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An integrated Fuzzy AHP-VIKOR method for gold potential mapping in Saqez prospecting zone, Iran

Farzaneh Mami Khalifani, Abbas Bahroudi*, Samaneh Barak, Maysam Abedi

Geo-Exploration Targeting Lab (GET-Lab), Department of Mining Engineering, College of Engineering, University of Tehran, Tehran, Iran.

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ABSTRACT

Mineral prospectivity mapping (MPM) is a Multi-Criteria Decision Making (MCDM) task that prioritizes mineralized areas from high to low potential through methodologies that deal with data fusion problems. The primary purpose of this research is to produce a mineral potential map of the Saqez area in Kurdistan, Western Iran, to delimit the promising areas for subsequent studies in gold exploration. This area is well-known for its orogenic gold occurrences where several deposits/prospects have been discovered recently. To seek blind targets in the region, three evidential criteria, including geological, remote sensing, and geochemical layers, were used to generate the gold potential map of the Saqez area. The technique used to gain the weights of evidential layers is the fuzzy analytical hierarchy process (fuzzy AHP). Regarding this technique, at least three expert decision-makers (DMs) are required to run the method, where the results have superiority compared to the conventional AHP method with high values of uncertainty. The obtained weights of criteria were used to integrate all indicator layers incorporated in geospatial datasets through three methods, including conventional VIKOR, modified VIKOR, and multi-class index overlay. In order to validate the final MPMs, the predication ratio of seven gold prospects along with favorable zones were calculated as an efficiency index, where it was 85.65, 85.29, and 78.47 %, respectively. It proved the applicability of the VIKOR approach in gold potential mapping in comparison to the multi-class index overlay. The southwestern portions of the prospecting zone were highlighted as the most favorable potential area for gold occurrences.

KEYWORDS

Fuzzy-AHP
VIKOR
Multi-class Index Overlay
Orogenic Gold Deposit
Saqez

1. Introduction

Geographic Information System (GIS)-based methods play important roles in integration and analysis of regional exploratory datasets in order to handle and support decision making in mineral exploration (Brown et al., 1999, 2000 Carranza, 2008, Carranza et al., 2015). Optimized and successful mineral exploration is a series of processes defined for discovering new mineral deposits in the region of interest, which are called Mineral Prospectivity/potential Mapping (MPM). To achieve this goal, the MPM processes utilize simultaneous consideration of various evidential layers or datasets such as geological, remote sensing, and geochemical layers (Abedi et al., 2013; Zhang et al., 2017). MPM is a Multi-Criteria Decision Making (MCDM) task, which aims to solve complex multi-disciplinary geospatial problems (Abedi et al., 2013). However, MPM is a predictive model for discovering any type of ore occurrences (Carranza, 2008). The MPM method is divided into two major groups of data- and knowledge-driven. Data-driven methods utilize

* Corresponding author
E-mail addresses: mami.farzane@ut.ac.ir (F. Mami Khalifani); bahroudi@ut.ac.ir (A. Bahroudi); Samaneh_barak@ut.ac.ir (S. Barak); maysamabedi@ut.ac.ir (M. Abedi)

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training datasets in ''brownfields'' or well-explored regions wherein the objective is to define additional targets for exploration. The most popular ones are weights of evidence (Agterberg and Bonham-Carter, 1999), and fuzzy weights of evidence (Cheng et al., 1999, 2007, Almasi et al., 2017, Barak et al., 2018a, b). The knowledge-driven methods, on the other hand, are suitable for ''greenfields'' or under-explored regions. An example of such a group can be the Fuzzy inference system (Porwal et al., 2015; Barak et al., 2018a, b). Both of these groups integrate various evidential layers to generate a final mineral potential map.

AHP is one of the most popular MCDM approaches that was introduced by Saaty (1980) when the best opinion among several decision criteria should be selected. Even though this method considers the experience and knowledge of experts capable of selecting the best choice, but traditional AHP cannot illustrate human critical thinking in real life. Therefore, as Laarhoven & Pedrycz (1983) represented for the first time, the use of fuzzy sets (Sets, 1965) with AHP or so-called Fuzzy AHP makes the decisions more flexible by human languages and human conceptions. This technique utilizes triangular fuzzy numbers in processes for pairwise comparisons (Laarhoven & Pedrycz, 1983, Abedi et al., 2013., Zhang et al., 2017), which is selected by decision-makers (DMs) according to their experiences and skills. After obtaining the weights of the Saqez area accurately through fuzzy AHP, these weights can apply on the evidential layers with various integrating methods. Since various geospatial indicator layers have different importance values, it is essential to differentiate them in mineral exploration. Therefore, fuzzy-AHP can play an important role in assigning a sub-optimal and accurate weight to each indicator layer before implementing a knowledge- or data-driven fusion algorithm.

Among various knowledge-driven methods, the VIKOR approach developed by Opricovic (1998), and later by Opricovic and Tzeng (2004) and Jahan et al. (2011), can be implemented in the MPM process. This method was used successfully in mineral exploration studies by Abedi et al. (2016). It ranks alternatives and diagnoses the solution named compromise, which is in adjacency to the idea. Furthermore, the idea of the compromise solution was proposed in MCDM by Zeleny (1984). Another popular MPM approach is the multi-class index overlay, developed by Carranza et al. (1999). This method was employed in mineral prospectivity mapping by various researches such as Mirzaei et al. (2014); Sadeghi et al. (2014) and Abedi et al. (2016). It should be noted that researches conducted for declining anomalous areas and accurately classifying mineralized areas have tried to investigate the applicability of the fractal method. This technique was first developed by Mandelbrot (1983) in the geosciences studies, and was employed later in many works (e.g., Wei & Pengda, 2002; Afzal et al., 2011; Barak et al., 2018a, b; Mami Khalifani et al., 2018a, b). Theoretically, this method illustrates the relationships between evidential layers and spatial information (Carranza, 2008; Carranza et al., 2009), where the generated fractal curve form such analyses indicates the threshold values of the desired map to classify it based on its favorability in mineral occurrences.

The applicability of various MCDM methods motivated us to take into account a combination of them in gold potential mapping in the Saqez prospect region, Iran. Based on previous geological and geochemical studies in this area (Aliyari et al., 2007, 2009, 2012, 2014; Tajeddin, 2011), the granite-gneiss units were the main host rocks of gold mineralization that were taken into account as the most efficient evidential layers in potential mapping. Many researchers have studied the other factors which are in close association with the gold mineralization (e.g., Aliyari et al., 2009, 2012; 2014, Tajeddin, 2011; Afzal et al., 2013, Almasi et al., 2014, 2017, Mami Khalifani et al., 2016, 2018a, b). As Almasi et al. (2017) stated, regarding the conceptual model of gold deposits in the study area and several correlations between ore mineralization and exploration appearances, the MPM methods can be utilized to integrate all evidential layers (Almasi et al., 2014, 2017).

The ultimate aim of this work is to generate potential map of gold in the Saqez area through implementing three MPM techniques, including conventional VIKOR, Modified VIKOR, and multi-class index overlay. In order to achieve this goal, various criteria, including geological, remote sensing, and geochemical layers, were incorporated in the geospatial decision matrix. The fuzzy analytical hierarchy process (fuzzy AHP) was used to assign the appropriate weight of each layer before implementing these fusion algorithms. The concentration-area (C-A) multifractal method was utilized to reclassify the generated potential maps, by which the favorable zones were proposed for further studies. The location of gold prospects in this region such as Hamzehqaranen, Qolqoleh, Qabagloujeh, Qarehchar, Kervian, Pir-Omran and Kasnazan (Aliyari et al., 2012, 2014; Tajeddin, 2011, Almasi et al., 2014, 2017) along with the favorable zones were used as the main objectives to evaluate the efficiency of each fusion algorithm. The outputs proved the superiority of the fuzzy AHP-VIKOR method compared to the conventional multi-class index overlay.

2. Geological setting of Saqez prospecting zone

The Saqez prospect area is located in the Kurdistan province of Iran (Figure 1a), and is a promising gold-bearing region in the Saqez-Sardasht zone. This region is structurally associated with the Sanandaj-Sirjan metamorphic-plutonic Belt (SSB) (Babakhani et al., 2003, Aliyari et al., 2007, 2009, 2014, Almasi et al., 2017). The geological setting of the Saqez area is divided into two major lithological groups. The first group of rocks has an affiliation with the Precambrian metamorphic rocks of the SSB, and the second one is similar to Precambrian carbonate units, late Cambrian, Paleozoic and Mesozoic rocks of the Alborz-Azerbaijan zone. The oldest rock units in the Saqez were composed of a thick sequence of gneiss, granite-gneiss, schist, marble, and amphibole. They are mostly sporadic in the W, SW, and SE of the prospect region, and are inconsistently covered with carbonatic-clastic rocks of Precambrian, late Cambrian, Permian, and Cretaceous. Gneiss and granitic gneiss units form a part of metamorphic Precambrian rocks outcrop in the SE to SW and W of the Saqez area (Figure 1b). Various researchers have stated that the orogenic gold deposits in this region are closely associated with structural lineaments (i.e., faults, contacts, shear zones) (e.g., Aliyari et al., 2007, 2009, 2014; BabaKhani et al., 2003; Tajeddin et al., 2011, 2016). Figure 1c presents the fault density map of the Saqez, where the SW portions with seven gold occurrences (Figure 1b) have indicated higher density. The rose diagram of faults shows two major strikes: an NW-SE trend parallel to the SSB and an NE-SW one perpendicular to the former faults.

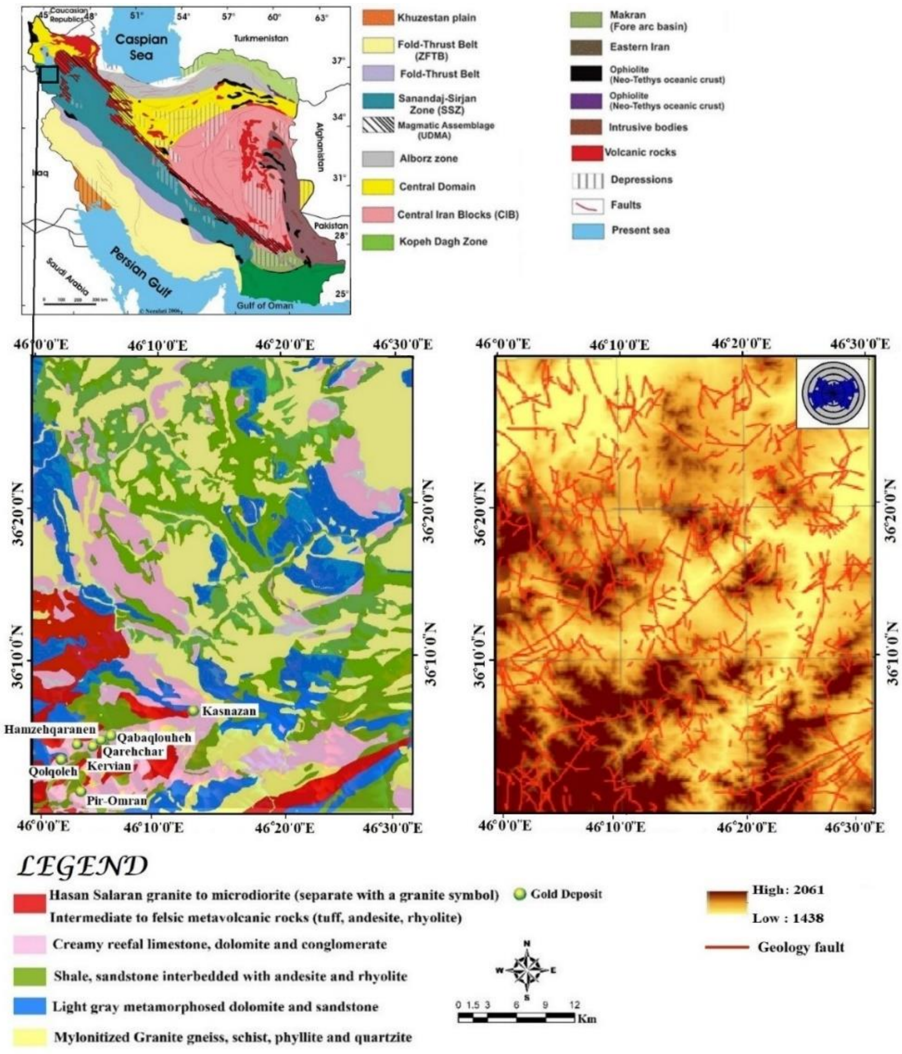

Figure 1. The location of the Saqez-Sardasht zone in the north of the Sanandaj-Sirjan Zone on the structural-geological map of Iran (a), the modified 1:100,000 scaled geological map of the Saqez (b), and (c) the rose diagram of all faults in the study area (Babakhani, 2003).

3. Materials and Methods

3.1. Geospatial datasets

The datasets built in this work are composed of six indicator layers, including rock units, tectonic (geological lineaments), remote sensing (alteration), and geochemical multi-element concentrations of Au, W, and Sb. These evidential layers were extracted and incorporated in the geospatial datasets based on the conceptual model of the orogenic gold occurrences. They make a hierarchical decision tree shown in Figure 2, where three main criteria of geology, remote sensing imagery, and geochemical data were used to prepare six indicators probably in association with the gold mineralization. All of the indicator layers have covered 88×109 pixels in easting and northing directions with 500 m of resolution.

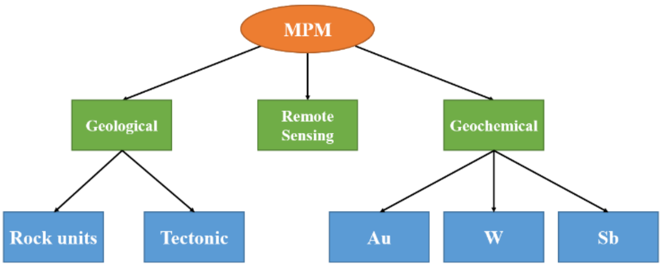

Figure 2. The hierarchical structure of the decision tree used for generating final gold prospectivity/potential map.

3.2. Geological indicators

Two evidential layers of tectonics lineaments (mostly faulted areas) and rock units were prepared through considering the conceptual model of orogenic gold deposits. The most significant rock units closely related to gold mineralization are gneiss and granite-gneiss units. To prepare the rock unit layer, the detailed geological map of the Saqez area was digitized in an ArcGIS environment. Then, the digitized rocks' polygons were prioritized by assigning different scores based on their importance in gold occurrences. Details of the score assignments are displayed in Table 1, and the final rock unit indicator has been presented in Figure 3. Such layers have been used in several studies in gold explorations (e.g., Aliyari et al., 2007, 2009, 2012, Tajeddin, 2011, Almasi et al., 2014, 2017, Mami Khalifani et al., 2016, 2018a, b).

The geological lineaments were extracted from the geological map and processed remote sensing imagery data. Four sub-groups of structural features were combined to generate the tectonic layer. The buffering zones were extracted from those faults detected by geological and remote sensing data, intersections of geological faults, and most likely fault trends (Figure 4). The assigned scores to theses structural features have been summarized in Table 1. The SUM operator (predefined in ArcGIS 10.3 software) was utilized to integrate all sub-groups of structural lineaments shown in Figure 4. It should be noted that the NE-SW trending faults are in association with the gold-bearing zones (Aliyari et al. 2007, 2009, 2012; Almasi et al. 2014, 2017, Mami Khalifani et al., 2018b). According to Carranza et al. (2015) and Mohebi et al. (2015), the zones adjacent to such structural lineaments have more potential for ore mineralization over the distant regions.

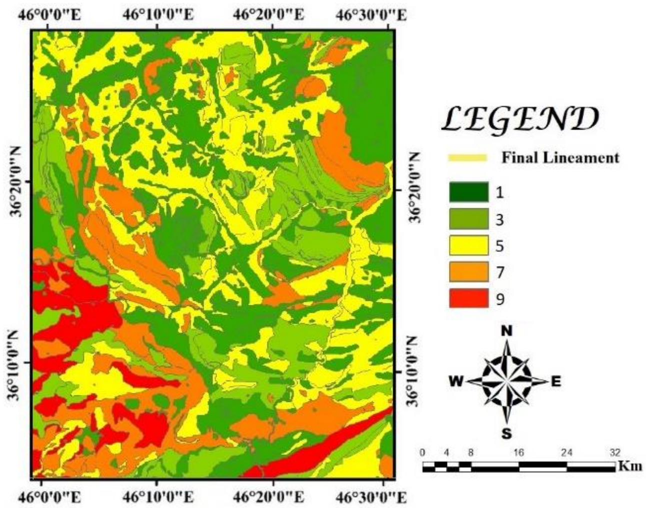

Figure 3. Rock unit evidential layer, where higher assigned scores correspond to more favorable zones responsible for gold mineralization.

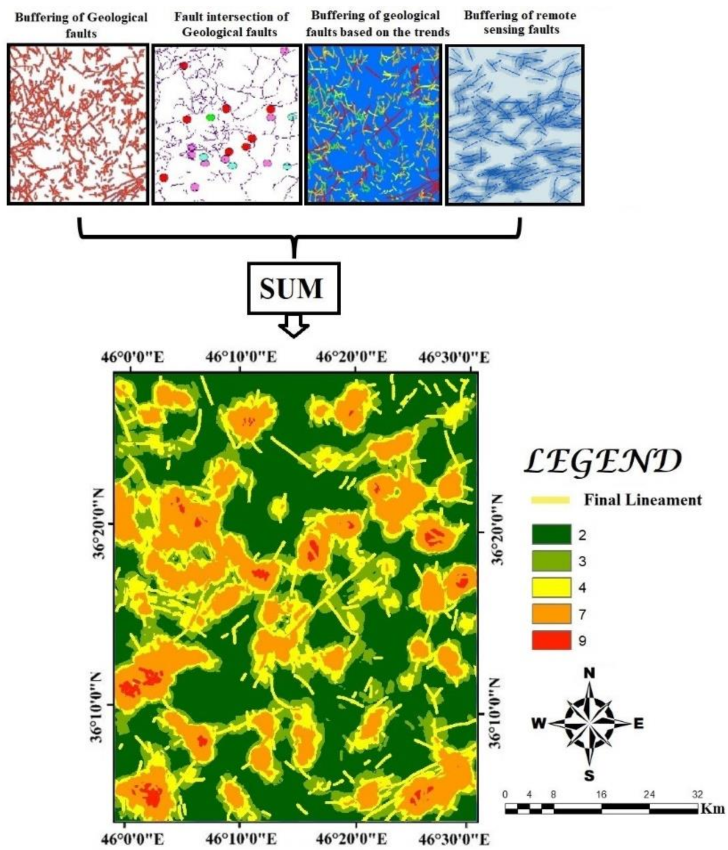

Figure 4. Final tectonic indicator layer showing the importance of geological lineaments in gold exploration. This map was generated by implementing a SUM operator to four sub-groups of structural features.

Table 1. A summary of assigned scores to the indicator layers in the Saqez prospect zone.

Layer	Class	Scores
Rock units	Hasan salaran granite to microdiorit (granite), Intermediate to felsic metavolcanic rocks (tuff, Andesite	9
	Creamy reefal limestone, dolomite, and conglomerate	7
	Shale, sandstone interbedded with andesite and rhyolite	5
	Light gray metamorphosed dolomite and sandstone	3
	Mylonitized Granite gneiss, schist, phyllite and quartzite	1
350 meters buffering of geological map faults	faults Buffering	
	50 meters	9
	150 meters	7
	200 meters	4
	250 meters	2
	350 meters	1
Geological map faults intersection	faults Azimuth	
	(A-B), (A-A)	9
	(A-D), (A-C)	7
	(B-D),(B-C)	5
	(C-D)	3
350 meters buffering of Geological map faults based on the trend	faults Trend	
	Northeast- Southwest (A)	9
	Northwest-Southeast (B)	7
	East-West (C)	5
	Others	2
350 meters buffering of remote sensing lineaments	Faults Buffering	
	50 meters	9
	150 meters	7
	200 meters	5
	250 meters	2
	350 meters	1
Geochemistry	Types of anomalies	
Au	Probable anomaly	9
	Possible anomaly	7
	Background	5
	Regional	1
W	Probable anomaly	8
	Possible anomaly	7
	Background	6
	Regional	2
Sb	Probable anomaly	8
	Possible anomaly	7
	Background	4
	Regional	1
Remote sensing	Types of alterations	
	Iron oxide	9
	Kaolinite	8
	Silicification	7
	Illite-sericite	5
	Propylitic	3
	Background	1

3.3. Geochemical indicators

An overall of 1063 stream sediment geochemical samples was collected over the whole prospecting zone in the Saqez to delineate anomalous regions based on the multi-element concentrations (Figure5). The samples were analyzed for 21 elements via the ICP-MS approach. After statistical processing of censored and outlier data, the descriptive statistics of main elements associated with the gold mineralization were conducted and the results are summarized in Table 2. The histogram and probability plots of the Au concentration are presented in Figs. 6a and 6b, showing a non-normal distribution probably related to gold mineralization. Consequently, for the sake of skewness and the low level of normality of the Au concentration, the Cox-Box technique (Cox, 1964) was used to normalize the geochemical data (Figs. 6c and 6d). Such normalization will lead to robust geochemical data processing and interpretation.

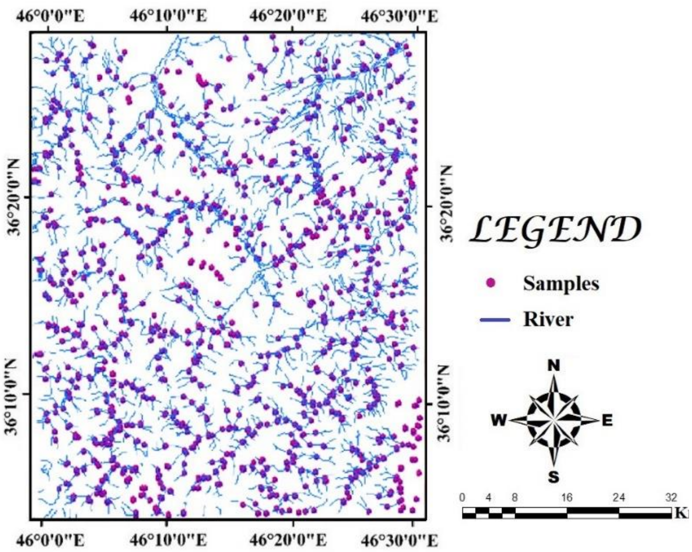

Figure 5. Stream sediment geochemical samples over the Saqez prospecting zone.

A cluster analysis was carried out to investigate the correlation of multi-elements in this region, where the dendrogram plot shown in Figure 7 indicates that W and Sb are trace elements of gold occurrences (Barak et al., 2016; Mami Khalifani et al., 2016, 2018a). For separating anomalous regions from the background, the concentration-number (C-N) multi-fractal method was utilized (e.g., Afzal et al., 2013; Hassanpour & Afzal. 2013; Barak et al. 2018a, b, Mami Khalifani et al., 2018a). This type of fractal analysis is not substantially sensitive to the preprocessing of geochemical data. Fractal curves for three elements of Au, W and Sb were plotted in the top row of Figure 8, while their reclassified concentrations based on the thresholds derived from those curves were shown in the middle row of this Figure 8. Appropriate scores were assigned to these reclassified maps to be incorporated in the final geospatial datasets. Table 1 and the lowest row of Figure 8 present the final geochemical indicators.

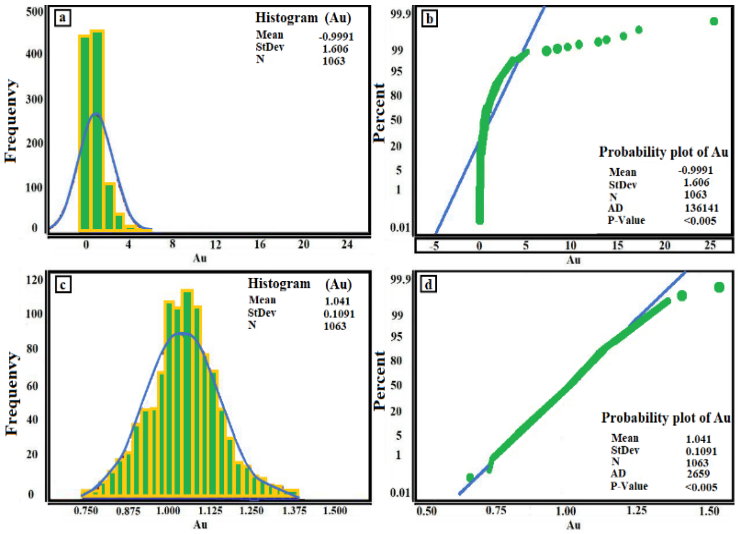

Figure 6. The histogram and the probability plots of the initial Au concentrations (a) and (b), and the normalized ones (c) and (d).

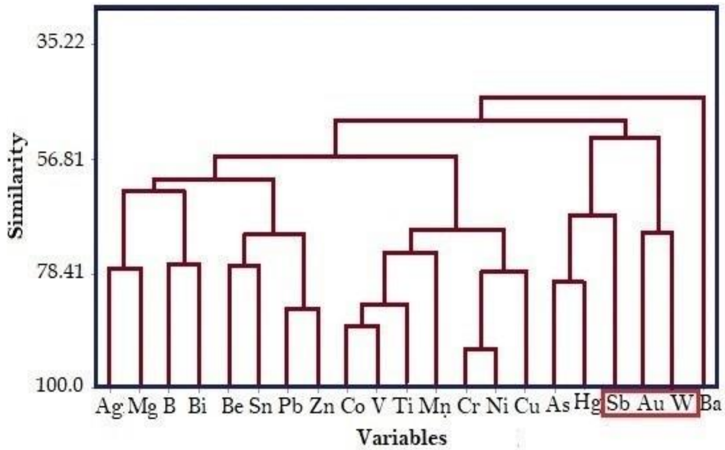

Figure 7. The result of cluster analysis for 21 geochemical elements in the Saqez prospecting zone.

Table 2. The statistical characteristics of geochemical concentrations of Au, W, and Sb elements.

	Range	Min	Max	Average	Std. deviation	Skewness	Kurtosis
Ag	0.448	0.028	0.476	0.088	0.033	2.258	17.151
Sb	159.6	0.4	160	0.921	9.316	11.32	148.517
W	9.6	2	11.6	2.5	0.904	3.682	19.389

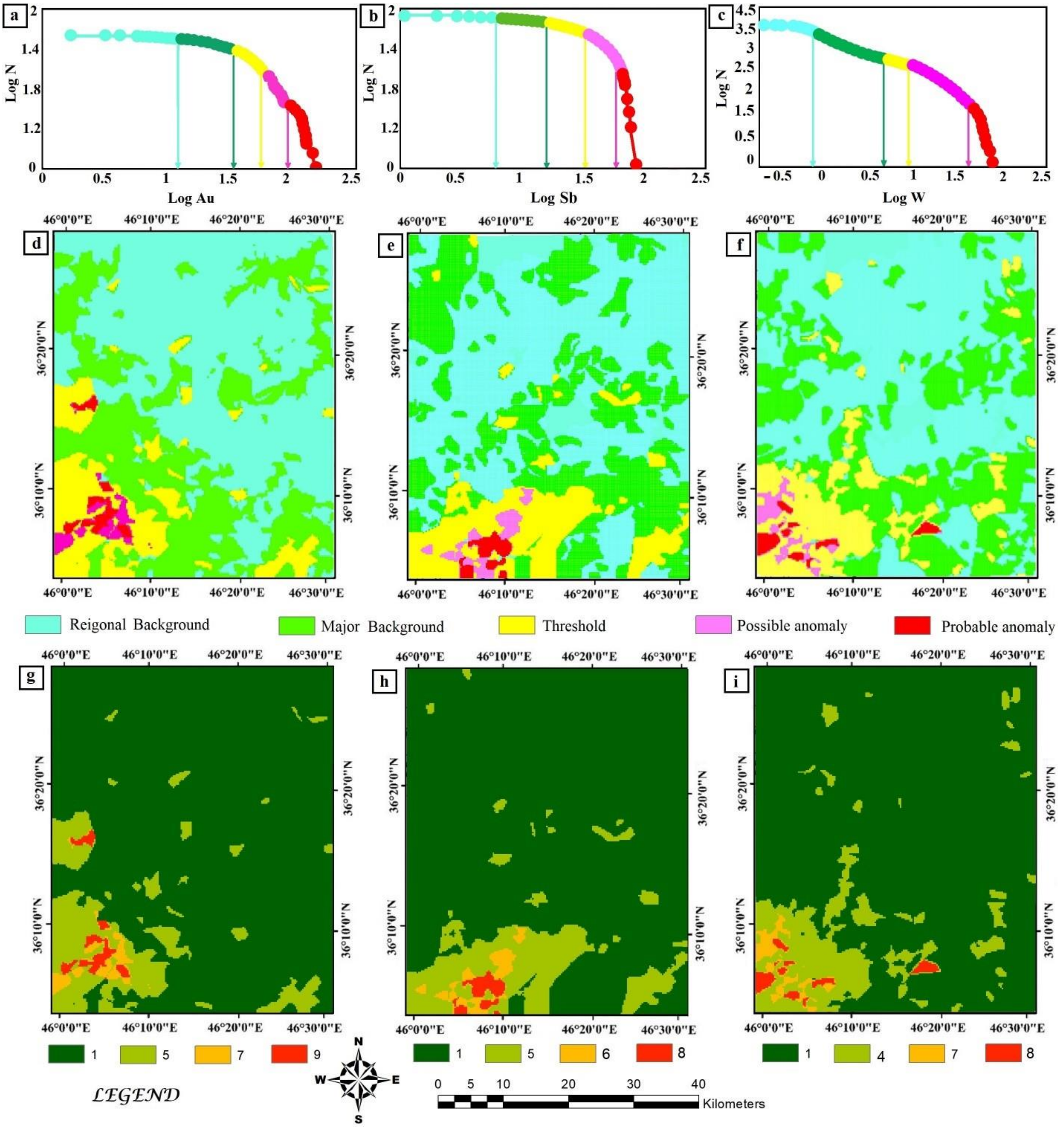

Figure 8. The log-log plots of C-N multi-fractal curves of stream sediment geochemical data for Au, Sb, and W (top row), the reclassified concentration maps based on the derived thresholds (middle row), and the geochemical indicator maps for three elements (bottom row).

3.4. Remote sensing indicators

According to the importance of various alteration systems similar to orogenic gold deposits, remote sensing imagery data was used to extract surface alteration indicators. Silicification, sericite, iron oxide, kaolinite, and propylitic alteration zones of are the most prevalent zones in gold mineralization systems (Craw et al., 2006; Aliyari et al., 2007, 2012., Sukumar et al., 2014; Mohebi et al., 2015, Mami Khalifani et al., 2018b). In this study, the ASTER datasets have been utilized to map those alterations. Before processing the ASTER images, geometric and radiometric corrections were performed. Information of SWIR (6 bands) and VNIR (3 bands) images were used to map the aforementioned alterations in an ENVI software environment. Image- and spectrum-based approaches were taken into account to extract the final indicator layer.

As mentioned, in gold potential mapping (Rowan & Mars, 2003; marth2006; Naghadehi et al., 2014), the ASTER TIR bands can be used in the detection of rich silica zone. In order to identify this alteration in the Saqez area, the band ration of b_{13}/b_{12} was exerted. The silicified portions were plotted in Figure 9a. There are some spectrum-based methods for distinguishing alteration zones in mineral exploration, including Spectral Angle Mapper (SAM), Spectral Feature Fitting (SFF) (Kruse et al.,1992,1993), etc. In this work, the SAM technique was implemented to map the Kaolinite, Propylitic, and Iron oxide alteration zones. The degree of similarity between two spectra is calculated by the angle between them, where the first spectrum belongs to the extracted indicator mineral from the ASTER images and the second one belongs to the indicator mineral of a predefined library (Weyermann, 2009). In the study area, the spectra of chlorite and epidote minerals were used for detection of propylitic alteration, and the spectra of hematite, goethite and jarosite were chosen for detection of Iron oxide alteration, and that of kaolinite mineral was used for detection of kaolinite alteration (Malekzadeh et al., 2009; Amer et al., 2012; Akbari et al., 2015, Barak et al., 2018a, b). Those regions correspond to this group of alteration that is shown in Figure 9a.

In order to map illite-sericite alteration (Figure 9a), the SFF approach was used by assuming the spectra of sericite and muscovite minerals (Azizi et al., 2010). As mentioned by Pan et al. (2013), the SFF is a commonly utilized method for hyperspectral imagery analysis to discriminate shallow targets. In the last stage, appropriate scores (Table 1) were assigned to each alteration zone for constructing the indicator layer shown in Figure 9b. The iron oxide alteration was the most important traces of gold mineralization in the region (Aliyari et al., 2007, 2012, 2014, Almasi et al., 2017, Mami Khalifani et al., 2018b).

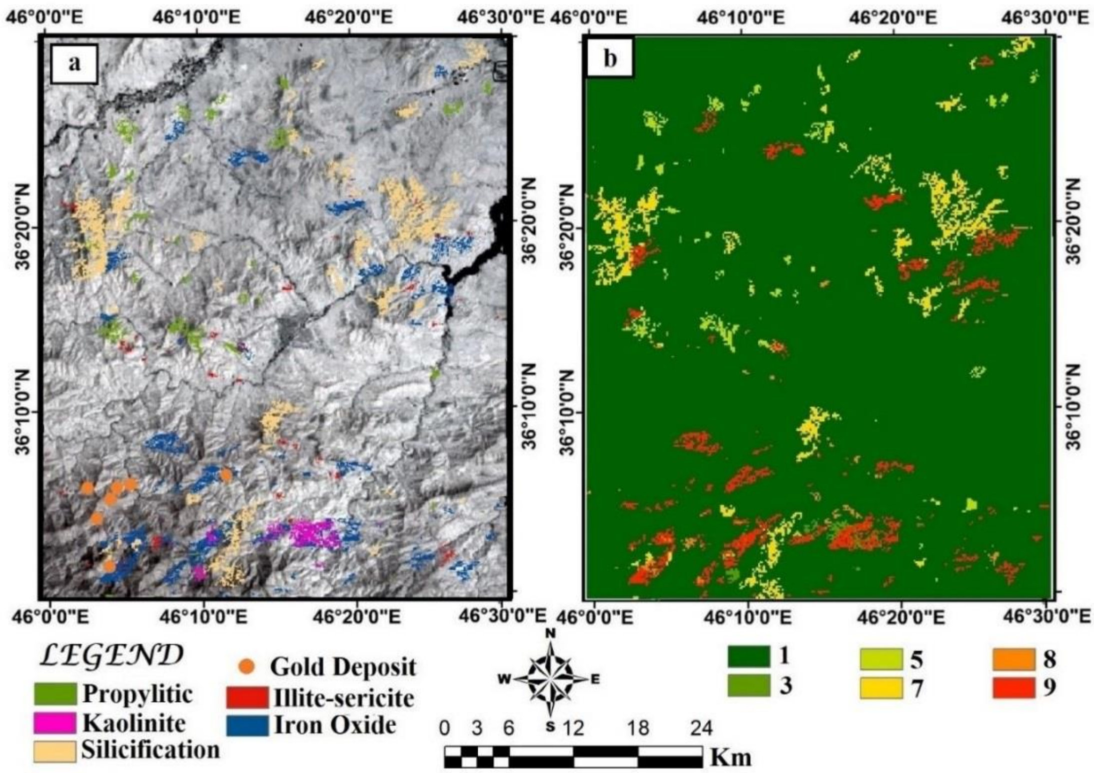

Figure 9. Detected alternations by image- and spectrum-based approaches (a), and the final alteration indicator (b) extracted from processing ASTER imagery data.

4. Gold prospectivity/potential mapping in Saqez

Six indicator maps were used to build the final geospatial datasets. These indicators are rock units and faults from geological criterion, Au, W and Sb from stream sediment geochemical data, and alteration map derived from satellite imagery data. Since the importance of each indicator in the final preparation of the MPM is different, it is required to differentiate their weights in data integration. A group of experts in the field of gold exploration was selected to decide on this issue in the MPM process. The fuzzy-AHP approach was used to extract the weight of each indicator in the final preparation of gold potential mapping. In order to run this technique, at least three decision-makers (DMs) are required to assign a fuzzy number (here triangular fuzzy number or TFN) for comparison of indicators (Abedi et al., 2016). The pairwise comparison matrices or tables were prepared after receiving the opinions of three experts in this field of study, as shown in Tables 3, 4, and 5 for the main criteria, geological, and geochemical indicators. The procedure of implementing the fuzzy-AHP technique has been presented in details by other researchers (e.g., Abedi et al., 2013; Zhang et al., 2017). Hence, the weights of six indicator layers were calculated and summarized in Table 6.

Table 3. Pairwise comparison matrix for the main criteria.

	Geological	Geochemical	Remote Sensing
Geological	(1,1,1)	(1/4,1/3, 1/2)	(2,4,6)
Geochemical	(2,3,4)	(1,1,1)	(3,5,6)
Remote Sensing	(1/6, 1/4,1/2)	(1/6, 1/5, 1/3)	(1,1,1)

Table 4. Pairwise comparison matrix for geological indicators.

	Faults	Rock units
Rock units	(1,1,1)	(2,3,4)
Faults	(1/4,1/3,1/2)	(1,1,1)

Table 5. Pairwise comparison matrix for geochemical indicators.

	Au	Mo	Sb
Au	(1,1,1)	(4,5,6)	(6,7,8)
W	(1/6,1/5,1/4)	(1,1,1)	(3,4,5)
Sb	(1/8, 1/7,1/6)	(1/5,1/4, 1/3)	(1,1,1)

Among the six indicator layers, Au geochemical anomaly and rock units gained the highest weights, showing the most significant impact on the prospecting gold occurrences. Having determined the importance of each indicator layer, it is required to integrate them into a single map of gold prospectivity. Here, the results of three algorithms such as conventional and modified versions of the VIKOR methods (Abedi et al., 2016; Jahan et al., 2011; Ghezelbash & Maghsoudi, 2018), and the multi-class index overlay method, were generated as a popular approach in MPM process (Abedi et al., 2016).

The VIKOR technique was first introduced by Opricovic (1998) for MCDM problems, where it suggests the multi-criteria ranking index due to the special assessment of “closeness” to the “ideal answer” (Opricovic & Tzeng 2004; Abedi et al., 2016; Ghezelbash & Maghsoudi 2018). For detailed studies, the procedure developed by Abedi et al. (2016) is suggested to how to implement the conventional and modified versions of VIKOR. To evaluate the performance of the VIKOR method in gold potential mapping, the generated maps were compared with the one from the multi-class index overlay that was firstly introduced by Carranza et al. (1999) and later employed successfully in MPMs (Sadeghi et al., 2014; Sadeghi & Khalajmasoumi 2015; Abedi et al., 2016). Finally, the outcome MPMs shown in the right column of Figure10 were reclassified into five mineral favorability zones through implementing the C-A multi-fractal cures (left column of Figure10). All generated maps indicated a high potential of the SW portions of the Saqez prospect zone.

Table 6. Final weights of criteria and indicator layers derived from the fuzzy-AHP method.

Criteria	Weight	Indicators	Weight	Final weights
Geological	0.351	Rock units	0.806	0.283
		tectonic	0.194	0.068
Geochemical	0.549	Au	0.700	0.384
		Sb	0.167	0.092
		W	0.132	0.073
Remote Sensing	0.100	Alteration	1.000	0.100

5. Result and discussion

The MPM process is recognized as an MCDM task which produces a predictive model for outlining prospective areas. To evaluate the performance of the applied methods in preparation of final potential maps, the higher ore prediction rate along with the lower predicted area are two essential keys for controlling the generated maps. Therefore, the MPM efficiency index (E.I.) was used to compare the produced maps. This index is defined as (Abedi et al., 2016):

$$E.I. = w_1(100 - predicted\ \ area\ \%) + w_2(ore\ \ prediction\ \ rate\ \ \%) \quad (1)$$

The prediction area was associated with the ratio of the favorable area to the whole study area. Ore prediction rate was also defined as the ratio of the predicted ore occurrences to all ore numbers in the studied region. In fact, the MPM output is selected based on this index that simultaneously predicts the highest numbers of known prospect/ore occurrences along with the lowest areas as favorable zones.

Assuming $W_1 \quad W_2 \quad 0.5$ (the best and unbiased weights), the MPM E.I. values are always more than 50%. Higher values of the index indicate that the produced MPM presents a better performance of the applied technique (Abedi et al., 2016). In this study, in order to validate the results, the information of seven gold prospects Hamzehqaranen, Qolqoleh, Qabagloujeh, Qarehchar, Kervian, Pir-Omran, and Kasnazan was used.

The values of this index for conventional VIKOR, modified VIKOR, and index overlay were 85.65, 85.29, and 78.47%, respectively. It shows the higher efficiency of the VIKOR method compared to the popular and conventional method of the multi-class index overlay.

The most favorable zones for probable gold mineralization in the SW of the area were covered by gneiss and granitic-gneiss host rocks. Some promising regions were suggested for detailed studies in the future exploration program (Figure11).

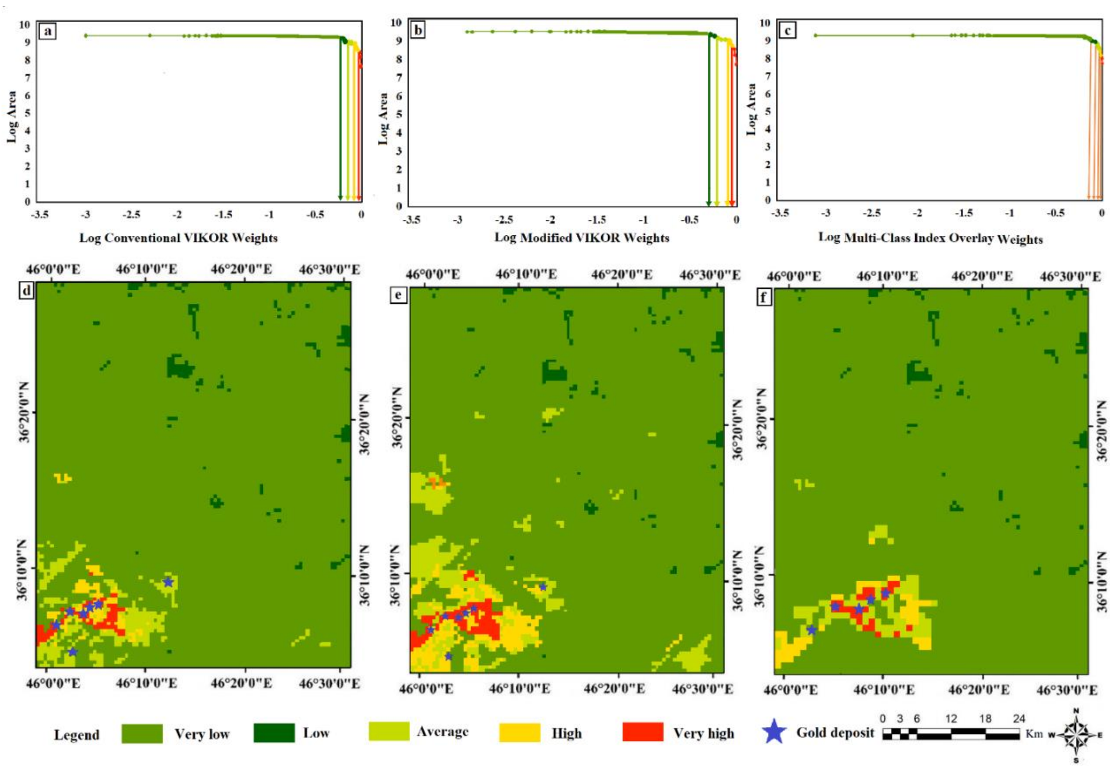

Figure10.Gold prospectivity/potential maps prepared by applying the VIKOR and multi-class index overlay approaches. The C-A multi-fractal curves for reclassifying the outputs are depicted in the left column, and the final potential maps are illustrated in the right column, while (a), (b) are for conventional VIKOR, (c), (d) for modified VIKOR, and (e) and (f) for multi-class index overlay.

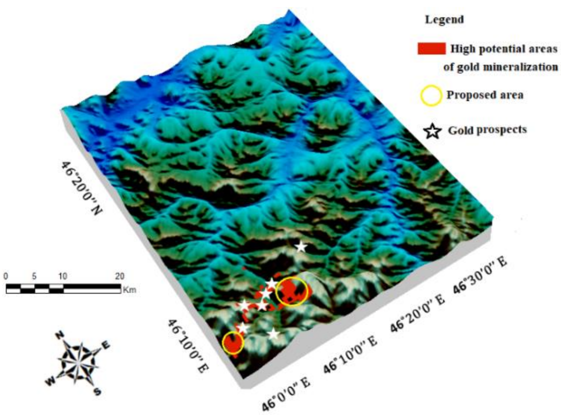

Figure11.The digital elevation map of the Saqez prospecting zone depicted in 3D, on which the most favorable zones for gold mineralization were superimposed.

6. Conclusion

The high potential of the orogenic gold mineralization in the Saqez and the lack of studies in generating mineral potential maps in this region motivated us to construct geospatial datasets for gold exploration. Six indicator layers were derived from three main criteria of geology, geochemistry, and satellite imagery data, where a group of geoscientists assigned appropriate scores to each of these datasets. The importance of each indicator was determined through implementing a fuzzy-AHP technique, showing a higher impact of Au concentration map and rock units on the gold occurrences. All weighted indicators were integrated by three methods of conventional and modified VIKOR along with the multi-class index overlay. The generated gold potential maps showed the superiority of the VIKOR outputs compared to the index overlay, where all maps proposed the SW portions of the area as the most favorable zones.

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