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IDENTIFICATION OF GOLD POTENTIAL AREAS USING GIS AND RS TECHNIQUES

A Case Study of Tarime District

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BSc Geographical Information Systems and Remote Sensing

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IDENTIFICATION OF GOLD POTENTIAL AREAS USING GIS AND RS TECHNIQUES

A Case Study of Tarime District

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A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfillment of the Requirements for the Award of Bachelor of Science in Geographical Information Systems and Remote Sensing (BSc. GIS & RS) of Ardhi University.

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University dissertation titled **"Identification of Gold Potential Areas Using GIS & RS Techniques"** in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geographical Information Systems and Remote Sensing at Ardhi University.

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Dr. Joseph Hayola	**Mr. Joseph Maziku**
(Main Supervisor)	(Second Supervisor)
Date ………………………	Date ………………………

DECLARATION AND COPYRIGHT

I, RYOBA, RYOBA J 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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RYOBA, RYOBA J

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DEDICATION

I dedicate this dissertation to my beloved family; my parents Mr & Mrs. Daniel Ryoba Irondo, whose endless love, guidance, and supports have been the foundation of my personal and academic growth. Your constant belief in my potential and your constant motivation has been the driving force behind my success. I am forever grateful for the sacrifices you have made to provide me with the best education and opportunities to pursue my dreams and that have brought me this far in life. This research is dedicated to you both, as a token of my love and appreciation for all that you have done for me.

ABSTRACT

Tanzania is known for its high concentration of gold deposits, but still remains largely unexplored, and the potential for gold deposits has not been fully realized. This is due to the fact that conventional exploration methods are inefficient because they cover a small area and can be time-consuming and resource intensive. This study employed GIS and RS techniques for gold exploration in the Tarime district. This approach was fast, covered a large area and did not consume many resources.

Gold exploration using Geographic Information System (GIS) and Remote Sensing (RS) techniques is an important approach to identifying areas with high potential for gold mineralization. This also focused on using Analytic Hierarchy Process (AHP) and Weighted Overlay methods. This study presented a case study of Tarime District in Tanzania where gold is known to occur in various forms. The main aim of this study was to use GIS and RS techniques for identification of potential areas with gold in the district.

This study included datasets such as geological, geophysical, Digital elevation Model (DEM), sentinel 2A image, as well as soil data. It involved the integration of geological, geophysical, sentinel 2A satellite imagery, digital elevation model (DEM) as well as soil map layers using GIS (Analytical Hierarchy process and Spatial Analysis tools) and RS techniques

The result was a map showing potential gold deposit areas in Tarime district. It showed that some areas had a very high probability of finding gold deposit while others had high, moderate, low and very low gold deposit (see figure 4.9). The result was validated using the existing gold mines and mineral occurrences (see figure 4.10 and 4.11).

Therefore, the integration of GIS and RS data has provided valuable insights into the geological potential of the Tarime district for gold exploration. Several high-priority targets have been identified based on geological indicators such as rock types, structures and soil. Ground truthing has validated the presence of gold mineralization in the identified areas.

AHP methods have great consistency in criteria judgment for complex decision making which indicates great accuracy in this study and also recommended to be used in other studies.

Keywords: Geographical Information Systems (GIS), Remote Sensing (RS), Analytic Hierarchy Process (AHP).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

AHP	Analytical Hierarchical Process
DEM	Digital Elevation Model
ESA	European Space Agency
GIS	Geographical Information Systems
GIS	Geographical Information Systems
GMIS	Geological and Mineral Information System
GST	Geological Survey of Tanzania
NASA	National Aeronautical Space Administration
NBS	National Bureau of Statistics
OSM	Open Street Map
QGIS	Quantum GIS
RS	Remote Sensing
SHP	Shapefile
TanSIS	Tanzania Soil Information Service
TIFF	Tagged Image File Format
TMI	Total Magnetic Intensity
USGS	United State Geological Survey
USGS	United States Geological Survey

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Tanzania is one of the largest gold-producing countries in Africa, with the majority of its gold deposits found in the Lake Victoria Goldfields located in the northern part of the country (Henckel *et al*., 2016). The Mara Region, which is situated in this area, is, therefore, a significant location for gold exploration and extraction.

However, the region remains largely unexplored, and there is a need for a more detailed exploration of gold deposits in Tarime district. The fact that the area is still largely unexplored, this led to the lack of enough information on the potential for gold deposits which makes the country lack enough income from the mining industry. To address this need, this study aims to find the potential for gold exploration in the Tarime district using the Remote Sensing technique.

The Tarime district is located in the northwestern part of the Mara region and is known for its high concentration of gold deposits. The Tarime district covers an area of approximately 5,000 square kilometers and a population of around 360,000 people, most of whom rely on small-scale gold mining for their livelihoods (Schubert *et al*., 2014).

The study will used GIS to create detailed map of the geological features of the Tarime district. The data were processed using ArcGIS software Spatial Analysis Tools and Analytical Hierarchy Process (AHP) to create models of the geological map, lineaments density map, geophysical map, soil map, and land cover map of the study area.

The study involved analyzing the geological data, geophysical data, lineament density data, soil data, and land cover data to identify areas with the highest concentrations of gold using Analytical Hierarchy Process (AHP) and Weighted Overlay method.

The results of the study could be used to guide future gold exploration efforts in the Tarime district, helping to optimize resource allocation and increase the efficiency of mining operations.

The aim of this study was to address this problem by using GIS and RS techniques to find the potential for gold deposits in the Tarime district, a significant location for gold mining activities in the Mara region.

GIS technology allows for the integration of different types of data such as geological, geophysical, and lineament density, soil, and land cover data to create detailed maps of the terrain. This can help identify areas that are more likely to contain gold deposits, based on the geology and mineralogy of the surrounding area (Evans, 1995).

Remote Sensing techniques, on the other hand, involve the use of satellite and airborne imagery to gather information about the terrain. These techniques can provide valuable information about the geological and environmental characteristics of a particular area. For this study, it will be applied in sentinel 2A satellite imagery which can be used for land cover generation, which can help identify areas that are more likely to contain gold deposits when integrated with other existing data (Rekhibi *et al*., 2015).

One of the key advantages of using GIS and RS techniques in gold exploration is that they can cover large areas of land in a relatively short amount of time, without the need for extensive fieldwork. This can save time and resources, while also reducing the environmental impact of exploration activities (Bonham-Carter *et al*., 1990).

1.2 Statement of the Research Problem

Tanzania renowned for its high concentration of gold deposits, yet the full extent of its gold potential remains largely unexplored, due to the inefficiencies of conventional exploration methods. These methods are limited in scope (coverage), time-consuming and resource intensive hindering comprehensive exploration (Otto *et al*., 2006).

To overcome these challenges, there is a need for the use of systematic approaches (GIS and RS techniques) to identify areas with high gold deposits potential, thereby guiding future mining.

1.3 Objectives of the research

1.3.1 Main objective

The main objective of this research was to use GIS and RS techniques for the identification of gold potential areas in the Tarime district.

1.3.2 Specific objectives

i. To extract lineaments and create lineament density from a hill shade generated from Digital Elevation Model (DEM) data
ii. To classify sentinel 2A satellite image of the study area to obtain land cover of the area
iii. To perform Analytical Hierarchical Process (AHP)
iv. To develop a weighted overlay model to generate a gold potential map for the Tarime district
v. To validate the identified gold deposit potential areas

1.4 Research Questions

i. How can lineaments be developed from a hillshade generated from Digital Elevation Model (DEM)?
ii. How can sentinel 2A imagery be classified?
iii. How can Analytical Hierarchical Process (AHP) be performed?
iv. How is a weighted overlay model showing gold potential map generated?
v. How can the identified potential gold deposit areas be validated?

1.5 Significance of Research

This research will be important as it provides valuable insights into the geological features of the Tarime district, which is a significant location for gold mining activities in the Mara Region. The study will identify areas with a high possibility of gold deposits and predict the likelihood of finding new deposits in unexplored areas. The study's findings will provide recommendations for future gold exploration in the Tarime district, guiding more efficient mining practices. The study will contribute to the broader understanding of the geology of the Tarime district and the potential for mineral exploration of the area. The study is also potential because it will attract more investment into the district, leading to economic development opportunities and potential partnership between local and international organizations, which in turn will create more job opportunities. The study's recommendations on sustainable mining practices can help ensure that the mineral resources in the Tarime district are extracted in a way that does not compromise the needs of future generations. The study can also contribute to advancement of knowledge in the field of geology and mining, particularly in the application of modern technologies in mineral exploration (Groves, 2003).

1.6 Beneficiaries

The beneficiaries of this research include mining companies, government agencies responsible for mineral resource management, and local communities. The mining companies can use the results of the study to identify potential areas for exploration and optimize their exploration strategies. The government agencies can use the study to update their information to monitor and regulate mining activities, and ensuring sustainable development of mineral resources. The local communities can benefit from employment opportunities, revenue from royalties, and infrastructure development associated with mining activities (Tagwai *et al.*, 2023).

1.7 Scope and limitation of the research

The study is focusing on the Tarime district in the Mara Region of Tanzania by utilizing GIS and RS based technique in identifying areas with high possibility of gold deposit. The study also focuses on developing a map that will help identify and prioritize areas for future gold exploration. Despite the study having these scopes, it faces various limitations because the study’s findings are limited to the specific geological and environmental conditions of the Tarime district and may not be applicable to other regions or countries. The study does not consider the social and economic impacts of gold exploration on local communities and may require additional research. The study does not account for the potential changes in regulations and policies related to mining in Tanzania that may affect the feasibility and profitability of gold exploration. Also, the study provides prior information on the presence or absence of gold deposits therefore cannot be used as guidance for mining activities. The Analytic Hierarchy Process (AHP) relies on subjective judgments and pairwise comparisons made by experts, this can introduce bias and inconsistencies in the decision-making process.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter explains the techniques or approaches used for this study and how they can be used for fitting this study, different literatures that have used the same approaches and the structural controls on gold for the study area.

2.2 GIS and Remote Sensing in Gold Exploration and Prospecting

Gold exploration has been a significant economic activity in many regions of the world, with numerous exploration techniques employed to identify and evaluate mineral resources. Traditional exploration methods such as geological mapping and drilling, have been augmented by remote sensing (RS) and Geographical Information System (GIS) technologies to enhance mineral exploration efficiency and effectiveness (Rekhibi *et al.,* 2015)

The use of GIS and RS techniques in gold exploration has gained popularity in recent years. The techniques have proven to be effective in identifying and mapping potential areas for gold exploration, thereby saving time and resources. This literature aims to examine studies that have explored the use of GIS and RS techniques in gold exploration and those that have shown the use of other methods.

2.2.1 Gold exploration using GIS techniques

GIS is a computer-based tool for collecting, managing, analyzing, and displaying spatial data. GIS technology has been used to explore gold deposits in various parts of the world. GIS technology can be used to integrate geological data, geophysical data, and geochemical data to produce 3D models of the subsurface. The 3D models can be used to identify areas with high potential for gold mineralization. GIS technology has also been used to develop predictive models that can be used to identify mineralization patterns. By analyzing mineralization patterns, it is possible to identify areas with a high likelihood of containing gold deposits. Several GIS techniques have been employed in gold exploration, including spatial analysis, terrain analysis, and 3D modeling. The spatial analysis involves analyzing the relationships between different spatial data layers to identify areas of high mineral potential. Terrain analysis involves analyzing topographic data to identify areas of structural complexity that may be associated with mineralization. 3D modeling involves creating 3D visualizations of mineral deposits based on geological and geophysical data. (Khaled, 2019).

2.2.2 Gold exploration using RS techniques

Remote sensing techniques have also been used to explore gold deposits. Remote sensing is a non-destructive exploration technique that uses electromagnetic energy to detect minerals and geological features from the air or space (Botwe *et al.,* 2018). There are two primary types of remote sensing: passive and active remote sensing. Passive remote sensing employs sensors that detect natural radiation emitted by the earth's surface, while active remote sensing uses sensors that emit their own radiation, such as radar or sonar. In the context of gold exploration, remote sensing has been used to identify structural features that may be associated with gold mineralization, such as faults and shear zones. RS technology can also be used to identify vegetation anomalies that may indicate the presence of gold mineralization (Sonmez and Gokceoglu, 1998). The technology can also be used to identify mineralogical anomalies that may indicate the presence of gold deposits

2.2.3 Combined use of GIS and RS techniques

The combination of GIS and RS techniques has been found particularly effective in identifying potential areas for gold exploration. According to (Botwe and Jnr, 2018), GIS and RS techniques can be used to identify mineralization patterns and structural features that may be associated with gold deposits. The combination of two techniques can also be used to identify areas with high vegetation cover, which may indicate the presence of gold deposits (Botwe and Jnr, 2018).

2.3 Definition of important terms

2.3.1 Geological data:

Geological data is information about the rocks and minerals that make up the Earth's crust. It includes data on the rock types, mineralization, and structural geology present in the study area, their age, and their distribution. This data can be obtained from geological maps, reports, and publications. Geological maps are usually created by geologists and are available in digital or paper format (Yusoff et al., 2015).

The reports provide detailed information about the geology of the study area, including the lithology, structure, mineralization, and other geological features. They may also include maps, cross-sections, and other geological data. Geological publications are books, articles, and other publications that provide information about the geology of the study area. They may be written by geologists or other researchers and may include geological maps, illustrations, and other data. (Bonham-Carter *et al.***,** 1990).

The analysis of geological data can be done using GIS software such as ArcGIS and QGIS. This software can be used to create geological maps, perform spatial analysis and generate geostatistics. For example, GIS can be used to create a digital elevation model (DEM) of the study area, which can be used to identify geological structures such as faults and folds. Geological data plays a crucial role in gold exploration, providing insights into the geological setting and potential mineralization zones.(Groves, 2003) utilized geological mapping and analysis to identify favorable host rock units and structural controls for gold mineralization. Similarly, the study by Bagheri *et al.* (2019) emphasized the integration of geological data including lithology, structure, and alteration, to delineate potential gold bearing areas.

2.3.2 Geophysical data

Geophysical data refers to the data collected from the Earth's subsurface using geophysical survey techniques. It is the information about the physical properties of the earth that can be measured and analyzed, such as magnetic, electrical, and seismic properties. These data can help to identify and locate potential mineral deposits and geological structures as different minerals have distinct physical properties that can be detected through geophysical surveys (Burley, 1978).

Magnetic surveys are used to measure the magnetic properties of rocks and minerals in the study area. They are often used to identify potential iron and nickel deposits, as well as to map the structure of the earth's crust (Dentith and Mudge, 2014).

The analysis of geophysical data can be done using specialized software such as Oasis Montaj, Geosoft, and Surfer. This software can be used to process and interpret geophysical data, create maps and cross-sections, and identify potential mineral deposits. For example, magnetic data can be processed and interpreted to create magnetic anomaly maps, which can be used to identify potential iron and nickel deposits (Schubert *et al.*, 2014).

Geophysical data plays a vital role in gold exploration, by providing information about subsurface geological structures and potential mineralization targets (Dentith and Mudge, 2014) emphasized the Application of geophysical methods, such as magnetic and gravity surveys in delineating structural features associated with gold mineralization.

2.3.3 Digital Elevation Model (DEM)

DEM data is a digital representation of the Earth's surface topography. It is created by collecting elevation data using various methods, such as LIDAR (light detection and Ranging) or photogrammetry, and then interpolating the data to create a continuous elevation model of the study area. DEM data is commonly used in GIS and Remote Sensing applications to support a variety of analyses, including terrain visualization, slope analysis, and hydrological modeling. It can be used to generate topographic maps and identify potential mineral deposits based on their geological setting (Brandmeier *et al*., 2020).

The primary source of DEM data was remote sensing which was the collection of data from a distance, often from aircraft or satellite-based sensors. These sensors measure the elevation of the earth's surface using various techniques, including LIDAR, interferometry, and stereo-photogrammetry. LIDAR, for example, uses a laser scanner to emit light pulses that reflect off the surface and back to the sensor, allowing for highly accurate elevation measurements (Hoja *et al*., 2006).

DEM data can be analyzed using a variety of software such as ArcGIS and QGIS. These tools can be used to visualize the topography of the study area, as well as to create derivative products such as hillshade, slope analysis, and aspect maps. For this research, the DEM obtained was required to be pre- processed using fill tool in order to give out good outputs of hillshade, which resulted to lineament extraction and lineament density (Javadnejad *et al.*, 2013).

2.3.3.1 Digital Elevation Model (DEM) Fill

Fill tool helps in identifying and correcting data anomalies such as spikes and voids in the elevation data which can affect the accuracy of subsequent analysis. These anomalies can occur due to various reasons such as data acquisition errors, atmospheric conditions, and processing errors (Lakshmi and Yarrakula, 2018).

This error correction involves applying interpolation techniques to the DEM data to remove or fill the anomalies. For example, the interpolation techniques such as kriging and inverse distance weighting (IDW) can be used to fill gaps or voids in the DEM data (Shikha *et al.*, 2022).

By correcting errors in the DEM data, the accuracy of subsequent analyses such as hill shade is improved, leading to more accurate identification of potential mineralization areas by generating better lineaments, and finally lineament density.

2.3.3.2. Hillshade

Hillshade is a visualization technique used to represent the three-dimensional terrain features of a DEM as two-dimensional shaded relief map. It stimulates the effects of light and shadows on the terrain, creating a visually appealing representation that enhances the perception of its topographic features. Hillshade maps provide a visually appealing representation of the topography, highlighting the slopes, ridges, valleys, and other landforms. they are widely used for cartographic purposes, landscape visualization, and terrain analysis. For example, Hillshade maps can aid in landform identification, siting of infrastructure, visualization of view shades, and understanding the exposure of slopes to sunlight. Hillshade can be created from a DEM using various software applications such as QGIS and ArcGIS (Hoja *et al.*, 2006).

2.3.3.3 Lineaments Analysis

Lineaments are direct highlights, which happen on the world's surface unmistakable from the encompassing highlights and reflect what the inconspicuous subsurface can be (Lakshmi and Yarrakula, 2018). Lineaments precedents are shortcomings, joints, break zones, dykes, lithological contacts and foliations . (Lakshmi and Yarrakula, 2018), It has turned out to be conspicuous all through the most recent couple of years to utilize lineaments considers in the evaluation of potential groundwater zones. They are linear geological features observed in the DEM that represent geological or structural features (the visible or near inferred alignments of geological elements) on the earth's surface. They can include faults, fractures, joints, fold axes, or other linear structures resulting from tectonic processes. Lineaments are identified by analyzing changes in topography, such as abrupt changes in slope or alignment of landforms. They can provide valuable insights into the underlying geological structures and help in geological mapping, mineral exploration, and assessing seismic hazards. Lineament Analysis involves the identification, mapping, and characterization of linear features within the study area. lineament extraction from a DEM involves various techniques, such as edge detection algorithms, for example onscreen digitization or visual interpretation, to identify and delineate these linear features (Hoja *et al.,* 2006).

2.3.3.4 Lineament Density

Lineament density refers to the spatial distribution of linear geological features, such as faults, fractures, and dykes, on the Earth's surface. It plays a significant role in gold exploration as lineaments often serve as pathways for hydrothermal fluids and mineralization. Research has shown that higher lineament densities are associated with increased chances of gold mineralization. According to research (Javadnejad *et al.*, 2013), lineament analysis using remote sensing data and GIS techniques has proven effective in identifying potential areas for gold mineralization. Similarly, the study by (Singh *et al.*, 2020), highlighted the significance of lineament density as a valuable indicator in gold exploration, emphasizing its application in targeting potential gold-bearing zones. The Lineament analysis such as lineament extraction and density mapping has been utilized to identify areas with higher gold prospectivity.

2.3.4 Soil

Soil is a crucial indicator in gold exploration studies. Studies have demonstrated the effectiveness of soil sampling and analysis for gold exploration, particularly using techniques such as soil geochemistry and soil geochemical surveys. By analyzing the distribution of various elements, including gold and associated pathfinder elements, researchers an identify anomalies that may indicate the presence of gold mineralization (Mshiu, 2020). Integration of soil data with GIS and RS techniques enhances the understanding of spatial patterns and the identification of prospective areas for further exploration.

Basing on the soil data for this research, Tarime soil consists of Umbric Nitisols, Eutric Planosols, Luvic phaeozems, Eutric Fluvials, Eutric Leptosols, Chromic Cambisols and Eutric vertisols. This is based on the main type. Due to the fact that soil is a product of rocks, formed through a complex process called weathering, which involves breakdown and alteration of rocks and minerals over time, for example Umbric Nitisols can form from meta-sediments, which are sedimentary rocks that have undergone metamorphism. The weathering and decomposition of these meta-sediments can contribute to the formation of umbric Nitisols (Martín-Méndez *et al.*, 2023).

Eutric Planosols can form from volcanic lavas, which are the solidified lava flows from volcanic eruptions. Luvic Phaeozems are fertile soils with a dark, organic-rich surface horizon. They are commonly formed in areas with high vegetation cover and moderate to high moisture availability. They can form from a combination of fine-corse clastic sediments. Eutric Fluvials are soils associated with river floodplains and alluvial deposits. They can form from sandy, gravelly, and silty sediments. These sediments are typically deposited by river systems (Martín-Méndez et al., 2023).

Eutric Leptosols are shallow soils with limited development, often found in areas with rocky or shallow parent materials. Eutric Leptosols can form from mafic volcanics, meta-basalts, phyllite, and BIF. Therefore, the above information tells that soil is also an important factor to include in gold exploration process (Mohamed K. El-Shafei, 2011).

2.3.5 Land cover

Land cover, referring to the physical coverage and vegetation type on the Earth's surface, also plays a role in gold exploration. Certain land cover types, such as altered or mineralized rocks can indicate the presence of gold deposits. Vegetation responses to underlying geological conditions can be detected through remote sensing data, aiding in the identification of potential gold-bearing areas. Studies have shown that land cover mapping and analysis, combined with other geological and geophysical, can provide valuable insights into gold prospectivity (Hoja *et al*., 2006).

2.4 Analytic Hierarchy Process

The Analytical Hierarchical Process (AHP) is a decision-making technique introduced by Thomas Saaty in the 1970s. It offers a systematic approach to analyze and prioritize multiple criteria or alternatives within a hierarchical structure. AHP involves decomposing complex decision problems into smaller components and evaluating and comparing them based on their relative importance. AHP employs a hierarchical model comprising a goal, criteria, and alternatives (Saaty, 1987). The goal represents the ultimate objective, while criteria are factors contributing to achieving the goal. Alternatives represent the available options or solutions that are assessed against the criteria. To determine the relative importance and alternatives, pairwise comparisons are conducted (Saaty, 1987). Decision-makers compare each element with others in the same level of the hierarchy and assign numerical values to express their preferences. These values typically range from 1 to 9, indicating equal to extreme importance. After completing the pairwise comparisons, the eigenvector method is utilized to calculate the relative weights of criteria and alternatives (Saaty, 1987). These weights represent the priority of each element concerning the goal. The results are then used to compute an overall score for each alternative, facilitating rational decision-making. AHP finds applications in diverse domains such as business, engineering, project management, and decision analysis, where complex decisions need to be made (Saaty, 1980). It provides a structured framework to systematically consider multiple criteria and alternatives, aiding in more objective and consistent decision-making.

2.4.1 How the AHP works

AHP involves decomposing complex decision problems into a hierarchy of criteria and alternatives, and then using pairwise comparisons to determine the relative significance of these elements (Saaty, 1987).

During pairwise comparisons, decision-makers assign numerical values on a scale of 1 to 9 to express the importance of each element compared to others (Saaty, 1987).These values are subjective and reflect the decision-maker's judgments and references. Saaty's fundamental scale is commonly employed for consistent comparisons (Saaty, 1987).

After completing the pairwise comparisons, AHP utilizes the eigenvector method, a mathematical process, to calculate the relative weights of criteria and alternatives (Saaty, 1987). By analyzing the pairwise comparison values, a priority vector is derived, indicating the relative importance of each element. Normalization ensures that the weights sum up to one (Saaty, 1987). The calculated weights enable decision-makers to determine the overall ranking or priority of the alternatives. multiplying the criteria weights by the performance of each alternative on those criteria yields a performance score for each alternative, representing the overall evaluation or preference. AHP provides decision-makers with a structured framework to systematically analyze and prioritize complex decision problems. It facilitates the consideration of multiple criteria and alternatives, incorporating decision-maker's preferences and judgments.

2.4.2 Various Researches on Gold Exploration using Suitability Analysis.

There have been various research studies conducted on suitability analysis for gold exploration using GIS (Geographical Information System) and RS (Remote Sensing) methods. These studies aim to identify favorable areas for gold mineralization based on various geospatial datasets and analytical techniques (Brandmeier et al., 2020). The studies highlight the effectiveness of integrating geospatial data and analytical techniques for identifying prospective areas for gold mineralization. Here are a few examples of such research:

Title: "Application of GIS and Remote Sensing for Gold Potential Mapping in the Lake Victoria Goldfields, Tanzania", done by Mkumbo, Mruma, and Zoboki and published in the year 2014. This research explored the Lake Victoria Goldfields in Tanzania, a region with significant gold deposits. The study integrated GIS and RS techniques to analyze geological, structural, and remote sensing data. The research employed various spatial analysis methods to generate a gold potential map, facilitating the identification of areas with high potential for gold mineralization.

Title: “Gold Potential Mapping in Kelantan, Using Geographical information System” Jamal, Hashim, and Hazrina (2014). This study utilized GIS techniques to assess gold potential in the Kelantan region of Malaysia. various Geospatial datasets such as geological, topographical, and geochemical data, were integrated to create a gold potential map. the study employed spatial analysis techniques to identify areas with high potential for gold mineralization.

“Integration of GIS and Remote Sensing for Gold potential Mapping in the Geita Greenstone Belt, Tanzania”, A Research carried by Kyessi, Tibaijuka, and Shirima published in 2018. This study focused on the Geita Greenstone belt in Tanzania, a region known for its gold mineralization. GIS and RS techniques were employed to integrate geological, geochemical, and geophysical data. the study utilized spatial analysis methods to generate a gold potential map aiding in the identification of promising areas for gold exploration.

“Gold Mineralization Potential Mapping Using GIS in Singida Region, Central Tanzania” The authors were Kazimoto, Mng’ong’o, and Lugwisha. It was then published in the year 2019. It focused on the Singida region in central Tanzania, aiming to assess the gold mineralization potential using GIS techniques. The Research incorporated geological, geochemical, and geophysical data into a GIS platform. Spatial analysis methods were also utilized to generate a gold potential map, aiding in the identification of prospective areas for gold exploration.

2.5 Weighted Overlay

The weighted overlay tool is a spatial analysis technique used to combine and integrate multiple layers of spatial data in a geographical Information System. it involves assigning weights to each layer based on their relative importance or significance in relation to a specific analysis or decision-making process. (Tobiszewski *et al.*, 2015). These weights reflect the degree of influence or contribution of each layer to the overall analysis.

Once the weights are determined, the tool performs a mathematical operation, such as addition or multiplication, on the values of each pixel from the corresponding layers. The result is a composite output layer that represents the combined effects of the input layers, reflecting the overall suitability, favorability, or suitability index of each location within the study area (Eastman, 2009).

The weighted overlay tool allows decision-makers to consider multiple factors simultaneously and assess the relative importance of each criterion (Voogd, 1982). It enables the integration of diverse datasets, such as environmental variables, social-economic factors, and land cover data, into a single analysis. By visualizing the results on a map, users can identify areas that meet specific criteria or exhibit a high degree of overall suitability, providing valuable insights for decision-making, spatial planning and resource allocation (Tobiszewski *et al.,* 2015). The weighted overlay tool finds applications in various fields, including land use planning, site selection, environmental impact assessment, and natural resource management (Tobiszewski *et al.,* 2015). It facilitates informed decision making by considering the complex interactions and relationships among multiple factors and supporting the identification of areas with the highest potential or suitability for a specific purpose. In this study the focus is using weighted overlay tool on natural resource management.

2.6 Structural controls on gold in Tarime district

Structural controls on gold refer to the geological structures that influence the formation, distribution, and concentration of gold deposits in the area. The Tarime district is known for its gold deposits, which are primarily found in structurally controlled deposits

One of the most important structural controls on gold in the Tarime district is the presence of fault zones. These fault zones are characterized by brittle deformation and deformation and are often associated with shear zones, which can act as conduits for gold-bearing fluids, gold deposits in these zones can either be primary (formed by direct precipitation from hydrothermal fluids) or secondary (formed by the mobilization and redeposition of gold from pre-existing deposits) (Blenkinsop *et al.,* 2021).

Another important structural control of gold in the Tarime district is the presence of fold structures. These structures can create traps for the gold-nearing of ore bodies. In addition, folds can cause changes in the permeability and porosity of the rocks, which can affect the movement and concentration of gold-bearing fluids (Blenkinsop *et al.,* 2021).

Other structural controls on gold in the Tarime district include lithology (the type of rock), alteration (changes in mineralogy and texture), and stratigraphy (the layering of rocks). For example, gold deposits may be associated with certain types of rocks, such as greenstone belts, which are known to host significant gold deposits globally. Alteration can also play a role in gold mineralization, as changes in mineralogy can affect the solubility and mobility of gold-bearing fluids (Blenkinsop *et al.*, 2021).

2.7 Geology of Tarime District.

The lithology of Tarime district in Tanzania encompasses a variety of rock types, including granitoids, migmatite, mafic and ultramafic rocks, meta-sediments, volcanic lavas, fine-coarse clastic sediments, sandy, gravelly, silty sediments, as well as mafic volcanic rocks, meta basalts, phyllite, and banded iron formations (BIF) (MacKenzie *et al.*, 2001).

According to Bauer, (2005), Granitoids are intrusive rocks characterized by their coarse-grained texture and predominantly granitic composition. Migmatite is a mixed rock type that exhibits both igneous and metamorphic features. It typically results from the partial melting and subsequent recrystallization of pre-existing rocks under high temperature conditions. Mafic and ultramafic rocks are rich in magnesium and iron, with mafic rocks containing higher proportions of iron and magnesium compared to ultramafic rocks. These rock types include basalt, gabbro, and peridotite among others. Intrusive rocks, including granitoids and mafic/ultramafic rocks, can host gold mineralization through various processes, including magmatic-hydrothermal systems and structural controls (Groves, 2003).

Meta-sediments are sedimentary rocks that have undergone metamorphic changes due to intense heat and pressure. they can include a wide range of sedimentary rock types that have been altered through metamorphism, such as sandstone, shale, and limestone (Hussain *et al.,* 2015). Meta-sedimentary rocks, such as meta-sandstones and meta-shales, are often associated with gold mineralization. they can act as favorable host rocks due to their ability to host hydrothermal fluids and trap gold (Blenkinsop *et al.,* 2021).

Volcanic lavas (nephelinite, phonolite, alkali basalts) are extrusive igneous rocks that solidify after volcanic eruptions. They can be composed of basalt, andesite, rhyolite, or other volcanic compositions depending on the eruptive conditions (Hussain *et al.*, 2015).

Fine-coarse clastic sediments encompass a range of sedimentary rock types that are formed from the accumulation and lithification of fragmented particles, including sand, silt, and clay. These sediments can form rocks such as sandstone, siltstone, and shale (Bauer, 2005). Clastic sediments, such as sandstones and conglomerates, can host gold deposits, particularly in fluvial or alluvial environments. These sedimentary environments are favorable for the concentration of gold particles (Blenkinsop *et al.*, 2021).

Sandy, gravelly, and silty sediments refer to various types of unconsolidated sediments that are composed predominantly of sand, gravel, or silt particle (Hussain *et al.*, 2015).

Mafic volcanic rocks and met basalts are volcanic rocks that have a high content of magnesium and iron. Phyllite is a fine-grained metamorphic rock with a well-developed foliation, resulting from the low graded metamorphism of clay-rich sedimentary rocks. Banded iron formations (BIF) are sedimentary rocks consisting of alternating layers of iron-rich minerals and chert (Bauer, 2005). BIFs can also be important hosts for gold deposits. their chemical and physical characteristics make them favorable for gold enrichment processes (Hussain *et al.*, 2015).

CHAPTER THREE

METHODOLOGY

3.1 Overview

This section involves the work flow of this study, including the data collected, the pre-processing, the processing of the data, and finally the outputs in this study, a range of geospatial techniques were employed to explore the potential for gold mineralization in the study area.

This methodology includes the collection and analysis of geological data, geophysical data, digital elevation model data, sentinel image, and soil data. To integrate all these datasets, GIS software that is ArcGIS was used to create maps and conduct spatial analyses. The methodology of this research is shown in Figure 3.1

3.2 Description of the study area

3.2.1 Location of the area

The study area is located in the Tarime district, which is located in Mara region in the northern part of Tanzania (See Figure 1.1). It lies within the Lake Victoria Goldfields, which is an important gold mining region in Africa. The district is situated between latitudes 1^0 05' S and $1^0$45'S and longitudes $34^0$00'E and $35^0$30'E. it covers an area of about 13,000km^2 and shares borders with Serengeti district in the north, Butiama district in the west, Rorya district in the south and Kenyan border.

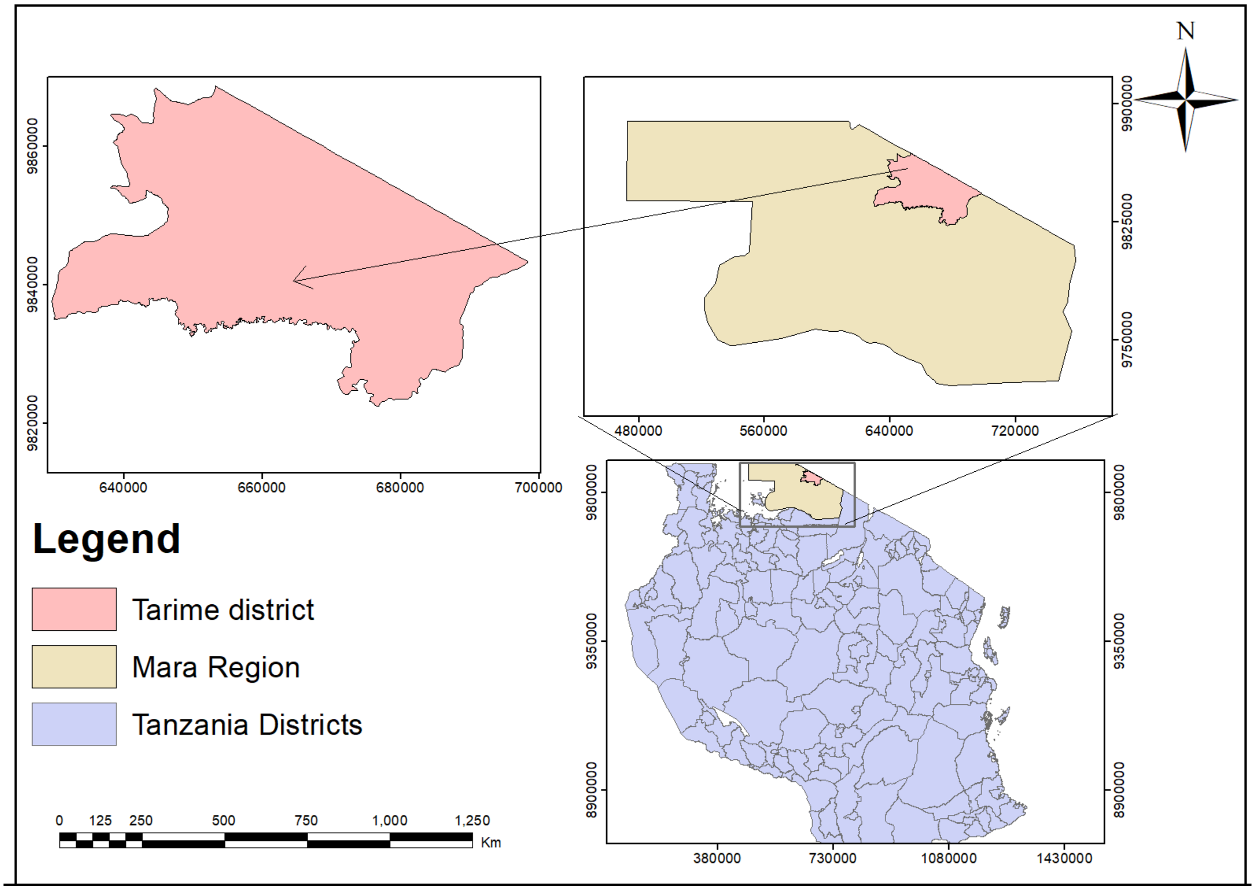


Figure 1.1: Location Map of Tarime district in Mara Region of Tanzania

3.2.2 Physiography of the area

The physiography of the Tarime district is characterized by diverse landscape ranging from undulating hills, ridges, plains, and scattered rocky outcrops, with altitudes ranging from 900 to 1800 meters above sea level. The district is part of the western Rift Valley which is marked by a series of fault lines that have created a complex terrain with a wide range of geological formations.

3.3 Methodological Workflow

The workflow of this research involved steps from the showing the start and the end of the research such data collection, data pre-processing, and data processing to obtain the required output. There were five datasets or input to this research where each data was processed according to its requirements to obtain the specific output.

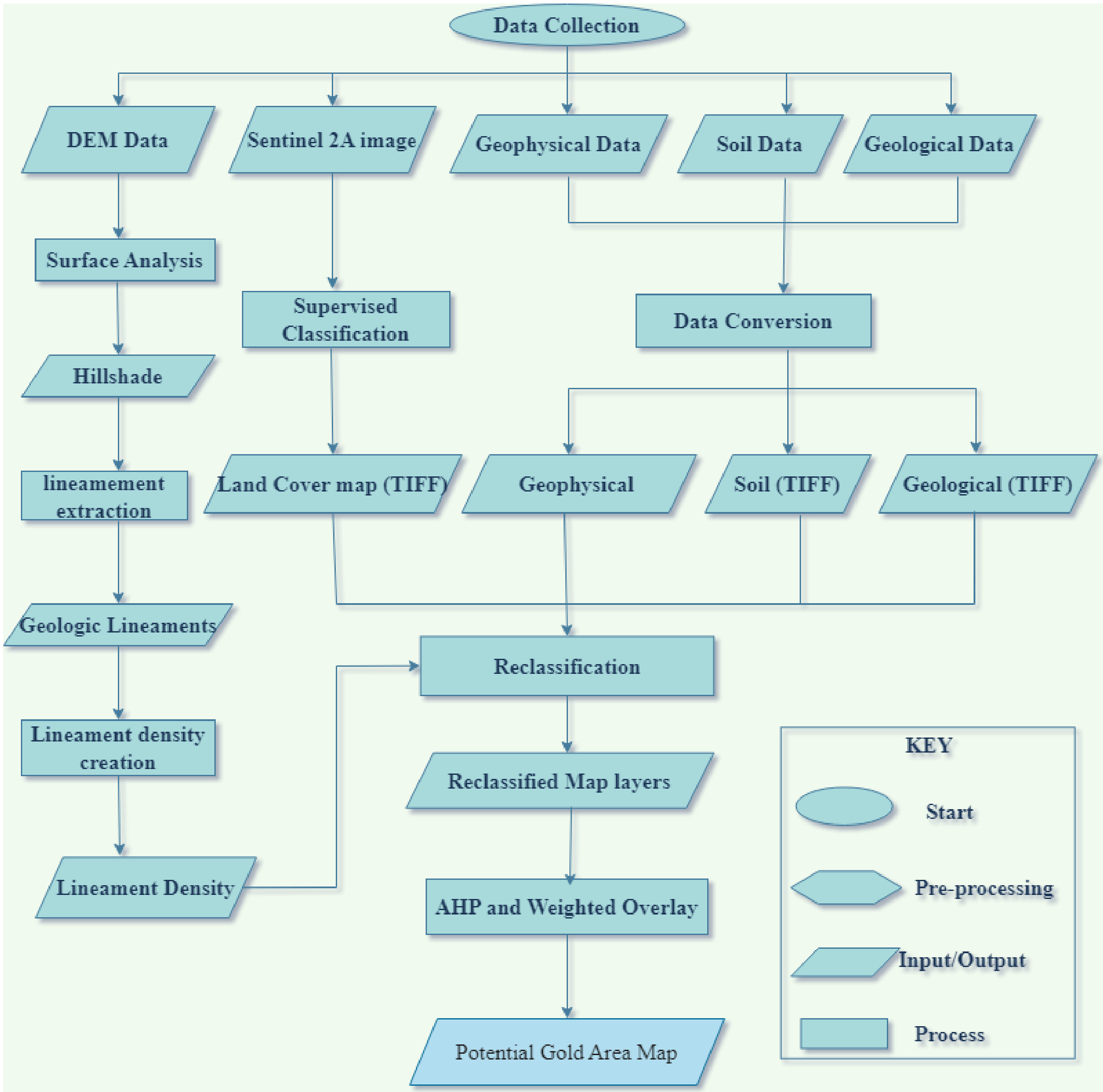


Figure 3. 1: Methodology Workflow

3.4 Reconnaissance

Reconnaissance involved a comprehensive literature review, data collection, field observations, and data analysis using GIS and RS techniques. The goal was to gain a better understanding of the study's area geological features, mineralization, and gold exploration potential.

3.5 Data Collection

The data collected are the geological data, geophysical data, Digital Elevation Model (DEM) data, Soil Type data, and sentinel 2A satellite data. Each data is provided in the table 3.1

showing the type of dataset, its spatial resolution, data format, data type, and the source or its availability.

Table 3. 1: Research Data Characteristics

Dataset	Spatial Resolution	Data Format	Data Type	Source	Use
DEM	30m	TIFF	Rater	Copernicus	For Hillshade, lineament, and lineament density creation
Geological Data		SHP	JPEG	GMIS-GST	For geological map layer creation
Geophysical Data		TIFF	Raster	Geophysical Instructor	For geophysical map layer creation
Administrative Boundary		SHP	Vector	DIVA-GIS	For study area specification
Sentinel 2A	10m, 20m and 30m	TIFF	Raster	Copernicus	For land cover map creation
Soil Type		SHP	Vector	Tanzania Soil Information Service (TanSIS)	For soil map layer creation

3.6 Data Pre-processing

For the DEM data, the data preprocessing began with quality check, to evaluate the potential errors, artifacts, or data gaps. It was then projected into Arc1960 UTM Zone 36S coordinate system because the geological data obtained was already in Arc1960 UTM Zone 36S, thus other datas*et al*so required to be transformed to this coordinate system. Data cleaning and Filtering followed which used where data cleaning operations were used to remove the outliers and spikes, or anomalies that could affect subsequent analyses. The DEM was filled with fill tool in order to remove errors that may be found on the data (noise). The fill tool was used to fill sinks or depressions in the DEM. The DEM was imported in the fill tool as an input surface raster dataset representing the elevation values of the terrain.

The downloaded sentinel 2A satellite image was projected from WGS 84 coordinate system into ARC 1960 coordinate system, a local coordinate system. It was then clipped using the ArcMap clipping tool. After the Projections and clipping, the image appeared to have noise, therefore, the noise was reduced using Image analysis tool in the ArcMap software, using 3*3 smoothing filter.

3.7 Data Processing

Data processing involves the conversion of raw data into useful information by applying various techniques such as filtering, enhancement, classification, and extraction. For this study, data processing will involve the use of GIS Spatial Analysis tools and RS tools to process and analyze the available data. This included the integration of the processed data sets such as geological, geophysical, DEM, as well as remote sensing images (Land Cover) using Analytical hierarchy Process (AHP) and weighted overlay method to identify potential gold mineralization areas.

Furthermore, the processed data was used for creating maps and visualizations purposes, identifying areas for further exploration, and optimizing exploration strategies. This part shows each dataset with its source and processing.

3.7.1 Digital elevation model (DEM)

Digital Elevation Model as an essential data source for many geospatial analyses and modeling. for this research, it was downloaded from the European Space Agency (ESA) in the Copernicus Open Access Hub in the EUROSTAT, a statistical office of the European Union (EU), which collects, processes, and publishes a wide range of statistical data on various topics including demography, economics, environment, agriculture, energy, transport, and social issues. The data had a spatial resolution of 30m as it was downloaded as a WorldDEM. This primary product was derived from the TanDEM-X mission data produced by Airbus Defense and Space GmbH. For this research, the processing of Digital Elevation Model (DEM) involved steps such as creation of hillshade feature extraction from the hillshade (lineament extraction), and finally lineament density. These steps helped in extracting value information about the topography of the study area, which is important for identifying potential mineralization areas.

3.7.1.1 Hillshade

Hillshade was generated from the Digital Elevation Model. Hillshade was generated using the Hill shade generation tool as one of the surface analysis tools found in Spatial Analyst tool from Arc toolbox. The DEM serve as an input raster where by the azimuth was 315, altitude45 and Z factor was 1 which are default settings in the ArcMap. From this process, a shaded relief was created from a surface raster which considered illumination source angle and shadows.

3.7.1.2 Lineament Extraction

Lineament structures were extracted manually using on screen digitizing approach. This approach extracted lines of identified shades from the hillshade image which represented lineaments. These lineaments were in form of shapefile. The lineaments are the indicative of geological structures such as faults, fractures, and joints. The validation of the lineaments was done using Data analysis by analyzing data gravity and anomalies from geophysical data.

3.7.1.3 Lineament Density

The generation of lineament density was dependent on the extracted lineaments. From the line density tool in ArcMap, the extracted lineaments were used as input polyline features and the lineament density was generated. It involved the following steps; ArcMap, Arc toolbox, Spatial Analysis Tools, density and finally line density tool.

Where there is high concentration of lineaments, the value lineament density also means it will be high. Basing on the geological formation of the area, lineament density can also be used for gold exploration purposes. Where there is high lineament density value, it means the probability of finding gold deposit in that area is also high, unlike to low value lineament density, which imply low probability of finding gold deposit in that area (Yusoff *et al.,* 2015).

3.7.2 Geological Data

Geological data for this study was collected from the GMIS (geological and mineral information system) GST Geological Survey of Tanzania. It provides important data about mineral deposits and their occurrence. From this website, different information such as mineral occurrences, mines, geology, structures, topography, mining licenses, etc. is shown.

For this research, the processing of geological data involved the clipping of the geological data with the study’s area shapefile extent using the clipping tool in ArcMap to obtain the geology of the study area only. It also involved the conversion of the clipped data from polygon to raster format. This step was essential as it helped to acquire data in raster format that matched with other layers in the weighted overlay for model generation.

3.7.3 Geophysical Data

The geophysical data for this research was obtained from a geophysical consultant at the University of Dar es Salaam, Dr. Isaac M. Marobhe. The data provided by the consultant included Total Magnetic Intensity (TMI). The data had an altitude of 120m above the ground, line spacing of 1km and 50m sampling. The Survey methodology used to acquire the data was airborne surveys.

The data was provided in form of x, y and z values. They were converted into csv format so as to be with the ArcMap software. The data was then interpolated using Inverse Distance Weighted (IDW), an interpolation method in ArcMap. This helped to fill the gaps that the dataset seemed to have. The data was converted into raster data format so as to be reclassified into five classes showing the values or the Total Magnetic Index values. For the magnetic anomalies map layer (geophysical map layer), where there are high magnetic anomalies, means there is high deposit of iron, nickel or other minerals. This implies that the deposition of minerals such as gold in those areas will also be high (Dentith and Mudge, 2014).

3.7.4 Soil Type

The Soil Type data for this research was obtained from The Tanzania Soil Information Service (TanSIS) as Vector data in form of shapefile for the whole country which was in Geographic Coordinate System of WGS 1984. It was converted into Arc 1960 Zone 36S, a local coordinate system and later on was clipped using the extent of study area shapefile. The clipped shapefile showed the soil information pertaining to Tarime district only. The data was then converted from polygon to raster data format so as to match with the other datasets which are input to the weight overlay tool as raster data. The raster data was then reclassified into five classes with five soil types that are Eutric Leptosols, Umbric Nitisols, Eutric Planosols, Luvic Phaeozems, and Eutric Fluvials. Soil is a product of rocks, formed through a complex process called weathering, which involves breakdown and alteration of rocks and minerals over time. These soil types may also result from different lithologies from the area hence they can also contribute to gold exploration process.

3.7.5 Sentinel 2A

The Sentinel 2A satellite image was obtained from Copernicus Open Access Hub. It included the recent data of 2022 and had a spatial resolution of 10m. Sentinel 2A image was utilized for land cover purposes which was essential for this study. The image was classified in Erdas Imagine using supervised classification whereby training samples basing on the crops, water, rangeland, built up, and vegetation (trees) were collected. The algorithm used was maximum likelihood.

For gold exploration, land cover important. For the land cover of this research, vegetation can indirectly indicate gold mineralization through the concept of biogeochemical cycling. Certain types of vegetation known as indicator plants may exhibit anomalous gold concentrations in their tissues. Water bodies such as rivers, streams, and lakes can play a role in transporting and depositing gold particles. Like vegetation, certain crop species may exhibit anomalous gold concentration in their tissues due to their ability to uptake and accumulate trace elements from the soil. Built up areas such as urban or residential developments, may have limited influence on indicating gold mineralization. Rangeland, characterized by natural grasslands or grazing areas, may have a limited direct influence on indicating gold mineralization (Stančič *et al.,* 2021).

3.7.6 Administrative Boundary

The administrative boundary data as the spatial information that delineates the administrative divisions of the country where the study area came from, was collected from DIVA-GIS website and was used to provide Spatial Context and facilitated Spatial Integration and Analysis. The administrative boundary was used to show the extent of Tarime district and for other purposes such as clipping other raster data such as geological, soil, geophysical, and sentinel 2A image. The aim was to obtain information of each dataset that rely only within the study area. It was also used for locating the study area of Tarime district.

3.8 Reclassification

Data were reclassified in ArcMap software according to their criteria. The following were processes before reclassification:

i. Vector data which involved geology and Soil type were first Clipped using Clip tool
ii. Conversion of geology and soil type feature class data into raster format in Arc toolbox (Conversion tool-To raster-feature to raster)
iii. Reclassification done using reclass tool found in Spatial analyst tools in ArcMap. Reclassification process included changing geological, geophysical, lineament density,

soil, and land cover layers to have the same number of classes which was specified to be five classes per each layer.

3.9 Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is widely recognized as a highly effective approach for conducting multi-criteria analysis. This method offered a valuable assistance by evaluating the relative significance of multiple criteria or options with respect to given criteria of this study. (Saaty, 1990). The primary objective behind adopting this approach was to facilitate decision making in multi-criteria scenarios. By converting pairwise comparisons among the standards into weights and numerical values, the AHP effectively demonstrates the relative importance of these criteria (Saaty1980 and Saaty, 1990). This method played a pivotal role by providing a structural framework for weighing criteria and determining their relative importance, thus aiding in the decision-making process.

3.9.1 Definition of Criteria

The Criteria used in this study were geological criterion, geophysical criterion, lineament density criterion, soil type criterion, and land cover criterion. Table 3.2 sourced from (Wahab, 2004) (Kebele *et al*., 2020) and (IMM:Vol. 7, 1989), shows the Criteria, classes class ranges and ratings, and class ratings for each class (Aktaş *et al.*, 2013).

Table 3. 2: Criteria Used in this Study

CRITERIA	CLASS	CLASS RANGES AND RATINGS	CLASS RATINGS
GEOLOGY	Granitoids, migmatite, mafic, ultra-mafic, meta sediments	High	4
	Volcanic lavas	Moderate	3
	Fine-Coarse clastic sediments	Low	2
	Sandy, gravelly, silty sediments	Very Low	1
	mafic volcanic, meta basalts, Phyllite, BIF	Very high	5
GEOPHYSICAL	33159.49219-33834.4977	Very Low	1
	33834.49771-34078.24969	Low	2
	34078.2497-34265.75123	Moderate	3
	34265.75124-34678.2546	High	4
	34678.25461-35550.13672	Very High	5
LINEAMENT DENSITY	0-0.257840057	Very Low	1
	0.257840057-0.57791737	Low	2
	0.57791737-0.88021261	Moderate	3
	0.88021261-1.235854068	High	4
	1.235854068-2.267214298	Very High	5
SOIL TYPE	Eutric Leptosols	Very Low	1
	Umbric Nitisols	Low	2
	Eutric Planosols	Moderate	3
	Luvic Phaeozems	High	4
	Eutric Fluvials	Very High	5
LAND COVER	Built-up	Very low	1
	Crops	Low	2
	Range Land	Moderate	3
	Water	High	4
	Vegetation	Very High	5

3.9.2 Evaluation of Criteria through Pairwise comparison and Weight Determination.

In this phase of the procedure, the relative significance of each criterion was established by means of pairwise assessments. For instance, the evaluation involved comparing the importance of option 1 to option 2. Ratings ranging from 1 to 9 were utilized to indicate different levels of significance, ranging from equal to moderate, strong, and very strong importance. The intensity of importance, their definition, and explanation is shown in table 3.3. It is crucial to ensure the consistency ratio, which guarantees the accuracy of the pairwise comparison procedure and reduces any disparities between comparisons and choices. According to (Kebele *et al.*, 2020) it is recommended that the consistency ratio should be maintained at 10%. In this study, the consistency ratio was found to be 0.079, indicating a successful and consistent pairwise comparison process.

Table 3. 3: Intensity of Importance

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favor one activity over another
5	Essential or equal importance	Experience and judgement strongly favor one activity over another
7	Demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent Judgement	When compromise is needed

3.9.3 Development of Pairwise comparison matrix

To construct the matrix, the assessment of attribute importance from table 3.4 was considered. The criteria employed to identify gold potential exploration areas in this scenario encompassed geological, geophysical, lineament density, soil type, and land cover. The pairwise comparison matrix for AHP is presented in the table 3.4.

Table 3. 4: Pairwise Comparison Matrix

Criteria	Geological	Geophysical	Lineament Density	Soil Type	Land Cover
Geological	1	3	5	5	7
Geophysical	0.333	1	3	5	5
Lineament Density	0.2	0.333	1	3	5
Soil Type	0.2	0.2	0.333	1	3
Land Cover	0.143	0.2	0.2	0.333	1

Table 3. 5: Pairwise Matrix comparison

Criteria	Weight (% of Influence)
Geology	48.717
Geophysical	26.196
Lineament density	13.837
Soil	7.256
Land cover	3.995

Table 3.5 indicates the weights in percentage of the criteria used for this study that were automatically generated by the AHP tool using the pairwise comparison matrix in table 3.4. To evaluate whether they are relevant, some mathematical operations are performed which also shows the scenario that took place behind the scene.

3.9.3.1 Calculation of Nth root of product value and weight

The determination of the nth root of the value and weight of a product is performed by calculating the combined values within each row of a pairwise matrix presented in table 3.4 and finding the nth root of their product. The relative weight or significance of the criteria known as Eigenvector is dependent on this nth root of the product. To calculate the weights of each criterion, the specific nth root of the product is divided by the total Nth root of all product values (Saaty, 1980). Table 3.6 provides a summary of the Nth root values and weights assigned to each criterion

The Nth root is computed as the square root of the product obtained by multiplying the entries in each row by 5, as shown in equation (3.1).

Nth root = $\sqrt[5]{(\text{Product of the entries in each row})}$………………………….….….……... (3.1)

For instance, the Nth root for the Geological Criterion can be calculated as;

$$\sqrt[5]{(1 * 3 * 5 * 5 * 7)}$$

The weight for each criterion is determined by dividing the Nth root of the product value by the total Nth root of all product values, as expressed in equation (3.2):

Weight= Nth root of product value / total Nth root of product values ……..……….…. (3.2)

Table 3. 6: The nth root and Weight of each Criteria

CRITERIA	NTH ROOT OF THE PRODUCT	WEIGHT
Geological	3.499708	0.48514615
Geophysical	1.903327	0.26384075
Lineament Density	0.999800	0.13859703
Soil Type	0.525200	0.07280572
Land use	0.285738	0.03961036
TOTAL	7.213719	1

From table 3.6, it was noted that the weights of the criteria corresponded to the weights automatically generated by the AHP tool.

3.9.3.2 Calculation of vector value and eigenvalue

The determination of vector values and eigenvalues (λmax) played a crucial role in calculating the Consistency Index (CI) and Consistency Ratio (CR). By multiplying the λmax values on the right of a judgement matrix with the corresponding eigenvector, a new vector is obtained.

The calculation of vector values was performed as follows:

For the geological criterion, the vector value is obtained by multiplying the weights (0.4851, 0.2638, 0.1386, 0.0728, and 0.0396) with their respective scores (1, 3, 5, 5, 7), resulting in a vector value of 2.6107. Similarly, the vector values for geophysical, lineament density, soil type, and land cover criteria were calculated and shown in table 3.7.

Table 3. 7: Criteria with their Vector values

CRITERIA	VECTOR VALUE
Geology	2.6109546268
Geophysics	1.4032658832
Lineament Density	0.7399541774
Soil type	0.3875869853
Land Cover	0.2137181174

The vector values of the five elements are then used to estimate the eigenvalues (λmax) by dividing each vector component by its corresponding weight value (Saaty, 1980). For example, the eigenvalue for the geological criterion was calculated as 2.6107 divided by 0.4851, resulting in 5.3818. Likewise, the eigenvalues for geophysical, lineament density, soil type, and land cover are were calculated too and shown in table 3.8.

Table 3.8: Criteria with their Eigen Values

CRITERIA	EIGEN VALUE
Geology	5.381789852
Geophysical	5.318809449
Lineament Density	5.338889288
Soil Type	5.323578828
Land Cover	5.395510723

The average of these eigenvalues is computed as 5.351715628, which serves as the estimate for the eigenvalue (λmax). Since λmax is not less than 5 (the number of attributes), there is no error in the calculation.

3.9.3.3 Calculation of Consistency Index (CI) for a matrix

The computation of the Consistency Index (CI) for a matrix can be performed using the following formula, as shown in equation (3.3);

$$\mathrm{CI} = (\lambda\mathrm{max} - \mathrm{n})/(\mathrm{n} - 1) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

In this equation by (Saaty, 1980), n represents the number of criteria present in the matrix. By substituting the values, the CI can be calculated as follows:

CI = (5.351715628 - 5) / (5 - 1) = 0.087928907

Therefore, the consistency Index (CI) for the given matrix is determined to be 0.087928907

3.9.3.4 Calculation of Consistency Ratio (CR)

According to (Saaty, 1980), the Consistency Ratio (CR) can be calculated using the following formula, as shown in equation (3.4):

CR = CI / RI…………………………………………………………………………………..… (3.4)

Here, RI represents Random Index obtained from a large sample matrix (table 3.9) derived from Saaty (1980). The upper row of the table corresponds to the number of criteria, while the lower row provides the corresponding random Index (RI) values.

To calculate the CR, we divide the CI value of 0.087928907 by the RI value of 1.12:

CR = 0.087928907 / 1.12 = 0.0785079527

Therefore, the Consistency Ratio for the given matrix is determined to be 0.0785079527 which is equivalent to 0.079.

According to CR condition, if the CR value is less than 0.10 (CR<0.10), the pairwise comparison are considered acceptable (Saaty, 1980). However, if the CR value is equal to or greater than 0.10 (CR≥0.10), it indicates unreliable decision-making.

Table 3.9: Random Index (RI) of the Corresponding values

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

3.10 Weighed overlay

The concept of a weighted overlay entailed conducting a multiplication-based overlay operation among multiple layers. It involved the multiplication of all reclassified layers containing weighted suitability criteria in order to obtain a comprehensive output. Each criterion was assigned scale values, and the weights for input raster were determined through the implementation of the Analytic Hierarchy Process (AHP) method.

3.10.1 Model Execution

The process of running the model served as the final step to assess the successful execution of all preceding procedures and obtain the desired output. The Weighted Overlay model was employed to identify suitable areas for potential gold deposit in Tarime district.

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

4.1 Overview

This Chapter provided an in-depth analysis and discussion of the research findings, primarily presented in the form of maps. Its primary objective is to assess whether the study's objectives have been achieved or not and the methodology used is reliable or not

The research result analysis encompasses the following components: Analytic Hierarchy Process (AHP), lineaments analysis, reclassified map layers of all criteria including reclassified map of Tarime Geological Structure, Reclassified map of geophysics, Reclassified map of lineament density, Reclassified map of Tarime Soil Type, Reclassified Map of Tarime land Cover, and Suitability Map of Potential Zones for gold deposit in Tarime district, Gold potential Map validated with mineral occurrences, and Gold Potential Map validated with existing Mines in Tarime district.

4.2 Lineaments

Mapping geologic lineaments is important for mineral exploration because of their potential for harboring ore bodies. In this study, lineaments were extracted from hillshade images which enhance these patterns (See figure 4.1). The image result of hillshade process showed linear features, such as valley, lineament or mountain peak on satellite image looked more prominent than surrounding area. The red lines represented the digitized lineaments from the hillshade. high values (379.938) represented mountain peaks while the lower values (from 0 to -1) or shades represent valleys or low land areas (See figure 4.1 and figure 4.2). The lineaments were then used to create lineament density (See figure 4.3).

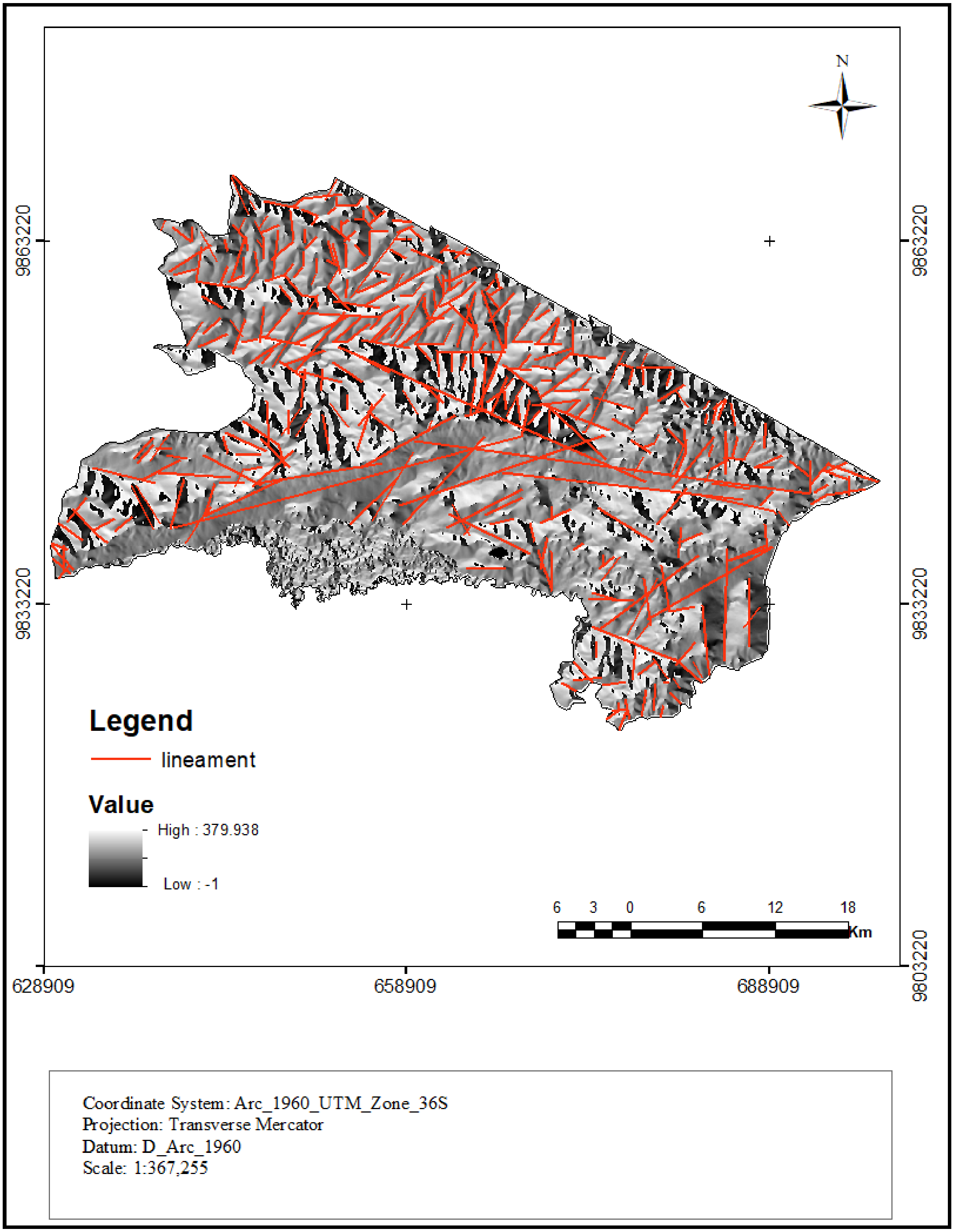


Figure 4. 1: Hillshade

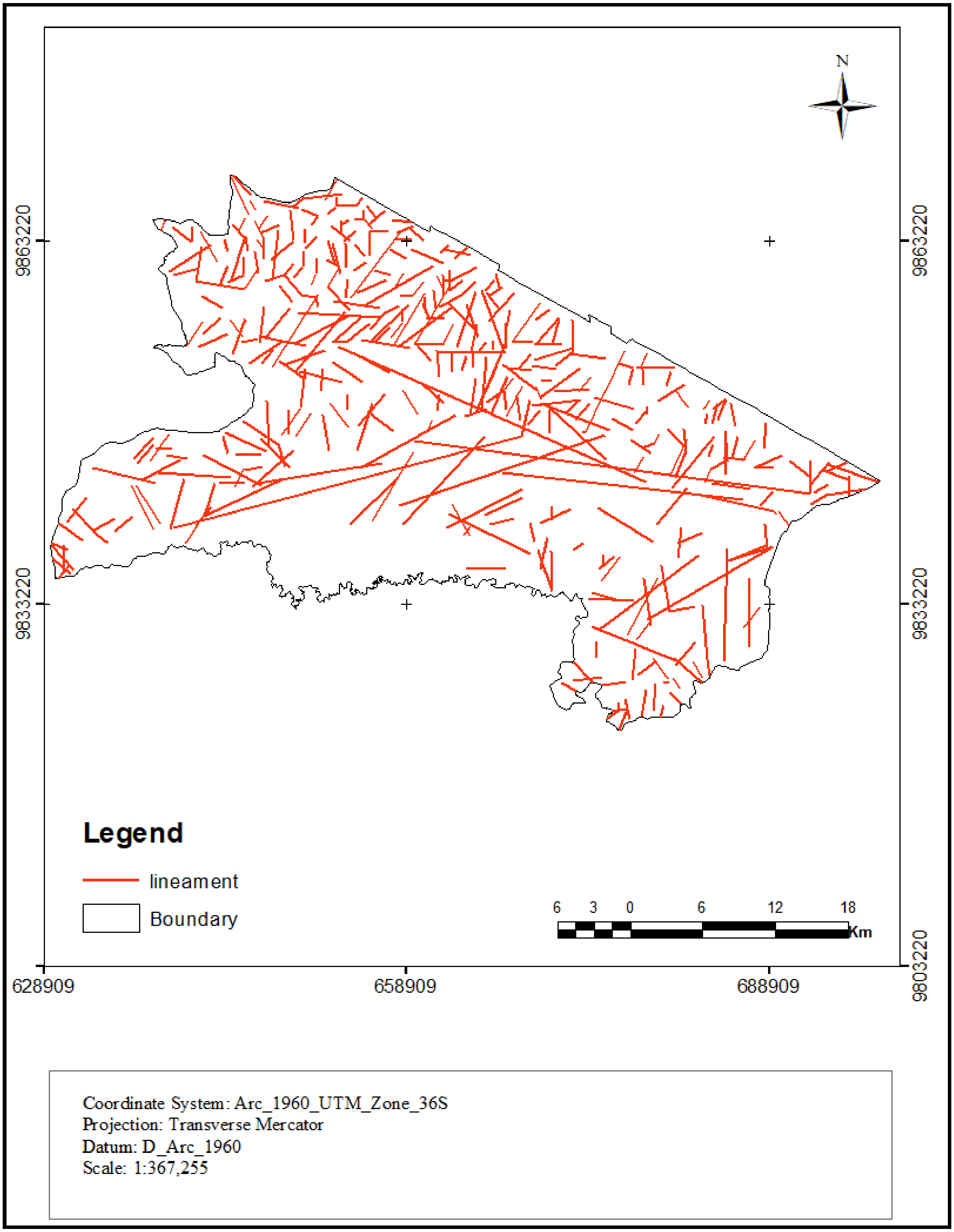


Figure 4. 2: The extracted Lineaments

4.2.1 Lineament density

The lineament density generated depended on the extracted lineaments. From the line density tool in ArcMap, the extracted lineaments were used as input polyline features and the lineament density was generated. Lineament density was essential for defining the extent of the buffer from the lineaments. The Buffering occurred on the areas covered with the digitized lineaments (See figure 4.3) whereby some lineaments appeared to cross each other, which defined that the area is likely to contain mineral deposit. the values represent the closest distance from the line to the furthest distance from the line. The blue color with the ranges 1.235854069 – 2,267214298 represents all areas that are very close to the lines. The ranges with lower value meant that the areas were very far from the lineament, those with moderate values meant that the area were near, while those with higher values meant that the areas were within the buffering distance. These values are what were termed buffering distance or range (See Figure 4.3).

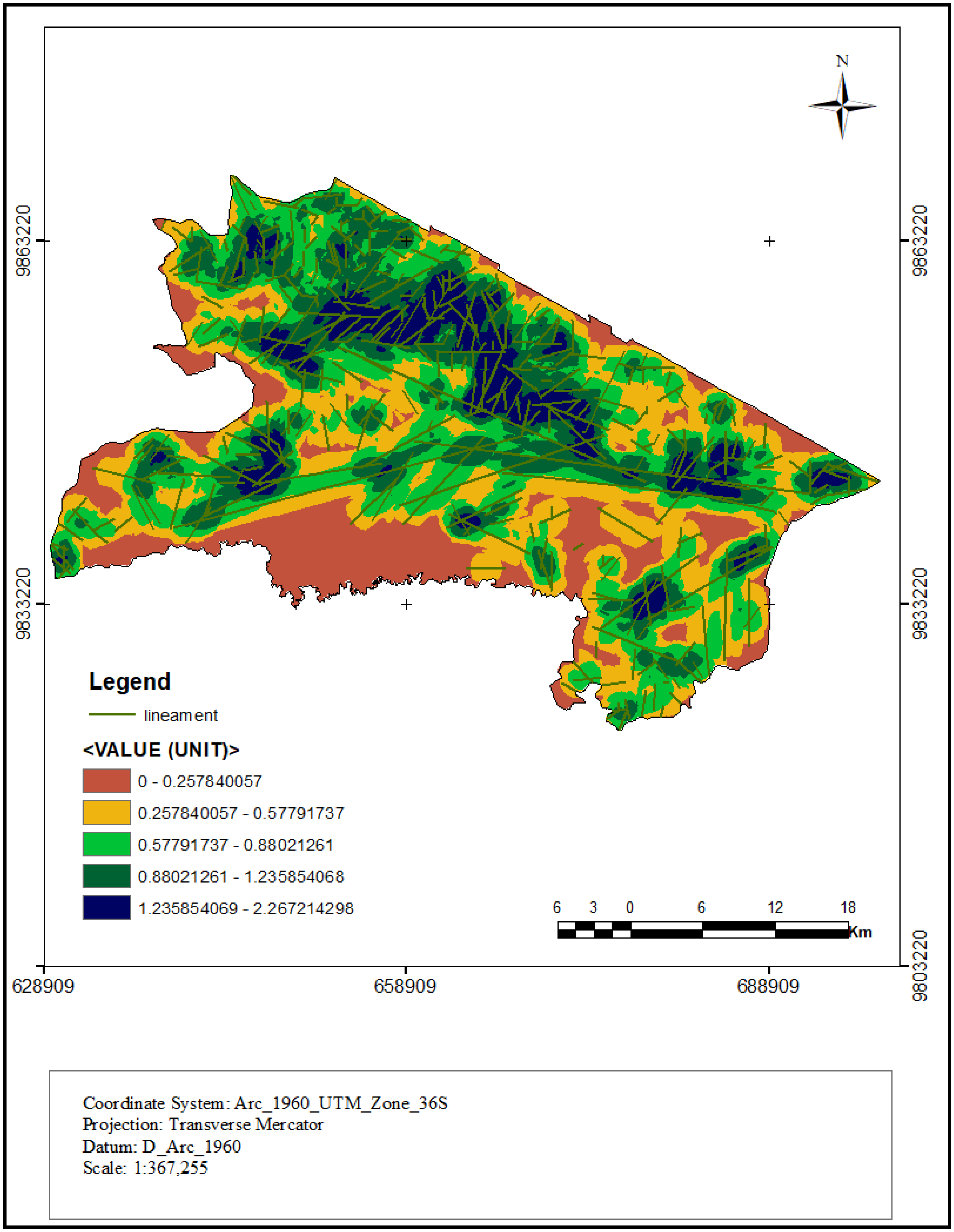


Figure 4. 3: Lineament Density

4.3 Reclassification

Reclassification involved changing geological, geophysical, lineament density, soil, and land cover layers to have the same number of classes which was specified to be five classes per each layer. The five classes for each criterion were specified to be very less suitable, less suitable, moderate suitable, high suitable, and very high suitable in terms of gold exploration purposes.

For the reclassified geological criterion, lithology of sandy, gravelly, and silty sediments represented areas with very low probability of finding gold deposit, while Fine-coarse clastic sediments represented areas of low probability of finding gold deposits. Volcanic lavas (nephelinite, phonolite, alkali basalts) lithologies represented areas with moderate gold deposits. Those with granitoid, migmatite, mafic and ultramafic, and meta-sediments meant high probability of gold deposit while those with Mafic volcanic, meta-basalts, phyllite, and BIF lithologies meant areas with very high probability of finding gold deposit. (See figure 4.4).

Geophysical map layer consisted of five classes. (See figure 4.5). These classes also ranged from very high suitable, high suitable, moderate suitable, less suitable, and very less suitable. Very high suitable areas contained high magnetic index which is a crucial indicator of mineral presence. Very less suitable areas contained less magnetic index meaning that the probability of finding mineral deposit in those areas was also low.

Reclassified Lineament density map layer consisted five classes too. (See figure 4.6). The classes consisted five different colors which indicated distances or ranges from the lineaments outwards. Brown color indicated those buffer zones nearer to the lineaments meaning that they were very high suitable in finding mineral deposits. The white color indicated those areas or zones that were very far from the lineament, meaning that those areas contained none or very low mineral deposit. (see figure 4.6). For the reclassified map of soil, five classes were shown which also indicated those areas that are likely to contain very high, high, moderate, low, and very low mineral deposit. (See figure 4.7). For the land cover reclassified map layer, there were also five land covers which meant five classes. The land covers were water, vegetation, crops, rangeland, and built up which respectively represented very high, high, moderate, low, and very low probabilities of finding gold deposit in the respective areas. (See figure 4.8).

The very high suitable values were highly considered to have high effect than other values in the weighted overlay, meaning that they are the area that are likely to contain very high gold deposit.

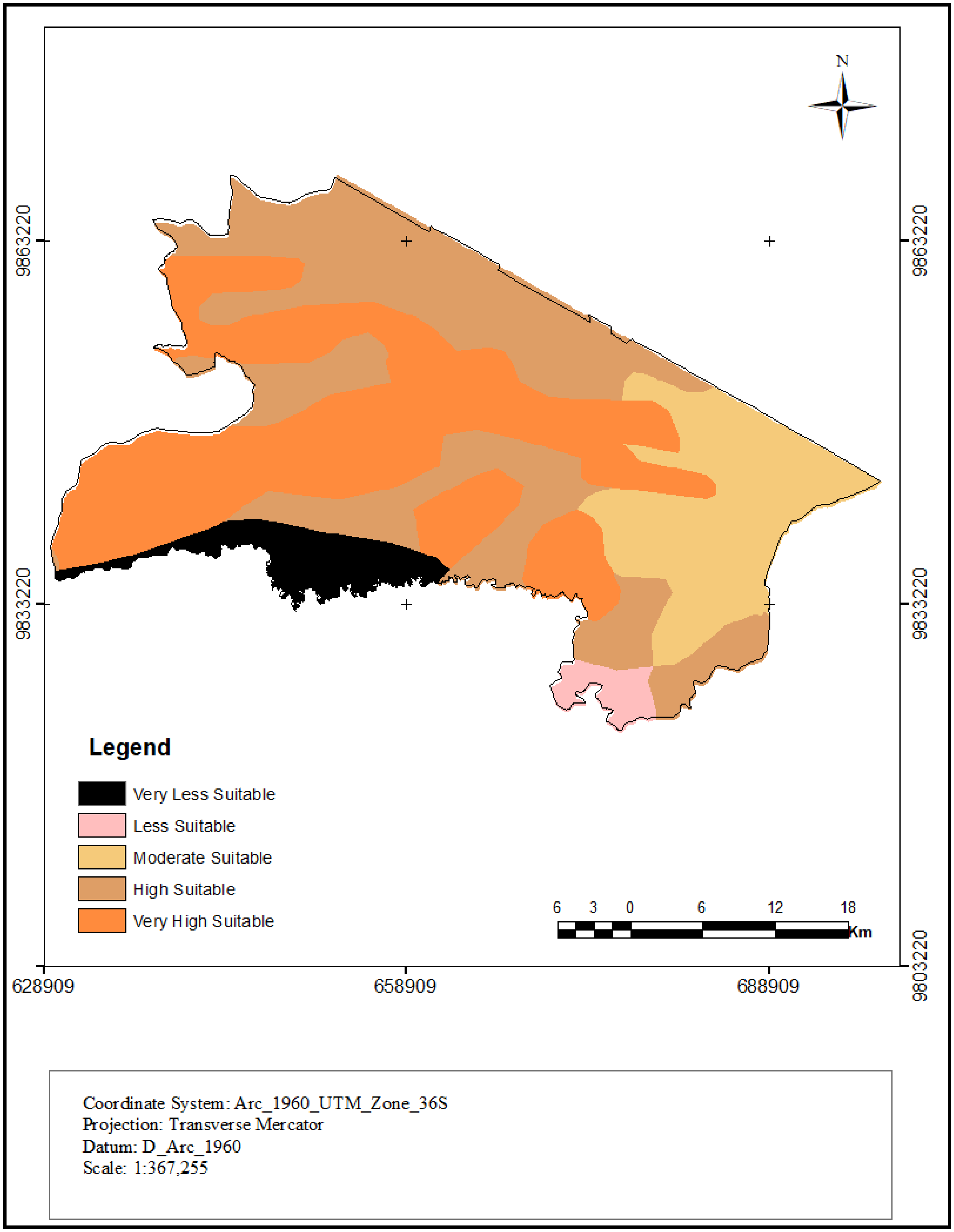


Figure 4. 4: Reclassified Map of Geological Criterion

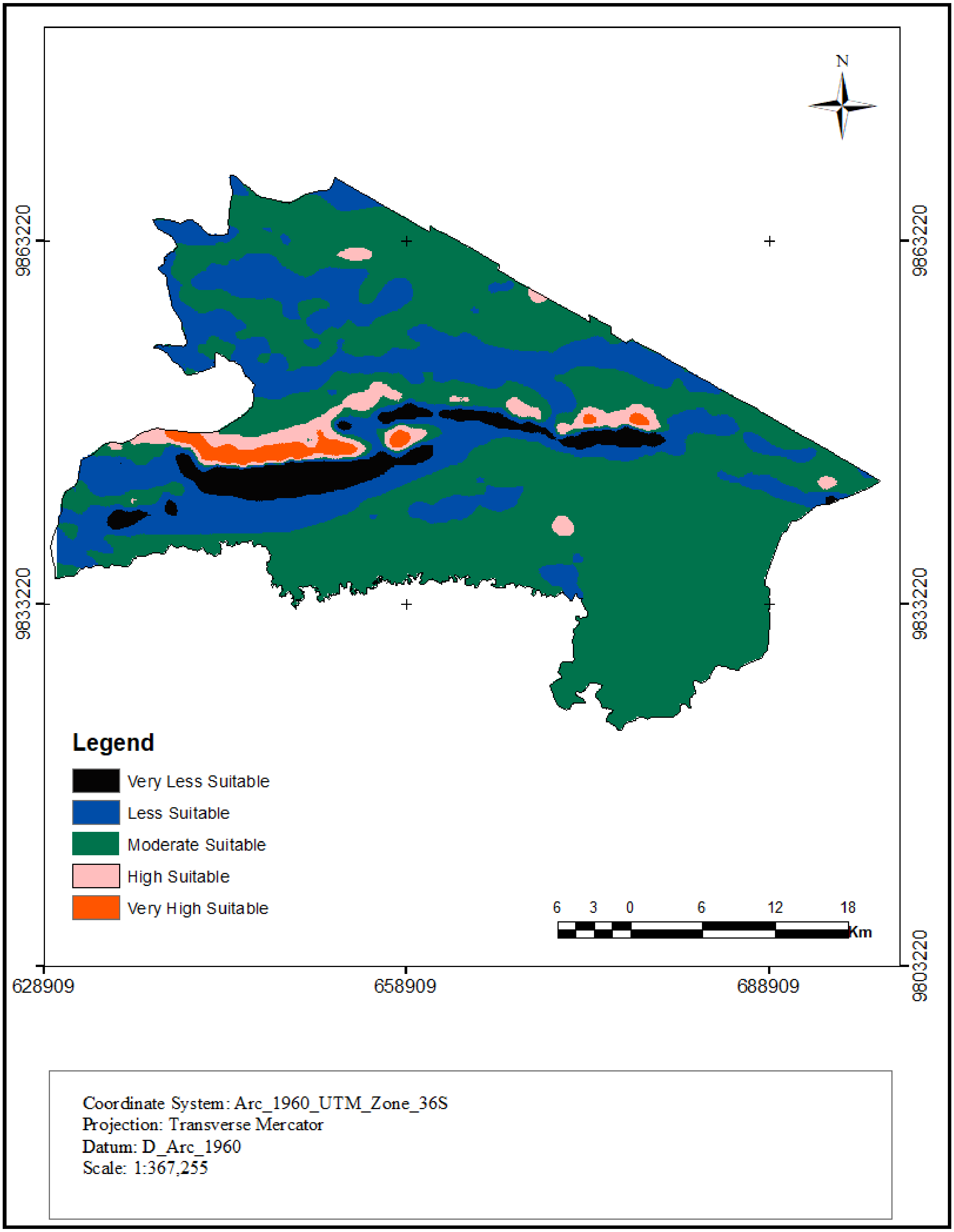


Figure 4. 5: Reclassified Map of Geophysical Criterion

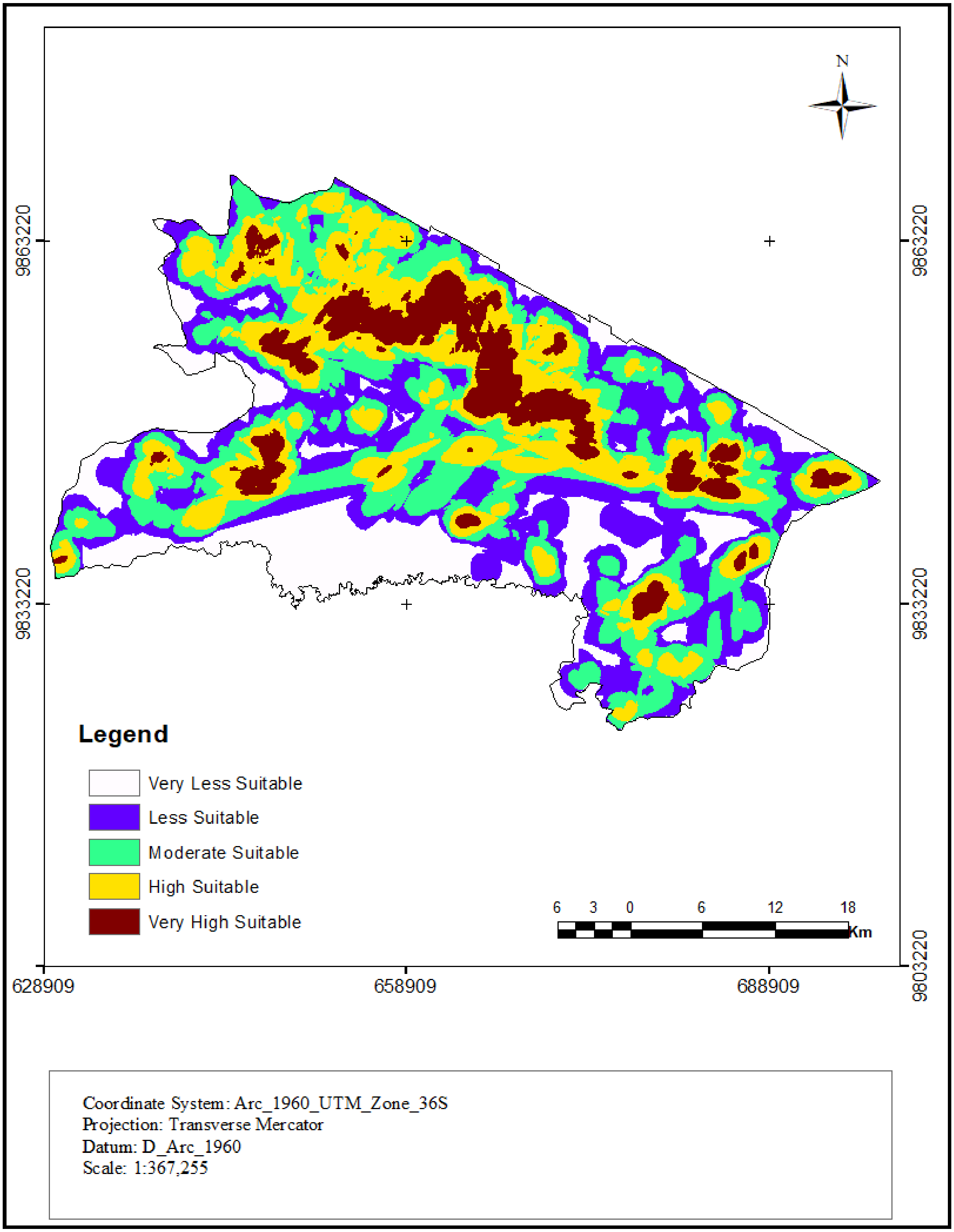


Figure 4. 6: Reclassified Map of Lineament Density Criterion

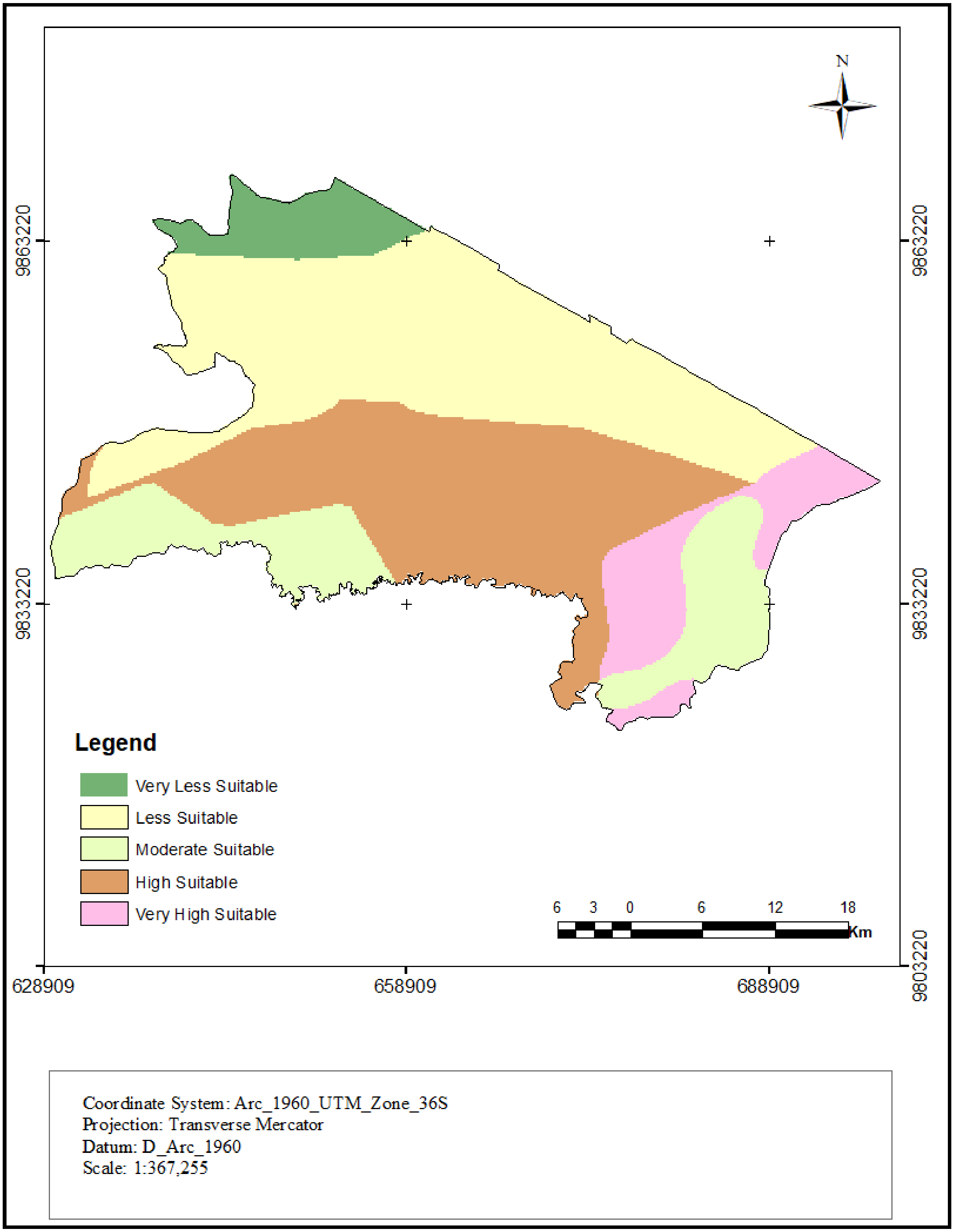


Figure 4. 7: Reclassified Map of Soil Type Criterion

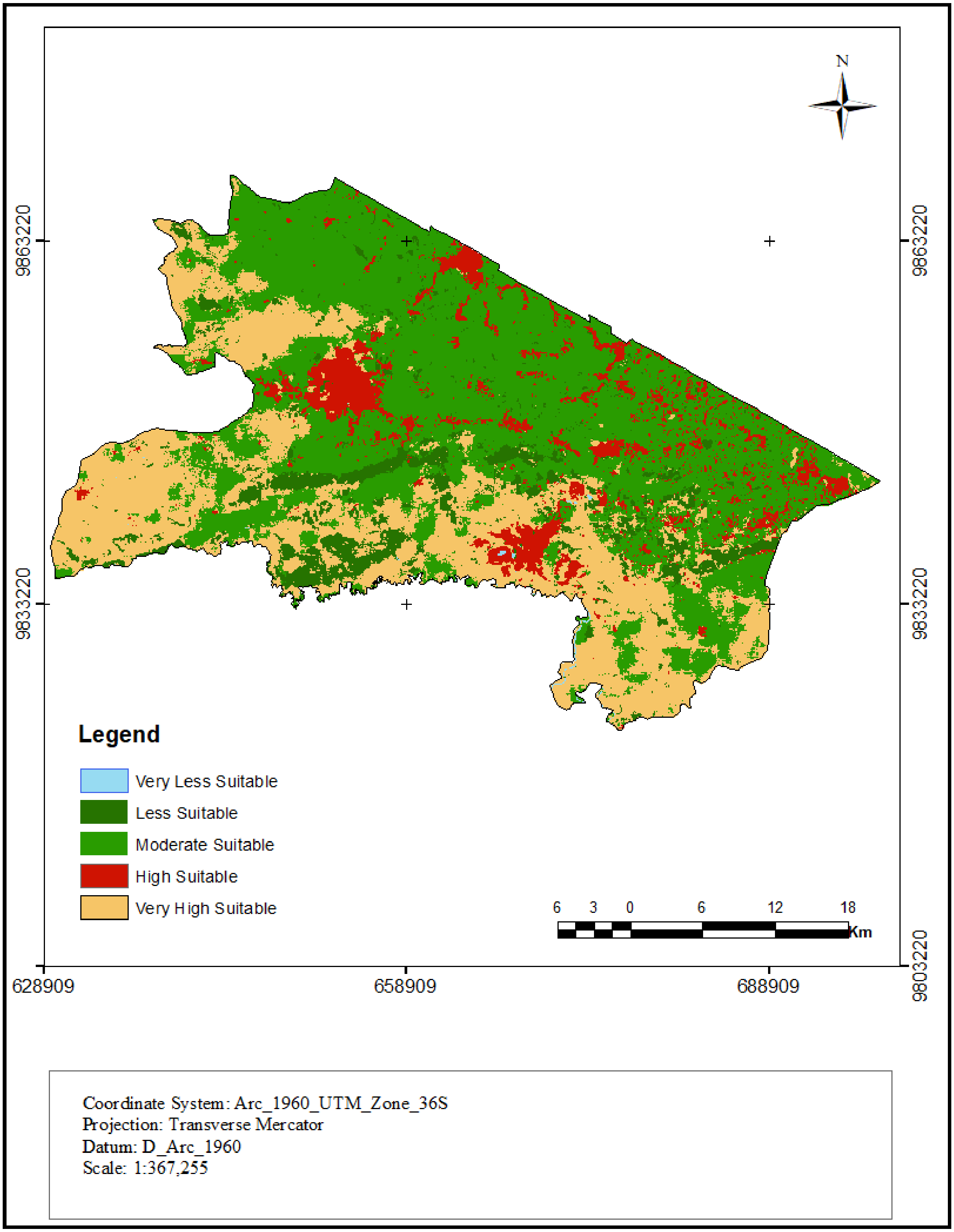


Figure 4. 8: Reclassified Map of Land Cover Criterion

4.4 Analytic Hierarchy Process (AHP)

The AHP involved the definition of criteria, evaluation of the defined criteria through pairwise comparison and weight determination, development of pairwise comparison matrix, and calculation of consistency ratio (CR) which was calculated by various processes such as Calculation of Nth root of the product value and weight, calculation of vector value and eigen value, and finally calculating the Consistency Index (CI) which together with the Random Index (RI) led to determination of the Consistency Ratio. The CR given by the AHP tool was 0.079and after calculations, it was 0.0749 which mean it is relevant and allowable for the weights to be used in the weighted overlay process.

The weights in percentage obtained from the AHP tool were 48.717, 26.196, 13.837, 7.256, and 3.995 for geological. Geophysical, lineament density, soil, and land cover criteria respectively, which altogether summed up to 100. After the calculation of the weights, they were proved to be 0.4851, 0.2638, 0.1386, 0.0728, and 0.0396 for geological. Geophysical, lineament density, soil, and land cover criteria respectively, which also summed up to 1 which when expressed in percentage is 100 too. From table 3.6, it was noted that the weights of the criteria corresponded to the weights automatically generated by the AHP tool.

The calculated weights were used to obtain the vector values for each criterion (see table 3.7). The obtained vector values were used to calculate the Eigen values for each criterion (see table 3.8). the eigen values were used to calculate the consistency index (CI) and then the consistency ratio (CR) was finally obtained using the calculated Consistency index and the available Random Index (RI) which is constant for each given number of criteria.

Therefore, the Consistency Ratio for the given matrix was determined to be 0.07849. According to CR condition, if the CR value is less than 0.10 ($CR<0.10$), the pairwise comparison are considered acceptable. However, if the CR value is equal to or greater than 0.10 ($CR\geq0.10$), it indicates unreliable decision-making. For this case, this method proves to be reliable decision making.

4.5 Weighted Overlay

In the weighted overlay, the reclassified layers were used as input raster starting with geological, followed by geological, line density, soil and finally land cover layer. in the weighted overlay table, the respective layers were assigned with their respective weights which were, 49, 26, 14, 7, and 4 for geological. Geophysical, lineament density, soil, and land cover criteria respectively.

The scale values were also specified and the model was allowed to run to obtain the final output which showed potential areas for gold exploration (see figure 4.9).

4.5.1 Gold Potential Map Areas

The final output or result represented gold deposit potential areas. The result showed that some areas or zones had very high gold deposit, while others had high to moderate, low and very low gold deposit potential areas (see figure 4.9). The red color represented those areas that are likely to contain very high gold deposit. The orange color only represents those areas that are just likely to have high potential gold deposit. The yellow color represents those areas that are likely to contain moderate gold deposit. The pale green color represents those areas with low concentration of gold deposit, meaning that the probability of finding gold deposit in those areas is low. Unlikely for the dark green color, this represent those areas that could have very low gold deposit in the area or none, meaning that there is no the probability of finding gold deposit in those areas, or the probability is very low. From figure 4.9, most wards consisted of areas with all characteristics meaning that there was very high, high, moderate, low, and very low probability of finding gold deposit in different zones of the same ward.

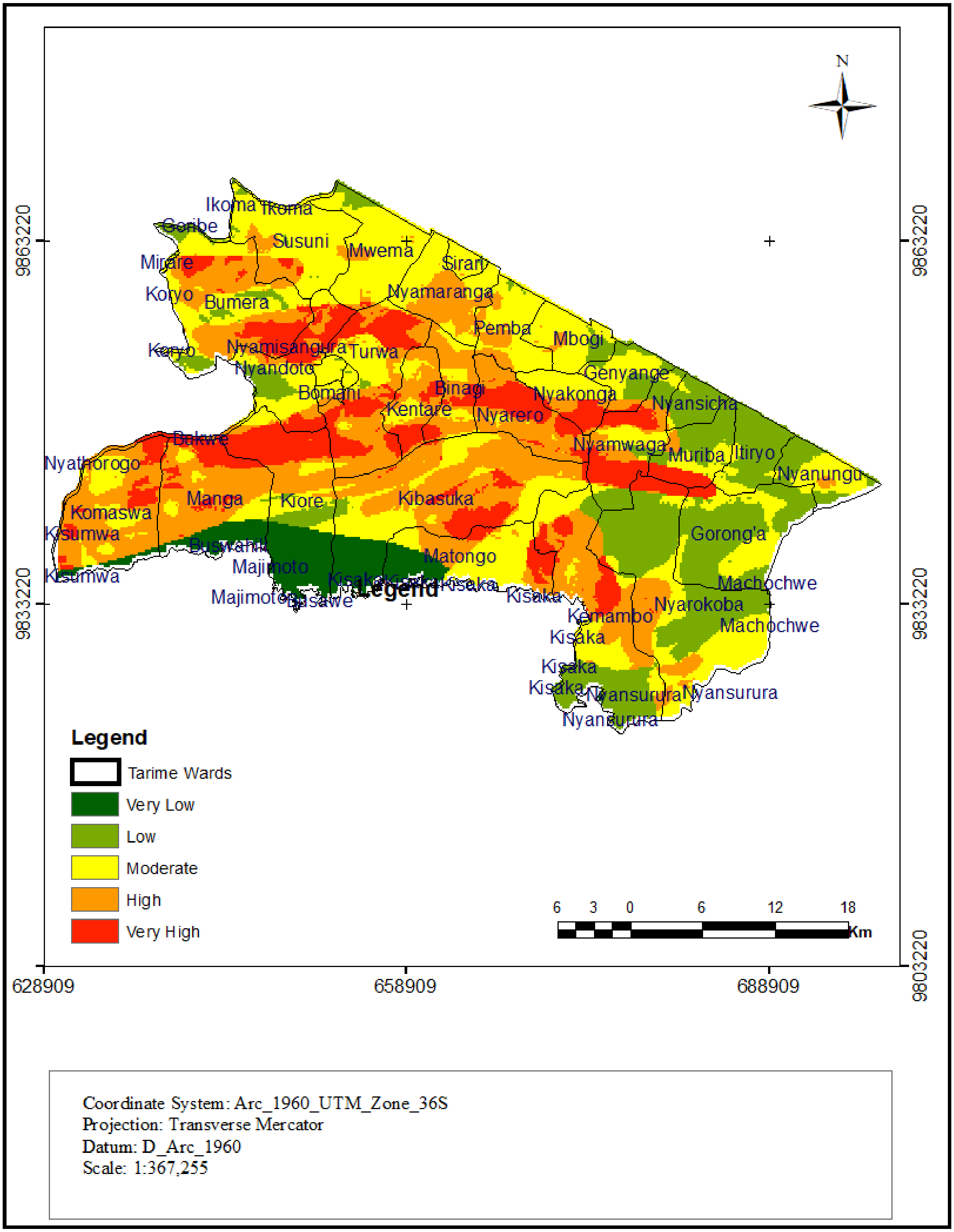


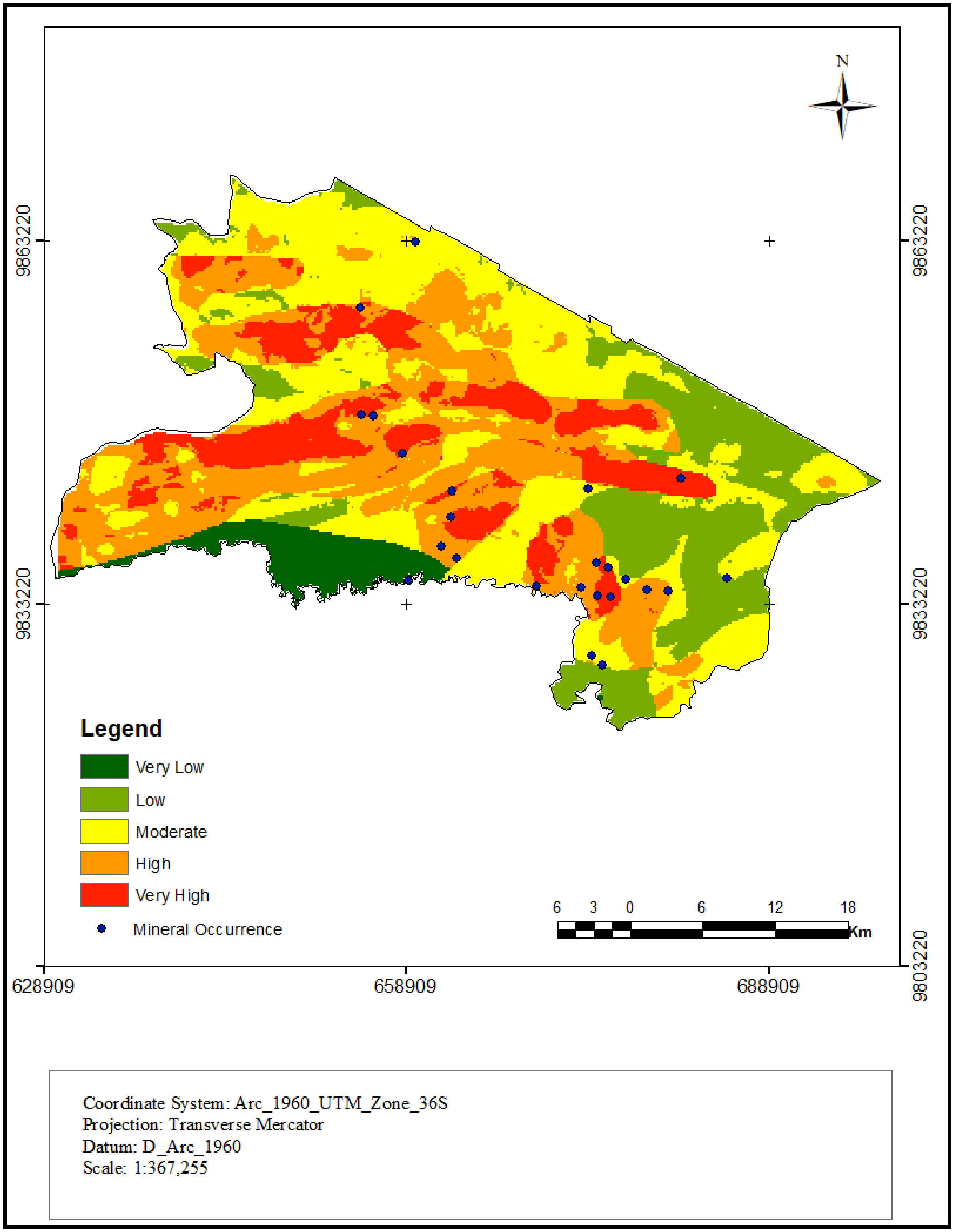
Figure 4. 9 Potential Gold Areas Map

4.5.1.1 Validation with Observed Mineral Occurrence

During the validation process, the map was compared with known mineral occurrences in the study area. The objective was to determine whether the map accurately predicted the location of these mineral occurrences or not, thereby providing confidence in the accuracy and reliability of the map.

From (figure 4.10), it was seen that most mineral occurrences lie or fall in areas that are likely to contain very high gold deposit. Others fall in those areas with high and few of them fall in those areas that have moderate probability of finding gold deposit. No mineral occurrences have fallen in the areas with very low potential of gold deposit in the area.

By analyzing the agreement between the map and known mineral occurrences, it was able to assess the performance of the AHP method in predicting mineral potential. Areas where the map closely aligned with mineral occurrences were considered indicative of accurate prediction and increased the confidence in the map's reliability.



4.10: Gold Potential Deposit Map Validated with Mineral Occurrences

4.5.1.2 Validation of Gold Potential Map with Existing Mines in Tarime district

The map was validated by comparing it with the location of existing mines in the study area. the aim was to determine if the map successfully identified the areas where mining activities were currently taking place, thus demonstrating the effectiveness of the AHP method in identifying rich mineral zones. (see figure 4.11).

Furthermore, the map was cross-referenced with the locations of existing mines to evaluate its ability to identify areas of active mining. If the map successfully captured the spatial distribution of existing mines, it provided further evidence of its reliability in identifying mineral-rich zones.

Overall, the validation of the map against observed mineral occurrences and existing mines provides insights into the reliability and robustness of the AHP method for determining mineral potential in the study area. the findings from this validation process formed the basis for refining the methodology and enhancing its accuracy for further mineral exploration efforts.

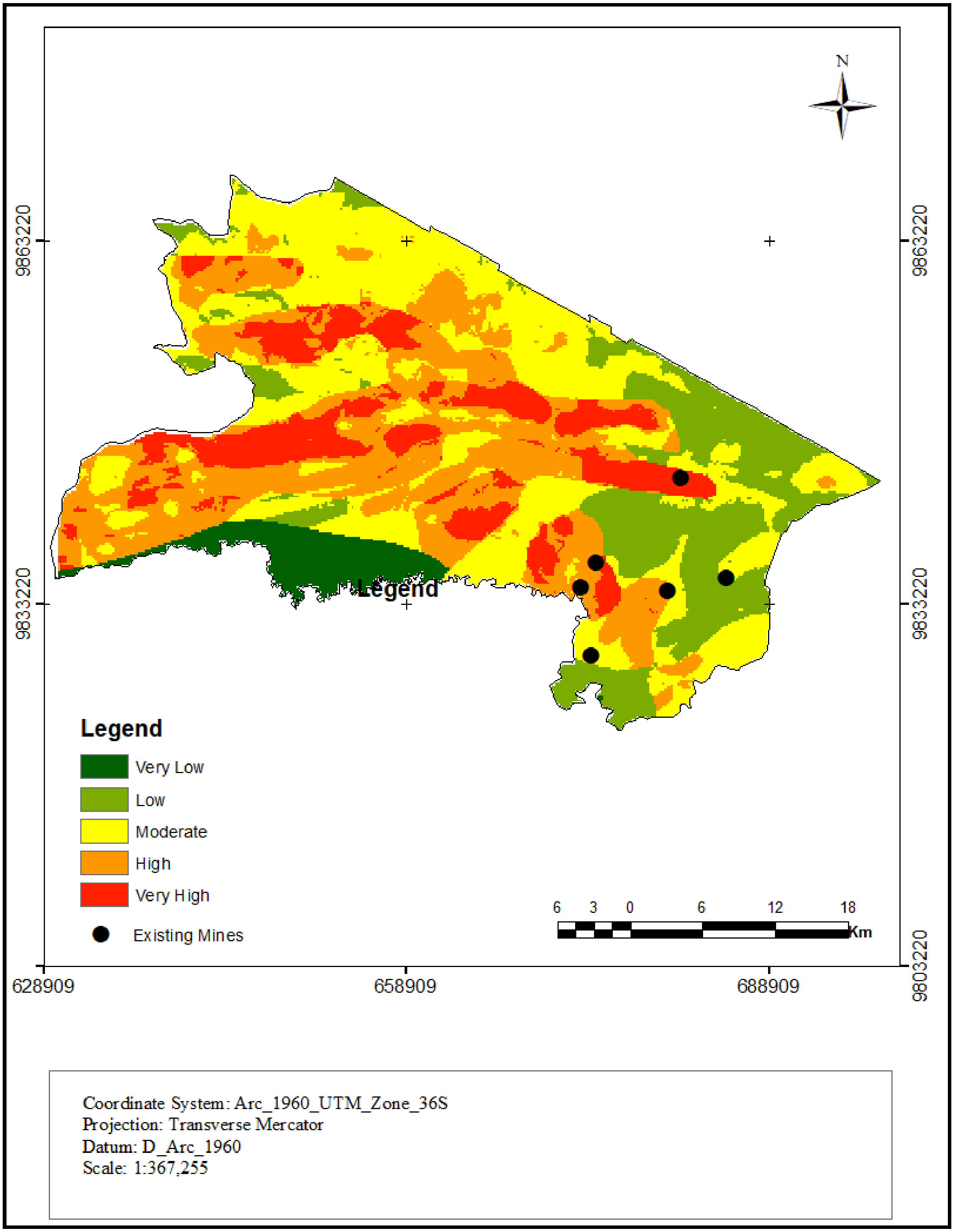


Figure 4.11: Gold Potential Deposit Map Validated with Existing Mines

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

To this study of identifying gold potential areas, the integration of GIS and RS data has provided valuable insights into the geological potential of the Tarime district for gold exploration. Several high-priority targets have been identified based on geological indicators such as rock types, structures and soil. Ground truthing has validated the presence of gold mineralization in the identified areas.

This study confirms the effectiveness of utilizing GIS and Remote Sensing techniques to identify potential areas for gold exploration. The utilization of the Analytic Hierarchy Process (AHP) and Weighted Overlay methods have to be efficient in determining areas associated with gold deposits.

The identification of extracted lineaments has been instrumental in recognizing fracture patterns that may have served as pathways for gold-bearing zones. The validation of the results by using mineral occurrence and existing mines shows that the results are relevant. Therefore, this research conclude that the methodology utilized can be applied for the identification of potential zones for gold exploration throughout the country to support the identification of mining areas for sustainable development.

5.2 Recommendations

The present study reveals potential areas for gold deposit in Tarime district which can be of vital importance to small scale miners, policymakers and other public and private organizations. The following recommendations are made according to this research;

5.2.1 AHP methods have great consistency in criteria judgment for complex decision making which indicates great accuracy in this study and also recommended to be used in other studies.

5.2.2 The study was limited to a small area (Tarime district). Further studies should be extended to neighboring districts or regions that could provide a broader understanding of the gold potential in Tanzania. This will help identify more potential areas with gold deposit in Tanzania.

5.2.3 Collaboration with local communities and stakeholders can provide valuable insights and enhance the efficiency of gold exploration efforts. Local communities and stakeholders can help in simplifying the research work through their efforts such as data provision and guidance.

5.2.4 Integrating advanced remote sensing techniques and geological mapping can improve the accuracy and efficiency of gold exploration. For example, Hyperspectral imagery, LIDAR which can help capture high-resolution images generates highly accurate and detailed.

Hence, by implementing these recommendations, Tanzania can unlock its gold potential and contribute to its economic growth and development.

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