

# Application of Remote Sensing and Spatial Data Integrations for Mapping Porphyry Copper Zones in Nuweiba Area, Egypt

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**Abstract**—Many diverse criteria should be considered to select the potential zones for mineral exploration. The study aims to provide potential map for porphyry copper zones in the Nuweiba area based on the criteria derived from geologic, geochemical, and remote sensing data. Field investigations, remote sensing and GIS techniques were applied jointly to prepare and integrate several factors contributing to mineralization occurrences. The remote sensing techniques such as Band Ratio (BR), Relative Absorption Band Depth (RBD), Principal Component Analysis (PCA), Minimum Noise Fraction (MNF), and Linear Spectral Unmixing (LSU) were used to define the geological characteristics of the study area including lithological units, structural features and hydrothermal alteration zones. Weight Linear Combination (WLC) was adopted as suitable GIS technique to integrate spatially several criteria having different weights of importance for mineralization occurrences. These criteria involve the lithological units, lineaments, major fault, alteration zones, and stream sediments anomaly. The weight of each criterion was evaluated using Analytical Hierarchy Process (AHP). The results of applications in this study provide acceptable map defining the zones of porphyry copper deposits in the Nuweiba area.

**Index Terms**—hydrothermal alterations, porphyry copper, remote sensing, GIS, nuweiba

## I. INTRODUCTION

The goal of this study is a construction of a predictive model defining the favorability or probability of porphyry copper occurrences. Traditionally, mineral exploration has depended on the several prospecting techniques including geochemistry, geophysics, geological mapping, aerial photointerpretation and ground surveys [1]. In this study, lithological mapping, structural mapping, alterations mapping, mapping of stream sediments anomaly, and data integration using Weight Linear Combination (WLC) were performed to define the favorable zones for porphyry copper deposits. Lithological units and structural features represent significant data sources for mineral exploration [2]. ASTER images were used as a successful data source in

several previous studies to delineate the hydrothermal alterations [3]-[5]. Several remote sensing techniques including Band Ratio (BR), Relative Absorption Band Depth (RBD), Principal Component Analysis (PCA), Minimum Noise Fraction (MNF), and Linear Spectral Unmixing (LSU), provide a suitable method for mapping hydrothermal alterations associating with porphyry copper deposits [6]. These techniques were applied in this study to delineate the alteration zones including phyllic, argillic, and propylitic zones. Stream sediments analysis represents a suitable method to build geochemical database using GIS for mineral resources assessment [7]-[9] recorded geochemical anomalous of copper and barium associating with different rock units in the Nuweiba area based on stream sediments analysis.

GIS was used as an effective tool for generating potential map for porphyry copper zones by integrating datasets with different weights. Generation of potential map for mineral exploration requires weighting values representing the importance of each layer classes and ranks for each layer based on its importance to mineralization [10], [11]. The weight and the ranks of each layer can be driven from two main methods including data-driven method (the importance of a layer is determined by the data itself) and knowledge-driven method (the importance of a layer is determined by the experts [12]). Based on these techniques, we could develop the predictive mineral potential model defining the most favorable zones for porphyry copper deposits in the Nuweiba area.

## II. STUDY AREA CHARACTERISTICS

The Nuweiba area located as fan delta which is shaped from the main channel of Wadi Watir between latitudes 28° 45' and 29° 35' N and longitudes 33° 53' and 34° 47' E covering approximately 1,600 km<sup>2</sup> (Fig. 1). The study area can be distinguished with rugged mountainous topography and high relief varying from gently inclined plains to rugged steep mountains with elevations from 33 to 1581 m. above sea level. In order to construct model defining the favorable zones for porphyry copper deposits, four characteristics of the study area should be evaluated and defined including lithological units, structural

features, hydrothermal alterations, and stream sediments anomalies

#### A. Lithological Analysis

Lithological units represent important layer in the mineral potential model. According to field studies in the Nuweiba area, gold was recorded at pyrite-bearing rhyolite dyke which cut the volcanics of W. Meknas and the altered diorite of W. Saada El. Beida. Copper was recorded at basaltic andesite dykes which cut the granitic gneiss of W. Samghi. Beryl was recorder at quartz veins which cut the biotitic muscovite granite of W. Nakhil. Hence, the high resolution SPOT5 (band 1, 2, 3 and Panchromatic at 5m×5m) were used and processed in ENVI 5.0 to identify different rock units. Several digital image processing techniques were performed for that purpose including principle components (Fig. 1), unsupervised and supervised classification. For supervised classification, training classes derived from the field investigations and previous geological maps [13]. The accuracy assessment of the classification was performed based on the Kappa Coefficient technique [14]. 15 different rock units were extracted from the SPOT5 image processing. The lithological units of Nuweiba area involve dioritic gneisses, meladiorite, granitic gneisses, old granitic series, coarse perthitic granite, fine perthitic granite, volcanics of wadi Meknas, biotite granite, muscovite biotite granite, Raha Formation, Wata Formation, Malha Formation, Mutalla Formation, Araba Formation, and Quaternary deposits (Fig. 1).

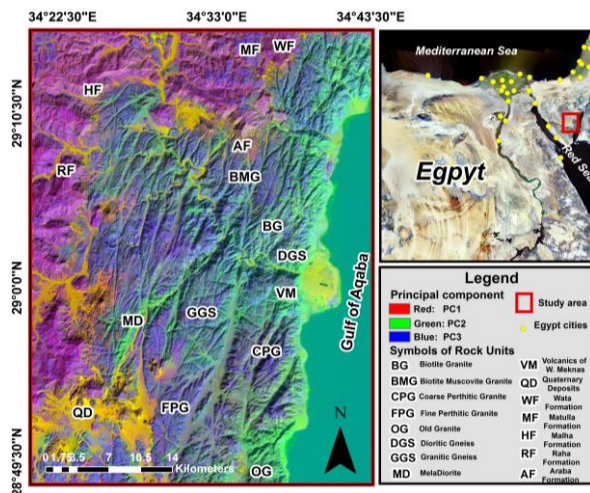


Figure 1. The location map of Nuweiba area showing by Landsat ETM and Principle components of SPOT 5 to distinguish between different rock units (RGB: PC1, PC2, PC3).

#### B. Structural Analysis

Generally, structure features play important role in controlling the mineralization in Sinai [15]. The field study with the aid of multispectral satellite images (ETM+7, SPOT5, and ASTER) indicate that the mineralization zones associating essentially with hydrothermal alteration zones, were controlled with major faults in the Nuweiba area. The directions of the major faults were measured and extracted by field studies and digital image processing. Based on the field studies,

the alterations and mineralization zones are located in the directions of NE-SW and N-S especially in the intersecting between the two trends. For major faults extraction, ETM+7 bands were merged with SPOT 5 panchromatic to enhance the spatial resolution (5m.). Then the all bands of ETM+7 were smoothed with an average low pass filter (5\*5) to eliminate the noise. Based on this analysis, most of the fault lines in the Nuweiba area were affected by Red Sea Rifting system. The conspicuous faults set in the investigated area are parallel to the well-known Gulf of Aqaba fault trend NE-SW direction (55%) and Gulf of Suez fault trend NW-SE direction (35%). It could be concluded that the main directions of the major faults in the Nuweiba area are NE-SW, NW-SW, and N-S (Fig. 2).

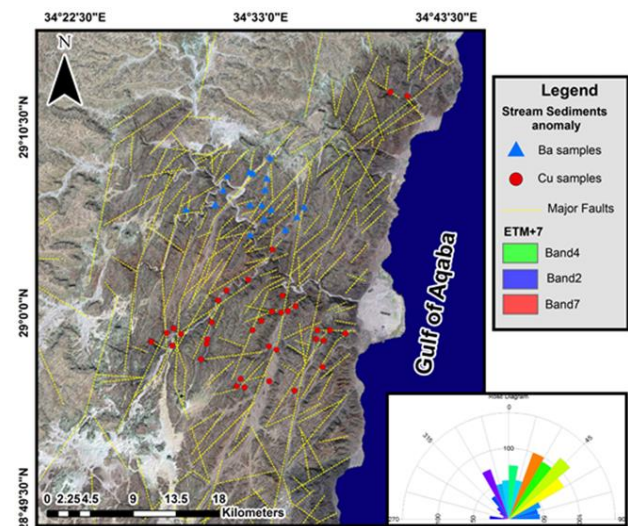


Figure 2. The trends of major faults in the study area and the samples location of the stream sediments anomaly.

Structure analysis also included the extraction of lineaments which refer to faults, dykes, veins, fractures and joints. As we mentioned in the lithological analysis, most of the mineralization located in the dykes and veins. Hence, the lineaments were considered as key layer in the mineral potential model. ETM+7 was enhanced using the directional filtering methods to extract linear features. The Gradient-Sobel was selected as suitable filter for edge detection the directional nature of Sobel kernels because this filter generates an effective and faster way to evaluate lineaments in four principal directions [16]. The image directional Sobel filter kernels were tabulated in four directions. A Sobel kernel of 3×3 pixel size was selected and performed along directions N (0°), NW (45°), NE (45°) and EW (90°) to highlight linear features in their respective directions. For the sedimentary rocks, band 1 and 2 were the best to extract linear features while bands 3, 4, 5 and 7 were the best for the basement rocks. It was clear that, the most extracted lineament trends were essentially associated with the main structure of Nuweiba area.

The final map of lineaments analysis exhibits eight main directions dominated in the study area including N-S, NNE-SSW, NE-SW, ENE-WSW, NNW-SSE, NW-SE, WNW-ESE, and E-W. However, the NE-SW, NNE-

SSW, NW-SE and N-S trends are more frequent in the study area as opposed to ENE-WSW, E-W, and WNW-ESE.

### C. Stream Sediments

More than 300 stream sediments samples of 25mm fraction were selected from the Nuweiba wadis of different orders by digging a small pit with average depth 0.15m [9]. These samples were analyzed semiquantitatively spectrographically at laboratories of Geological Survey [9]. This geochemical analysis was used in this study as a significant geodatabase to define the most favorable zones for mineral exploration in the Nuweiba area. GIS was considered as a powerful tool for analysis of georeferenced spatial data to use in mineral exploration helping in target area selection tasks [1]. Therefore, several maps represent geochemical anomalies of stream sediments samples were georeferenced in this study to increase the accuracy of samples locations (Fig. 2). The distance from the anomalies of the stream sediments was used as essential thematic layer in the mineral potential model.

Based on the geochemical analysis of the stream sediments samples, anomalous content of Copper (100-200pm) and Barium (600pm) at W. Samghi, W. Nakhil respectively were recorded [9]. Based on the field investigations, gold and chalcopyrite was noted in pyrite bearing rhyolite at W. Saada El-Beida

### D. Hydrothermal Alteration Zones

Two scenes of ASTER images level 1A were used in the current study to delineate the hydrothermal alterations. These scenes acquired on 16 Oct. 2007 and 5 Dec. 2008. These images were firstly georeferenced to UTM zone 36 north projection using the WGS-84 datum. Atmospheric correction was applied by using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) algorithm. The two senses were integrated using georeferenced mosaicking.

In order to map the hydrothermally alteration zones associated with porphyry copper deposits, different digital image processing techniques were tested and used for mapping the phyllic, argillic, and propylitic alteration zones. These techniques include Band Ratios (BR), Relative Absorption Band Depth (RBD), Principal Component Analysis (PCA), Minimum Noise Fraction (MNF) transformation and Linear Spectral Unmixing (LSU).

Band ratio (BR) transformation is useful for qualitative detection of hydrothermal alteration minerals. ASTER SWIR bands were selected for three BRs using ENVI 5.0 software including:

- Ratio of band 4/5 for identifying laterite [2].
- Ratio of band 4/6 for identifying Al-OH and Fe-OH minerals [2].
- Ratio of band 4/7 for identifying alteration minerals with Al-OH and Fe-OH [2].

RGB color composite was depicted as a first approach of qualitative detection of alteration minerals. RGB of

band 4/5 - band 4/6 - band 4/7 is sensible to absorption features at 2.2, 2.16 and 2.26 mm and alteration minerals with Al-OH and Fe-OH absorption features appear in pinkish color.

Relative Absorption Band Depth (RBD) was adopted in this study for more clarification of the hydrothermal alterations zones. This technique depends on a useful three-point ratio formulation for displaying Al-O-H, Fe, Mg-O-H, and CO<sub>3</sub> absorption intensities. Three RBD ratios of ASTER bands were selected and applied in the two ASTER scenes; RBD5, RBD6, and RBD8. These RBD ratios were assigned for RGB (red, green, and blue) color combination to delineate argillic, phyllic, and propylitic hydrothermal alteration zones using ASTER SWIR bands (Fig. 3). These RBD ratios were derived based on [17] as follows:

- $RBD5 = (B4 + B6)/B5$
- $RBD6 = (B5 + B7)/B6$
- $RBD8 = (B7 + B9)/B8$

Based on Relative Absorption Band Depth (RBD), alteration mineral assemblages are demonstrated with different colors, narrow argillic areas as brownish red and broad phyllic as red color that occupied major parts of the hydrothermal alteration mineral haloes, and propylitic zone as light green that surrounded outside of these hydrothermal alteration mineral zones (Fig. 3). The location of the alteration haloes are corresponded with highlighted ellipsoidal polygons in the BRs images.

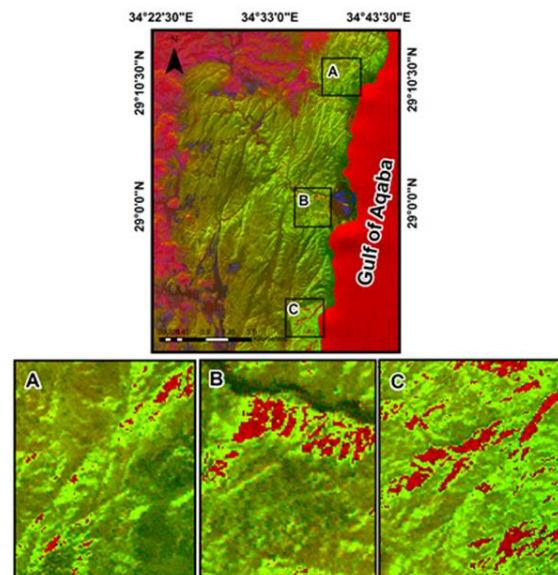


Figure 3. Three RBD ratios of ASTER bands (RBD5, RBD6, and RBD8) were depicted as RGB showing the hydrothermal alteration halos.

Principal Component Analysis (PCA) was applied for Band Ratio (BR) images and Relative Absorption Band Depth (RBD) images to enhance the separation between the three alteration zones. The calculated PCAs agree very well and give similar information about the location of alteration zones. PCAs enhance the intensity of phyllic, argillic, and propylitic zones. RGB color composite of PC1, PC2, and PC3 images were generated and adopted to show the different hydrothermal alteration zones in the



Nuweiba area. Alteration halos are depicted as orange color (argillic zones), green color (phyllic zone) and pink color (propylitic zone) that surrounds phyllic and argillic zones, which are easily recognizable from surrounding rocks (Fig. 4).

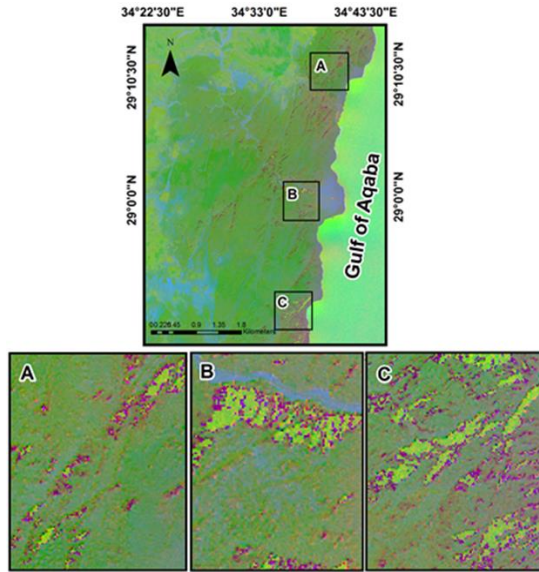


Figure 4. RGB color composite image of PC1, PC2, and PC3 images of RBDs shows the alteration mineral assemblages with different colors, narrow argillic areas as orange and broad phyllic as light green color that occupied major parts of the hydrothermal alteration mineral haloes, and propylitic zone as pink color that surrounded outside of these hydrothermal alteration mineral zones.

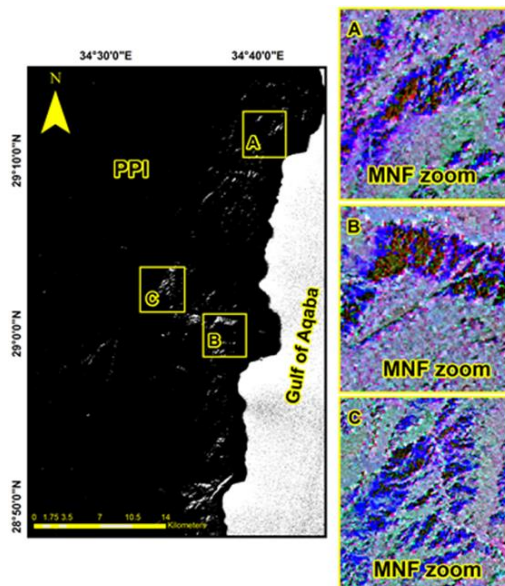


Figure 5. Pixel Purity Index-Mapping (PPI) and Minimum Noise Fraction (MNF) band composite (4, 5 & 6) shows the alteration mineral assemblages with different colors (narrow argillic areas as red and broad phyllic as green color, and propylitic zone as violet color).

The Linear Spectral Unmixing (LSU) also was performed in this study to enhance the separation of the alteration zones. LSU depend on four essential steps include Minimum Noise Fraction (MNF), Pixel Purity Index-Mapping (PPI), and the n-Dimensional-Visualizer tool (n-D-Vis). Minimum Noise Fraction (MNF) transform is the first step to reduce abundant information

and define their inherent dimensionality and to separate the noise fraction from the true signal. Pixel Purity Index-Mapping (PPI) is the second step for the determination of the purest pixels in the image. Purity Index-Mapping (PPI) was applied to the MNF bands to locate the most spectrally extreme pixels that typically correspond to mixing end-members (Fig. 5). The n-Dimensional-Visualizer tool (n-D-Vis) was used to extract the end-members. The three alteration zones were extracted using the n-Dimensional-Visualizer tool. Spectral unmixing in n-dimensional spectral feature space was used as final step to separate these alteration zones.

This method turned out to be very accurate, separating the extent and main trend of the alteration zones around the Nuweiba area. The band combination of MNF bands 4, 5, and 6 which extracted from PC4, PC5, and PC6 were displayed as RGB band composite. This band composite shows argillic zone as red color, phyllic zone as green color, and propylitic zone as violet color.

Moreover, the band combination of image LSU2, LSU3, and LSU4 images were displayed as RGB band composite. This band composite represent the best band combination showing the alteration mineral assemblages with different colors, narrow argillic areas as pink and broad phyllic as violet color that occupied major parts of the hydrothermal alteration mineral haloes, and propylitic zone as green that surrounded outside of these hydrothermal alteration mineral zones (Fig. 6).

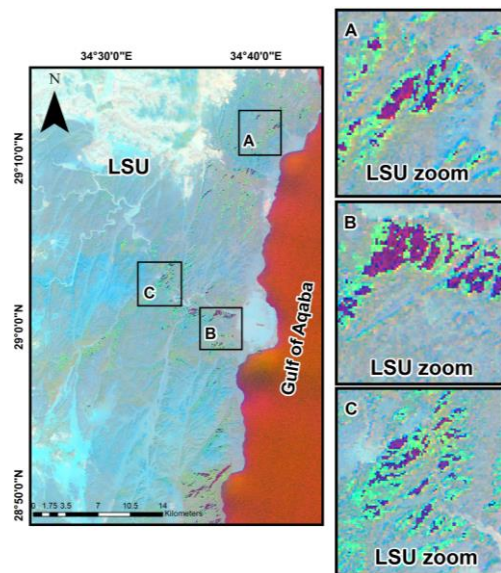


Figure 6. RGB band composite of LSU2, LSU3, and LSU4 shows the alteration mineral assemblages with different colors, narrow argillic areas as pink and broad phyllic as violet color that occupied major parts of the hydrothermal alteration mineral haloes, and propylitic zone as green color.

### III. MULTI-CRITERIA EVALUATION

In order to develop model defining the porphyry copper zones, multi-criteria evaluation represent essential step. Multi-criteria evaluation depend on four main steps including determine the effective criteria, standardize the criterion scores, determine the weight of each criterion, and aggregate the criteria (Table I and Table II).

TABLE I. PAIRWISE COMPARISON MATRIX

	AZ	FI	MF	SS	LD	LG
AZ	1	1	3	5	9	9
FI	1	1	1	3	7	7
F	0.33	1	1	3	7	7
SS	0.2	0.33	0.33	1	3	3
LD	0.11	0.143	0.143	0.333	1	1
LG	0.11	0.143	0.143	0.33	1	1
Sum	2.75	3.616	5.616	12.663	28	28
Weight	0.377	0.257	0.216	0.085	0.033	0.033
Consistency Index =0.023 and Maximum Eigen Value =6.11823						
Where AZ is alteration zone, FI is distance to fault intersections, MF is distance to major fault, SS is distance to stream sediments anomaly, LD is lineaments density, and LG is lithology.						

TABLE II. STANDARDIZED SCORES AND WEIGHTS OF DIFFERENT CRITERIA IN THE MINERAL POTENTIAL MODEL

Criteria	Classes	Classes		Weight
		Values	Normalized score	
Alteration zone	Phyllic	8	1	0.377
	Argillic	6	0.67	
	Propylitic	4	0.33	
	Host Rocks	0	0	
Distance to faults intersections	0-100m.	8	1	0.257
	100-200m	6	0.67	
	200-300m.	4	0.33	
	300-400m	2	0.25	
Distance to major faults	400-500m.	0	0	0.216
	0-100m.	8	1	
	100-200m	6	0.67	
	200-300m.	4	0.33	
Stream sediments anomaly	300-400m	2	0.25	0.085
	400-500m.	0	0	
	0-150m.	8	1	
	150-300m	6	0.67	
Lineament density	300-450m.	4	0.33	0.033
	450-600m	2	0.25	
	600-750m.	0	0	
	0-0.512	0	0	
Lithology	0.512-1.024	2	0.25	0.033
	1.024-1.536	4	0.33	
	1.536-2.048	6	0.67	
	2.048-2.56	8	1	
	Granitic and dioritic gneiss	8	1	
Lithology	Biotitic muscovite granite	6	0.67	0.033
	Coarse and fine perthitic granite	4	0.33	
	Old granitic series	2	0.25	
	Sedimentary succession	0	0	

#### A. Determine the Effective Criteria

Six criteria were adopted and prepared in this study based on the relevance with respect to porphyry copper exploration criteria including alteration zones, major faults, major faults intersections, stream sediment anomaly, lineaments density, and lithology (Table I).

Based on the field investigations, most of the porphyry copper mineralized zones were recorded associated with the hydrothermal alterations. Therefore, the alteration zones including phyllic, argillic, and propylitic reflect the

most important criteria. The buffer map of alterations zones was prepared using ArcMap10.2 in which the distances 500, 750, and 1000m from each alteration zones were considered (Table II).

In the Nuweiba area, the porphyry copper mineralized zones which associating with hydrothermal alteration locate in the same directions of the major faults including NE-SW, NNE-SSW, NW-SE, and N-S directions especially in their intersections. Hence, the distance from the major faults and their intersections followed the hydrothermal alteration zones in its importance to mineral occurrences. Major faults and their intersections layers were buffered to 100, 200, 300, 400, and 500m (Table II). The 100 m from the major faults intersection represent the most favorable zones for porphyry copper occurrences.

Generally, the distance from stream sediments anomaly represent important layer for mineral exploration. However, it followed the alteration zones and major faults in this study considering the accuracy of samples locations. The samples of stream sediments anomaly were buffered to 150, 300, 450, 500, and 750 m (Table II). The 150 m from the anomaly samples represent the most favorable zones for gold and copper occurrences.

Lineaments density was considered also in this study for two main reasons. Firstly, all the mineralized zones were recorded in the field studies locating in the dykes and veins. Secondly, joints, fractures, and faults represent suitable conditions to rise and fill with the hydrothermal solutions associating with mineralization in the last magmatic stage. The lineaments density was prepared using the line density analyst extension of Arc View GIS. They were classified into five classes from low to high density. The lithological units were considered the less importance layer because each unit covers wide area in the Nuweiba and porphyry copper mineralization occupies very narrow zones of each unit.

#### B. Standardize the Criterion Scores

It is necessary step to standardize the scores of each criterion which discussed previously because the criteria were measured on different scales. A linear scaling represents the simplest procedure for standardization [18] based on the minimum and maximum values as scaling points.

$$(X - X_{min}) / (X_{max} - X_{min}) \quad (1)$$

The all criteria were assigned values from 0 to 1 in which 0 represent the less importance for mineral occurrences and 1 represent the highest importance for mineralization occurrences (Table II).

#### C. Determine the Weight of Each Criterion

According to the contribution to mineral potential occurrence, weights of the thematic layers were assigned. The weights were adopted by the extracted factors based on field investigations for the mineralization occurrences and the knowledge of experts in the previous studies on mapping of favorable zone for mineralization [10], [12]. The evaluation of each layer weight was applied using

Analytical Hierarchy Process (AHP). The AHP represent a suitable technique to compute relative importance weights for each layer with a pairwise comparison method [19] based on the pairwise comparison matrix (PCM). PCM was complied with the following attributes:  $a_{ii} = 1$  and  $a_{ij} = 1/a_{ji}$ . Pairwise comparisons of all the related attribute values were applied to establish the relative importance of each layer (Table I). The importance of pairs of grouped layers was assigned based on their contribution to the higher hierarchy. The weights of the thematic layers were calculated by normalizing their weight (Table I). The application of the AHP method for the predictive mineral potential mapping provides a strong theoretical framework for multi-criteria evaluation. The Consistency Ratio (CR) was also calculated in this study using equation 2 and 3 to evaluate how much each criterion is more importance than other. The acceptable value for CR is usually less than 0.1 (10%).

$$CR = CI/RI \quad (2)$$

$$CI = (\lambda_{max} - n)/(n - 1) \quad (3)$$

where  $CI$  is consistency index,  $RI$  is Random Consistency Index depending on the number of factors and equal to 1.24 in this study [19].  $\lambda_{max}$  is the Principal Eigen Value;  $n$  is the number of factors.

#### D. Aggregate the Criteria

Index overlay method was adopted in this study as a suitable GIS technique to integrate the thematic layers in which each class within each layer gives a weight score depending on its relative importance to mineralization. Assignment of weights on different layers was performed using knowledge- driven approach. The Mineral Potential Index (MPI) was finally derived using the following equation (4)

$$MPI = \sum_{i=1}^6 S_{ij} W_i / \sum_{i=1}^6 W_i \quad (4)$$

#### IV. RESULTS

AHP was applied successfully in this study with Consistency Index equal to 0.023 which represent very good value for the evaluation the importance of each criterion to other (Table I). The alteration zone got the highest weight in this analysis equal to 0.377 and was followed by distance to faults intersection which equal to 0.257 (Table II). The lithology and lineaments density got the lowest weight equal to 0.033 (Table II). The final mineral potential map was delineated by multiplying the weights of all criteria by their standardizing scores and added all results. The mineral potential map was classified to five major classes including very poor to very good potentiality. The produced mineral potential map suggests the promising locations for porphyry copper exploration which are almost always located at W. Samghi, W. Nakhil, and W. Saada El-Beida. The identified mineralized zones are located mainly at the eastern part of Nuweiba area, especially at rhyolite dykes and quartz veins cutting dioritic and granitic gneisses (Fig.

7). Zones of very good potentiality for porphyry copper occurrences cover 0.9% of the Nuweiba's total area, whereas regions characterized by very poor mineralization potentiality cover about 35% of the Nuweiba's total area. The good potential for porphyry copper occurrences occupies 2.8% of the mapped area, while the poor potential rank covers about 34.6% of Nuweiba area.

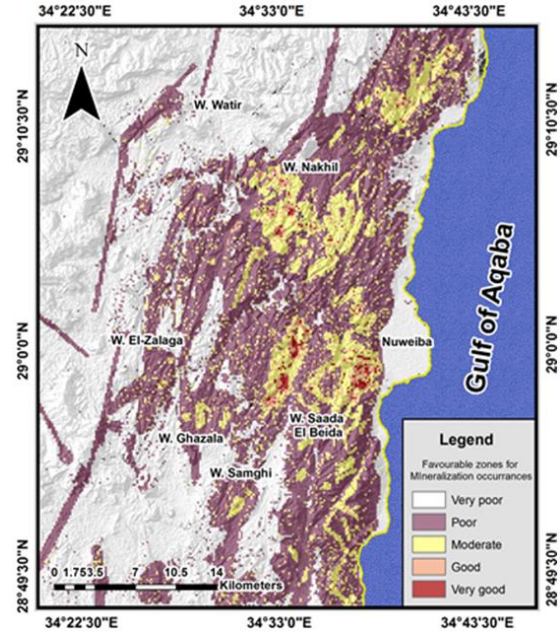


Figure 7. The porphyry copper potential map of Nuweiba area, Egypt.

The porphyry copper potential map defines spatially zones for porphyry copper exploration. These zones were not discovered before in the previous studies. The Nuweiba area needs more geochemical analysis for these zones to study the economic importance for the porphyry copper deposits.

#### V. CONCLUSION

Several criteria were prepared in this study to define the favorable zone of porphyry copper occurrences. These layers include lithology, lineaments density, major faults, faults intersections, and alteration zones. These criteria were prepared using different remote sensing techniques including Band Ratio (BR), Relative Absorption Band Depth (RBD), Principal Component Analysis (PCA), Minimum Noise Fraction (MNF), and Linear Spectral Unmixing (LSU). The linear Spectral Unmixing (LSU) gave successful results to enhance the separation of the three alteration zones involving phyllic, argillic, and propylitic zones. These alteration zones represent the highest important factor in this study. The weights of all criteria were calculated using AHP. Weighted Linear combination analysis was applied finally in GIS environment in order to integrate all criteria and define the favorable zones for porphyry copper deposits. The final porphyry copper potential map suggests new promising areas for porphyry copper occurrences at W. Samghi, W. Nakhil, and W. Saada El-Beida.



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