MAPPING SOLID MINERAL DISTRIBUTION OF THE UPPER BENUE TROUGH NORTHEASTERN NIGERIA USING LINEAR SPECTRAL UNMIXING

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Abstract- The Gongola arm of the Upper Banue Trough, Northeastern Nigeria is predominantly covered by the outcrops of Limestone-bearing rocks in form of Sandstone with intercalation of carbonate clay, Shale, Basaltic, Felsphatic and Migmatite rocks at subpixel dimension. In this work, subpixel classification algorithm was used to classify the data acquired from landsat 7 Enhance Thematic Mapper (ETM+) satellite system with the aim of producing fractional distribution image for three most economically important solid minerals of the area: Limestone-bearing Sanstone, Basalt and Migmatitic Schist/Gneiss. Linear Spectral Unmixing (LSU) algorithm was used to produce fractional distribution image depicting the abundance of the three mineral resources within a 100Km^2 portion of the area. The results show that the minerals occur at different proportions all over the area. The fractional map could therefore serve as a guide to the ongoing reconnaissance for the economic potentiality of the formation.

Key Words- Linear Spectral Unmixing, Upper Benue Trough, Gongola arm

I. INTRODUCTION

The geology and mineral deposits of the Gongola Arm of the Upper Benue Trough have been subjects of relevance by many researchers due to their enormous economic potentialities and environmental impact. The Cretaceous inland basin is believed to be the stratigraphic continuity of the rift basin of the Niger, Chad, Sudan and Cameroun within the same train (Akande et al., 2012). The discovery and the successful exploitation of hydrocarbon deposit in significant commercial quantities at the Chad and Cameroun segments of the basin is one of the major factors that necessitates the need for intensive research toward understanding the lithologic characteristics, sedimentology and kerogen studies of the basement.

The Trough is structurally made up of the Albian Bima Sandstone overlying unconformably on the Precambrian Basement (Samaila et al., 2006). The formation, which was deposited under continental condition, is characterized by coarse to medium grained Sandstone intercalated with carbonaceous clay, shale and mudstone (Obaje, 2009). The carboniferous shale of the Bima Sandstone appears relatively dark in color due to its limestone content which was thought to be deposited under aqueous anoxic condition (Obaje, 2009). This is in contrast with the fine and mediun-grained Felspathic oldest Sandstone described as red and purple in color (Kogbe, 1976). In the upper portion of the formation, the Sandstone is the most widespread unit and is relatively homogenuous in appearance (Ismaila et al., 2006). There is therefore a clear evidence of optical contrast between these most dominant lithologies of the area. The lithographic units of the formation can thus be delineated by the virtue of their reflectance signatures which are unique for each mineral. It is specifically established that the visible and near infrared (VNIR), short wave infrared (SWIR) and thermal infrared (TIR) regions of the electromagnetic spectrum provide complementary data for geological investigation (Drury, 1987). The intensity of the spectral reflection and absorption of rocks and carbonic minerals are functions of their chemical composition and purity (Sanjeevi, 2008). Hence multispectral remote sensing data has the capability of discriminating various units of the formation based on the variation in their reflectance and absorptance spectra.

Remotely sensed images can be classified using either discrete or fuzzy technique. Discrete classification is based on the assumption of pixel homogeneity where each land cover type is large enough to cover pixel size. (Pope and Greene, 2005). This classification technique is suitable for large land cover type. In a situation where pixel size is smaller than the patch of land cover components such as highly conglomerate geologic formation, the homogeneity assumption becomes inappropriate. In such formation, components of the rock fragments are mixed and held together within a sub-meter dimension and therefore discrete classification will not provide accurate coverage.

Linear Spectral Unmixing (LSU) is a fuzzy classification technique that provides sub pixel estimate of land coverage. LSU is based on the assumption that the spectral response of land cover materials recorded as digital number represents a relative mixture of pure spectra where each mixture is related to a particular land cover material. Thus each pixel in a particular band at a given location is a linear combination of pure spectra of a unique land cover type. Consequently a pixel in a multispectral band image represents a mixture of spectra from different land cover types within the area of coverage. Thus based on the material spectral properties, the technique can be used to determine the relative abundance of mineral deposits within the outcrops of geologic formation.

In LSU classifier, each pixel is assumed to consist of n components of land cover type where n is less than or equal to the number of spectral bands in the data (Lu et al., 2004). Training set or endmembers are selected for the n component materials and used to model the measured signals at any given pixel. The algorithm is based on the fact that the spectrum measured by the sensor is a linear combination of the spectra of all components within the pixel (Boardman, 1993). The spectral reflectance of a pixel R_i that contains one or more endmembers with respect to band i is mathematically model as (Sanjeevi, 2008)

$$R_i = \sum_{k=1}^{n} f_k R_{ik} + e_i \qquad (1)$$

where k is the number of endmembers, f_k is the proportion of endmember k within the pixel, R_{ik} is the known spectral reflectance of endmember k within the pixel in band i and e_i is the error for band i.

Two solution methods, the constrained and the unconstrained solutions could be used for the LSU model. The constrained solution model is subject to the restriction

$$\sum_{k=1}^{n} f_k = 1, \text{ and } 0 \le f_k \le 1 \qquad (2)$$

In the unconstrained solution, f_k could have value less than 0 or greater than 1, which do not reflect the true abundance fraction of endmembers (Lu et al., 2004).

In this work, Landsat ETM+ coverage of a portion of the Gongola Arm of the Upper Benue Trough was used to map the geologic outcrops of the formation. Discrete classification technique was used to classify the image into three major geologic units based on the observed geomorphologic map of the area. LSU technique was then used to map the relative abundance of solid minerals associated with the three major geologic units. The fractional map will serve as a guide for the ongoing mapping and analysis of the economic potentialities and environmental impact of the formation.

II. MATERIALS AND METHODS

Study area

The Upper Arm of the Bima Formation is a linear extension of the main Cretaceous sediment of the Benue Trough, extending northward to a length of about 250 km. It lies from latitude 11^0 49' 18.74"N longitude 11^0 54' 6.57"E at the southern end, to latitude 9^0 4' 29.82", 12.12 N longitude 5^0.0'36.00"E at the extreme northern end (Fig. 1). The depocentres of the Gongola Arm comprises Pindiga, Gombe, Nafada, Ashaka all in the present Gombe state.

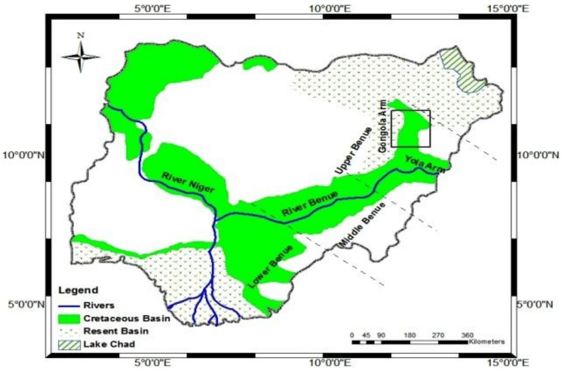


Fig 1, Map of Sedimentary Basin of Nigeria, showing the study area in rectangular box (Digitized from Obaje, 2009)

Geologic setting

The outcrops of various lithologic units of the Upper Benue Trough are inliers of the prominent Bima Sandstones (Onuba et al., 2008) and deposited as extrusive lithographic units during the Albian transgressive phase (Ukaegbu and Akpabio, 2009). This transgressive episode led to the deposition of the various formations that made up the sedimentary basin which outcrops or occur as shallow marine deposit of limestone, shale and mudstone. Ogungbesan and Akaegbobi (2011) however observed that the outcrop units of the formation consist of Sandstone, Shale and Basaltic rocks lying unconformably on the Basement rocks. These Aptian-Albian pyroclastics sediments were described as the earliest sedimentation of the entire Benue Trough.

Data acquisition and preprocessing

Landsat satellite platform provides the most useful medium resolution remote sensing data for the description of lithological units of geologic formations on the bases of variation in color, texture and erosion characteristics. The satellite series provides the longest continuous record of remote sensing images that are invaluable resources for monitoring global changes at a medium spatial resolution (Chander et al., 2009). The latest group of these satellite series, Landsat 7(L7) is equipped with Enhanced Thematic Mapper Plus (ETM+) sensor, providing nine spectral band images (three visible, four infrared, two thermal and one high spatial resolution panchromatic bands), providing imagery of the global land surface for variety of application such as monitoring land cover changes (Hansen, et al., 2012), mapping vegetation canopy in mangrove forest (Kasawani et al., 2010), and geologic lineament mapping (Saadi and Watanabe, 2009).

The data used for this study is Landsat Thematic Mapper Plus (ETM+) acquired on 19^{th} of July, 1999. The nine spectral bands of Landsat Enhanced Thematic Mapper ETM+ include three visible bands (1-3) with a wavelength range between 0.4 and 0.7 µm and one near infrared NIR band (4) with a wavelength between 0.76-0.90 µm. Others are two infrared IR bands (bands 5 and 7) with a wavelength between 1.55 and 2.35 µm, and one panchromatic band 8 with a wavelength between 0.52-9.0 µm. The additional two thermal infrared bands (bands 61 and 62) with wavelength between 10.40 and 12.5 µm are not used for this work. The multispectral bands have a spatial resolution of 30 m while the panchromatic band has a resolution of 15m.

The scene utilized for this work covers the central portion of the study area with upper left corner coordinate at latitude 9.6177648N, longitude 11.8908392E and lower right corner coordinate at latitude 7.7366057N, longitude 14.0351291E. All image processing and analyses are executed in ENvironment for Visualizing Image (ENVI) processing software, version 4.5. The seven bands of the multispectral images were stacked and fused with the higher resolution panchromatic image. Multiplicative fusion technique was used in which the panchromatic image was resampled to a 0 - to - 1 range pixel levels. Each pixel is then multiplied by its corresponding pixel of the multispectral image. The spatial resolution of the resulting image was therefore enhanced to 15 m value of the panchromatic image while the spectral resolution of the multispectral image was retained (Svab and Ostir, 2006).

The image was geometrically corrected using 13 ground control points whose coordinates were precisely recorded with GPS. It was then resampled and subset to an area of more prominent geologic scene and less vegetation covers. Bands 7, 4 and 1 of the resultant fused and resized 15m spatial resolution image were selected to be the RGB coordinates as shown in Fig. 2(a). The bands were selected based on the reflectance signature of various solid minerals formations on Landsat image in which the three bands appear to be sensitive to geologic formation (Corral et al., 2011).

Endmember collection

LSU model required spectral reflectance of pure spectrum for the various land cover type as training data. This could ideally be obtained using ground-based spectra measurement. They are however practically obtainable with minimal error by sampling the endmembers within a centre of known features in the scatter plot of the first few principal components of the data (Keshava, 2003). The application of PCA in endmember identification has been demonstrated by many authors (Theseira et al, 2003; Smith et al., 1985). It has been observed that for a mixture of three substances, the scatter plot of the first two principal components produce a triangle in which the pure endmembers are located at the vertices (Theseira, 2003). Thus PCA transform was used to identify the individual end-members of multiple surface components..

Fig.2 (b) is the Principal Component Analysis (PCA) transformed image of the fused sample of the data. It could be observed from the image that PCA bands are more color composite than the original spectral bands and therefore more interpretable.

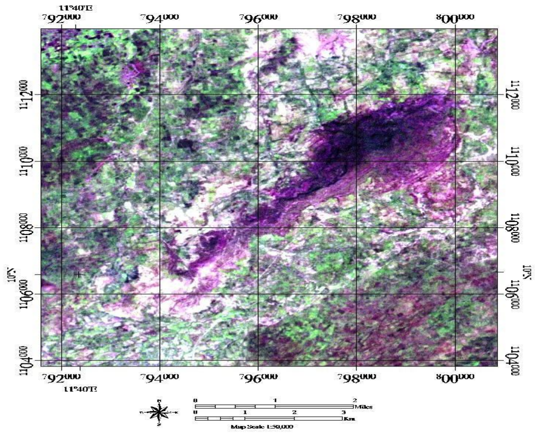


Fig. 2(a) bands 7,4,1 color composite of the fused image resized to the sample area

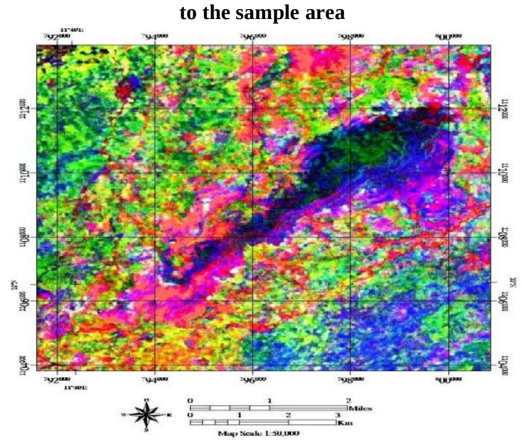


Fig. 2(b) PCA of the fused and resized Landsat ETM+ image

Endmembers collected from the resulting PC scatter plot were geologically identified with the help of a geomorphology map of Northeastern Nigeria developed by DOS (1971). The auxiliary map was registered and rectified to the coordinate of the study area using image-to-image registration. The map is a detail map of the area with lithologic units such as shale, basalt, Sandstone, Clay, and Limestone found to be interbedded in different forms. It is however observed that three most abundant units are Sandstone mixed with Shale/Limestone, Basalt, and Shist Gneiss mixed with Migmatide. They occur at different combination with other units such as Clays and Shale with thin Limestone and Standstone, Older Granite with some Schist Gneiss and Migmatite, Basalt Pyroclassic Deposit etc.

Preview of the selected endmembers were identified in the auxiliary map. A selected region correspond to the region of higher concentration of anyone of the three units is accepted as a representative of the unit. The three units were therefore identified and labeled appropriately. The LSU was implemented with respect to the three units in order to develop the relative fraction map depicting the fractional distribution of the units within the study area.

Image classification

The resulting PCA-transformed image was classified to obtain an overview of the various geological units of the area. Unsupervised classification was initially used to identify signatures of geologic units. About 13 outcrop classes were initially identified from the unsupervised classification. Supervised classification was next performed using the three selected endmenbers. Lithologic units of the area were classified based on the Geomorphology map. The field identification data were compared with the Geomorphology map in order to enhance classification accuracy and identify class name based on the developed geomorphology data.

The training signatures were evaluated using contingency matrix utility in which the resulting classified raster image was evaluated with ground control points initially recorded and used for image rectification. About 12 geologic outcrop classes were identified based on maximum likelihood classification. Signature severability utility was used to computes the statistical distance between the signatures. This technique determines how distinct a class signature is from others. Based on the signature reparability, the 12 outcrop classes were reduced to four major geologic classes commonly identified at the study area. They consist of combination of Sandstone/Shale/Limestone as a unit, Basalt and Schist/Gneiss/Migmatite as a unit. The forth class are unclassified coverage. The classification accuracy was assessed by generating the confusion matrix which gives the accuracy assessment report with respect to the 13 ground control points together with the computed overall accuracy and the kappa statistics with respect to the four classes.

Relative fractional maps of the three predominant lithologic units were produced based on their respective endmember spectra. A constrained LSU algorithm was used which scale the image map to a range 0 (absence of a cover type) to 1 presence of pure cover type.

RESULTS AND DISCUSSION

Visual assessment of the classified image shows that the medium resolution image has successfully delineated prominent geologic outcrops of the formation. The classified image is shown in Fig. 3. The map indicates the variation in the feature targets digitally separated based on the difference in the spectral response of the target. According to the map, the most prominent geologic outcrop within the study area is a conglomerates of sandstone, Shale and Limestone which covers about 76.435% of the sampled area. Physical observation shows that this is the most prominent outcrop of the Bima and Yolde Formations around the study area. It is therefore the major constituent of the Bima Sandstone deposited around Billiri-Bambam area. The other outcrops are the conglomerates of Schist, Gneiss and Migmatites which covers about 10% of the total area under study. Next most prominent rock mineral is Basalt (2.63%). The basalt is specifically identified as parts of the basaltic flow remnants among the Cretaceous sediments found in both Middle and Upper Benue Trough (Obaje, 2009).

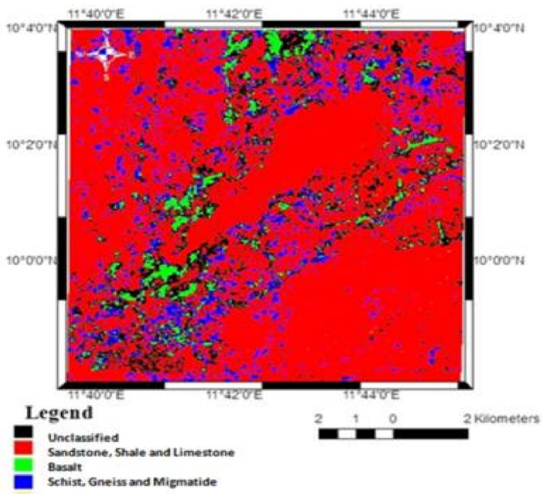


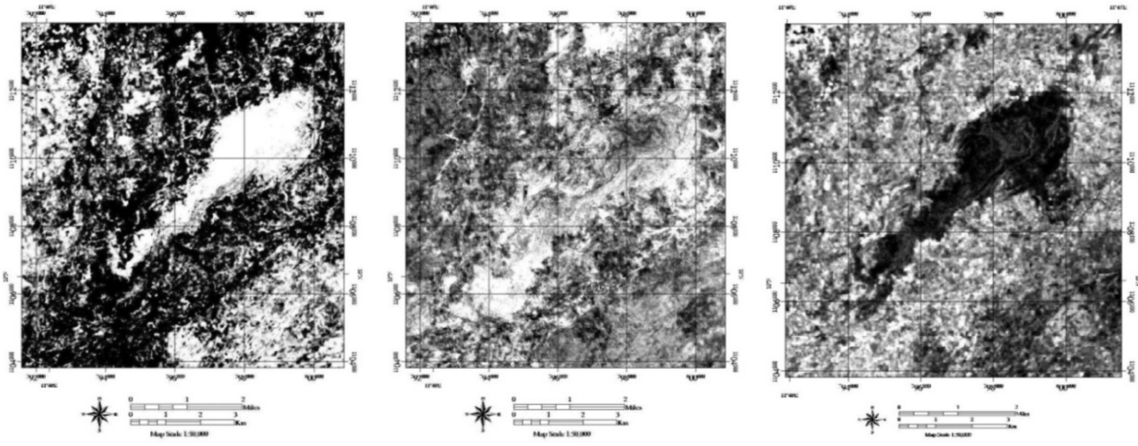
Fig 3 Classified image obtained /produced geologic map of the study area.

Accuracy assessment of the classification technique performed based on the confusion matrix shows an overall accuracy of 92.6829%. This is therefore an indication of about 92.7% accuracy in classification of the outcrop units. The kappa coefficient of 0.8893 is also another measure of accuracy of the classification with respect to spatial (ground truth) data. Thus the classified image is about 88.93% accurate in comparison of the map with the real ground truth objects.

Table 1 Class Distribution Summary

Class	Area (m^2)	Area(%)
Sandstone/Shale/Limestone	138,097,574.00	76.435%
Schist/Gneiss/Migmatide	19,480,500.00	10.782%
Basalt	4,747,950.00	2.628%
Unclassified	18,279,450.00	10.117%
Overall Accuracy = (1064/1148) = 92.6829%		
Kappa Coefficient = 0.8893		

The fractional cover map for each of the three land cover types gives the plot of the fractional distribution of the material based on the endmember spectra representing the pure spectra of the material. Figs. 4 (a-c) are fractional maps for the distribution of the three land cover types. The fractional values are scaled from a maximum value of 1 (brightest) representing maximum proportion of the material to 0 (dark) representing minimum or absence of the material. It could be observed from the maps that the distributions of the three minerals are highly erratic and complementary. For instance high concentration of Sandstone/Shale/Limestone in the associated bearing rocks along the central region of the map (Fig. 4(b) correspond to near absence of Basaltic rocks (Fig. 4a). The Schist/Gneiss/Migmatite bearing rocks however appears to have higher regional distribution with relatively lower proportion as shown in Fig. 4(c).



a b c

Fig. 4 fractional images obtained: (a) Sandstone, Shale with Limestone, (b) Schist, Gneiss and Migmatide, (c) Basalt

CONCLUSION

In this work, fractional distributions of three most dominant mineral resources within the outcrops of the Cretaceous Formations of the Gongola Arm of the Upper Benue Trough were mapped using optical satellite remote sensing data. The three most prominent mineral resources of the formation notably Limestone-bearing Sandstone with shale, Basalt and Schist/Gneiss with Migmatite, occur as conglomerates of different geologic units such as Felspathic Samdstone and Shale with Limestone, Basalt intercalated with Pyroclastic deposits, older Granites with Schist , Gneiss and Migmatite etc. This implies that the minerals are spatially distributed over the area at subpixel dimension. Spectral mixture analyses was used to map the spatial distribution of these minerals in order to produce fractional map for each component material. Training data were created for the three components using endmembers of the scatter plot of the image's principal component. LSU algorithm was used to map and plot the fraction of each component materials in the pixels. Thus the outputs are set of three fraction planes with each plane reporting the fractional amount of the mineral material in each pixel. The algorithm could therefore be regarded as a tool for decomposition of pixel into its abundance components. The work will therefore serve as an effective tool for mineral prospecting within the study area.

REFERENCES

[1]. Akande, S. O., Egenhoff, S. O., Obaje, N. G., Ojo, O. J., Adekeye, O. A. and Erdtmann, B. D. (2012). Hydrpcarbon potential of Cretaceous sediments in the lower and Middle Benue Trough, Nigeria: Insights from new source rock facies evaluation. Journal of African Earth Science. 64, 34-47.

[2]. Boardman, J. W. (1993). Automated Spectral Analysis: A geological example using AVIRIS data, north Grapevine maintains, Nevada. Proceding, ERIM tenth thematic Conference on geologic Remote sensing, Ann Arbor, MI. pp: 407-418.

[3]. Chander, G., Markham, B. and Helder, D. (2009). Summary of the current radiometric calibration coefficients for Landsat MSS, TM, ETM+ and EO-1 ALI sensors. Remote Sensing of Environment. 113, 893-903.

[4]. Corral, I., González, F., Griera, A., Corbella, M., Gómez-Gras, D., Cardellach, E. (2011). Landsat etm+ imaging for the exploration of epithermal deposits in the azuero peninsula (Panama). Revista De La Sociedad Española De Mineralogía Macla. No 15. Septiembre.

[5]. DOS (1971). Geomorphology of Northeastern Nigeria; Map 2. Prepared by the Directory of Overseas Surveys (DOS, British Government Overseas Development Administration.

[6]. Drury, S.A., (1987). Image interpretation in Geology. Blackwell Science Inc. USA.

[7]. Hansen, M. C. and Loveland, T. C. (2012). A review of large area monitoring of land cover change using Landsat data. Remote Sensing of Environment. 122, 66–74

[8]. Kasawani, I., Norsaliza, U. and Hasmadi, I. M. (2010). Analysis of spectral vegetation indices related to soil-line for mapping mangrove forest using satellite imagery. Applied Remote Sensing Journal. 1(1), 25-31.

[9]. Keshava, N. (2003). A Survey of Spectral Unmixing Algorithms. Lincoln Laboratory Journal, 14(1), 55-78.

[10]. Kogbe, C. A. (1976). Palaeogeographic history of Nigeria from Albian times. In: Kogbe, C. A. (Ed). Geology of Nigeria. Elizabethan Publ. Co. Nigeria, p436

[11]. Lu, D., Batistella, M., Moran, E. and Mausel, P. (2004). Application of spectral mixture Analysis to Amazonian land-use and land-cover classification. International Journal of . Remote Sensing, 25,(23), 5345-5358.

[12]. Obaje, N. G. (2009).Geology and Mineral Resources of Nigeria. Springer, Verlag Berlin Heidelberg., Germany.

[13]. Ogungbesan, G. O. and Akaegbobi, I. M. (2011). Petrophysical and geochemistry of Turonian Eze-Aku Sansdtone ridges, loer benue Trough, Nigeria implication for provenance and techtonic settings. Ife Journal of Science, 13 (2), 263-277.

[14]. Onuba, L. N., Onwuemesi, A. G., Anudu, G. K., Chiaghanam, O, I. and Ifelunni, C. D. (2008). Interpretation of aeromagnetic anomalies over Upper Benue Trough, Northeatern Nigeria. Natural and Applied Science Journal 9(1),

[15]. Pope, P. A. and Greene, M. K. (2005). Geologic Mapping Through Linear Spectral Unmixing of MTI Imagery. Pecora 16 Global Priorities in Land Remote Sensing. October 23-27, 2005 Sioux Falls, South Dakota

[16]. Saadi, N. M. and Watanabe, K. (2009). Multisource data integration for geological mapping in Gharyan area, Libya. International Conference on Earth Science and Technology, Yogyakarta, Indonesia, 6-7 August.

[17]. Samaila, N. K., Abubakar, M. B., Dike, E. F. and Obaje, N. G. (2006). Description of Soft-sediment deformation structures in the Cretaceous Bima Sandstone from Yola Arm, Upper Benue Trough. Journal of African Earth Sciences. 44, 66-74.

[18]. Sanjeevi, S. (2008). Targeting Limestone and Bauxite Deposits in Southern India by Spectral Unmixing of Hyperspectral Image Data The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B8. Beijing 2008

[19]. Smith, M.O., Johnson, P.E. and Adams, J.B., 1985, Quantitative determination of mineral types and abundances from reflectance spectra using principal components analysis, Journal of Geophysical Research, 90, C797-C804

[20]. Svab, A. and Ostir, K. (2006). High-resolution image fusion : method to preserve spectral and spatial resolution . photogrammetric Engineering and Remote Sensing. 72(5), 565-572.

[21]. Theseira, M.A., Thomas, G., Taylor, J.C., Gemmell, F. and Varjo, J., (2003), Sensitivity of mixture modelling to endmember selection, International Journal of Remote Sensing, 24, 7, 1559-1575

[22]. Ukaegbu, V. U. and Akpabio, I. O. (2009). Geology and stratigraphy of Middle Cretaceous Sequences Northeast of Afikpo Basin, Lower Benue Trough, Nigeria. The pacific Journal of Science and Technology,. 10(1), 518-527.

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