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Research Article

Hydrothermal Altered Mineral Deposits Mapping Using Landsat 8 Etm+ in Parts of the Middle-Benue Trough, Nigeria

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Abstract

The studies utilized landsat-8 ETM+ to delineate and unravel hydrothermal altered structures with mineralisation potential in parts of the Middle-Benue trough, Nigeria. The study area contained metal sulphides in the Cenomanian fractures of the Asu River Group. In the processing and analysis of the landsat-8 ETM+, Single Band Combinations, Band Ratio, Principal Component Analysis (PCA) and reference spectra analysis method were employed using ENVI 4.3. Results revealed hydrothermal altered minerals around Gidan Shehu, east of Wukari, Kuka, Bambam, Uzam, Agor and minor alteration at Bangalala, Akwana and Dongwan. A composite using the bands 7, 5, 2 (RGB) highlighted areas with abundant iron oxides bearing minerals, and Clay minerals, as illite, kaolinite, and montmorillonite. The technique adopted is effective in mineral exploration as it covers large area without any form of environmental degradation

***Keywords**: Mineralization, Delineate, Analysis, Structures and Degradation.*

Introduction

Hydrothermal mineral deposits involve the movement of hot concentrated fluids deposited through faults (structures). Hydrothermal mineral deposit any concentration of metallic minerals resulting from the precipitation of solids from hot mineral-laden water (hydrothermal solution). The action of deeply circulating water heated by magma solutions are thought to have given rise to the hydrothermal solution. Energy released by radioactive decay or faulting of the Earth crust is also sources of heating that may be involved.

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The waters may precipitate their dissolved minerals in rocks openings or they may displace the rocks themselves to form so-called replacement deposits.
Poormirzaee & Oskouei (2009) pointed out the importance of Landsat data for mineral exploration as it has a broad regional coverage with multispectral and multitiming features capable in indicating states, belts, mineralization areas and structures controlling mineralization like,contacts, linear and circular structures. Several studies around the world related to hydrothermal alteration mapping using multispectral satellite images especially with the use of Landsat and Aster (e.g., Ananaba & Ajakaiye 1987; Ramadan *et al.* 2001; Abdelsalam *et al.* 2000; Ramadan & Kontny 2004; Madani *et al.* 2003). The visible and infrared spectrum of hydrothermal alterations is possible with Thematic mapping multispectral images from Landsat satellites (Hunt & Ashley 1979; Hunt 1979). Alteration types are associated with diagnostic minerals in their respective rocks. Satellite imaging plays a perfect role in differentiating the representative minerals for the different types of alterations. According to Akande et al. (1988) the lead-zinc copper –barite deposits in the Benue Trough resulted from the hot basinal fluids leached metals from arkosic sediments and later precipitated them as metal sulphides in Cenomanian fractures of the Asu River Group.

The main objective of this study is to employ the use of Landsat 8 ETM+ interpretation to delineate altered zones i.e structures that might have been altered due to heat from hydrothermal fluid.

Materials and method

Location of the Study Area

The area of study is the Middle Benue Trough and it cuts across parts of four (4) states (Benue, Nasarawa, Plateau, and Taraba) within latitudes $7^{0}30'$–$9^{\circ}00'$N and longitudes $9^{0}00'$– $10^{0}30'$E as shown in Figure 1.

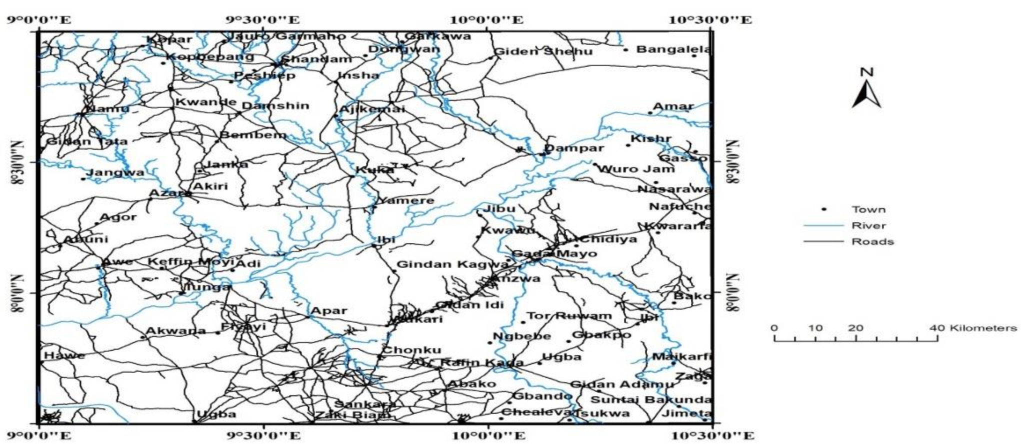

Figure 1. Accessibility/Location map of the study area (Modified after NGSA, 2010)

Geology of the Study Area

The Benue Trough is approximately 1,000-km northeast-southwest trending intra-cratonic rift structure that extends from the northern limit of the Niger Delta to the southern margin of the Chad Basin and is partitioned geologically and geomorphologically into Lower, Middle, and Upper Benue Troughs (Figure 2). It is resting unconformably upon the Precambrian Basement of Nigeria. The Middle Benue is the near linear parts of the basin while the Lower Benue Trough, which shifts SW, includes two main structural units: the N6^{0}E trending Abakaliki Anticlinorium that is flanked by the Anambra Syncline trending N3^{0}E. Many models have been proposed for the origin of the Benue Trough (King, 1950; Stoneley, 1966; Wright, 1968; Grant, 1971; Burke and Dewey, 1974; Olade, 1978; Thiessen et al., 1979; Mascle et al., 1986; Nurnberg & Muller, 1991).

All agreed that the origin of the Benue Trough is related to the continental separation of Africa and South America. The lithological units of the Middle Benue Trough have been detailed by (Offodile, 1976). The oldest sediments of the Middle Benue belong to the Asu River Group: A mixture of shale and siltstones of marine origin, and lava-flows, dykes, and sills overlie the Basement complex rocks. The youngest sediment is the Maastrichtian Lafia Formation. One of the sediment of interest is the Agwu Formation. The Coniacian Agwu Formation consists mainly of black shale, sandstones, and local seams of coal. Around the Obi/Lafia area, this Formation is coal-bearing and has been shown to fall within the oil window (mature) rich in organic matter. It could, therefore, be the source of significant quantities of hydrocarbons (HC) in the deeper portions of the basin (Obaje, 2000). The Lafia/Obi coal is also known to have moderate sulphur content and so making it favorable for the production of solid fuel for metallurgical process and its high volatility content makes it disposed of for use as coking coal (Ehinola et al., 2000).

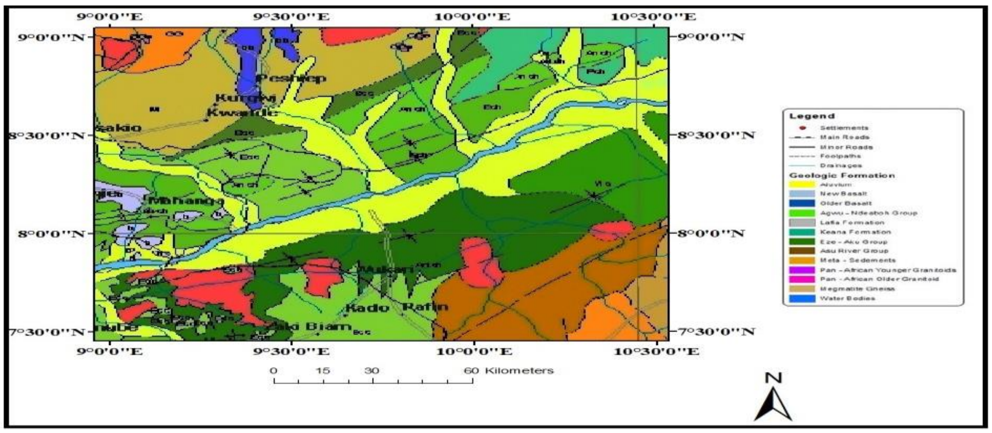

Figure 2. Geological map of the study area (Modified after NGSA, 2010**)**

Remote Sensing Data Source

The Remote sensing data was obtained from the Earth Science Data Interface (ESDI) of the National Aeronautic and Space Agency (NASA). A Shuttle Radar Topographic Mission (SRTM) image of the same area was also obtained. For better interpretation of the Landsat 8 ETM+ imagery, it was acquired at the peak of dry season.

Single band combinations were applied in a first approach, in order to analyze the study area and visually interpret the multispectral imagery for a preliminary geological study; a contrast-enhanced RGB combination (SWIR, NIR, and Visible) was created. The most contrasting band combination for lithological features and that provide more detail without additional enhancement should include one visible (2, 3 and 4), one NIR (5) and one SWIR (6 or 7) band (USGS, 2015a; USGS, 2015b). Band Ratio Images enhancing hydrothermal altered rocks using band ratios with distinctive reflection features were produced. This corresponds directly to minerals associated with this alteration and represents surface expression for auriferous deposits. Thus, we applied the ratio of Landsat 8 ETM+ OLI band 4 over band 2, to highlight areas with abundant iron oxides bearing minerals, as brighter pixels. Vegetation density is a limiting factor when detecting and mapping hydrothermal altered rocks by band rationing. In order to minimize this limitation a spectral unmixing technique, as Principal Component Analysis was applied. This analysis was applied to the six Landsat 8 ETM+ bands (2, 3, 4, 5, 6, and 7) that output an eigenvector matrix, represented in Table 1.

Results and discussion

Single Band Combinations

Using Landsat 8 ETM +, six bands (B2, B3, B4, B5, B6 and B7) were available to produce different band combinations, some of them enhancing relevant features for mineral exploration. A true colour image was produced with Landsat 8 visible bands 4, 3 and 2 (Red, Green and Blue, respectively) (Figure 3). With this band combination, it's possible to do an exploratory analysis of the area, identifying rock exposure areas (brown), vegetated areas (green), rivers and lakes (blue) and urbanized areas. In addition, some structural features such as faults and fractures were observed around Bangalala, Giden Shehu, Amar, Dongwan, Garkawa, Ajikemai, Kishr, Dampar, Kuka, Yamere, Shamankar, Bembem, Janka, Akiri, Yalwa, Shandam, JauroGarmaho, Adi, Apar, Hundu, Fiyayi, Kwana, Ugba, ZakiBiam, Sankara, Chonku, Wukari,Gidan Idi, Ngbebe, Donga, Avermun, Akume, Dooga, Gankol, Kurgwi, Kande and Bakin Chiwe.

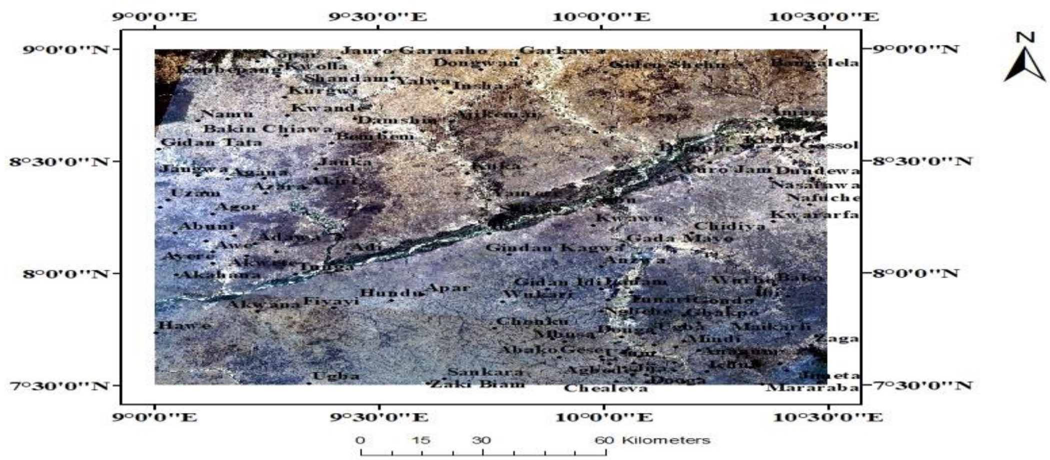

Figure 3. True Colour image. RGB combination of bands 4, 3, 2. Green colour represent vegetation, brown and brown represent soil or rock and blue water.

A False Colour image was created, using bands 5, 4 and 3 (R, G, B) (Figure 4). This band combination allows a better differentiation between vegetated areas (red areas) and good exposure outcrops (greyish colours). Light blue colour represents urbanized areas.

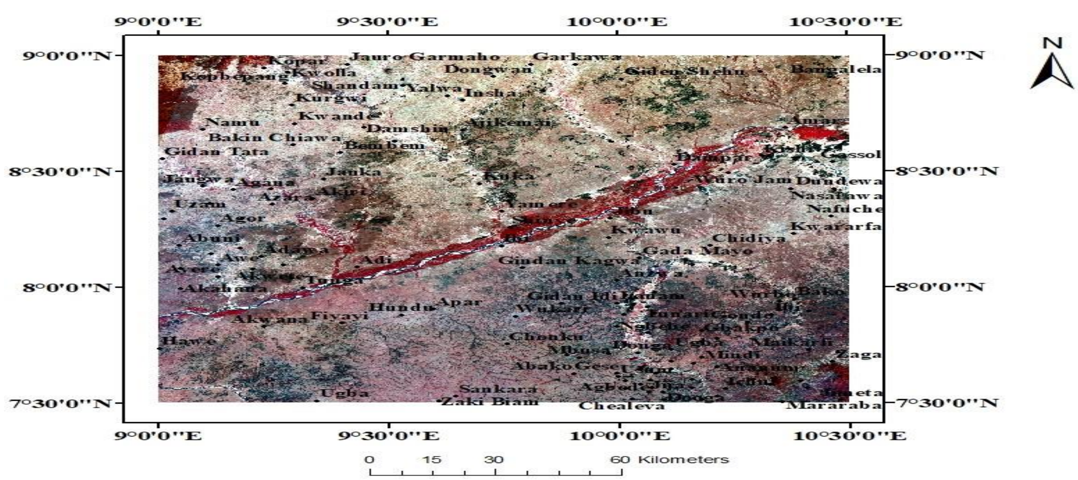

Figure 4. False Colour Composite. RGB combination of bands 5, 4, 3. Red colour represent vegetation, black represent water and rock or soil are represented by greyish colour. This RGB combination highlights the boundaries between vegetated and outcrop areas.

A composite using the bands 7, 5, 2 (RGB) was created (Figure 5) where it's possible identify outcrops as shades of orange and red, vegetation in light green and water in black.

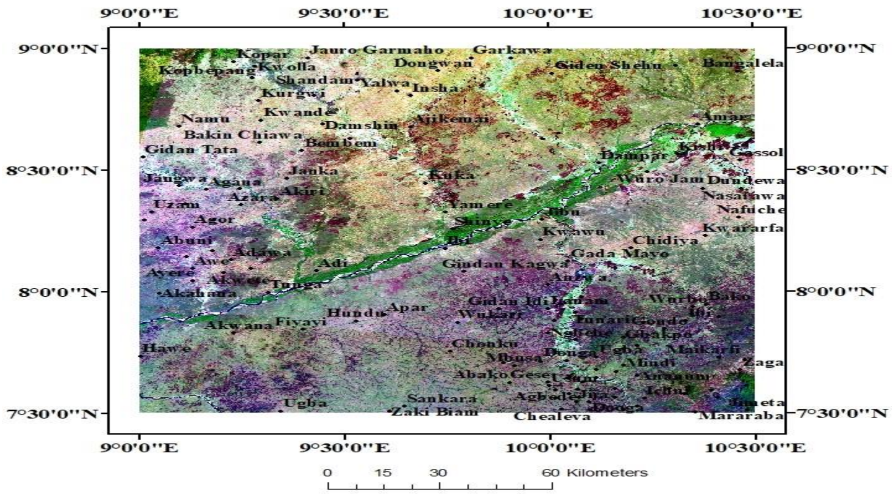

Figure 5. RGB combination for bands 7, 5, 2. Enhanced image where outcrops are represented in shades of orange and red, Vegetation in light green and water in black.

A band combination with a NIR band (band 5) and two SWIR bands (band 6 and band 7) was created, allowing a regional scale detection of geological features like faults, and differentiation of rock outcrops from vegetation (Figure 6). In this image, outcrops show a light blue colour, while vegetated areas an orange colour and water a black. Some hydrothermal alteration in outcrops areas can be identified as blue. The altered area is seen around Bangalala, Giden Shehu, Ajikeman. Kuka, Gessol, Akiri, Janka, Bembem, Wukari and Akwana.

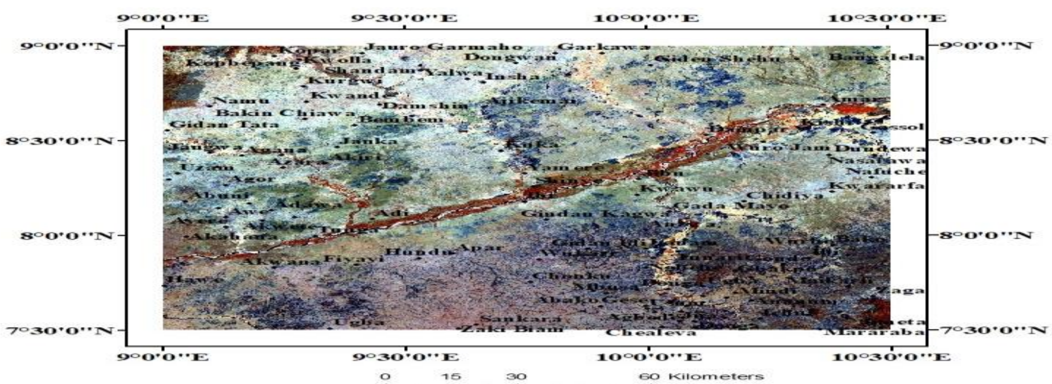

Figure 6. RGB combination for bands 5, 6, 7. In this image vegetated areas appear in orange colour, outcrops in light blue and water in black. Some hydrothermal altered rocks can be identified as blue.

Band Ratio

Thus, it was applied the ratio of Landsat 8 ETM band 4 over band 2, to highlight areas with abundant iron oxides bearing minerals, as brighter pixels (Figure 7). Ratio of Band 6 over band 5 discriminate ferrous minerals in bright tone (Figure 8). Clay minerals, as illite, kaolinite, and montmorillonite are discriminated with the ratio image of band 7 over band 5 as bright pixels (Figure 9). The ratio image of band 6 over band

7 distinguished altered rocks containing clays and alunite from unaltered rocks, where pixels are bright (Figure 10). Pronounced alteration mapping interpreted by the occurrence of iron oxides bearing minerals as observed in ratio band 4 over band 5, Clay minerals, as illite, kaolinite, and montmorillonite in ratio of band 7 over band 5 and clays; and alunite in ratio of band 6 over band 7, indicted major anomalous alteration at Gidan Shehu, east of Wukari, Kuka, Bambam, Uzam, Agor and minor anomalous alteration at Bangalala, Akwana and Dongwan.

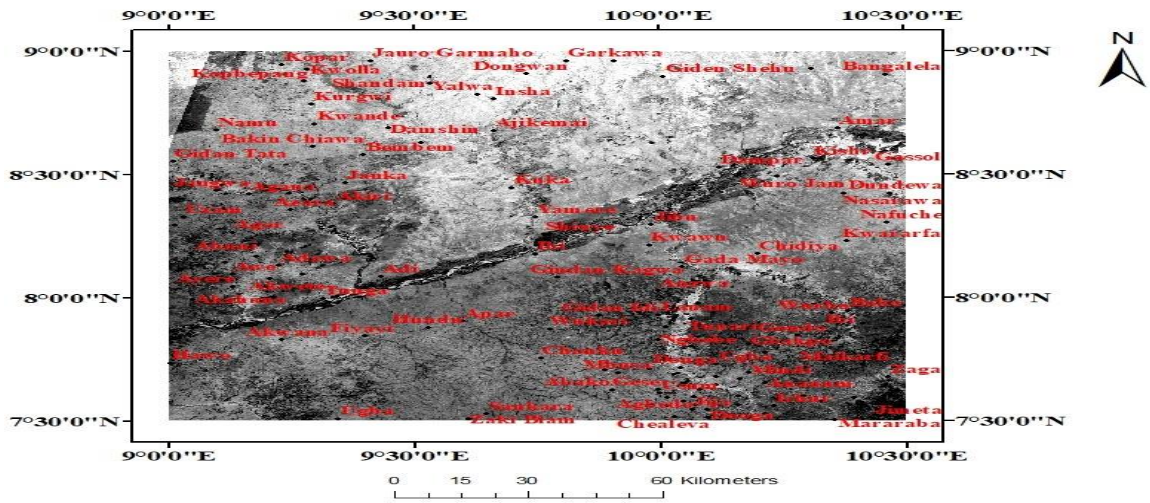

Figure 7. Landsat 8 band ratio 4/2 image reveals areas where iron minerals (hematite, goethite, limonite, etc.) are abundant shown in bright tones.

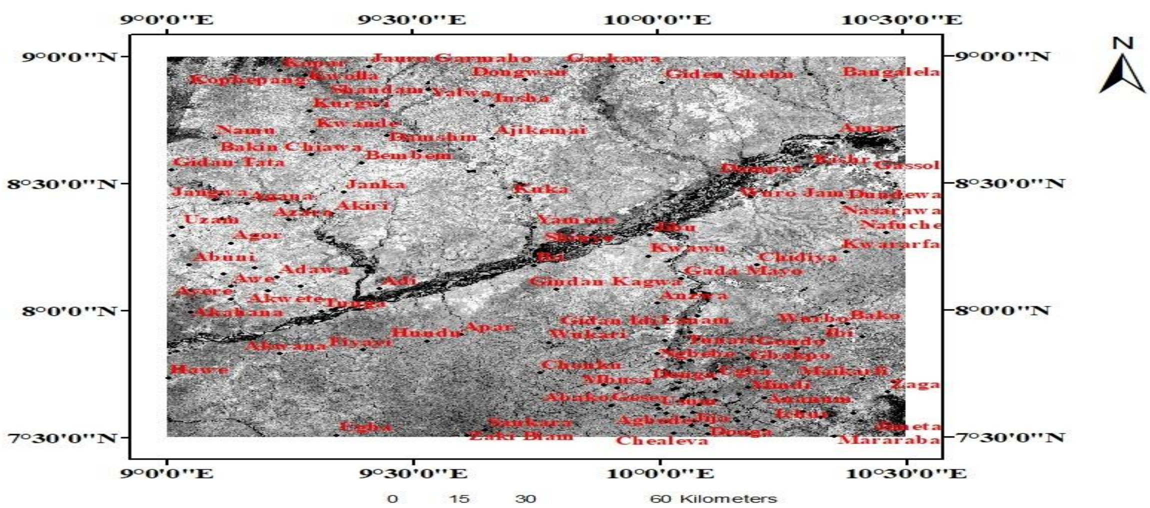

Figure 8. Landsat 8 band ratio 6/5 image discriminates ferrous minerals with bright tone.

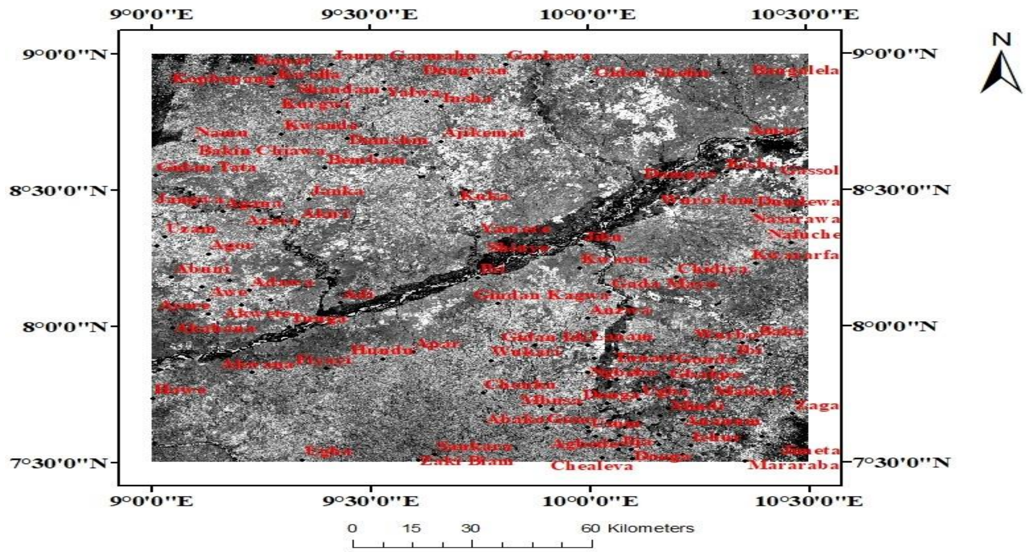

Figure 9. Landsat 8 band ratio (7/5) image reveals clay minerals, as illite, kaolinite and montmorillonite, in bright tones.

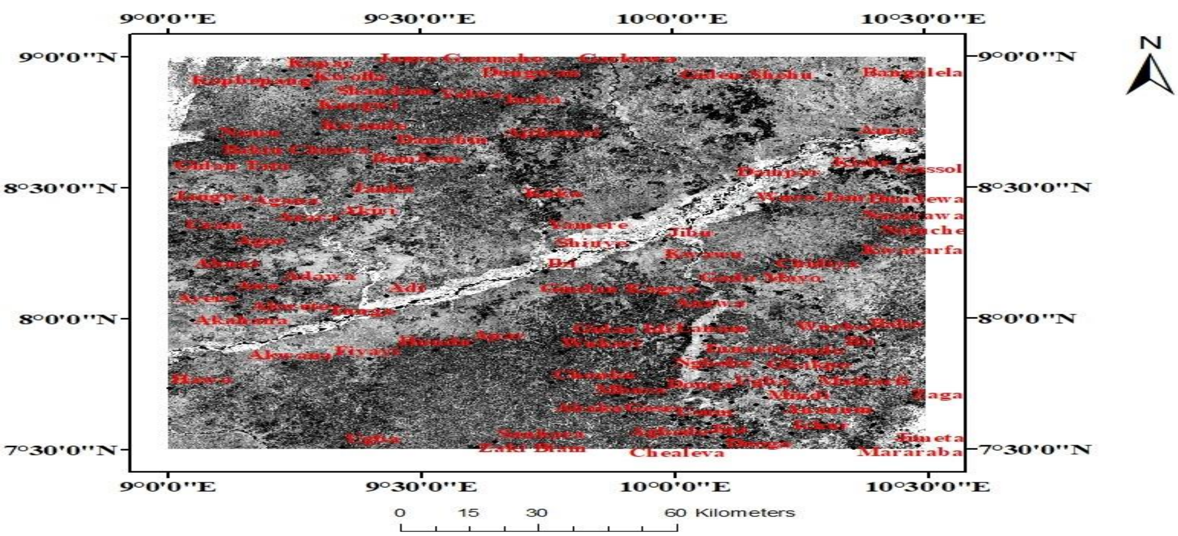

Figure 10. Landsat 8 band ratio 6/7 image shows alunite and hydrothermal clay minerals in bright tones.

An image incorporating these band ratios will discriminate altered from unaltered outcrop and highlight areas where concentration of these minerals occurs. An image using Sabin's ratio (4/2, 6/7 and 6/5 as RGB) was produced for lithological mapping and hydrothermal alteration zones (Figure 11). The ratio 4/2 was used for mapping iron oxides as hematite, limonite and jarosite, and has high reflectance in red region. The ratio 6/7 it's used to map clay minerals as kaolinite, illite and montmorillonite. The ratio 6/5 shows high reflectance in presence of ferrous minerals. In this Figure 11, light blue yellow colour represents outcrops and blue areas represent vegetation. Light green areas highlight hydrothermal alteration in outcrop rocks.

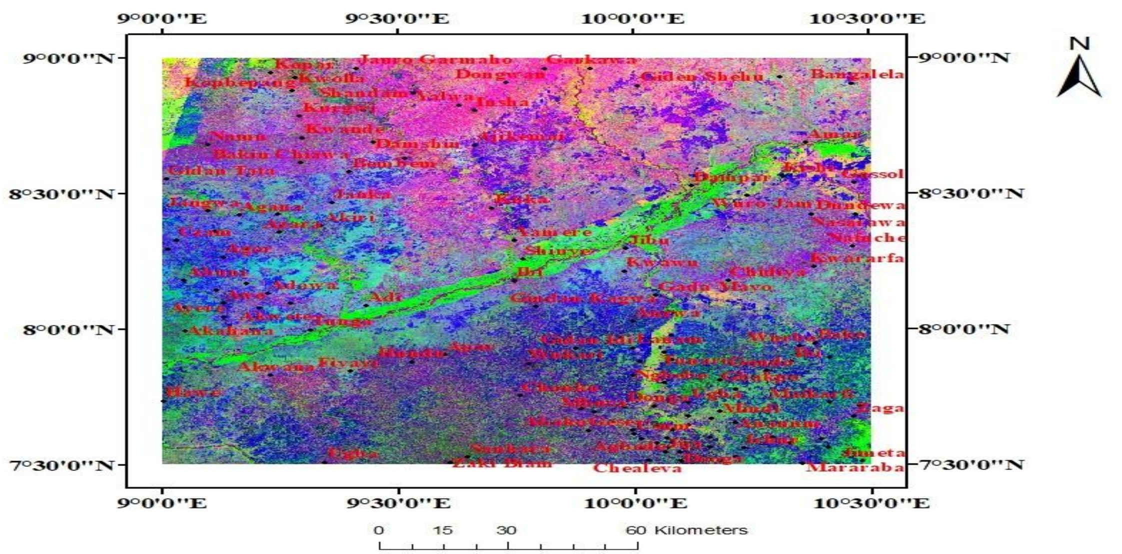

Figure 11. Sabin's ratio image (4/2, 6/7, 6/5). Outcrops are represented in light blue-yellow colour, vegetation in blue and water in dark green. Strong yellow represents buildings and other human constructions and light green altered rocks.

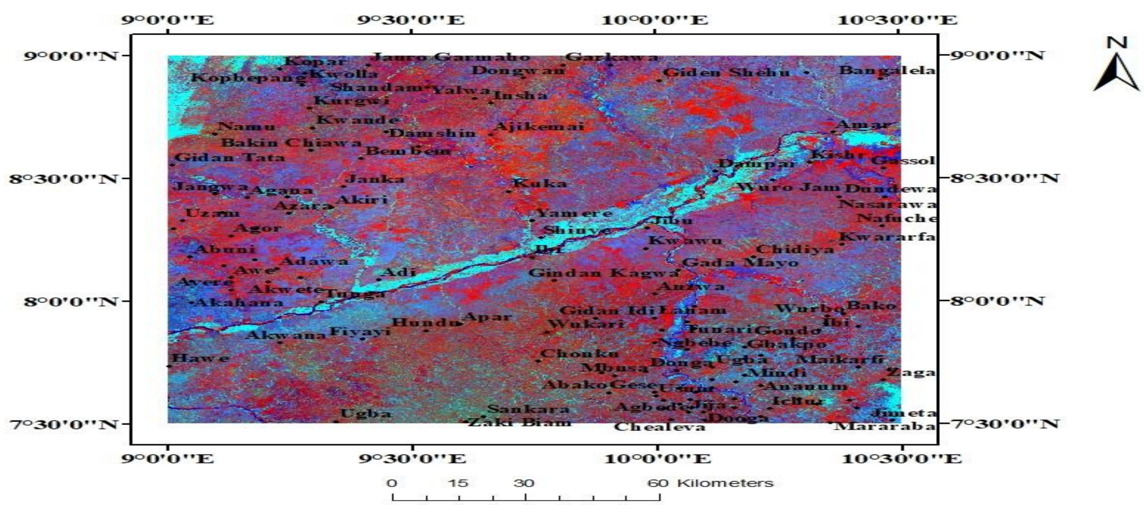

Figure 12. Kaufmann ratio (7/5, 5/4, 6/7). This band ratio combination high light metasediments as dark green and granite outcrops are represented as rose, vegetation as light blue and water as red. Some red areas can be related to the hydrothermal alteration.

Principal Component Analysis (PCA)

This analysis was applied to the six Landsat 8 bands (2, 3, 4, 5, 6, and 7) that output an eigenvector matrix, represented in Table 1. This result allowed identifying which PC contains more useful spectral information from Landsat 8 bands which has much higher contrast than the original bands.

Table 1. Eigenvectors and eigenvalues of PCA on Landsat 8 imagery.

	PC1	PC2	PC3	PC4	PC5	PC6
BAND 2	0,33541	0,44101	0,47773	- 0,53674	0,17977	- 0,37997
BAND 3	0,32237	0,31849	0,27952	0,08211	- 0,11697	0,83432
BAND 4	0,30589	0,34953	,05763	0,66891	- 0,42059	- 0,39573
BAND 5	0,60051	- 0,73032	0,29534	0,10042	0,07808	- 0,05112
BAND 6	0,45833	0,01101	- 0,63896	- 0,43077	- 0,44251	0,01313
BAND 7	0,34545	0,22004	- 0,44139	0,24917	0,75841	0,01221
EIGENVALUES	0,06686	0,00279	0,00102	0,00004	0,00002	0
PERCENT OF EIGENVALUES	**94,5305**	**3,9425**	**1,4443**	**0,0549**	**0,0227**	**0,0051**
ACCUMULATIVE OFEIGENVALUES	94,5305	98,473	99,9173	99,9722	99,9949	100

The sign and magnitude of eigenvector loadings in each PC correspond to the spectral properties of surface materials such as rock, vegetation, and soils (Crosta and Moore, 1989).

PC1 explains 94.5% of the total variance of the data, as shown in Table 1. This PC is composed of positive values of all 6 bands and is being responsible for the overall scene brightness. PC2 contains 3.9% of the original data variance and PC3 represents just 1.4%. The firsts three PC that contain the most data variance was combined in an RGB composite (Figure 13) and it is useful for lithological mapping purposes.

Green-yellow colours represents granite outcrops, while blue colour represent metasediments; purple represent vegetation and light blue water bodies. Light green areas highlight hydrothermally altered rocks.

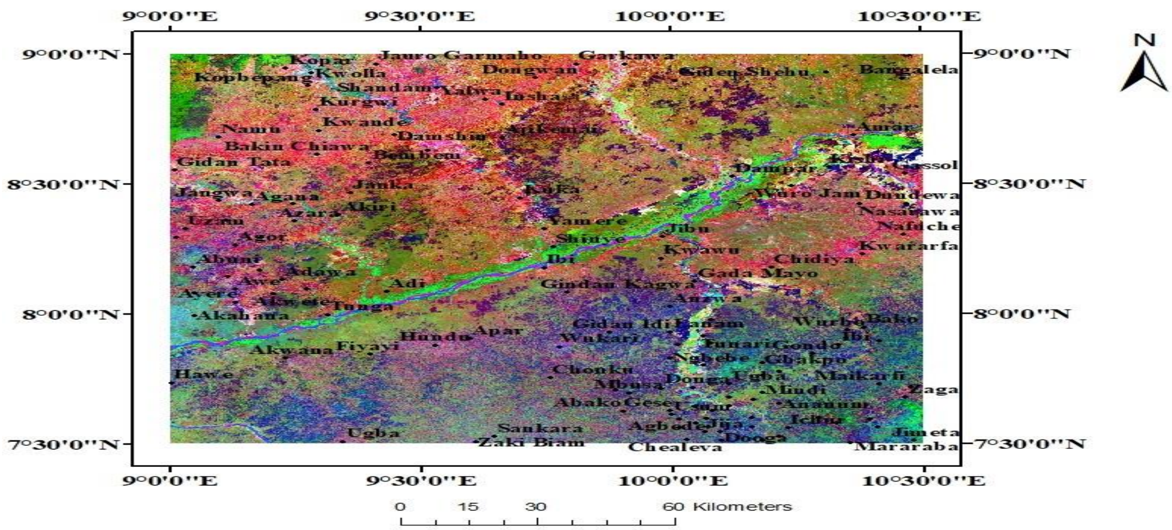

Figure 13. RGB colour combination of Principal Component Analysis 1, 2, 3 components. Green-yellow colours represent outcrops, vegetation in purple, water as light blue and metasediments as blue*.*

Conclusion

From the Landsat 8 ETM imagery data processing and analysis, an alteration map was produced. The alteration map represents the map of thermally altered rocks in parts of the Middle Benue Trough. Results revealed that the colour composite and band ratio methods is efficient in delineating hydrothermal alteration area. An image incorporating these band ratios discriminate altered from unaltered outcrop and highlight areas where concentration of these minerals occurs.

Principal component Analysis clearly showed the iron-oxides and hydroxyl altered in the study area. The altered iron-oxide deposits were observed more around Bangalala, Giden Shehu, Ajikeman. Kuka, Gessol, Akiri, Janka, Bembem, Wukari and Akwana. The spatial distribution of Clay minerals, as illite, kaolinite, montmorillonite and alunite have been successfully mapped with the aid of Landsat 8 ETM+ in parts of the Middle Benue Trough, Nigeria.

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