

**APPLICATION OF REMOTE SENSING METHOD TO LITHOLOGIC
MAPPING IN AKOKO EDO AREA OF SOUTHERN NIGERIA**

BY

Elisha Ebubechukwu OKOLIE

PSC1607431

**DEPARTMENT OF GEOLOGY
FACULTY OF PHYSICAL SCIENCES
UNIVERSITY OF BENIN, BENIN CITY**

JULY, 2021.

**APPLICATION OF REMOTE SENSING METHOD TO LITHOLOGIC
MAPPING IN AKOKO EDO AREA OF SOUTHERN NIGERIA**

BY

Elisha Ebubechukwu OKOLIE

PSC1607431

**A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF
GEOLOGY, FACULTY OF PHYSICAL SCIENCES, UNIVERSITY OF
BENIN, BENIN CITY IN PARTIAL FULFILMENT FOR THE
REQUIREMENT OF THE AWARD OF BANCHELOR OF SCIENCE (Bs.c.)
DEGREE IN THE DEPARTMENT OF GEOLOGY, UNIVERSITY OF
BENIN, BENIN CITY**

JULY, 2021.

CERTIFICATION

This is to certify that this work was carried out by Elisha Ebubechukwu OKOLIE with matriculation number PSC 1607431 of the Department of Geology, University of Benin, Benin City.

DATE: _____

DR. S. A. SALAMI

(Project Supervisor)

DATE: _____

PROFESSOR O.I. IMASUEN

(Head of Department)

DEDICATION

This project is dedicated to God almighty who in his agape love made it possible for me to be able to carry out this work. Also, to my parents, late Mr. Francis Isichei and Mrs. Miriam Isichei, and my siblings.

ACKNOWLEDGEMENT

It is with much gladness that I thank my project supervisor, Dr. S.A Salami, a senior lecturer with a fatherly voice and the interest of his students at heart. I am very privileged to have been one of his project students. My gratitude also goes to the Head of Department, Professor I.O. Imasuen.

I Acknowledge every member of staff in the Department of Geology. Thanks for keeping the department running. I am grateful to all my lecturers in the department who have imparted knowledge in me over the past few years. Much appreciation also goes to my mum for constantly giving me moral support throughout the duration of this work.

And lastly, special thanks to Mr. Nicholas O. Uwadia who was kindly instrumental in the success of this work.

TABLE OF CONTENTS

Title page	-	-	-	-	-	-	-	-	-	-	-	ii
Certification	-	-	-	-	-	-	-	-	-	-	-	iii
Dedication	-	-	-	-	-	-	-	-	-	-	-	iv
Acknowledgement	-	-	-	-	-	-	-	-	-	-	-	v
List of Figures	-	-	-	-	-	-	-	-	-	-	-	x
List of Tables	-	-	-	-	-	-	-	-	-	-	-	xi
Abstract	-	-	-	-	-	-	-	-	-	-	-	xii
CHAPTER ONE: INTRODUCTION	-	-	-	-	-	-	-	-	-	-	-	1
1.2 Aim and Objectives	-	-	-	-	-	-	-	-	-	-	-	3
1.3 Rocks	-	-	-	-	-	-	-	-	-	-	-	3
1.4 Application of Remote Sensing and GIS to Lithologic Mapping	-	-	-	-	-	-	-	-	-	-	-	4
CHAPTER TWO: LITERATURE REVIEW AND GEOLOGICAL SETTING	-	-	-	-	-	-	-	-	-	-	-	
2.1 Previous Works	-	-	-	-	-	-	-	-	-	-	-	5
2.2 Remote Sensing	-	-	-	-	-	-	-	-	-	-	-	9

2.2.1 Stages in Remote Sensing	-	-	-	-	-	-	-	10
2.2.2 Components and principle of Remote Sensing	-	-	-	-	-	-	-	11
2.2.3 Electromagnetic Radiation	-	-	-	-	-	-	-	11
2.2.4 Sensor and Platform	-	-	-	-	-	-	-	12
2.2.5 Types of Platforms Used for Remote Sensing	-	-	-	-	-	-	-	13
2.2.6 Flow Process of Remote Sensing	-	-	-	-	-	-	-	14
2.2.7 Limitations of Remote Sensing	-	-	-	-	-	-	-	15
2.2.8 Types of Remote Sensing	-	-	-	-	-	-	-	16
2.2.9 Application In The Field Of Geology	-	-	-	-	-	-	-	17
2.3 Geographic Information Systems (GIS)	-	-	-	-	-	-	-	19
2.3.1 Mapping the Subsurface GIS	-	-	-	-	-	-	-	20
2.4 Satellites	-	-	-	-	-	-	-	22
2.4.1 LANDSAT	-	-	-	-	-	-	-	25
2.5 Review on The Basement Complex Geology Of Nigeria	-	-	-	-	-	-	-	28
2.5.1 Lithologic Units and Locations	-	-	-	-	-	-	-	30

2.6 Review on the Sedimentary Basins of Nigeria	-	-	-	-	-	-	-	-	-	34
---	---	---	---	---	---	---	---	---	---	----

2.7 Review On The Basement Complex Geology Of Southwestern Nigeria	-	-	-	-	-	-	-	-	-	35
--	---	---	---	---	---	---	---	---	---	----

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the Study Location	-	-	-	-	-	-	-	-	-	38
---------------------------------------	---	---	---	---	---	---	---	---	---	----

3.2 Materials	-	-	-	-	-	-	-	-	-	40
---------------	---	---	---	---	---	---	---	---	---	----

3.3 Methodology	-	-	-	-	-	-	-	-	-	41
-----------------	---	---	---	---	---	---	---	---	---	----

3.3.1 Image Acquisition and Processing	-	-	-	-	-	-	-	-	-	42
--	---	---	---	---	---	---	---	---	---	----

3.3.2 Band Ratio	-	-	-	-	-	-	-	-	-	42
------------------	---	---	---	---	---	---	---	---	---	----

3.3.3 False Color Composite	-	-	-	-	-	-	-	-	-	42
-----------------------------	---	---	---	---	---	---	---	---	---	----

3.3.4 Image Classification / Training Sites	-	-	-	-	-	-	-	-	-	43
---	---	---	---	---	---	---	---	---	---	----

CHAPTER FOUR: PRESENTATION AND DISCUSSION OF RESULTS

4.1 Band Ratio	-	-	-	-	-	-	-	-	-	44
----------------	---	---	---	---	---	---	---	---	---	----

4.2 Image Classification	-	-	-	-	-	-	-	-	-	46
--------------------------	---	---	---	---	---	---	---	---	---	----

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion	-	-	-	-	-	-	-	-	-	48
----------------	---	---	---	---	---	---	---	---	---	----

5.2 Recommendation - - - - - 48

REFERENCES - - - - - 49

LIST OF TABLES

Table 3.1: Data Requirement - - - - - 40

Table 3.2: Analytical Software Requirement - - - - - 40

ABSTRACT

In this study, remote sensing data were integrated into GIS softwares for lithological mapping. The Landsat 8 OLI data were processed in order to see the lithological distribution in Akoko Edo area, Southern Nigeria. To achieve this purpose, products of Landsat 8 OLI digital data such as false color composite images (7, 5, 2 in RGB) and a band rationing image (6/7, 6/5, 4/2) were generated. Products of image processing improved lithological discrimination. Image classification was used to recognize and discriminate between the different rock units. In the result, four major classes were generated with two major geological features namely granite and migmatite with Bare earth surface and vegetation making up about 52% of the surface. The major geological features covered about 48% of the region. The band ratio classification using maximum likelihood classification was fairly accurate and matched the geologic map of Akoko Edo. The methodological approach used in this study for lithological mapping can be used to explore for mineral deposits, so more field works should be done to validate the gotten data and improve this method.

CHAPTER ONE

1.0 INTRODUCTION

Lithologic mapping is simply the process of generating a map that shows the different rock types in an area.

Almost all digital or topographic mapping and most mapping projects require the digital maps generated using the integrated geographic information systems (GIS) and remote sensing techniques with geospatial databases. The use of remote sensing (RS) and radar images to produce geological maps is seen as making it possible to reveal those elements of geological features from images which should be reflected in the geo-spatial databases and digital maps (Ezabti and Jovanović, 2015).

According to Frei et al. (2006), in Africa, remote sensing studies can contribute significantly to geological projects and to sustainable development of the continent. Vast regions in Africa are in need of basic topographic and geologic maps, and in many parts of the continent, remote sensing data are often the only available, most effective and efficient way for the extraction of new geological information (Oyawale et al., 2020).

Since July 1972 for the launch of the first Landsat 1, remote sensing (RS) has been broadly used in geoscientific fields especially in some of the mature domains

such as mineral alteration mapping (Mainta, 2016 and McCurry, 1973), due to their special advantages in the cyclical, macro- and systematic aspects (Olatunji, 1979). The spectral patterns of rocky outcrops relying mainly on rock-mineral components, are always the foundation of RS-based outcrops recognition, which may provide a breakthrough point into the lithological mapping. Nonetheless, current studies mainly focus on (semi-) arid environments with few loess, snow, vegetation, regolith coverage, and only several studies can be found in the literatures (Lin et al., 2019).

Remote Sensing is a technique in which acquisition of data for deriving information about objects or materials located on the earth surface or on its atmosphere is made without any direct contact.

Remote sensing may be more formally defined as the acquisition of information about the state and condition of an object through sensors that are not in physical contact with it. A remote observation requires some kind of energy interaction between the target and the sensor. The sensor-detected signal may be solar energy (from the Sun) that is reflected from the Earth's surface or it may be self-emitted energy from Earth itself. We can also build sensors that produce their own energy source, which is then measured after interacting with the Earth's surface. The radiant energy signal that is detected and measured by the satellite sensor is then either stored in memory on board the satellite or transmitted to a ground receiving

station for later interpretation. Remote sensing also includes the analysis and interpretation of the acquired data and imagery. For environmental scientists this is the most important aspect of remote sensing, since the main value of this technique is to provide relevant information for monitoring Earth resources (Chuvienco and Huete, 2009, pp. 1-2).

1.2 AIM AND OBJECTIVES

The aim of this work is to use remote sensing data and GIS to generate a map showing the spatial distribution of the different lithologic units in Akoko Edo, Edo State.

Objectives

1. To develop a map of the study area
2. To carry out image classification of the satellite Imagery of the area
3. To develop a lithological map of the study area

1.3 ROCKS

A rock is a naturally formed, consolidated material usually composed of grains of one or more minerals. There are generally three types of rocks: igneous rocks, sedimentary rocks and metamorphic rocks. This work however focuses on basement rocks (igneous and metamorphic) due to the study area.

1.4 Application Of Remote Sensing And GIS To Lithologic Mapping

Remote sensing, as a direct adjunct to field, lithologic and structural mapping, and more recently, GIS have played an important role in the study of mineralized areas.

Reconnaissance lithologic mapping is usually the first step of mineral resource mapping (Rajesh, 2004).

CHAPTER TWO

LITERATURE REVIEW AND GEOLOGICAL SETTING

2.1 PREVIOUS WORKS

Quite a number of works have been done across several fields of study using GIS and remote sensing techniques.

Ourhzif et al. (2019) worked on lithological mapping using landsat 8 oli and aster multispectral data in imini-ounilla district south high atlas of Marrakech. A comparative study showed that the significant lithologic groups such as marly limestone, Limestone dolostone, sedimentary breccias limestone, Triassic basalt and the clay can be extracted well from ASTER data however the rhyolite, schist, the quaternary red bed, conglomerate and recent alluvium are mapped well in the OLI image using SVM classification.

Es-Sabbar et al. (2020) used composite color, PCA and band ratios techniques to effectively determine lithological units outcrop in Ras Kammouna arid area (eastern anti-atlas, morocco). Combining results of applied remote sensing techniques and field investigations showed them a close spatial relationship between fractured zones and mineralization occurrences.

Kamel et al. (2016) carried out a work on the Utilization of ETM+ Landsat data in geologic mapping of wadi Ghadir-Gabal Zabara area, Central Eastern Desert, Egypt. They used the ratio image (5/1, 3/2 and 7/2 in RGB) to differentiate between serpentinites and different rock types. Another ratio image (3/1, 4/2 and 5/7 in RGB) was used to separate between syn-tectonic granite and late tectonic granite.

Rajesh (2004) worked on application of remote sensing and GIS in mineral resource mapping. The steps he used for mineral resource mapping was reconnaissance lithologic mapping, structural mapping and alteration mapping. In conclusion remote sensing is an important tool for locating mineral deposits while for the exploration stage, GIS is the perfect tool in integrating and analyzing various georeferenced geosciences data in selecting the best sites of mineral deposits.

Fashae et al. (2014) worked on delineation of groundwater potential zones in the crystalline basement terrain of south west Nigeria: an integrated GIS and remote sensing approach. They determine that due to complex and erratic nature of groundwater occurrences in crystalline basement terrains, groundwater development in form of boreholes/wells without the necessary pre-drilling hydrogeological investigations usually results in failure. The study approach involved integration of nine different thematic layers namely geology, rainfall, geomorphology, soil, drainage density, land use, slope and drainage proximity based on weights assignment and normalization with respect to the relative contribution of the difference themes to groundwater occurrence using Saaty's Analysis(MCDA), Remote Sensing(RS), Geographical Information System(GIS) techniques to delineate groundwater potential zones in crystalline basement terrain of SW-Nigeria and with existing borehole/well yield data which resulted into three

different groundwater potential zones: high, medium and low. 78% of the total area fall within the medium groundwater potential zone which are generally underlain by medium-porphyrific granite, biotite-hornblende granite and granite gneiss bedrock settings. 17% fall under high groundwater potential zone which are characterized by weather/fractured quartzite, quartz schist, amphibolites schist and phyllite bedrock settings. 3% fall under low groundwater potential zone which are characterized by migmatite, banded and augen gneiss bedrock settings.

Abdullah et al. (2013) worked on remote sensing and Geographical Information System for fault segments mapping a study from Taiz area, Yemen. They used landsat ETM-7 satellite data images and band for lineament delineation based on the geological features. The used of four factors namely drainage patterns, faults, lineament and lithological contacts layers were parameters used in the study that produces a faults potential prediction map using overlay model techniques which was classified into five potential zones namely very low, low, moderate, high, very high potential. Fault segment were considered to be covered by moderate to the highest potential zones. They makes use of GIS matching techniques in comparing between potential map and the published fault map which shows that 75 fault lines in the study area. The correlation between fault lines and fault data collected from field works stations shows that being identified.

Nasir et al, (2017) worked on the role of remote sensing applications in mineral exploration and sustainable development in Oman. They used remotely sensed satellite data in mapping out different lithologies, mineral resources and ore deposits. Satellite images are capable in differentiating rock types useful for geological application and significantly used in identification in mineral resources. Oman had potential occurrence of the industrial minerals and ore deposits which are mostly occurred in inaccessible mountains and desert regions where it was difficult to do conventional geological mapping Thus having the knowledge of the techniques to map and explore potential resources by the geologist was highly important. They made use of advanced space borne thermal emission and reflection radiometer (ASTER) and selected imaging processing methods namely de-correlation stretching, band ratios, Linear Spectral Un-mixing(LSU) and Mixture Tuned Matched Filtering (MTMF) to map several mineral deposits and different rock lithologies in Oman which includes limestones, marl, listwaenites, carbonatites, metamorphic zones, caves, karst, springs, vegetation's rock fall and slide, moho, copper, chromite, awaruite, manganese and gold deposit in different part of the sultanate in Oman. It demonstrates the spectral sensitivity of such rocks for simple interpretation over satellite data and describes and distinguishes them based on the absorptions of hydrous minerals in the spectral bands of ASTER for mapping and exploration studies.

Dash (1999) worked on remote sensing and GIS applications in seismic hazard studies in NW Himalayas. He used GIS in evaluation, management and monitoring of hazards while remote sensing data and its analysis of natural hazard helps in monitoring the changes in surfacial feature. The uses of GIS module, integration of the past earthquake data, lineaments, stress pattern and the geological information have been attempted to evaluate the seismic risk in the study area.

Moujahid et al, (2016) worked on mapping and analysis of geological fractures extracted by remote sensing on landsat TM images. Various analytical techniques were used to enhance lineaments in the corresponding perpendicular directions and obtaining a good discriminating structures, dominant geological fracturing trending ENE/WSW with 52% of the total lineaments, a second fracturing trending WNW/ESE with 23%, a third fracturing trending NE/SW with 20% and finally a minor series of fractures trending NW/SE with 5% of the total lineaments. Distribution and statistical relationship between fractures and the affected surface and fracture length shows a network of well- structured fractures.

2.2 REMOTE SENSING

The term “Remote Sensing” was first coined by Evelyn Pruitt at the United States office of novel research in 1958. Landsat– 1 is the first earth observation satellite. It was launched in 1972. Since then, remote sensing has become widely used.

Remote sensing is defined as the science and technology by which the characteristics of objects of interest can be identified, measured or analyzed the characteristics without direct contact. According to Colwell (1997), remote sensing is “the art, science, and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from non contact sensor systems”.

2.2.1 Stages in Remote Sensing

- i. Emission of electromagnetic radiation or EMR (sun/self-emission)
- ii. Transmission of energy from the source to the surface of the earth, as well as absorption and scattering
- iii. Interaction of EMR with the earth’s surface: reflection and emission
- iv. Transmission of energy from the surface to the remote sensor
- v. Sensor data output
- vi. Data transmission, processing and analysis

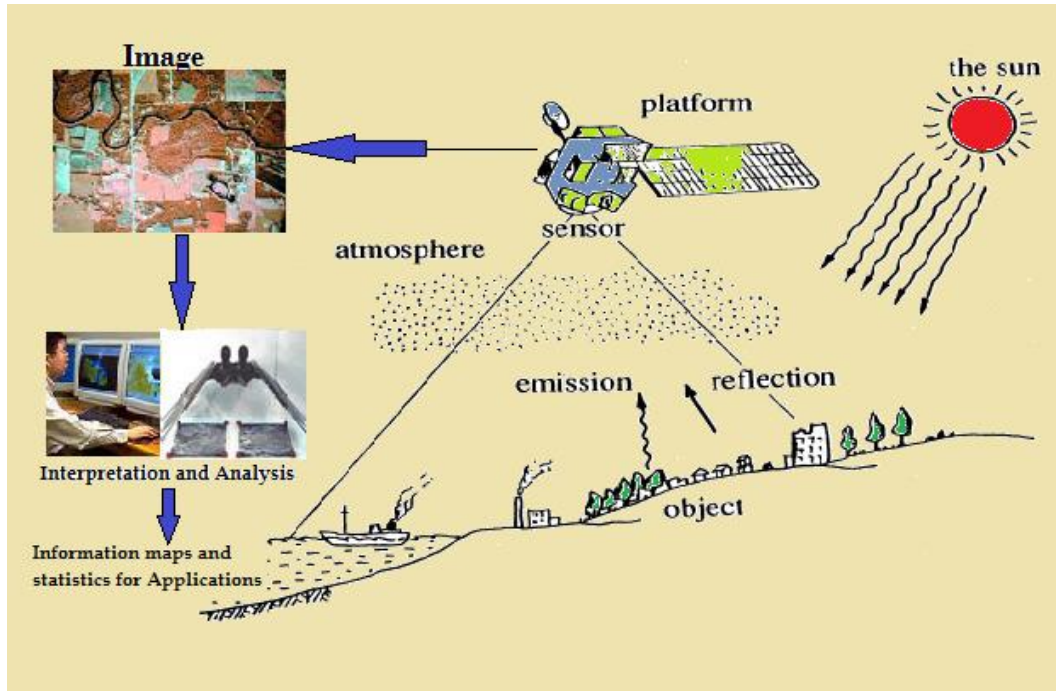


Fig. 2.1: Data Collection by Remote Sensing

2.2.2 Components and Principle of Remote Sensing

The component of remote sensing are object, source of electromagnetic radiation, sensor, platform, image research, data interpretation etc.

2.2.3 Electromagnetic Radiation

Electromagnetic radiation which is reflected or emitted from an object is the usual source of remote sensing data. However, any media such as gravity or magnetic fields can be utilized in remote sensing. Electromagnetic radiation is a carrier of electromagnetic energy by transmitting the oscillation of the electromagnetic field through space or matter. The transmitting the electromagnetic radiation is derived from the Maxwell equations. Electromagnetic radiation has the characteristics of both wave motion and particle motion.

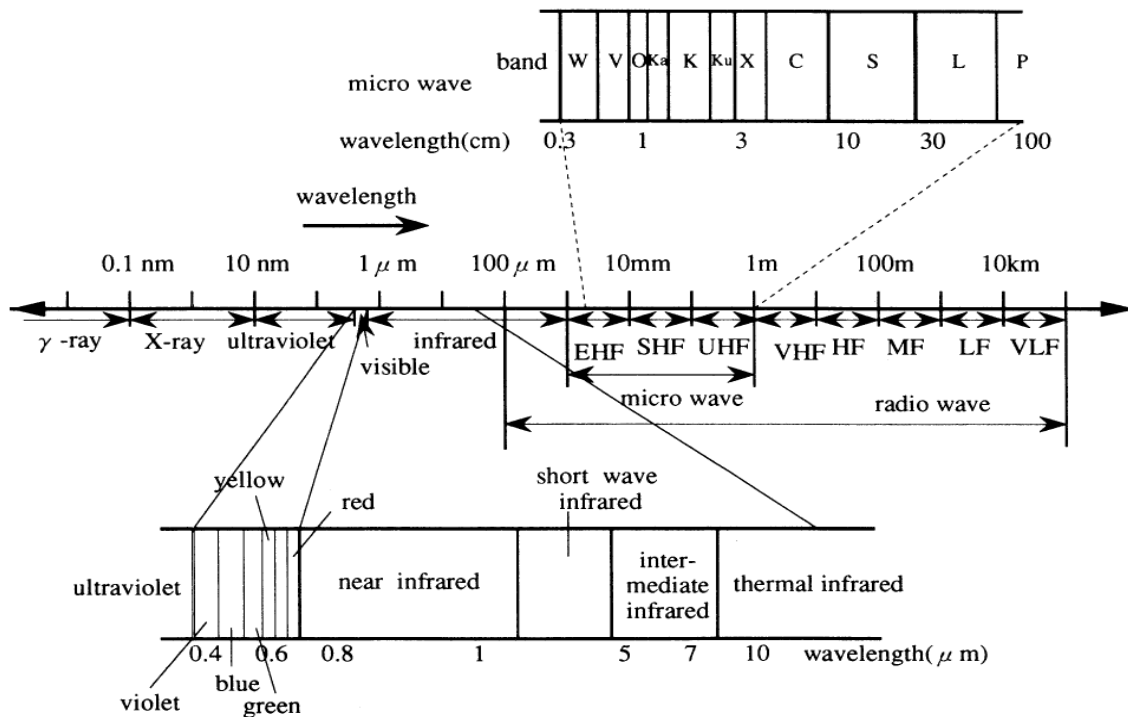


Fig. 2.2: Bands Used in Remote Sensing

The characteristics of an object can be determined, using reflected or emitted electromagnetic radiation, from the object. That is “each object has a unique and different characteristic of reflection or emission if the type of object or the environmental condition is different.” Remote sensing is a technology to identify and understand the object or the environmental condition through the uniqueness of the reflection.

2.2.4 Sensor and Platform

A device to detect the electromagnetic radiation reflected or emitted from an object is called remote sensor or SENSOR. Cameras or scanners are examples of

sensors. A vehicle to carry the sensor is called a platform. Aircraft or satellites are used as platforms. Sensors are classified into the following types:

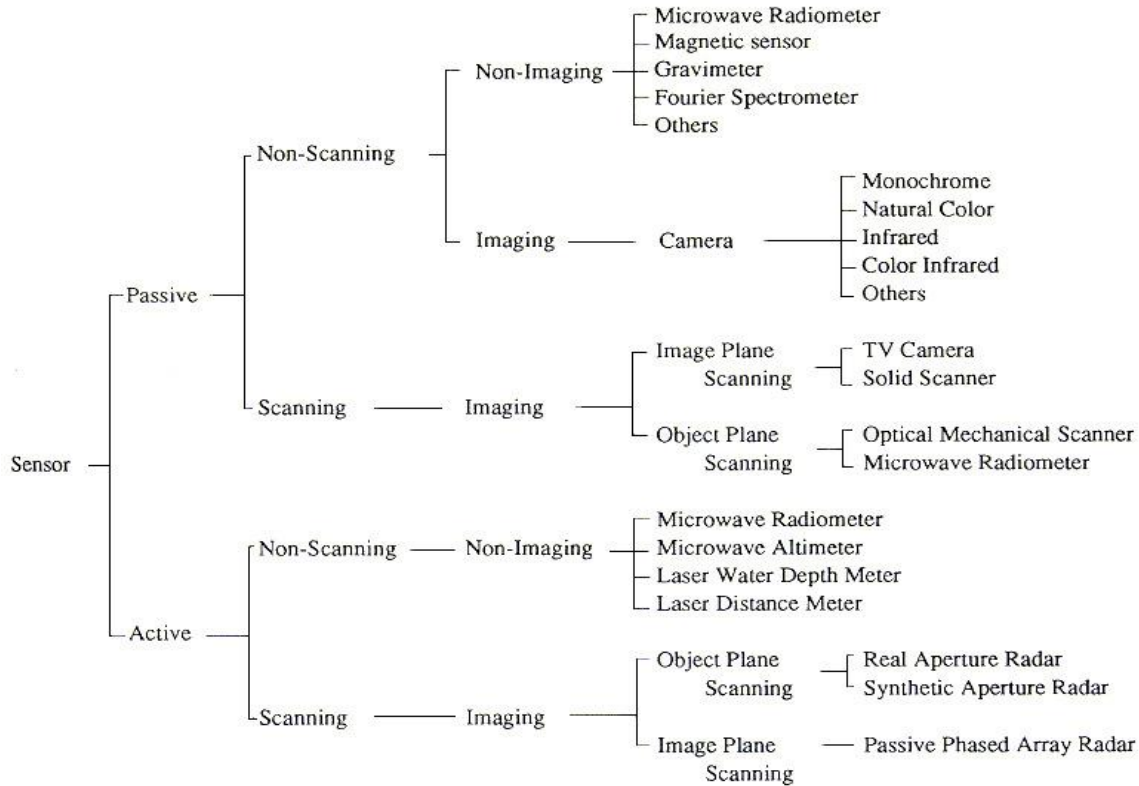


Fig. 2.3: Types and Examples of Sensors

2.2.5 Types of Platforms used for Remote Sensing

- i. Ground-based platforms: ground, vehicles and/or towers → up to 50m
- ii. Airborne platforms: airplanes, helicopters, high-altitude aircrafts, balloons → up to 50km
- iii. Spaceborne: rockets, satellites, shuttle → from about 100km to 36000km

Space shuttle: 250 - 300km

Space station :300 - 400km

Low-level satellites: 700 - 1500km

High-level satellites: about 36000km

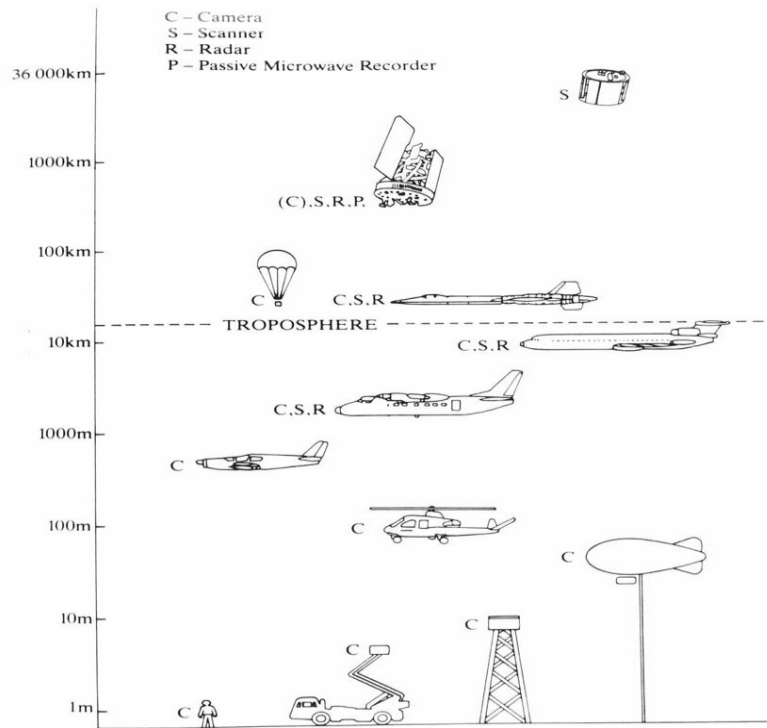


Fig. 2.4: Examples of Platform

2.2.6 Flow Process of Remote Sensing

The flow process of remote sensing, where three different objects are measured by a sensor in a limited number of bands with respect to their, electromagnetic characteristics after various factors have affected the signal. The remote sensing data will be processed automatically by computer and/or manually interpreted by humans, and finally utilized in agriculture, land use, forestry, geology, hydrology, oceanography, meteorology, environment etc.

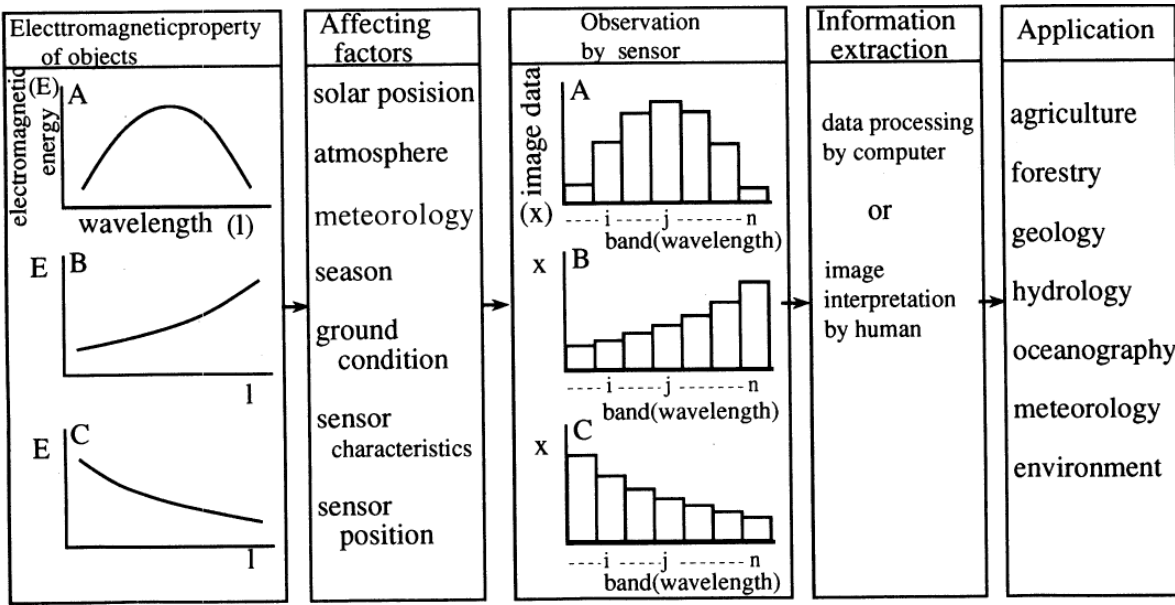


Fig. 2.5: Flow Process of Remote Sensing

2.2.7 Limitations of Remote Sensing

The use of remote sensing technology in the monitoring and management of tropical waters is likely to face some limitations as outlined below:

- Practical limitations, which are usually inherent in the technology itself. For instance, the limited ability of light to penetrate in water and atmospheric attenuation.
- User limitations referring to difficulties of assessing suitability of certain sensors. For example, remote sensing tends to provide geo-morphological rather than ecological information on reef structure. This is due to limited spectral and spatial resolution of the sensors, and factors that confound image interpretation such as turbidity and variation in water depth. A more

pronounced limitation in the tropics is cloud cover which significantly reduces the number of suitable images (Bainbridge, 1988) to be available at all seasons. This situation has serious implications on change detection studies and efforts to relate field data to images.

2.2.8 Types of Remote Sensing

Remote sensing can be either passive or active. Active systems have their own source of energy (such as RADAR) whereas the Passive systems depend upon external source of illumination (such as SUN) or self-emission for remote sensing. So, on the basis of energy sources remote sensing is of two types:

1. Active Remote Sensing
2. Passive Remote Sensing

The remote sensing is classified into three types with respect to the wavelength region. They are as follows:

1. Visible and Reflective Infrared Remote Sensing

The energy source used in the Visible and reflective infrared remote sensing is the Sun. The sun radiates electromagnetic energy with a peak wavelength of 0.5 μm and remote sensing data obtained mainly depends on the reflectance of objects on the ground surface.

2. Thermal Infrared Remote Sensing

The source of radiant energy used in Thermal infrared remote sensing is the object itself because any object with a normal temperature will emit electromagnetic radiation (Thermal radiation) with a peak about $10\mu\text{m}$.

3. Microwave Remote Sensing

In the micro wave region, there are two types of microwave remote sensing namely Passive microwave and Active microwave remote sensing. In passive microwave remote sensing the microwave radiation emitted from an object is detected while the back coefficient is detected in active microwave remote sensing.

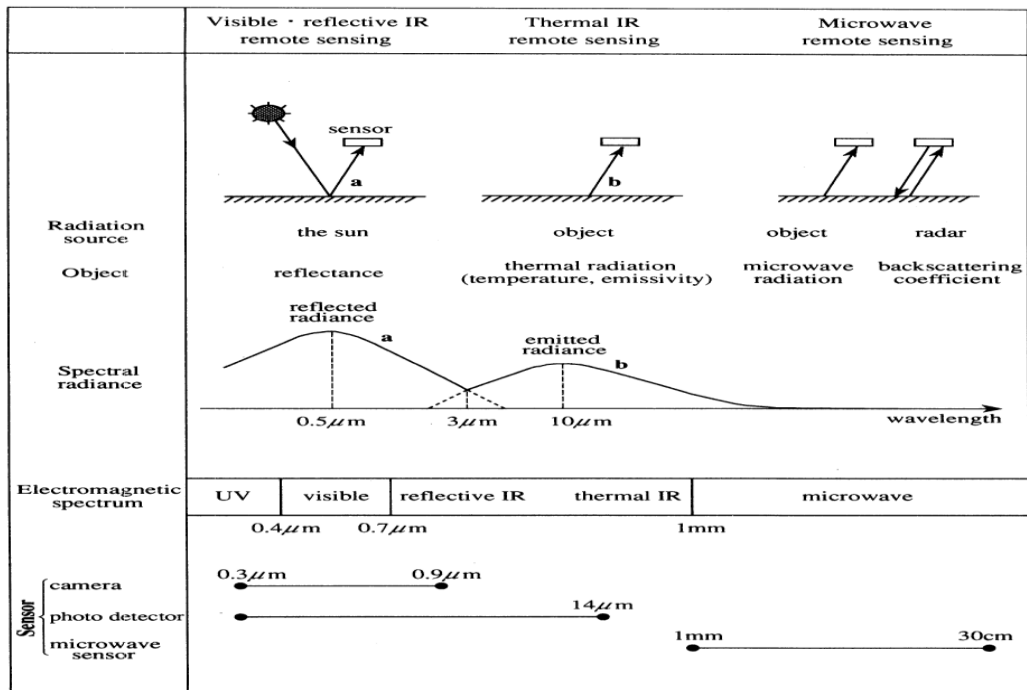


Fig. 2.6: Three Types of Remote Sensing with Respect to Wavelength Region

2.2.9 Application in the Field of Geology

Geology involves the study of landforms, structures, and the subsurface, to

understand physical processes creating and modifying the earth's crust. It is most commonly understood as the exploration and exploitation of mineral and hydrocarbon resources, generally to improve the conditions and standard of living in society.

Geological applications of remote sensing include the following:

1. surficial deposit/ bedrock mapping
2. lithological mapping
3. structural mapping
4. sand and gravel (aggregate) exploration/ exploitation
5. mineral exploration
6. hydrocarbon exploration
7. land resource assessment
8. environmental geology
9. geobotany
10. baseline infrastructure
11. sedimentation mapping and monitoring
12. identification of rock types
13. location of geological faults and anomalies
14. event mapping and monitoring
15. geo-hazard mapping

16. planetary mapping

2.3 GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Geographic Information System (GIS) refers to a system used for storing, manipulating, and retrieving spatially referenced data. This definition also includes systems designed to capture spatial information and to process it. Data in a GIS are its database, usually composed of data planes derived from different data sources. A data plane is composed of one data type, for example, digitized elevation data. Digital data may either be in form of written text, maps, tables or photographs.

In order to manage tropical waters effectively it is inevitable that a large amount of data is handled. Those involved in the general management of these resources require rapid access to statistical data and thematic maps. Manual interpretation only allows integrating of relatively small amounts of field data, maps and aerial imagery. A GIS brings together spatially referenced statistics and remotely sensed imagery into one integrated system. GIS can also be useful in improving information extraction capabilities from remotely sensed data. The integration of remote sensing into GIS has provided environmental studies with a genuine investigation power. Nevertheless, it is only a potential source of data among others whose use finds its justification in the aim to be reached. At the spatial scales at which satellites observe the Earth, one cannot seriously envision to use satellite imagery to monitor the dynamics of small environments on short time-

scale, e.g. every 5 years. To detect space changes in these areas, data-acquisition and-analysis scales must be greater than 1:50,000 with a measurement precision of 1 meter. Today, numerical ortho-photographies or aerial remote- sensing (CASI) can punctually overcome the too low resolution of satellite sensors; so, one can use them to monitor tropical shallow lakes.

A GIS must be able to present information to users in a language and format that is not only accurate, but also graphic and comprehensible to all users. To facilitate urgent response from decision-makers in matters related to tropical water management, it is prudent to have a high ratio of maps and diagrams in written text. Such documents constitute a visual help essential for field staff, an aid for drawing up inventory as well as a mean of information and communication. In a short access time GIS allows one to store data from various origins, facilitates the design of maps meeting specific needs, e.g. scale, typology, and enables one to spare time in the production information through a possible automation of design. All these characteristics not only increase map production, but also improve their quality by a better adequacy with the objectives to be reached.

2.3.1 Mapping the subsurface using GIS:

The mapping or modeling of the subsurface of earth is difficult to understanding our abilities and limitations regarding to oil and gas resources, mineral exploration, and environmental management.

The geologic modeling of the subsurface is a complex task for GIS technology. But, the spatial nature of the geologic objects always makes GIS to be an important part of the modeling and mapping systems.

The conventional activities in which GIS involved in geosciences are data display, data administration, area analysis, and support making decision. But, now the evolution allows the GIS capabilities on just a desktop computer with full possibility to integrate the industry-standard Relational Database Management System, 3D visualization, geostatistical functionality, 3D geoprocessing capabilities, and Web-based mapping. All these advantages make GIS the most useful and attractive tool for comprehensive and essential geoscientist's needs.

The latest GIS software's made on an open standard technology ensure that GIS can be easily integrated with advanced solid 3D geosciences software's to gain a solution for complex geologic problems. But until recently, although it's become easier, visualizing the subsurface of the earth within GIS has been a complex technical challenge.

These challenges are:

- Multiple data sets and maps.
- Efficiency of data combination and integration along various formats.

Nowadays, GIS subsurface modeling tools allow the geologists to present normally visualized on separate maps in an integrated form as well as deal and

process surface data.

In addition to that, the possibility to display wells (drill holes and borehole), and other data from subsurface in 2D and 3D. Users can manipulate a large volume of surface and subsurface geological, geochemical and geophysical data in 3D within a single or transparently-linked interactive environment. They can enhance the drilling results and the environment that data was collected from. Also, they can display geochemical surface data and query geological mapping regions.

Geologists and geoscientists with these tools can integrate and manipulate all available data at each stage of the exploration program to gain a better understanding of the underlying subsurface geology, check their assumptions, and share their ideas with others on their exploration teams.

2.4 Satellites

One of the earliest dreams of humans has been to fly and observe Earth and its landscapes from above. This has been realized only recently with the advent of balloons, gliders, and airplanes. Today, as a result of rapid technological advances, we routinely survey our planet's surface from airplanes and we can now, for the first time in human history, observe the entire Earth as a planet from space. The photographs and digital images sent back from satellites have revolutionized our knowledge and understanding and have enabled new discoveries about our planet's environment and its inhabitants (Chuvienco and Huete, 2009, p. 1).

There are two types of satellites that orbit the Earth which includes Geostationary Operational Environmental Satellites (GOES). Placed above a fixed location on the Earth's surface, the elevation is approximately 22,500km above the equator. They rotate the Earth. Polar orbiting satellites are not placed in a fixed location but rather on each orbit which observe a new path. The orbits have a lower elevation of (800-900 km). The orbit path is 2,400km wide centered at the orbit path.

Satellite images (also known as Earth observation imagery, spaceborne photography, or simply satellite photo) are images of earth collected by imaging satellites operated by governments and businesses around the world. Satellite imaging companies sell images by licensing them to governments and businesses such as Apple maps and Google maps. It should not be confused for astronomy images collected by space telescope. Satellite images are one of the most important and powerful tools used in geological interpretation or investigation, meteorologist, scientific studies, geopolitical matters etc. They are the eyes In the sky, the images gotten from the satellite helps forecasters to the behavior of the atmosphere as they give a concise, clear and accurate representation of how events are folding. Satellite images aid in showing what cannot be measured or seen which can be said to be truth and no chance for error. Data, satellite, and forecasting are essential for the understanding of how the atmosphere and earth behaves.

Satellite images have many uses in meteorology studies, geology, regional planning, biodiversity conservation, landscape, forestry, and education. Images can be in visible colors and in other spectral, elevation maps are made by radar images. Analysis and interpretation of satellite imagery can be done using specialized remote sensing software. The resolution of satellite images varies depending on the altitude of the satellite's orbit and the type of equipment used. Satellite imagery have a higher resolution which make it more expensive per square meter, it can be combine with raster or vector data in GIS provided that the imagery has been spatially rectified so that it will properly align with the other data sets.

Limitations of satellite imagery are as follows:

Due to the fact that the total area of land on the Earth is very great and the resolution is very high, satellite databases are huge and creating useful images from the data is time consuming, preprocessing is usually required. Depending on the sensor that is been used, weather condition can affect image quality, for instance areas with relatively high humidity, rainfall, cloud etc such as mountains, high reliefs place etc.

commercial satellite companies do not place their imagery for public use and do not sell their images; instead one must be licensed to use it and few licensed people

may be given the imagery for use. The ability to legally make use of the item from commercial satellite imagery is limited.

2.4.1 LANDSAT

LANDSAT stands for Land Remote-Sensing Satellite (System), Land-use Satellite. Landsat satellites provide relatively high-quality, multi-spectral imagery of the surface of the Earth. This moderate resolution, remotely sensed images are not just pictures, but contain many layers of data collected at different points along the visible and invisible light spectrum. The data can be manipulated to reveal what the Earth's surface looks like, including what types of vegetation are present or how a natural disaster has impacted an area (USGS). Landsat satellite have the optimal ground resolution and spectral bands to efficiently track land use and to document land change due to climatic changes, drought, wildfire, urbanization, biomass changes, and a host of other natural and human-caused changes. Landsat satellite collect data by using passive sensors onboard the satellite that detect radiation emitted from the Earth in different bands of the satellite. There are eight types of landsat satellites in the landsat program, which are as follows: Landsat 1, 2,3,4,5 uses Multispectral Scanner (MSS). Landsat 4 and 5 uses both MSS and Thematic Mapper (TM) instrument. Landsat 7 uses the Enhanced Thematic Mapper Plus (ETM+) scanner. Landsat 8 uses both the Operational Land Imager (OLI) for optical bands and the Thermal Infrared Sensor (TIRS) for thermal bands.

Currently, there are two satellites that is producing imagery which are Landsat 7 operating since 1999, and Landsat 8 operating since early 2013. Meanwhile others Landsat satellite produce images but they are outdated.

Landsat 8 was formally known as the Landsat Data Continuity Mission, (LDCM) is the most recently launched landsat satellite. It was launched on the 11th of February 2013 on an Atlas-V rocket from Vandenberg Air Force Base, California. It is carried out by two instruments which are OLI and TIRS. Its orbits the Earth in a sun-synchronous, near polar orbit, at an altitude of 705km (438mil), inclined at 98.2 degrees, one completion of the Earth's orbit every 99 minutes. The satellite has a 16-day repeat cycle with an equatorial crossing time: 10:00 a.m +/- 15 minutes. A landsat8 scene size is 185km x 180km (114mi x 112mi) and the nominal spacecraft altitude is 705km. It is the collection of valuable data and imagery used in science, government, business, education, and agriculture.

Operational Land Imager (OLI) captures data with improve radiometric precision over a 12-bit dynamic range, which improve overall signal to noise ratio. OLI generates 9 spectral bands which are coastal/aerosol, visible blue, visible green, visible red, near-infrared (NIR), short wavelength infrared (SWIR-1), short wavelength infrared (SWIR-2), panchromatic, and cirrus(Band 1 to 9). These 8 bands have a ground resolution of 30 meters while the panchromatic band has a finer resolution of 15 meters. Thermal Infrared Sensor (TIRS) generates 2 thermal

bands which is band 10 long wavelength infrared(LWIR-1) and band 11 long wavelength infrared (LWIR-2) that measure Earth's thermal energy and has a resolution of 100meters.

On May, 2013 Landsat 8 Operational Land Imager (OLI) became available as well as Thermal Infrared Sensor (TIRS) imagery. This data consists of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9, and 15 meters resolution for Band 8 (panchromatic). New band 1 (ultra-blue) is useful for coastal and aerosol studies and new band 9 is useful for cirrus cloud detection. Bands 2-4 are visible bands whereas band 5 corresponds to near infrared (NIR). In addition, Band 6 and 7 correspond to shortwave infrared (SWIR) spectrum. Thermal bands 10 and 11 are useful in providing more accurate surface temperatures and are collected at 100 meters resolution. Approximate capture scene size is 170 km (north-south) by 183 km (east-west) (Ourhzif et al., 2019).

Landsat 8 is the collaboration between NASA and U.S. Geological Survey. The spectral coverage and radiometric performance (precision, accuracy, and dynamic range) are designed to discover and depict multi-decadal land cover change in concert with significant landsat data. The landsat program provides repeating acquisition of high resolution multispectral data of the Earth's surface on a global

basis, the data from the landsat spacecraft compose the longest record of the Earth's continental surfaces as seen from space.

2.5 REVIEW ON THE BASEMENT COMPLEX GEOLOGY OF NIGERIA

The basement complex is one of the three major litho-petrological components that make up the geology of Nigeria. The Nigerian basement complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons and south of the Tuareg Shield (Black, 1980). It is intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is unconformably overlain by Cretaceous and younger sediments. The Nigerian basement was affected by the 600 Ma Pan-African orogeny and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin (Burke and Dewey, 1972; Dada, 2006). The basement rocks are believed to be the results of at least four major orogenic cycles of deformation, metamorphism and remobilization corresponding to the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan African cycles (600 Ma) (Obaje, 2009). The Pan-African deformation was accompanied by a regional metamorphism, migmatization and extensive granitization and gneissification which produced syntectonic granites and homogeneous gneisses in the basement region (Abaa, 1983). Late tectonic emplacement of granites and granodiorites and associated

contact metamorphism accompanied the end stages of this last deformational cycle. The end of the orogeny was marked by some faulting and fracturing (Gandu et al., 1986; Olayinka, 1992).

Within the basement complex of Nigeria four major petro-lithological units are distinguishable, namely:

1. The Migmatite-Gneiss Complex (MGC)
2. The Schist Belt (Metasedimentary and Metavolcanic rocks)
3. The Older Granites (Pan African granitoids)
4. Undeformed Acid and Basic Dykes

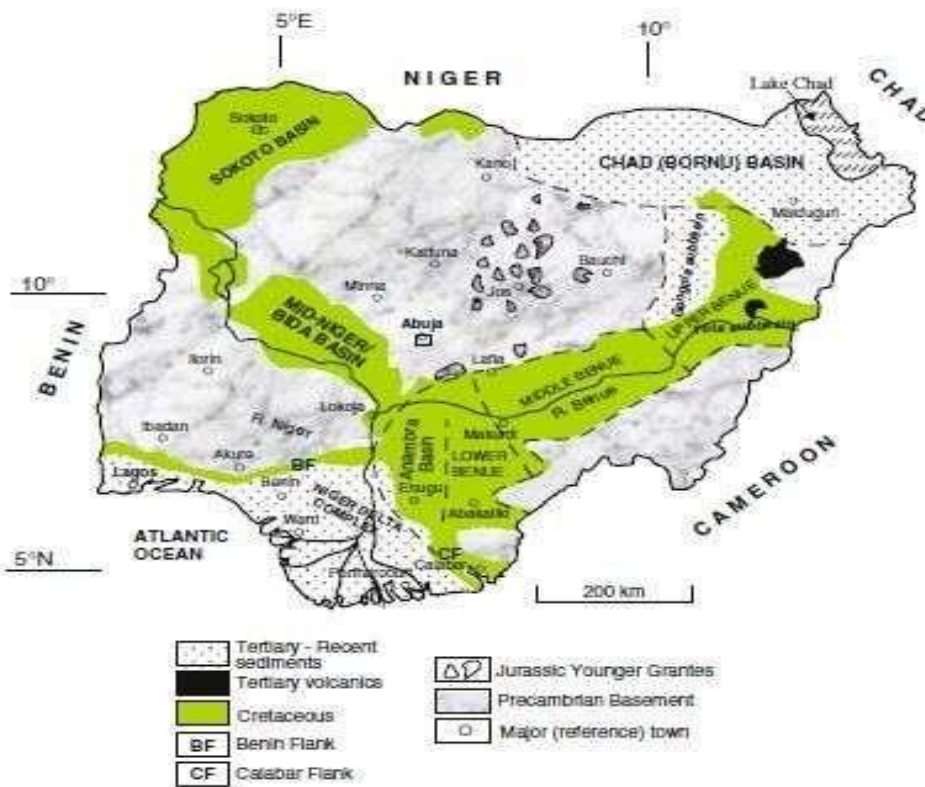


Fig. 2.7: Geologic Map of Nigeria (Obaje, 2009)

2.5.1 LITHOLOGIC UNITS AND LOCATIONS

Migmatite-Gneiss-Quartzite complex

The Migmatite– Gneiss Complex is generally considered as the basement complex *sensu stricto* (Rahaman, 1988; Dada, 2006) and it is the most widespread of the component units in the Nigerian basement. It has a heterogeneous assemblage comprising migmatites, orthogneisses, paragneisses, and a series of basic and ultrabasic metamorphosed rocks. Petrographic evidence indicates that the Pan African reworking led to recrystallization of many of the constituent minerals of the Migmatite–Gneiss Complex by partial melting with majority of the rock types displaying medium to upper amphibolite facies metamorphism. The Migmatite Gneiss Complex has ages ranging from Pan-African to Eburnean.

The Migmatite-Gneiss Complex makes up about 60% of the surface area of the Nigerian basement (Rahaman and Ocan, 1978).

Schist belts of Nigeria

These are supra crustal assemblages of low grade Meta-sediments and metavolcanics that crop out in well-defined belts in Northern and Southern Nigeria. The schist belt occurs in a 400 KM wide zone trending NNE parallel to the boundary between the Pan African province and West African craton. A polycyclic migmatite gneiss-granite terrain separates the individual belts in the zone.

The schist belt zone in Nigeria can be divided into two major areas in Nigeria.

They are the Northern and the Southern schist belts.

1) The Northern Schist Belts:

These include the following:

- i. The Kuseriki schist belt
- ii. The Karaukarau belt
- iii. The Maru schist belt
- iv. The Zuru belt

2) The Southern Schist Belts:

These include the following:

- i. The Iseyin-Oyan River Schist belt
- ii. The Ilesha Schist Belt
- iii. Igarra Schist Belt

The schist belts fall into two main age groups;

- i. The kibarano orogeny at 1100ma and
- ii. The Pan African orogeny

The Pan African Granitoids (The Older Granites)

The Pan-African granites are syn-to late-tectonic intrusions into the “MGC” and the Schist belts. They are otherwise referred to as the ‘Older granites’ to distinguish them from the Jurassic granites which are also found alongside their outcrops in the Jos Plateau and adjoining localities. Dada (2006) was of the opinion that the term “Pan African Granitoids” be used for the Older Granites not only on the merit of age which was not available at the time they were named Older Granites, but because it covers several important petrologic groups formed at the same time.

The Pan-African granites suite consists mainly of granites and granodiorites (Rahaman, 1976). They range in size from small sub-circular cross-cutting stocks to large elongate concordant batholiths. They are often weakly foliated and described as foliated granites and gneissic granites. Contacts of these Older granites with the Basement Complex rocks are characteristically gradational suggesting a non-magmatic origin, possibly emplaced during the last of the reactivation events to affect the Basement Complex, i.e. during deformation and metamorphism of the supracrustals (Pan-African orogeny) (Rahaman, 1976).

They occur in 3 main areas of basement complex and they are:

- i. In the South West from Akure to Ado-Ekiti to the Okene axis

- ii. North- central Nigeria accounting 70% of the basement.
- iii. The Eastern border of the country to Cameroun.

Rahaman (1988) classified the members of the Older Granite suite on the basis of their texture, mineralogical composition and the relative timing of their emplacement. Members of the Older Granite suite were classified as follows, based mainly on the textural characteristics:

1. Migmatitic granite;
2. Granite gneiss;
3. Early pegmatites and fine-grained granite;
4. Homogeneous to coarse porphyritic granite;
5. Slightly deformed pegmatite aplites and vein quartz; and
6. Undeformed pegmatites, two-mica granites and vein quartz.

The most popular and common of the older granite is the coarse porphyritic variety. The mineralogy consists of Quartz (20-30%), Feldspar, Biotite or Hornblende. They outcrop as low hummocky hills as well as turtle and whale backs

The origin of the older granite can be subdivided into the following. They can be formed by the following processes:

- i. Fractional crystallization

- ii. Metasomatism
- iii. Partial melting.

2.6 Review On The Sedimentary Basins Of Nigeria

The Sedimentary Basins, containing sediment fill of Cretaceous to Tertiary ages, comprise the Niger Delta, the Anambra Basin, the Lower, Middle and Upper Benue Trough, the Chad Basin, the Sokoto Basin, the Mid-Niger (Bida-Nupe) Basin and the Dahomey Basin. Sedimentary successions in these basins are of middle Mesozoic to Recent age. Older sedimentary deposits were not preserved, probably because during the Paleozoic - early Mesozoic, what is now Nigeria was a broad regional basement uplift, with no major basin subsidence for sediment accumulation. Nigerian basins are broadly divisible into coastal Calabar Flank, Niger Delta, Dahomey Basin and interior basins (Benue Trough, Chad Basin, Nupe Basin, SE Iullemmeden Basin). However, the sedimentary successions in these basins are broadly divisible into: (1) Basal continental sandstones, siltstones, and mudstones; (2) Middle marine shales and

limestone's interceded with sandstones and siltstones; (3) Upper sandstone sequence that is continental or paralic. Although a tripartite subdivision is also applicable to the Niger Delta, this sequence has been growing seaward with lower marine shales grading through thick ancient coastal sandstones and shales, into an

upper continental sequence. The middle ancient coastal sediments are oil-and gas-bearing.

2.7 REVIEW ON THE BASEMENT COMPLEX GEOLOGY OF SOUTHWESTERN NIGERIA

The Precambrian rocks of Southwestern Nigeria is part of the larger Nigeria basement complex. Five main lithologies can be recognized. They are as follows:

- 2.7.1 Migmatite-Gneiss-Quartzite complex which comprise the biotite hornblende gneiss, quartzite, and calcsilicate lenses
- 2.7.2 Slightly migmatized paraschists and meta igneous rocks
- 2.7.3 Charnockites
- 2.7.4 Older Granites
- 2.7.5 Unmetamorphosed dolerite dykes.

The minor rock types observed in the region include the following:

- i. Pegmatites dykes
- ii. Quartz veins
- iii. Dolerite dykes.

The Migmatite-gneiss complex is thought to have developed from the complex association of deformative shearing and folding, granitization and magmatic processes. The structural elements mainly found here are as follows: Foliation,

Lineation, Minor folds, Major folds, faulting. The Charnockites are mainly magmatic in origin and not as a result of high grade metamorphism in the granulite facies. They belong to two generations: the older granites and the last stages of the emplacement of the older granites.

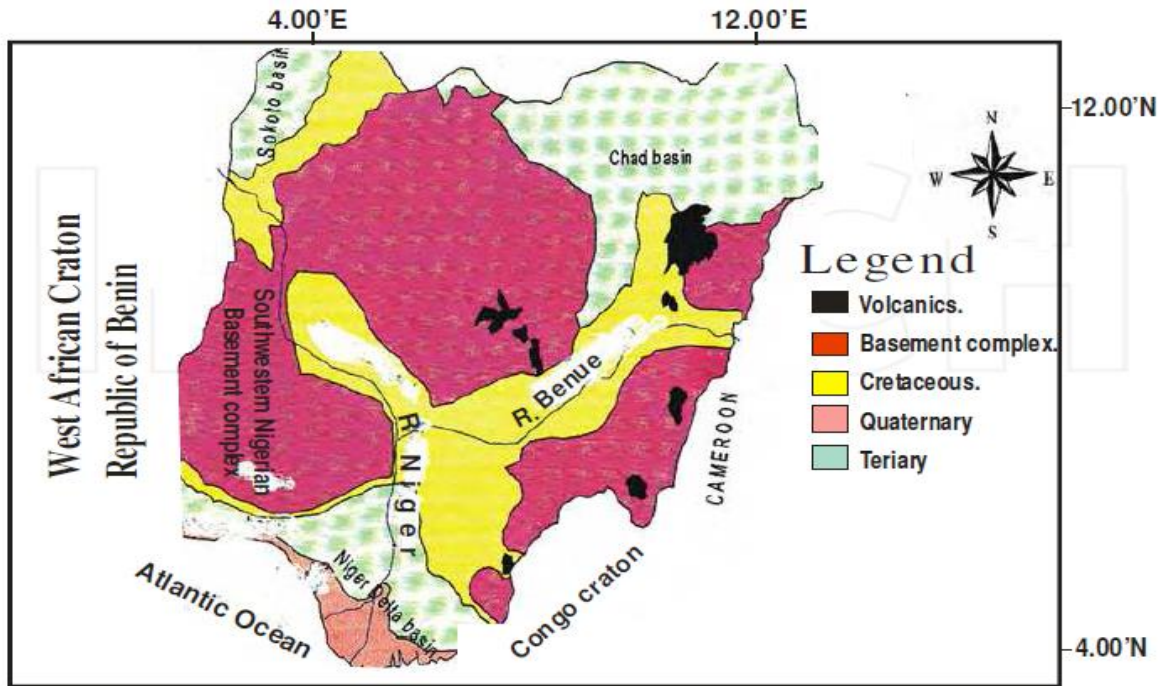


Fig. 2.8: Map of Nigeria showing the southwestern basement complex (Oyinloye, 2004).

The radiometric data from rocks indicate two orogenic processes

- i. The Eburnean
- ii. The Pan African.

The South West segments differ from the northern segments in that the schist belts don't form well defined belts and they are not well exposed. They are low grade

schist, a series of ancient meta-sedimentary and meta-volcanic rocks belonging to the migmatite-gneiss complex and are well developed in the south west region and occur as small relics in the North West.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Location

The study area is Akoko Edo Local government area which is found in the Northern region of Edo state in Nigeria.

The Ancient Akoko-Edo area is situated in the northern part of Edo state in the south of the Niger-Benue Confluence. Its dominant geographical and environmental features comprise chains of ancient ridges of rugged rocky hills and a cave, stretching across the length and breadth of what is now known as the Akoko-Edo LGA of the present Northern Edo State, located between latitudes 45 N 35 N and longitudes 55 E, 45 E. Akoko-Edo occupies a land area of about 1, 371 square kilometers or 6.5% of Edoland. Akoko-Edo is bounded in the North by the present Kwara state and parts of the present Kogi state, in the north-west by the present Ondo state, in the south-east by both Etsako west (Auchi clans) and Etsako north (Okpella), and in the south-west by Owan. Figure 3.1 shows a map of the study area.

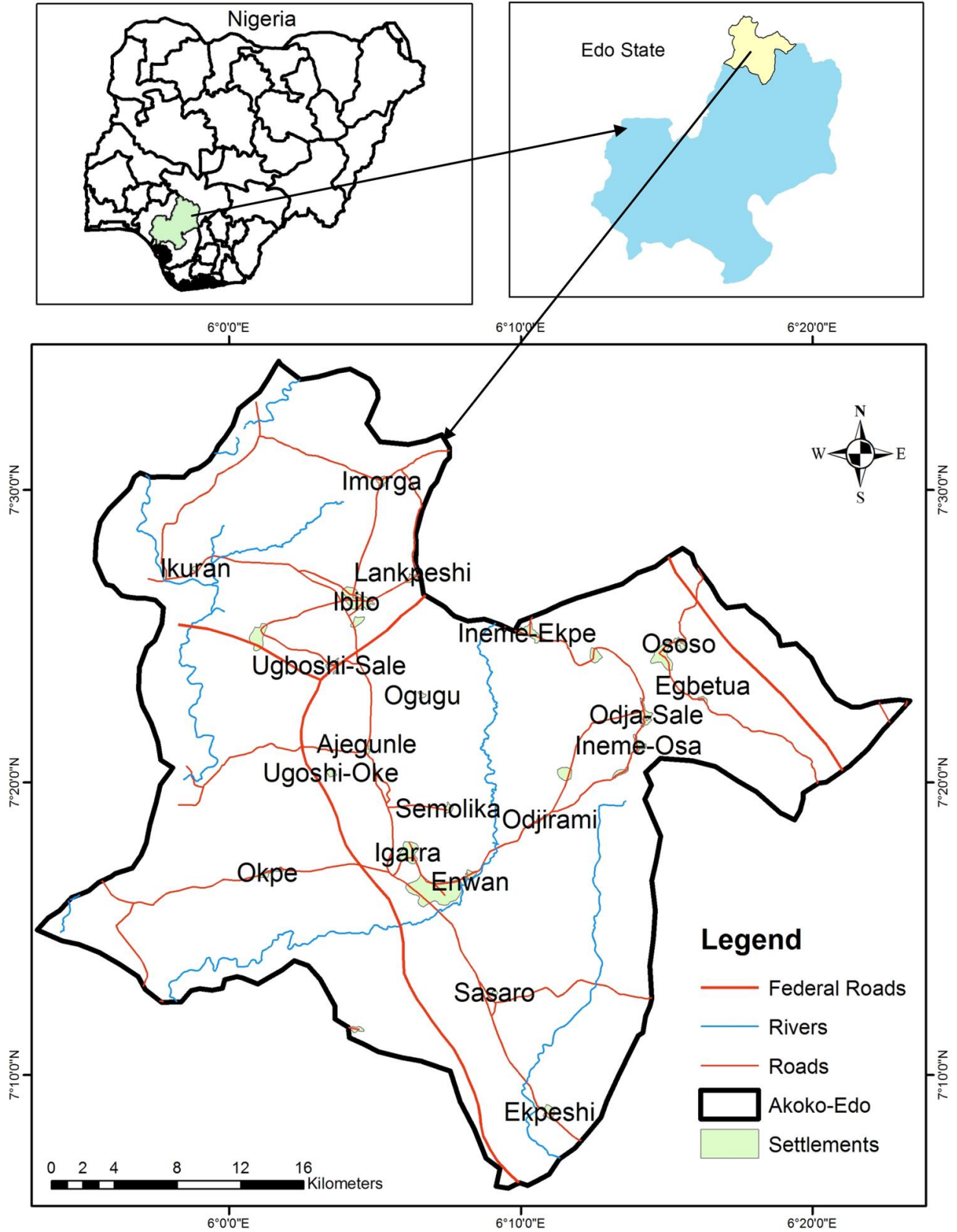


Fig. 3.1: Location Map Of The Study Area (Aluko and Igwe, 2018)

3.2 Materials

The following data and software were required for carrying out the study methodology:

Table 3.1: **Data requirement**

Data Type	Source	Date
Landsat-8 OLI/TIR	https://earthexplorer.usgs.gov	Nov. 2020
Digital Elevation Model (30m resolution)	https://earthexplorer.usgs.gov	2014

Table 3.2: **Analytical Software requirement**

Software	Purpose
Environment for Visualizing Images (ENVI) 4.3	Used for Satellite image processing and image enhancement
ArcGIS 10.2	geospatial analysis of the enhanced images and visualization of maps
Google earth Image	Global Visualization of high resolution image

3.3 Methodology

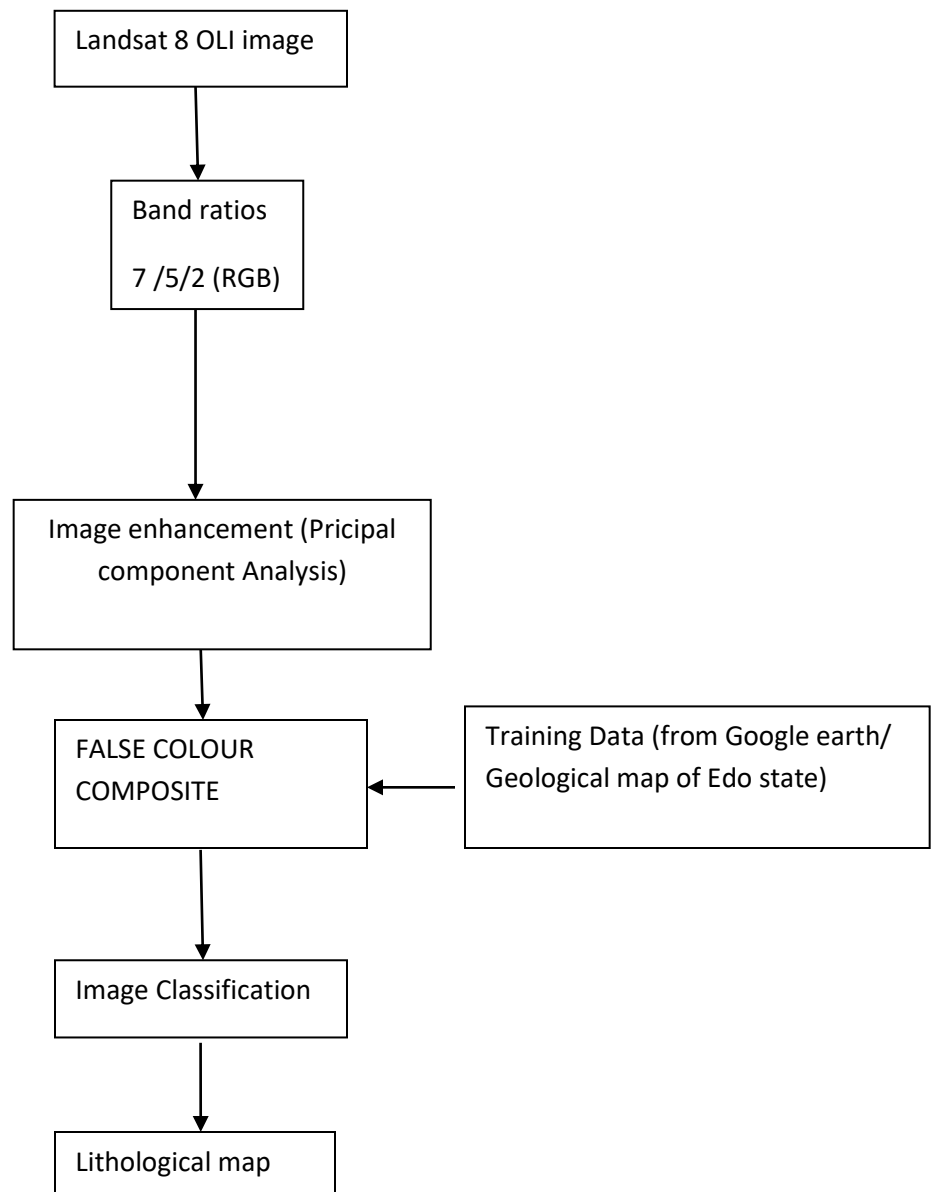


Fig. 3.2. Flowchart Showing The Main Steps Of The Methodology Used

2.7.6 Image Acquisition and Preprocessing

Four Landsat-8 OLI/TIR scenes (path 189, row 55) with 10% cloud cover were acquired for the year 2020 from the US Geological Survey. The images were Level 1T standard terrain corrected

images were processed using the Environment for Visualizing Images (ENVI) version 4.3 software. The Landsat images were spectrally subset to contain OLI bands of Band 1 (coastal/aerosol, 0.433 – 0.453 μm), Band 2 (blue, 0.450 – 0.515 μm), Band 3 (green, 0.525 – 0.600 μm), Band 4 (red, 0.630 – 0.680 μm), Band 5 (NIR, 0.845 – 0.885 μm), Band 6 (SWIR, 1.560 – 1.660 μm), Band 7 (SWIR, 2.100 – 2.300 μm). Finally, the mosaicked scenes were spatially subset to Akoko Edo area using a shape file in order to focus classification efforts on the study area.

The effect of cloud cover was minimal as there was no cloud cover influence on the data.

3.3.2 Band Ratio

Band ratio is a simple technique where the digital number (DN) value of one band is divided by the digital number value of another band (Sabins, 1999). Band ratios are very useful for highlighting certain features or materials that cannot be seen in the raw band. This operation was performed by selecting the band with high reflectance for a mineral as the ‘numerator’ and another band with high absorption as the ‘denominator’ in the ENVI software band ratio interface. Three ratios were performed and each pair was assigned to RGB respectively.

3.3.3 False Colour Composite

A false colour composite for the study area was produced in order to map lithological variations in the study area. Band 7, 5, 2 was used to map lithological variations in the study area.

Decorrelation stretch was applied to enhance variations in lithologies. This combination is also applicable for agricultural and wetland studies

3.3.4 Image Classification / Training Sites

Classification is a key procedure for creating information from data. Image analysis classification identifies pixels with similar spectral signatures through statistical analysis of multiband images (Ahmed, et al., 2014). Groups of pixels with similar spectral signatures can be identified as features based on their geometric relationships and the knowledge and interpretive skills of the analyst. Supervised classification utilizes class information input by the analyst before statistical analysis and classification of the image. Selected training samples contain pixels that represent the spectral characteristics of only the feature or feature class to be identified. Several training samples can be selected and combined to make a single class.

In this study, the selection of training sites was done using the region of interest tool in ArcGIS10.2. Visual selection was done using Google earth engine and False colour composite image Classification was performed using the maximum likelihood method for supervised classification. The number of proposed classes was requested after which shapefiles were created for the respective classes.

CHAPTER 4

Result and Discussion

4.1 BAND RATIO

In the current contribution, the band ratios were applied on the Landsat8 OLI subset covering the study area. The color band ratio image of the map shown in Fig.4.1 shows fluorescent green to represent regions covered in vegetation, and areas covered in Deep Purple are major rock outcrops, light brown to white represent bare earth surfaces on the map shows areas of Iron enrichment. All three ratios (6/7, 6/5 and 4/2) were merged using RGB colour representation to produce a band ratio map. This band combination ratios show clear lithological discrimination as shown in the figure

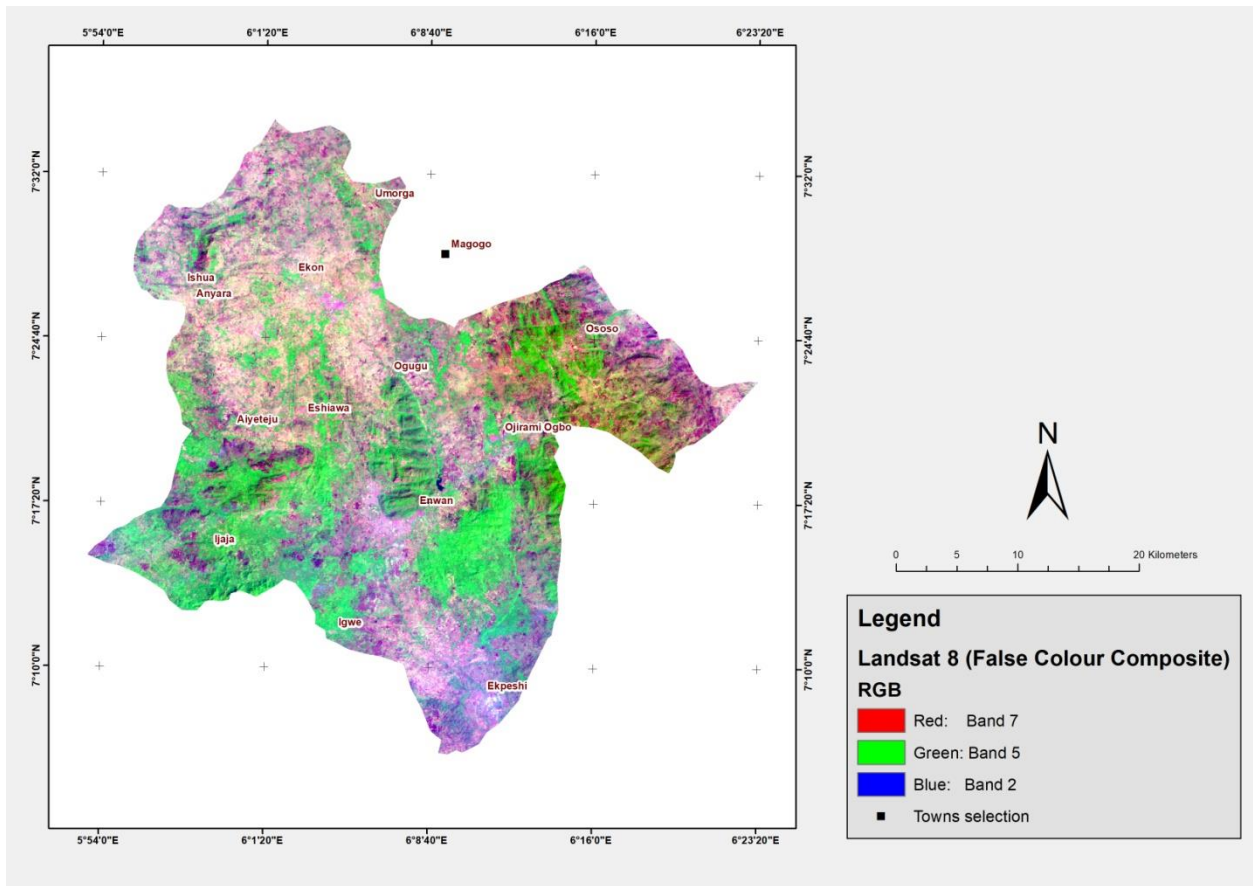


Fig. 4.1: Band Ratio map (6/7, 6/5 and 4/2)

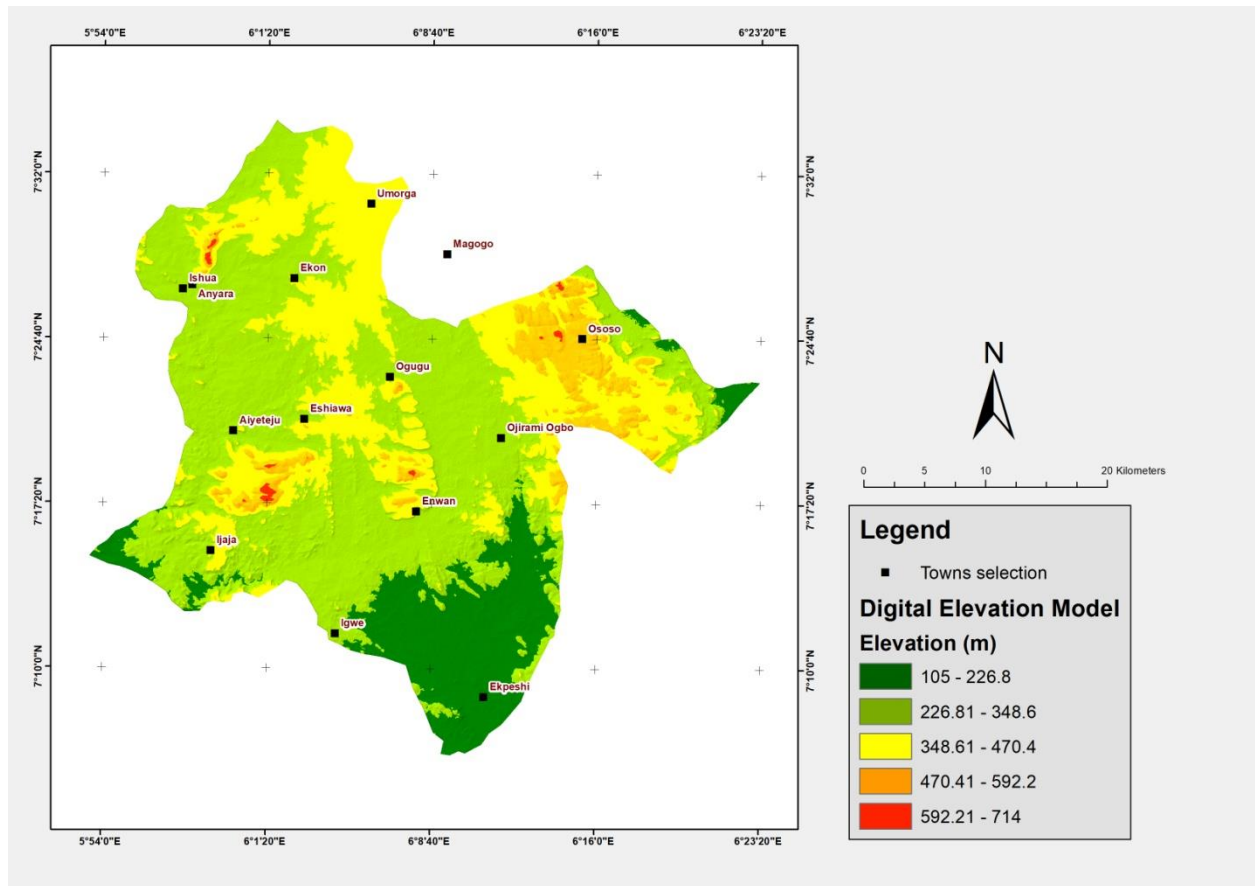


Fig. 4.3 : Digital Elevation map of Akoko Edo

4.2 IMAGE CLASSIFICATION

The result of this classification of the Landsat band ratio data in Figure 4.3 appears to fairly accurately represent the surface geologic character in comparison to the geologic map and in the original band ratio image. In the Landsat band ratio classified image, many pixels are displayed in green (vegetation). In contrast, the results of the band ratios (4/2 , 6/5 , 6/7) result appear to have some significant differences from the image classification product. Four major classes were generated with two major geological features namely granite and migmatite with Bare earth surface and vegetation making up about 52% of the surface. The major geological features cover about 48% of the region.

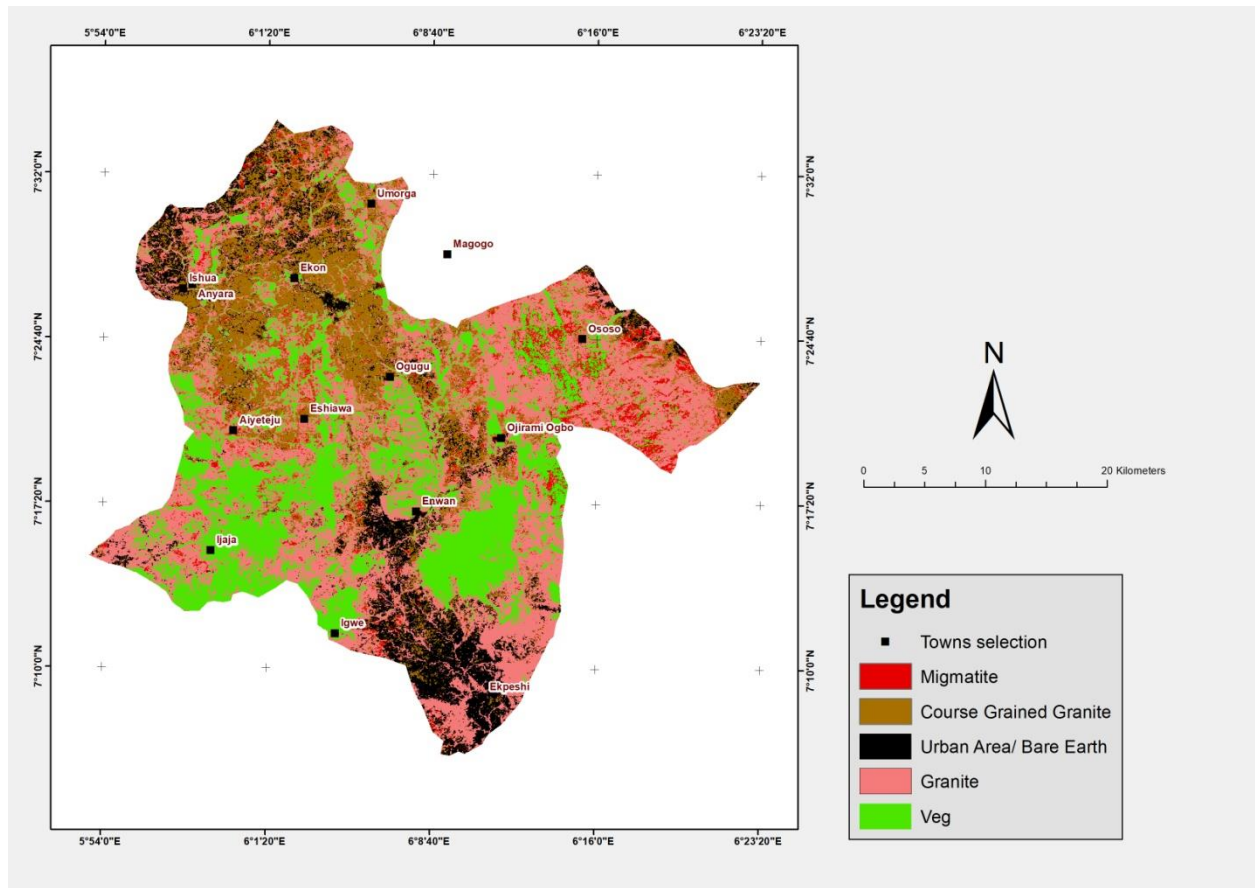


Fig. 4.4: Supervised Image Classification

The classification shows that Akoko Edo is majorly covered by granite. The major granite outcrops are found in the western region.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Remote sensing method employing techniques such as band combination, band ratio and supervised image classification can be an appropriate tool in mapping the geology of a vast region of area especially when combined with field investigations and existing maps. Based on the classification method used (maximum likelihood classification), the band ratio (6/7 , 6/5 , 4/2) produced a fairly good representation of the of the geology of Akoko Edo.

5.2 RECOMMENDATION

It is clear that the abundance of vegetation cover in this region acts as a major interference in the accurate classification of rock minerals.

I recommend that field visit be conducted in certain regions to identify rock covers and validate classification of the regions' lithology to improve this method.

REFERENCES

- Abaa, S.I. (1983).** The structure and petrography of alkaline rocks of the Mada Younger Granite Complex Nigeria. *Journal of African Earth Science* 3:107-113
- Abdullah, A., Nassr, S., Ghaleeb, A. (2013).** Remote Sensing and Geographic Information System for Fault Segments Mapping a Study from Taiz Area, Yemen. *Journal of Geological Research*, Vol. 2013, 16.
- Ahmed, S. and Amin, B. (2014).** Lithological mapping and hydrothermal alteration using Landsat-8 data: a case study in Arab mining district, red sea hills, Sudan. *Intl. J. Basic and Applied. Sci.*, 3(3), 199-208
- Aluko, O.E. and Igwe, O. (2018).** Automated Geological lineaments mapping for groundwater exploration in the basement complex terrain of Akoko-Edo area, Edo-State Nigeria using remote sensing techniques. *Model. Earth Syst. Environ.* 4, 1527–1536 (2018). <https://doi.org/10.1007/s40808-018-0511-4>
- Black, R. (1980).** Precambrian of West Africa. Episodes; 3:38. <https://doi.org/10.18814/epiiugs/1980/v3i4/001>
- Black, R. and Liegeois, J.-P. (1993).** Cratons, mobile belts, alkaline rocks and continental lithospheric mantle: the Pan-African testimony: *Journal of the Geological Society*, 150, 89-98, 1 January 1993, <https://doi.org/10.1144/gsjgs.150.1.0088>
- Burke, K.C and Dewey, J.F. (1972).** Orogeny in Africa. In: Dessaugie TFJ, Whiteman AJ (eds). *Africa geology. University of Ibadan Press, Ibadan* pp. 583-608.

- Chuvieco, E. and Heute, A. (2009).** Introduction. *Fundamentals of satellite remote sensing* (pp. 1-2).
- Dada, S.S. (2006).** Proterozoic evolution of Nigeria. In: OshiO (ed) *The basement complex of Nigeria and its mineral resources (A Tribute to Prof. M. A. O. Rahaman)*. Akin Jinad and Co.Ibadan pp. 29-44.
- Dash, P. (1999).** Remote sensing and GIS applications in seismic hazard studies in NW Himalayas.
- Es-Sabbar, B., Essalhi, M., Essalhi, A., Mhamdi, H.S. (2020).** Lithological and structural lineament mapping from landsat 8 oli images in ras kammouna arid area (eastern anti-atlas, morocco). *Econ. Environ. Geol.*, 53(4), 425-440.
- Ezabti, A. and Jovanović, V. (2015).** GIS and Remote Sensing Application in geological mapping and 3D terrain modeling: a case study in Eghei Uplift, Libya. Paper presented at Synthesis 2015 - International Scientific Conference of IT and Business-Related Research. doi:10.15308/Synthesis-2015-615-619.
- Fashae, O.A., Tijani, M.N., Talabi, A.O., Adedeji, O.I. (2014).** Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach. *Appl Water Sci* **4**, 19–38 (2014).
<https://doi.org/10.1007/s13201-013-0127-9>.
- Frei, M., Abdel, S. MG, Baghdadi, NN (2006).** Remote Sensing Application to Geological Problems in Africa. *Journal of African Earth Sciences* 44(2):7-10.
- Gandu, A.H., Ojo, S.B., Ajakaiye DE (1986).** A gravity study of the Precambrian rocks in the Malumfashi area of Kaduna State, Nigeria. *Tectonophysics* 126:181 194.

- Kamel, M., Youssef, M., Hassan, M., Bagash, F. (2016).** Utilization of ETM+ Landsat data in geologic mapping of wadi Ghadir-Gabal Zabara area, Central Eastern Desert, Egypt. *The Egyptian Journal of Remote Sensing and Space Science*, 19(2), 343-360.
- Lin, J., Wang, R., Zhao, B. & Cheng, S. (2019).** A comprehensive scheme for lithological mapping using Sentinel-2A and ASTER GDEM in weathered and vegetated coastal zone, Southern China. *Open Geosciences*, 11(1), 982-996. <https://doi.org/10.1515/geo-2019-0076>
- Mainta, Y. I. (2016).** Application of Landsat (ETM+) in geologic mapping, A case study of Sheet 102 (Zaria SW) and its environs, Nigeria. . An unpublished Post Graduate Diploma (PGD) Thesis, Ahmadu Bello University, Zaria, Nigeria.
- McCurry, P. (1973).** Geology of degree sheet 21, Zaria, Nigeria. *Overseas Geology Mineral Research*, 45, 45.
- Moujahid , H.A., Ibouh, H., Bachnou , A., Babram, M.A., Harti, A. (2016).** Mapping and analysis of geological fractures extracted by remote sensing on Landsat TM images, example of the Imilchil-Tounfite area (Central High Atlas, Morocco). *Estudios Geológicos* 72(2): e051. <http://dx.doi.org/10.3989/egeol.42328.394>
- Nasir, S., and Sankaran, R. (2017).** Review of the role of remote sensing applications in mineral exploration and sustainable development in oman. *International Journal of Environment and Sustainable Development* 6(3):24-55.
- Obaje, N.G. (2009).** Geology and Mineral Resources of Nigeria, Springer Books. USA pp. 15-35.
- Obaje, N.G. (2009).** The Basement Complex. *Geology and Mineral Resources of Nigeria*. Abs.

- Olatunji, A. J. (1979).** Structural Setting and Genetic Significance of Minor Dyke-Like Bodies in South-West Zaria Kaduna State Nigeria. . 14th Annual conference of Nigerian Mining and Geosciences Society.
- Olayinka, A.I. (1992).** Geophysical siting of boreholes in crystalline basement areas of Africa. *Journal of African Earth Science* 14:197- 207.
- Ourhizif1, Z., Algouti, A., Algouti., A., Hadach, A. (2019).** Lithological mapping using landsat 8 oli and aster multispectral data in imini-ounilla district south high atlas of Marrakech. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 1255-1261.
- Oyawale, A. A., Adeoti, F. O., Ajayi, T. R., Omitogun, A. A. (2020).** Applications of remote sensing and geographic information system (GIS) in regional lineament mapping and structural analysis in Ikare Area, Southwestern Nigeria. *Journal of Geology and Mining Research*, 12(1), 13-24.
- Oyinloye, A.O. (2004).** Geology and the geotectonic setting of the basement complex rocks in southwestern Nigeria: Implications on provenance and evolution. *Global Journal of Geological Sciences*. P. 98.
- Rahaman, M.A and Ocan, O.O. (1978):** On relation in the Precambrian migmatitic gneises of Nigeria *J. Min. and Geol.* Vol. 15, No. 1 (abs).
- Rahaman, M.A. (1976).** Review of the basement Geology of southwestern Nigeria.
- Rahaman, M.A. (1988).** Recent advances in the study of the basement complex of Nigeria. In: *Precambrian geology of Nigeria.* Geological Survey of Nigeria, Kaduna South, pp 11–43.

Rajesh, H.M. (2004). Application of remote sensing and GIS in Mineral resource mapping – an overview: Journal of mineralogical and petrological sciences Vol. 99 pp. 83-103, 2004.

Sabins, F. (1999). Remote sensing for mineral exploration, Ore Geology Review, 14, 157-183

Sploos, L.L. & Speed, R.C. 1974. Relationship of cratonic and continental margin

tectonic episodes. In: Dickinsen, E. (Ed): Tectonics and sedimentation. Spec. Publ. Soc.

Econ. Paleont. Min., 22, 98 -119