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RESEARCH ARTICLE

Porphyry Cu potential area selection using the combine AHP - TOPSIS methods: a case study in Siahrud area (NW, Iran)

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Abstract In this article, by using AHP-TOPSIS technique we propose a new method for mineral potential mapping that commonly used to other science. AHP and TOPSIS are practical and useful techniques respectively for determining the relative importance of the criteria and ranking - selection of a number of externally determined alternatives through distance measures. AHP method employed to determine the importance weights of evaluation criteria, then TOPSIS technique use for selection and ranking of study area. We used AHP-TOPSIS and GIS to provid potential maps for porphyry copper mineralization on the basis of criteria derived from geological and geochemical controls, and remote sensing data including alterations and faults in Siahrud area in North West Iran. The results demonstrate the acceptable outcomes for copper porphyry exploration.

Keywords AHP-TOPSIS · Potential mapping · Cu porphyry · Siahrud

Introduction

Geographic information systems (GIS) technology has shown growing application in many areas of knowledge, but especially in the mineral exploration (Pazand et al. 2011). Mineral exploration generally starts on a small scale (large areas) and, then, progresses to a larger scale (small areas) to define targets for more detailed investigations (Quadros et al. 2006) and is a multi-disciplinary task requiring the simultaneous consideration of numerous geophysical, geological, and geochemical data sets. Selection of the appropriate target area is a complex problem and requires an extensive evaluation process that considers the requirements of the metallogenetic processes involved during the formation of mineral deposits. Furthermore, many potential criteria, such as geology setting, geochemical anomaly, geophysical evidence, tectonic and alteration evidence must be considered for the selection procedure of a target area (Pazand et al. 2012a, 2014). Therefore, mineral potential mapping can be assumed as a multiple criterion decision-making (MCDM) problem. A MCDM method allows the analyst and the decision-makers to understand the problem, the feasible alternatives, different outcomes, conflicts between the criteria and level of the data uncertainty (Mergias et al. 2007). MCDM methods deal with the process of making decisions about the presence of multiple criteria or objectives. A decision-maker is required to choose among quantifiable or non-quantifiable criteria. The objectives of decision-makers are usually conflicting and therefore, the solution is highly dependent on the preferences of each decision-maker. Several methods exist for MCDM (Cheng et al. 2002; Opricovic and Tzeng 2004). The most popular ones are scoring models (Nelson 1986), analytic hierarchy process (AHP) (Göleç and Taşkın 2007), analytic network process (ANP) (Yuksel and Dağdeviren 2007), axiomatic design (AD) (Kulak and Kahraman 2005), utility models (Munoz and Sheng 1995), technique for order preference by similarity to ideal solution (TOPSIS) (Kahraman et al. 2007), ELECTRE III (Abedi et al. 2012a), PROMETHEE II (Abedi et al. 2012b) and compromise ranking method (called VIKOR) (Opricovic 1998). The choice of which model is most appropriate depends on the problem and decision maker(s). AHP is one of the popular approaches of MCDM (Sadeghi and Keshanian 2011) and because the AHP method

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has important advantages for weight calculation procedures based on a pairwise comparison, it has been used for mineral potential mapping (Wilkinson et al. 1999; Hosseinali and Alesheikh 2008; Pazand et al. 2011). Another important method is TOPSIS (Parkan and Wu 1999) which is one of the well known classical MCDM methods. The technique for order preference by similarity to ideal solution (TOPSIS) is one of the well known classical MCDM methods. TOPSIS, is a widely accepted multi-attribute decision-making technique due to its sound logic, simultaneous consideration of the ideal and the anti-ideal solutions, and easily programmable computation procedure. This technique is based on the concept that the ideal alternative has the best level for all attributes, whereas the negative ideal is the one with all the worst attribute values (Onut and Soner 2008). The TOPSIS is a powerful method to evaluate several selected cases (such as potential mapping) to identify a suitable design solution (Pazand et al. 2012a). Despite ability and allowing two methods alone, experience has shown that combine the two methods and the simultaneous use of the potentials of them give better results. However, the AHP-TOPSIS combination method that obtains acceptable results (Lin et al. 2008; Onut and Soner 2008; Dagdeviren et al. 2009; Tavanna and Hatami-Marbini 2011) less has been used in mineral exploration, consequently, in this paper, application and ability of AHP-TOPSIS method to mineral potential mapping explains. TOPSIS is used to area selecttion and the AHP is applied to calculate criteria weights.

In this paper, we report the results of mapping porphyry copper potential in the Siahrud area. This area is a part of the zone of Ahar-Arasbaran in North West Iran that has been studied for several decades because of its mineral potential for metallic ores, especially copper (skarn and porphyry types) and gold sulphide (Mollai et al. 2004; Mollai et al. 2009; Hezarkhani and Williams-Jones 1996; Hezarkhani et al. 1997, 1999; Hezarkhani 2006; Hezarkhani 2008). The aim here is to demonstrate the ability of AHP-TOPSIS for processing relevant data and producing a porphyry copper prospective map.

Methods

The AHP method

Analytic hierarchy process method (AHP), developed by (Saaty 1994), addresses how to determine the relative importance of a set of activities in an MCDM problem. The process makes it possible to incorporate judgments on intangible qualitative criteria alongside tangible quantitative criteria. The AHP method is based on three principles: first, the structure of the model; second, comparative judgment of the alternatives and the criteria; third, synthesis of the priorities (Dagdeviren et al. 2009). In the first step, a complex decision problem is structured as a hierarchy. AHP initially breaks down a complex MCDM problem into a hierarchy of interrelated decision elements (criteria, decision alternatives). With the AHP, the objectives, criteria and alternatives are arranged in a hierarchical structure similar to a family tree. A hierarchy has at least three levels: overall goal of the problem at the top, multiple criteria that define alternatives in the middle, and decision alternatives at the bottom (Albayrak and Erensal 2004).

The second step is the comparison of the alternatives and the criteria. Once the problem has been decomposed and the hierarchy is constructed, the prioritization procedure starts in order to determine the relative importance of the criteria within each level. The pairwise judgment starts from the second level and finishes in the lowest level, alternatives. In each level, the criteria are compared pairwise according to their levels of influence and based on the specified criteria in the higher level (Albayrak and Erensal 2004).In AHP, multiple pairwise comparisons are based on a standardized comparison scale of nine levels (Table 1).

Let C={Cj | j =1, 2,…, n} be the set of criteria. The result of the pairwise comparison on n criteria can be summarized in an (n×n) evaluation matrix A in which every element a_{ij} (i,j=1,2, …,n) is the quotient of weights of the criteria, as shown:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}, \quad a_{ii} = 1, a_{ji} = \frac{1}{a_{ij}}, a_{ij} \neq 0. \tag{1}$$

At the last step, the mathematical process commences to normalize and find the relative weights for each matrix. The weight vector W can be determined by solving the following characteristic equation:

$$A.W = \lambda_{\max}.W \tag{2}$$

Table 1 Nine-point intensity of importance scale and its description (Saaty 1994)

Intensity of importance	Definition
1	Equal importance or preference
2	Equal to moderate importance or preference
3	Moderate importance or preference
4	Moderate to strong importance or preference
5	Strong importance or preference
6	Strong to very strong importance or preference
7	Very strong importance or preference
8	Very to extremely strong importance or preference
9	Extreme importance or preference

Where $\lambda_{\max}$ is the maximum eigen value of A. It should be noted that the quality of the output of the AHP is strictly related to the consistency of the pairwise comparison judgments. The consistency is defined by the relation between the entries of A: $a_{ij} \times a_{jk} = a_{ik}$. The consistency index (CI) is

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

The final consistency ratio (CR), usage of which let someone to conclude whether the evaluations are sufficiently consistent, is calculated as the ratio of the CI and the random index (RI), where RI is the average of the resulting consistency index depending on the order of the matrix (Ying et al. 2007), as indicated.

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \tag{4}$$

The number 0.1 is the accepted upper limit for CR. If the final consistency ratio exceeds this value, the evaluation procedure has to be repeated to improve consistency. The measurement of consistency can be used to evaluate the consistency of decision-makers as well as the consistency of overall hierarchy (Pazand et al. 2011, 2014).

The TOPSIS method

The TOPSIS was first developed by Hwang and Yoon (1981). According to this technique, the best alternative would be the one that is nearest to the positive-ideal solution and farthest from the negative ideal solution (Ataei et al. 2008; Samimi Namin et al. 2008). The ideal solution (also called the positive ideal solution) is a solution that maximizes the benefit criteria/attributes and minimizes the cost criteria/attributes, whereas the negative ideal solution (also called the anti-ideal solution) maximizes the cost criteria/attributes and minimizes the benefit criteria/attributes. The so-called benefit criteria/attributes are those for maximization, while the cost criteria/attributes are those for minimization. The TOPSIS method consists of the following steps (Dagdeviren et al. 2009):

Step 1: Establish a decision matrix for the ranking. The structure of the matrix can be expressed as follows:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \cdot \\ \cdot \\ A_3 \\ \cdot \\ \cdot \\ A_J \end{array} \begin{array}{c} \begin{array}{ccccccc} F_1 & F_2 & \cdots & F_j & \cdots & F_n \end{array} \\ \left[\begin{array}{ccccccc} f_{11} & f_{12} & \cdots & f_{1j} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2j} & \cdots & f_{2n} \\ \cdot & \cdot & \cdots\cdots & \cdot & \cdots\cdots & \cdot \\ \cdot & \cdot & \cdots\cdots & \cdot & \cdots\cdots & \cdot \\ f_{i1} & f_{i2} & \cdots & f_{ij} & \cdots & f_{in} \\ \cdot & \cdot & \cdots & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot & \cdots & \cdot \\ f_{J1} & f_{J2} & \cdots & f_{Jj} & \cdots & f_{Jn} \end{array}\right] \end{array} \tag{5}$$

where $\mathrm{A_j}$ denotes the alternatives j, j=1, 2, …,J; $\mathrm{F_i}$ represents $\mathrm{i^{th}}$ attribute or criterion, i =1, 2, …, n, related to $\mathrm{i^{th}}$ alternative; and $\mathrm{f_{ij}}$ is a crisp value indicating the performance rating of each alternative $\mathrm{A_i}$ with respect to each criterion $\mathrm{F_j}$.

Step 2: Calculate the normalized decision matrix R (= $[\mathrm{r_{ij}}]$). The normalized value $\mathrm{r_{ij}}$ is calculated as (Pazand et al. 2012a):

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{n} f_{ij}^2}}, \quad j = 1, 2, \ldots, J; i = 1, 2, \ldots, n \tag{6}$$

Step 3: Calculate the weighted normalized decision matrix by multiplying the normalized decision matrix by its associated weights. The weighted normalized value $\mathrm{v_{ij}}$ is calculated as (Pazand et al. 2012a):

$$V_{ij} = w_i \times r_{ij}, j = 1, 2, \ldots, J; i = 1, 2, \ldots, n \tag{7}$$

where $\mathrm{w_i}$ represents the weight of the $\mathrm{i^{th}}$ attribute or criterion.

Step 4: Determine the positive-ideal and negative-ideal solutions (Pazand et al. 2012a).

$$A^{+} = \left\{v_1^{+}, v_2^{+}, \ldots, v_i^{+}\right\} = \left\{\left(\max v_{ij} \middle| i \,\varepsilon\, I'\right), \left(\min v_{ij} \middle| i \in I''\right)\right\} \tag{8}$$

$$A^{-} = \left\{v_1^{-}, v_2^{-}, \ldots, v_i^{-}\right\} = \left\{\left(\min v_{ij} \middle| i \,\varepsilon\, I'\right), \left(\max v_{ij} \middle| j \in I''\right)\right\} \tag{9}$$

where I' is associated with the positive criteria, and I'' is associated with the negative criteria.

Step 5: Calculate the separation measures, using the n-dimensional Euclidean distance. The separation of each alternative from the positive-ideal solution (D_j^{+}) is given as (Pazand et al. 2012a):

$$D_j^{+} = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^{+}\right)^2} \qquad j = 1, 2, \ldots, J \tag{10}$$

Similarly, the separation of each alternative from the negative-ideal solution (D_j^{-}) is as follows:

$$D_j^{-} = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^{-}\right)^2} \qquad j = 1, 2, \ldots, J \tag{11}$$

Step 6: Calculate the relative closeness to the ideal solution and rank the performance order. The relative closeness of the alternative A_j can be expressed as (Pazand et al. 2012a):

$$CC_j^+ = \frac{D_j^-}{D_j^+ + D_j^-} \qquad j = 1, 2, \ldots, J \qquad (12)$$

Since $D_j^- \geq 0$ *and* $D_j^+ \geq 0$, then clearly $CC_j^+ \in [0,1]$. The larger the index value, the better the performance of the alternatives (Pazand et al. 2012a).

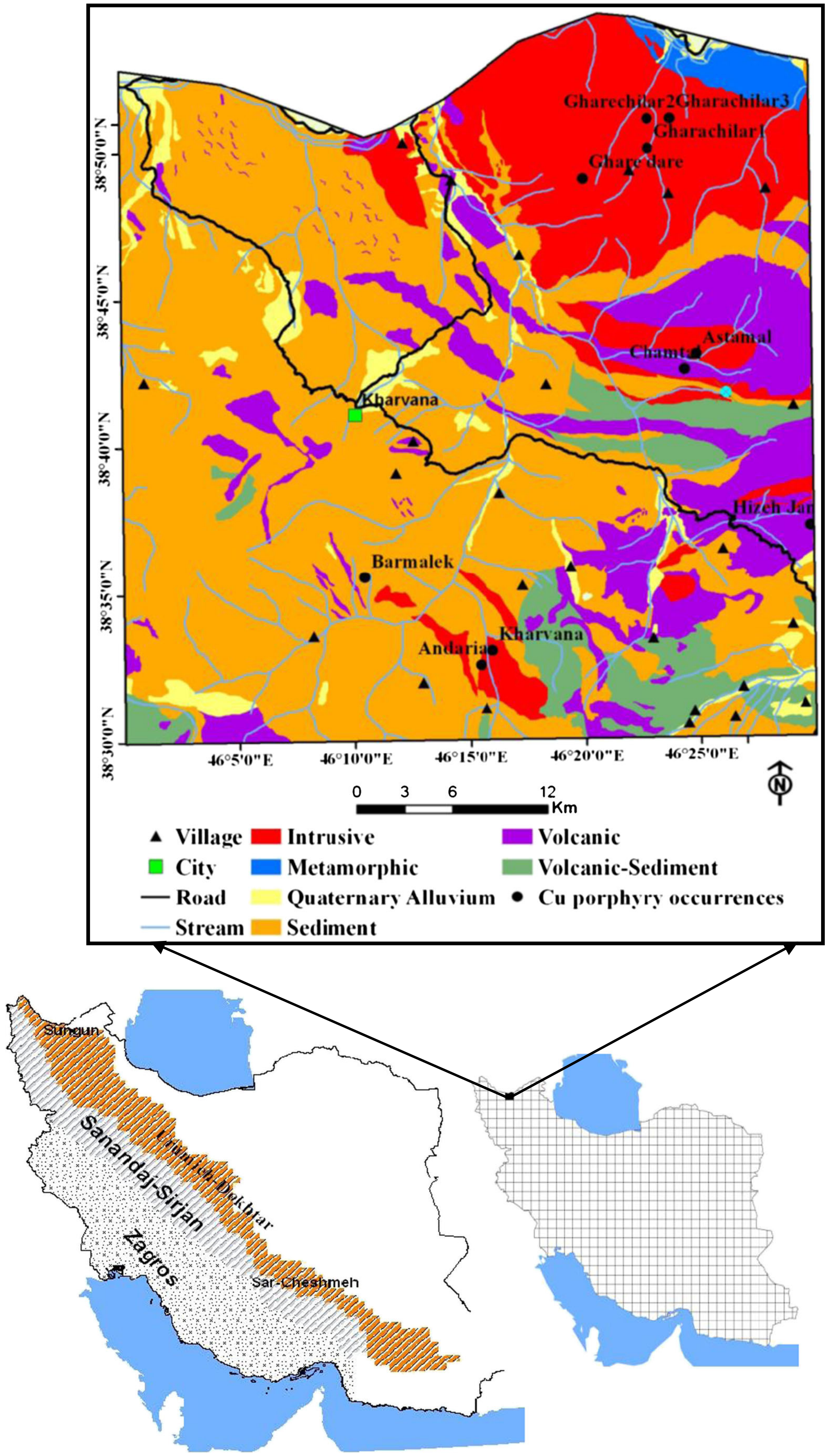
Study area

The Siahrud area (one of 1:100,000 sheets in Iran) is located in the East Azarbaijan province, NW Iran, in the northern part of the Cenozoic Urumieh–Dokhtar magmatic arc (Fig. 1). Continental collision between the Afro-Arabian continent and the Iranian micro-continent during closure of the Tethys ocean in the Late Cretaceous resulted in the development of the Urumieh-Dokhtar magmatic arc (Mohajjel and Fergusson 2000; Babaie et al. 2001; Karimzadeh Somarin 2005). The entire known porphyry copper mineralization in Iran occurs in the Urumieh–Dokhtar orogenic belt (Fig. 1). This belt was formed by subduction of the Arabian plate beneath central Iran during the Alpine orogeny (Berberian and King 1981; Pourhosseini 1981) and hosts two major porphyry copper deposits. The Sarcheshmeh deposit is the one of these being mined, and contains 450 million tons of sulfide ore with an average grade of 1.13 % Cu and 0.03 % Mo (Waterman and Hamilton 1975). The Sungun deposit, which contains 500 million tons of sulfide reserves grading 0.76 % Cu and 0.01 % Mo (Hezarkhani and Williams-Jones 1998), is currently being developed. A number of economic and sub-economic porphyry copper deposits are all associated with mid- to late-Miocene diorite/granodiorite to quartz-monzonite stocks in Ahar-Arasbaran zone in this belt (Hezarkhani 2008). In Siahrud area, volcanic activity started in the upper Cretaceous with marine facies and in the middle Eocene by marine-land facies has reached its peak. In the upper Eocene - Oligocene igneous activity as has been plutonism and in the Neogene these activities as a shallow intrusive dacite, rhyodacite, trachyte, trachyandesite and basalt has been continued. The effect of volcanism as andesite and latite domes can be seen. Regionally, the oldest country rocks are Devonian metamorphic complex (meat diabase-gabbro, amphibolites, biotite schist, and marble) that has appeared in the northern region. The Oligocene–Miocene intrusive rocks include granodiorite, diorite, granite, and monzonite (Mehrpartou 1997). The youngest rocks of the region are Quaternary sediment. Ten porphyry copper occurrences in district have been identified (Fig. 1). Here we describe summary the two of these deposits. The Hizeh-jan deposite is comprised tuff and volcanic rocks including trachyandesite domes with Pliocene age. The dominant hydrothermal alteration in the studied area is prophyllic alteration. Other types of alteration such as argillic and silicification are seen as more limited. The Gharechilar deposit is located in the North West study area and its host rock is granite and is accompanied by granodiorite. Several andesitic and diorite dykes are seen in the whole area. Mineralization is controlled by fault and shears zones and potassic, prophyllic and iron oxide alteration are wide spread (KarimzadehSomarin et al. 2001; Pazand et al. 2013).

Fig 1 Major structural zones of Iran (after Nabavi 1976) and the ▶ locations of these zones in the Siahrud area with its modified and simplified geologic map (after Mehrpartou 1997)

The AHP-TOPSIS method

The AHP-TOPSIS model for the Porphyry Cu potential area selection problem, composed of AHP and TOPSIS methods, consists of three basic stages: (1) identify the criteria to be used in the model, (2) AHP computations, (3) evaluation of the study area with TOPSIS and the determination of the potential area (Dagdeviren et al. 2009). At the first stage, the main porphyry copper exploration criteria which will be used in area potential evaluation are determined and the decision hierarchy is formed. AHP model is structured such that the objective is on the first level, criteria are in the second level and alternative areas are on the third level. In the last step of the first stage, the decision hierarchy is approved by decision-making team. After the approval of decision hierarchy, criteria used in the potential area selection are assigned weights using AHP in the second stage. In this phase, pairwise comparison matrices are formed to determine the criteria weights. The experts from the decision-making team make individual evaluations using the scale provided in Table 1, to determine the values of the elements of pairwise comparison matrices. Computing the geometric mean of the values obtained from individual evaluations, a final pairwise comparison matrix on which there is a consensus is found. The weights of the criteria are calculated based on this final comparison matrix. In the last step of this phase, calculated weights of the criteria are approved by decision-making team. The potential area ranks are determined by using TOPSIS method in the third stage. Schematic diagram of the proposed model for Porphyry Cu potential mapping is provided in Fig. 2.


Gharechilar2
Gharachilar3
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Astamal
Chamta
Kharvana
Hizeh Jan
Barmalek
Kharvana
Andaria
38°50'0"N
38°45'0"N
38°40'0"N
38°35'0"N
38°30'0"N
46°5'0"E
46°10'0"E
46°15'0"E
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Sanandaj-Sirjan
Urumieh-Dokhtar
Zagros
Sar-Cheshmeh

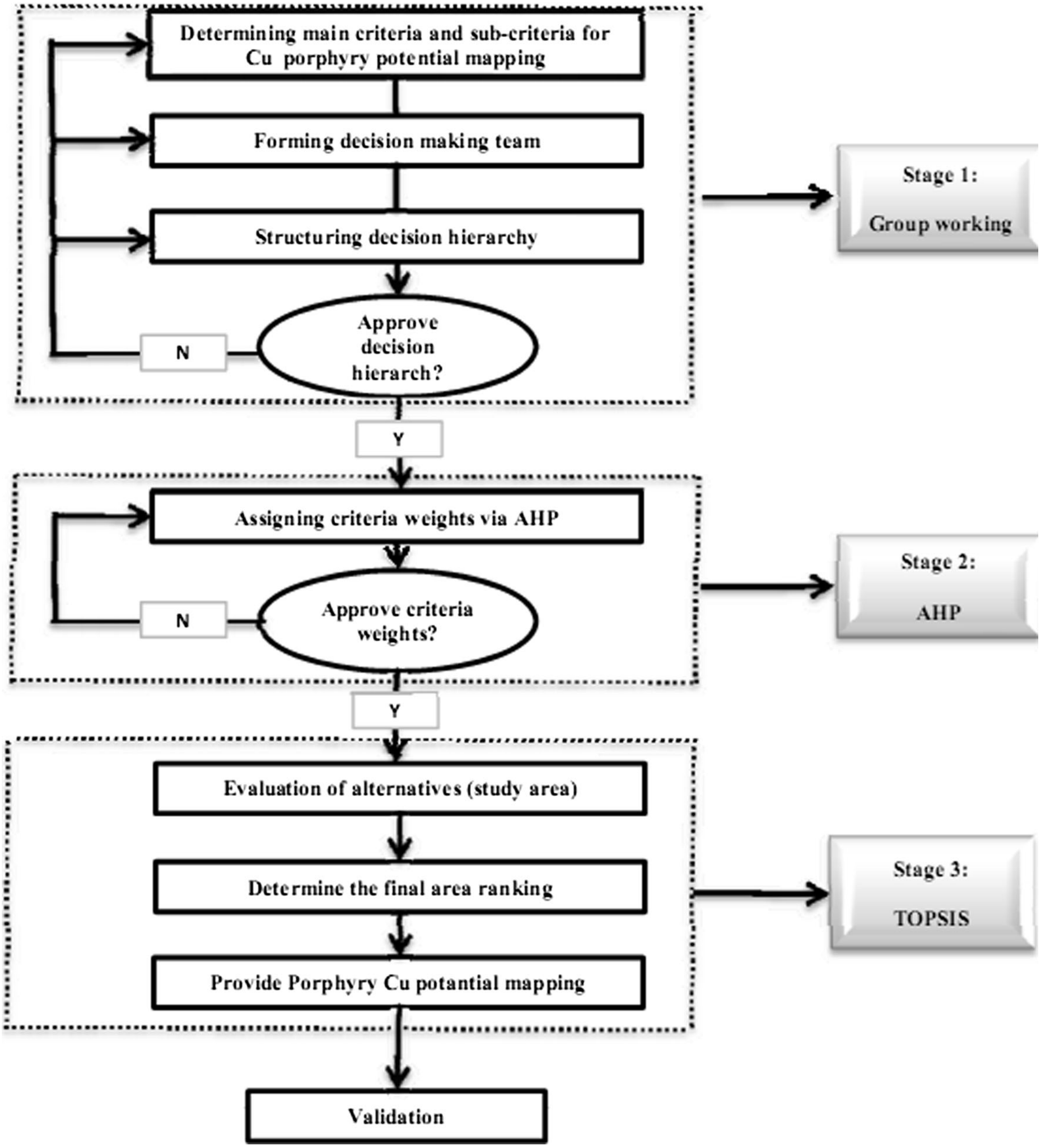

Fig. 2 Schematic diagram of the proposed model for Porphyry Cu potential area

Application of the AHP-TOPSIS method to porphyry copper potential mapping

The research on porphyry copper deposits has been a popular topic, because of its large benefits (Guangsheng et al. 2007). Exploration activities are associated with a high risk. Therefore, efforts should be made to the maximum precision to reduce this risk. Mineral exploration in regional scale is very important and the results are based in further exploration work. But due to complicated geological conditions it is hard to choose the most potential area. Mineral potential mapping is a method for helping this area selection and is multi-criteria decision-making task in which diverse geo-data sets including airborne geophysical data, geochemical layers, remote sensing and geological evidential ones are used to generate final potential map that will be used not only to summarize the regional geology setting and the regional metallogenetic theory but also to show models for exploration targeting (Pazand and Hezarkhani 2013; Gongwen and Jianping 2008). Both the global and Iranian statistics indicate that porphyry copper deposits play a significant role in the copper resources. For the application of AHP-TOPSIS model, relative importance of the criteria was analyzed by called Expert Judgment System. In this research, we invited experts with Cu porphyry backgrounds to give the corresponding relative importance of each factor and then analyzed all the opinions, and finally, gained the rank of relative importance for each factor by nine basic terms as shown in Table 1. Pairwise comparison matrices used to calculate criteria weights were also formed by the same experts.

Identification of necessary criteria

Porphyry copper deposits due to the large and important reserves have been well studied. Most of the porphyry copper deposits have been intensively studied (e.g., Sillitoe 1973; Ahmed and Rose 1980; Dilles and Einaudi 1992) and their properties are relatively well understood. Several conceptual models have been proposed to explain the different styles of porphyry Cu mineralization (Sillitoe 2010; Gruen et al. 2010; Volkov et al. 2006). In the study area also porphyry Cu mineralization was completely studied (Hezarkhani 2006, 2008; Hezarkhani et al. 1997, 1999; Hezarkhani and Williams-Jones 1996; Mollai et al. 2004; Mollai et al. 2009). Consequently, the data used in this study based on these studies were selected. The four main criteria as input map layers include stream sediment geochemical data, geology, structural data, and remote sensing are considered and determined by the expert team. Geological data input into the GIS were derived and compiled from a 1:100,000 scale geological map, from which lithologic units were handed-digitized into a vector (segment) format. Each polygon was labeled according to the name of each litho-stratigraphic formation and two host rock evidential maps were prepared to include intrusive and volcanic rocks (Fig. 3).

There are 1,215 geochemical samples of stream sediment that have been analyzed. After normalization, the data were assigned to five classes. The pathfinder element values equal to or less than the mean ($\overline{x}$) are considered low background. Values between the mean and mean plus one standard deviation (SD) are high background ($\overline{x}$ +SD). Values greater than $\overline{x}$ +SD however less than or equal to $\overline{x}$ +2SD are slightly anomalous. Values greater than $\overline{x}$ +2SD but less than or equal to $\overline{x}$ +3SD are moderately anomalous and values greater than $\overline{x}$ +3SD is highly anomalous. This classification was applied to data for Cu, Mo, Pb, Zn, As, Sb and Ba as pathfinder element porphyry copper mineralization and geochemical evidence maps were prepared for each of these elements (Fig. 4).

A number of fractures and lineaments in the mineralization zone can be guided for exploration. These fracture zones form duct for fluid hydrothermal in porphyry copper deposits. Linear structural features interpreted from aeromagnetic data and remotely sensed data were combined with faults portrayed on the geological map in order to generate a structural evidence map. This layer was buffered with 500 and 1,000 m distance (Fig. 5).

Remote sensing data (ASTER) were used for extraction argillic, phyllic, prophyllitic and iron oxide alteration layer

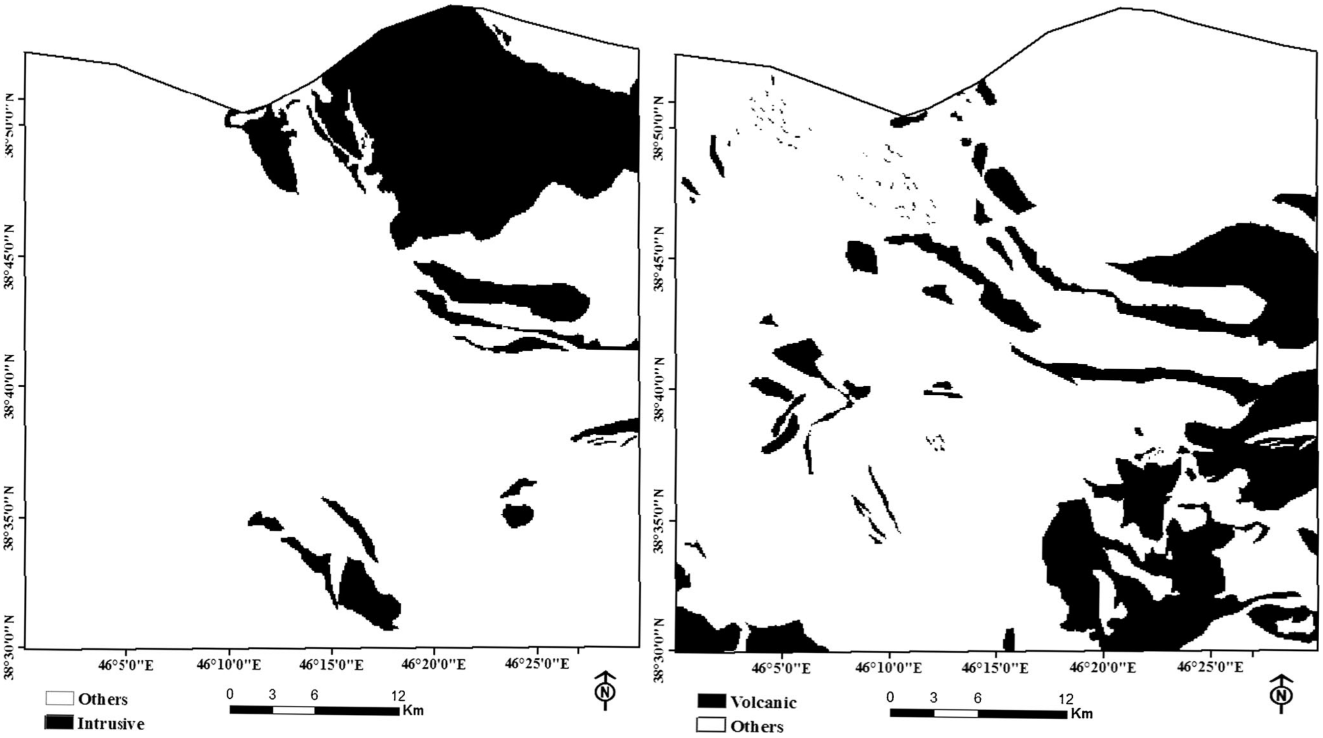

Fig. 3 Geological layers of intrusive and volcanic rocks

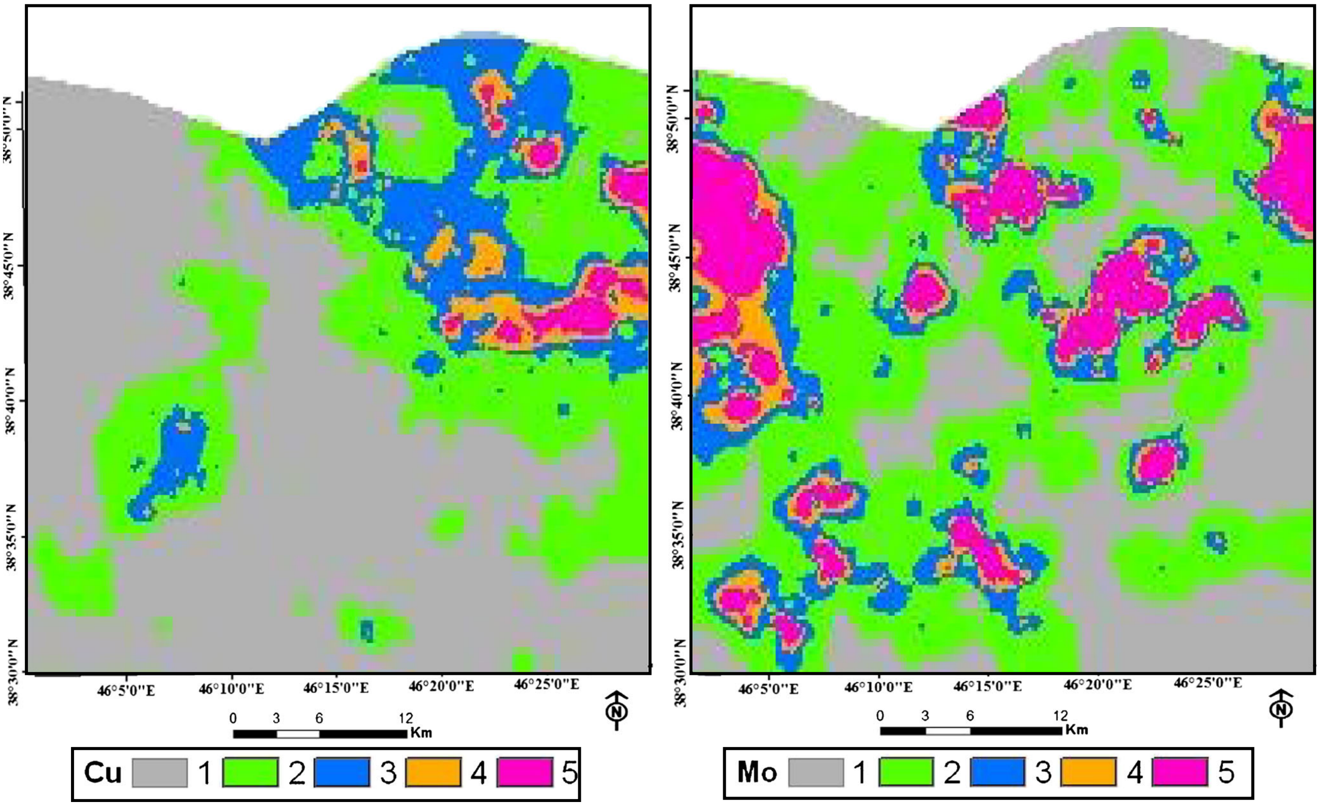

Fig. 4 Geochemical layers of Cu and Mo

(Azizi et al. 2010; Pazand et al. 2012b) as four alteration sub-criteria and for preparing an alteration evidence map (Fig. 6).

Each of the evidence maps has been converted to raster with cell size 100 × 100 m in ArcGIS software. There are four levels in the decision hierarchy structured for the mineral potential mapping process. The overall goal of the decision process determined as porphyry Cu favorability is in the first level of the hierarchy. The criteria are on the second level and sub-criteria are on the third level of the hierarchy. At fourth level the alternative area (cells) for porphyry Cu mineralization is located (Fig. 7).

Calculate the weights of criteria

After forming the decision hierarchy for the problem, the weights of the criteria to be used in the evaluation process are calculated by using the AHP method. In this phase, the experts in the group of the DMs are given the task of forming individual pairwise comparison matrix by using the scale given in Table 1. The geometric means of these values are found to obtain the pairwise comparison matrix on which there is a consensus. Finally, all the values for a given attribute were pairwise compared. The weight (W) of each criterion in each hierarchy was calculated by their structural models (Fig. 7). Criteria weighting (Wi) was calculated by

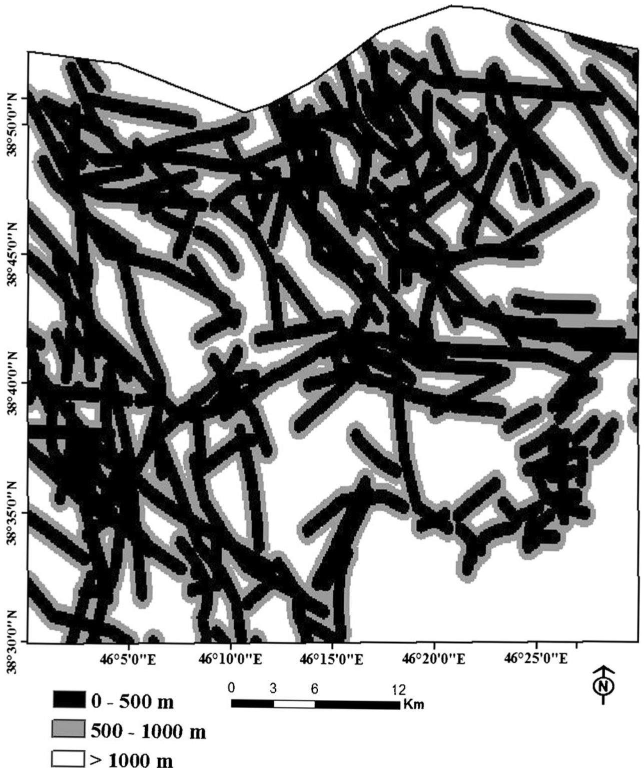

Fig. 5 distribution of faults in study area

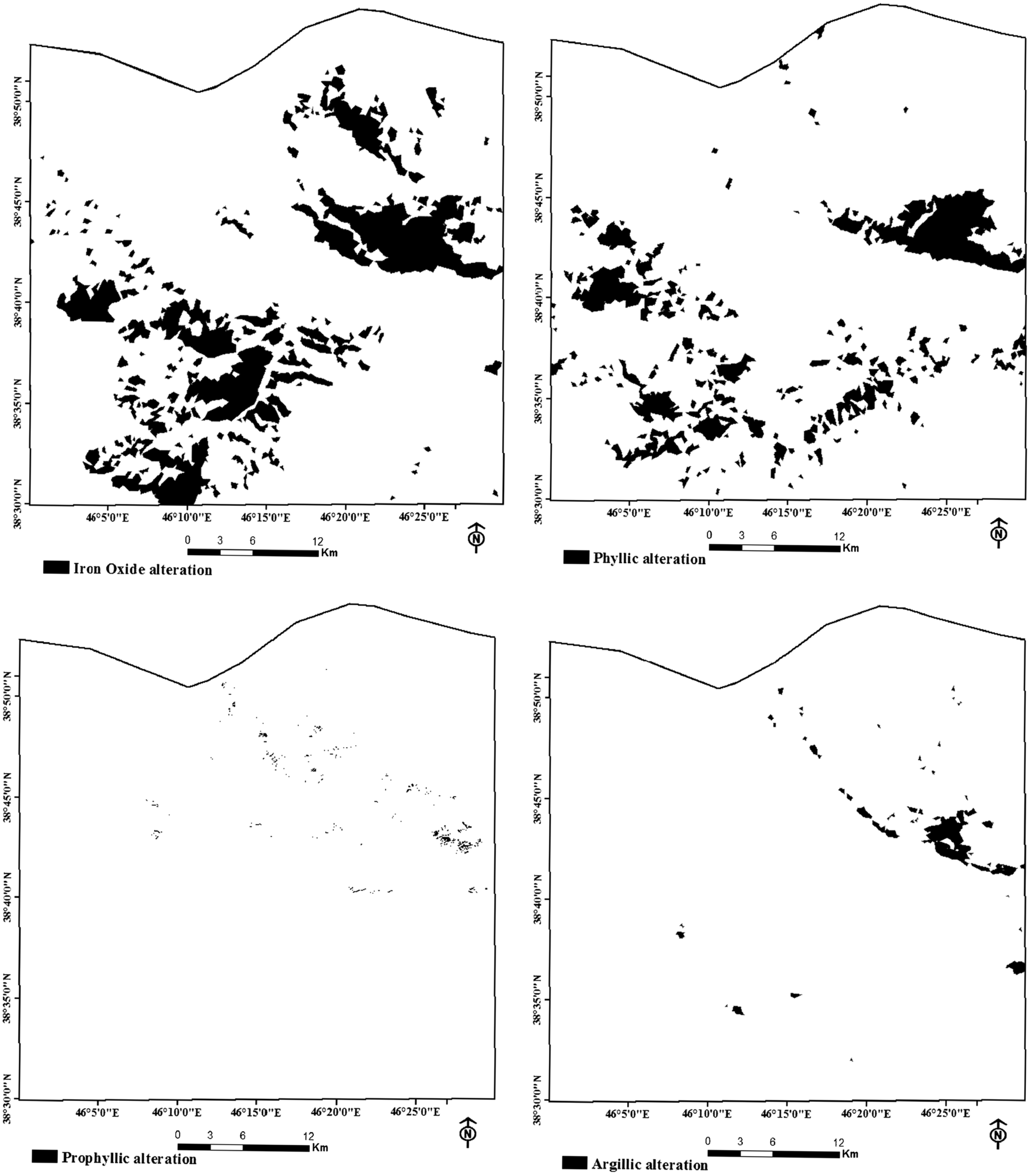

Fig. 6 Alteration layers of Iron oxide, Phyllic, Prophyllic and Argillic

normalizing the weight (W) of each factor. Wi is the criteria weight, i.e., the CR values of all the comparisons were lower than 0.10, which indicated that the use of the weights was suitable (Saaty 1996). Based on the results of the main criteria, including geochemistry, geology, alterations, and faults calculate the final matrix, were used. In this comparison matrix, criteria importance coefficients were calculated (Table 2). In Table 2, it is shown that the alteration is the most important factor (Weight=0.398345), followed by geology being the next most important factor with W=0.26208.

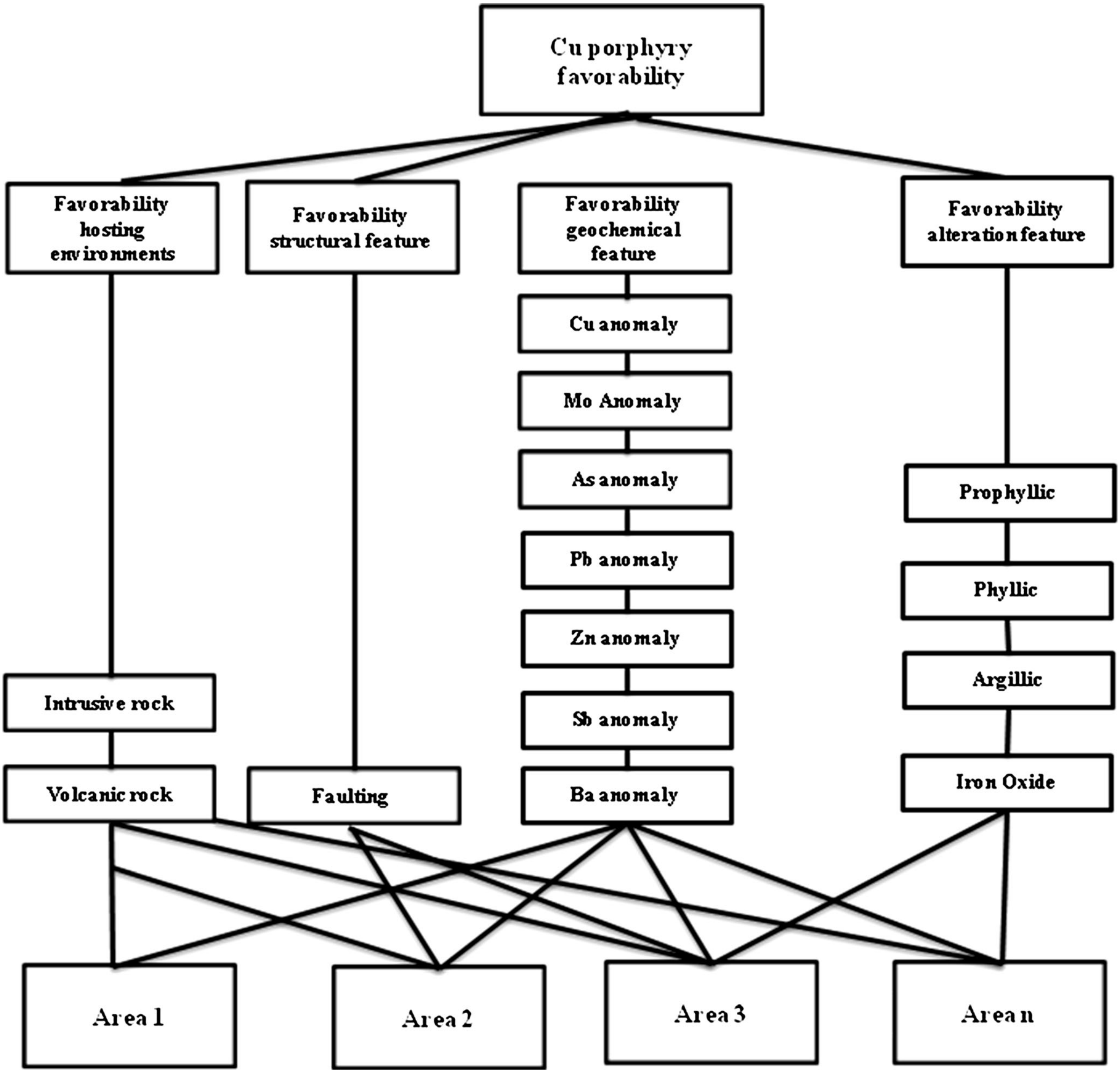

Fig. 7 The decision hierarchy of porphyry Cu potential area

Table 2 Pairwise comparison between main criteria

	Geochemical	Alteration	Geology	Fault	W
Geochemical	1	0.5	1	5	0.255354
Alteration	2	1	2	5	0.398345
Geology	1	0.5	1	5	0.26208
Fault	0.2	0.2	0.2	1	0.084221
	CR=0.0658				

Table 3 Pairwise comparison between geochemical sub-criteria

	As	Ba	Cu	Mo	Pb	Sb	Zn	W
As	1	2	0.2	0.3333	2	2	2	0.0976
Ba	0.5	1	0.1429	0.2	1	1	1	0.0527
Cu	5	7	1	3	7	7	7	0.4453
Mo	3	5	0.3333	1	5	5	5	0.2463
Pb	0.5	1	0.1429	0.2	1	1	1	0.0527
Sb	0.5	1	0.1429	0.2	1	1	1	0.0527
Zn	0.5	1	0.1429	0.2	1	1	1	0.0527
	CR=0.0088							

Table 4 Pairwise comparison between alteration sub-criteria

	Prophyllic	Argillic	Phyllic	Iron Oxide	W
Prophyllic	1	0.5	0.2	1	0.1093
Argillic	2	1	0.3333	2	0.209
Phyllic	5	3	1	5	0.5725
Iron Oxide	1	0.5	0.2	1	0.1093
	CR=0.0015				

Geochemistry weight is equal to 0.255354 and for the faults layer with equal weight is 0.084221. The consistency ratio is CR=0.0658, which for the pairwise comparison of the criteria is reasonable (CR<0.1).

A pairwise comparison matrix of geochemical criteria is shown in Table 3, and the importance of each factor as weight (W) of factor is calculated.

It is apparent that the Cu anomaly is the most important factor (weight=0.4453), followed by Mo being the next most important factor with W=0.2463. CR=0.0088 for the pairwise comparison of the criteria, which is considered reasonable (CR<0.1). The calculations for the sub-criteria of alteration are performed and their weights obtained (Table 4).

Other criteria and sub-criteria were calculated with this method. The final weights of each sub-criterion are shown in Table 5.

Evaluation of study area and provide the predictive porphyry Cu potential mapping

At this stage of the decision procedure, establish the decision matrix by comparing alternatives (cells) under each of the criteria separately according Eq. (5). After the evaluation matrix was determined, the second step is to obtain a weighted decision table. Using the criteria weights calculated by AHP in this step, the weighted evaluation matrix is established with Eq. (7). For the third step, the distance of each alternative from A^+ and A^- can be currently calculated using Eqs. (8) to Eq. (11). The fourth step solves the similarities to an ideal solution by Eq. (12) (Dagdeviren et al. 2009) and the mapping of potential for porphyry copper mineralization in the Ahar-Arasbaran area, was prepared by ArcGIS software (Fig. 8).

Table 5 The final weights of each sub-criteria

Main criteria	Sub-criteria	Sub-class	Weight	Main criteria	Sub-criteria	Sub-class	Weight
Geochemical	AS	As < x	0.001515141	Alteration	Prophyllic	Yes	0.03170442
		x < As < x+SD	0.002884682			No	0
		x+SD<As<x+2SD	0.005869464		Argillic	Yes	0.060624187
		x+2SD< As<x+3SD	0.011898177			No	0
		As> x+3SD	0.023332257		Phyllic	Yes	0.166063863
	Ba	Ba < x	0.000818114			No	0
		x < Ba < x+SD	0.00155761		Iron Oxide	Yes	0.03170442
		x+SD<Ba<x+2SD	0.00316927			No	0
		x+2SD< Ba<x+3SD	0.006424528	Geology	Intrusive	Yes	0.10925739
		Ba> x+3SD	0.012598463			No	0
	Cu	Cu < x	0.00691283		Volcanic	Yes	0.087646046
		x < Cu< x+SD	0.013161363			No	0
		x+SD<Cu<x+2SD	0.026779431	Fault	< 500 m	0.03511052	
		x+2SD< Cu<x+3SD	0.054285435		500-1,000 m	0.01170348	
		Cu> x+3SD	0.106453423		> 1,000 m		0
	Mo	Mo < x	0.003823557	Geochemical	Sb	Sb < x	0.000818114
		x < Mo < x+SD	0.007279685			x < Sb < x+SD	0.00155761
		x+SD<Mo<x+2SD	0.014811977			x+SD<Sb<x+2SD	0.00316927
		x+2SD< Mo<x+3SD	0.03002583			x+2SD< Sb<x+3SD	0.006424528
		Mo> x+3SD	0.058880481			Sb> x+3SD	0.012598463
	Pb	Pb < x	0.000818114		Zn	Zn < x	0.000818114
		x < Pb < x+SD	0.00155761			x < Zn < x+SD	0.00155761
		x+SD<Pb<x+2SD	0.00316927			x+SD<Zn<x+2SD	0.00316927
		x+2SD< Pb<x+3SD	0.006424528			x+2SD< Zn<x+3SD	0.006424528
		Pb> x+3SD	0.012598463			Zn> x+3SD	0.012598463

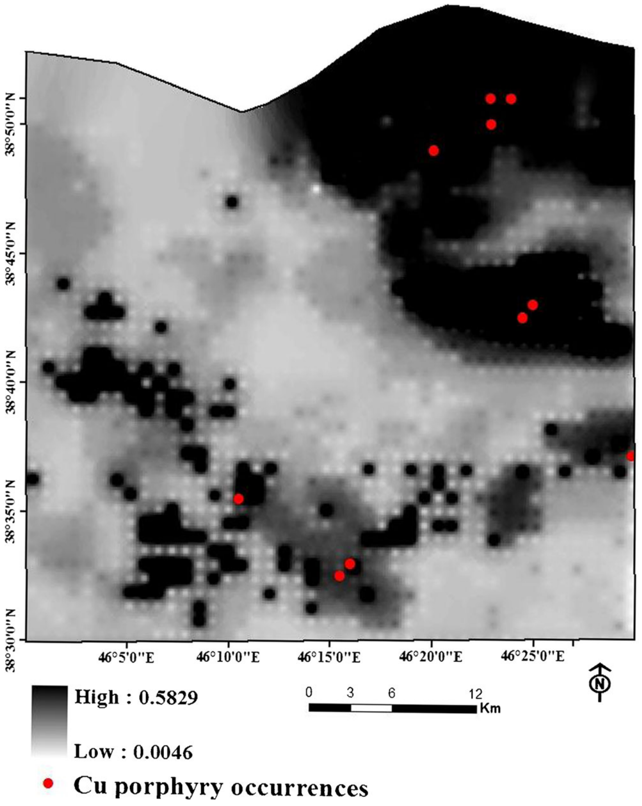

Fig. 8 Potential mapping for Cu porphyry mineralization in Siahrud area

Discussion

Each modeling method for predictive mineral potential mapping offers advantages and disadvantages, and this paper has endeavored simply to illustrate a possible methodology for producing a mineral prospect map using a GIS (Pazand et al. 2012a). Application of AHP-TOPSIS to mineral-potential mapping is knowledge-driven method that is based on expert knowledge of spatial association between known deposits and spatial features representing geologic controls of deposit occurrence. The basic concept behind this method is that the criteria weights are derived by using AHP based on pairwise comparison and the chosen prospect area using TOPSIS should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. In the approaches to exploration modeling, one of the most significant procedures is the definition of weight for each criterion. Inaccuracies in determining the criteria weights can cause errors in estimating the potential areas. To avoid this mistake and accurate estimate of potential areas, we used experience of experts in porphyry copper exploration. Thus from geologists with expertise in the copper exploration and geologists who were familiar with the metallogeny of the study area were invited to make the score of each criteria. The ultimate test of AHP-TOPSIS model for porphyry Cu deposit is the predictive ability of the favorability map. A suitable method for measuring the performance of a model for mineral potential maps consists of attempting to predict occurrences of deposits within the study area (Pazand et al. 2012a). As seen in the maps of the total number of the 10 known porphyry copper occurrences in the region, 8 occurrences were located in areas with high potential; this means that model predicts 80 % of the known porphyry copper deposits, and 2 occurrences were located in areas with moderate potential, so ability and the accuracy of the method confirmed. Furthermore, a preliminary field study in two new areas that introduced in northern and western parts of the study area was conducted and the direct effects of copper mineralization as malachite and hydrothermal alteration processes were observed.

Conclusions

Explores strategies for non-renewable resources have been changing rapidly along with the accelerating innovations in computer hardware and information- processing technology. The aim of this research is to construct AHP-TOPSIS model to provide potential mapping. In this study, a previously developed knowledge-driven method called the AHP-TOPSIS method was used to produce a prospectivity map in the Siahrud area located in north eastern of Iran. The results demonstrated the following:

1- The methodology combining the multiple criterion decision-making problems with GIS provided an improved method for potential mapping, which enhanced the capability of spatial analysis by the GIS and the capability of multi layer analysis by the AHP-TOPSIS.
2- The qualitative and quantitative knowledge of spatial association between known mineral occurrences and geological features are together useful in the subjective decision on the appropriate scores.
3- The design of the AHP-TOPSIS procedure applying to the evidence for mapping mineral potential must be based on the knowledge of the geological controls and the genesis or the mode of formation of known mineralization in a particular area.
4- The AHP method has high potential in determining the relative importance of the exploration criteria.
5- Validity of the results was confirmed by the distribution of the known deposits and field checking.
6- This method is useful for the exploration of Cu porphyry deposits because of incorporating very significant pathfinder features, such as hydrothermal alteration, geochemical patterns, and geological setting.

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