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New Approach in Application of the AHP–Fuzzy TOPSIS Method in Mineral Potential Mapping of the Natural Bitumen (Gilsonite): A Case Study from the Gilan-e-Gharb Block, the Kermanshah, West of Iran

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Abstract: The Gilan-e-Gharb block is known as a prospective area for hydrocarbon resources in the form of oil, gas in deep potential and natural bitumen (Gilsonite) on the surface. Natural bitumen is not clearly detectable by geochemical or geophysical methods. Hereupon, identifying high potential areas for further exploration, attempted with the help of AHP-Fuzzy and TOPSIS methods. The comprehensive database of geological and geostructural records, satellite imagery analysis by remote sensing and mine indexes counted as the inputs for this method. First, the lithological unit as the main mineralization hosts determined with respect to the dominant geological structures as a factor of controlling natural bitumen placement (fold, fracture and faults) in the Gilan-e-Gharb block. The Gachsaran, Asmari, Pabdeh and Gurpi Formations identified as the most important lithological units for mineralization. Placement and distribution of natural bitumen mineralization in the form of mine indexes are added to the geology database. Finally, we assigned appropriate weights to applied information layers using Analytical Hierarchy Processing (AHP) based on knowledgeable information and field studies to synthesize exploratory data. Then, we used the FTOPSIS method to define the Positive Ideal Solution (FPIS, A+) that allows maximizing the beneficial characteristics and minimizing the impediment characteristics and the Negative Ideal Solution (FNIS, A-) that minimizes the beneficial characteristics and maximizes the impediment characteristics. This method, as a new approach in the exploration of minerals with a shortage of data, is applicable to other mineral deposits.

Keywords: AHP-Fuzzy, MPM Hierarchy, TOPSIS, Natural Bitumen, Gilan-e-Gharb Block

Introduction

When crude oil escapes from the depths of the earth over time and evaporates because of exposure to the atmosphere, the black mineral known as natural bitumen or Gilsonite is remained (Pruitt, 1961; Meyer *et al.*, 2007; Akbari Nasrekani *et al.*, 2018; Rahimi *et al.*, 2019). This heavy hydrocarbon material is classified into various groups, such as asphaltic pyrobitumen, non-asphaltic pyrobitumen, asphaltites, etc. These groups are divided into different subgroups based on formation, physical properties, solubility in carbon tetrachloride and chemical composition. Asphaltites are categorized into three groups of Gilsonite, Grahamite and Glance pitch (Rahimi *et al.*, 2019). Gilsonite is one of the highest qualities and the most desirable type of bitumen, which is observed in terms of liquid, semi-solid and solid according to its purity and life span. Based on the aforementioned features of this mineral, many industries benefit by the use of natural bitumen in the fields of asphalt binder, road paving, pigment, waterproof coating, etc. (Joseph, 1961). Moreover, there are some elements like trace and rare earth elements into the natural bitumen and oil sands, which makes them more valuable as a by-product (Tsoy, 2015; Rahimi *et al.*, 2016; Shekarian *et al.*, 2017).

The largest reserves of natural bitumen mines are located in the United States, Canada, Iran, Iraq, Russia, Venezuela, China, Australia, Mexico, Albania and the Philippines, respectively (Pruitt, 1961; Meyer *et al.*, 2007). In the US, the largest Gilsonite reserves have been found in Utah and Colorado and are estimated to have a reserve of 45 million tons, according to the US Geological Survey (Pruitt, 1961). Iran seems to be the third-largest natural bitumen reserve in the world, with around 15% of these reserves (Meyer *et al.*, 2007; Rahimi *et al.*, 2019).

Delineating prospective zones within an area of interest as the main purpose of mineral exploration is the initial step of discovering minable deposits in the development process (Parsa *et al.*, 2017; Ghezelbash *et al.*, 2019). Numerous spatial datasets compiled, analyzed and integrated into a geographic information system in order to provide a model of mineralization in an area (Abedi *et al.*, 2012a). A predictive model of prospective zones is resulted by using Mineral Prospectivity Modeling (MPM), which is a representative Multiple Criterion Decision-Making (MCDM) function in the area of interest (Zuo and Carranza, 2011; Abedi *et al.*, 2012b; Karbalaei Ramezanali *et al.*, 2020).

MCDM is defined as a combination of values that figured out by researchers in order to decide close to the actual outcomes. Analytical Hierarchy Process (AHP) is one of the popular methods of multiple criteria decision-making for mineral prospectivity modeling (Geranian *et al.*, 2015; Pazand and Hezarkhani, 2015; Abedi and Norouzi, 2016). The typical of AHP is to make a set of criteria and weight methodically based on their importance. In this procedure, parameters measured according to the aforementioned produced criteria and a final score is attributed based on the weight (Abedi and Norouzi, 2016; Asadi *et al.*, 2016; Feizi *et al.*, 2017a).

Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) is another method that is usually used as a comparing approach in parameters (Dagdeviren *et al.*, 2009; Awasthi *et al.*, 2010; Abedi and Norouzi, 2016; Asadi *et al.*, 2016; Feizi *et al.*, 2017b). To achieve the advantages of these two methods, this paper applies a combination of both AHP-FTOPSIS with a focus on mapping the high-potential zones of natural bitumen mineralization in the Zagros fold-thrust belt, which is a few known for natural bitumen deposit occurrences. The process of evaluation in this research is shown in Fig. 1. This diagram illustrates how to reach a final decision gradually by defining a problem, introducing choices, determining evaluation criteria and collecting data to analyze different processing methods for natural bitumen resources. In the following, the criteria weight vector is obtained from the AHP method and for integrating different data sets, the FTOPSIS algorithm is used in the final steps. TOPSIS operates in terms of pixels considered as attributed distances to positive (best alternative) and negative (the worst alternative) ideal solution (Chen, 2000; Kahraman *et al.*, 2003; Abedi *et al.*, 2012b). The user chooses ideal solutions based on the evaluation of existing data. The simplicity of this method and more importantly, no need of prior knowledge by the decision-maker considered as the most significant advantages of this method when comparing to other MCDM algorithms, such as ELECTRE (Abedi *et al.*, 2012a) and PROMETHEE (Abedi and Norouzi, 2016). TOPSIS method requires the only criteria of the weight vector, unlike other knowledge-driven algorithms that are determined by the AHP method. Fuzzy set the theory combined with the MCDM method that has been extensively used when dealing with variables (Lee, 2009; Abedi *et al.*, 2012a; Chai *et al.*, 2013). This methodology provides a suitable language to manage imprecise criteria that will be able to integrate the analysis of qualitative and quantitative factors (Chen *et al.*, 2006; Liao and Kao, 2011; Zouggari and Benyoucef, 2012; Abedi and Norouzi, 2016).
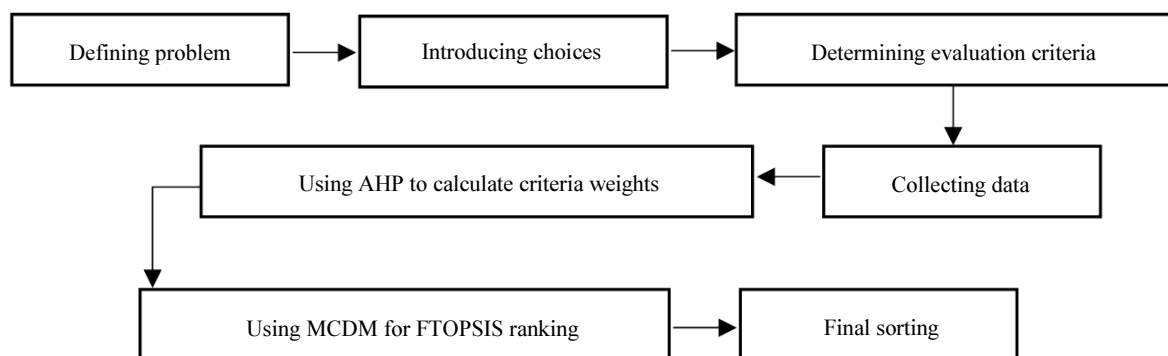

Fig. 1: Research procedure stages of finding the best evaluation of criteria (Chen, 2000).

The integration of AHP and TOPSIS in a fuzzy environment has not been studied in the field of mineral prospectivity modeling in the initial exploration of the natural bitumen deposits. However, there have been several studies on implementing these methods and their combination for exploration of ore deposits such as copper, gold, iron, etc., (Pazand and Hezarkhani, 2015; Asadi *et al*., 2016; Feizi *et al*., 2017a; 2017b). This paper presents a new technique of combining the proposed methods using MPM in a fuzzy environment and examines this method in this case study. The rest of this paper is organized as follows: In section 2, the geological setting of the Gilan-e-Gharb block is provided, especially from the tectonic viewpoint, since the outcrop of the natural bitumen occurs with structural geology exposures. In addition, the mining and mineralization indexes are defined. Moreover, remote sensing as an important tool for satellite images processing represents the distinction of stratigraphy and also help to indicate key beds and lineaments for exploration of this mineral. In section 3, all the data layers are presented in the hierarchical structure of the proposed mineral potential mapping model. In this section, evaluations are made by different groups of DNs for all data layers, which contain lithology, mineralization and remote sensing using Expert Choice Software. For running the AHP analyses, a tool was written in Excel (Oztaysi *et al*., 2017) that the linguistic variables from the Excel-based investigations were converted into TFNs. Based on these numbers, the priority weights for the evaluation DNs were derived. The outputs of the AHP are used as inputs for the Fuzzy TOPSIS analysis procedure to calculate the CC_i values for MPM. The sensitivity analysis is the last step is also implemented in Excel. For the different steps of the MCDM process, the results can be illustrated graphically or in the form of tables. Finally, based on the priority in criteria weighting, the Mineral Potential Mapping (MPM) for natural bitumen is presented. This approach can be developed in the exploration of a new mineral deposit with a limited database. In this study, the result of potential natural bitumen map in the Gilan-e-Gharb block is reported. This area is one of the most promising zones that has been studied for natural bitumen a few decades ago. The objective of this paper is to show AHP-Fuzzy TOPSIS ability to process relevant data and produce a prospective map of natural bitumen, thereby, can be used for further exploration in a mine developing area.

Materials and Methods

Case Study

The Gilan-e-Gharb block is located structurally on the Zagros fold-thrust belt, which includes the east Lurestan sedimentary basin and the west part of the Northern Dezful sedimentary basin (Fig. 2) (Rahimi *et al*.,

2019). This block has an area of 1277 square kilometers in the Kermanshah province, located between the Qasr-e Shirin and the Gilan-e-Gharb towns and to the city of the Sumar southward near to the border of the Ilam province (Fig. 2). This zone of study includes hydrocarbon potential surface and deep anomalies, with the superficial potential, mainly consisted of natural bitumen, Gilsonite in particular (Rahimi *et al*., 2019).

The studied area was considered as a part of the Zagros fold-thrust belt. The bituminous outcrops demonstrate that this area is affected by structural and stratigraphical factors. Hydrocarbon materials moved through the seams and gaps from the bottom to the surface, which leads to forming oil and bitumen basin (Meyer *et al*., 2007; Akbari Nasrekani *et al*., 2018). More than 90% of the natural bitumen accumulation areas are located in the Gilan-e-Gharb block, which shows the bituminous prospectivity of this zone (Rahimi *et al*., 2019).

Geology and Stratigraphy

The Zagros fold-thrust belt is classified into five tectonic fault zones from northeast to south-west based on topography and structural morphology, deformation, evidence, geostructural and regional seismology (Bordenave, 2014; Asgari *et al*., 2019). Five tectonic zones are the high-Zagros thrust belt, folded belt, the Dezful embayment, the Zagros coastal plain, Persian Gulf low land and Mesopotamian, which are separated by deep and discontinuous thrusts (Hessami *et al*., 2001; Asgari *et al*., 2019). The only possibility of exposing hydrocarbon minerals to the surface is provided with a folded belt of these five tectonic zones (Sepehr and Cosgrove, 2004). Fault severity of the high-Zagros deteriorated formation of the reservoir and buried them with a thick covering of sediments in the Dezful embayment, the Zagros coastal plain, the Persian Gulf low land and Mesopotamian. This impeded hydrocarbon mineral to be outcropped on the surface, especially natural bitumen (Falcon, 1974). The Zagros fold-thrust belt is also divided into various geological regions from the north-west to south-east: The Lurestan, the Dezful embayment and the Fars region (Fig. 3) (Sepehr *et al*., 2006; Asgari *et al*., 2019). The stratigraphic and structural properties in these three geologic regions are different from each other and created a distinct folding and structural type (Sepehr and Cosgrove, 2004).

The stratigraphy of the Zagros plays an important role in the morphology and the main development of the Zagros structures. Moreover, the thickness of the sedimentary sequences presents the complexity of its tectonic history. Major changes can be seen from the sideways in the belt area which indicates the mechanical stratigraphy is not the same throughout the Zagros. Hereupon, the physical properties of the sedimentary rock coverage change

laterally, which resulted in different substructures in the Zagros belt and revealed different structural types (the Lurestan, Dezful and the Fars) (Bordenave, 2014). Several horizons of active detachment are in sedimentary rock coverage, including the Cambrian saline formation (Hormoz Formation), the Triassic evaporate sedimentary (Dashtak Formation), the Cretaceous shale (Kazhdomi Formation) and the Miocene evaporate sedimentary (Gachsaran Formation). These formations play a significant role in geometry and structural formation of the Zagros fold-thrust belt (Fig. 3) (Berberian, 1995; Hessami *et al.*, 2001; Sepehr and Cosgrove, 2004; Asgari *et al.*, 2019). The oldest rock units in the Gilan-e-Gharb block belong to the upper Cretaceous of the Gurpi Formation. These units outcropped along with rock units, include the Pabdeh, Asmari, Gachsaran, Aghajari and Quaternary sediments (Fig. 3) (Berberian, 1995).

Folds are the dominant structures of the Gilan-e-Gharb block, which observed in the sequences of anticline and syncline on the surface (McQuarrie, 2004; Sepehr *et al.*, 2006). In some parts of the area where the proper outcrops of the Pabdeh and Gachsaran formations are observed, this sequence of anticline and syncline were intensified and seen as minor folds as a subsidiary of the main large folds in the region (Berberian, 1995). These anticlines, as a host of mineralization of natural bitumen, had a principal role in this area. Faults in the study area are mostly small scale and include different trends and mechanisms (Falcon, 1974; McQuarrie, 2004). The thrust and inverse faults in this region are following the general trend of anticlines and the transverse faults acted as strike-slip faults with the trend of the northeast to the south-west (Bordenave and Hegre, 2010). In parts of this area, where formations of Pabdeh and Gurpi are considerably expanded, the characteristics of flexibility in these formations can be seen. From another aspect, the extensive outcrops of the Gachsaran Formation in the area resulted in the minimizing of rapture on the surface. Consequently, faults observed with a short length and low-depth that could not exceed the thickness of Aghajari and Gachsaran formations (Bordenave, 2008).
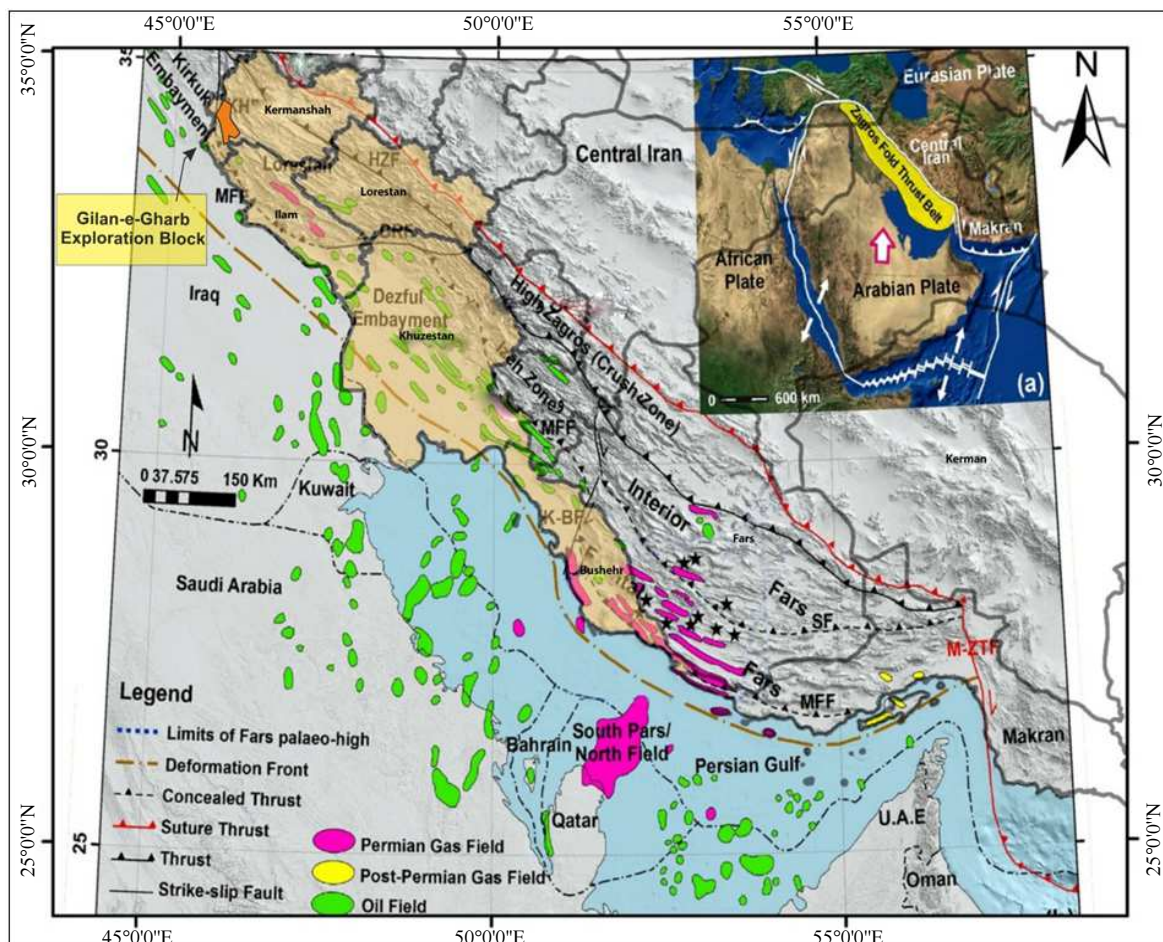
Fig. 2: The Lurestan-Dezful structural zone in the yellow strip shown within oil and gas fields, illustrating the prospectivity of bituminous mineralization in the Gilan-e-Gharb Exploration Block, which signified in an orange hue (Bordenave, 2014)
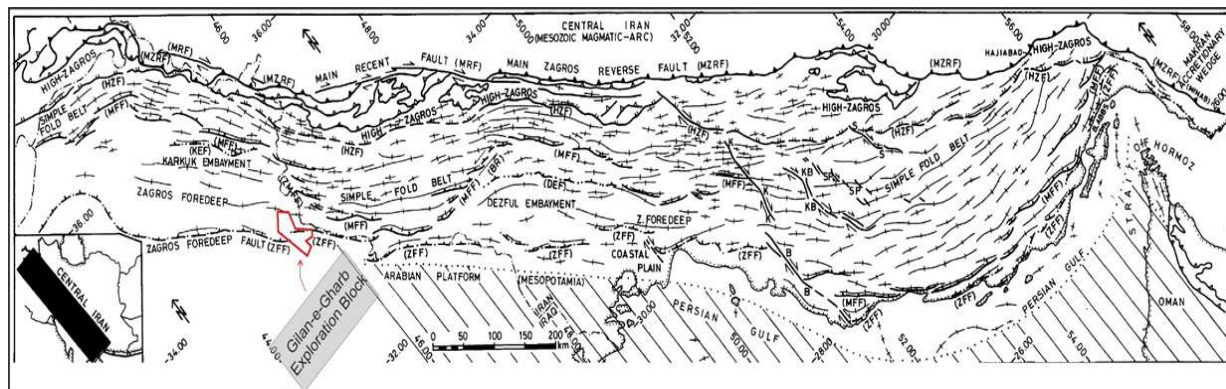
Fig. 3: Structures and zones of the Zagros thrust-fold belt and the location of the Gilan-e-Gharb block indicated (Berberian, 1995)

According to stratigraphic sequences of the region, folding of the area is divided into major and minor folds (McQuarrie, 2004). The Gurpi and the Pabdeh formations form the core of the major folds and the edges consist of the Asmari and the Gachsaran formations, which form the highlands of the region (Falcon, 1974; Sepehr and Cosgrove, 2004; Sepehr *et al*., 2006). The Gachsaran Formation has filled the distance between anticline structures of major faults. Minor faults normally formed into the Gachsaran formation that stratigraphically is only part of this formation and lithologically, the sequence of green marl, red marl and anhydrides observed (Sepehr *et al*., 2006).

The main anticlines of the Gilan-e-Gharb block from north-east to south-west consist of Imam Hassan, Vijenan, Shotoran, Darvana and Siah-Kouh. According to the existence of natural bitumen mines and outcrops on the edges of these anticlines, especially the south-west, these structures had high preferences in terms of exploration tracks (Rahimi *et al*., 2019).

More than 90% of oil accumulations are in the Asmari (early Miocene) and the Bangestan (the Sarvak Formation with Cenomanian-Turonian age and the Ilam Formation with age of Santonin) (Bordenave, 2008). The reservoir and cap rock of the oil system are based on the source rock in the Zagros (Bordenave and Hegre, 2010; Rahimi *et al*., 2019). The source rock is completely mature in all parts of the Lurestan and the Asmari formations that have been covered by the Gachsaran Formation. This formation is known as a suitable cap rock for oil accumulation that originated from the Pabdeh Formation (Fig. 4) (Bordenave, 2008). These source rock, reservoir and cap rock are the most expanded rock units in the Gilan-e-Gharb block. This factor has caused the Gilan-e-Gharb block to be known as the most prospective area for shallow reservoirs, near the surface and the outcrop of hydrocarbon minerals in the Zagros belt (Bordenave, 2014).

Mines and Mineralization Indexes

The Kermanshah Province is known as a rich region for natural bitumen resources in Iran (O'Brien, 1950; Dehghani and Makris, 1984; Bordenave, 2008; Rahimi *et al*., 2019). The most crucial host of natural bitumen mineralization (in terms of reserve and quality) is the Gachsaran Formation in the Gilan-e-Gharb exploration block (Hessami *et al*., 2001; Sepehr and Cosgrove, 2004; Sepehr *et al*., 2006; Rahimi *et al*., 2019). Moreover, the Kalhor anhydrite member of the Asmari and the Pabdeh formation and in some cases the Gurpi formation, are also significant in some potential sites (Bordenave and Hegre, 2010). The location of several important natural bitumen mines displayed on a satellite image in Fig. 5. According to the anhydrite member of Kalhor in the Asmari formation, in some places, there is enough space for the accumulation of natural bitumen. In these areas, a low-quality natural bitumen is largely involved in the anhydrite and mines are mostly abandoned in these areas. On the contrary, active mines like Cham-Emam Hasan and Graveh in the Gachsaran formation have good qualities and considerable reserve due to the presence of suitable space and mineralogical rock units (Rahimi *et al*., 2019). The Marjani and Kalkin-Sumar mines, with the production of 2000 tons per year, each can be named among large mines in the region. The significant feature of mine occurrences of this formation is that they are mainly observed with north-west to south-east trends and parallel with layering (Rahimi *et al*., 2019). Mineralization of natural bitumen in the Pabdeh formation is mainly observed with low reserves but high quality along

with the transverse fractures. Among mines mentioned in Fig. 5, the Babre-soukhteh mine found in the Pabdeh formation.

Remote Sensing Processing

One of the challenges in natural bitumen exploration is having no outcrops and located in the lower layers, which, if there are fractures and related structures, can reach the surface. According to field observations, most of these natural bitumen mines are located mainly in the Gachsaran Formation, the anhydritic part of the Asmari Formation (Kalhor member), the boundary of Asmari and Gachsaran Formations and to a smaller extent in the Pabdeh, Gurpi and Aghajari Formations. Many fractures are observed in the above-mentioned units, while the major mines of the region have been developed and exploited along with these fractures. In this section, the determination of the range and extension of these susceptible units are considered. In addition, the

identification of structural factors, including faults and fractures as structural controllers of bituminous mineralization, is presented as a result of satellite image processing using ENVI 4.3 software (Fig. 6).

The philosophy utilized in this part is shown in the above flowchart. This provides a well-ordered breakdown of the stages needed to achieve the desired outcome. To process satellite images using ENVI 4.3 software, Landsat 7 ETM+ containing six bands and 10m DEM was obtained from the GSI (Fig. 7). The image was geometrically projected to UTM Zone 38N and WGS-84 in order to avoid distortion and then converted to radiance from Digital value (DN). The view of the geological rock unit boundaries, such as the Gachsaran and Asmari Formation, are recognized and differentiated by the composition of bands. It should be noted that validation of results from remote sensing processing was carried out by 1: 100,000 geologic maps of the exploration area provided by the GSI (Fig. 7).

(a)   (b)
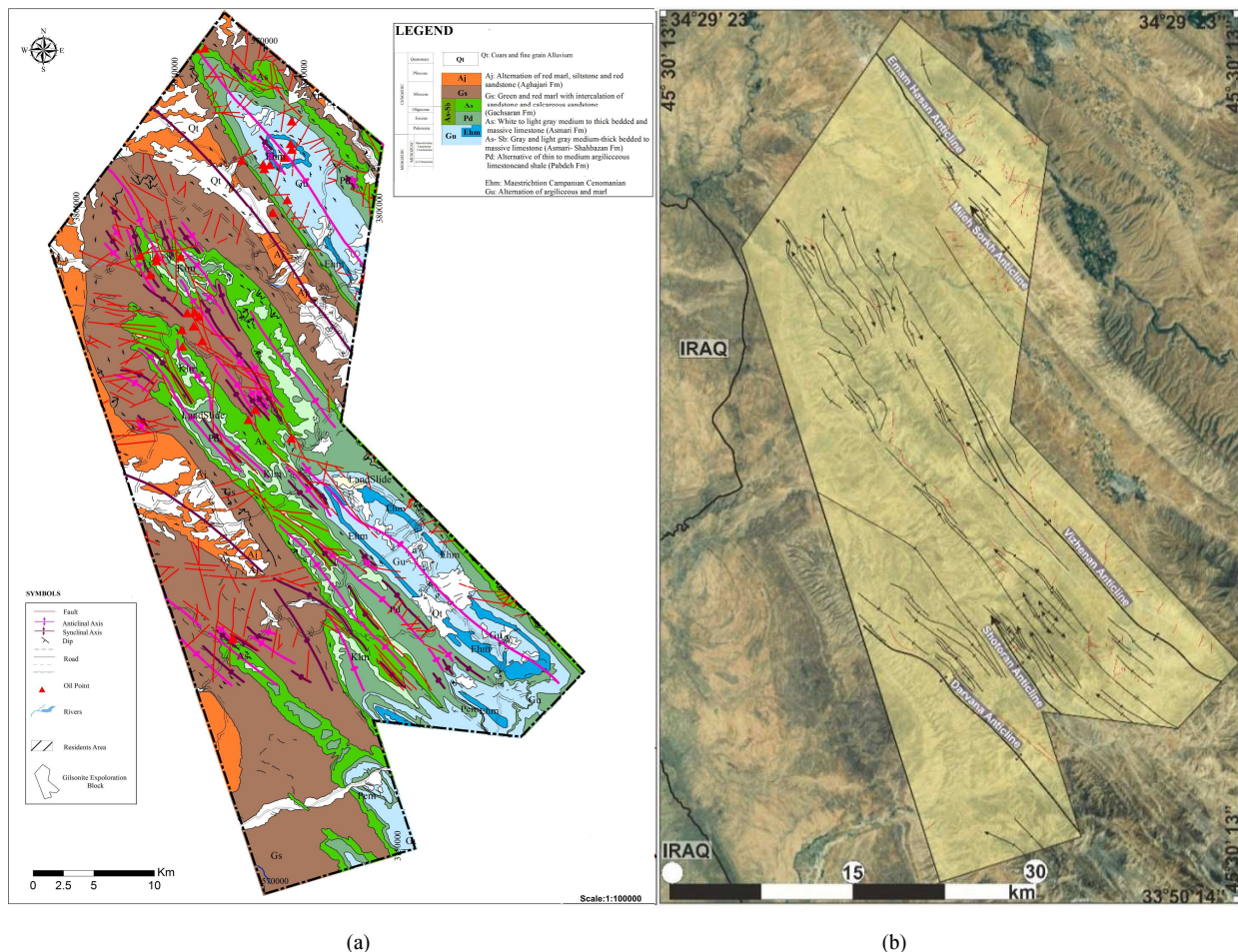
Fig. 4: The views of geological (a) and structural (b) map of the Gilan-e-Gharb exploration block modified from1: 100,000 geological maps (Sarpol-e-Zahab and Sumar) of National Iranian Oil Company (NIOC) (Rahimi *et al*., 2019)
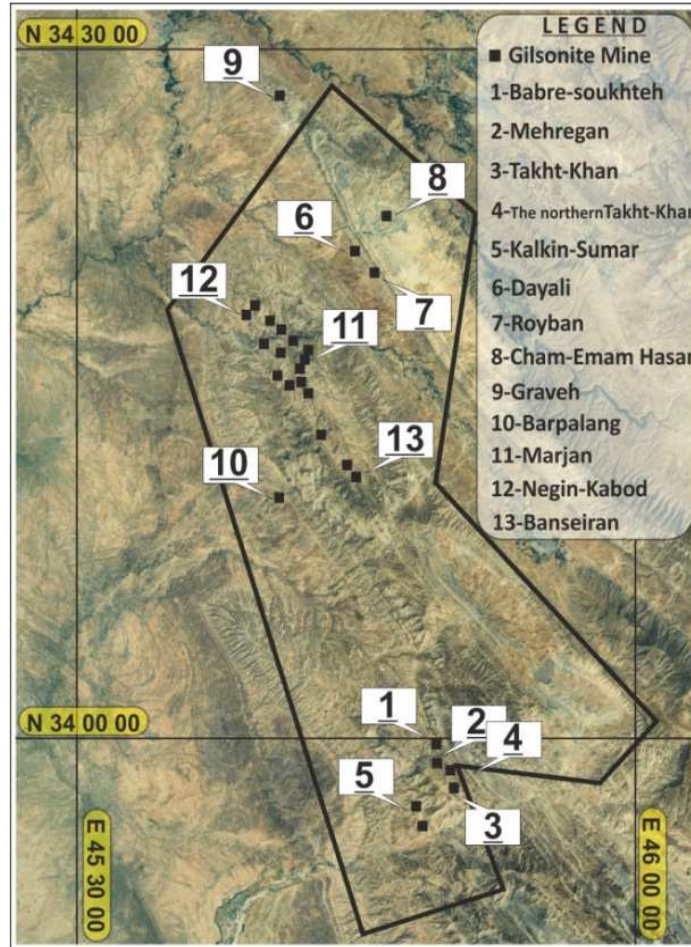
Fig. 5: The biggest major natural bitumen mines in the Gilan-e-Gharb Block listed on the right top that roughly produce more than 30,000 tons per year (Rahimi *et al*., 2019)
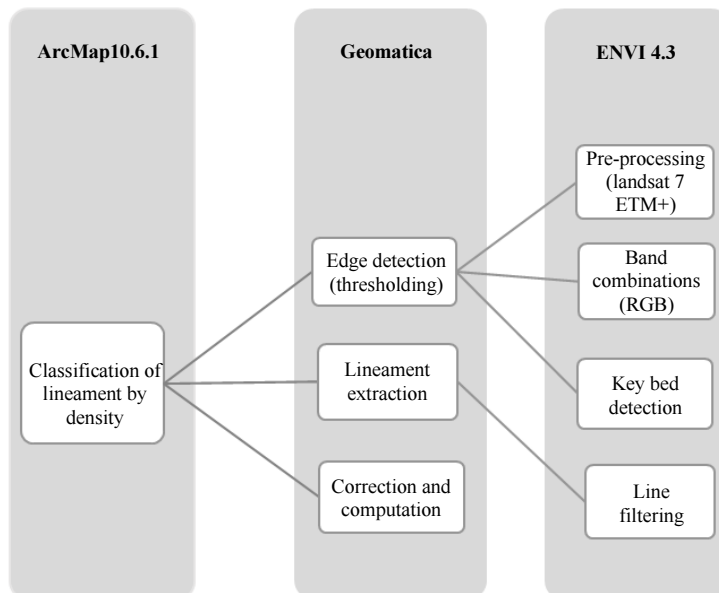
Fig. 6: Flow chart of lineament and bands combination analysis by remote sensing processing
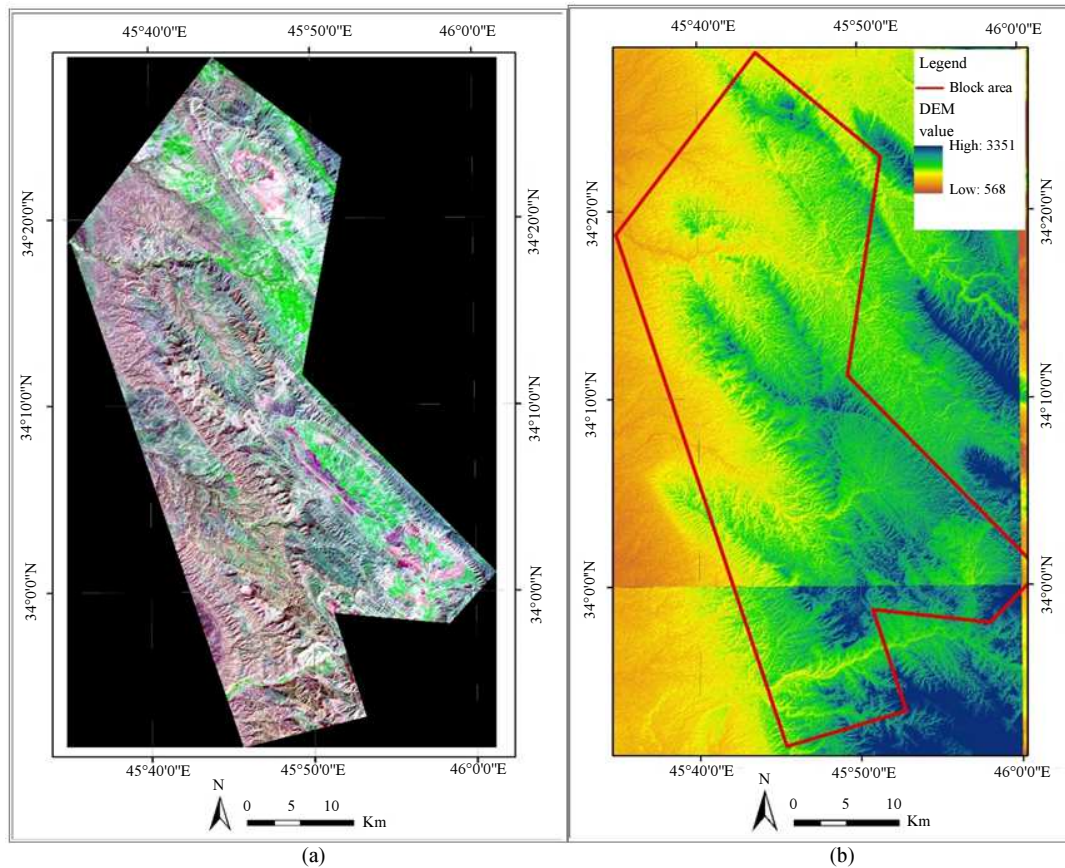
Fig. 7: A view of (a) False Color Composition of Bands (147) distinguishing lithological units and Vegetation (Green), (b) digital elevation map of the area

Key Bed Enhancement

Based on field observations, to identify and explore bituminous mineralization in the Gilan-e-Gharb block, some areas (layers) identified as a key bed in which more evidence of further mineralization was exposed. These layers carefully processed for the purpose of key beds as green/red marl (Fig. 8a) and anhydrite (Fig. 8b) as host units for natural bitumen emplacement in the Gachsaran and Asmari Formation (Fig. 8c) (the Kalhor member). These key beds are introduced by field observation as the main host rock for accumulation of natural bitumen, which image processing was able to highlight these areas and extend to the whole exploration block. In some areas, target rock units have been clearly identified and validated by satellite imagery accommodation (Fig. 8). The stratigraphy of rock units in details can be seen in geological map of the area in Fig. 4.

Structural Lineament Enhancement

The analysis of structural lineament is one of the criteria for tectonic studies and mapping geologic lineament is crucial for solving problems in various fields, especially mineral exploration (El-Sawy *et al.*, 2016; Floyd and Sabins, 1999). This importance of structural lineaments is considered since they can be one of the most effective and controlling factors of mineral accumulation and can play the role of channels for the penetration and placement of fluids containing minerals of interest. In this methodology, the Canny edge detection calculation of the Geomatica V9 is applied to the pre-processed PC1 image and DEM, where the images are filtered by the Laplacian and Sobel function which radius is given by the RADI parameter. Likewise, Gradient calculation is used, followed by the removal of the maximum non-local gradient, which produces an edge strength image. In order to produce a binary object, the image is then subject to a further threshold (Sadiya *et al.*, 2016). After the thresholding and filtering processes have been carried out, structural lines are extracted from the binary edge by sending it to a Geomatica V9 line algorithm (Sadiya *et al.*, 2016). The extracted structural varieties have subsequently been exported to ArcGIS v10.1 and corrected using expertise in the field of study through removing and filtering irrelevant structures. (Sadiya *et al.*, 2016; Floyd and Sabins, 1999). The resulting structure lines were geometrically designed to produce polyline angles that integrated the Rose diagram with the RockWorks 16 software. The rose graph shows a linear sequence, followed by a map of structural linear density (Fig. 9 and 10).
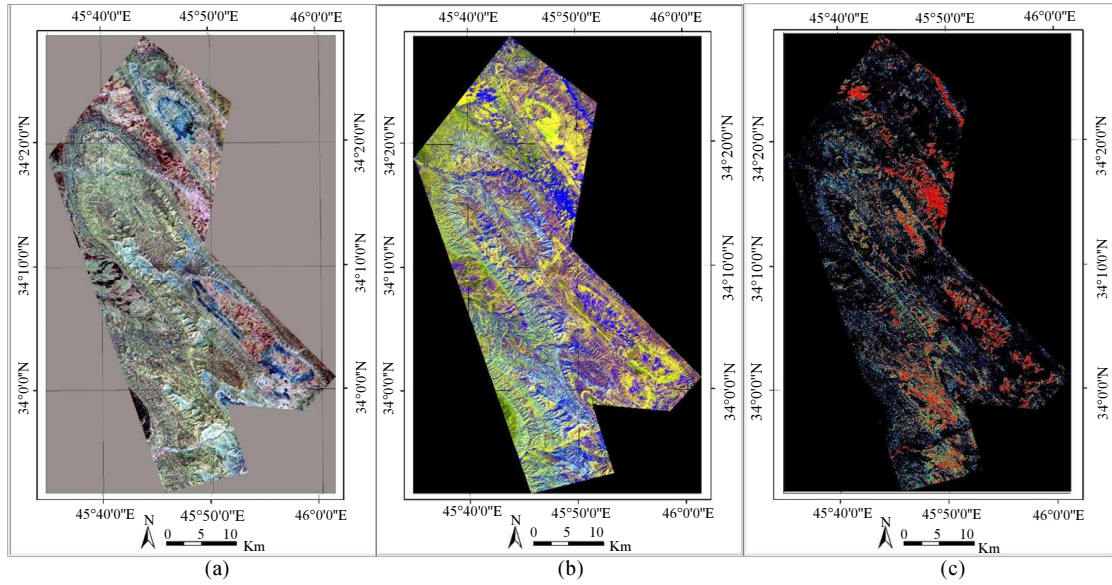
Fig. 8: A view of (a) Clay mineral enhancement using the band ratio method, band 5 (maximum reflection) to band 7 (minimum reflection). (b) False Color Combination of bands (53(5/7)) identifying salty-clay areas in yellow hue and marl in olive hue. And, (c) The RGB image of argillic minerals consists of diaspore/kaolinite/pyrophyllite by Match Filtering Method (MFM)
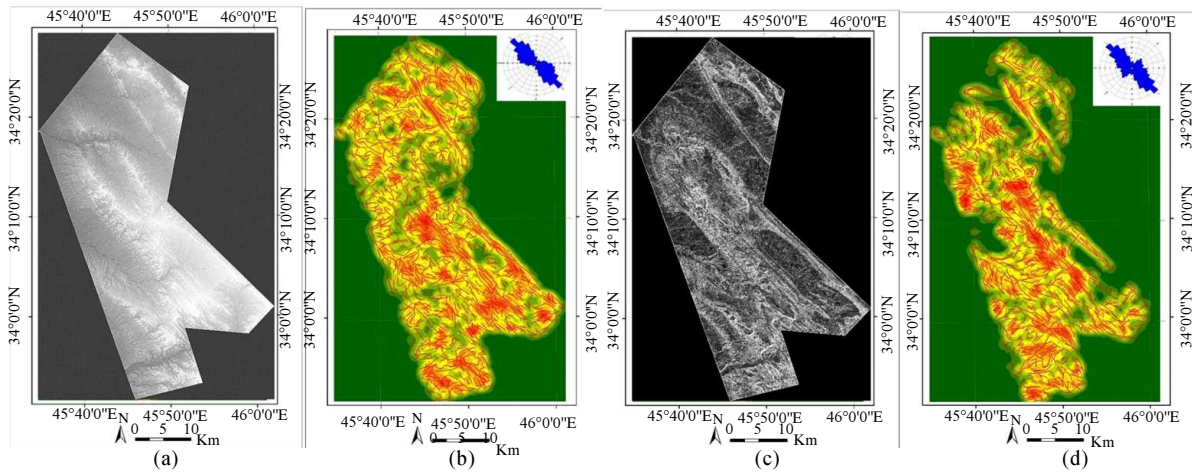
Fig. 9: Filter on PC1. A and b: Lineament enhancement by applying Laplacian Filter on the digital elevation model
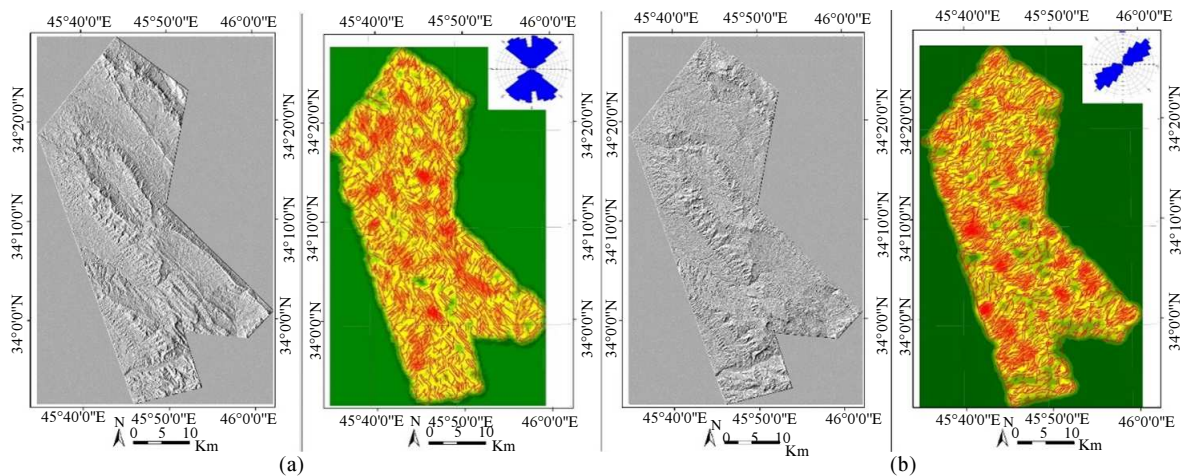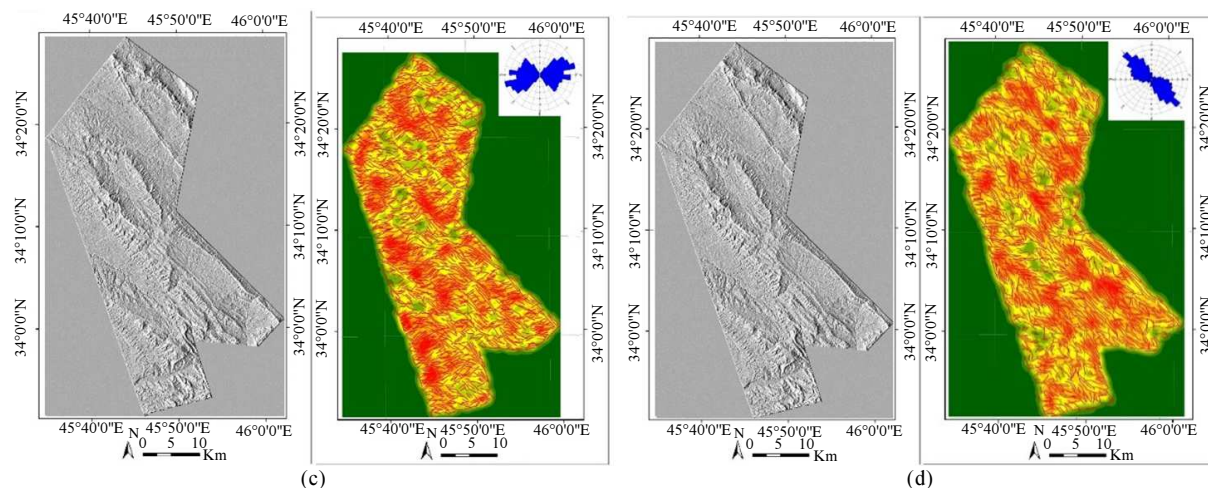
Fig. 10: Lineament enhancement by applying the directional filter on directions 0, 45, 90, 135 degrees (a, b, c, d) on the main component of PC1

The images of the structured lineament are mainly a north-west to south-eastern trend. The lines related to each section are derived from the application of a directional filter on four main directions 0, 45, 90, 135 degrees on the main component of PC1. The abundant fractures are observed in the above-mentioned units, while the major mines of the area have been developed along with these fractures and exploited. The structural factors of mineralization, including faults, fractures, etc. have been identified and applied to the satellite images to be introduced as a controller for mineralization of natural bitumen.

MPM Model

The aim of natural bitumen exploration in the Gilan-e-Gharb block is to identify high potential areas by using all previous exploration data at the least cost and time spent. The various issues associated with this complex decision-making process have led to the participation of the essential rules in this sector, including their interests. After that, the MCDM techniques will balance their different interests in the decision-making problem (Zyoud *et al*., 2016). Team workers who have an in-depth understanding of the decision-making problem are proposed to participate in this work. They were encouraged to evaluate the general framework of the decision-making problem in order to find an efficient and robust exploration management tool.

Finally, three groups of DNs were identified (Geology, Mineralization and Remote Sensing), each of which has sub-DNs. Figure 11 shows the hierarchical structure of the proposed exploration management framework. It consists of four levels: The overall goal that aims to build an MPM assumes the top position of the structure, the second level displays the primary DNs which accounts for Geology, Mineralization and Remote Sensing of the decision problem, the third level presents the evaluation sub DNs to

assess alternatives efficiency and distinguish between alternatives in order to achieve the general goals (They have codes from S1 to S8). These are including rock unit information and structural factors as sub DNs of Geology Data, active/inactive mine and exploratory indexes as sub DNs of Mineralization database and band combination, stratigraphic key beds and structural lineament as sub DNs of Remote sensing data. Further details of sub DNs are described in levels 2 and 3. Lastly level is reserved for the set of options which have codes from A_1 to A_n which refers to the total weight of criteria (Zyoud *et al*., 2016).

Results and Discussion

Applying AHP Technique

The application of the AHP method involves the building of the hierarchical framework of four layers of Pairwise Comparison (PC) (Fig. 11). Firstly, there was a balance between the components at each stage in favorite language rather than with exact and rigorous principles with regard to the components at the above stage (Feizi *et al*., 2017a). Secondly, a compromise was made between the primary requirements for the general objective in stage 1. Finally, the compromise was made between the components of assessment factors in relation to the second stage, DNs' own criterion (Feizi *et al*., 2017a). The findings of aggregation by AHP are shown in Table 1.

In the approaches to exploration modeling, one of the most significant procedures is the definition of weight for each criterion. Inaccuracies in determining the DNs weights can cause errors in estimating the potential areas. To avoid this mistake and get accurate estimates of potential areas, the experience of experts in natural bitumen exploration was used. Geologists and tectonic specialists who are accustomed to natural bitumen mineralization were invited to make scores of each DNs.
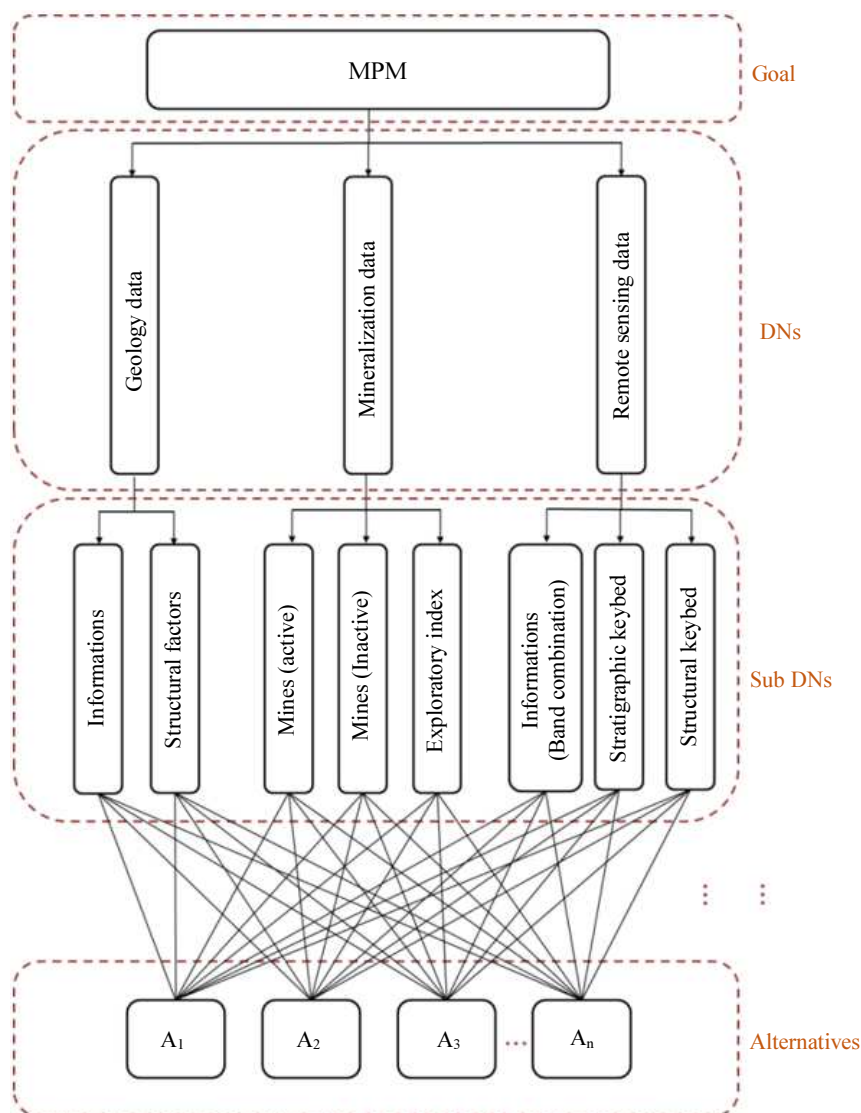
Fig 11: The hierarchical structure of the proposed MPM. The main DNs are defined as Geology, Mineralization and Remote Sensing data. Level 2 as the sub DNs presents the detail of each DNs. Further sub DNs information are mentioned in Table 1

Applying FTOPSIS Technique

This section uses the FTOPSIS method to classify alternative areas. The priority weights of each AHP computed sub DNs can be used as inputs in FTOPSIS (Zyoud *et al.*, 2016). In addition, the weighted normalized decision matrix is achieved. Then, the decision-makers calculate appropriate rankings based on the PIS and NIS for alternative locations (i.e., A+ and A). Consequently, the best alternative can be identified as the one with the shortest distance to PIS and the longest distance to NIS (Zyoud *et al.*, 2016; Feizi *et al.*, 2017b). Non-renewable resource exploration strategies have rapidly changed and innovative data processing and data management technologies have grown increasingly (Zyoud *et al.*, 2016). This section has the aim of providing AHP-FTOPSIS mineral potential modeling.

This research used the AHP-FTOPSIS tool, previously developed in the exploration zone in the west of Iran (the Gilan-e-Gharb block), to generate a prospective map for the natural bitumen mineralization. The advantages and disadvantages of each MPM method were demonstrated by Abedi *et al.* (2012a) and this paper has shown another method for drawing a potential mineral map. Representing the geological databases using the AHP method is feasible for the representation of evidence of potential mapping related to natural bitumen accumulation. Regarding only the likelihood of having a specific incident, not the significance of occurrences (DNs) itself, is one of the AHP technique's drawbacks that can be addressed by combining with other techniques. Therefore, the FTOPSIS was applied in this study.
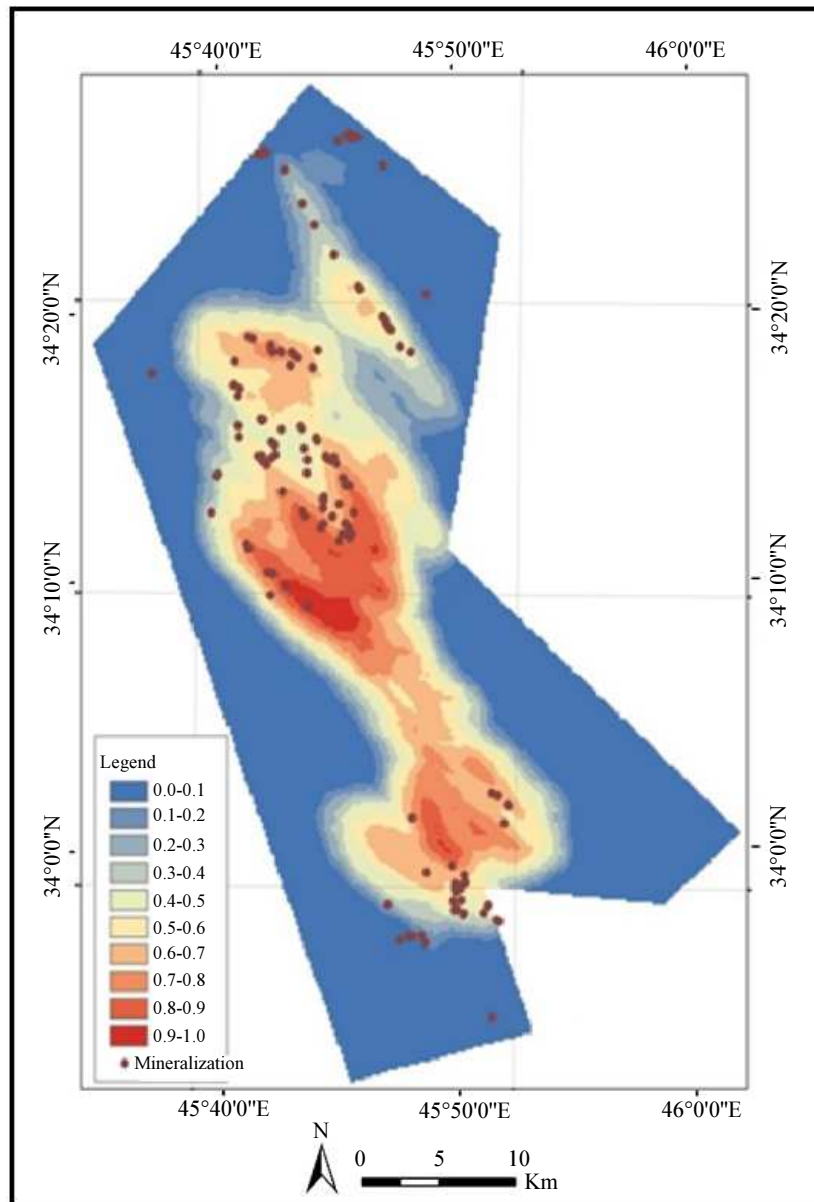
Fig. 12: MPM for natural bitumen in the Gilan-e-Gharb exploration block in the west of Iran

AHP-FTOPSIS application is a knowledge-driven technology based on specialist knowledge of spatial relationships and spatial characteristics between the known deposits comprised of geological data collection of deposits. The key idea of this procedure is that the DNS weight is extracted from the AHP in pairs, while the selected target area with the FTOPSIS should be as close as possible to the ideal positive solution and as far as the negative ideal solution is concerned (Feizi *et al.*, 2017b).

The predictive ability of the potential map is the ultimate AHP-FTOPSIS for modeling natural bitumen potential. The potential output map was assessed by field check and 122 points were finally identified as previously unknown prospective areas (Fig. 12). A follow-up exploration of these high-potential areas is recommended. As shown in Fig. 12, the total number of 121 natural bitumen occurrences in the region known through field checking, 94 occurrences were located in areas with high potential; this means that the model predicts 78% of known natural bitumen occurrences and 13 occurrences were located in areas with moderate potential, which is a confirmation of reliability and accuracy of the method.

Table 1: Weight of each DNs to evaluate MPM

DN_S	weight	Sub DN_S (level 1)	weight	Sub DN_S (level 2)	weight	Sub DN_S (level 3)	weight
Geology	0.806	Rock units	0.178	Aghajari	0.006	-	0.006
				Gachsaran	0.075	-	0.075
				Asmari	0.025	-	0.025
				Kalhor	0.051	-	0.051
				Pabdeh	0.011	-	0.011
				Gorpi	0.010	-	0.010
		Structural factors	0.628	Fault	0.304	Cross fault	0.122
						longitudinal fault	0.182
				Fold	0.106	-	0.106
				Layers contact	0.218	-	0.218
Mineralization	0.146	Mines (Active)	0.076	-	0.076	-	0.076
		Mines (Inactive)	0.024	-	0.024	-	0.024
		Exploratory index	0.046	-	0.046	-	0.046
Remote sensing	0.048	Information (Band combination)	0.012	Aghajari	0.001	-	0.001
				Gachsaran	0.005	-	0.005
				Asmari	0.001	-	0.001
				Kalhor	0.003	-	0.003
				Pabdeh	0.001	-	0.001
				Gorpi	0.001	-	0.001
		Stratigraphic key bed	0.018	-	0.018	-	0.018
		Structural key bed	0.018	-	0.018	-	0.018

Conclusion

Using AHP and fuzzy TOPSIS methods, uncertainty from subjective perception and decision-maker experiences can be adequately represented and a more effective decision can be achieved by decision-makers. This study evaluated the criteria of geological database aiming to determine the order of alternatives priority in the exploratory process. The decision-makers used the linguistic factors in the AHP technique to evaluate the significance of the criteria and to evaluate each option according to each criterion. These linguistic variables have been converted to fuzzy numbers, forming the fuzzy decision matrix. Then, the normalized matrix of the fuzzy decision and the weighted normalized matrix of the fuzzy decision were formed. By defining FPIS and FNIS, the distance of each alternative to FPIS and FNIS was calculated. Then, the closeness coefficient related to each alternative was calculated separately. As a result of the integration of AHP-FTOPSIS with the field study database, we could detect areas with the potential of natural bitumen accumulation. Applying FPIS and FNIS to a benefit attributes, the areas of interests in the Gilan-e-Gharb exploration block are generally exposed on geostructural occurrences (faults and folding), northwest to southeast trend. This strategy leads us to develop software contributing to mineral discovery with restricted data or challenging situations of recognition in order to achieve the greatest advantages of accessible deposits. To demonstrate the effectiveness of the proposed approach, the accuracy of the final mineral potential map was assessed by core drilling and field checking that approved the results from the approach methodology. Finally, this method is strongly recommended to find new resources of natural bitumen accumulation, particularly in the west and southwest provinces of Iran.

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Author's Contributions

Elham Rahimi: Participated in data analysist working on image processing, GIS, Geomatica RockWorks, etc. and also, inscribed the manuscript.

Younes Shekarian: Cooperated in data acquisition including field observation, geology and tectonic, drilling, etc. Also, participated in writing the manuscript.

Salman Mastri Farahani: Performed modeling with MCDM technique on Mineral Potential Mapping. Also, participated in writing the manuscript.

G.h. Reza Asgari: Guided the research development and cooperated in data acquisition including field observation, geology and tectonic, drilling, etc. Also, participated in writing the manuscript.

Ali Nakini: Cooperated in data acquisition including field observation, geology and tectonic, drilling, etc. Also, participated in writing the manuscript.

Ethics

On behalf of all authors, the corresponding author states this article is an original research paper and there is no conflict of interest.

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