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Discriminating Mineral Deposits Using Hyperspectral And Optical Imaging: A Case Study Of Ngaski Local Government, Kebbi State Nigeria

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ABSTRACT

The identification and characterization of mineral deposits in geologically complex and relatively remote environments require efficient techniques capable of providing extensive spatial and spectral information. Conventional mineral exploration methods are often associated with high operational costs, extensive field requirements, and considerable time consumption. This study investigates the application of hyperspectral and optical satellite remote sensing techniques for discriminating mineral-bearing lithologies, intrusive bodies, alteration zones, and structural features in Ngaski Local Government Area of Kebbi State, northwestern Nigeria. Landsat-8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), Landsat-7 Enhanced Thematic Mapper Plus (ETM+), ASTER, and selected high-resolution satellite datasets were integrated for geological interpretation and mineral exploration. Image-processing techniques, including Principal Component Analysis (PCA), band-ratio analysis, Hue-Saturation-Intensity (HSI/IHS) transformation, image fusion, and supervised and unsupervised classification, were applied to enhance spectral and spatial differences among geological materials. Migrating Means Clustering (MMC) was employed for unsupervised classification, while Maximum Likelihood Classification (MLC) was applied using selected training samples and classification outputs derived from the unsupervised approach. The results demonstrate the potential of integrated multispectral and hyperspectral imagery for enhancing lithological discrimination, delineating intrusive bodies, extracting structural lineaments, and identifying areas exhibiting spectral characteristics associated with hydrothermal alteration and mineralization. Principal component composites and selected band ratios provided enhanced visual discrimination of geological units and altered zones, while image fusion improved the spatial definition of relatively small geological features. Integration of the remotely sensed outputs with existing geological information and field observations provided an improved basis for geological interpretation of the study area. The findings demonstrate that the combined application of hyperspectral and optical remote sensing provides a cost-effective and spatially extensive approach for preliminary mineral exploration and geological mapping in Ngaski and comparable basement-complex terrains of northwestern Nigeria.

Keywords: Hyperspectral imaging; optical remote sensing; mineral discrimination; lithological mapping; hydrothermal alteration; Principal Component Analysis; Landsat-8; ASTER; Ngaski; Kebbi State.

INTRODUCTION

Mineral resources constitute important components of national economic development and industrial growth. The discovery and effective exploitation of metallic and non-metallic mineral deposits require reliable information about their geological setting, spatial distribution, mineralogical characteristics, and structural controls. However, mineral exploration, particularly in remote and geologically complex environments, is frequently constrained by the high cost of field investigations, limited accessibility, extensive terrain coverage, and the uncertainties associated with conventional exploration approaches.

Remote sensing has emerged as an important component of modern mineral exploration because it provides synoptic and multispectral observations of the Earth's surface. The technique involves the acquisition and interpretation of information about objects and materials without direct physical contact, primarily through the measurement of electromagnetic radiation reflected or emitted from the Earth's surface. Since different rocks and minerals exhibit characteristic spectral responses, remotely sensed data can be processed to enhance and discriminate geological materials with different mineralogical and compositional properties.

The application of optical and hyperspectral remote sensing has significantly improved the ability of researchers to identify lithological variations and mineral-related alteration zones. Multispectral sensors such as Landsat and ASTER provide several strategically positioned spectral bands that can be used for lithological discrimination, structural interpretation, alteration mapping, and mineral exploration. Hyperspectral sensors, on the other hand, acquire data in numerous contiguous and relatively narrow spectral bands, thereby providing greater capability for recognizing diagnostic absorption features associated with specific minerals.

Mineral deposits are commonly associated with geological structures such as faults, fractures, shear zones, contacts, and intrusive bodies. Hydrothermal fluids circulating through these structures may alter the surrounding rocks and produce mineral assemblages with distinctive spectral characteristics. Consequently, the identification of alteration zones and their structural relationships can provide important indications of potential mineralization. Remote sensing techniques such as band ratios, Principal Component Analysis (PCA), spectral classification, and colour-space transformations are therefore increasingly employed to highlight these features.

Ngaski Local Government Area of Kebbi State is situated within the broader geological framework of the Nigerian Basement Complex. The region contains Precambrian metamorphic and igneous rocks, including gneiss-migmatite complexes, supracrustal rocks, and granitoid intrusions. The geological complexity of the area provides a suitable setting for investigating the relationship between lithology, structural features, intrusive activity, alteration, and mineralization.

Despite the mineral potential of northwestern Nigeria, detailed and systematic remote sensing investigations of some areas within Kebbi State remain limited. The application of modern hyperspectral and optical imaging techniques can therefore provide additional information for geological mapping and preliminary mineral exploration. In particular, the integration of datasets with different spectral and spatial characteristics can improve the identification of small intrusive bodies, geological contacts, alteration zones, and structural lineaments that may not be readily distinguishable from conventional imagery.

This study consequently focuses on the discrimination of mineral deposits and associated geological features in Ngaski Local Government Area using integrated hyperspectral and optical remote sensing techniques. The study combines satellite imagery, digital image-processing techniques, geological information, and field observations to improve the identification of lithological units and potential mineralized zones.

Aim and Objectives

The primary aim of this study is to assess the effectiveness of hyperspectral and optical satellite imaging techniques in discriminating mineral deposits and associated geological features in Ngaski Local Government Area of Kebbi State, Nigeria.

The specific objectives are to:

process and interpret multispectral and hyperspectral satellite imagery using Principal Component Analysis, band-ratio techniques, HSI/IHS transformations, image fusion, and classification methods;

discriminate major lithological units and identify geological boundaries within the study area;

delineate small intrusive bodies and identify previously unrecognized geological features using imagery with enhanced spectral and spatial resolution;

identify and map hydrothermal alteration zones and investigate their spatial relationship with potential mineralization;

extract geological lineaments, including faults, fractures, and other structural features that may influence mineral occurrence;

evaluate the effectiveness of supervised, unsupervised, and hybrid classification techniques for mineral and lithological discrimination; and

integrate remote sensing results with existing geological information and field observations to develop an improved geological and mineral-potential map of the study area.

Significance of the Study

The study is significant because it demonstrates the application of modern Earth-observation technologies to mineral exploration within a basement-complex terrain of northwestern Nigeria. Hyperspectral and optical imagery can provide extensive coverage of geological environments at comparatively lower costs than conventional exploration methods.

The resulting geological and mineral-potential information may provide useful preliminary guidance for subsequent field investigations, geochemical sampling, geophysical surveys, and mineral exploration programmes. The study may also contribute to the growing body of knowledge on the application of remote sensing to geological investigation in Nigeria.

Furthermore, the integration of different satellite platforms provides an opportunity to examine the complementary advantages of spectral and spatial resolution. While multispectral imagery provides broad regional coverage, hyperspectral data can potentially offer more detailed mineral discrimination because of its higher spectral resolution. High-resolution optical imagery can additionally improve the delineation of small geological structures and intrusive features.

Geological and Geographical Setting of the Study Area

2.1 Location and Extent

The study area is located in Ngaski Local Government Area of Kebbi State, northwestern Nigeria, approximately around latitude 10°44′33.59″ N and longitude 4°46′23.99″ E. The area is characterized generally by relatively flat terrain, although local variations in elevation and drainage patterns reflect underlying geological and geomorphological controls.

The geographical setting of the area, together with its geological characteristics, provides an appropriate environment for investigating the application of satellite remote sensing to lithological and mineral discrimination.

Geological Setting

Ngaski Local Government Area forms part of the Nigerian Basement Complex, which constitutes an important geological component of the West African Craton and its surrounding Pan-African mobile belt. The basement terrain consists of a variety of metamorphic and igneous rocks that have undergone several episodes of deformation, metamorphism, magmatism, and structural modification.

The principal lithological components relevant to the study include the gneiss-migmatite complex, supracrustal rocks and schist belts, and Pan-African granitoids. The gneiss-migmatite complex contains rocks associated with Precambrian geological events and generally exhibits medium- to high-grade metamorphic characteristics. Previous geological investigations have reported complex structural relationships within these basement rocks and extensive intrusion by granitoid plutons.

The Pan-African granitoids constitute an important component of the regional geological framework. They include granites, granodiorites, and diorites, with local occurrences of gabbroic and syenitic rocks. These intrusive rocks occur in different structural and textural forms and may be associated with mineralization and hydrothermal alteration.

Fitches et al. (1985) described the gneiss-migmatite complex within the Nigerian Basement Complex as containing rocks with Archean and Early Proterozoic isotopic characteristics and generally amphibolite-facies metamorphic assemblages. Wright et al. (1985) further documented the importance of Pan-African granitoid intrusions, including granites, granodiorites, and diorites, in the geological development of the Nigerian basement terrain.

Geological Implications for Mineral Exploration

The combination of metamorphic basement rocks, supracrustal units, granitoid intrusions, and complex structural features makes the study area potentially favourable for mineral exploration. Geological contacts and structural discontinuities may control the emplacement of intrusive bodies and the circulation of hydrothermal fluids.

The identification of alteration zones is consequently an important component of the investigation. Altered rocks may exhibit spectral differences from unaltered country rocks because hydrothermal processes can modify their mineralogical composition. Remote sensing provides an opportunity to map such variations over relatively large areas and to identify zones that warrant detailed field investigation.

The geological setting therefore provides a suitable basis for applying hyperspectral and optical imaging techniques to discriminate lithological units, intrusive bodies, alteration zones, and mineral-related spectral anomalies.

REVIEW OF RELATED LITERETURE

Remote Sensing Applications in Mineral Exploration

Remote sensing has become an increasingly important tool in geological investigation and mineral exploration because of its ability to provide synoptic coverage, multispectral information, and repeated observations of extensive areas. The technique is particularly valuable in regions where conventional geological mapping is constrained by difficult terrain, limited accessibility, dense vegetation, or the high cost of field-based exploration.

Mineral exploration using remote sensing is principally based on differences in the spectral responses of minerals and rocks. When electromagnetic radiation interacts with geological materials, specific absorption and reflection characteristics are produced according to their mineralogical and chemical composition. These characteristics can be enhanced through image transformation, spectral analysis, classification, and band-ratio techniques.

Optical satellite sensors such as Landsat, ASTER, and Sentinel provide multispectral observations that have been widely applied to geological mapping. These datasets can enhance lithological contacts, identify alteration zones, delineate geological structures, and provide regional information useful for targeting mineral exploration sites.

The Landsat-8 satellite carries the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), providing observations across visible, near-infrared, shortwave-infrared, and thermal infrared regions. The combination of these spectral regions makes Landsat-8 particularly useful for geological investigations.

The shortwave-infrared bands are especially relevant to mineral exploration because several minerals associated with hydrothermal alteration exhibit diagnostic spectral responses in this portion of the electromagnetic spectrum. Consequently, combinations of spectral bands and band ratios can be used to enhance ferric iron, ferrous iron, clay minerals, carbonates, and other alteration-related materials.

Pour and Hashim demonstrated the usefulness of Landsat-8 data for mineral exploration by applying spectral band combinations, band ratios, and Mixture Tuned Matched Filtering to identify hydrothermal alteration zones and mineral assemblages associated with porphyry copper mineralization. Their work illustrates the potential of Landsat-8 for regional mineral targeting.

Similarly, Pour (2014) demonstrated that spectral variations associated with hydrothermally altered rocks could be identified using Landsat imagery. The distinction between altered rocks and surrounding country rocks is important because alteration halos may extend beyond the immediate mineralized zone and consequently serve as indirect indicators of mineralization.

ASTER Data and Mineral Discrimination

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) has been extensively used in geological and mineral exploration because of its relatively detailed spectral coverage, particularly in the shortwave-infrared and thermal-infrared regions.

ASTER data are useful for discriminating lithological units and identifying mineral assemblages associated with hydrothermal alteration. The sensor's spectral configuration enables researchers to exploit variations in

the reflectance characteristics of minerals that may not be sufficiently distinct in conventional visible and near-infrared imagery.

Safari et al. (2017), for example, investigated porphyry copper exploration in southern Iran using Landsat-8 and ASTER data. Their findings demonstrated that remote sensing techniques could identify hydrothermal alteration zones related to Cenozoic magmatic intrusions. The study highlights the advantage of integrating datasets with complementary spectral characteristics for mineral exploration.

Khan et al. (2019) also employed ASTER-based remote sensing techniques to investigate gypsum potential in the Kohat Plateau of northern Pakistan. The study successfully identified gypsum-bearing outcrops through the application of several remote sensing techniques. This demonstrates that ASTER imagery can be useful not only for metallic mineral exploration but also for the identification of economically important industrial and non-metallic minerals.

Majid Rahim zadegan et al.,(2018), asserted that the output of the algorithm is an image where the gray value of each pixel corresponds to the probability of similarity to the training data.Morteza, Safari et al., (2017), carried out investigation for porphyry copper exploration in south of Iran using Landsat-8 and ASTER satellite remote sensing data. The result show hydrothermal alteration zones that are related to Cenozoic magmatic intrusions in Shahr-e-Babak region.

Min Yang et al., (2018), integrate Landsat 8 OLI and ASTER data for interpreting lead–zinc mineralization in the Huoshaoyun in the west Kunlun Mountains. It is concluded that some BR color composites and principal components of each imagery contain useful information for lithological mapping.Asad Khan et al., (2019); uses ASTER-based remote sensing data to investigate gypsum potentiality in the Kohat Plateau, north Pakistan. The results map out the outcrops of gypsum through several remote sensing mapping techniques.

Anass and Abdallah., (2022), asserted that Lithological discrimination and lineaments extraction can be achieved through Landsat 8 & ASTER data. Pour (2014) used Landsat-8 data to distinguish the mineralized alteration zone from the surrounding country rocks in a mining district southeast of Iran. Spectral variations associated with altered rocks caused by hydrothermal fluids can be detected on Landsat images.

Research Gap

Although numerous studies have demonstrated the usefulness of Landsat, ASTER, and hyperspectral imagery for geological mapping and mineral exploration in different parts of the world, relatively limited attention has been devoted to the integrated application of these techniques in Kebbi State, particularly within Ngaski Local Government Area.

Previous investigations have largely focused on other geological environments, including porphyry copper systems in Iran, lead-zinc mineralization in the western Kunlun Mountains, and gypsum deposits in Pakistan. The geological and environmental conditions of these areas differ substantially from those of the Nigerian Basement Complex. Consequently, methods developed elsewhere require contextual evaluation before being directly applied to Ngaski.

Furthermore, many remote sensing studies rely primarily on individual satellite datasets or individual image-processing techniques. Such approaches may not fully exploit the complementary spectral and spatial information available from multispectral, hyperspectral, and high-resolution optical platforms.

The present study addresses this gap by integrating multiple satellite datasets and image-processing techniques to investigate mineral and lithological discrimination in Ngaski Local Government Area. Particular emphasis is placed on the combined use of PCA, band ratios, HSI/IHS transformation, image fusion, hyperspectral analysis, and supervised and unsupervised classification.

The study also seeks to strengthen remote sensing interpretation through integration with geological information and field observations. This integrated approach is intended to improve the reliability of mineral exploration targets and provide a more detailed understanding of the relationship among lithology, intrusive bodies, geological structures, alteration zones, and potential mineralization.

The research therefore contributes to the application of modern remote sensing approaches to mineral exploration within the Nigerian Basement Complex and provides a methodological framework that may be applicable to similar geological environments elsewhere in Nigeria.

MATERIALS AND METHODS

Research Design

The study adopted an integrated remote sensing and geological mapping approach for the discrimination of mineral deposits and associated geological features in Ngaski Local Government Area, Kebbi State, Nigeria. The methodology combines multispectral, hyperspectral, and high-resolution optical satellite imagery with digital image-processing techniques and geological interpretation.

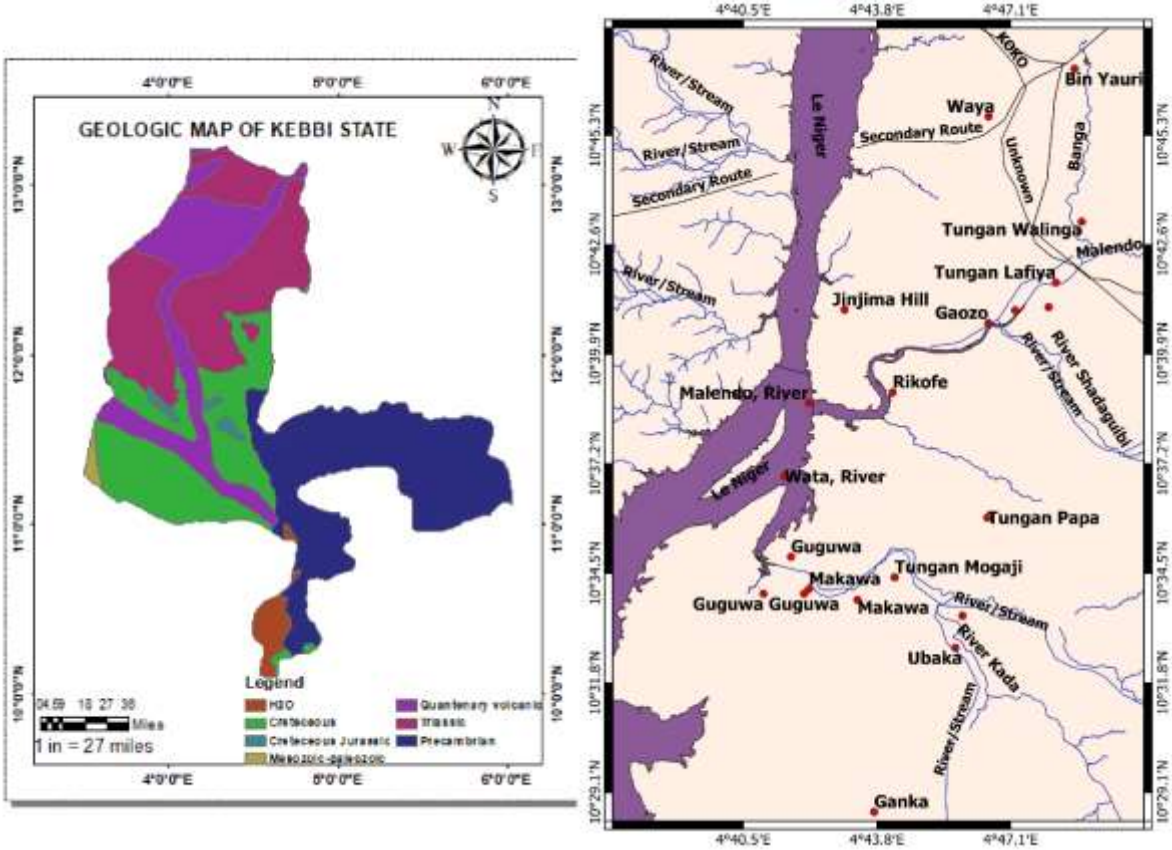
The analytical framework was designed to exploit differences in the spectral and spatial characteristics of rocks, minerals, alteration products, and geological structures. The major procedures comprised image acquisition, preprocessing, spectral enhancement, dimensionality reduction, band-ratio analysis, colour-space transformation, image fusion, image classification, geological interpretation, and integration with existing geological information and field observations.

Data Acquisition

A combination of satellite datasets was employed to provide complementary spectral and spatial information. The principal datasets considered in the study include Landsat-8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), Landsat-7 Enhanced Thematic Mapper Plus (ETM+), ASTER, and high-resolution optical imagery.

The Landsat-8 OLI/TIRS scene used in the investigation was acquired on 10 June 2020, while the Landsat-7 ETM+ scene was acquired on 21 November 2015. Additional high-resolution datasets included SkySat-C19, TripleSat-2, Resursat-P3, and Cartosat-2D imagery. These datasets were selected to improve the identification of geological features occurring at different spatial scales.

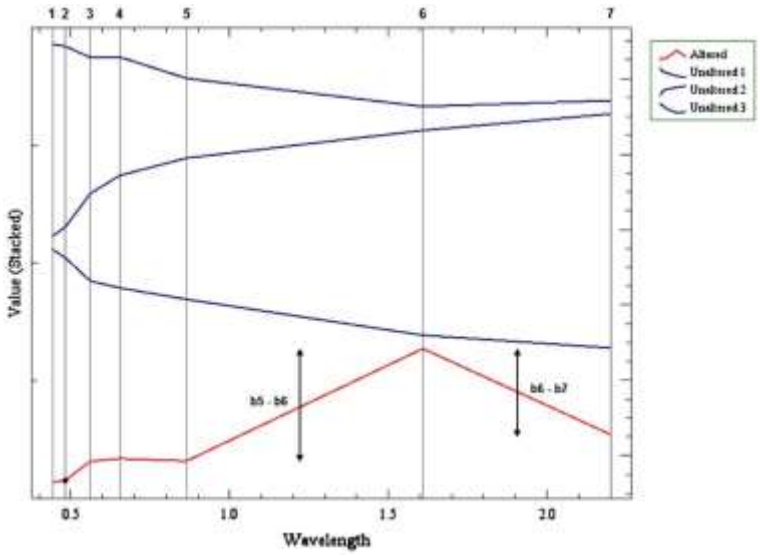
The use of multiple satellite platforms was intended to overcome the limitations associated with relying on a single sensor. Landsat and ASTER imagery provide broad-area multispectral information, while high-resolution optical imagery provides improved spatial detail for the interpretation of relatively small intrusive bodies, structural lineaments, lithological contacts, and other geological features.



multispectral observations covering the visible, near-infrared (NIR), and shortwave-infrared (SWIR) portions of the electromagnetic spectrum, while TIRS provides thermal infrared observations.

The spectral configuration of Landsat-8 makes the imagery useful for geological investigations because variations in the spectral response of rocks and minerals can be examined across several wavelength regions. The SWIR bands are particularly relevant to the detection of alteration-related minerals, while the visible and NIR bands can provide information useful for distinguishing surface materials and vegetation.

Landsat-8 also provides improved radiometric resolution compared with earlier Landsat sensors. Its 12-bit radiometric resolution permits a larger range of digital values and can enhance the detection of relatively subtle differences in surface reflectance.



Reflectance spectra of altered and unaltered rocks from the study area that is plotted to VNIR and SWIR spectral bands of Landsat-8.

Band-Ratio Analysis

Band-ratio analysis was employed to enhance spectral differences associated with selected geological materials and mineral alteration products. The technique involves dividing the digital values of one spectral band by those of another, thereby emphasizing relative spectral responses rather than absolute reflectance values.

Appropriate band combinations were selected according to the spectral characteristics of the target geological materials and the available sensor bands. Ratio images were examined individually and in combination with other enhanced datasets to identify areas exhibiting spectral characteristics potentially associated with iron oxides, hydroxyl-bearing minerals, clay minerals, carbonates, and other alteration products.

Band-ratio composites were subsequently compared with known geological information to facilitate the interpretation of lithological boundaries and possible alteration zones.

Hyperspectral Spectral Analysis

Hyperspectral analysis was used to exploit the detailed spectral information available from hyperspectral imagery. Unlike conventional multispectral data, hyperspectral imagery contains numerous contiguous spectral bands, allowing more detailed examination of the absorption and reflectance characteristics of geological materials.

The spectral characteristics of image pixels were analysed to identify variations that could be associated with specific mineral groups and alteration products. Particular attention was given to spectral features associated with iron-bearing minerals, hydroxyl-bearing minerals, clay minerals, carbonates, and other mineral assemblages commonly associated with hydrothermal alteration.

Where suitable reference spectra were available, image-derived spectral characteristics were compared with known mineral spectral signatures. This procedure provided a basis for distinguishing mineral-related spectral anomalies from general lithological variations.

RESULTS

Spectral Characteristics of the Study Area

The processing of the satellite imagery revealed considerable spectral variation across Ngaski Local Government Area. The observed variations reflect differences in lithology, surface mineral composition, degree of weathering, vegetation cover, soil characteristics, and geological alteration.

The multispectral and hyperspectral datasets provided complementary information for distinguishing geological materials. While the multispectral imagery was useful for regional characterization and identification of broad lithological patterns, the higher spectral resolution of hyperspectral data provided greater potential for distinguishing mineral-related spectral responses.

The spatial distribution of the spectral classes also revealed several areas of contrasting reflectance characteristics. These areas were subsequently investigated using Principal Component Analysis, band-ratio transformations, colour composites, and classification techniques.

Band-Ratio Results

The band-ratio analysis enhanced specific spectral differences associated with geological materials and alteration products. The resulting ratio images showed spatial variations that were useful in identifying areas with potentially anomalous mineralogical characteristics.

The distribution of the ratio anomalies was not uniform throughout the study area. Instead, anomalous responses occurred in specific zones and, in some locations, appeared to coincide with geological contacts, intrusive bodies, or structural features.

The spatial coincidence of spectral anomalies and geological structures is of particular significance because hydrothermal fluids responsible for mineral alteration commonly migrate through fractures, faults, shear zones, and intrusive contacts.

However, spectral anomalies cannot automatically be interpreted as confirmed mineral deposits. They may also result from variations in soil moisture, vegetation, weathering, surface coatings, or other environmental factors. For this reason, the band-ratio results were interpreted together with PCA products, hyperspectral information, geological maps, and field observations.

Image-Fusion Results

Image fusion produced imagery with improved spatial detail compared with the original medium-resolution datasets. The fused products enhanced the visualization of small geological features, including narrow lithological contacts, linear structures, intrusive boundaries, and other surface expressions of geological discontinuities.

The improved spatial resolution was particularly useful for interpreting relatively small intrusive bodies that may be difficult to delineate using Landsat or ASTER imagery alone.

Integration of high-resolution optical data with multispectral imagery therefore improved the geological interpretation by combining detailed spatial information with broader spectral information.

Hyperspectral Mineral Discrimination

The hyperspectral analysis provided more detailed spectral information than the conventional multispectral datasets. The narrow and contiguous spectral bands enabled the identification of subtle variations in the spectral response of geological materials.

Several spectral patterns were associated with mineralogical differences and possible alteration processes. Particular attention was given to spectral responses corresponding to iron-bearing minerals, clay minerals, hydroxyl-bearing minerals, carbonates, and other alteration-related mineral groups.

The hyperspectral results were interpreted in conjunction with the geological setting rather than being treated as independent evidence of mineral deposits. This approach is important because similar spectral responses can occasionally be produced by different minerals or by combinations of minerals.

Where hyperspectral anomalies coincided with geological structures, intrusive bodies, or alteration zones identified through optical imagery, the areas were regarded as higher-priority targets for further investigation.

Lithological Discrimination

Integration of PCA composites, band-ratio products, HSI/IHS transformations, classification results, and high-resolution optical imagery improved the discrimination of the major lithological units in the study area.

The geological interpretation indicates that differences in spectral response can be used to distinguish granitoid intrusive rocks from surrounding metamorphic country rocks. The boundaries between contrasting lithological units were more clearly expressed in enhanced and fused imagery than in the original multispectral datasets.

The results demonstrate that the combination of spectral and spatial information is more effective for lithological mapping than reliance on a single satellite image or individual spectral band.

DISCUSSION

Effectiveness of Integrated Remote Sensing

The results demonstrate the usefulness of integrating hyperspectral and optical remote sensing data for geological and mineral exploration in Ngaski Local Government Area. Individual datasets provide different types of information, while their integration improves the overall interpretability of the geological environment.

Landsat-8 OLI/TIRS provides broad regional coverage and multispectral information suitable for identifying large-scale lithological and alteration patterns. ASTER contributes additional spectral information, particularly in wavelength regions useful for mineral and alteration mapping. High-resolution optical imagery provides improved spatial detail for identifying smaller geological structures and intrusive bodies.

The combined use of these datasets therefore provides a more comprehensive representation of the geological environment than any single sensor could provide independently.

Significance of Hyperspectral Information

The results further demonstrate the particular importance of hyperspectral imagery for mineral discrimination. The availability of numerous contiguous spectral bands allows subtle absorption and reflectance characteristics to be investigated in greater detail.

This capability is especially relevant where different minerals exhibit similar responses in conventional multispectral imagery. Hyperspectral data can potentially distinguish mineral assemblages on the basis of diagnostic spectral features and therefore provide more detailed information for mineral targeting.

However, the effectiveness of hyperspectral mineral identification depends on the quality of atmospheric correction, spectral calibration, reference spectra, and field validation. Consequently, hyperspectral anomalies should be interpreted within their geological context.

Comparison with Previous Studies

The findings are broadly consistent with previous research demonstrating the usefulness of Landsat and ASTER imagery for geological mapping and mineral exploration. Studies conducted by Pour and Hashim and by Pour demonstrated the ability of Landsat imagery to identify spectral variations associated with hydrothermal alteration and mineralized zones.

Similarly, Safari et al. (2017) demonstrated the usefulness of Landsat-8 and ASTER data for identifying hydrothermal alteration associated with magmatic intrusions. Yang et al. (2018) showed that the

integration of Landsat-8 OLI and ASTER data could improve lithological interpretation and the investigation of lead-zinc mineralization.

The present study extends these applications to the geological environment of Ngaski Local Government Area. The integration of multiple datasets and several image-processing techniques provides a framework for investigating mineralization within the Nigerian Basement Complex.

Implications for Mineral Exploration in Kebbi State

The results have important implications for mineral exploration in Kebbi State. The identification of lithological contrasts, intrusive bodies, structural lineaments, and possible alteration zones provides a preliminary basis for prioritizing areas for detailed investigation.

Remote sensing cannot, by itself, establish the economic viability of a mineral deposit. Rather, it provides a means of reducing the exploration area and identifying locations where detailed geological, geochemical, and geophysical investigations are most justified.

The integrated approach used in this study can therefore serve as a cost-effective first-stage exploration tool. Areas showing coincident spectral anomalies, favourable lithology, structural complexity, and alteration should receive greater attention during subsequent field investigations.

ACCURACY ASSESSMENT AND VALIDATION

The reliability of the classification outputs should be assessed using independent reference data. A confusion matrix provides a systematic means of comparing the classified geological units with reference observations.

Overall accuracy should be calculated as the proportion of correctly classified reference samples relative to the total number of samples. Producer's accuracy provides information about the probability that a reference class has been correctly mapped, whereas user's accuracy indicates the probability that a pixel classified into a particular category actually represents that category on the ground.

Where sufficient reference observations are available, the Kappa coefficient may also be calculated to provide an additional measure of agreement between the classification and reference data.

Field observations are particularly important for validating mineral-related spectral anomalies. Geological samples collected from selected target areas can be subjected to appropriate laboratory analyses to confirm their mineralogical composition.

The final interpretation should therefore distinguish clearly between:

spectral anomalies identified from remote sensing;

geologically interpreted alteration zones;

field-verified mineral occurrences; and

confirmed mineral deposits.

This distinction is essential for maintaining scientific reliability and avoiding overinterpretation of remotely sensed anomalies.

CONCLUSION

This study demonstrates the potential of integrating hyperspectral and optical satellite imagery for mineral discrimination and geological mapping in Ngaski Local Government Area of Kebbi State, Nigeria. The application of Principal Component Analysis, band-ratio analysis, HSI/IHS transformation, image fusion, and supervised and unsupervised classification enhanced the spectral and spatial characteristics of geological materials within the study area.

The integration of Migrating Means Clustering and Maximum Likelihood Classification provided complementary approaches for discriminating spectrally distinct classes. The comparison of classification outputs further indicates that the statistical characteristics of training samples have a significant influence on classification performance and the occurrence of unknown pixels.

The combined interpretation of multispectral, hyperspectral, and high-resolution optical imagery improved the identification of lithological boundaries, intrusive bodies, geological lineaments, and areas exhibiting spectral characteristics associated with hydrothermal alteration. The spatial relationship

between alteration anomalies, intrusive features, and geological structures provides useful information for identifying priority areas for further mineral exploration.

The study further demonstrates that hyperspectral data have particular potential for mineral discrimination because of their high spectral resolution. Nevertheless, remotely sensed spectral anomalies should not be regarded as definitive evidence of economically viable mineral deposits without field and laboratory verification.

Overall, the integrated remote sensing approach provides a practical and cost-effective method for preliminary mineral exploration and geological mapping in Ngaski Local Government Area and potentially in other parts of the Nigerian Basement Complex. The resulting exploration targets can serve as a basis for subsequent geological mapping, geochemical sampling, geophysical investigation, and detailed mineral-resource assessment.

RECOMMENDATIONS

Based on the findings and methodological framework of the study, the following recommendations are made:

Detailed field verification should be undertaken in areas identified as having strong spectral anomalies and favourable geological characteristics.

Geochemical sampling and laboratory mineralogical analysis should be conducted to confirm the minerals responsible for the identified spectral responses.

Geophysical surveys, particularly magnetic, radiometric, electrical, electromagnetic, or other suitable methods, should be conducted over priority targets to investigate subsurface geological structures.

Higher-resolution hyperspectral imagery should be considered where available to improve mineral-specific discrimination.

Future studies should incorporate field and laboratory spectral measurements into the remote sensing workflow to improve the reliability of mineral identification.

Classification accuracy should be evaluated using a sufficiently large and independent set of ground-truth samples.

Areas where lithological contacts, structural intersections, intrusive bodies, and alteration anomalies coincide should be prioritized for detailed mineral exploration.

The integrated geological and mineral-potential map produced from the study should be updated as new field, geochemical, and geophysical information becomes available.

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