Geospatial Profiling for Threshold Mapping of Hydrothermal Alterations within Kushaka Schist Belt, North Central Nigeria: Implications for Mineral Exploration

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Authors' contributions

This work was carried out in collaboration between all authors. Author JNG designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Author WTA managed the analyses of the study. Author EAK managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Determining thresholds are very useful and efficacious in hydrothermal alteration mapping because of their association with mineral deposits. Thus, quantifying the degree of association can serve as a reliable and definitive way of separating highly to less altered zones. This can be achieved through the application of the knowledge of the threshold values. The aim of the study is to propose a new and more effective method for defining thresholds from spatial profiles in thematic images. To achieve this, band ratio technique and threshold mapping of the study area were carried out. The band ratio method was used to delineate clay alteration by dividing band 5 on band 7. Ten (10) profiles each were generated within the study area and the maximum and minimum threshold values were determined. The results showed a close agreement and consistency between the

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thresholds values derived from spatial profiling method with the values computed from other established method of threshold determination. It is also important to note that known gold mineralization points in the study area were observed to occur within the highly clay altered zones. Therefore, this study have shown that spatial profiling technique can be regarded as a valid and plausible method for determining threshold values in thematic images.

1. INTRODUCTION

The concept of remote sensing applied to mineral exploration utilizes the identification of alteration zones from well processed satellite images. In simplifying this concept with respect to mineral prospecting, it is believed that hydrothermal alteration zones are generally associated with mineral deposits [1]. Consequently, the higher the degree of alterations, the greater the tendency of finding mineral deposits. Therefore, quantifying the degree of alteration is sure and reliable way of separating highly altered areas from less altered ones. Thus, defining a threshold values are dependably useful in such endeavors. In mineral exploration, threshold is a term use to signify a specific value that effectively separate high and low data value of fundamentally different character that reflect different causes [2]. The term is usually applied to a value that distinguishes between the upper or anomalous datasets from lower or background datasets [2]. Determination of threshold values have been carried out for various types of geoscience related datasets ranging from geochemical, geophysical, remote sensing and environmental studies using a heterogeneity of statistical techniques [2,3,4]. This study is aimed at inventing an innovatively new method for defining thresholds from spatial profiles in thematic images. The invention of this new technique known as spatial profiling method for threshold determination is targeted towards determining maximum and minimum threshold values by dint of constructing profiles across very high and very low altered zones.

2. REGIONAL GEOLOGY OF THE STUDY AREA

The study area is situated within latitudes 10° 33' 32.7"N to 10° 39' 50"N and longitudes 6° 38' 38"E to 6° 43' 40"E (Fig. 1). It is located within the Nigerian Basement Complex which forms part of the Pan African mobile belts. It occupies the reactivated region, a product of plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin affected by the Pan African Orogeny [5,6,7]. Lithologically, the Nigerian Basement Complex can be sub divided into Migmatite Gneiss Complex (MGC), the Older Metasediments, the Younger Metasediments and the Older Granites. The Migmatite Gneiss Complex (MGC), is the oldest rock units of the Basement Complex, and dated as Birrimian in age (about 2500Ma). It is believed to be of sedimentary origin but was later profoundly altered under metamorphic and granitic conditions [8,9]. The Migmatite Gneiss Complex (MGC) comprise of Archean polycyclic grey gneiss of granodiorite to tonalitic composition and is considered to be the basement Sensu Stricto [10,7].

The Older meta-sediments (aged between 1100-900Ma) are among the earliest rocks form on the Nigerian Basement Complex, initially of sedimentary origin with a more extensive distribution. The Older meta-sediments have undergone prolonged, repeated metamorphism and now occurs as quartzites, mudrock and other calcareous relics of highly altered clay sediments and igneous rocks. Conversely, the Younger Metasediments, aged between 850-700Ma, are late pelites (represented by phyllites, muscovites schists and biotite schists) with quartzites forming the dominant ridge severally and conspicuously in most parts of the belts. Some belts of the Younger Metasediments contain ferruginous and banded quartzites, spassetite-bearing quartzites, conglomerates, horizon marbles and calc-silicates.

The Older Granites of Nigeria dated 750-450Ma [5] are widely spread throughout the basement complex and occurs as large circular masses. They consist of a wide spectrum of rocks which vary in composition form tonalite through granodiorite to granite, syenite and charnokitic rocks [11]. The granitoids have been emplaced into both the Migmatite-Gneiss Complex and the schist belts. The north-south linear aggregation of many large batholiths within the Basement Complex suggests that they may
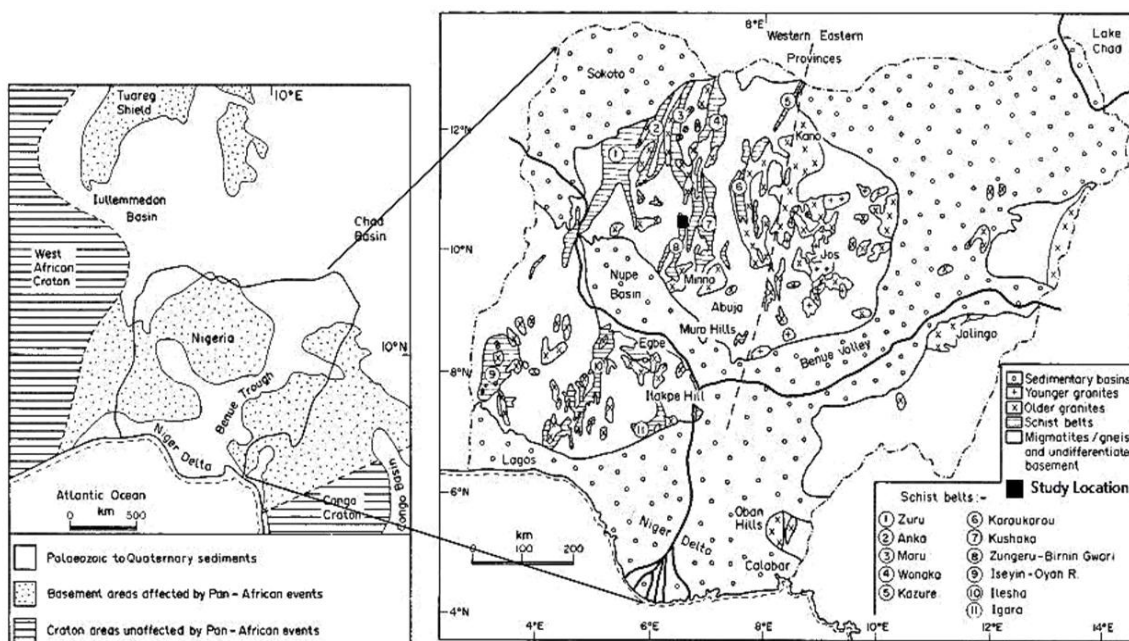
Fig. 1. Regional Geology of the Study area (Modified after [12])

be related to deep-seated pre-existing plutonic episodes controlled by deep mantle structures [13]

3. METHODS

3.1 Band Ratio

Band ratio is an image processing method where digital numbers (brightness values) of one band is divided by that of another band. It corresponds to the peak of high and low reflectance curves [1]. Band ratio technique improves the contrast and enhances compositional information while suppressing less useful information like earth's surface and topographic shadow, thus, highlighting some features that cannot be seen in raw data [14,15,16]. Since gold mineralization within the study area is associated with clay alterations, a band ratio image 5/7 was generated to show the intensity of the clay alterations from dark colours to white. The dark colours represents low clay alteration while the white represents high clay alterations (Fig. 2A). For a better display, ENVI 4.5 colour tool was used to display these variations in clay alteration intensity from blue which represents low to red which represents high zones (Fig. 2B).

4. RESULTS

Gold mineralization within the study area is known to be associated with clay alterations,

band ratio image 5/7 generated displayed the intensity of the clay alterations from dark to white (Fig. 2A). The low clay alteration zones are displayed in dark colour while the white represents high clay alterations (Fig. 2A). For better display, ENVI 4.5 colour tool was used to display these variations in clay alteration intensity from blue which represents low to red which represents high zones (Fig., 2B).

4.1 Threshold Mapping

Threshold mapping involves determination of that value which separates regions of high and low alteration from background. To proof the efficacy of the spatial profiling method for threshold determination, 10 profiles each were constructed from anomalous high and low altered zones.

4.1.1 Maximum threshold mapping

To determining the maximum threshold value using spatial profiling method, 10 micro profiles were constructed across highly altered zones within the study area (Fig. 3). From these profiles, the maximum reflectance value for all the 10 profiles were extracted, summed and the mean and standard deviation calculated (Table 1). The mean value was assumed to be the maximum threshold value. The maximum threshold value for each of the 10 profiles was then used to segregate and delineate

highly altered areas within the study location (Fig. 4).

4.1.2 Minimum Threshold Mapping

This study constructed 10 profiles across least altered zones (Fig. 5) and the extraction of their minimum values (Table 1) ushered in the first step towards calculating the minimum threshold using spatial profiling method. The minimum values, their summed, standard deviation and the calculated threshold is presented on Table 1. Using the minimum value to segregate low altered zones, it was observed that the least altered zones dominates the eastern and western parts of the study area (Fig. 6).

4.1.3 Validation of threshold method

The validation of spatial profiling method for calculating threshold values for this geodata set were carried out by comparing threshold values obtained from spatial profiling method to threshold values computed using other established methods. To underscore the validity of the spatial profiling method, the spatial profiling threshold values were compared to a known statistical method for calculating the threshold as stated below.

Maximum Threshold = Mean + 2 Standard deviation*

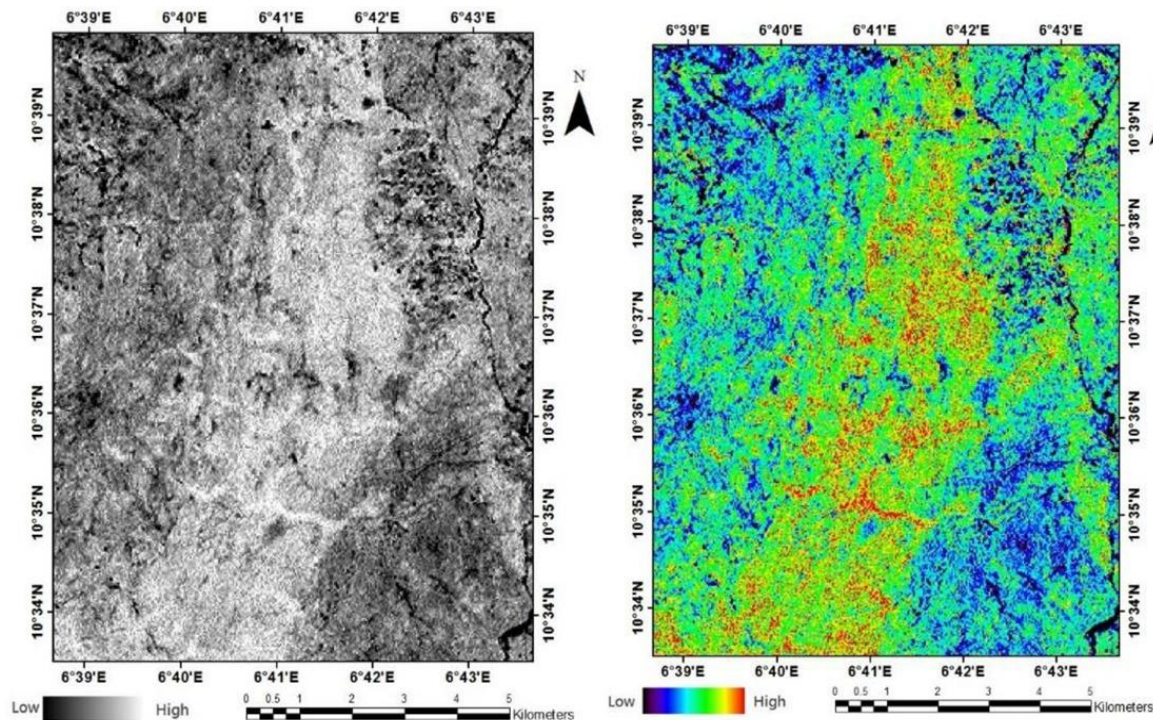*Minimun Threshold = Mean − 2* Standard deviation*

Fig. 2. Band ratio image 5/7 displaying clay alterations within the study area
A = Black and white image, B = Colour image.

Table 1. Threshold statistics for altered imagery along profiles

	P1	P 2	P 3	P4	P 5	P 6	P7	P8	P9	P10	STD	Total	Threshold
Min	1.55	1.5	1.48	1.63	1.36	1.47	1.59	1.55	1.55	1.59	4.14	15.27	1.527
Max	2.1	2.09	2.05	2.29	2.28	2.15	1.932	1.95	2	1.94	0.313	20.782	2.078

Table 2. Threshold validation for spatial profiling method

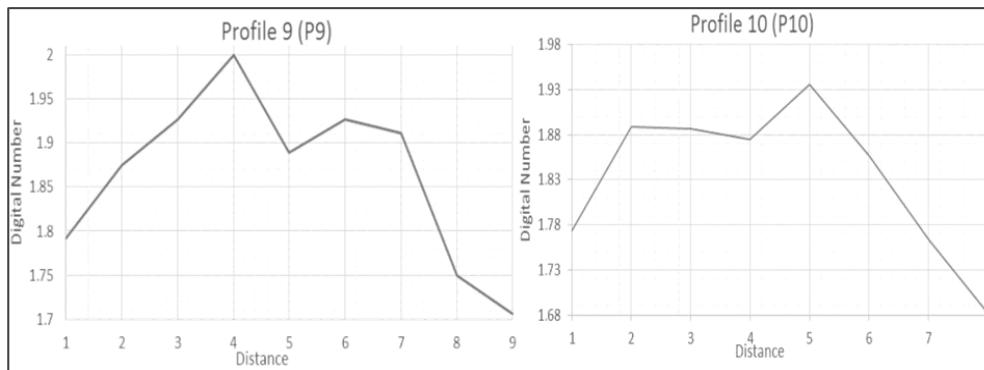| S/N	Threshold	Method	Result
1	Maximum Threshold	Maximum Spatial Profiling	2.078
		Mean + 2* Standard deviation	2.06
2	Minimum Threshold	Minimum Spatial Profiling	1.527
		Mean − 2* Standard Deviation	1.5
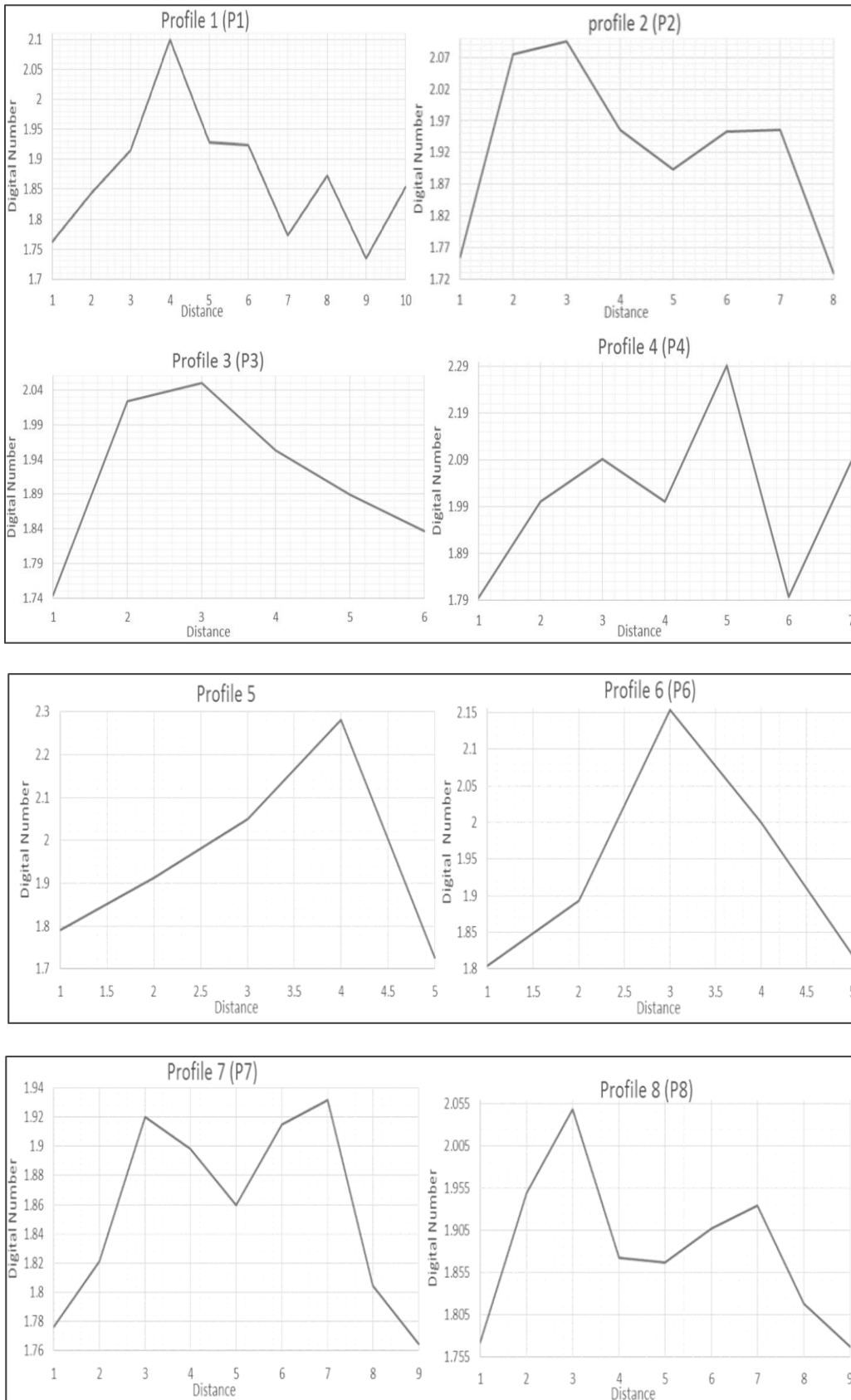
Fig. 3. Spectral Profiles across high anomalous zones within the study area (within Kushaka Schist belt)
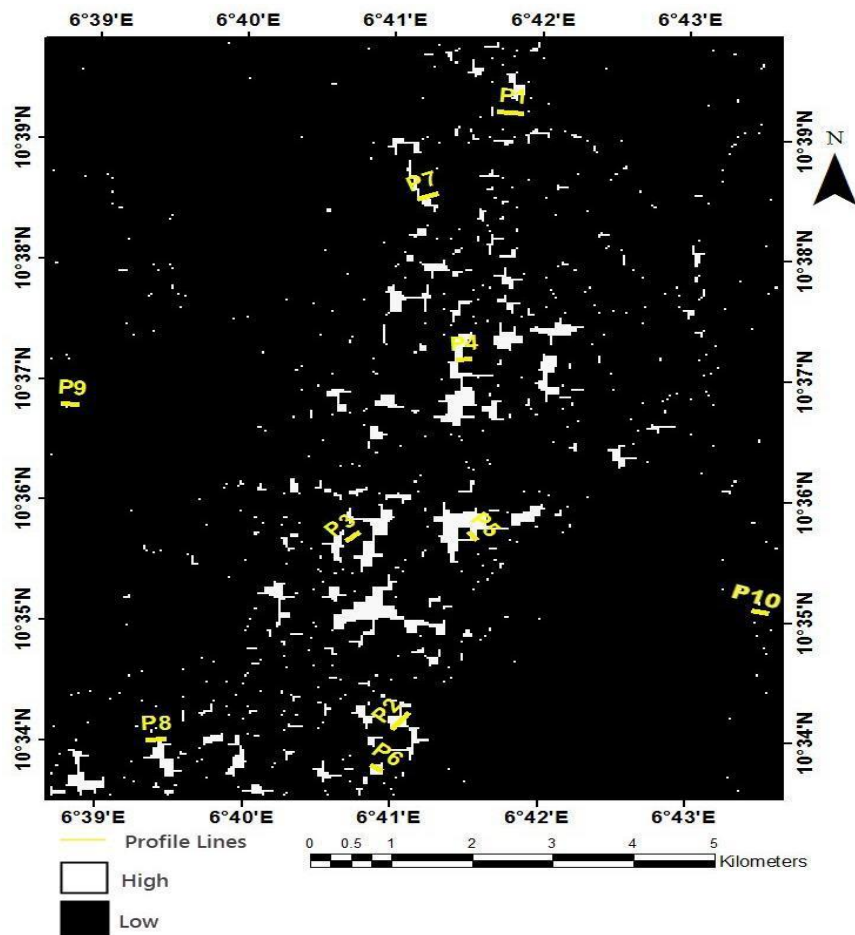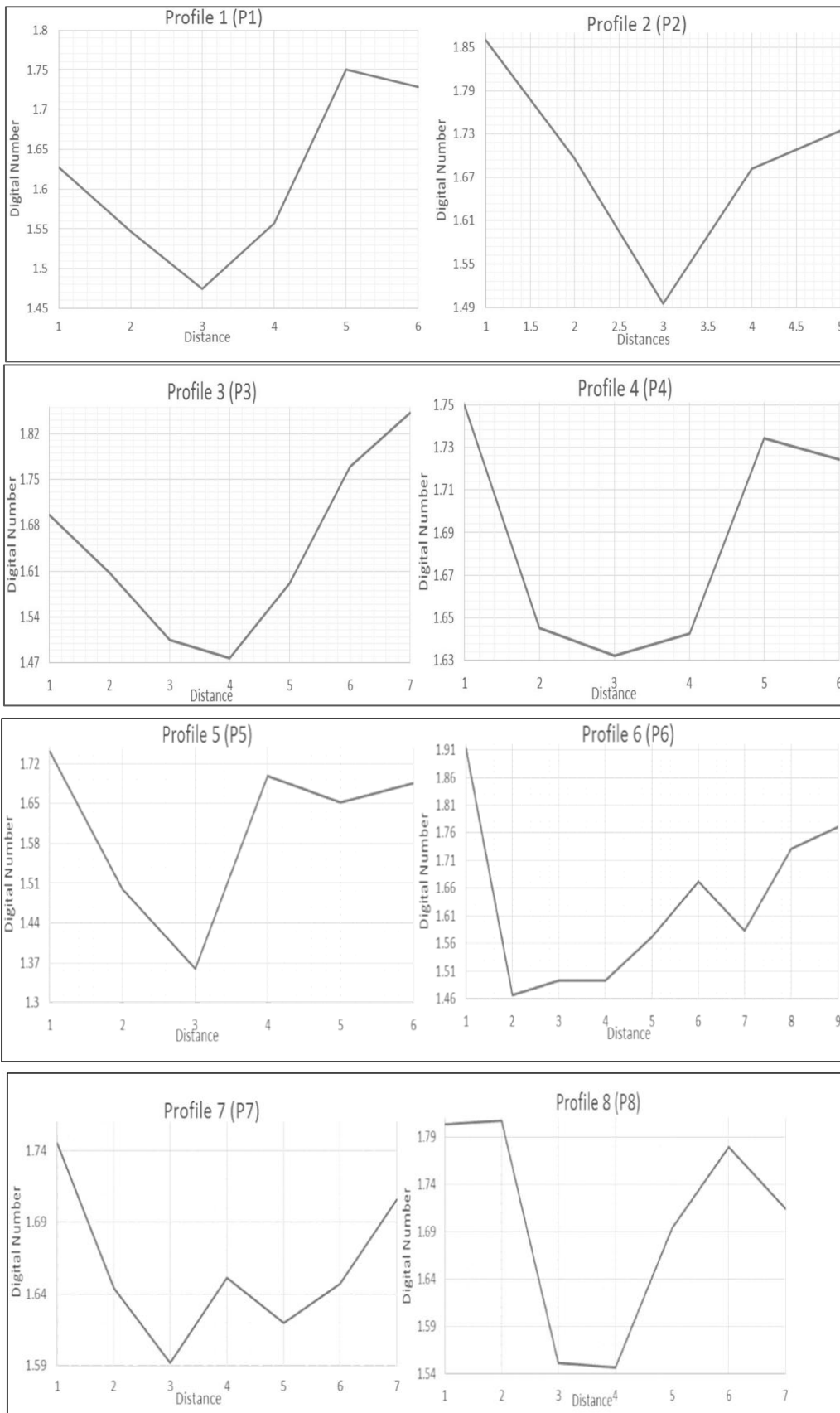

Fig. 4. Threshold image showing high threshold zones, the profile lines and their locations within the study area

The comparison of threshold values from both methods are presented in Table 2. The maximum threshold value obtained from the application of spatial profiling method is 2.078 and closely agrees with 2.06 calculated using Mean + 2* Standard Deviation, a statistical method of calculating maximum threshold. Similarly, the minimum threshold for the study area as calculated using the statistical method of Mean – 2* Standard Deviation was 1.5 while 1.527 was obtained from the application of minimum spatial profiling technique. This shows the reliability of the application of spatial profiling method.
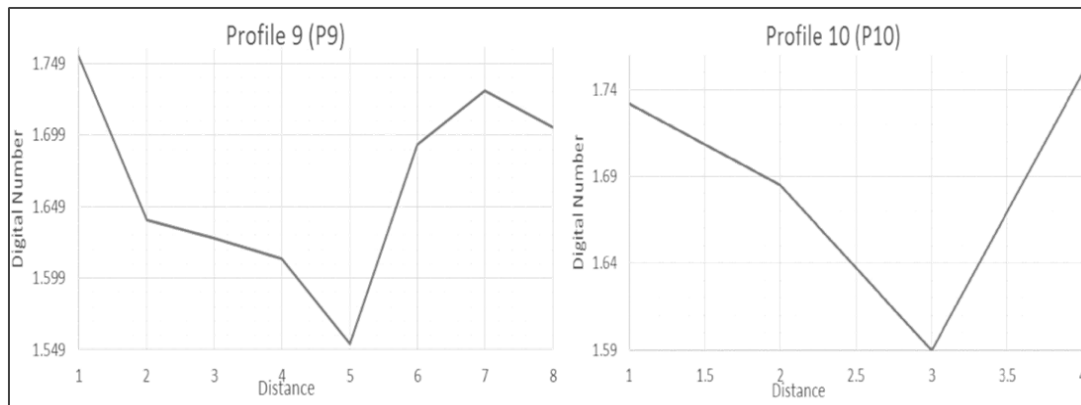
Fig. 5. Spectral profile across low anomalous zones within the study area (within Kushaka Schist belt)
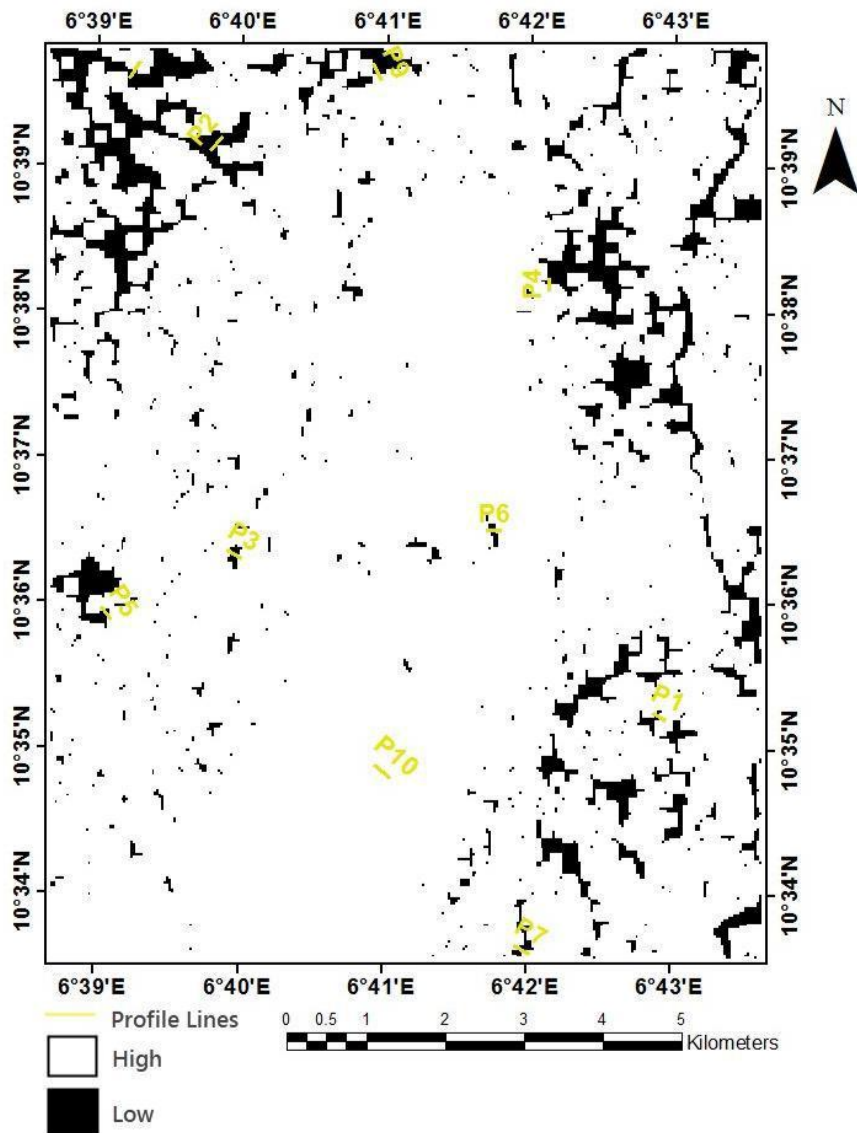

Fig. 6. Threshold image showing low threshold zones, the profile lines and their locations within the study area
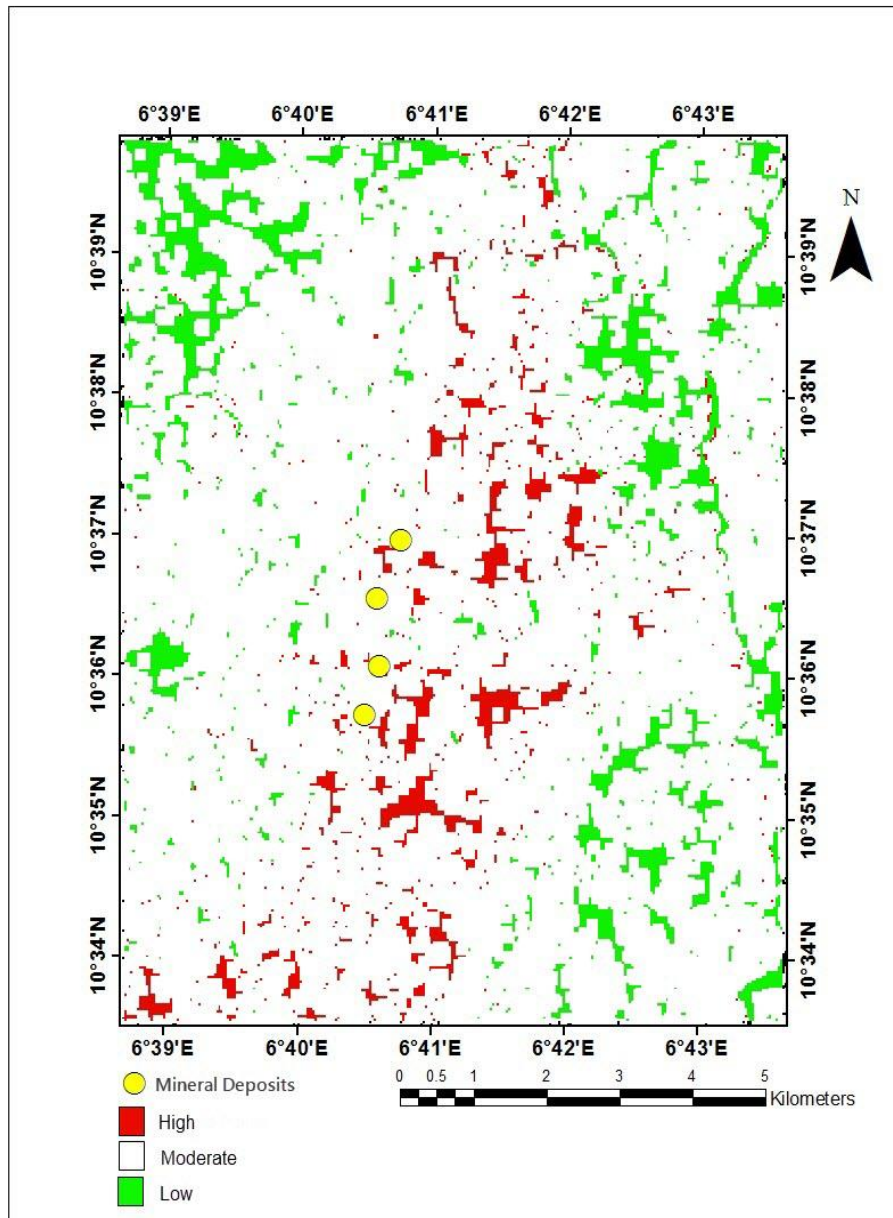
Fig. 7. Relationship between gold mineralization and alterations within the study area

4.2 Implications of Spatial Profiling Technique for Mineral Exploration

Mineral exploration deals with sequential processes of information gathering that help in assessment of the mineral potential of an area of interest. Mapping hydrothermal alterations is one of the important process in gathering valuable information on ore mineralization of any area of interest. Thus, Remote sensing technique is highly valuable in exploration programs due to its ability to map not just alterations types associated with mineralization but also the degree of alteration. Therefore, the higher the degree of alteration the greater the chances of finding a mineral deposit [2]. Mapping the degree of alteration is possible by defining threshold values and using these values for segregating and delineating areas of low, moderate and high alterations (Fig. 7). Consequently, this underscores the imperativeness of the knowledge of alterations associated with mineralization in the area of interest. Furthermore, clay alteration from satellite imagery was quantified using threshold values derived from spatial profiling method in the study

area. Known zones of gold mineralization were plotted to establish relationship between clay alteration and gold mineralization as determined using the new method. This study, has therefore proven that gold mineralization is associated with clay alteration in the study area

5. DISCUSSION

There are several methods of threshold determination. Iterative Mean ±2SD statistical method (as applied in Galuszka, 2007; Hawkes and Webb, 1962), the Box-plot method (as applied in Turkey, 1997), the Fence method (as applied in Schwertman and Silva, 2007; Schwertman et al., 2004) and so many other techniques including the probability graph, univariate analysis, multivariate analysis of Stanley and Sinclair, 1989, multifractal models (as applied in Cheng and Aterberg, 1996, Aterberg et al., 1996) have also been widely used in threshold determination [17];[18]. Unlike some of the methods mentioned above, this method which is a new and innovative method of threshold determination, does not require full statistical details but detail knowledge of high and low signal input zones. Spatial profiling method also has addition advantage when used in thematic images because it is a location-specific data handling method, the high and low alteration zones can easily be identify and isolated for threshold determination in any area of interest. The use of remote sensing technique in mapping mineral deposits associated with alteration has proven to be easier when threshold values are defined and used to segregate highly altered zones from low altered zones. The rationale behind this method relies on the fact that mineralization tend to increase with the degree of alteration. From this study, it was observed that the spatial profile method is a reliable alternative method for defining and quantifying geo-data set within any thematic layer of interest. This is evident from the close similarities of threshold values computed from standard techniques to those obtained using spatial profiling method. Applying the computed values to a well processed band ratio imagery was able to define regions of low and high alteration within the study area. The resulting imagery revealed highly altered zones as dominating the central parts of the study area along a N-S trend and is being flanked by a low altered zone. Conversely, zones of intermediate alterations are peppered throughout the study area. Well known zones of gold mineralization within the study area all plotted within the highly altered zones confirming locations of gold mineralization within the highly altered zones.

6. CONCLUSION

The spatial profile method for defining threshold values in any geoscience dataset is valid and effective especially for data displayed in thematic layer format as shown from this study. The application of this method for mapping hydrothermal alterations have proven to be very effective and can be relied upon in defining zones of high alterations within the study area. A close correlation has been seen to exist between highly altered zones and known mineralization points within the study area. Spatially, the highly altered zones assumed a general N-S trend within the central parts. Therefore, the higher and the degree of alteration the greater the chances of finding a mineral deposit. Mapping the degree of alteration is possible by defining threshold values though the application of spatial profiling method and using these values to segregate and delineate areas of low, moderate and high alterations. The study established that known gold mineralization points in the study area were observed to occur within the highly altered clay alteration zones.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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