry through surface processes (Scanlon et al., 2005).

Lineament is a very important feature in groundwater exploration, especially in crystalline igneous rock (Ballukraya & Kalimuthu, 2010; Mseli et al., 2021; Saraf & Choudhury, 1998). They are defined as mappable, simple or composite linear features of a surface, whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differ distinctly from the patterns of adjacent features and presumably reflect a subsurface phenomenon (Khodaei & Nassery, 2013). They are characterized by a length greater than 300 m, and those whose length is longer than 10 km have the potential for groundwater, as joints and faults serve as conduits for the movement of groundwater (Saraf & Choudhury, 1998; Teeuw, 1995). Lineament, such as faults and other deeper fractures, can cause an interchange between the surface and groundwater (Yeh et al., 2009). Studying the lineament in an area can be done using both image and nonimage data, where image analysis is the best due to oblique constant illumination, suppression of spatial detail and regional coverage (Waters et al., 1990). Lineament density is obtained by dividing the lineament length by the catchment area. Areas with high lineament density are favoured for groundwater potentiality (Mdee & Tembo, 2021).

Groundwater potential is heavily influenced by soil texture. Soil texture directly affects infiltration, aquifer conditions (Pal et al., 2020) and runoff (Chakrabortty et al., 2018). Permeability and porosity vary significantly with the soil texture (soil texture directly influences the infiltration rate as the porosity and permeability vary with the texture (Das & Pal, 2019). In comparison to fine-grained soil, coarse-grained soil has a higher infiltration capacity based on porosity and permeability (Pal et al., 2020).

2.5 Climate change

Climate change can have significant on groundwater resources, it can lead to change in precipitation patterns, including increased frequency and intensity of extreme weather events such as droughts. These changes can affect the recharge of groundwater aquifers, which are replenished by rainfall and percolation. Droughts can reduce the amount of water infiltrating into the ground, leading to decreased groundwater recharge, while intense rainfall events can result in rapid runoff, limiting the amount of water that can recharge the aquifer.

According to Intergovernmental Panel on Climate Change (IPCC) (2013), climate change has the potential to degrade groundwater availability, water quality, and water supplies. The majority of current studies concentrate on surface water resources focusing water quality and quantity. However, the analysis of groundwater resource is much more needed especially amidst the presence of climate change and variability in order to sustainably balance the recharge and abstraction of the available groundwater resource.

In Sub-Saharan Africa, a large population lacks the accessibility to clean water and is more vulnerable to the anticipated changes and variability in climate. For rural populations and many growing cities, groundwater is the primary supply of clean drinking water, and often the only source of water in dry lands. Groundwater resource exploration is rising quickly in Africa and is obviously featured in national development plans, particularly to meet the demand for improved access to safe water and agricultural intensification in the face of fast-growing populations and economic development. Therefore, proper planning of such a scarce water resource in terms of storage, allocation, return flow and environmental services are vital for optimization of the resource.

The mean values of climatic variables have been projected to change, especially temperature increase in the dry areas and decrease in wet areas. These have implications on both groundwater quality and quantity. In recent times, groundwater resources have more competitive advantages than other water resources because in most of the areas, groundwater resource is used as adaptation measures to climate variability and change. Additionally, groundwater has sustainability potential over surface water due to its relatively lower exposure to pollution and in most cases complex reservoir can exist throughout the year. In a similar vein, the impact of climate change on groundwater has been observed in the resident time of the groundwater recharge, which ranges from days to tens of thousands of years. The prolonged resident time delays and disperses the effects of climate and challenges efforts to detect responses in the groundwater to climate variability and change. However, renewable groundwater is directly tied to near-surface hydrologic processes; the hydrologic cycle could be directly affected by climatic change.

In Tanzania, heterogeneous climate condition is experienced due to the complicated topography, numerous inland water bodies, variation in vegetation types and land-ocean contrasts (Kijazi & Reason, 2009). This complexity leads to a variety of climate among different areas even within a relatively small distance, depending on the sensitivity of the hydrological response and processes towards the different geophysical feature of the area . The country's populace relies on both surface water and groundwater resources for water supply. However, in semi-arid locations, groundwater is the primary source of water due to the limited availability of surface water. In these areas, groundwater account for about 60 to 80% of water supply to the population for domestic and agriculture uses. Despite the importance of groundwater resource in semi-arid areas, limited information is available on the recharge amount and potential recharge zones. This presents substantial challenge in the management of the groundwater resource.

2.6 Geographic Information Systems

The full potential of remote sensing and GIS can be utilized when an integrated approach is adopted. Integration of the two technologies has proven to be an efficient tool in groundwater studies (Krishnamurthy et. al 1996, Sander 1996, Kamaraju et. al 1996, Saraf and Choudhury

1998). For effective groundwater exploration and exploitation, it is important to study the different parameters in an integrated approach. The integration of multiple data sets, with various indications of groundwater availability, can decrease the uncertainty and lead to 'safer' decisions (Sander 1996). The Geographic information system offers spatial data management and analysis tools that can assist users in organizing, storing, editing, analysing, and displaying positional and attribute information about geographical data (Burrough 1986). Remote sensing data provide accurate spatial information and can be economically utilized over conventional methods of hydrogeological surveys. Digital enhancement of satellite data results in extraction of maximum information and an increased interpretability. GIS techniques facilitate integration and analysis of large volumes of data. Whereas field studies help to validate results further. Integrating all these approaches can offer a better understanding of groundwater controlling features in hard rock aquifers.

CHAPTER THREE
METHODOLOGY

Geographic Information System and remote sensing were used in this study to map groundwater potential zones by examining analytical hierarchy process. Totally eleven thematic layers including lithology, slope, drainage density, landcover/land use, lineament density, rainfall, soil depth, curvature, Topographic Wetness Index (TWI), Topographic Position Index (TPI), and roughness were generated and weighted considering the expert ideas and previous literature. For this researchh numerous spatial data sets shown on (Table 3.1), have been utilized to analyse probable potential zones of groundwater.

3.1 Data collection

Three kinds of data were used in this research;

i. Satellite imagery data
ii. Conventional data
iii. Climate data

3.1.1 Satellite imagery data

Two types of remote sensing data were utilized;

- A digital elevation model (DEM) with a 30 m resolution was obtained from Shuttle Radar Topography Mission (SRTM)
- A satellite image of Landsat 8/9 ETM+ covering study area, was downloaded from the USGS explorer website

(a) Digital Elevation Model (DEM)

The Shuttle Radar Topography Mission (SRT) obtained elevation data of a near-global scale to generate the most complete high-resolution digital topography thematic layers. A digital elevation model with 30m resolution was downloaded from USGS EarthExplorer. SRTM digital elevation model that cover the whole area of interest was pre-processed using GIS soft-wares to remove any inconsistencies. This involve filling data voids correcting elevation errors and filtering noise in the elevation data. Various terrain parameters were derived from the SRTM digital elevation model that are relevant to groundwater potential. Commonly used parameters include slope, curvature, drainage density, elevation, roughness, Topographic Wetness Index, and Topographic Position Index. All parameters were derived using GIS software with the support of hydrological modelling tools.

(b) Satellite images

The two Landsat 8/9 ETM images with 30m resolution covering a whole study area, were downloaded from USGS EarthExplorer. The satellite images registration, correction (geometric and atmospheric) and other image preprocessing and processing (such as enhancement, filtering, classifications, resolution merge), of the relevant area were applied. These image scenes after merged and then reprojected band-wise using RStudio software prior to classification. Reprojection involved transforming and rectifying the image to a standard Universal Transverse Mercator projection system. Images classification with true color composite was performed to prepare LULC.

Images Processing

Two digital images of the Landsat TM and ETM+ were acquired for this study but only with cloud cover less than 30% were utilized. Ruaha national park, comprises of two Landsat image scenes for its entire coverage, only these two images 2022 were used. Digital image composed 11 bands, but in classification of land cover features required combining together band 2, 5, and 7. Image layer stacking were conducted using RStudio software to obtained the stacked images which were merged together. After images merged, the study area was extracted by masking the two merged images using study area boundary. Then, using RStudio software image classification was performed in order to classify different land cover features.

3.1.2 Conventional data

Two types of conventional data were used in this study;

- Geological data of the study area was obtained from Geological Survey of Tanzania (GST)
- Soil data also was obtained from Geological Survey of Tanzania

(a) Geological data

Lithology of an area is the most critical factor while considering groundwater potential zones, as rock porosity and permeability have direct impact on groundwater movement and availability. Lithological thematic layer of the study area was prepared from geological map, lithological layer was processed and reclassified for analysis in using ArcGis 10.8.

(b) Soil data

Soil type is another important control factor on groundwater potential, play an important role on the amount of water that can infiltrate into the subsurface formations and hence influence groundwater recharge. The soil texture and hydraulic characteristics are the main factors considered for estimation of rate of infiltration. Preparation of soil type thematic map was carried out in ArcGIS software.

3.1.3 Climatic data

The climatic data used for determination of groundwater potential zones was rainfall distribution in the study area. Rainfall is the major water source in the hydrological cycle and the most dominant influencing factor in the groundwater of an area. Rainfall data of the study area was downloaded from TerraClimate data source with spatial resolution 4km for 4 years between 2018 to 2022 through RStudio software. An average annual rainfall data was downloaded in raster format, the rainfall map of the study area was generated and resampled as raster in ArcGIS Desktop.

3.2 Description of the study area

Ruaha National Park chosen for this study and it is located in western of Tanzania in Iringa region, where the climate is semi-arid and arid and small portion found in Mbeya region as shown on (Figure 3.1). The total area square is 20,226km^2. The park consists number of reserves includes Rungwa Game Reserve, the Kizigo and Muhesi Game Reserves, and the Mbomipa Wildlife Management Area.

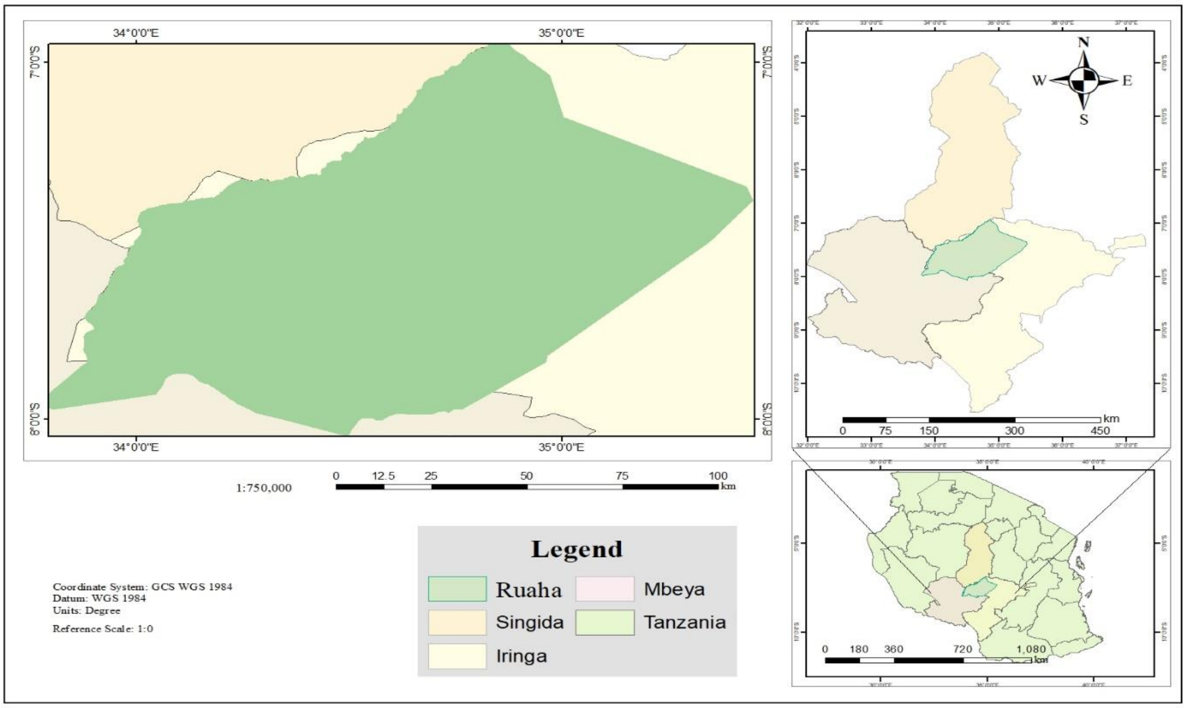

Figure 3.1: The methodology workflow

The workflow that indicates the process and the techniques undertaken throughout the research as shown on (Figure 3.2).

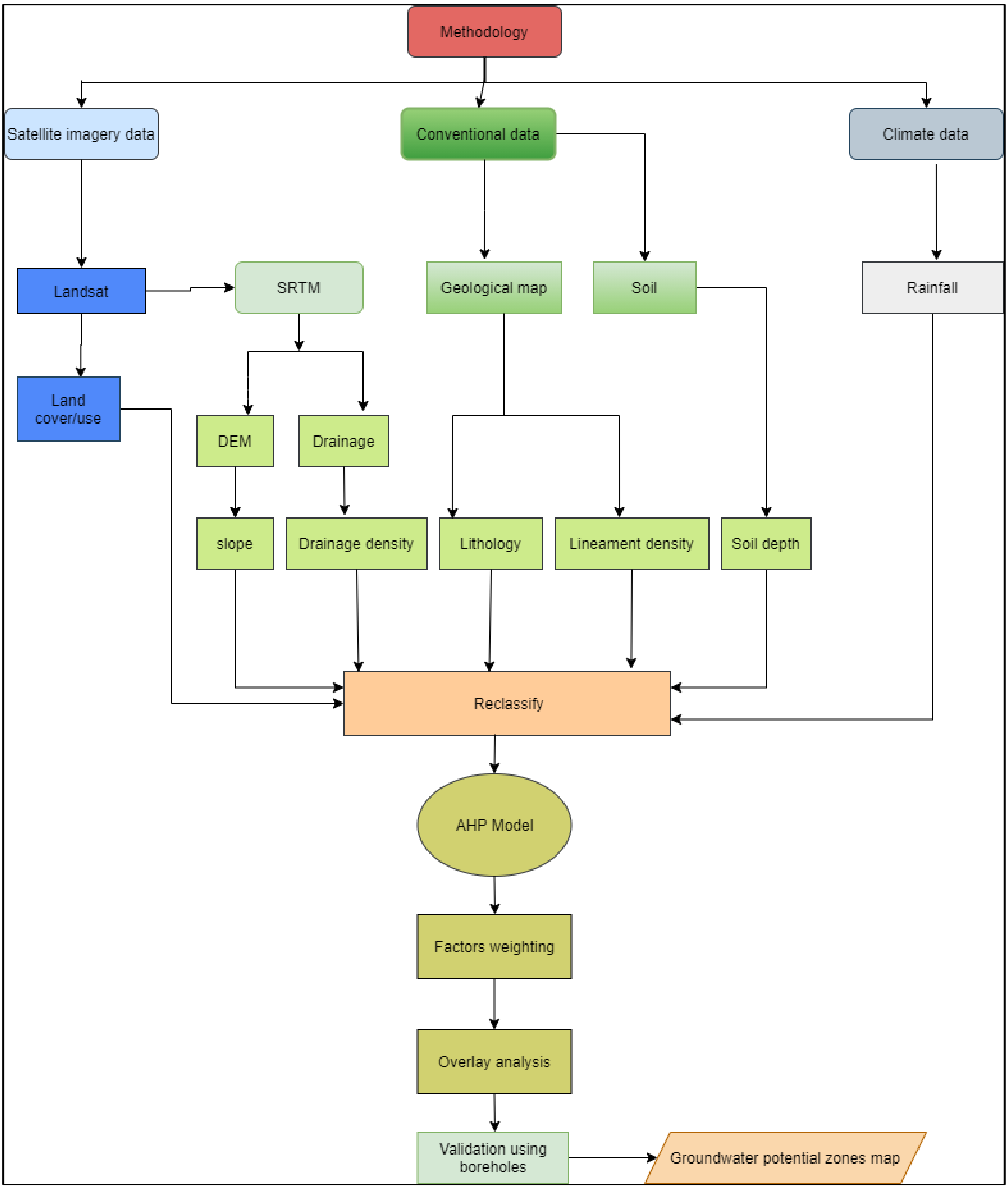

Figure 3.2: The methodology flow chart

The potential zones of groundwater were obtained by overlaying all thematic layers based on weighted overlay method. Weighted overlay index analysis was carried out to give rank for each parameter of each thematic layer.

The weight was given for each thematic layer depending on the Analytic hierarchy process (AHP) technique. These thematic layers were then subjected to a weighted overlay analysis and the final resulting map is acquired and classified based on the groundwater potential index determined.

Table 3.1: The table shows the data that were used in this study

S/No.	Data used	Parameters	Sources	Application
1.	Geological data	Lithology, Lineament density	Geological Survey of Tanzania	Calculate groundwater potential zones
2	Soil data	Soil type	Geological survey of Tanzania	Calculate groundwater potential zones
3	Landsat images	Land cover/use	USGS EarthExplorer	Calculate groundwater potential
4	SRTM Digital Elevation Model	Slope, drainage density, roughness, curvature, TWI, TPI, elevation.	USGS EarthExplorer	Calculate groundwater potential
5	Climate data	Rainfall distribution	TerraClimate	Calculate groundwater potential
6	Administrative boundary	Location map with boundary	DIVA GIS	Boundary preparation of area of interest

3.3 Data Development for Parameters Related to Groundwater Potential

Several thematic layers that favour the groundwater occurrence have been combined and a groundwater potential map has been prepared in GIS software. In the in study, eleven criteria geology, lineament density, slope, soil depth, rainfall, drainage density, Topographic Wetness Index (TWI), Topographic Position Index (TPI), roughness, curvature and LULC were considered to assess potential groundwater zones in the area. The RS and GIS techniques were employed to prepare different thematic layers which are discussed as follows.

3.3.1 Drainage Density

Drainage density indicates the closeness of spacing of stream channels and can be calculated as the total length of all the streams and rivers in the park divided by the total area of drainage. The drainage density has an inverse relationship with groundwater prospect. The higher the drainage density is the lower the probability of groundwater potential zone. Hence, the kernel density method in Arc GIS has been carried out to calculate drainage density. The drainage network within the area was extracted from the DEM and updated from the satellite image. Hence, the kernel density method in Arc GIS has been carried out to calculate drainage density using formulae (1) as given below (Singh et al 2007). The map (Figure 3.2) shows that most of the study area is covered by moderate to low drainage density that refers to more infiltration and recharge to the groundwater.

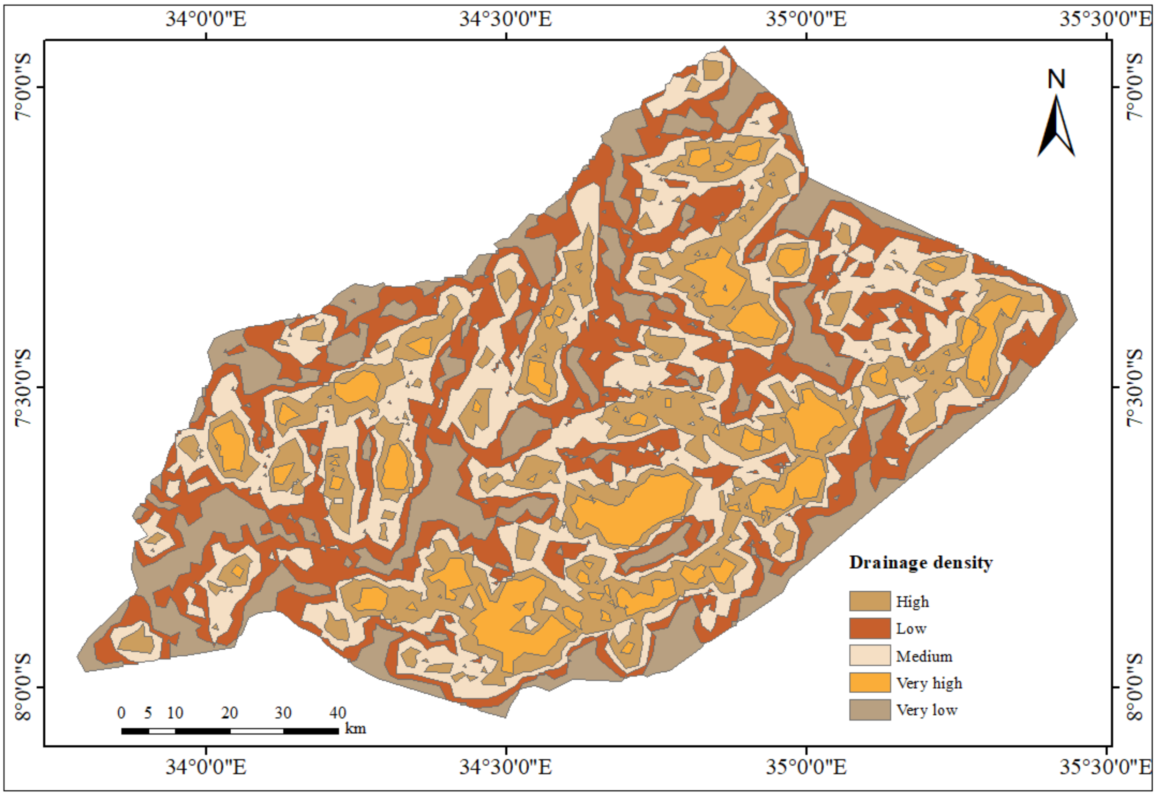

Figure 3.3: Drainage density

$$DD = \Sigma \frac{LWS}{AWS} \qquad (1)$$

where DD is the drainage density, LWS is the total length of streams in the park, and AWS is the area of a park.

3.3.2 Lineament Density

A lineament is a linear feature in a geographical landscape that is a manifestation of fundamental geological structure. The lineament density was defined as the total length of all the recorded lineaments divided by the area under consideration. The lineament density map of Ruaha national park as shown on (Figure 3.3) was prepared by using the line feature collected from the Geological data of Tanzania. The present study used lineament density, which represents the total length of lineament as a unit area, as expressed on the equation (2) below according to Singh et al (2007)

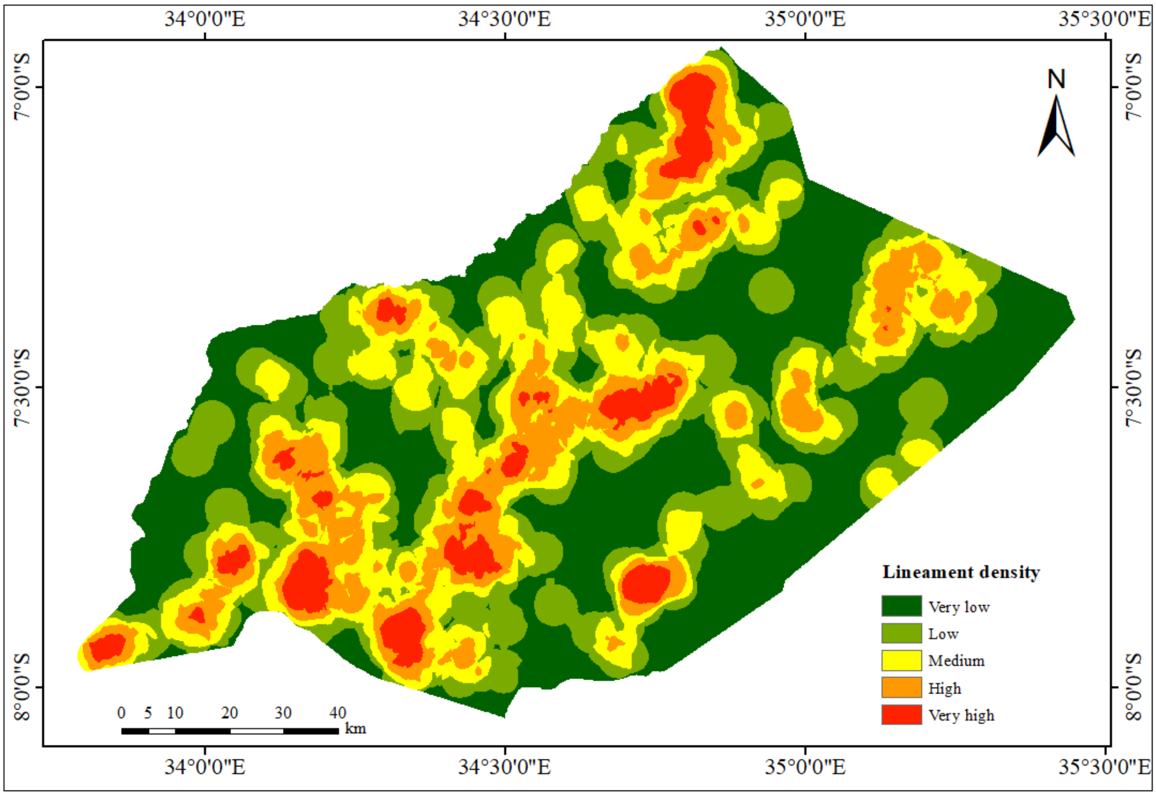

Figure 3.4: Lineament density

$$Ld = \frac{\sum_{i=1}^{i=n} Li}{A} \qquad (2)$$

Where $\sum_{i=1}^{i=n} Li$ denotes the total length of lineaments and A denotes the unit area

Lineament density is directly proportional to the groundwater recharge zone. The purpose of the lineament analysis is to improve understanding of the relationship between the surface water penetration and fracture systems, controlling water infiltration and mobility. The lineament density map shows that the upper, middle and lower part of the studied area was considered an excellent and promising groundwater zone.

3.3.3 Slope

The amount of water available for recharge and the ruggedness of the terrain of any area is described by the slope of that areas. A large volume of runoff and lower infiltration are related to regions with steep angles of elevation.

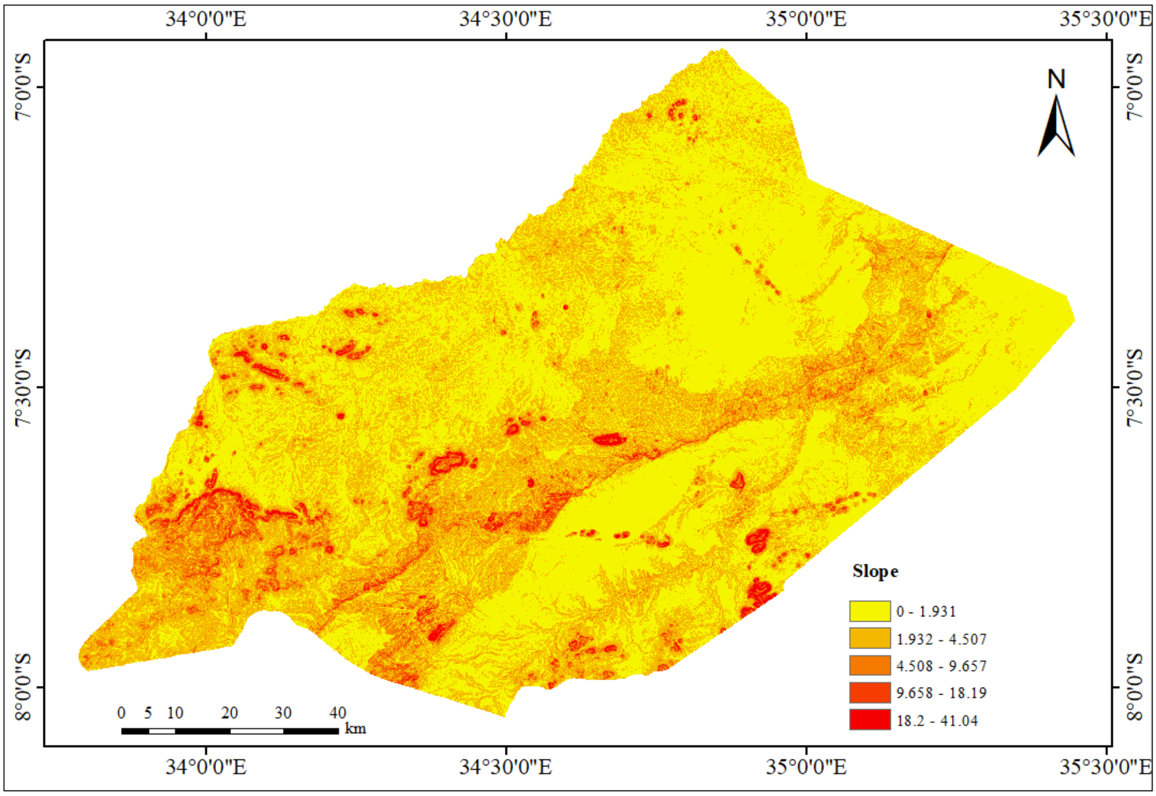

Figure 3.5: Slope

Hence, slope is one of the influential factors affecting runoff and infiltration rate. The slope of the present study was developed from SRTM DEM. Weights for each slope class were assigned based on the level of groundwater potential. For the effect of assigning ranks, the slope of the region is categorized into five categories. The highest rating was assigned to the flat terrain with a slope value 0–1.931, and the ratings were gradually decreased as the slope value increased as shown on (Figure 3.4). The steeper slope value ranging from 18.19–41.04 with the lowest rating of 1.931 was found in the upper and lower escarpment part of the study area.

3.3.4 Land Use Land Cover

Land use land cover (LULC) is an important factor affecting groundwater recharge, groundwater occurrence, and availability. LULC map data was derived from the Landsat 8 (OLI) satellite image of 2022 with 30- m spatial resolution. Supervised image classification was conducted to classify and identify the type of LULC. The study area consists of four types of LULC (Figure 3.5), namely; water, vegetation, forest, and bare land One of the dominant land use/land cover categories in the study area is vegetation land followed by bare land. Vegetation land is considered to be the most suitable zone for recharge as it favors the percolation of rainwater.

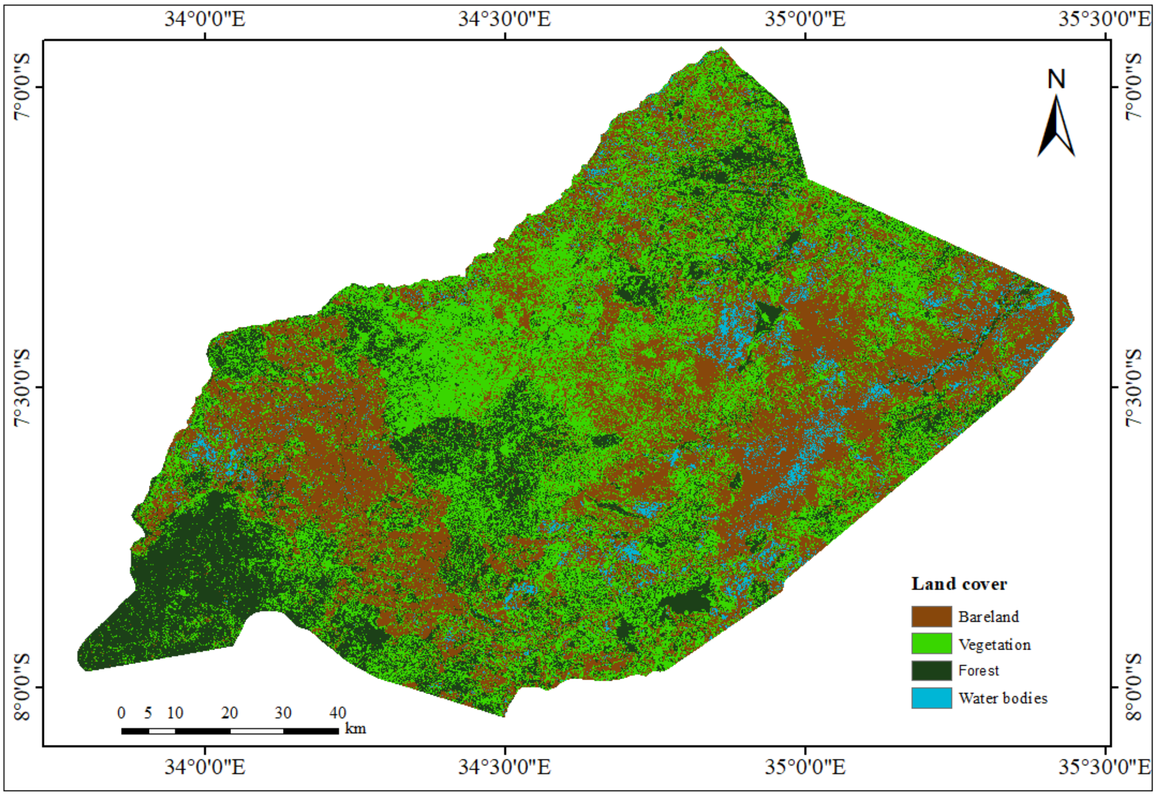

Figure 3.6: Land cover

3.3.5 Soil

Soil types of the area are playing a significant role in groundwater recharge and water holding capacity of the area. Consequently, it could be considered as one of the important factors for the delineation of groundwater potential zones. The major soils found in the study area are Ferralic cambisols, Chromic Cambisols, Eutric Leptosols, Eutric Fluvisols, and Haplic

Solonetz as shown on (Figure 3.6). Weights are assigned subjectively to each soil unit after taking into consideration the type of soil and its water holding capacity.

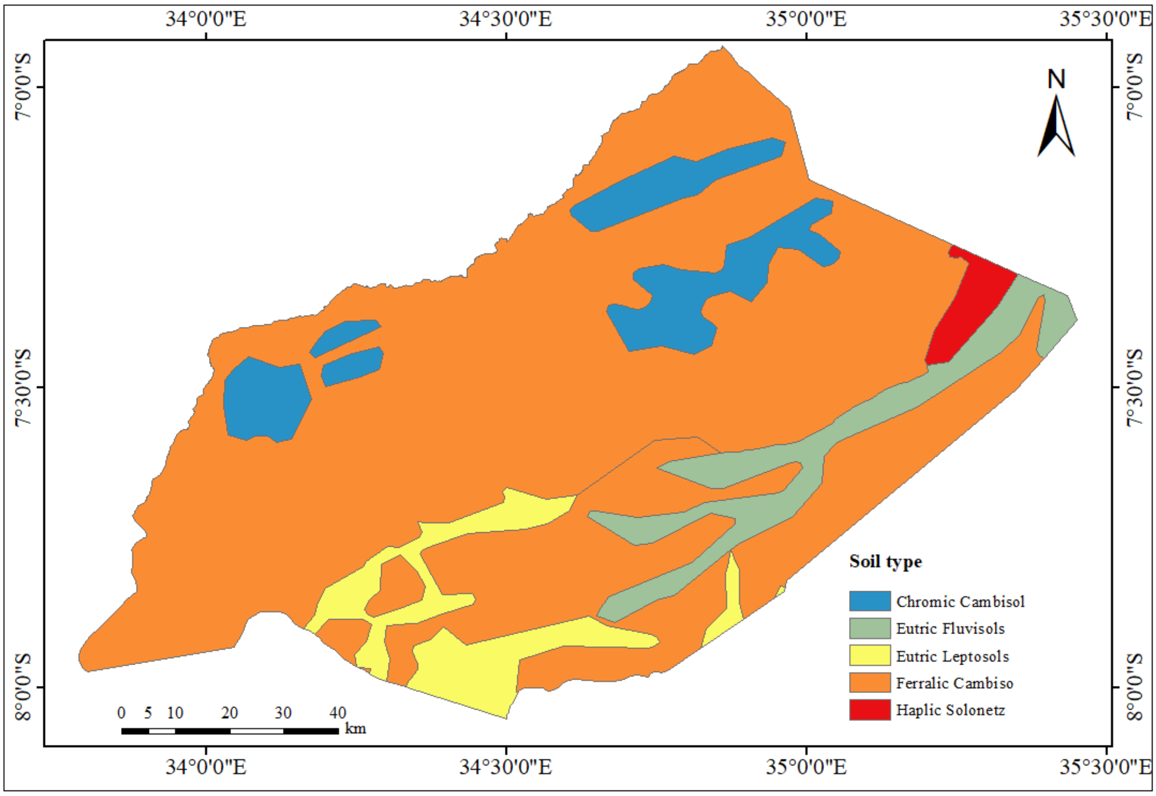

Figure 3.7: Soil type

3.3.6 Rainfall

Rainfall is an important parameter to delineate groundwater potential and major hydrological sources of groundwater storage. About 85% of the rainfall falls during the rainy season (May to October). The amount of rainfall is higher in the lower part of the study area and decreased toward the Eastern part (Figure3.7). The rainfall map for the study area was classified into five categories having maximum and minimum rainfall as 63.72 and 98.80 mm, respectively. The highest rating was assigned to the Southern (lower escarpment of the park) areas receiving the highest rainfall, whereas the rainfall magnitude was found decreasing toward the Eastern escarpment of the park and the rating thus assigned also decreased toward the Eastern direction (lower escarpment of the watershed).

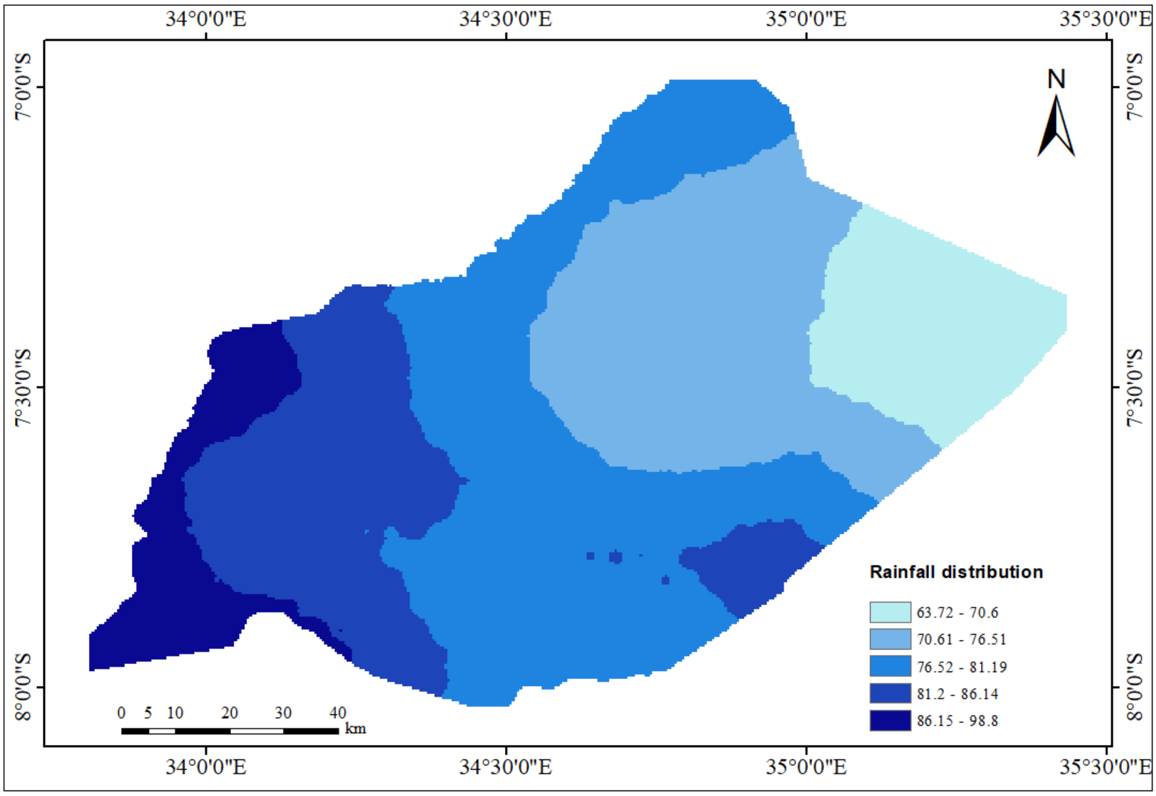

Figure 3.8: Rainfall distribution

3.3.7 Lithology

Groundwater potential is highly determined by the occurrences of lithological features. The lithological features of the study area consist of Felsic igneous rocks, Fine clastic sediments, Granites, Granitoids, migmatite Mafic dykes, Meta-igneous, Meta-sedimentary, Sandy, Gravelly and slity sediments (Figure 3.8). Fine clastic sediments are compact and insignificant in terms of permeability and porosity. A major part of the study area is covered by sandy, gravelly and silty sediments. The weightage of lithology is assigned based on mineral, alteration, fractures, and weather conditions.

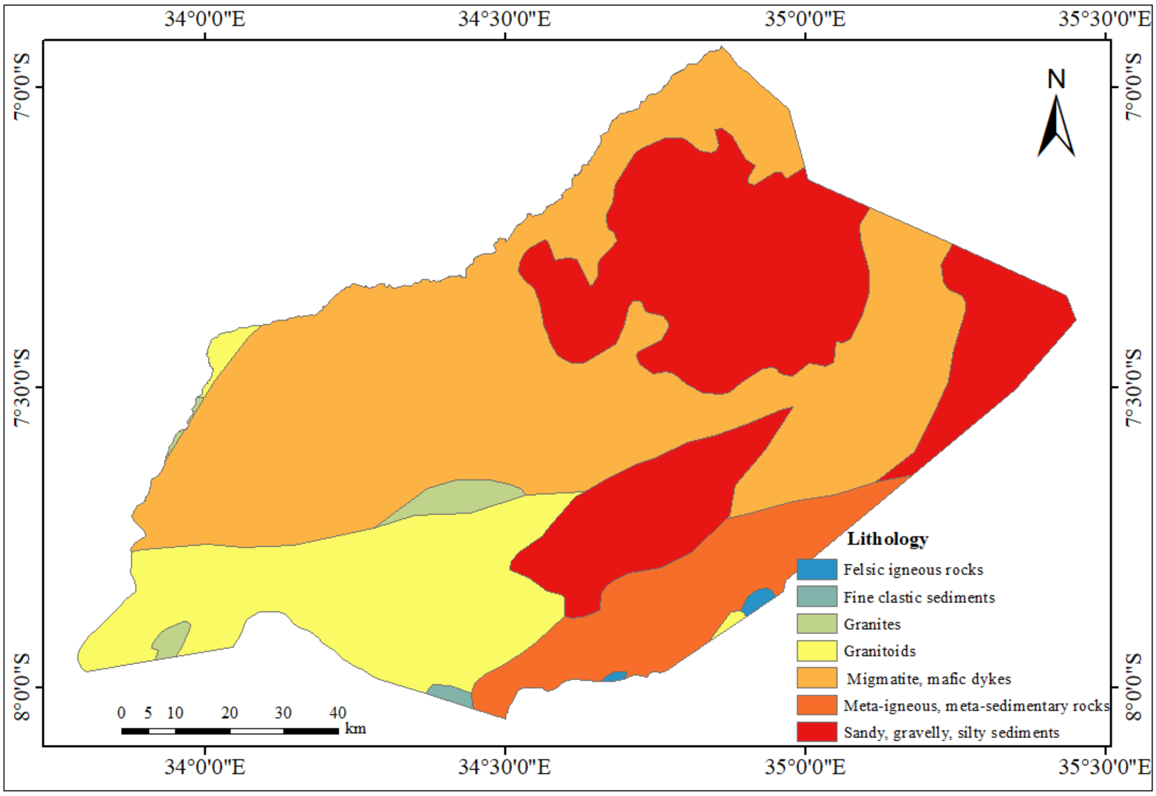

Figure 3.9: Lithology

3.3.8 Curvature

Intuitively, the curvature is the amount by which a curve deviates from being a straight line, or a surface deviate from being plane. Curvature is a topographical-based factor, which shows the direction flow and clarifies at which rate the slope changes in the maximum slope direction. For the present study Curvature was generated from DEM as presented in (Figure 3.9).

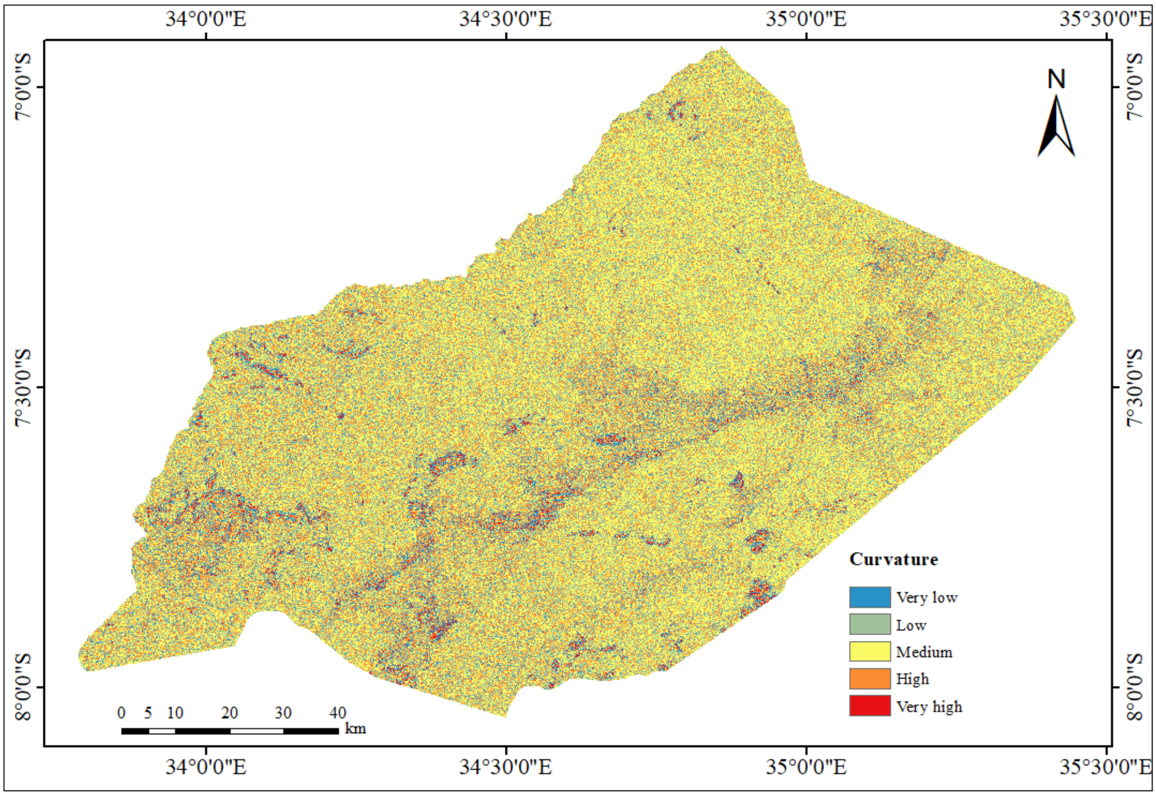

Figure 3.10: Curvature

3.3.9 Topographic Wetness Index (TWI)

Topographic Wetness Index (TWI) (Figure 3.10) plays a significant role in the hydrogeological system. TWI can explain the effect of topographic conditions on the size and location of saturated sources of surface runoff generation. Many researchers have been used TWI as a parameter to delineate the groundwater potential zones.

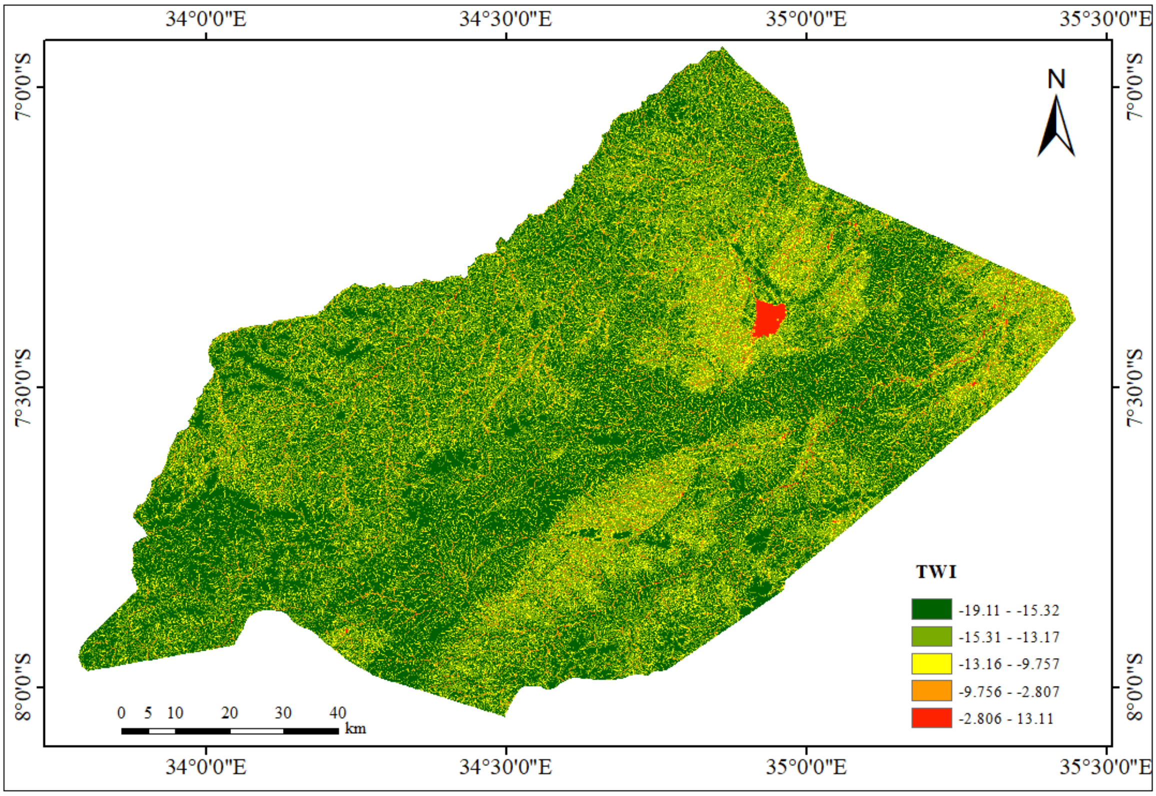

Figure 3.11: Topographic Wetness Index (TWI) map

The secondary topographic factor, TWI was calculated using the equation (3) (Naghibi et al 2017).

$$TWI = ln\left(\frac{AS}{tan\,\beta}\right) \qquad (3)$$

where AS and tan β are the specific catchment area and the slope angle at the point, respectively. In the present study, TWI was classified into five classes.

3.3.10 Topographic Position Index (TPI)

Topographic Position Index (TPI). Topographic position index (TPI) is an algorithm which is widely used to measure topographic slope positions and to automate landform classifications. Many physical processes such as hilltop, valley bottom, exposed ridges, flat plain, upper and lower slope actions on landscape are correlated with topographic position index. Equation (4) given below was used for the estimation of TPI (Kumar et al 2015).

$$TPI = \frac{M_o - \Sigma_{n-1} M_n}{n} \qquad (4)$$

Where, Mo - elevation of the model point under evaluation, Mn - elevation of grid, n - the total number of surrounding points employed in the evaluation. TPI ranges varied from -174.34 to 362.69 in the study area. TPI values zero indicate the flat ground surface. The high weights assigned for low TPI value and vice versa. Figure 3.11 shows the TPI map of theRuaha park.

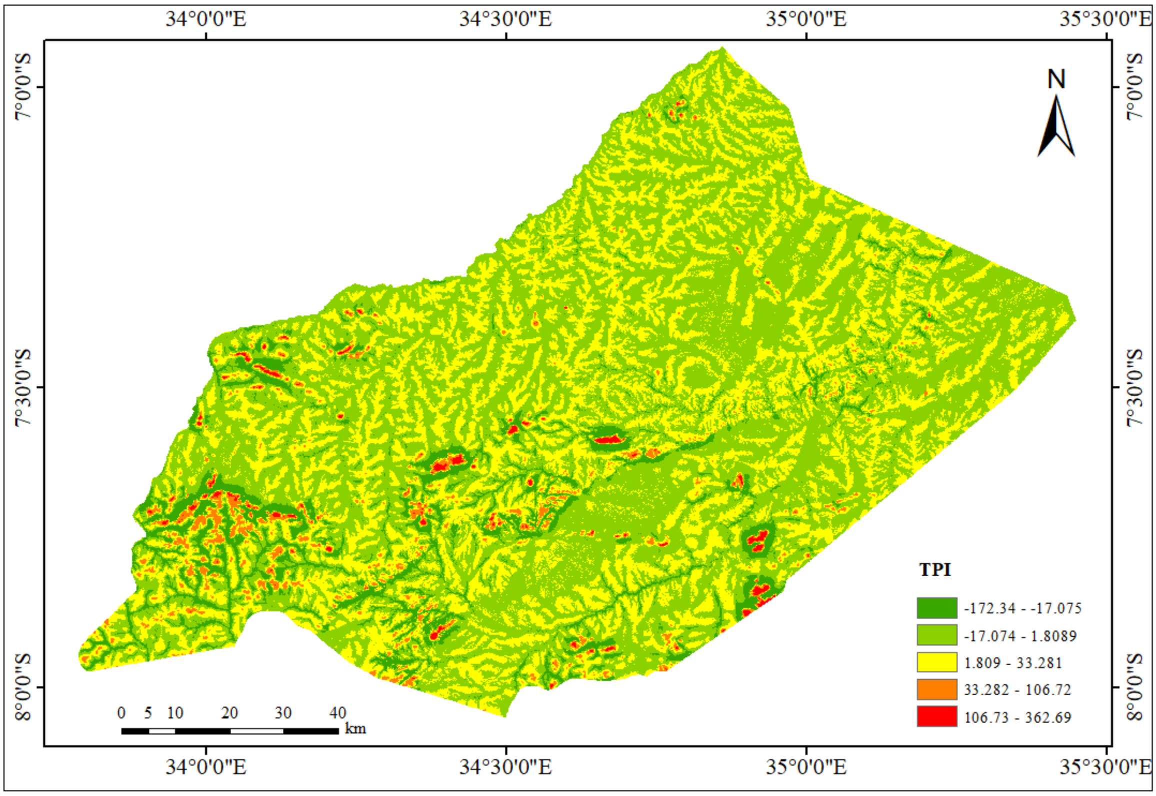

Figure 3.12: Topographic Position Index (TPI) map

3.3.11 Roughness

The roughness index expresses the amount of elevation difference between adjacent cells of a digital elevation model (DEM). Roughness index generally expresses the undulation of the topography. Higher the roughness, more the undulation and vice versa. Undulated topography is characteristic of a mountainous region where weathering and erosion processes continuously modify the landscape of a rugged into a smooth and plane surface in long run. The values varied from 0.1111 to 0.8889 as expressed on (Figure 3.12). The values were reclassified into five categories; 0.1111–0.3807, 0.3807–0.4576, 0.4577–0.5262, 0.5263–0.6048 and 0.6049–0.8889. The high weights are assigned for low roughness value and vice versa.

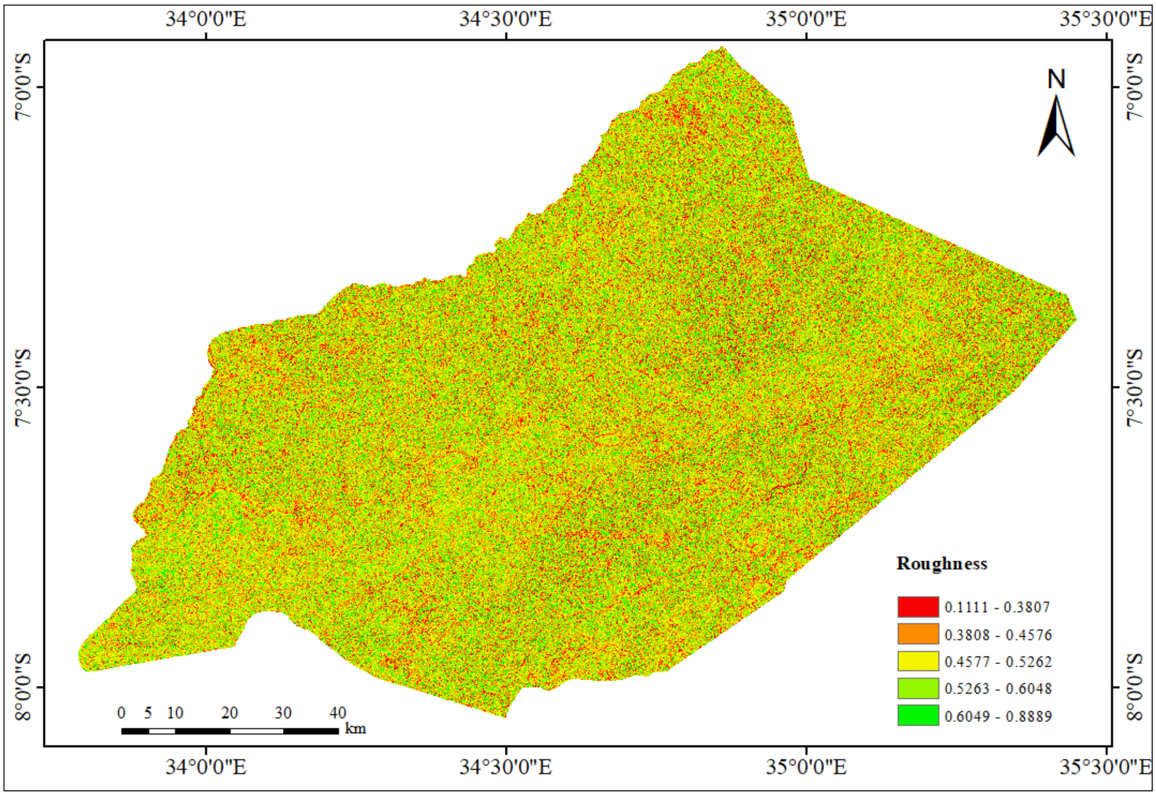

Figure 3.13: Roughness map

3.4 Generation of Weight for Groundwater Prospecting Parameters

The weight for each factor was assigned based on the influence or impacts on the availability of groundwater. They have different impacts on the occurrence of groundwater, and weights were assigned using multi-criteria decision analysis method.

3.4.1 Multi criteria decision analysis using GIS techniques

Multi criteria decision analysis using Analytical Hierarchical Process (AHP) is the most common and well-known GIS based method for delineating groundwater potential zones. This method helps integrating all thematic layers. A total of 11 ddifferent thematic layers were considered for this study. These 11 thematic layers are supposed to control factor of flow and storage of water in the area. The association of these influencing factors are weighted according to their reaction for groundwater occurrence and expert opinion. A parameter with a high weight illustrates a layer with high impact and a parameter with a low weight illustrates a small impact on groundwater potential. The weightages of each parameter were assigned according to Saaty's scale (1–9) of relative importance value as expressed on (Table 3.2). Further, the weights were assigned with consideration of the review of past studies and field experience.

Table 3.2: The Saaty's 1–9 scale of relative importance shown on table below

Scale	Importance
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong plus
6	Strong importance
7	Very strong importance
8	Very, very importance
9	Extreme importance

3.4.2 Analytical Hierarchical Process (AHP)

Analytical hierarchical process (AHP) model is one of a multicriteria decision-making (MCDM) tool used to provide solutions for complicated decision-making problems. AHP is a widely accepted model used to assign a normalized weight for each thematic layer of groundwater prospecting factor. As per the classification, weights are assigned to the thematic layers based on their importance and water holding capacity. Accordingly, all the thematic layers have been compared with each other in a pair - wise comparison matrix. The sub – classes of thematic layers were re - classified using natural breaks classification method in GIS platform for assigning weight. The sub - classes of each thematic layer rank was allocated on a scale of 0 to 9, according to their relative influence on the groundwater development The final weight of each thematic layer was generated from the principal Eigenvalue of the generated matrix. The reliability of the output was determined by the calculated consistency index (CI) and consistency ratio (CR) values. The formula (5) below has been used (Saaty et al 1980)

$$CR = \frac{CI}{RI} \tag{5}$$

Where CR indicates consistency ratio, RI indicates random consistency index whose values depend on the order of the matrix (Table 4.2), and CI indicates consistency index which can also be calculated using the formula (6) (Saaty et al 1980)

$$CI = \frac{\lambda \max - n}{n-1} \tag{6}$$

where λ indicates the principal eigenvalue of the matrix and n is the number groundwater prospecting factors. Saaty has opined that the value of CR must be <0.1, If the consistency value is greater than 0.10, then there is a need to revise the judgment to locate causes of inconsistency and correct it accordingly. If the CR value is 0; it means that there is a perfect level of consistency in the pair – wise comparison matrix. To determine the weight of each conditioning factor of prospecting parameters. The conditioning factors were compared against each other through a pairwise comparison matrix. The inverse ranking method has been adopted to assign a normalized weight for each thematic layer. The potential of groundwater is represented by the rating of 1–5, where 1, 2, 3, 4, and 5 for very low, low, medium, high, and very high.

3.5 Groundwater Potential Index (GPI)

The groundwater recharge potential map was generated by considering the comparative importance of various thematic layers and their corresponding classes. GWPI, a dimensionless quantitative approach was adopted to delineate groundwater potential zone. Considering all the themes of and features in an integrated layer, the groundwater potential index is calculated using equation below (Kumar et al 2015);

$$GPZ = \sum_{1}^{n} (x_A \cdot y_B) \tag{7}$$

[where GPZ=Groundwater Potential Zone, X- represents the weight of the thematic layers; Y - represent rank of the thematic layers' sub – class. The A term (A=1, 2, 3, ……, X) represents the thematic map and B term (B=1, 2, 3, ……, Y) represents the thematic map classes].

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Weight Assigning and Normalization

In the present study, 11 groundwater conditioning factors were identified and classified based on expert opinion and literatures. To determine the weight of each conditioning factor, the weights were assigned with consideration of the review of past studies and field experience.

Using AHP model, the pairwise comparison matrix was prepared to obtain the final geometric mean for each factor, and feature normalized weight of each conditioning factor was presented on normalized comparison matrix table.

As suggested by Saaty (1987), the following step-by-step procedures were used to assign relative weights factors for elements;

- The relative importance of a value ranging from 1 to 9 as shown on Table 3.2 were assigned to each factor to construct the pairwise comparison matrix (Table 4.1).
- Next, the normalized pair-wise comparison matrix table (Table 4.4) were prepared by dividing each value in the column in the pairwise comparison matrix by the sum of the column.
- Then, the weight of each criterion/factor were computed by dividing the sum of each row in the normalized pairwise comparison matrix table by the number of factors.
- The principal Eigenvalue of matrix (λ) were obtained from result of consistency ratio (Table 4.5) by dividing weighted sum of each row by criteria weight value of each factor.

The AHP model contains the determination of required criteria, pairwise comparison and matrices preparation, determining relative weights using Eigenvalue technique, calculating consistency ratio of model, and final decision-making. The influence and importance of each factor are defined by making a pairwise comparison matrix as illustrated by the (Table 4.1)

Table 4.1: The pairwise comparison matrix of 10 groundwater prospecting factors for the AHP mode;

Layer	Assigned Weight	Lt	Ld	Dd	Rf	So	Sl	TWI	Cu	LULC	TPI	Ro	Geometric mean
Lt	6.00	1.00	1.00	1.20	1.20	1.00	1.20	1.50	2.00	0.86	2.00	2.00	1.36
Ld	6.00	1.00	1.00	1.20	1.20	1.00	1.20	1.50	2.00	0.86	2.00	2.00	1.39
Dd	5.00	0.83	0.83	1.00	1.00	0.83	1.00	1.25	1.67	0.71	1.67	1.67	1.13
Rf	5.00	0.83	0.83	1.00	1.00	0.83	1.00	1.25	1.67	0.71	1.67	1.67	1.13
So	6.00	1.00	1.00	1.20	1.20	1.00	1.20	1.50	2.00	0.86	2.00	2.00	1.36
Sl	5.00	0.83	0.83	1.00	1.00	0.83	1.00	1.25	1.67	0.71	1.67	1.67	1.13
TWI	4.00	0.67	0.67	0.80	0.80	0.67	0.80	1.00	1.33	0.57	1.33	1.33	0.91
Cu	3.00	0.50	0.50	0.60	0.60	0.50	0.60	0.75	1.00	0.43	1.00	1.00	0.68
LULC	7.00	1.70	1.70	1.40	1.40	1.17	1.40	1.75	2.33	1.00	2.33	2.33	1.59
TPI	3.00	0.50	0.50	0.60	0.60	0.50	0.60	0.75	1.00	0.43	1.00	1.00	0.68
Ro	3.00	0.50	0.50	0.60	0.75	0.50	0.60	0.75	1.00	0.43	1.00	1.00	0.69
Sum		8.83	8.83	10.60	11.05	8.83	10.60	13.25	17.67	7.57	17.67		12.05

Lt: Lithology; Dd: Drainage density; Ld: Lineament density; Rf: Rainfall; So: Soil; Sl: Slope; TWI: Topographic Wetness Index; Cu: Curvature; LULC: Land use/ land cover; TPI: topographic Position Index; Ro: Roughness.

Once the weight assigned, it is required to calculate consistency of the matrix, it is judged by the Consistency Ratio (CR) from equation (5):

$$CR = \frac{CI}{RI}$$

Where, CR is consistency ratio, CI is consistency index, RI is random index which is taken from the table of Saaty's ratio index for different values of N as shown on (Table 4.2).

Table 4.2 Table of Saaty's ratio index:

Order of the matrix												
N	1	2	3	4	5	6	7	8	9	10	11	12
RI value	0.00	0.00	0.58	0.98	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

Table 4.3: Categorization of factors influencing of Groundwater Potential Zones;

Influencing factor	Feature	Assigned rank	Groundwater prospect
Litholology	Felsic Igneous rock Fine clastic sediments Granites Granitoids Migmatite, Mafic dyke Meta-igneous, meta-sedimentary rocks Sandy, gravelly, silty sediments	High Very low Low Medium Low Low Very high	4 1 2 3 2 2 5
	-34.5 to -3.92	Very low	1

Lineament density	-3.92 to -1.16 -1.16 to 1.03 1.03 to 4.06 4.06 to 35.75	Low Medium High Very high	2 3 4 5
Drainage density	0 – 0.15 0.15 – 0.47 0.47 – 0.67 0.67 – 0.85 0.85 – 0.95	Very low Low Medium High Very high	1 2 3 4 5
Rainfall	63.72 -70.6 70.61-76.51 76.52 – 81.19 81.2 – 86.14 86.15 – 98.8	Very low Low Medium High Very high	1 2 3 4 5
Soil	Ferallic cambisols Haplic solonetz Eutric fluvisols Chromic cambisols Eutric leptosols	Very high Very low Medium High Low	5 1 3 4 2
Slope	0 – 1.931 1.932 – 4.507 4.508 – 9.657 9.658 – 18.19 18.20 – 41.04	Very high High Medium Low Very low	5 4 3 2 1
TWI	-19.11 - -15.32 -15.31 - -13.17 -13.16 - -9.757	Very high High Medium	5 4 3

	-9.756 - -2.807	Low	2
	-2.806 – 13.11	Very low	1
Curvature	-39 to -4.70 (100^{-1}m)	Very low	1
	-4.69 - -1.47	Low	2
	-1,46 – 0.57	Medium	3
	0.56 – 3.5	High	4
	3.4 – 35.75	Very high	5
LULC	Bare land	Very low	1
	Water bodies	Very high	5
	Vegetation	Medium	3
	Forest	High	4
TPI	-172.34 - -17.075	Very high	5
	-17.074 – 1.808	High	4
	1.809 – 33.281	Medium	3
	33.282 – 106.72	Low	2
	106.73 – 362.69	Very low	1
Roughness	0.1111 – 0.3807	Very high	5
	0.3808 – 0.4576	High	4
	0.4577 – 0.5262	Medium	3
	0.5263 – 0.6048	Low	2
	0.6049 – 0.8889	Very low	1

Table 4.4: The normalized pairwise comparison matrix and weights of each factor;

	Ge	LD	DD	RF	So	SL	TWI	CU	LULC	TPI	ROU	Sum	Criteria weight
Ge	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	1.24	0.11
LD	0.11	0.11	0.11	0.14	0.11	0.11	0.11	0.11	0.11	0.11	0.11	1.27	0.12
DD	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	1.03	0.09
RF	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	1.03	0.09
So	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	1.24	0.11
SL	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	1.03	0.09
TWI	0.08	0.08	0.08	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.83	0.08
CU	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.62	0.06
LULC	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	1.45	0.13
TPI	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.62	0.06
ROU	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.63	0.06

4.2 Consistency Ratio check

Saaty has opined that CR of 0.10 or less is acceptable to continue the analysis. If the consistency value is greater than 0.10, then there is a need to revise the judgment to locate causes of inconsistency and correct it accordingly. If the CR value is 0; it means that there is a perfect level of consistency in the pair - wise comparison.

The consistency ratio calculated using the (5) equation;

$$CR = \frac{CI}{RI}$$

Consistency Index (CI) was calculated from equation (6) given below:

$$CI = \frac{\lambda\, max - n}{n-1}$$

The consistency index (CI) and consistency ratio (CR) were cheeked while a pairwise comparison matrix of 11 groundwater prospecting factors was generated in AHP process. Hence the principal Eigenvalue (λ) of the matrix obtained from on the results of consistency ratio table ($\lambda_{\max}$ = 11.08), n = 11. Principal Eigenvalue obtained by calculating average of the ratio of weighted sum and criteria weight (CW).

$$CI = \frac{11.08 - 11}{11 - 1}$$

CI = 0.008

Then,

CR = (0.008 / 1.51)

CR = 0.0053

Hence, based on the result which obtained in the analysis, the CR was found below 10%. The result was acceptable since the value of CR < 0.1 is reasonable.

Table 4.5: Results of Consistency Ratio;

CW	0.12	0.12	0.10	0.08	0.12	0.10	0.08	0.06	0.13	0.06	0.06		
Layer	Lt	Ld	Dd	Rf	So	Sl	TWI	Cu	LULC	TPI	Ro	Weighted sum	λ
Lt	0.12	0.12	0.12	0.09	0.12	0.12	0.12	0.12	0.12	0.12	0.12	1.25	10.80
Ld	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	1.27	11.00
Dd	0.10	0.10	0.10	0.08	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.04	10.80
Rf	0.10	0.10	0.10	0.08	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.04	13.50
So	0.12	0.12	0.12	0.09	0.12	0.12	0.12	0.12	0.12	0.12	0.12	1.25	10.80
Sl	0.10	0.10	0.10	0.08	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.04	10.80
TWI	0.08	0.08	0.08	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.83	10.80
Cu	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.62	10.80
LULC	0.13	0.13	0.13	0.11	0.13	0.13	0.13	0.13	0.13	0.13	0.13	1.45	10.80
TPI	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.62	10.80
Ro	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.63	11.00
													11.08

High lineament density indicate channelled runoff is concentrated in in the central portion of the park. Based on lineament density classification medium, high and very high portion of is found in the central and southern part of the study. Based on pairwise comparison results, the rolling hill shape and flat terrain are performed as a higher weight and a mountainous shape was calculated as a lower weight. Low topographic relief as designated by low altitude, gentle slope and almost flat curvature indicate best infiltration conditions.

The drainage density of the study area is reclassified in five classes: “very low” (0–0.15 km km−2), “low” (0.15–0.47 km km−2), and “medium” (0.47–0.670 km km−2), and “high” (0.67–0.85 km km−2), and “very high” (0.85–0.95 km km−2). Low, very low and medium drainage density encircled large area of the study. The northern part receives rainfall of 1288–1427 mm whereas the vast portion receives 70.61–81.20 mm. The infiltration rate and the possibility of groundwater potential zones in the eastern portion of the study area is directly influenced by the rainfall distribution of the southern-east area. The very high potential zone of groundwater is characterized by the lithology type such as sandy, gravelly and silty sediments in Ruaha national park.

The slope gives essential information on the nature of the geologic and geodynamic processes operating at regional scale. Surface run - of and rate of infiltration are influenced essentially by slope of the surface. Larger slopes produce smaller recharge because the water received from precipitation flows rapidly down a steep slope during rainfall. The slope values were reclassified and categorized into five classes such as fat (0–1.931), gentle (1.932–4.507), medium (4.508–9.657), steep (9.658–18.19) and very steep 18.20–41.04). Large part of park slope ranging 0-9.657.

4.3 Groundwater Potential Zones

The final output of the model for the groundwater potential zones (Figure 4.1) indicated that the potential recharge is strongly determined by such important parameters like lineament density, geology, elevation, slope etc. Based on the groundwater potential zone map the northern part of the study area is characterized by high-water storage on account of higher rainfall and lesser degree of slope. From the lithological point of view the sandy, and gravelly bears high amount of groundwater potential as compared to others in study area. Vegetation coverage is almost dominantly found in all parts that can generate high potential groundwater. The result is similar with other study. The groundwater potential map generated by AHP model demonstrated acceptable result in predicting the groundwater recharge in Ruaha national park, Tanzania.

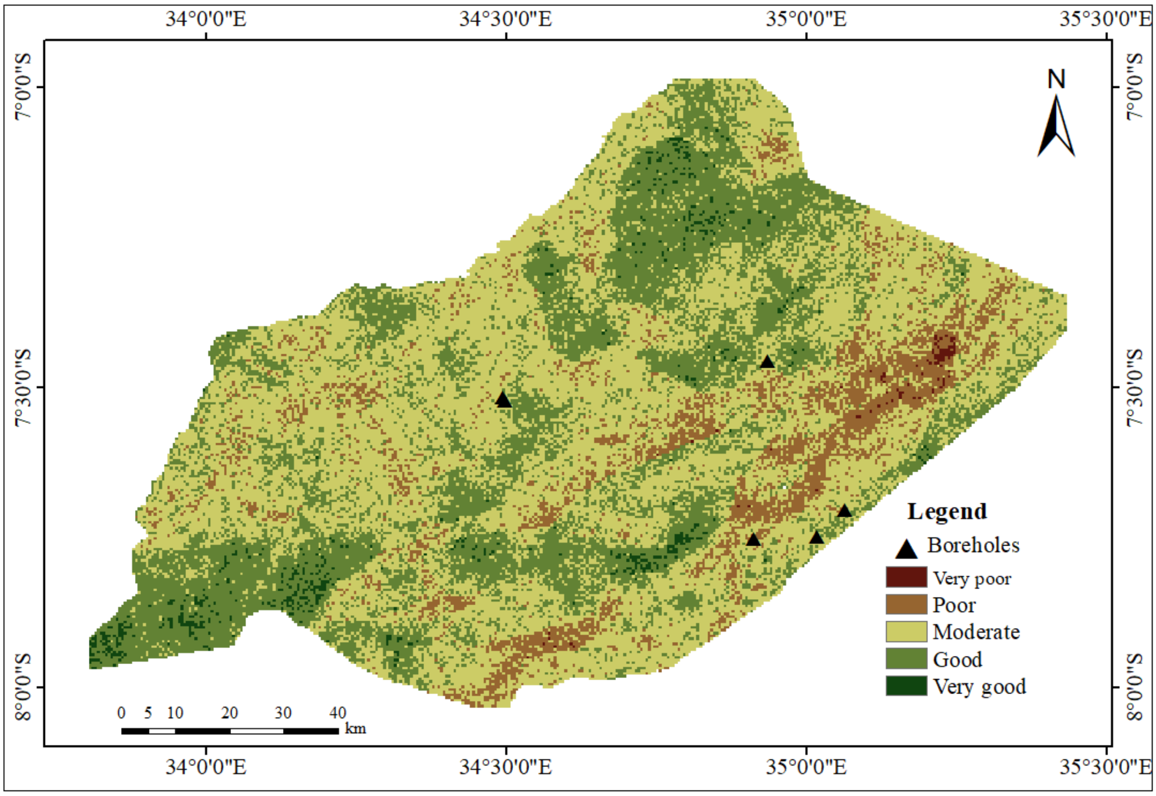

Figure 4.1: Groundwater Potential Zones map

Validation is the most important process in the modelling of the resultant map of groundwater potential map developed by the thematic layers. In the present study, verification was done by considering the groundwater boreholes locations from the datasets. Boreholes data was generated from Borehole Database (2010) - Tanzania and then overlaid groundwater recharge map of the study area.

The groundwater potential map was validated with 6 boreholes. All boreholes were overlayed on the groundwater potential zone map. From the total of bore wells, 2 found over good groundwater potential zone. 3 boreholes fall under moderate water potential zone level, and the remain well found on very good potential zone. Based on the final output map, other areas with same potential characteristics for groundwater resources also can be drilled and pump groundwater up the surface. This leads the availability of water on all potential zones in the park.

4.4 Distribution of Groundwater Potential and Its Implication for Groundwater Resources

The groundwater potential zones were estimated based on the weightage of individual features of thematic layers in the GIS environment. The GWPI values were adopted to classify whether an area of groundwater potential is very good, moderate, poor, and very poor. The total areal extent of the very good potential zone covers 1415.46 km^2 (12.3%). The good potential zone also covers 2981.91 km^2 (25.9%). The moderate part covers 3516.36 km^2 (30.6%). The remaining parts comprises of poor and very poor zone which consists of about 3592.16 km^2 (31.2%) of the study area (Figure 4.2).

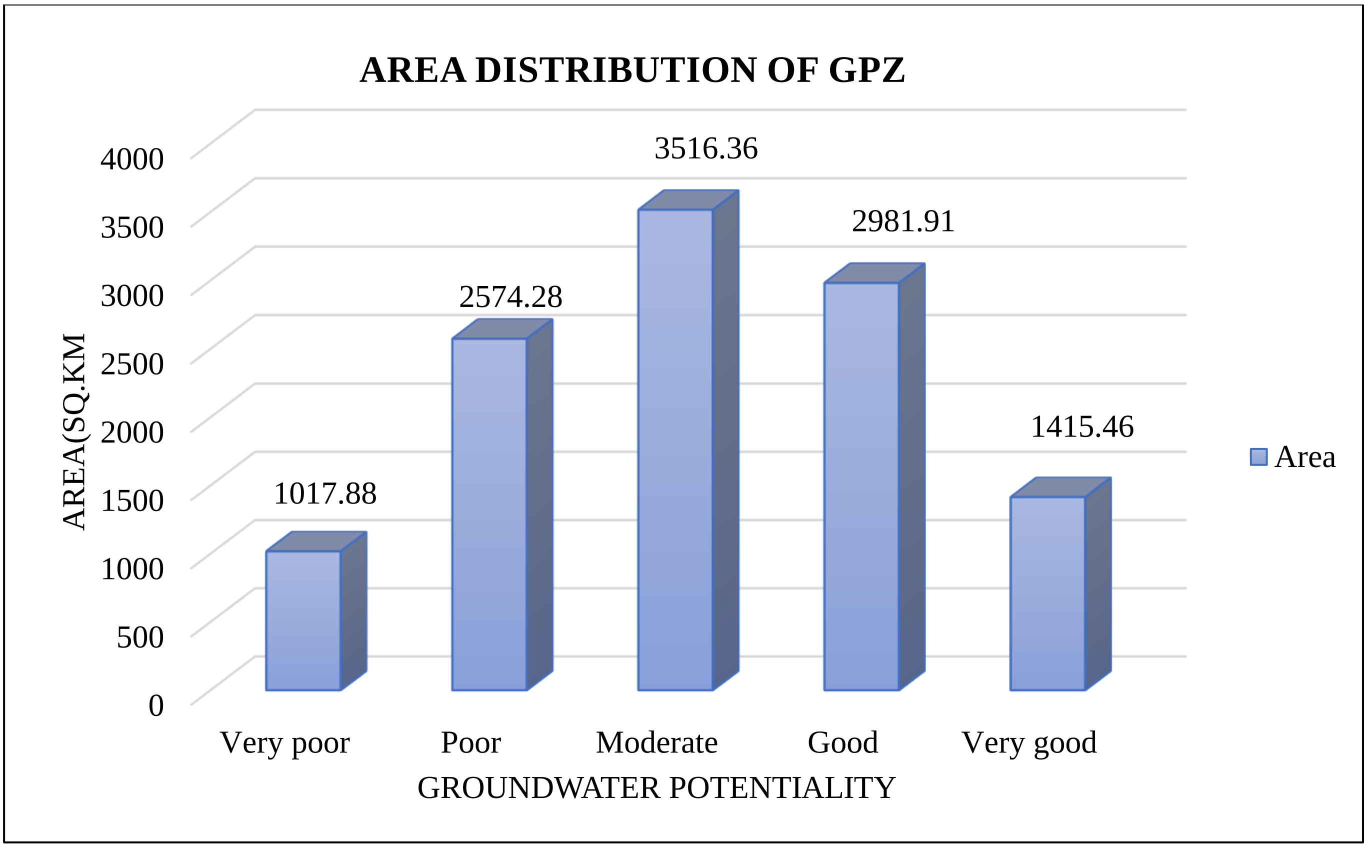

Figure 4.2: Graph of areal distribution of groundwater potential zones

The AHP map display groundwater distribution with high GWP potentials predominantly in the northern and south-western part of the study. Some portion of study area from north to south may have greater potential to exploit their groundwater resources. While the vast majority of the watershed is designated as moderate, small areas of high and very high GWP exist across the northern and the southern tips in the study area. East part and some western portion of Ruaha national park is characterized by poor and very poor groundwater potential due to lesser rainfall and geological characteristics. The final result of groundwater potential map produced by AHP method is agreed with the boreholes yield data. Hence the movement and occurrence of groundwater in the study area is controlled by land use land cover, rainfall, elevation and drainage density as revealed from the result and checked directly from field observation. Based on the result, it is possible to develop sustainable groundwater management. Further investigations need to be carried out to assess groundwater salinity.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

Assessment of groundwater potential is a vital step to use and manage resources effectively as well as efficiently. In the present study GIS, remote sensing and AHP technique proved to delineate GWPI like geology, rainfall, slope, soil, curvature, topography wetness index, elevation, drainage density, land use land cover, and lineament density in Ruaha national park. The weight of thematic layers of groundwater prospect was depending on AHP process results. The groundwater potential zones were obtained by overlaying all the thematic maps in terms of weighted overlay methods using the spatial analysis tool in ArcGIS 10.3, and it was found that the potential zones in terms of very high, moderate and good potential zones occupied an area of 1415.46 km^2, 3516.36 km^2 and 2981.91 km^2, respectively. The remaining part comprises of poor and very poor zone that covers an area of 3592.16 km2 of the study park.

In conclusion, the result of the groundwater potential map can serve as a base for planners in water resource management and land use planning. The application of geospatial technology with the integration of AHP techniques is a practical approach to groundwater prospecting and can be used in a similar environment.

5.2 Recommendation

Delineating distribution of groundwater resources in national parks is crucial for effective water resources managements, conservation efforts and sustainable development. Based on delineation results, may develop tailored management strategies for each groundwater potential zone. Implement appropriate measures for groundwater extraction, recharge enhancement, land use planning and conservation practices. Considering the ecological, and social aspects to promote sustainable utilization and protection of groundwater resources.

By identification of these zones also will support ecosystem health, visitors' experiences, and the socio-economic well-being of surrounding communities while promoting the conservation and responsible use of valuable groundwater.

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