USING LANDSAT 8 (OLI) REMOTE SENSING DATA TO MAP LITHOLOGY AND MINERALOGY FOR GEOTHERMAL RESOURCE EXPLORATION

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ABSTRACT

Exploiting geothermal resources requires first and foremost locating suitable areas for its development. Remote sensing offers a synoptic capability of covering large areas in real time and can cost effectively explore prospective geothermal sites not easily detectable using conventional survey methods, thus can aid in the prefeasibility stages of geothermal exploration by narrowing targets for later comprehensive surveys. The focus of this paper is to explore the applicability of mapping geothermal related anomalies by identifying mineralogy and lithological features at regional scale using image enhancement techniques on Landsat 8 data such as Band ratios, as a preliminary exploration tool in an unexplored savanna environment. However, the application of satellite data for geothermal area characterization, despite being cost effective, available and suitable for regional scale survey, have been constrained by poor spectral and spatial resolution of data. While airborne data offers an alternative exploration means using better spatial and spectral resolution, such data are prohibitively expensive, unavailable and site specific for localized scale surveys. This paper is intended to investigate the application of the available and spatially and spectrally improved Landsat 8 (OLI) VNIR-SWIR bands in highlighting, discriminating and mapping geothermal potential areas, for cost effective exploration of known and possibly unknown geothermal systems in an uncharted tectonically stable, sparsely vegetated savanna environment characterized by obvious geothermal surface manifestations such as hot springs. The study employed a combination of established Band ratios from literature on visible, near infrared to shortwave infrared (VNIR-SWIR) Bands of Landsat 8 and innovative digital image processing techniques which enhanced surface mineralogy including; clay rich rocks, iron oxides, micas, carbonates and possible hydrothermal alteration zones related to geothermal anomaly. The results could have implication for GT exploration in especially unexplored savanna regions where expensive airborne surveys are unaffordable.

1. INTRODUCTION

Globally, there is a serious energy concern as a result of the combustion of fossil fuels which causes climate change. The exhaustibility of fossil fuels, their unreliability and environmental implications have resulted in the search for alternative sources of energy. Geothermal (GT) energy, which is the energy of the 'Earths Heat', offers a renewable and reliable source of energy. However, as with most renewable energies, it is inherently regional and site specific, mostly associated with areas of magmatic episodes and crustal plate movements. Exploiting geothermal resources requires first and foremost locating suitable areas for harnessing it. Remote sensing data can be used to detect indicator minerals as surrogates for assessing potential GT sites. The techniques involved in GT exploration using remote sensing, despite being complementary to in-depth geological surveys, has nevertheless establishes itself as an invaluable step in the prefeasibility stages of GT exploration due to its synoptic capability of covering large areas cost effectively, by narrowing targets prior to a substantial survey. Detailed mineralogical studies of GT fields have been done by previous studies, which revealed an array of alteration minerals related to GT settings (Calvin *et al.*, 2015; Littlefield and Calvin, 2014; Vaughan *et al.*, 2003). The class of common alteration minerals associated with GT systems which are detectable in remote sensing are limited. Many minerals have diagnostic spectral properties and features such as; band center, strength, shape and width which are used to identify species with high confidence (Pour and Hashim, 2015b). Laboratory and remote sensing spectral data are usually separated into wavelength ranges on the basis of their absorption features and the atmospheric windows through which the earth surface is measured (Calvin, *et al.*, 2015). In the visible, near infrared, and short-wave infrared (VNIR/SWIR) (0.4to~2.5 m), moderate and low-temperature surfaces are sensed because of the sunlight they reflect (Pour and Hashim, 2011a). Absorption features occur as a result of electronic orbital configuration of transition metals (generally iron or copper) in various crystallographic sites and from the combination and overtones of molecular vibrations from species such as hydroxyl, water, carbonate, and sulfate (Clark, 1999). This region of the electromagnetic spectrum is most sensitive to iron oxides, oxy-hydroxides, and ligands resulting from high or low temperature alteration (Clark, 1999). The ability to readily discriminate minerals by their unique spectral characteristics has been, in general, the basis for the use of the techniques in economic mineral exploration (Pour and Hashim, 2011b) , and in particular, the basis in geothermal exploration using associated minerals as surrogates (Calvin, *et al.*, 2015). The objective of this study is to enhance geothermal potential zones using hydrothermal alteration mineral indicators by applying Band ratioing as image transformation technique to VNIR- SWIR bands of Landsat 8 at regional scale.

2. MATERIALS AND METHODS

2.1 Study Area, Geology and Geothermal Implications

The Yankari Park is located in the south-central part of Bauchi State, in northeastern Nigeria. It covers an area of about 2,244 square kilometers (866 sq. mi) (Olokesusi, 1990) and is chosen for the study because the Park is not within the urban fringe thus satellite image data from the area may not be affected by the effect of urban heat island (UHI) characterized by built up areas in the city which could affect or distort the results of subtle geothermal anomalies. Spectral reflectance characteristic of specific earth features will also be more highlighted for detection. Satellite sensors which produce images are capable of detecting "Blind geothermal sources" not easily detectable using conventional survey methods (Heasler *et al.*, 2009). Thermal springs in the Park include; Dimmil, Gwan and Nawulgo. The famous Wikki thermal spring which has a temperature of about 37 degrees Celsius have been used as a tourist attraction in the Park. The presence of the thermal springs which are hydrothermal systems, within the Park motivates the study. Geologically, Yankari Park lies on the Kerri formation, of Tertiary age, which is composed of sandstone, silt stones, kaolinites and grits. Underneath this lies the Gombe formation, of Cretaceous age, composed of sandstones, silt stones, and ironstones. The valleys of the Gaji, Yashi and Yuli Rivers are filled with Alluvium of more recent age. Sandy loams and clayey soils of riverine alluvium occur in the valley of the Gaji, Yashi and Yuli Rivers. East of the Gaji valley is a 5–7 km wide band of very poor sandy soils that support a shrub savanna formation (Ubaru, 2000). Nigeria, being in a tectonically stable region rarely experiences crustal instability, except for the occasional minor earth tremor in the southwestern part of the country (Osagie, 2008). The Nigerian land mass has always been regarded as an aseismic intra-plate, however, historical data indicated that minor crustal disturbances have occurred in the last 50 years in different locations in the country (Ajakaiye *et al.*, 1988). There is however, many extinct volcanic features in the Jos plateau and the north eastern and western part of the country. Surface expressions such as warm springs have been identified including; Ikogosi, Ruwan Zafi, Akiri, and Wikki are some of the obvious manifestations (Kurowska and Krzysztof, 2010). In 2011, a fumarole activity occurred where gaseous emissions were observed in Ndanijan Kargo hill at Abaduguri range in Funakaye local government of Gombe state northeast of the Yankari Park. This occurred for 7 months, experts from Nigeria's Center for Geodesy and Geodynamics have tested the gaseous emissions, which had an odour of burning plastic, and revealed that the emission had magmatic origins and may be related to dormant volcanic system of the Pindiga formation (Abdullahi *et al.*, 2014). There may be several undocumented or unexplored geothermal manifestations around the country which could serve as sources for renewable energy use or other GT exploitation requiring less heat from the ground. Recent technological advances in satellite remote sensing could aid a comprehensive and cost effective exploration and mapping of potential areas in the country which could lead to geothermal resource exploitation and development. A simplified geology map in figure 1 illustrates Nigeria's geological areas with Yankari Park location (Study area) in box.

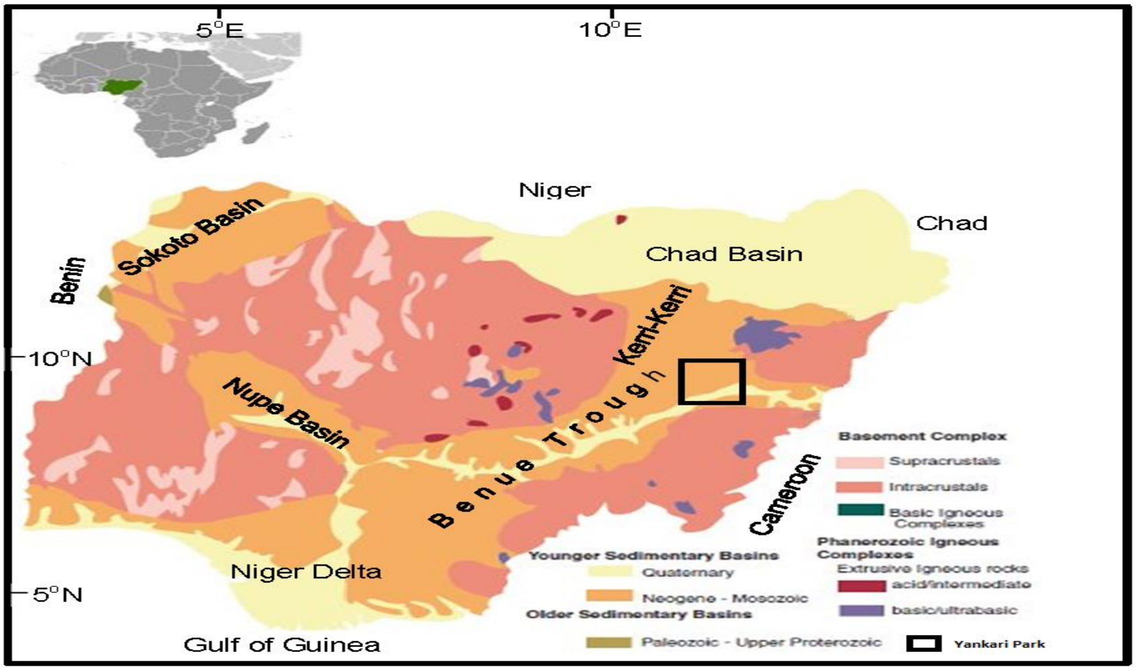

Figure 1. Simplified Geological Map of Nigeria showing Yankari Park

2.2 Remote sensing data

In this study, the Landsat 8 imagery is used. The Landsat-8 was launched on the 4th of February, 2013 from the Vandenberg Air force Base in California as part of the Landsat Data Continuity Mission (LDCM). This has been in operation since 1972 resulting in a generation of earth orbiting satellites including Landsat 1, 2, 3 and 4, 5 and 7. The satellite is a successor to its immediate predecessor; Landsat 7. The Landsat 8 is an American Earth Observation Satellite operated by NASA. It is characterized by two sensors; the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) (Storey *et al.*, 2014). The OLI collects image data in nine (9) channels or bands ranging from the VNIR to SWIR portions of Electromagnetic Spectrum (EMS). The Landsat 8's objective is to provide timely, high quality visible and infrared images of all landmass and near coastal areas of the earth. It has a design life time of five years and carries 10 years of fuel consumables. Designed for a 705 km sun- synchronous orbit, Landsat 8 offers a 16-day repetitive Earth coverage, completely orbiting the earth every 98.9 minutes. It builds and periodically refresh a global archive of sun-lit, substantially cloud free land images. The Landsat 8 system is robust, providing high resolution multispectral data, high volume of data by routinely collecting 650 scenes per day as opposed to 400 scenes in previous Landsat missions (Storey, *et al.*, 2014). The OLI sensor collects image data for nine shortwave spectral bands over a 190 km swath with a 30 m spatial resolution for all bands except the 15 m panchromatic band. The widths of several OLI bands are refined to avoid atmospheric absorption features within ETM+ bands. The biggest change occurs in OLI band 5 (0.845–0.885 μm) to exclude a water vapor absorption feature at 0.825 μm in the middle of the ETM+ near infrared band (band 4; 0.775–0.900 μm) (Markham *et al.*, 2014). The OLI panchromatic band, band 8, is also narrower relative to the ETM+ panchromatic band to create greater contrast between vegetated areas and land without vegetation cover (Storey, *et al.*, 2014)

2.3 Data processing

2.3.1 Atmospheric correction

The Landsat 8 image data was first layer stacked using the Environment for Visualizing Imagery (ENVI) software and then atmospherically corrected using the Internal Average Relative Reflection - IARR method in ENVI. The method is suitable where the study area is sparsely vegetated (Pour and Hashim, 2014) in this case a Sudan savanna region. The IARR algorithm is also preferred in mineralogical mapping especially as it does not necessitate a prior knowledge of samples to be collected from the field (Pour and Hashim, 2015a).

2.3.2 Band ratio transformation

Band rationing is a multispectral image processing method that involves the division of one spectral band by another. This division results in the ratio of spectral reflectance measured in the one spectral band to the spectral reflectance measured in another spectral band. Identical surface materials can give different brightness values because of the topographic, slope and aspect, shadows, or seasonal changes in sunlight illumination angle and intensity. These variations can influence the viewer's interpretations leading to misguided results. Band rationing transforms the data thereby minimizing the effects of such environmental conditions (Jensen and Lulla, 1987). In addition to reducing the effects of environmental factors, band ratios may also provide unique information not available in any single band that is useful for discriminating between soils and vegetation (Satterwhite *et al.*, 1984). Dividing one ratio by the other produces images that shows relative intensities. There are many sensitive bands for ratios and in this study we employed the (Sabins, 1997, Abrams, 1983 and Kaufmann, 1988) band ratios from literature. The band equivalents from previous Landsat bands were substituted to correspond to their equivalents in Landsat 8 in terms of VNIR and SWIR portions of the EMS. This ensures the accomplishing of similar results despite the variation in band designation. The Band ratios were executed using standard routine ENVI transformation and processing tools.

3. RESULTS AND DISCUSSION

The Sabins (1997) band ratio as in (Sabins, 1999) used Landsat TM bands combinations using bands 7, 3, 5, 2 and 4. This correspond to bands 7, 4, 6, 3 and 5 in Landsat 8. Thus, the band ratio 7/3, 5/2, 4/7 is equivalent to band ratio 7/4, 6/3, 5/7 in RGB. The resulting image as shown in figure 2, indicates yellow as hydrothermal alteration areas, black identifies water, the green indicates vegetation (dark green) and clay rich rocks (light green), blue shows sand, red, pink or magenta indicates some mineral rocks-iron oxides (Sabins, 1999).

Band ratios 5/7, 3/2 and 4/5 of Landsat TM used in (Abrams *et al.*, 1983) are selected for the red, green and blue (RGB) channels equivalents 6/7, 4/3 and 5/6 on Landsat 8 which correspond to wavelength regions 1.65 / 2.2 μm, 0.66 / 0.56 μm and 0.83 / 1.65 μm in EMS. The results of the band combinations indicates Iron oxide-rich areas displayed as green due to the presence of ferric iron charge transfer band in the ultraviolet, and clay-rich areas are displayed as red, due to presence of hydrous mineral absorption displayed as red, due to presence of hydrous minerals absorption band near 2.2 μm. Yellow or orange areas represent the areas where both clay and iron oxide minerals are present (Abrams, *et al.*, 1983). The result is shown on figure 3.

The (Kaufmann, 1988) ratio combinations using bands 7, 4, 3 and 5 in Landsat TM, is equivalent to bands 7, 5, 4 and 6 in Landsat 8. The ratio 7/4, 4/3 and 5/7 thus corresponds to ratio 7/5, 5/4 and 6/7 using Landsat 8 bands. The result indicates band 5/4 displays vegetation in bright tones caused by high reflectance of mesostructure in NIR band in contrast to the steep fall-off of reflectance towards the visible (Landsat 8 band 4 or band 3 in Landsat TM) due to intense chlorophyll absorption (Kaufmann, 1988). Clay minerals containing water (bound or unbound) micas, carbonates and hydrates are enhanced by band ratio 6/7 (5/7 in TM). The ferric and ferrous iron is best enhanced by band ratio 7/5 (7/4 in TM) due to major electronic transition bands in NIR (at ~ 0.87um) and the visible charge transfer bands in ultra violet and unaffected SWIR range (Kaufmann, 1988). The composite color image created by band ratio 7/5, 5/4, 6/7 (7/4, 4/3, 5/7 in TM) displayed as RGB, results in an image which shows red color represents minerals containing iron ions, green represent vegetated zones and blue represent OH/H2O-, SO4- or CO-bearing minerals (Kaufmann, 1988). This is illustrated in figure 4.

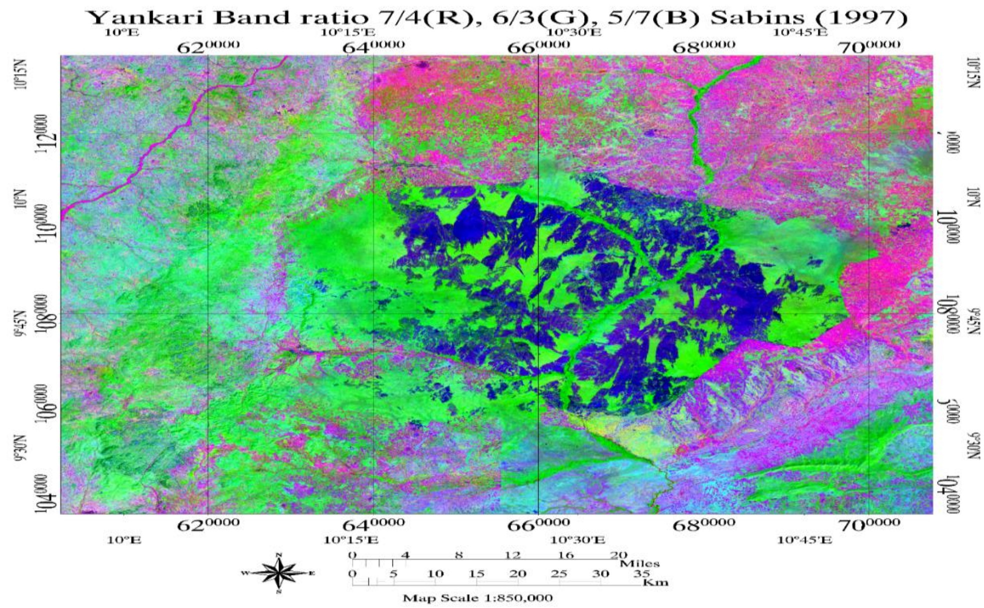

Figure 2**:** Landsat 8 band ratio 7/4, 6/3, 5/7 image for Yankari scene and environs**.**

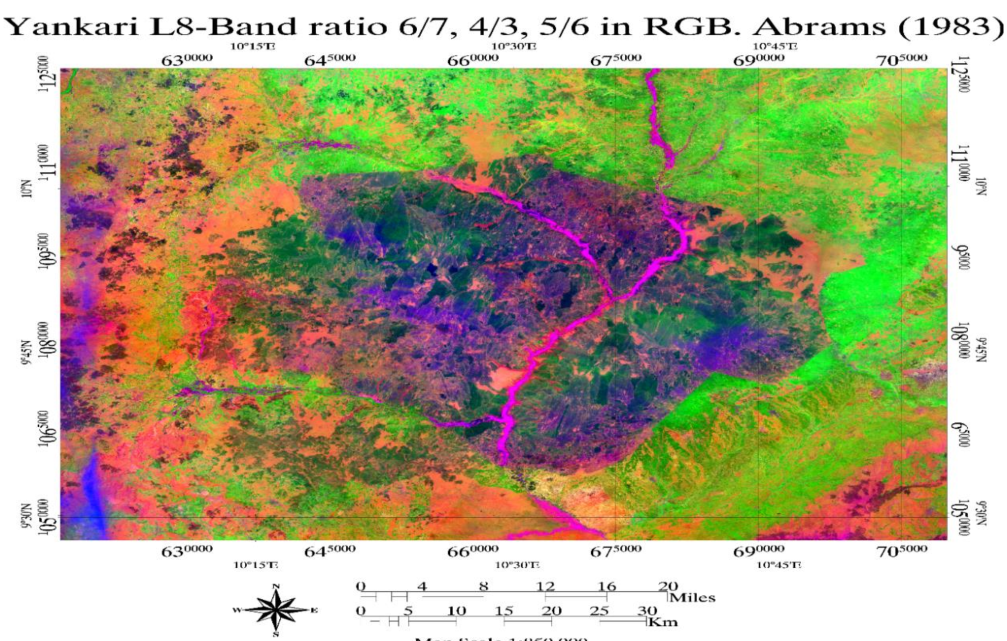

Figure 3**:** Landsat 8 band ratio 6/7, 4/3, 5/6 image for Yankari scene and environs

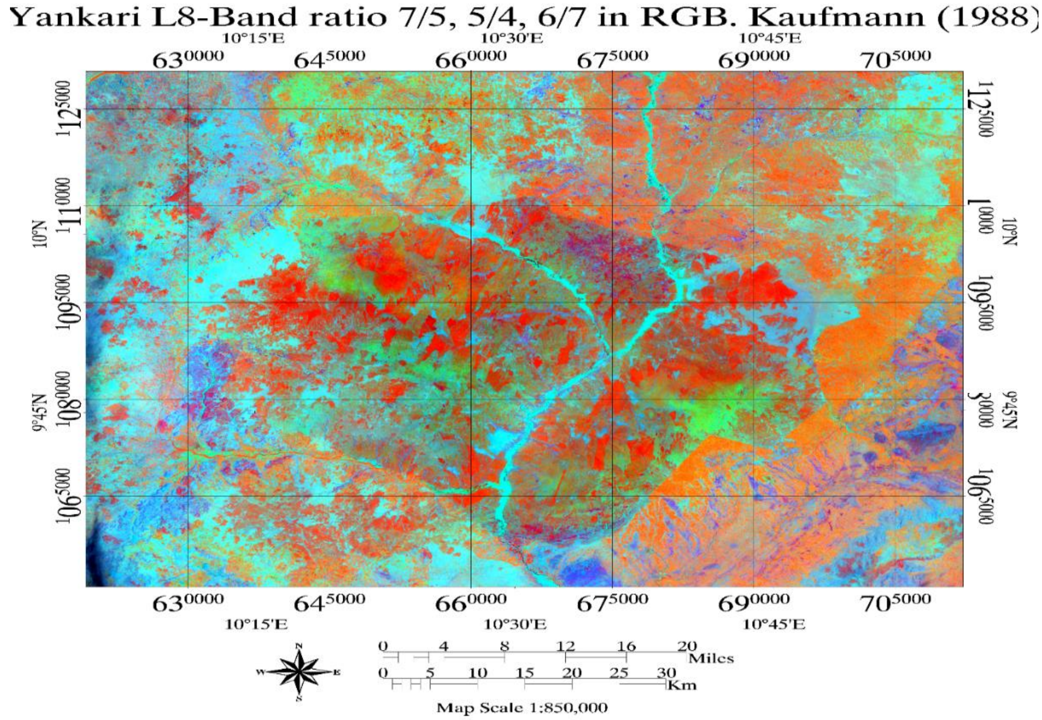

Figure 4: Landsat 8 band ratio 7/5, 5/4, 6/7 image for Yankari scene and environs

4. CONCLUSIONS

As observed from the results of the investigation, the Landsat 8 VNIR-SWIR data successfully highlighted lithology, vegetation and important mineralogy such as clay-rich zones, iron-oxides, mica, sulfates and carbonates. Although no hot springs are identified directly, identification of minerals especially clay, sulfates and carbonates which are related to hydrothermal alteration could serve as surrogates to help narrow targets for locating possible blind or fossil geothermal systems and aid cost effective ground surveys. This has implication for GT exploration in especially unexplored savanna regions where expensive airborne surveys are unaffordable. The results of the ratios also similarly corroborate the identification of iron oxides minerals, especially as observed in the north eastern part of the image scene in that while the band ratio in figure 2 identified red-pink-magenta as mineral rocks iron-oxides areas, the ratios in figure 3 also identified same areas as iron-oxide rich as green.

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