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Application of Geospatial Techniques for Gold Potential Mapping in Osun State, Nigeria.

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ABSTRACT

Gold mineral prospectivity models (GMPMs) are significantly important in delineating target zones with the optimum likelihood of containing a gold mineral deposit. Osun state is part of a basement complex of southwestern Nigeria, Africa with abundant gold deposits, and has been an important target for gold exploration. Because of the high rate of illegal mining activities in the area, there is a continuous quest for new methods of gold mineral explorationsuch as geospatial techniques to reduce the activities of illegal mining, save cost and time in identifying the gold mineral potential zones. The study demonstrated the importance of the geospatial techniques method in mapping the gold mineral prospectivity of the area. For this purpose, data was acquired through conventional and remotely sensing methods. Seven criteria were identified as contributing factors to delineate prospective areas for gold deposits.The seven factors identified were lithology, Lineament density, hydrothermal alteration, drainage density, land use/land cover, existing gold location, and land surface temperature. These factors were analyzed using GIS software such as ArcGIS 10.5, Idrisi selva, ENVI 5.1, PCI geomatica and Rockworks. The factors identified were carefully analyzed to demonstrate how suitable each of them can be utilized to determine gold mineral potential. The remote sensing methods adopted was band ratio, buffering, principal component Analysis (PCA), color composites, supervised classification. These factors were reclassified and exported into idrisi selva to carry out MCDA and assigned weighs before imported back to ArcGIS 10.5 for final integration to produce mineral potential map of Osun state using weighted overlay tools in ArcGIS 10.5. The result shown that a systematic integration of all the exploration data review spatial distribution of gold mineral potential zones in the study area was estimated as, the very high areas covered 0.4232km^2, the high areas covered 156.584km^2, the moderate areas covered 4684.824km^2, the low areas covered 4198.144km^2 and very low areas covered 80.8312km^2.The analysis revealed that well-processed satellite images are effective in detecting, locating, and mapping gold potential zones. With geospatial techniques to gold mineral mapping in Osun State can play a pivot role and significantly enhance proper decision making, exploration efforts and improve the identification of both unknown and known prospective gold zones in the area.

KEY WORDS: Lineament, Gold, Geospatial Techniques, Mineral, Hydrothermal alteration, and AHP

I. INTRODUCTION

Mineral exploration is the process of identifying and evaluating valuable mineral resources within the Earth's crust. In the context of Nigeria, a country rich in mineral resources, this process is of paramount importance. Mineral resources are vital for a nation's development (Ojiako et al., 2016), and the ability to explore, exploit, and utilize these resources significantly contributes to a country's economic diversity and overall prosperity (Uzoka 2002, Irmiya et al., 2010 and Sadiya et al., 2014). Nigeria's expansive territory contains significant mineral deposits, yet most of these resources remain unexplored and unexploited. (Ojiako et al., 2016). The country has significant untapped potential in various minerals, such as Gold, Talc, Granite, Tinstone, Tantalum, Feldspar, Kaolin, Columbite, and Clay.

Unfortunately, despite the wealth of resources, Nigeria's mineral sector contributes only about 1% to the country's Gross Domestic Product (GDP). This underwhelming contribution is attributed to government neglect and the proliferation of small-scale illegal mining operations (Sadiya et al., 2014). Historically, gold mineral resources played a pivotal role in Nigeria's economic development. Coal production, for instance, powered electricity generation and railways, while minerals like tin, columbite, lead, and zinc were valuable exports. Nigeria even held the title of the largest global producer of columbite at one point (Aniobi et al., 2021)). However, with the discovery of oil, Nigeria's overdependence on oil exports led to the neglect of the solid minerals sector most especially gold minerals which are very crucial assets to national development. This overreliance on oil made the country vulnerable to international oil politics and hindered the development of other sectors. Traditional gold mineral mapping methods can be costly and time-consuming, and in some cases, they are impractical due to inaccessibility (Karimi and Valadan,2004). One promising avenue for mineral exploration is the use of modern technology which can used to reverse the lost glory in gold mineral exploration. Geospatial technology, which is the integration of geographic information systems (GIS), remote sensing, global positioning systems (GPS), and data analysis methods, plays a vital role in gold mineral exploration. Remote sensing has emerged as a powerful tool for the detection, identification, and mapping of mineral deposits (Kutina, 1969; Katz, 1982; Liu et al., 2000; Rein and Kaufmann, 2003; Rajesh, 2004). Remote sensing technology, which encompasses advancements in spatial, temporal, and spectral resolution, has become a game-changer in the field. It is particularly useful for mapping minerals in inaccessible regions, challenging terrains, and wider areas (Zhhe Zhu et. al,2022). GIS has the ability to integrate data from multiple sources, allowing for a systematic approach to modeling, analyzing, and presenting spatially and temporally distributed data. Spatial modeling, powered by GIS, can generate robust distribution patterns of ore-related geological features, shedding light on the relationships between these features and mineral deposits coupled with the aid of AHP to evaluate the priority of the different criteria. AHP has been widely used to solve problems of multiple criteria in different research. Velmurugan et al., (2011) used AHP to demonstrate a concept that can assist designers in effective evaluation. GIS plays a very essential role in the study of mineral resources (Rajesh, 2004). The need for a systematic approach for modeling, analyzing and or presenting huge amounts of data (spatially and temporally distributed) could be answered by GIS (Khatami and Bahram, 2014). GIS can be differentiated from other information systems through its capability of handling and performing operations on geospatial data. The spatial data may be the location while the attribute data is the characteristics possessed by that location (Chang, 2012, Abdulwahab, 2018).Sayed and Mahmoud (2018) utilized airborne magnetic and radiometric data to identify potential gold mineralization zones in Egypt's central-eastern desert. They found that areas with coinciding alteration zones and high complexity lineaments, as well as porphyry, showed a strong likelihood for gold mineralization. Tao et al. (2019) investigated machine learning methods for GIS-based mineral prospectivity mapping in the Tongling ore district, eastern China. The study emphasized that spatial modeling helps delineate complex distribution patterns of ore-related geological features and uncover correlations between these features and mineral deposits. Yao et al. (2020) applied knowledge-driven methods for mineral prospectivity mapping (MPM) to identify polymetallic sulfide deposits in the Southwest Indian Ridge (46° to 52°E). The study emphasized the potential of seafloor polymetallic sulfides as important targets in marine mineral exploration. By using fuzzy logic and fuzzy analytic hierarchy process (AHP), the researchers integrated topographic, geophysical, and geological data to develop exploration criteria for mapping prospective areas. Despite the absence of certain critical exploration evidence (such as hydrothermal alteration and geochemical anomalies), the knowledge-driven methods effectively predicted favorable metallogenic zones, offering a basis for future exploration of seafloor sulfide resources. Rakotondramano et al. (2021) used remote sensing techniques to estimate gold mineralization in the Betsiriry region, western Madagascar. They highlighted the importance of gold for national development and demonstrated how satellite remote sensing, especially ASTER mineral index maps, has been a valuable tool for mineral exploration. Results showed gold mineralization associated with quartz veins, with potential zones for gold identified in amphibolite, granodiorite, gabbro, and gneiss formations. Khalid et al. (2020) applied remote sensing and GIS techniques for gold prospecting and regional geological mapping in North Kordofan State, central Sudan. Landsat 7 Enhanced Thematic Mapper Plus (ETM+) imagery, field observations, digital image processing, chemical analysis, and petrographic investigations were used to explore the area. The study demonstrated that remote sensing data, combined with field observations, is effective for mapping gold mineralization, with both methods producing consistent results. Botwe and Osei (2018) explored the use of remote sensing and GIS as effective tools for gold potential mapping in the Prestea Concession of Golden Star Bogoso/Prestea Ltd, Ghana.They employing methods such as band rationing, automatic extraction, reclassification, weight overlay, and validation. ASTER and Landsat ETM+ data were utilized alongside ESRI ArcGIS, ENVI, and PC1 Geomatica software. The results produced a gold potential map of the area, confirming the effectiveness of Landsat ETM+ in identifying key parameters like hydrothermal alteration and lineaments for mineral exploration.The study of mineral deposits in Nigeria shows that 90% of the country's natural resources are unexploited because many have not been discovered and decomposed (Aliyu 2013). Osun state, Nigeria, serves as a case study for GIS-based data-driven mineral potential mapping. This region is well endowed with gold mineral resources most especially Atakunmosa East Last, Atakunmosa West, Ife and Oboku (Ajeigbe et al., 2014), making it an ideal candidate for such exploration. Rampant artisanal mining activities in Osun State have led to environmental degradation and safety issues (Ojo et al., 2024). The coexistence of informal mining practices with formal exploration efforts presents challenges in terms of regulation and environmental management (John et al., 2023, Izerimana and Godwin, 2024). Osun is believed to be home to gold minerals but the lack of a gold database has impeded their exploitation. Therefore, there is a need to provide acute and timely spatial information due to increased interest in the mining sector. With technological advancement, new discoveries can be made and this study therefore focuses on how geospatial techniques can be applied to identify gold mineral potential zones in Osun state.Utilizing modern technology, including remote sensing and geospatial tools, offers the potential for transformative economic growth, diversification, and minimizing environmental hazards. By harnessing their mineral wealth, nations like Nigeria can reduce their overdependence on oil, creating a more sustainable and prosperous future.

II. MATERIALS AND METHODS

2.1 Study Area

Osun State is located in Southwestern Nigeria and has 30 Local Government Areas. Osun State lies within latitudes 7.0^0 and 9.0^0 N of the Equator and longitudes 2.8^0 and 6.8^0E of the Greenwich Meridian (Borisade et al., 2021).The study area covers approximatelyabout 9,251 km². The region has a total population of over 4.7 million people (Demographic Statistics; 2018. It is enclosed by Kwara State in the north, Ekiti and Ondo in the east, Ogun State in the south, and Oyo State in the west. Sub ethnic groups can be broken down into Ife, Ijesha, Oyo, and Igbomina, which were the political divisions of the region. Osun state is a part of Southwestern Nigeria's underlain by Precambrian rocks Basement complex and is typically covered in crystalline igneous and metamorphic rocks. The prominent outcrops and inselbergs that define the region's topographic highlands are made up of these rocks (Osun State Water Corporation Report, 1994). The two prominent seasons in Osun State are the rainy and dry seasons. The two season, dry season is short, usually lasting four months (October-January) (Borisade et al., 2021). The average rainfall ranges from 1125 mm in derived savanna to 1475 mm in the rainforest belt of the state. The mean annual temperature ranges from 39.0 °C in the month of December to 27.2 °C in June. Fig. 1 shows the map of the study area.

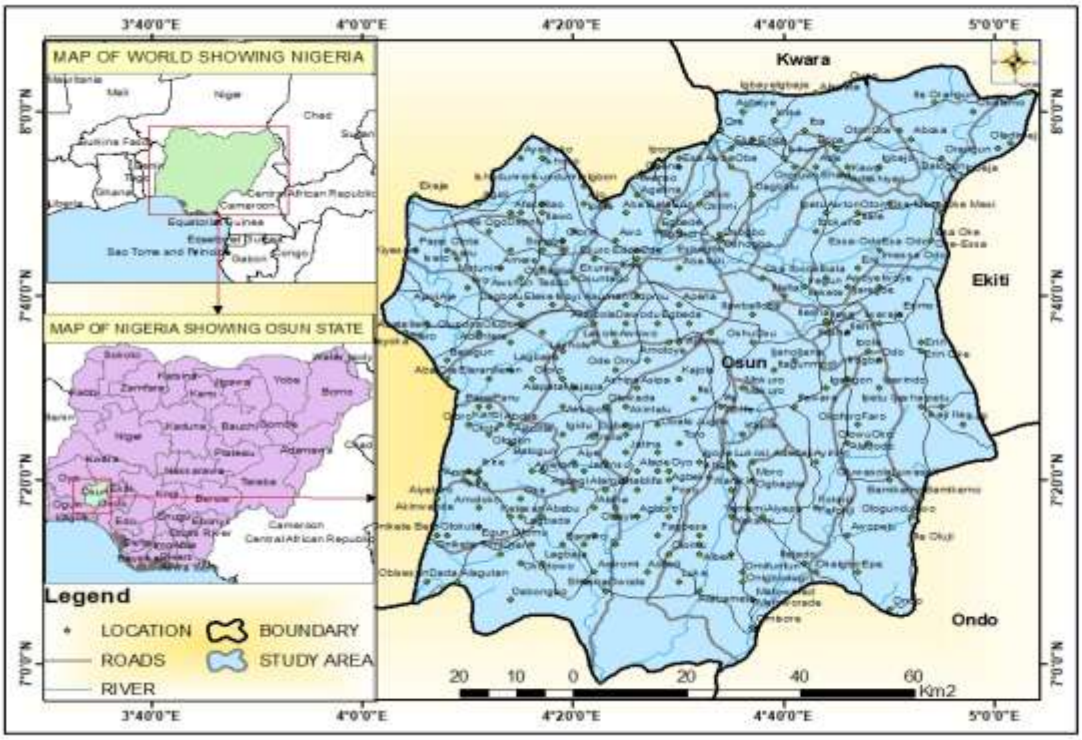

Fig. 1: Map of the study area.

2.2 MATERIALS

In this study, Table 1. Show the different datasets used for this study and their sources.

S/N	Data Type of the study area.	Source	Format	Spatial Resolution/ Scale
1	State & L.G.A. Boundaries	Ministry of Lands And Town Planning Authority, Osun state	Analogue	1:50,000
2	Landsat 8 ETM$^+$	http://earthexplorer.usgs.gov/	Raster(GeoTiff)	30,15m
3	Copernicus DEM	http://earthexplorer.usgs.gov/	Raster (GeoTiff)	30m
4	Quick bird	NARSDA, Abuja	Raster (GeoTiff)	0.65m
5	Geological Map	Nigeria Geological survey Agency	Raster(jpg)	1:125000
6	Mineral map of Osun sate	Nigeria Geological survey Agency	Raster(jpg)	1:125000

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2.3 Methods

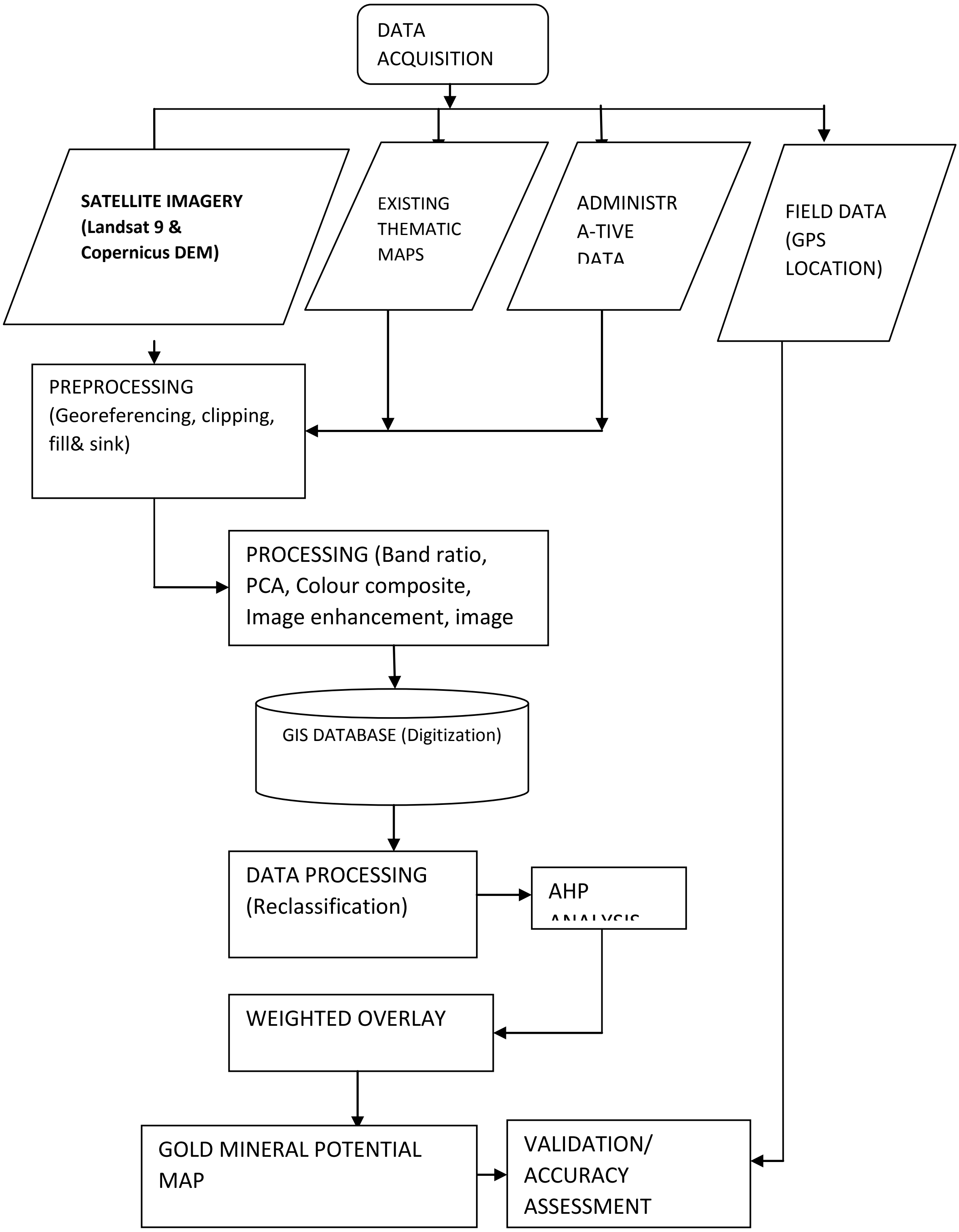

Fig 2: Map of the study Area.

2.4Data and Software Requirements

The data used for this work was principally based on Landsat imagery of the year 2023, Quick bird, and the Copernicus digital elevation model (DEM) covering Osun state. Other useful data were administrative map, geology, and global positioning system (GPS) data acquired from the field. The software utilized to achieve the goal of this work were ArcGIS 10.5, rockworks, QGIS 2.4.0, PCI Geomatics, IdrisiSelva, and ENVI 5.0.

2.5 Data Processing

2.5.1 Pre-processing

Fig 2 gives an overview of the methods adopted. Pre-processing was done before data analysis and extraction of information. Preprocessing involves two major processes: geometric correction and radiometric correction(Shrinivas Khandare and Urmila Shrawankar, 2016). Remote sensing imageries are inherently subjected to geometric distortions. These distortions may be due to the perspective of the sensor optics, the motion of the scanning system, the motion of the platform (the platform altitude, attitude, and velocity), the terrain relief, or the curvature and rotation of the earth (Lillesand, 2004). Radiometric corrections may be necessary due to variations in scene illumination and viewing geometry, atmospheric conditions, and sensor noise and response. Image clipped using ArcGIS 10.5 software to extract the area of interest using the Nigeria shapefile.

2.5.2 Image Enhancement

The objective is to improve the information content of the image for better visualization. Image enhancement was used in order to increase the details of the image by assigning maximum and minimum brightness values to maximum and minimum display values, and to be done on pixel values. This makes the visual interpretation easier and assists the human analyst. This was done to assist in Land use/land cover mapping analysis and lineament extraction.

2.5.3 False color composite (FCC)

When displaying a multi-spectral image in color (Red, Green, and Blue) a combination of three bands was selected. By using different ETM bands for (RGB), different color composite was created for the study area, each with its characteristics. By comparing the different color composites, a selection was made, which could be used for vegetation and bare soil differentiation. For instance, color composite 742 can be found best to be used for water bodies (flooded areas) identification while 432 is for vegetation cover and 472 or 471 can be used for identifying the shrubs lands.

2.6 Data Processing and Modelling

The above-mentioned hardware and software requirements were used to process and carry out the mapping of the following sets of data mentioned earlier.

2.7GIS Data Processing and Database Creation

Before all the datasets were captured in the GIS environment by scanning, Geo-referencing, and digitizing, projecting to the US WGS 84 was done. Attribute tables were created using ArcMap 10.5. Datasets were re-projected to UTM zone 31N and rasterized using the data management tool and conversion tool of the Arc map 10.5 software.

2.7.1 Band Rationing.

Sabins (1999) describes band ratio as a method where the digital number (DN) value of one band is divided by the DN value of another band to enhance the contrast between different materials. Typically, the band with lower reflectance is used as the numerator and the band with higher reflectance as the denominator. Band ratios help reveal specific characteristics hidden in raw images through enhancement. Using ENVI software, high reflectance and absorption bands are selected for different minerals. For instance, the ratio 4/2 is useful for mapping iron oxides, and ratios like 6/7 or 7/5 are effective for identifying clay minerals. A band ratio map was created using ENVI 5.1 and validated with ArcGIS 10.5.

2.7.2 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a statistical technique used to select uncorrelated linear combinations of variables, with each principal component capturing similar variance. In Landsat ETM+ and OLI imagery, PCA helps handle the similarity between bands by deriving new orthogonal axes that maximize data variance. This study applies PCA to identify hydroxyl (OH) components, which indicate water interaction with rock units and signal areas of alteration, a key factor in identifying potential mineral presence.

2.7.3 Mineral Potential Factors Reclassification and Ranking

AHP is a multi-criteria decision making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative information.It is a methodology used to systematically evaluate, often conflicting, qualitative criteria (Saaty, 1980 cited in Bapalu and Sinha, 2006). In ranking method, every criterion under consideration will be rank into the order of the decision maker's preference. Therefore, the factors identified as a contributing agent will be analyze and reclassify into high, moderate, low, and very low.

Table 2: Saaty scale (1980)

Intensity	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, it dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

2,4,6,8 can be used to express intermediate values

2.7.4Weighted Overlay Analysis and Delineation of Mineral Potential Map.

After conducting a weighted overlay analysis, the study achieved its final objective by integrating results from various factors influencing mineral resource availability. Factors included hydrothermal alteration maps, geological maps, lineament density, and normalized difference vegetation index (NDVI). Each factor was analyzed using a hybrid method before assigning weights (table 3) to assess the study area's suitability for mineral exploration. Mineral potential zone mapping is a valuable tool for exploration companies, government agencies, and researchers, helping to optimize resource allocation, reduce exploration risks, and inform decision-making. However, the accuracy of the mapping depends on the quality of input data, criteria selection, and the expertise of the geologists involve

Table 3: Normalized Weight Assessment by Ranking

S/N	FACTORS	Values	Ranking	% Influence	Gold prone classes
1	Existing Gold	1000m	5	40.22	Very High
		2000m	4		High
		3000m	3		Moderate
		4000m	2		Low

		100000m	1		Very Low
2	Hydrothermal Alteration	Altered rock	5	13.54	Very High
		Rock	4		High
		Water	3		Moderate
		Vegetated	2		Low
		Non-vegetated	1		Very Low
3	Lithology	Metadiorite,pegmatite	1	23.22	Very Low
		Granite,charnockite	2		Low
		Quartz veins, Quartz& Schist,	3		Moderate
		Schist,	4		High
		Migmatite, Banded gneiss,	5		Very High
4	LAND USE/LAND COVER	Built_up	1	2.30	Low
		VEGETATION	2		Moderate
		Bare surface	3		High

		Waterbody	4		Very High
5	Land Surface Temperature	67-71	1	5.50	Very Low
		72-72	2		Low
		73-73	3		Moderate
		74-75	4		High
		76-81	5		Very High
6	DRAIANGE DENSITY	0 – 0.097	1	3.46	Very Low
		0.098 – 0.19	2		Low
		0.20 - 0.29	3		Moderate
		0.30- 0.39	4		High
		0.40 – 0.49	5		Very High
7	Lineament density	0- 0.07	1	11.67	Very Low
		0.071-0.15	2		Low
		0.16-0.12	3		Moderate
		0.23-0.31	4		High
		0.32 -0.51	5		Very High

III. RESULTS AND DISCUSSION

3.1 Identification of criteria that influence Gold mineralization.

The study selected conditioning factors based on a literature review, expert opinion, and available data for the study area. Seven factors, lithology, lineament density, drainage density, land

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use/land cover, hydrothermal alteration, existing gold locations, and land surface temperature were identified and processed into thematic layers using GIS software. These criteria were crucial for assessing the potential gold areas in the study.

3.2 GIS-based analysis of gold mineral resources based on conditioning factors identified.

3.2.1 **Lithology Layer and Proximity Analysis for existing Gold minerals**

Lithological and structural criteria are key for gold exploration in the study area, based on the geological setting and controls of gold mineralization. A thematic map represents different rock types using unique gray levels, aiding visualization. The study area in Osun state, Nigeria, falls within the crystalline basement complex of the West African Craton, dating back to the late Precambrian to early Proterozoic. The lithology was generated using ArcGIS pro through digitalization and findings indicated that the lithology of the areas includes migmatite-gneiss, quartzite, calc-silicate rocks, biotite hornblende schist, and amphibolites, with minor rock types like pegmatite (fig 3). These geological features provide a foundation for identifying gold exploration prospects. Fig. 4 shows the buffered existing gold location. The spatial distribution of gold present in the study area was captured through digitalization from a Nigeria mineral map obtained from the Nigeria Geological Survey Agency. Existing gold location data was ranked highest or considered first in mineral exploration as one of the evidence of gold present in the study area. The data was created firstly by georeferencing the image and creating a geodatabase then digitized all the gold present in the study area. The result shows the eight locations identified and buffered using a distance of 1000m to 100,000m through the help of buffer tools in ArcGIS 10.5.

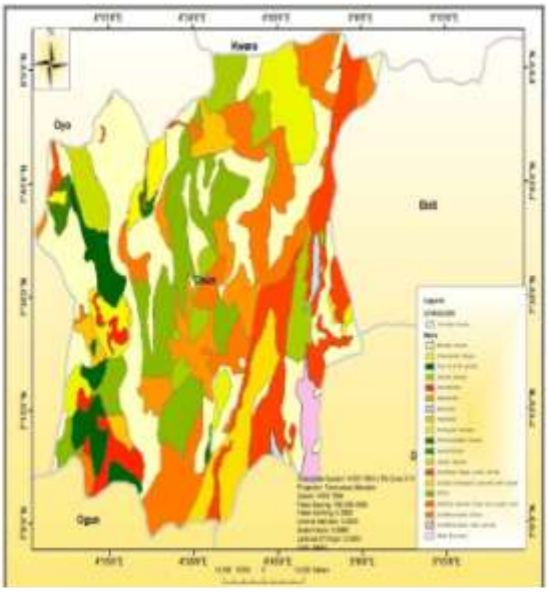

Fig. 3. Lithology map of the study area.

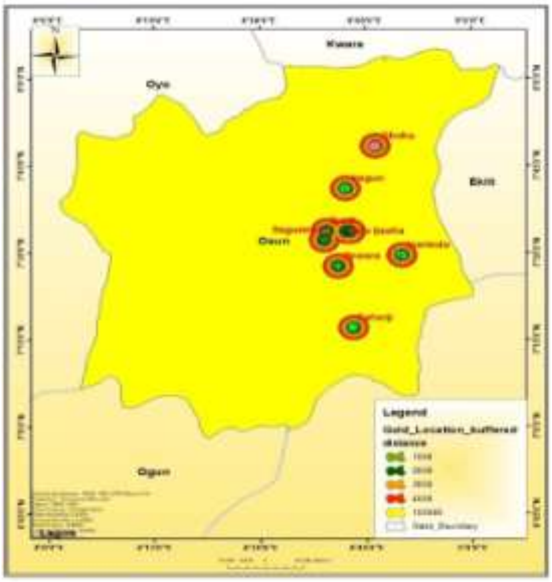

Fig 4: Buffered of existing Gold map of the study area.

3.2.2 Surface Cover Analysis and Land Surface Temperature

The gold mapping process faces challenges due to subsurface geology and surface cover such as dense vegetation, thick soil layers, and urban development, which obscure underlying geological features. The surface cover reflects what we have under the earth. The reaction of underground activities can be determined through the surface cover. Traditional mapping techniques are limited, but remote sensing technologies like satellite imagery, LIDAR, and ground-penetrating radar can penetrate some surface cover, aiding in identifying gold-bearing structures. Surface cover, including soil, vegetation, water bodies, and urban areas, plays a critical role in exploration. Remote sensing, geochemistry, and geophysics techniques help overcome these obstacles. The study used Landsat 9 imagery and supervised classification (maximum likelihood algorithm) to map surface cover which is popularly known as land use/ land cover mapping. Four categories were identified, water bodies, built-up areas, bare soil, and vegetation (fig.5). Water bodies and vegetation can serve as biogeochemical indicators, with plants sometimes showing stress or unusual growth due to

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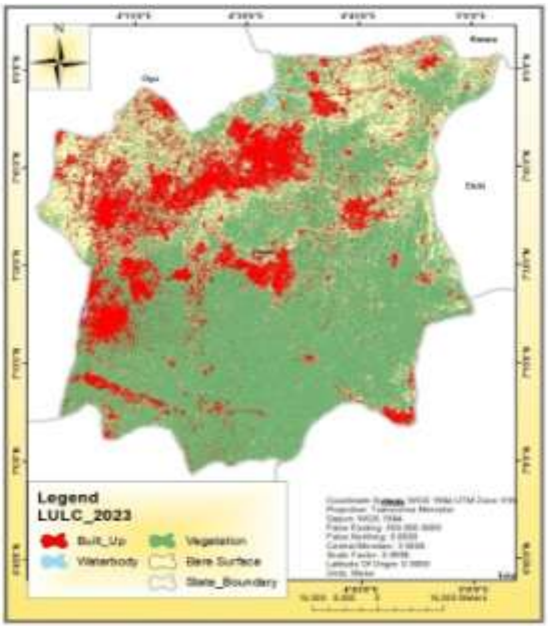
elevated metal concentrations, hinting at underlying gold deposits. Table 4 shows the area covered by each class and their respective percentage.Land surface temperature (LST) contributes to regional and global climate change variation. Land surface temperature (LST) refers to the radiative skin temperature of the Earth's surface, influenced by solar radiation and measurable through satellite or aerial remote sensing techniques (Yang et al., 2017, Ojolowo et al., 2024). It is a vital parameter of the Earth’s surface systems that governing energy flow on the surface at both micro and macro scales (Mao et al., 2021, Ojolowo et al., 2024). Assessing vegetation stress can be achieved via changes in LST. Stress in vegetation cover due to changes in LST, which may be related to underlying mineralization processes is very crucial in gold exploration. LST data can help identify thermal anomalies that may indicate the presence of hydrothermal systems associated with gold deposits. Gold mineralization often occurs in zones of hydrothermal alteration. LST can assist in mapping these zones by detecting variations in surface temperature related to different mineral compositions and alterations (Mamouch et al., 2022). The spatial analysis performed revealed that the maximum land surface temperature (LST) for the year 2023 was 81°F and minimum was 67°F (fig. 6). The high temperature was dominated in Atakumosa West/East, Ife Central, Osogbo, Ola-Oluwa, Iwo, Ayedire, and Obokun area which aligns with (Ojolowo et al., 2024) results. LST invoked the tectonic activities on the earth's crust. Areas with high temperatures can therefore help pinpoint potential gold-bearing hydrothermal systems.

Table 4: Land use/ Land cover statistical analysis.

Classes	Area(km2)	Area (%)
Built up	1871.161	20.36253
Waterbody	19.1619	0.208525
Vegetation	5189.99	56.47953
Bare surface	2108.925	22.94999



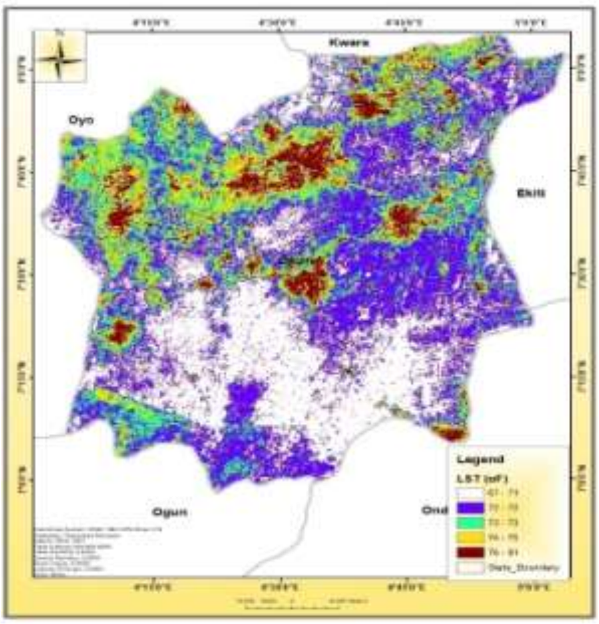


Fig. 5: Land use/Land cover map of the study area.Fig.6: Land surface Temperature map of the study are

3.2.3 Hydrothermal Alteration Processing

Landsat 9 satellite imagery was used for band ratios (4/2, 6/5, and 6/7) to detect iron, ferrous, and clay alterations in the study area. Through image processing and field observations, different alteration zones were identified for detailed gold exploration. The band ratio 6/7 captured clay alterations (fig.9), with blue pixels indicating high clay alteration and red pixels representing low clay alteration. The band ratio 6/5 ratio mapped ferrous iron alterations (fig.8), and the 4/2 ratio identified iron oxide (fig.7), both with

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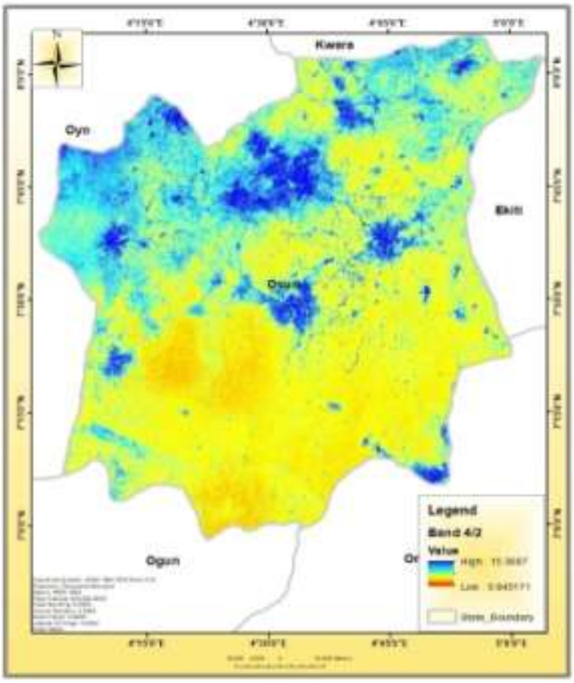
color variations from blue (low alteration) to red (high alteration). Areas with high Digital Numbers (DNs), depicted as bright tones, indicated zones of altered rocks in each alteration map. The band ratios helped in recognizing different features, such as altered rocks, outcrops, vegetation, and water bodies. The combination of these band ratios allowed for the mapping of hydrothermal alteration (fig.10), which is crucial for understanding mineral accumulation and targeting gold deposits.



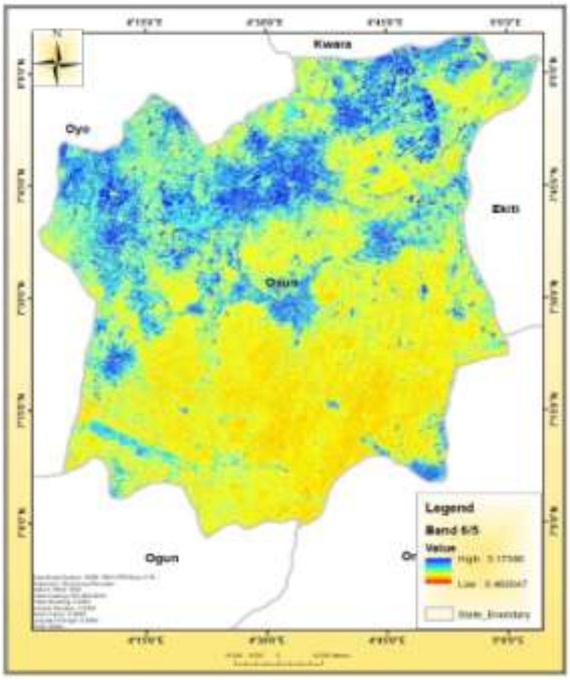


Fig 7. Band ratio 4/2 image of the study area.**Fig.8:** Band ratio 6/5 image of the study area.

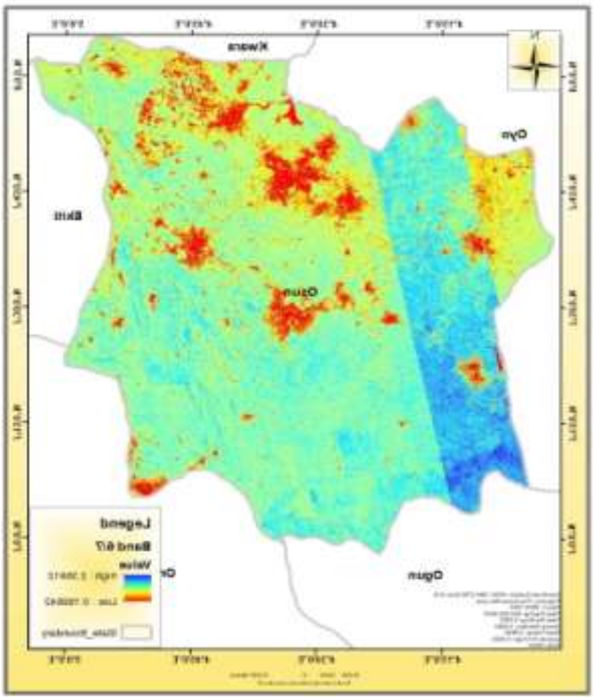


Fig. 9. Band ratio (6/7) image of the study area.Fig 10: Hydrothermal alteration map

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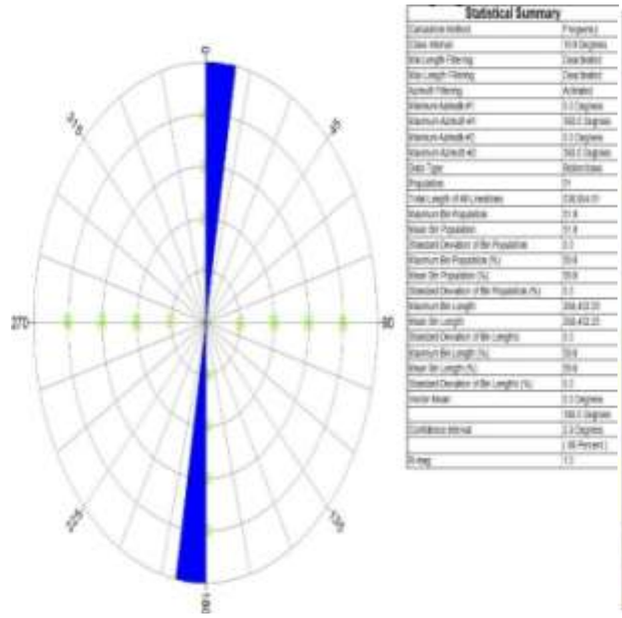
3.2.4 Lineament Density

Lineament mapping and analysis using remote sensing data is a vital approach for regional structural and tectonic studies (Masouda and Koikeb, 2017). Lineaments representing faults or fractures in the Earth's crust(Ahmadi, and Pekkan, 2021) were mapped using Copernicus Digital Elevation Model (DEM) data, with various hillshade angles applied. The lineamentwas then digitized and overlaid on high-resolution imagery to differentiate between natural, man-made, and structural features. The study used ArcGIS 10.5 to create a lineament density map, which highlights areas with a high concentration of fractures and faults. These high-density areas are associated with increased tectonic activity, which is favorable for gold mineralization due to the movement of fluids carrying dissolved gold. Fig. 12 shows the lineament density as raster images ranging from 0-0.51. The 0.32 – 0.51 as the highest lineament density in the study area indicated as blue color. Area with high lineament density tends tectonic activity which plays a vital role in the formation of gold deposits. Areas in the study region, including Ife, Atakunmosa, Oriade, and Ilesha, were identified as having high tectonic activity and potential for gold deposits.Fig. 11 shows the rose diagram of the study area which gives a visual representation of the dominant orientations of lineaments in an area and indicates the total length of all lineaments as 538864.51m. The lineaments mainly trend in the NE-SW direction. Lineament density mapping helps identify weak zones, potentially speeding up the discovery of mineral deposits. Based on the determination of weak zone density using lineament density, mineral prospects can be known faster (Verdiasyan,2015, Udhi and Anum,2016). The weak zone can be caused by a tectonic process.



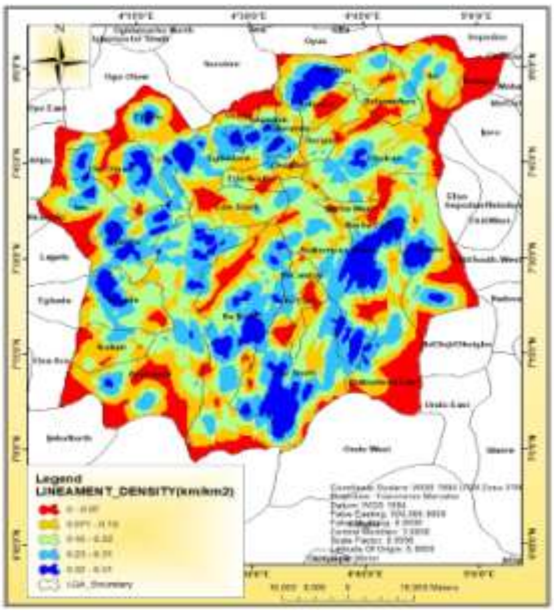


Figure 11: Rose diagram Figure 12: Lineament density map of the study area.

3.2.5 Drainage Density Analysis.

Drainage density analysis is one of the key factors to consider in gold mineral potential mapping as it provides insights into the hydrological and geomorphological characteristics of the study area, which can be associated with mineralization processes. The drainage pattern of the area is dendritic drainage which is a trees like pattern. Through this, the geomorphology of the area can be predicted and soil type. Drainage density has an indirect influence or implication on the infiltration of soluble material into the earth's surface. The infiltration process determines the hydrothermal alteration process which is one of the major activities or agents in determining the mineral potential zone in an area. Figure 13 shows that Atakunmosa East, Ife East, Iwo, Ibokun, Ife Central, and Oriade all fall into high drainage density. These areas were identified with anomalously high drainage density, which may indicate regions with increased fracturing and hydrothermal activity.

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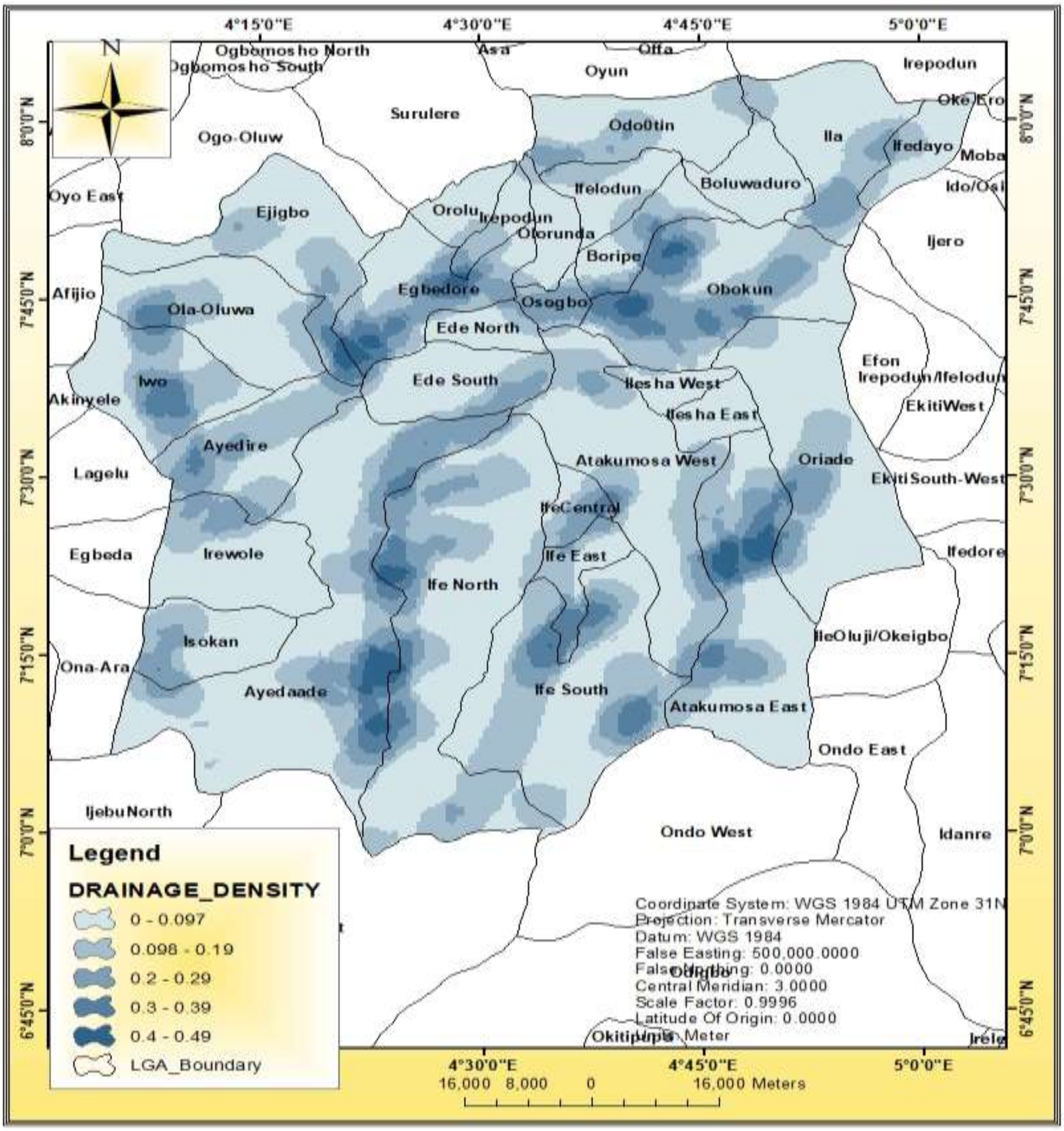

Figure 13: Drainage density map of the study area.

3.3 Pairwise comparison

Table 5 and table 6 show the results of the pairwise comparison and the interpretation of symbols (Normalized principal Eigenvector) used in depicting the different criteria.To determine the robustness of the expert view, the Consistency Ratio (CR) was calculated using Equation 1.

Consistency ratio= $\frac{CI}{RI}$ …………………….. (1)

Thus, since 0.064 < 0.1, it indicates that there is a realistic degree of consistency in the pairwise comparison and as a result, the weights 0.4022,0.1354,0.023, 0.0346, 0.055, 0.2332, and 0.1167 (i.e. 40.22, 13.54, 2.30, 3.46, 5.50, 23.32 and 11.67% respectively) can be assigned to existing gold, hydrothermal alteration, land use/ land cover, drainage density , LST, Lithology, and lineament density respectively

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Table 5: Matrix of pair-wise comparisons of the seven (7) criteria for the AHP process

Matrix		EXISTING GOLD 1	LITHOLOGY 2	HYDROTHERMAL 3	LINEAMENT DENSITY 4	LULC 5	DRAINAGE DENSITY 6	LST 7
EXISTING GOLD	1	1	3	5	4	9	7	6
LITHOLOGY	2	1/3	1	3	2	7	9	5
HYDROTHERMAL	3	1/5	1/3	1	3	7	3	2
LINEAMENT DENSITY	4	1/4	1/2	1/3	1	7	5	3
LULC	5	1/9	1/7	1/7	1/7	1	1/2	1/3
DRAINAGE DENSITY	6	1/7	1/9	1/3	1/5	2	1	1/2
LST	7	1/6	1/5	1/2	1/3	3	2	1

Table 6: Interpretation of criteria symbols (Normalized principal Eigenvector)

Factor No	factors	Weight (%)
1	Lithology	23.32
2	Existing Gold	40.22
3	Hydrothermal	13.54
4	LULC	2.30
5	LST	5.50
6	Drainage density	3.46
7	Lineament density	11.67

3.4 Weighted Overlay for Gold Potential Mapping

Multi-criteria analysis was applied in producing and combining spatial data identified as factors attributing to the presence of gold mineralization area. All criteria (gold potential zone factor maps) were combined by weighted overlay analysis where continuous criteria (factors) were standardized to a common data model that was in a raster layer with a common resolution and the analytical hierarchical process (AHP) method was used, where, every criterion under consideration is ranked in the order of universally acceptable gold mineralization influence. To generate criterion values for each evaluation unit, each factor was weighted according to the estimated significance. With this method, 1 was the least important and 5 was the most important factor (Table 4), this was based on the Saaty scale (table 6). The criterion maps in raster grids (Fig.2- 12) were mathematical processed and spatial analyst tool in ArcGIS 10.5 version was used. The weighted overlay tool of ArcGIS software combined the weight and ratio of each susceptibility factor by multiplying of their calculated ratio to determine its total weight. The weighted overlay method was applied to produce the gold potential zone map. The AHP and overlay weighting methods were used for the weight estimation, and eventually, a combined (Hybrid) weight was adopted in the GIS environment.

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3.5Generating Gold Mineralization Potential Zone

The application of weighted overlay modeling allowed us to map the spatial distribution of gold mineral potential zones in the study area. According to the result(fig. 14), the area was divided into five zones, very low, low, moderate, high, and very high following the type and degree of alteration and other parameters such as geological formation, surface cover, lineament density, drainage density, existing gold location, and LST overlaying. Figure 13 shows the gold potential zone areas based on the contribution of the factors identified in the study area. The result shows that very high (blue), high (green), moderate (butter), low (orange), and very low (brunt orange) were identified. The corresponding percentage of the gold potential zone areas were qualitatively classified. Also, the area covered was estimated as, the very high areas covered $0.4232km^2$, the high areas covered $156.584km^2$, the moderate areas covered $4684.824km^2$, the low areas covered $4198.144km^2$ and very low areas covered $80.8312km^2$ as shown in Table 7. The percentage of various classes of gold potential zone areas is shown (table 7) as well. Based on the resulting (figure 15) field surveys, and mineral analyses, the most prospective zones in the study area were identified and mapped. The analysis revealed that well-processed satellite images are effective in detecting, locating, and mapping gold potential zones. Additionally, the synthesized results demonstrated the potential to develop a model capable of identifying prospective gold zones within the study area. The mineral potential mapping was achieved through the integration of the aforementioned factors after each of the factors was carefully analyzed.

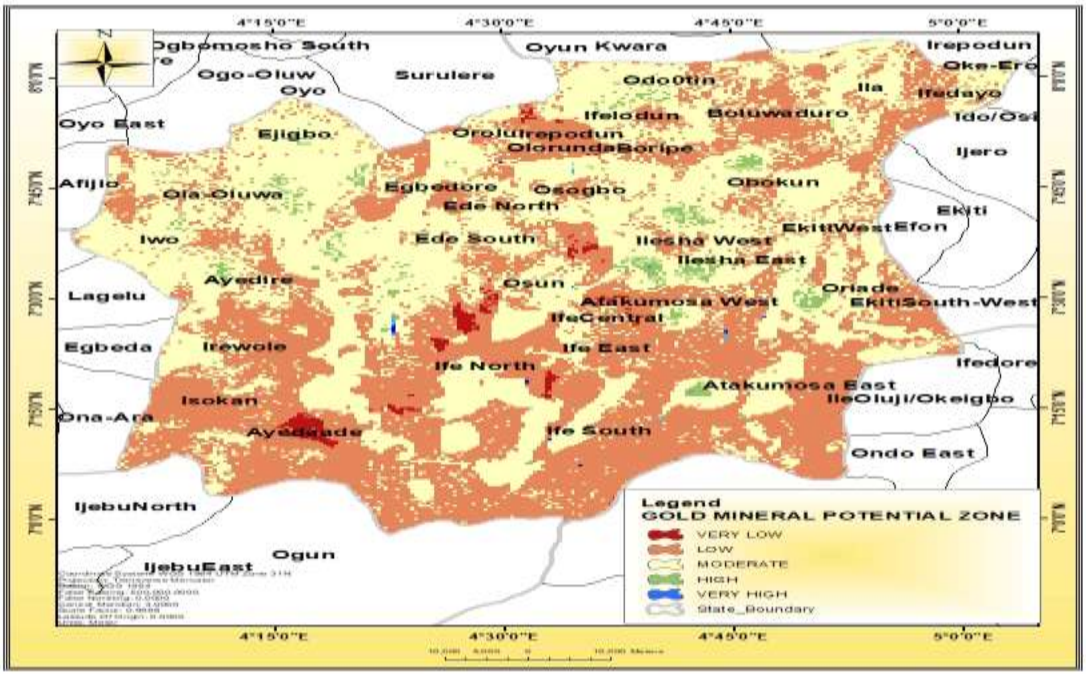

Figure 14: Gold Mineral Potential Zone Map of the Study Area

Table 7: Classification statistics of prospectivity map.

S/N	Prospectivity	Area(Km2)	Percentage (%)
1	Very low	80.8312	0.886229
2	Low	4198.144	46.028211
3	Moderate	4684.824	51.364143
4	High	156.584	1.716778
5	Very high	0.4232	0.00464

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3.6 Validation of the result

Fieldwork was conducted to confirm the discussed image interpretation and validate the occurrence of gold minerals and rocks of the study area. In the field, most of the rock formations of Tertiary age are exposed well on the surface and outcrops out at different locations such as Ife Central, Atakunmosa West/East, and Osu town in the study area. Along the Ifewara zone, the formations have massive limestones and various quartz and schist lithology with ophiolite clasts. Table 8 shows the GPS coordinates points obtained from the field for validation of the gold potential zone map and plotted on the map (fig 15).

Table 8: GPS coordinate of Gold mining locations.

Latitude	Longitude	Locations
7.495311	4.82355	Iperindo
7.528894	4.649228	Itagunmodi
7.464061	4.681858	Ifewara
7.802992	4.770431	Oboku
7.681733	4.700986	Iregun
7.5034	4.5142	OAU EDE ROAD
7.55805	4.60454	Itamerin,along Ilesha road
7.562506	4.656	Ibodi
7.600294	4.712892	Akad Ilesha
7.780569	4.704125	Ado Ijesha
7.285306	4.719714	Faforiji
7.339153	4.595342	Yekemi

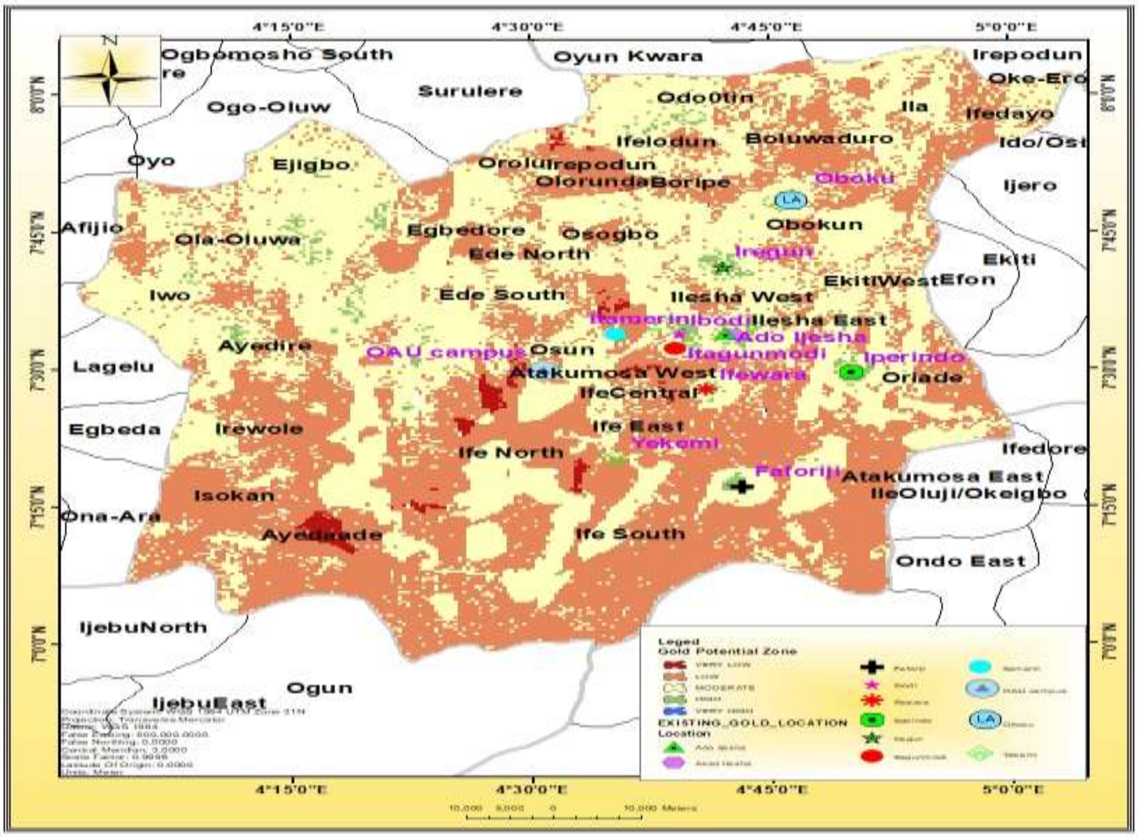

Figure 15: Map shows the filed verification data overlay on gold potential zone.

3.7 Discussion

The application of geophysical and geology surveys in mineral exploration is a preliminary step of great importance for recognizing new potential targets for mining (Mamouch et al., 2021) but time and cost implication are another great challenges that serve as limitations. Over the past few decades, remote sensing has demonstrated its effectiveness across various branches of geology, especially in structural geology, tectonics, lithological mapping, earthquake monitoring, and most importantly mapping inaccessible areas with low cost and considerable time. Lineaments, which encompass geological features such as faults, fractures, joints, and lithological boundaries, play a significant role in these applications (Ahmadi and Pekkan, 2021). Lineaments can influence the local geophysical characteristics of an area, such as magnetic or electrical properties. Tectonic processes play a significant role in the formation of gold deposits. Higher lineament density can indicate areas where tectonic activity has been intense, potentially creating the conditions necessary for gold mineralization. In mineral exploration, identifying areas with high lineament density can help prioritize targets for further investigation. Areas with intersecting or parallel lineaments, especially in conjunction with other geological and geochemical indicators, are often selected for detailed exploration efforts.The alteration of minerals may have a spatial relation with gold mineralization within the area. Areas with these alterations fall within the Obukun, Atakunmasa west/east, and Ife zone where gold is mined as observed during the ground truthing and also with the local geology of the area. Further evidence is revealed that the area is characterized by gently dipping mineralized quartz veins.Gold mineralization in the area predominantly occurs within undifferentiated metasediments, with potential sites also present within Older Granites. The ranking was based on the age of the rocks. Previous studies have indicated that the hydrothermal fluids responsible for altering and mineralizing the rocks in the belts originate from either metamorphic dewatering or late-stage fluids from intrusive plutons within the belts (Garba, 1988, 2003 and Andongma et al., 2020).

IV. CONCLUSION

The probability of success in discovering an economic deposit has also been examined by the use of these techniques. Theoretically, it has been shown that a systematic integration of all the exploration data in a given area significantly improves the chances of making a discovery. Digital image processing algorithms were applied to Landsat 9 scene and elevation data products (digital terrain models and hill shade maps). Lineaments were extracted and used to produce lineament density as well as a rose diagram to determine the lineament direction and bearing. The application of weighted overlay modeling allowed us to map the spatial distribution of gold mineral potential zones in the study area. The result shows that very high (blue), high (green), moderate (butter), low (orange), and very low (brunt orange) were identified. The corresponding percentage of the gold potential zone areas were qualitatively classified. Also, the area covered was estimated as, the very high areas covered 0.4232km^2, the high areas covered 156.584km^2, the moderate areas covered 4684.824km^2, the low areas covered 4198.144km^2 and very low areas covered 80.8312km^2 as shown in Table 7. The percentage of various classes of gold potential zone areas is shown (table 7) as well. Based on the field surveys, and verification exercise, the most prospective zones in the study area were identified and mapped. The analysis revealed that well-processed satellite images are effective in detecting, locating, and mapping gold potential zones.In conclusion, the authors stress the critical importance of field validation of remotely sensed data and its integration with other data types. Only through this approach can remote sensing be effectively utilized as a decision support tool, guiding further detailed mineral exploration efforts.

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