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Mapping Groundwater Resource using Multispectral Sentinel 2 and Fuzzy Logic method, Case Study: Salafchegan, Qom, Iran

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Abstract. Groundwater is one of the essential freshwater sources for human consumption, with the highest reserves of fresh water on earth after glaciers and glaciers. Conservation and maintenance of groundwater quality in a large area require an overview of the status and potential of groundwater resources in that area, which can be applied to potential areas using remote sensing technology. In this study, after extracting the factors influencing the formation of groundwater aquifers from the Sentinel satellite image, appropriate information layers were prepared and integrated into the ArcGIS using different fuzzy operators and potential maps prepared with the location of groundwater wells. The area was validated. The results of combining slope layers, slope direction, lithology, drainage length density, lineament length density, lineament buffer, drainage buffer, and vegetation in the area showed that fuzzy multiplication and gamma operators could be used as suitable operators for Introducing information layers to identify groundwater potential in the area. Also, using the gamma numbers 0.1 gave better results than larger gamma numbers. The research results showed that 15.9% of the studied area has good and very good potential for the presence of underground water in the production map using the fuzzy gamma with gamma 0.1 method. Also, this map was validated by 70.1% of water wells in the region. The normalized ratio of accuracy to validity in the final production model with this method was estimated to be 54%, which is entirely acceptable compared to other methods.

Keywords: Remote Sensing, groundwater, potential detection, multispectral imagery, fuzzy algebra.

1. Introduction

Iran is an arid and semi-arid land with very little rainfall, so its average annual rainfall is less than one-third of the world's average annual rainfall. This extensive geographical area has unique hydrological characteristics such as 413 atmospheric precipitation, 296 evapotranspiration, 117 billion available water volume, 1900 per capita renewable water, and consumption of 3.4 billion cubic meters, about 65% of groundwater supplies. It is facing difficult conditions in the field of water supply (Alizadeh &Yaghoubi, 2010; Rahimi, 2011). Depending on the type of soil, slope, and vegetation of each region, water resulting from rainfall and snowmelt penetrates the soil and continues its deep movement inside the soil to hit and stop impermeable layers (Shooshtari, 2013). These impermeable layers eventually form a hydrated aquifer by preventing further water infiltration. If wells are drilled in random and uncontrolled places to supply drinking water, agriculture, and industry, aquifers will be destroyed quantitatively and qualitatively (Joven et al., 2010). Suri et al., In their research, identified areas with high groundwater potential in the Romeshgan Plain using a fuzzy hierarchical method, remote sensing technology, and GIS (Souri et al., 2017). The results of Ahmadi et al.'s research show that Asmari Formation has the highest groundwater potential at the location of the essential syncline axis, and the compliance of these areas with wells with high discharge indicates that the proposed thematic map is well (Ahmadi et al., 2018). In a study, after performing advanced step-by-step logistic regression analyses, the most important factors influencing the occurrence of the spring, which were statistically significant, were selected. The statistical model and zoning map accuracy were evaluated and confirmed based on the percentage of occurrence of experimental springs in the sensitivity map and statistics and Snell (Zandi et al., 2015). To find the potential of groundwater resources in the Sirjan catchment using the Hierarchical analysis method and GIS. This study showed that the high potential zone for extraction of groundwater resources is more consistent with the coarse-grained sediments of the fourth period and alluvial fans (Seif & Kargar, 2011). Using the fuzzy method groundwater resources in the Yazd-Ardakan basin were identified. Their research showed that about 70% of the study area has excellent and outstanding potential in groundwater (Mofidifar et al., 2014). Moghaddam et al. Used the network and fuzzy analysis method to find the potential of groundwater resources in the catchment area leading to the Tabriz Plain. Based on the results of these studies, geological factors, lineages, faults, and vegetation have the most role in the potential of groundwater resources in the region, and areas with high groundwater potential are consistent with low altitudes and karst sediment (Moghaddam et al., 2011). The groundwater resources of Pohang in Korea were identified using GIS. The results showed that the accuracy of the resulting map is more than 77%. Also, based on the obtained results, the slope layer had the most significant effect, and the slope direction had a minor effect on the potential of groundwater resources in the study area (Hyun-Joo, et al., 2011). In a groundwater study in the Unao region, India was identified. This study showed that about 15% of the area has excellent potential in groundwater supply, using remote sensing, GIS, and fuzzy logic to potentialize groundwater resources in the Comoros Basin located in East Timor. Based on the obtained results, the alluvial plain in the northwest region has a high potential (Etishree et al., 2013). In order to identify, evaluate, and produce a groundwater potential map for the Firan Desert Basin, Arnis prepared eight layers of slope information, drainage density, lithology, landform, line density, precipitation, altitude, and curvature based on each layer. Ability to store and transfer weighted water. Finally, after combining the information layers, the final groundwater potential map was prepared by the multiple criteria evaluation method (Arnous, 2016). Amin et al. Estimated the total weight of nutrients and sediment by combining soil and water models and effective parameters in the hydrology of Center County, Pennsylvania, USA (Amin M et al., 2017). Swakumar et al. Identified potential areas in the hard rocks of the Tamil Nadu region of India. In order to identify these areas, different thematic layers, such as geomorphology, linearity, slope, and drainage, were prepared using remote sensing data and combined in a GIS environment (Sivakumar et al., 2015). Mohammad al-Milad in the Alcademos region of Banias predicted groundwater recharge by combining rainfall, topography, drainage, faults and lines, petrology, land use, and soil type data using the Analytic Hierarchy Process (AHP) (Almilad, 2021).

Zoran Stevanovic and others propose a new GIS-based CC-PESTO approach to successfully assess and map the karstic aquifer's vulnerability/resilience to the effects of climate change (Stefanovic et al., 2021). Groundwater potential detection requires collecting large volumes of spatial data from various sources, management, and analysis. In this regard, remote sensing capabilities can prepare data, process satellite images of the region, and use GIS to store, analyze, retrieve, update, and display information. The combination of remote sensing techniques and GIS has been used as an effective tool in groundwater studies. The study area is located in the west of Qom province. This region is part of the western plains of Salafchegan. The purpose of this study is to find the potential and zoning of Salafchegan to pave the way for the study of suitable places for drilling wells and for the extraction of karst water to meet some of the current water needs.

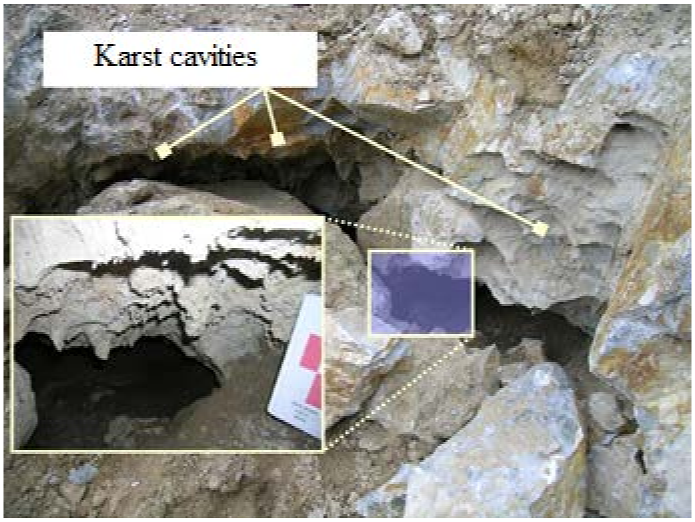

Figure 1. Karst cavities

Groundwater flow in karst rocks is different from water flow in non-karst areas. This indicates the hydrogeological characteristics of karstic soils. Almost all underground and surface phenomena in karst areas are related to water flow. For this reason, careful study and complete studies on the types of water flows and the duration of these flows in karst areas will be necessary and valuable. However, due to the geological conditions, it is challenging to study the effect of water cessation on karst areas that lead to water saturation, water movement in these areas, and a reasonable conclusion. Figure 2 shows how a groundwater system is formed in karst areas.

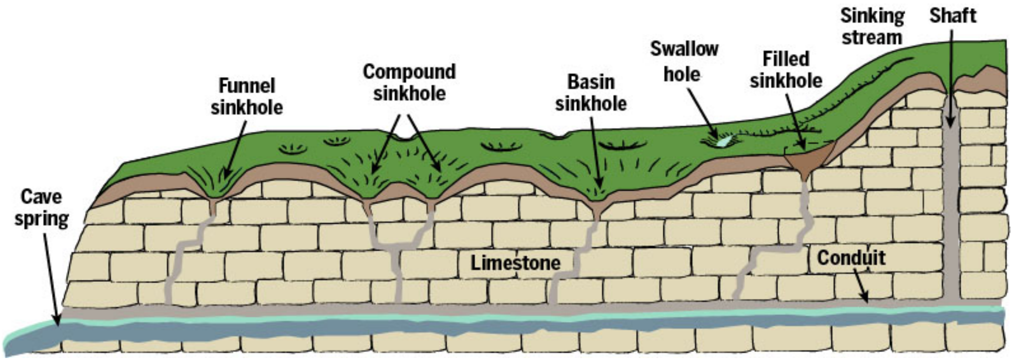

Figure 2. How to form an aquifer in a karst environment (Indiana Geological and Water Survey (IGWS), 2023)

This study aimed to use remote sensing technology and GIS to identify and map the potential and zoning of groundwater resources in the Salafchegan area of Qom province, Iran. We aimed to provide an overview of the status and potential of groundwater resources in the region, which could be used to identify suitable places for drilling wells and extracting karst water to meet current water needs. The study focused on factors influencing the formation of groundwater aquifers, such as slope layers, lithology, canal length density, fracture length density, fracture buffer, canal buffer, and vegetation. It used different fuzzy operators to integrate this information into a final potential map validated with the location of groundwater wells. The study highlights the importance of using remote sensing techniques and GIS as practical tools for groundwater studies, especially in arid regions like Iran, where access to freshwater is limited.

2. Materials and methods

2.1. Study area

The study area is located in the central part of Iran, southwest of Qom city and in the west of Salafchegan, between the northern offerings 3813400 and 3831560 and the length of 443390 and 466300 (Fig. 3). The study area is in one of the Salafchegan plains with mainly calcareous rocks about 500 km^2 with 23 by 17 kilometers. The topography of the area is gentle and has slight elevation changes.

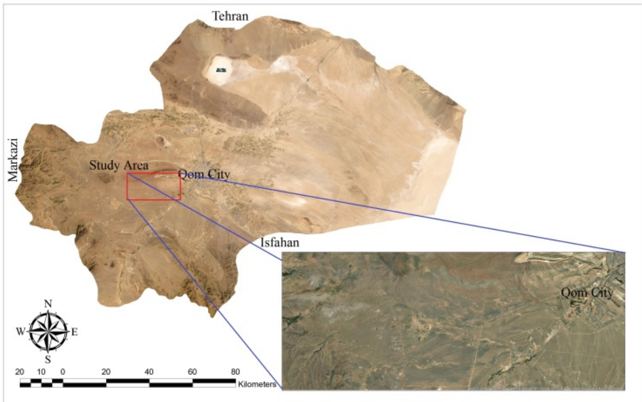

Figure 3. The study area

2.2. Data used

Geological map of the region

One of the most critical layers of information in finding the potential of groundwater resources is the layer of lithological features of the region. For this purpose, the country's Geological Survey has prepared a geological map of one hundred thousandths of the region. Figure 4 shows the location of the study area in the one hundred thousandths geological sheet of Qom.

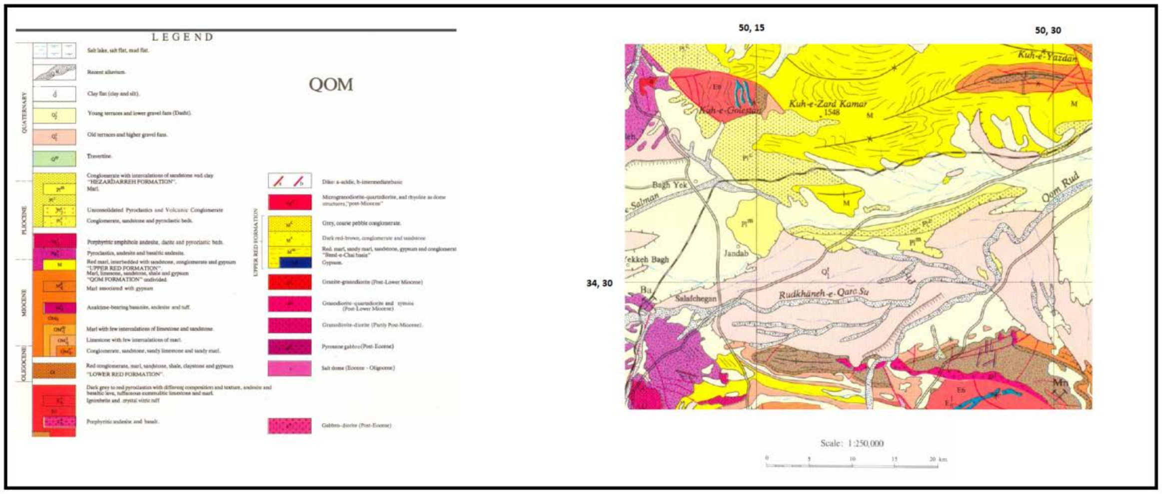

Figure 4. Geological Map of the Study Area (from Qom 1:100000 geological base map)

Elevation digital data

Another data used in this research is the digital elevation model. This data was received from the Alos Palsar satellite through the US Geological Survey with a spatial resolution of 12.5 meters.

Sentinel satellite data

Sentinel-2 is an Earth observation project developed by the European Space Agency as part of the Copernicus program to improve Earth observation missions and support services such as forest monitoring, land cover change, and natural disaster management. This project includes two identical satellites, Sentinel-2A and Sentinel-2B. The two Sentinel-2 project satellites also work in opposite directions. Sentinel-2 has a spatial resolution of 5 days at the equator and three days at mid-latitudes. The spatial resolution of this image has 13 spectral bands, in bands 2, 3, 4, 8, 10 meters, in bands 5, 6, 7, 9, 12, 13, 20 meters, and in bands 1, 10, and 11 It has a spatial resolution of 60 meters.

3. Methodology

After extracting the influential factors in the formation of groundwater aquifers from the Sentinel satellite image, appropriate information layers are prepared and integrated with the QGIS, using different fuzzy operators and potential maps prepared with the location of groundwater wells in the region. Validated. The research has been done using the introduced flowchart (Fig. 5):

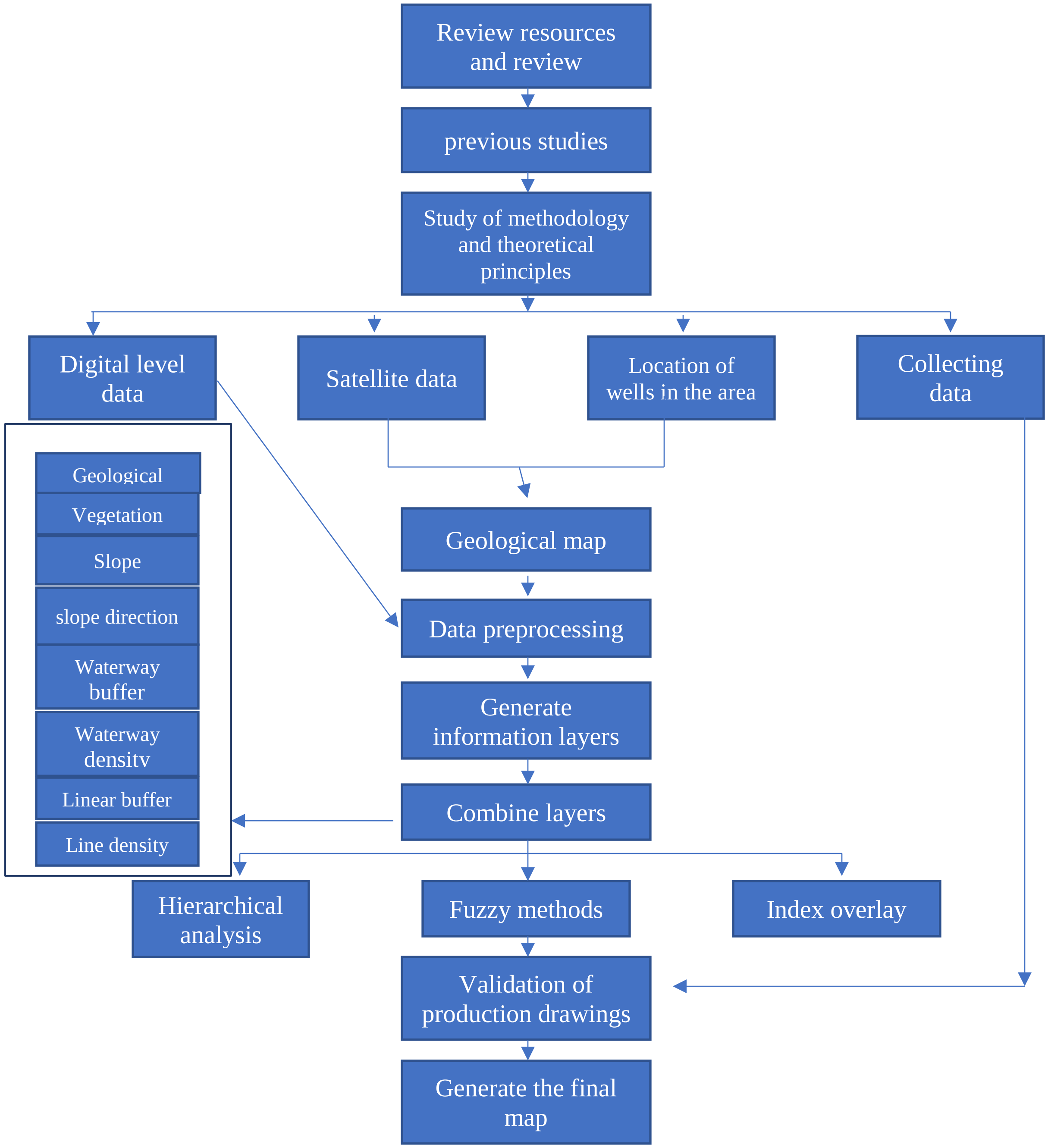

Figure 5. Research flowchart

The results showed the combination of slope layers, slope direction, lithology, canal length density, fracture length density, fracture buffer, canal buffer, and vegetation in the area.

4. Results

4.1. Preparing information layers

Slope layer and slope direction

Slope and slope orientation layers are information layers used in various researches to find groundwater potential. These two layers of information were extracted using digital elevation data and classified into 9 and 5 classes, respectively (Fig. 6-A and Fig. 5-B). The basis for classifying different slope directions in different categories in Table 1.

Table 1. Scoring for different slope directions in the information layer for slope direction.

slope direction	Point
North	9
Northeast, Northwest	7
Eastern Western	5
Southeast, Southwest	3
South, no slope	1

Lithological layer

Another essential information layer in the potential of groundwater resources is the layer of lithological features of the region. For this purpose, a geological map of one hundred thousandths of the region has been used. The information layer of different stone units in the study area was digitized, then each of the different classes of this layer was appropriately scored according to Table 2 and Figure 6-G.

Table 2. Weighting based on different rock units in the study area.

Stone unit	Area (km^2)	Percentage of coverage in the whole range	Lithological features	Class weight
Qt2	157	32.0%	Young alluvial garrison and alluvial sediments (clay and carbonate rocks)	**5**
Qt1	149	30.2%	Old Alluvial Base and Marne Gravel (Clay and Carbonate)	**5**
M	41.5	8.7%	Red marl, gypsum, and sandstone	**3**
P1c	37	7.7%	Volcanic conglomerate	**1**
P1m	34	6.9%	Conglomerate and sandstone	**1**
Qal	33.5	6.8%	Calcareous sediments	**9**
Ngv1	27.5	5.7%	Thick limestone and chert limestone	**7**
E5	5.5	1.2%	Lime, gypsum, and sandstone	**5**
Ngv2	3.5	0.8%	Andesitic mass	**1**

Vegetation information layer

The vegetation information layer has also been used in many groundwater potential research studies as one of the information data. This information layer was considered one of the information layers in this research. The vegetation layer was prepared based on the normalized difference vegetation index using Sentinel satellite data processing, classified into five classes, and calculated using the following formula (Fig. 6-H):

$$NDVI = \frac{Band4-Band3}{Band4+Band3}\frac{\mathrm{NIR-Red}}{\mathrm{NIR+Red}}$$

This band ratio is always a number in the range of "0" to "255" that the closer this number is to zero, the less vegetation and the closer the ground to soil or water, and the closer this number is to 255, the vegetation increase.

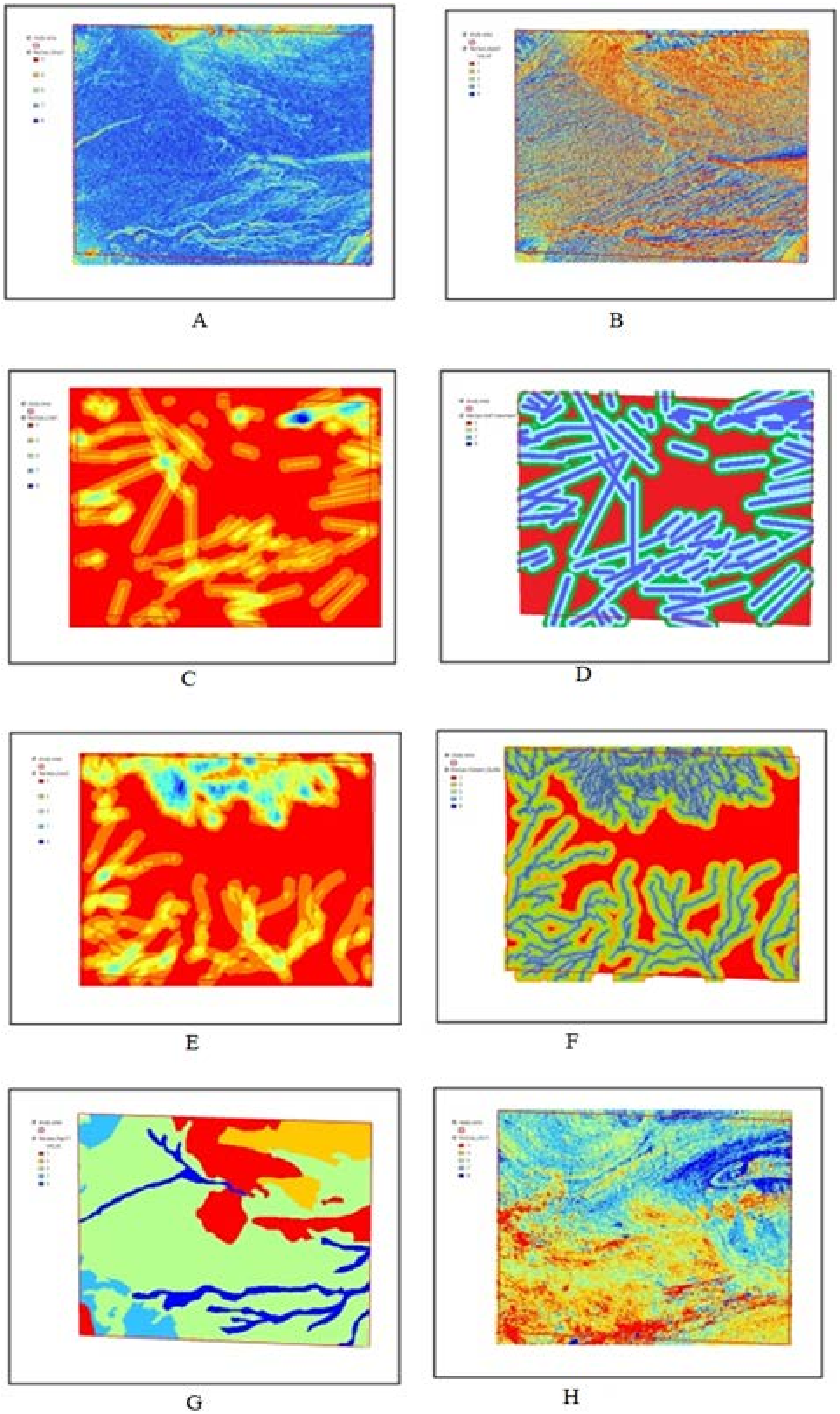

Figure 6. Categorized information layers

Layers of lines and fractures

Lineages are always an excellent place to form groundwater aquifers (Ghobadi, 2007). Sentinel satellite image processing was used to extract the lines, and finally, the line density and line buffer layers were classified into 5 and 4 classes, with the highest line density of 9 points and the lowest line density, respectively. Score 1 was assigned (Fig. 6-C and Fig. 6-D). The scoring for the density of line lengths ranges from 9 for greater than 1.5 km/km² to 1 for less than 0.5 km/km².

Information layer of waterways and drainage of the region

One of the essential information layers in finding the potential of groundwater aquifers is the drainage layer and waterways of the region. This information layer can be extracted using a digital elevation model and a geological map of the region. This data prepared two layers of waterway density in 5 classes (Fig. 6-E) and waterway buffer in 4 classes (Fig. 6-F). The scoring for the drainage density of the area ranges from 1 for greater than 1.5 km/km² to 9 for less than 0.5 km/km².

Modeling

After generating information layers of groundwater potential detection parameters, the mentioned layers should be weighed and combined. The weight of each item in an information layer indicates its importance and value compared to other criteria in potentially identifying the probability of occurrence of the target phenomenon. Given that the criteria studied in each project are often not many and have the same value, considering the importance of the criteria and their immediate consideration in the zoning to combine the layers, the need to weigh the criteria is a matter of denial. It is impossible. There are several ways to integrate information layers into mine and mineral potential exploration. In general, these methods are based on data (data-driven) or based on conceptual models of mineralization and expert knowledge (knowledge-driven) (Davoodabadi et al., 2018). The correct and accurate use of all available data is vital in determining the areas with high potential for mineral reserves.

There is no limit to the number of layers of information in the data weighting method, and all relevant and practical information in identifying mineral reserves can be evaluated. In this method, after reviewing and processing, the data are classified as binary or multiple evaluated information layers and are ready for final analysis, and finally, the output is presented as an information layer. In methods based on the conceptual model of mineralization and expert opinion, the expert's opinions are valuable after analysis and review are determined as new layers of information. In a data-driven and expert knowledge-based integration, the information layers determined by the expert are added to the data-based information layers as equivalent or higher value information layers. The following are various methods of combining information, description, and appropriate method (s) for integrating exploratory information in GIS. Standard methods of combining information include the following:

1- Boolean logic model (Maholi, et al., 2011);
2- Index overlay model (IO) (Koshari, 2006);
3- Fuzzy logic model (dumb) (Mohammadi, 2012).

Weights are often made based on expert knowledge and experts' opinions, taking into account various factors such as study area, location parameters, and the impact of each parameter (Mousavi et al., 2016).

Boolean model

In this model, the weighting is based on one (low to the very suitable occasion) and zero (inappropriate). Therefore, the final map is divided into only two parts, appropriate and inappropriate. After defining the item, the numbers zero and one must be entered. The placement order is such that the number zero is used only for the unsuitable case, and the number one is used for all cases except the unsuitable one, where assigning numbers requires an expert opinion. These output maps are called binary maps (Siti et al., 2010).

The input maps are combined with logical operators to determine the number of output pixels to produce the final map. This section also defines the type of logical operator for each layer composition. Depending on the values the input pixels and the type of map combination, it is clear that the values the output units will also be zero or one. In other words, the units that reach the final value of one are suitable for the project. Boolean model is fast and easy to implement due to the simplicity of logic and calculations, but due to the impact of other parameters on the location process, this method can not be used as a suitable model for combining maps. Because in addition to the fact that the weight of all parameters in this model is assumed to be the same and equal to one, it is impossible to classify each parameter into separate classes to weigh each class.

In the Boolean model, input maps are combined with logical operators such as AND, OR, XOR, and NOT in modeling expressions to create an output map. Boolean logic uses these operators to see if a particular condition is true or false.

This method of combining information layers has not been used in this study because in this method, according to its definition, the occurrence of a phenomenon is expressed as zero and one; In other words, the probability of an event is either zero or one, which is contrary to the purpose of this study, which is to determine the location of groundwater in terms of location and analysis of the study area based on the probability of groundwater presence (Hekmatpour et al., 2007).

Index overlay model

This method can be called one of the simplest and most common methods of combining information. In this method, each classified class is given an expert weight for each of the parameters involved in the desired potential, and thus each of the available information layers is weighted. Finally, each pixel in all layers has taken on a certain weight and is displayed by summing all the weights applied to that pixel in the final potential map. In this method, each map has different classes that have different scores; these scores are multiplied by the corresponding weight as follows, and the average weight given point for each subject (polygon or pixel) is calculated in this way, then They are added together with all the combining maps and finally normalized by adding the weights:

$$S= (\Sigma_i^n S_{ij} W_i)/(\Sigma_i^n W_i)$$

In this equation, S is the weight of the data weight for each complication, Wi is the weight of the ith of the input map, sij is the score of the jth of the ith class of the map, and j belongs to the class that is scored and weighted in the maps (Malekian, 2012).

Fuzzy logic model

The fuzzy logic method is one in which different layers are weighted with different topics, and expert knowledge has the most role. This method, which depends on both the conceptual models of mineralization and the information to be interpreted, was identified as the most appropriate method for combining information layers to identify potential areas in this project in the fuzzy method, according to the conceptual model of the desired deposit and expertise, a specific load (weight) is determined for each of the controlling factors. This method combines the mentioned factors to determine the potential areas, and finally, the proposed ranges are determined (Malczewski et al., 2006). This theory is a generalization of the classical theory of sets in mathematics. In this theory, according to the following formula, the membership of the members of the set is determined by the function u (x) that x represents a definite member, and u is a fuzzy function that determines the degree of membership of x in the relevant set and its value is between zero and one.

$$\mathcal{A} = \{(x, \mu_A(x)) \mid x \in X\}_O.$$

Combining information layers with different methods

After preparing information layers related to each influential factor in groundwater resources, the method of index overlay and weighted index overlay was combined. Because the importance of each layer of information is different, the weighted index overlay method has been proposed for integration to correct this problem. In this method, weight is also applied to each layer of information. The results are presented in Figure 7-A and Figure 7-B Weighing each layer to produce a groundwater potential map was performed by the weighted index overlay method according to Table 3. After producing the mentioned map, the study area was divided into five periods, including areas with very high, high, medium, weak, and fragile potential, to analyze the possibility of the presence and absence of groundwater. Accordingly, the highest potential for groundwater presence is dark blue, and the lowest potential for this phenomenon is dark red.

Table 3. Weights assigned to each of the information layers for integration by weighted index overlay method.

Information layer	Number of layer classes	Dedicated weight
Slope	9	3
Slope direction	5	1
Line density	9	4
Linear buffer	4	3
Waterway density	9	4
Waterway buffer	5	3
Vegetation	5	2
Material of stone	5	2

Another method of integrating information layers in the Arc GIS software environment is fuzzy integration. Fuzzy logic is one of the most advanced methods used to classify and integrate data. Membership in the fuzzy logic method is expressed on a scale grouped from "one" (full membership) to "zero" (non-full membership) and then used for this method. The fuzzy integration tool can analyze the probability of a phenomenon belonging to several sets (Shams et al., 2011).

Membership in fuzzy logic is expressed differently, and one should be very careful in choosing it. Membership in fuzzy logic depends on the expert's experience and knowledge of the area under study, and everyone chooses it based on their experience. The fuzzy method combines information layers in several ways, each of which does its job by considering a specific feature of the information layers.

Before the data integration operation can be performed, the data layers must be prepared for this method. This means weighing the factors in each layer in the range of zero and one, which is the basis of this method. After producing fuzzy information layers, it is time to combine this layer in a fuzzy way. For the same set, various operators can combine membership values with two or more maps with fuzzy membership functions. The five operators that are useful for combining data are: fuzzy AND operator, fuzzy OR operator, fuzzy algebraic product, fuzzy algebraic sum, and fuzzy gamma operator, which below will generate a potential map for each of these methods.

The fuzzy combination of "and" is based on the value of the minimum cells, or in other words, the minimum point of each pixel is considered and combined. This method is proper when identifying the lowest common denominator for each cell membership of all input criteria. This method has been introduced as a pessimistic method for decision making, and many areas in the production map are introduced with undesirable groundwater aquifer potential (Fig. 7-C).

The "or" fuzzy combination is based on the maximum value of the cells, or in other words, the maximum point of each pixel is considered and combined. The amount of membership combined in one place is limited only by this operator's most appropriate marker maps. This method is proper when identifying the most common denominator for each cell membership of all input criteria. This operator is used in some cases where the desired indicators in mineralization are scarce, and the presence of any indicator can be sufficient to express the desirability to prepare potential mineral maps (Ismail & Mallikarjuna, 2011). The production map in this way is very optimistic, and many areas in the production map by this method are introduced as desirable areas for the presence of groundwater aquifers (Fig. 7-D).

Fuzzy integration is the product of fuzzy algebra multiplication for each cell, the product of the multiplication of each fuzzy value for all input criteria. The resulting product will be less than any of the inputs. Relating the product to all input criteria with a relative relation is challenging, which can be done by combining the fuzzy algebraic operator. The result of merging the layers using this operator is shown in Figures 7-8.

The fuzzy algebraic sum is the type of fuzzy value of each set of cell locations to which it belongs. The sum leads to an increase in the performance of the linear composition based on several criteria entered into the analysis. Fuzzy integration works as a whole based on the following function:

$$\boldsymbol{Fuzzy\ Sum\ Value} = \mathbf{1} - \prod_{\mathbf{i=1}}^{\mathbf{n}} (\mathbf{1} - \mu\mathbf{i})$$

The result is always greater than or equal to the most significant amount of joint fuzzy membership. Therefore, its effect is additive. Two pieces of evidence supporting the same hypothesis reinforce each other, so it is better to use a combination of pieces of evidence than to use each piece of evidence separately. The fuzzy algebraic sum is not the result of the algebraic sum and should not be confused with the additive method used in the weighted sum method. In these two coverage methods, it is assumed that a more desirable and better input to add to all membership values fuzzy sum analysis necessarily means a more appropriate location. Fuzzy algebraic sum combinations are not very common (Bonham-Carte, 1994). The production map with this operator is shown in Figure 7-F.

Gamma fuzzy combination is the algebraic product of the combination of "algebraic multiplication product" and "fuzzy algebraic sum-product," both of which cause a "gamma" fuzzy combination. The general function is as follows:

$$Fuzzy\ Gamma\ Value = (fuzzy\ algebraic\ sum)^{\gamma} * (fuzzy\ algebraic\ product)^{\gamma}\ ,$$

where γ is the selected parameter in the range of zero and one, when γ is one, the composition will be the same as the fuzzy algebraic sum, and when it is zero, the composition is equal to the product of the fuzzy algebra. The correct and conscious choice of γ creates values the output, each establishing a flexible correlation between the increasing tendencies of the fuzzy algebraic sum and the decreasing effects of the algebraic multiplication. As explained, each operator has different applications, but using several operators in different stages in each project is better.

Gamma fuzzy integration creates relationships between multiple inputs that fuzzy and fuzzy or "fuzzy" or "fusion" methods alone cannot. The "gamma" fuzzy combination method is used when the researcher wants to score more than "fuzzy or" and less than "fuzzy algebraic sum" fuzzy. Figure 8 is a potential map of the presence of groundwater in the study area, which has been prepared by the fuzzy integration method with the help of fuzzy operator "gamma" with gamma values 0.1, 0.3, 0.5, 0.7, and 0.9.

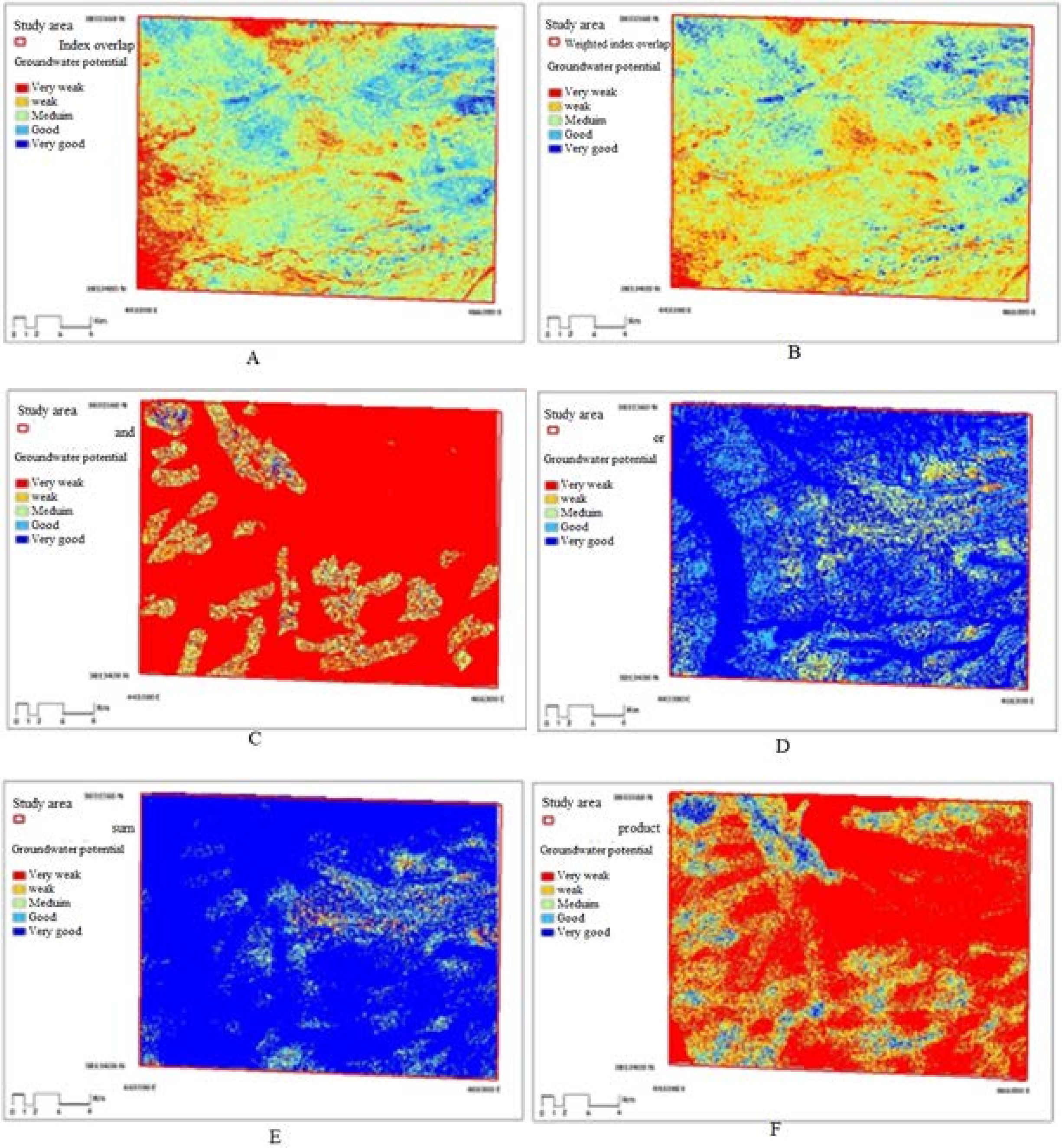

Figure 7. Groundwater potential map using the methods of index overlay, weighted index overlay, fuzzy And, fuzzy Or, fuzzy product, and fuzzy sum

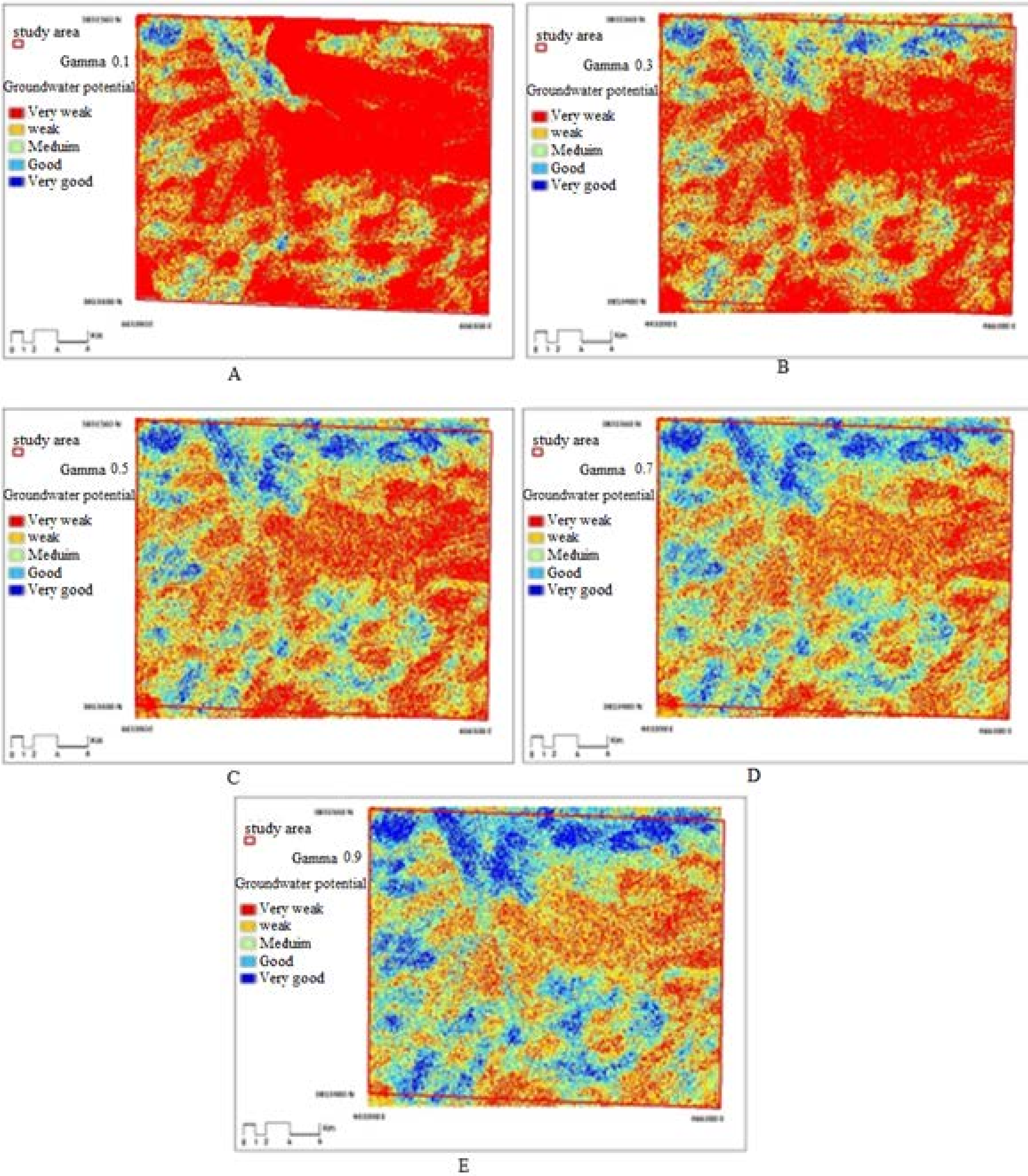

Figure 8. Groundwater potential map using fuzzy gamma operator

Validation of production maps

The data of regional water extraction wells are used (Table 4). By preparing the digital layer of water wells in the region and combining it with potential groundwater maps, two results are obtained:

1- Validation of information layer integration methods

2- Comparison of potential groundwater maps with each other

Table 4. Location of water wells in the region

LINE	X	Y	Watering condition
1	450682	3828567	active
2	461770	3817935	active
3	464406	3828298	active
4	452453	3828543	Inactive
5	454085	3828910	active
6	460286	3817039	active
7	460123	3815938	active
8	452657	3827727	active
9	446171	3828706	active
10	460979	3828502	Inactive
11	444213	3823933	active
12	444417	3821363	active
13	446946	3822016	Inactive
14	449272	3822587	active
15	444539	3818589	Inactive
16	448374	3815938	active
17	446783	3830501	active
18	450414	3815652	active
19	465589	3820343	active
20	464365	3817365	active
21	445396	3819609	active
22	444336	3830623	active
23	445804	3830542	active
24	448252	3830542	Inactive
25	462693	3829604	active
26	464936	3830379	Inactive
27	461102	3829685	active

Figure 9 and Figure 10 show the production maps in different ways, along with the location of water wells in the area. The layer of water wells does not show the area. To numerically calculate the accuracy of matching the layer of water wells in the area and production maps, the number of water wells introduced in two classes of good and very good in the maps is divided by the total number of wells and in the Accuracy column in the table. Five are given.

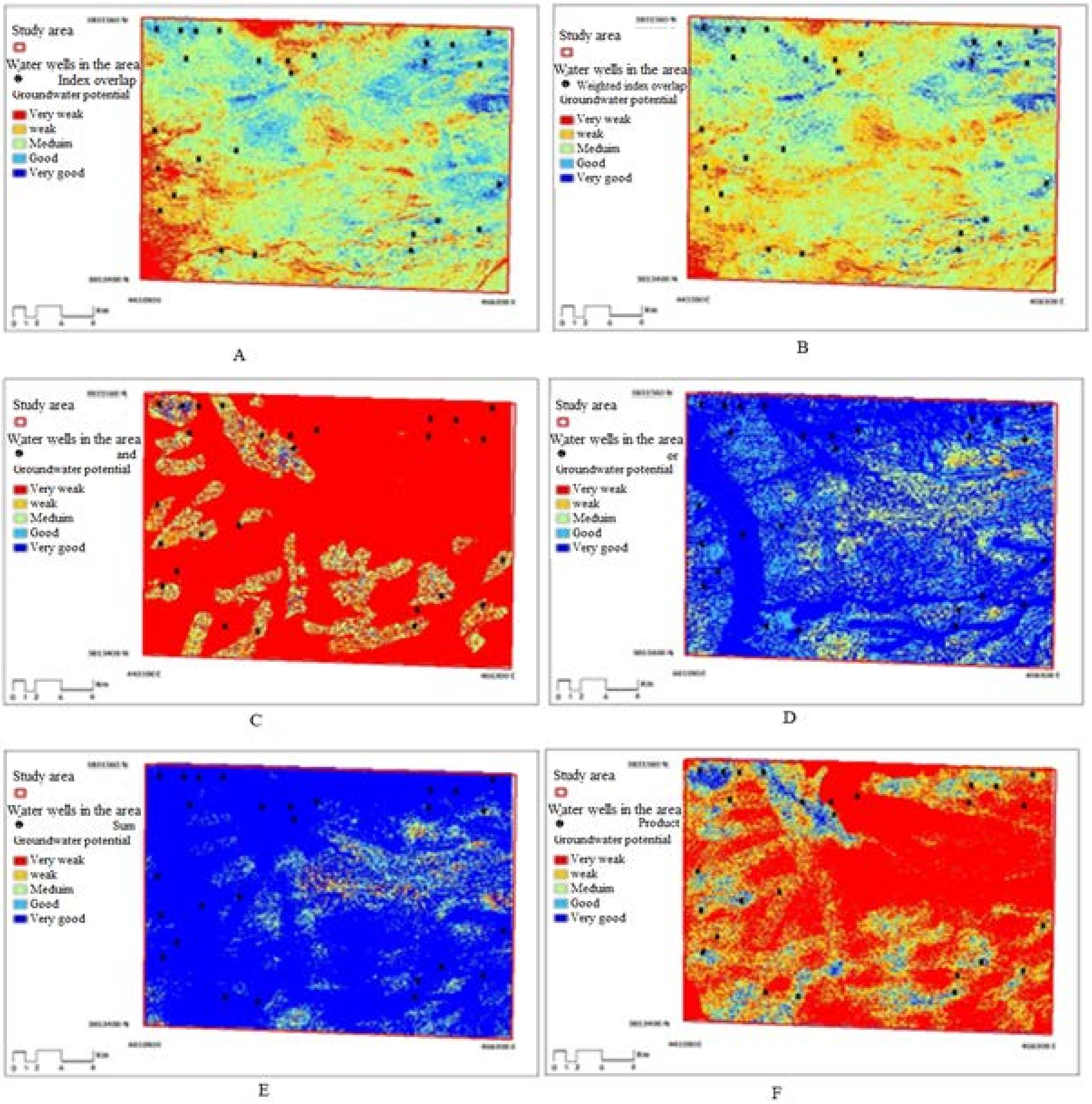

Figure 9. Groundwater potential map using the methods of index overlay, weighted index overlay, fuzzy And, fuzzy Or, fuzzy product, and fuzzy sum with the layer of water wells in the area

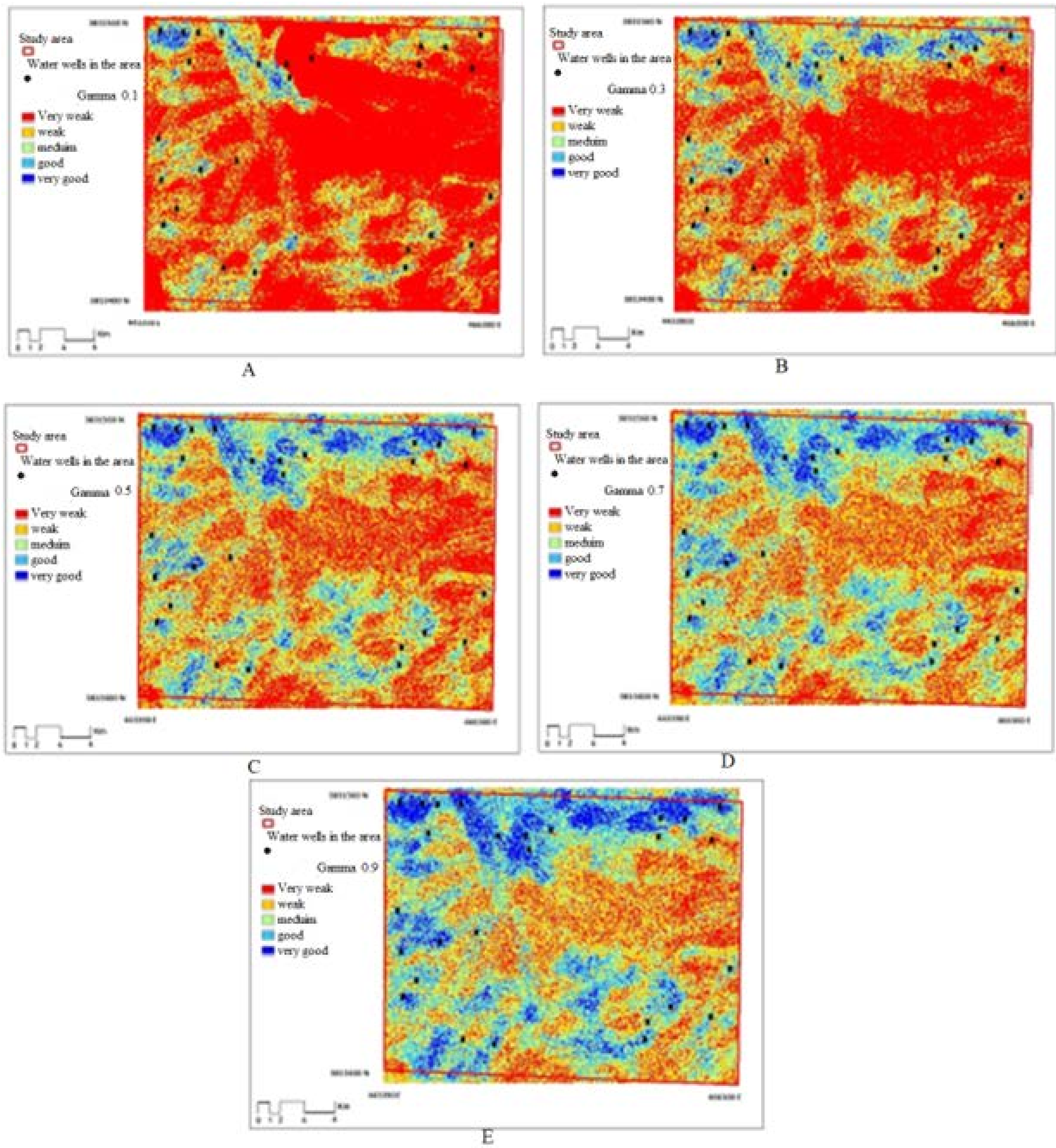

Figure 10. Groundwater potential map using fuzzy gamma operator with a layer of water wells in the area

This index introduces the OR operator and the fuzzy sum with the highest accuracy in the production drawings. However, the reason for this high accuracy is that in these slabs, a massive part of the area has been designated as areas with optimal groundwater potential. Therefore, to make a more appropriate decision about the most appropriate method of combining information layers, we defined the ratio of the area of good and very good classes to the total area for each production map as R = AG / AT. We introduced this parameter as a suitable indicator to decide on the proper performance of each combined method.

In this case, the combined method will be more appropriate, which shows both higher accuracy and timeless space in the map, allocated to two classes, good and very good in terms of groundwater potential. Based on this parameter, production maps using fuzzy multiplication and 0.1 fuzzy gammas are the most suitable methods for combining information layers (Table 5).

The normalized ratio of accuracy to validity can be seen in the right column of the table. This value for the production map with the fuzzy gamma method (gamma=0.1) 54% has been determined as the best production model.

Table 5. The most appropriate way to integrate information layers.

COMBINATION METHOD	VALIDITY RATIO OF AREA OF GOOD AND VERY GOOD CLASSES TO THE WHOLE AREA)	ACCURACY	ACCURACY/VALIDITY	NORMALIZED A/V
INDEX OVERLAY	42.7%	51.8%	1.21	0.15
WEIGHTED INDEX OVERLAY	29.3%	59.3%	2.02	0.25
FUZZY AND	7.5%	18.6%	2.48	0.31
FUZZY OR	89.1%	96.3%	1.08	0.13
FUZZY SUM	94.6%	96.3%	1.02	0.13
FUZZY PRODUCT	24.2%	77.8%	3.21	0.40
FUZZY GAMMA 0.1	15.9%	70.1%	4.41	0.54
FUZZY GAMMA 0.3	27.8%	81.5%	2.93	0.36
FUZZY GAMMA 0.5	35.0%	81.5%	2.32	0.29
FUZZY GAMMA 0.7	38.4%	85.1%	2.21	0.27
FUZZY GAMMA 0.9	48.2%	88.9%	1.84	0.23

5. Discussion

The primary objective of remote sensing and GIS surveys in groundwater studies is to identify and remediate potential areas of poor groundwater quality. To achieve this goal, we conducted a comprehensive assessment by collecting primary data, such as Sentinel satellite data, geology, and digital altitude data. We then utilized ArcGIS software to extract maps of effective groundwater parameters from the collected data. These maps were subsequently transformed into weighted information layers using overlaying (weighted) and fuzzy methods. The resulting output includes potential groundwater maps for the western region of Salafchegan in Qom province. To validate these maps, we also generated a digital water well density map.

Our findings demonstrate that remote sensing technology is a highly efficient means of determining groundwater resources. This technology enables the study of water sources in different areas and facilitates the identification of suitable locations for drilling water wells. Additionally, we have determined that GIS is a valuable tool that can be utilized in conjunction with various methods to combine layers, identify new groundwater and surface water areas, and manage water resources.

We have found that the weighted index overlay method in ArcGIS software is a suitable method for detecting groundwater potential. This method helps to determine areas of high groundwater potential based on the results obtained from the maps of effective groundwater parameters. In contrast, the "or" operator in the fuzzy method was deemed unsuitable for integrating groundwater information layers, as it does not adequately account for the maximum value of cells.

Furthermore, we have found that the fuzzy gamma method and the product of fuzzy algebraic multiplication are desirable methods for integrating groundwater information layers. The former is particularly useful when using lower gamma numbers. At the same time, the latter method is optimal for determining areas prone to the presence of groundwater aquifers due to the continuity of the output map intervals and the proximity of the area with very high potential to the range of dense well presence.

6. Conclusion

This study aimed to use remote sensing technology and GIS to identify and map the potential and zoning of groundwater resources in the Salafchegan area of Qom province, Iran. We aimed to provide an overview of the status and potential of groundwater resources in the region, which could be used to identify suitable places for drilling wells and extracting karst water to meet current water needs. The study focused on factors influencing the formation of groundwater aquifers, such as slope layers, lithology, canal length density, fracture length density, fracture buffer, canal buffer, and vegetation. It used different fuzzy operators to integrate this information into a final potential map that was validated with the location of groundwater wells. The study highlights the importance of using remote sensing techniques and GIS as effective tools for groundwater studies, especially in arid regions with limited access to freshwater. It provides a framework to characterize groundwater potential for targeted well siting and development of water supplies. It provides a framework to characterize groundwater potential for targeted well siting and development of water supplies.

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