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Geospatial Groundwater Potential Zone Mapping using Geological, Remote Sensing Data and Multi Criteria Analysis Techniques

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ABSTRACT

The purpose of this paper is to assess the potential of groundwater regions in the northwestern part of Iran's central province by integrating satellite imaging and geological data. For the possibility of groundwater identification, a comprehensive understanding of the criteria is necessary, which, in addition to satellite imagery of nine effective geological data, was employed in this work. All of the thematic layers were given weights based on their relative importance, and their normalized weights were determined after the ranking using the pair-wise comparison matrix of the analytical hierarchy process. The weighted data were then merged to generate a groundwater potential map in three distinct conditions. This map revealed five different kinds of groundwater potential: very good, good, medium, moderate, and very low. According to the findings, 14.51% of the region has extremely low groundwater potential, 7.9% has poor, 21.10% has average, 34.50% has well, and 22.50% has very good groundwater potential. Zones with no promise were linked to places with maximum heights and volcanic and granite rocks, and higher potential zonation is more consistent with alluvial deposits and coarse alluvial deposits. The placement of the piezometric wells was used for validation findings, which revealed that 74% of the wells are in locations with extremely high potential. Although there are few of them in other areas, this could be due to the high slope and water outcrop. The obtained results show that the majority of the groundwater area is distributed in the west, southwest, southeast, and center of the research region.

KEYWORDS

Groundwater,
Remote sensing,
Geological,
Satellite imaging,
Landsat

1. Introduction

Groundwater is thought to encompass a wide range of the world's freshwater resources. With a growing population, urbanization, and agricultural production, there has been an increased emphasis on surface and subsurface water management. One method of managing water resources is to identify water resources with varying potentials and use them based on their capacity. Rapid population growth, agricultural development, and climate change have increased the demand for groundwater for residential, agricultural, and industrial use in many countries, including Iran. Accessing groundwater resources has become more important as water demand has increased, particularly in dry and semi-arid areas. Despite the fact that groundwater is the world's most significant source of fresh water and over two billion people have drinking water provided directly from groundwater (Gadgil, 1998). However, groundwater supplies are depleted in many regions of the world because they are extracted from the groundwater faster than rain and snow. Declining groundwater levels result in decreasing groundwater inflows into rivers, wetlands, and lakes, resulting in dry rivers, unsustainable wetlands, and groundwater-dependent ecosystems. Obviously, the instability and decrease in groundwater levels will reduce local growth. As a result of humans' reliance on groundwater resources, the detection, research, and management of aquifers is critical. However, due to the lack of permanent or even seasonal surface water flows in parts of the country's plains, groundwater reserves are the only source of water abstraction. As a consequence, it is critical to investigate the state of these resources and the variables influencing them. Hydrogeological mapping of groundwater resources is an important technique for the controlled development of groundwater resources. The mapping of groundwater requires substantial use of integrated remote sensing (RS) and geographic information systems (GIS). The necessity for efficient management of its limited fresh water resources is one of the most serious challenges to IRAN's sustainable development. With the introduction of various satellite imagery, locating potential groundwater targets has become easier, less expensive than intrusive methods, and more efficient. The objective of groundwater exploration using RS is to find all possible variables linked with groundwater localization. RS data assists decisions on sustainable development and groundwater management. Quantitative analysis, good groundwater management, and proper groundwater utilization are therefore crucial. Rainfall is the major source of groundwater; droplets can either enter the ground instantly or form stagnant water or a lake before slowly entering the earth. In addition, melting snow and ice on the surface and the natural penetration of the resulting water into the earth supply some groundwater, which water settles in the gaps and pores. Furthermore, the gravity of the earth and the property of water penetration into the subsurface are the key factors in the development of groundwater; it penetrates until it is no longer feasible to enter and then ceases (Dasho, Ariyibi, Akinluyi, Awoyemi, & Adebayo, 2017). The depth of these impermeable data fluctuates, which is the main reason for the variation in groundwater resource depth.

Over the last several decades, the international scientific community has shown a substantial level of interest in this subject, and as a result, many scientists have used RS and GIS to potentially find groundwater resources. (Shabani, Masoumi, & Rezaei, 2022) undertook a study to analyze the potential of groundwater resources in the Zanjanrood Catchment and the Tarom area, both situated in northwest Iran. Slope, land-use, drainage density, spring density, lithology, lineament density, and rainfall were among the seven effective parameters evaluated. The Analytical Hierarchical Process (AHP) approach was used to weight the criteria, which was then overlaid by the technique for order preferences by similarity to the ideal (TOPSIS) model. Their results demonstrate that high-discharged wells are generally clustered in the very excellent zone and, in some cases, in the good zone in both areas. Furthermore, the geoelectrical field survey's two-dimensional models of resistivity and induced polarization contradict those of the TOPSIS technique.

Jhariya et al. (2021) assessed the groundwater potential zones (GWPZs) in Raipur, Chhattisgarh, India, using GIS-based multi-influencing factors, multi-criteria decision analysis, and electrical resistivity survey methodologies. They integrated modern techniques and technologies such as RS, GIS, electrical resistivity, and MCDA to analyze possible groundwater occurrence zones. Several predefined thematic layers were weighted based on their effect on groundwater potential, including geology, geomorphology, rainfall, lineament, land use, land cover, drainage density, soil type, slope, and soil texture. Their acquired result was confirmed using well-yield data and the ROC technique, with a result accuracy of 80% and an area under the ROC curve of 0.857 at a significance value of less than 0.001, demonstrating the usefulness of the suggested strategy in the delineation of GWPZs. (Chatterjee and Dutta, 2022) GWPZs assessment for sustainable water resource management in the southwestern region of Birbhum District, West Bengal. They propose a study to delineate the groundwater potential zone utilizing MCDA and GIS. Seven thematic layers dealing with geology, geomorphology, hydrology, land use, land cover, and edhaphic factors were used. Using an analytical hierarchy method, the entire research region was divided into four zones ranging from outstanding to poor. To ensure the accuracy of the results, primary field data and secondary data on groundwater depth were compared. (Ifediegwu, 2022) used an integrated strategy to analyze the GWPZs in the Lafia district, which included the use of RS, GIS, and AHP. For this purpose, eight thematic maps governing groundwater occurrence and transportation (geology, rainfall, geomorphology, slope, drainage density, soil, land use/land cover, and lineament density) were created. The GWPZ map is split into four zones (good, moderate, poor, and extremely poor). Finally, the GWPZ map was confirmed using borehole data from 50 wells distributed throughout the research region to assess the approach's efficacy. (Ghosh et al., 2022) used MCDA and AHP to identify GWPZs in the Kangsabati River basin in east India. Geology, geomorphology, elevation, slope, drainage, lineament, curvature, topographic wetness, land use/land cover, and soil criteria were retrieved from satellite data, and weights were assigned to each characteristic and its sub-parameters using an analytical hierarchy approach. The area is represented by extremely low, low, moderate, high, and very high groundwater potential. Their findings were validated using pre- and post-monsoon groundwater depth measurements, demonstrating that the technique is best suited for this location. (Abebrese et al., 2022) employed an integrated method integrating GIS and RS techniques on thematic layers such as geology, geomorphology, drainage density, lineament density, slope, soil, and land use land cover. The final output map depicts several zones of groundwater potential ranging from very good to good, moderate to mediocre, and poor. The GWPZs map was eventually confirmed using borehole yield data from 22 boreholes, which demonstrated a high connection and is useful in designing improved groundwater exploitation techniques. (Doke, Zolekar, Patel, & Das, 2021) investigated multi-criteria decision-making (MCDM), AHP, and RS-based integrated technique for spatial mapping of groundwater using GIS. Despite the fact that the high and low groundwater sites were detected more accurately by the user than other places, the likely groundwater regions, i.e., the high, medium, and poor suitability maps, were computed perfectly in contrast to the "low" area. (Forootan & Seyedi, 2021) examined two methods for determining groundwater potential zones in Iran's arid region: AHP and entropy. In this regard, the training approach included groundwater level decline in 16 piezometer wells as well as eight groundwater potential mapping (GWP) conditioning parameters: slope degree, stream power index (SPI), land use, geology, rainfall volume, elevation, soil, and lineament density. Finally, the models' performances were compared using statistical measures including sensitivity, and true skill statistics (TSS). In terms of prediction performance, their data indicates that TSS beats the AHP approach. (Masoud, Pham, Alezabawy, & El-Magd, 2022) used multi-criteria decision analysis (MCDA), GIS, and groundwater field data to identify prospective groundwater zones in the Tushka area, west of Lake Nasser, Egypt. To achieve the current work's purpose, eight regulatory elements, namely the AHP and frequency ratio (FR) models, were employed in conjunction with MCDA approaches. In the AHP and FR models, high-potential zones account for around 61% and 52% of the overall area, respectively. (Ejepu, 2020) identified groundwater potential zones using RS, GIS, and MCDA techniques. To do this, seven components were developed that are expected to have a significant impact on the occurrence and flow of groundwater: geology, lineament density, slope, drainage density, rainfall, land-use/land cover, and soil class. Their findings resulted in four groundwater potential zones: extremely excellent, good, moderate, and poor, with 7%, 27%, 43%, and 23%, respectively. (Arabameri, Lee, Tiefenbacher, & Ngo, 2020) developed a one-of-a-kind ensemble technique for GWP mapping in the Bastam watershed, Iran, by integrating frequency ratio (FR), and random forest (RF) models. A geographical geo-database was utilized to construct seventeen physiographic, hydrological, and geological groundwater conditioning parameters (GWCFs). According to the conclusions of the RF analysis, the most important aspects of groundwater occurrence are land use and land cover, lithology, and elevation. (Das, Pal, Malik, & Chakrabortty, 2019) used RS and GIS methodologies to predict the groundwater potential zones of the Puruliya district in West Bengal, India. Using a weighted overlay approach, a groundwater potential map was constructed in GIS after integrating all the thematic data. Potential zones were confirmed using groundwater yield data, with 10 of 14 validation sites (71.43 %) matching the expected yield classes. It illustrates that the technique employed yields very accurate results for the current research, which can assist decision-makers in developing an effective plan. (Díaz-Alcaide & Martínez-Santos, 2019) demonstrated the state of the art in groundwater potential mapping, an exploratory method based on RS and geographical databases that has witnessed substantial advances in recent years. They detected twenty elements that are typically used in groundwater potential investigations, with eight of them almost always present: geology, lineaments, landforms, soil, land use/land cover, rainfall, drainage density, and slope. Satellite imagery is being used in novel ways to provide indicators for vegetation, evapotranspiration, soil moisture, and temperature anomalies, among other factors. (Ahmed II & Mansor, 2018) examine how geospatial technology might be utilized to identify groundwater potential. They in the first stage was to collect a global perspective on advancements in the use of geospatial technology for groundwater mapping, from which the application's strengths and weaknesses in terms of data extraction, modeling, and validation methodologies were assessed.

(Nayak, Rai, & Tripathy, 2017) investigated different aspects of the Indian Mahanadi Basin, including geomorphology, lithology, topography, soil type, and drainage pattern, to find potential regions for prospective groundwater research. Based on the various weights attributed to geological variables, surface runoff, intrusion, and other considerations, it was discovered that around 42% of the overall region has good groundwater potential, while approximately 21% has a rather poor outlook. (Jam.S, Abadi.SH, Vafaeinejad.A, Moridi.A, & Khazaee.S 2017) examined the ability of groundwater resources in the Mehran region using a hybrid method that included a particle swarm optimization algorithm and a spatial information system. The maps were then weighted and blended using a particle swarm optimization technique. Finally, they got two groundwater potential maps: one with the optimization equation equal to the good density map and another with the optimization equation equal to the particular discharge map. Their findings revealed that 2.40 % of the land had a high potential for groundwater resources. (Selvam et al., 2016) investigated Indian groundwater using a combination of RS and geographic information derived from satellite images and publicly available maps, geological topic data, soil, slope, line density, drainage density, and land use. They next created a map of groundwater areas with three classes: high, medium, and low, utilizing weight overlap. (Rahmati & Melesse, 2016) used the Dempster-Schaefer theory to analyze groundwater potential and nitrate contamination in Khuzestan's Samirad area. They created a methodological framework for developing a suitable drinking water map using GIS, remote sensing, and field surveys. Their findings revealed that the groundwater quality map has an accuracy of 87.76 % and that unsatisfactory regions make up the bulk of the study's coverage (60 %). (Elbeih, 2015) offered an overview of the factors influencing Egypt's groundwater by utilizing IRS satellite imagery and existing maps, as well as thematic data on geology, soil, slope, surface area, and land use. Then, using weight overlap, they built a model of groundwater regions classified as high, medium, or low. Their findings highlighted the benefits of integrating GIS and RS in groundwater prospective regions. (Hammouri, Al-Amoush, Al-Raggad, & Harahsheh, 2014) investigated groundwater growth using GIS and the SLUGGER-DQL index model in their research. In this study, sensitivity analysis was done on each model parameter. According to their findings, the slope parameter is the most sensitive model parameter, followed by the geology parameter, and other elements such as summer water level, well density, water quality, and runoff are in the early planning. The Slugger model index was used to establish the effective weight for each parameter, and then the groundwater resource potential map was created. (Khodaei & Nassery, 2013) researched groundwater expansion in the Urmia region using a GIS and RS. They created thematic maps and digital image processing techniques using secondary porosity/permeability indices such as lines, vegetation, lithology, drainage pattern, drainage density, and so on, as well as Landsat ETM^{+} and IRS satellite images. Filtering, false color composite, principal component analysis, and classification were employed. Finally, they mapped groundwater vulnerable zones using weight overlap. (Saberi, Kazem, Reza, & Agriculture, 2012) used RS and GIS to explore suitable areas for supplying the groundwater of the Kamestan anticline. Geology, geomorphology, fractures, soil science, land cover, slope, and precipitation were employed as effective data. These data were collected using ETM^{+} sensor imagery, topographic maps, geology, and weather information from the research region. The information sets were weighted using specialized viewpoints and hierarchical analysis, and the groundwater potential of numerous locations was determined. Finally, the groundwater potential map was compared to the location and discharge map of the region's springs to validate the results. Their findings revealed that almost half of the study region had a high potential for groundwater extraction. (Rahimi,2012) used GIS to investigate the potential of groundwater resources in the Shahrekord plain. In this study, the weight of the data was determined using the Delphi technique, and a prospective map of groundwater resources was generated by integrating information data such as geology, lithology, porosity, topography, slope, and canal network. According to their findings, 5900 hectares of plains have a high potential for harvesting, artificial feeding, and drilling wells; 1600 hectares have a medium potential; and 4802 hectares have a low potential. Using a GIS, (Lshkaripour, Nakhaee, & Behzadifar, 2012) quantified the groundwater of the Quchan plain. Their research data include slope, waterway density, geology, geomorphology, and soil type. Without specifying a little quantity, their outcomes were examined using piezometric wells. According to research, integrating RS methods with GIS is a powerful tool for groundwater mapping and investigation (Machiwal, Jha, & Mal. , 2011). Because of their capacity to manage information, speed of operation, and lower cost than traditional approaches, these techniques are a great tool for this type of research. Furthermore, in addition to assisting in the discovery of viable sites for groundwater research, the combination of RS and GIS can assist in estimating total groundwater resources and selecting acceptable sites for drilling and artificial feeding (Agarwal & Garg, 2016).

A comparison of past research reveals three significant distinctions. First, each of them has been employed in a distinct place with specific environmental, geological, and climatic circumstances, resulting in the usage of different data of information in those areas. Second, effective groundwater data has not been widely utilized in the majority of them. In most of these investigations, in addition to the kind of information layer employed, multiple approaches are used to weigh information data, including the Delphi approach, the particle swarm optimization method, the traditional AHP method, and the experimental interpretation method. Third, the majority of this research employed GIS or RS techniques to identify prospective groundwater sites independently. As a result, no groundwater potential studies have been conducted in the current research region. To that end, the purpose of this research is to determine the potential for groundwater in the part of the north of the central province of Iran. As a result, this study differs from past studies in three aspects. First, for complete research in this study, various groups of geological and environmental data, satellite images, and terrestrial data from field studies were quantified and then integrated into the potential of groundwater regions using RS techniques and GIS. In addition, the weighting of the effective data in the areas prone to groundwater has been investigated by the methods of nine-degree hierarchical analysis, fuzzy hierarchical analysis, and structured hierarchical analysis. The final map is produced from the average of the three mentioned cases with the least amount of error, and it has been validated using piezometric wells in the region. Furthermore, the potential of Landsat 8 reflective and thermal images in groundwater investigations has been examined and assessed in the subject and region studied.

2. Study Area and Dataset

2.1. Study Area

The research region, which is approximately 9000 square kilometers in size, is located in northern Markazi province, from latitude 34 degrees and 45 minutes to 35 degrees and 34 minutes north latitude and 49 degrees and 15 minutes to 50 degrees and 56 minutes east longitude. Figure 1 illustrates the research region's area. This research region has a hot and dry environment due to its closeness to the desert and low heights, and its annual rainfall is just approximately 213 mm. The majority of this area is flat and plain. The research area, which includes an irrigation and drainage network, is located on one of the most fertile plains in the country. Agriculture and horticulture consume 95 % of groundwater. As a result, locating and identifying groundwater resources, as well as finding regions with high potential in this area, is critical. Obviously, understanding groundwater growth and identifying locations with acceptable potential is critical in order to manage, assess, and avoid inappropriate exploitation of these resources.

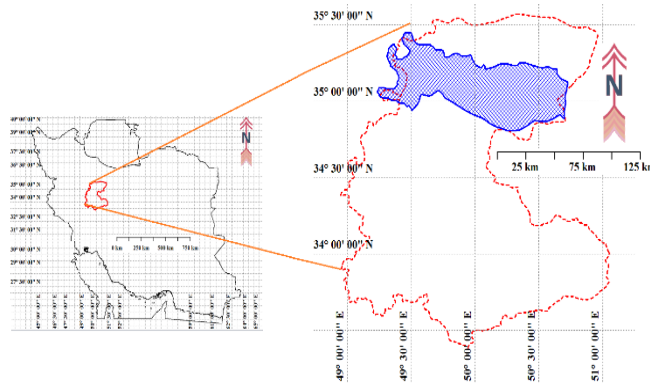

Figure 1. Study area

2.2. Dataset and Pre-Processing

The data for this research is shown in Table 1. Groundwater is utilized for several things, including drinking, industrial, and agriculture. A significant portion of groundwater comes from surface water. Simply said, the goal of groundwater monitoring is to identify the physical, chemical, and biological properties of the surface and subsurface environment.

MODTRAN5 (MODerate resolution atmospheric TRANsmission) radiation transfer model database (Richter & Schläpfer, 2013). This software is based on atmospheric physics and was implemented by the DLR—German Aerospace Center—in the ENVI/IDL software programming, taking into consideration all of the various atmospheric conditions and states, three million modes. The ground-level reflection parameters are extracted after atmospheric and topographic correction of the imagery. The digital elevation model (DEM) employed in this study is a product of the US Geological Survey Shuttle Radar.

Table 1. Research data

Row Data Type	Data Specifications	Reference
Satellite imagers	Landsat 8 satellite data with 165 passes and 36 rows as of 2021	United States Geological Survey (USGS)
Digital elevation model	Shuttle Radar Topography Mission digital elevation model	United States Geological Survey (USGS)
Geological data	Lithology	Geological Survey and Mineral Exploration of IRAN
	Geological Line density	Geological Survey and Mineral Exploration of IRAN
Environmental data	Digital elevation model and its derivatives	United States Geological Survey (USGS)
	Land use and drainage density	Extracted from Landsat 8 satellite data
	Rainfall map	Markazi Province Meteorological Organization
	Temperature map	Extracted from Landsat 8 satellite data
Other data	Distribution map of wells in the study area for validation	Central Province Water and Sewage Company

3. Research method

This research was carried out in four stages, as seen in Figure 2.

The data and images needed for the project were collected and prepared in the first step. The essential data preparation and preprocessing, as well as radiometric correction of satellite images, were completed in the next step. In the third stage, the necessary analysis and classification were performed on each of the data, and the importance of each of the factors and criteria was determined based on expert opinions and the method of hierarchical analysis, and the criteria were weighted. Then, all produced data were combined and, by a weighted combination of criteria, the potential of groundwater-susceptible areas was identified and validated**.**

Spatial analysis is the process of investigating the properties, locations, and interactions of spatial data features. It addresses relevant knowledge by utilizing analytics, computational models, and algorithms. Statistical analysis based on patterns and underlying processes is referred to as "spatial analysis." Location analysis is a type of geographical analysis that elucidates patterns of attributes and spatial appearance in terms of geostatistics and geometric forms. It comprises statistical and processing approaches that might be used for a specific geographic database. On the other hand, spatial analysis of individual maps and layers entails two-dimensional processing and geostatistical methods such as reclassification and thresholding; neighborhood functions using spatial filters; distance and buffer calculations; 2D spatial transformations; and, most importantly, gridding or interpolation. Spatial data is often classified into two forms based on its storage technique: raster data and vector data. This study's data had varied sizes, distinct classes, raster or vector, etc., and the process of combining them in a coordinate system is comparable to spatial analysis. In this study, ARCGIS spatial analysis capabilities were employed, with ArcGIS Spatial Analyst offering sophisticated spatial modeling and analysis tools. It aids in terrain modeling, locating acceptable places and routes, detecting spatial trends, and performing hydrologic and statistical analysis.

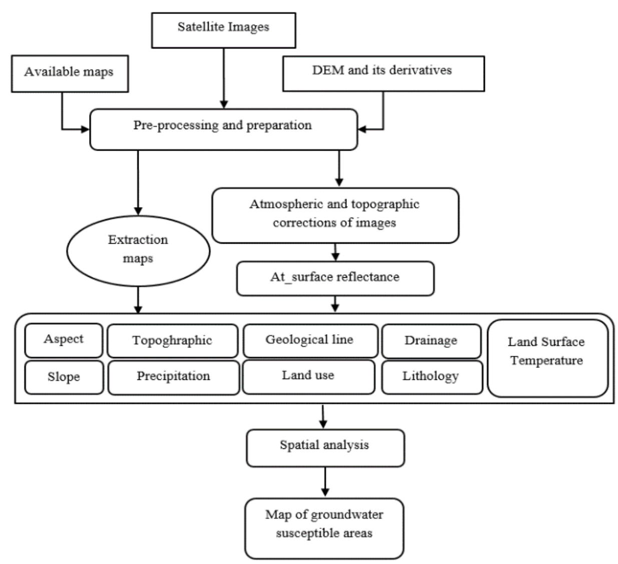

Figure 2. The process of conducting research

Usually, groundwater mapping needs a collection of both qualitative and quantitative data that is either not available or very limited. To that end, the AHP and FAHP approaches give a reasonable framework for a required choice by quantifying its criteria and alternative possibilities, as well as tying those parts to the overall goal. They address the multi-indicator issue by building a hierarchical structure, quantifying the hierarchical decision-making process, and integrating qualitative and quantitative conclusions in a reasonable manner. Knowledge-based approaches such as deep learning, on the other hand, have successful applications in big data. They often demand more information than classic AHP and FAHP approaches. Because they require massive quantities of data to train, they are not considered general-purpose algorithms. Knowledge-based approaches require a large quantity of data in order to outperform competing technologies. Furthermore, because topology, training technique, and other parameters are required, there is no standard theory to guide users in picking the correct deep-learning tools. As a result of the limited amount of data in this study, knowledge-based approaches were not utilized.

3-1. Preparation of Data

First, the criteria and factors, as well as their relationship to groundwater, were determined in this section. Because groundwater follows a pattern similar to surface water, both flat and steep slopes are excellent areas for water to penetrate. The main and effective parameters in groundwater, such as precipitation, lithology, drainage density, land use, geological line density, topography, slope, aspect, and land surface temperature, were investigated in the present study. Table 2 demonstrates the relationship between groundwater and the factors used to establish the major and effective parameters of groundwater. These parameters include precipitation, which is directly related to the amount of infiltration and increases the potential for underground water formation; Lithology: The type of lithology and its related features, such as the texture and degree of purity of the stones, play an important role in porosity, primary permeability, and groundwater flow concentration in rocks. High porosity rocks have high permeability, which increases or decreases permeability. A drainage network's characteristics and density indirectly indicate the level of permeability as hydrological factors and climatic parameters, such as precipitation, play a role. Therefore, if the ground conditions are ready, a high-density waterway indicates a reduction in infiltration, while a low-density waterway means a decrease in infiltration. Therefore, drainage density affects the spatial distribution of runoff and groundwater. Land use: vegetation decreases surface water flows and allows more water to penetrate the soil, increasing underground water levels and amounts. Thus, land use is important for water penetration. Geological line density: Structural and tectonic factors such as seams and faults are considered the weak points of geological units, which are called lines, which are a way for water to pass easily and a place for its accumulation in the form of underground tanks. When joints and faults are denser, underground water is more likely to be infiltrated and transferred, so the density of a line plays a crucial role in permeability. It increases water penetration vertically, which is a positive effect. Another important factor in determining the potential of underground water sources is the topographic layer, which determines their runoff and permeability coefficients. It plays a crucial role in determining the direction in which underground water moves and the location of aquifers. As a result, at high altitudes, water penetrates the ground less and runs off more, thus increasing altitude reverses the effect on underground water resources. A low slope retains water for a long time, causing more infiltration or feeding, whereas a high slope has a lot of runoff and little infiltration. Aspect: All lands that have slopes facing north receive less sunlight. As a result, they tend to accumulate more snow and underground water. Therefore, the slope direction influences the melting of snow, and the movement of water currents affects the melting of snow. Land surface temperature: a high surface temperature affects land cover and evaporation, so areas with high surface temperatures have little or no vegetation cover. Table 2 shows the relationship between groundwater and the factors used in this study.

Table 2. The relationship between groundwater and the research factors

No.	Research Data	Data Attributes	Connection with Groundwater	
			Qualitative Quantity	Valuation
1	Lithology	Kind	Much	Alluvial sediments, sandstone, sand
			Little	Basaltic lavas, igneous rocks
2	Rainfall	Neighbourhood	Much	High
			Little	Low
3	Drainage density	Density	Little	High
			Much	Low
4	Land use	Land cover	Much	Forests and grass
			Little	Wasteland
5	Geological line density	Proximity	Much	Nearest
			Little	Farthest
6	Topography	Height	Little	High
			Much	Low
7	Slope	Rating	Much	Too low
			Little	Too high
8	Aspect	Direction	Much	North
			Little	South
9	Surface temperature	Grade	Little	High
			Much	Low

In addition, 1: 100,000 geological maps were used to extract lithology and area lines. Furthermore, the thermal bands of Landsat 8 images were used to generate a land surface temperature map while the reflective bands were used to create a land use map. A DEM was also considered when creating the topographic map, slope, aspect, and drainage density. Finally, the results were validated using data from existing wells in the region. There are various weighting methods for evaluating the importance of criteria, with differences in the principles of theory, accuracy, ease of use, and comprehensibility for decision-makers. The simplest way to assess the weight of criteria is to rank them according to the decision maker's importance and priorities. The opinions of experts and specialists are used to rank the parameters in this method. As a result, several experts are asked to rank the desired criteria based on their knowledge. Then, by summarizing all experts' opinions, a matrix is formed, the values of which represent the percentage of experts' opinions who have assigned the *i* parameter the *j* rank (McDevitt, Kligman, & Withee, 2002).

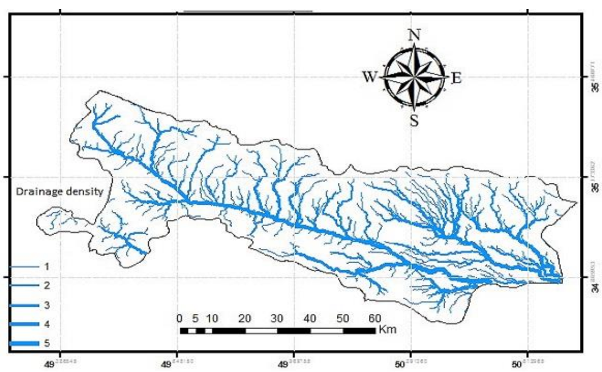

Figure 3. Drainage density map

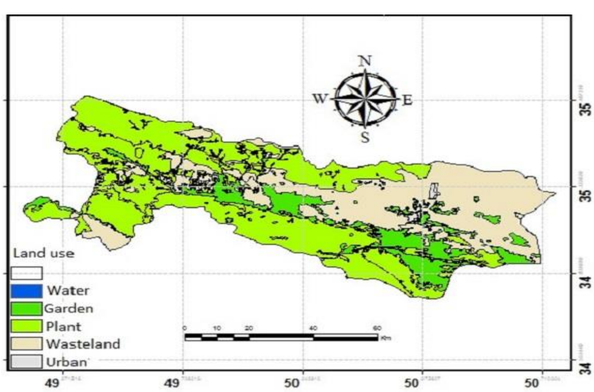

Figure 4. Land use map

In this study, three different hierarchical analysis methods were used for weighting. This method has been used in several applications, including nine-degree hierarchical analysis, fuzzy hierarchical analysis, and structured hierarchical analysis. After weighing all of the information data, the overlap method was used to integrate them, obtaining three groundwater potential maps based on the three weighing methods. The final map was produced by averaging the three maps. Figures 3 and 4 show an example of raw data.

4. Results and Discussion

4.1. Ranking of Data

Lithological data: Porosity, initial permeability, and concentration of groundwater flow inside rocks are all affected by the type of lithology and its associated properties such as texture and purity of rocks. High permeability rocks have high porosity (Ganapuram, Kumar, Krishna, Kahya, & Demirel, 2009). The geological data has been studied due to the effect of geological formations, lithology, texture, and purity of rocks on porosity, permeability, and concentration of groundwater flow inside the rocks. In this study, the lithological map of the region was created utilizing geological maps from around the country. It is necessary to explain that the geological map of the entire country used in this research was used to extract the rock data of the study area, and these geological maps were prepared and produced by the Geological Survey of the country at a scale of 1: 100000 and by digitizing in 2011. It is obvious that changing the geological structure of an area in a short period is impossible, and the time difference does not affect the extraction of the area's lithological data. In this study, forty rock species from the region were extracted from the lithological map and classified based on their porosity and permeability. Finally, the area's lithological map was created based on its weight and importance in the presence of groundwater. According to Table 3, igneous rocks composed of flow lavas have the lowest weight, and alluvial sediments have the highest weight.

Table 3. Classification of stone units.

Rank	Qualitative Relative value	Types of Stone Units
5	Very good	Alluvial sediments, sand, sandstones
4	Good	Cavity limestone, Cretaceous rocks
3	medium	Gypsum
2	Weak	Shales, tuffs and rolls, clay
1	Very weak	Basaltic lavas and igneous rocks

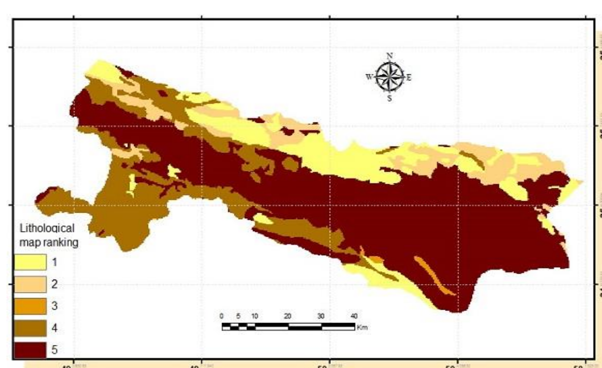

Figure 5. Ranking of geological maps

Precipitation data: The average annual rainfall in the study area is approximately 200 mm. Rainfall distribution can directly affect the infiltration rate and increase groundwater potential (Magesh, Chandrasekar, & Soundranayagam, 2012). In this study, the precipitation map was created by scanning the precipitation line map of the entire country and fitting it to the study area. According to Figure 6, a precipitation map was created using data from synoptic stations and meteorological rainfall stations using the interpolation method. The precipitation map was then weighted. Areas with high rainfall gained weight, while areas with low rainfall lost weight.

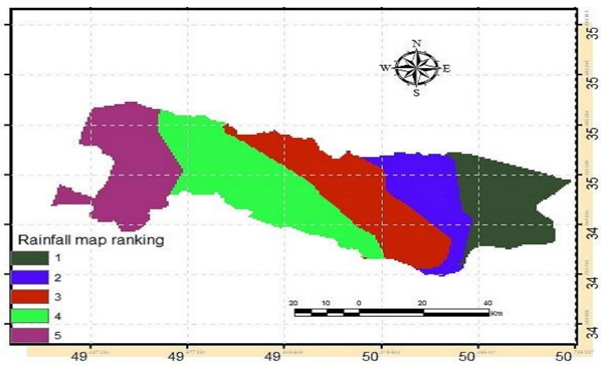

Figure 6. Ranking of rainfall map

Drainage density data: According to research, the type of drainage network in each region is determined by the lithology of geological units, topography, and tectonic structures (Rahimi & Mousavi, 2013) .The hydrological characteristics of each aquifer are one of the most telling aspects in the exploration and potential identification of water resources (Jha, Chowdhury, Chowdary, & Peiffer, 2007). The role of hydrological elements in connection to climatic indicators such as precipitation, drainage network properties, and canal density indirectly reveals the degree of permeability, with high density indicating low permeability and geological conditions. According to the data obtained from the DEM, it was discovered in this study that the drainage network pattern is of the tree branch type in the majority of the studied areas. This type of drainage network is typically found in areas with nearly identical rocks. According to Figure 7, a drainage network density map of the study area was created using a DEM ranking.

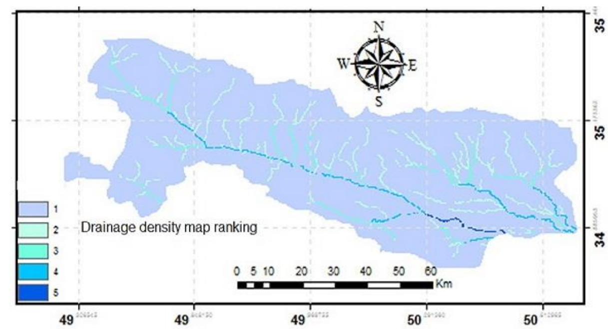

Figure 7. Ranking of the drainage network map

The STRAHLER method was used to rank drainage density maps (Carrara, 1988). With this method, the branch of any waterway that begins at the heights is referred to as a first-class waterway. A Category 2 river is formed by joining at least two Category 1 rivers. When at least one other class 2 river joins a category 2 river, it becomes a category 3 river, and so on until the catchment is exhausted. The river category number at the focal point indicates the state of the canal network in the basin upstream of that point. In other words, the drainage density and the water infiltration rate have an inverse relationship. Wherever there is a large drainage network, the concentration of water as runoff increases, reducing water infiltration.

Land use: Each area's vegetation slows surface water flows and allows more water to permeate the soil. As a response, the amount and level of groundwater increased. For example, forest environments have a high degree of permeability. As a result, rainfall minimizes drainage, with the bulk of water flowing into groundwater (Saberi.A, Rangraz.K, Mahjori.R, & Keshavarzi.MR, 2013). As a consequence, the rate of water infiltration can be influenced by different land uses. For example, there is almost no infiltration in urban and residential land uses, whereas very good pastures can cause large amounts of water to infiltrate the basement. The land use map used in this study was created using the supervised classification method on Landsat 8 corrected satellite images. According to Figure 8, the map's output was divided into five classes: water areas; soil areas; areas with soil composition and vegetation; vegetation areas; and urban areas. The resulting land use map was classified into five categories, with urban areas with almost very low permeability having the lowest weight and areas with gardens and bushes having the highest weight.

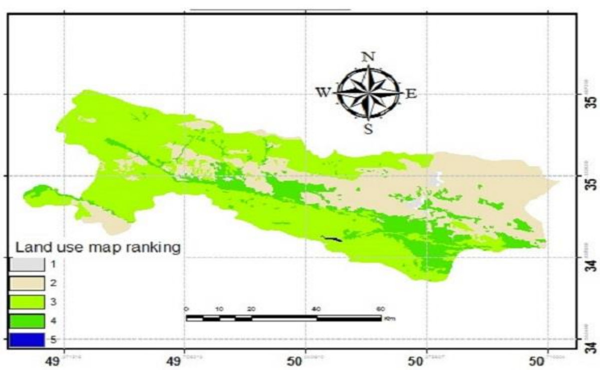

Figure 8. Ranking of Land use map

Geological Line density data: Joints and faults are considered structural and tectonic weaknesses of geological units, which are called geological line density data and provide a way for easy passage of water and a place for water accumulation in the form of underground reservoirs. Increased joint density and faults, in general, play an important role in groundwater infiltration and transfer (Rahimi & Mousavi, 2013). The final geological line density map in this study was created using the fault map of the entire country, as shown in Figure 9. In order to rank the density map, the lines with the shortest distance from the fault had the highest weight, and the lines with the greatest distance had the lowest weight.

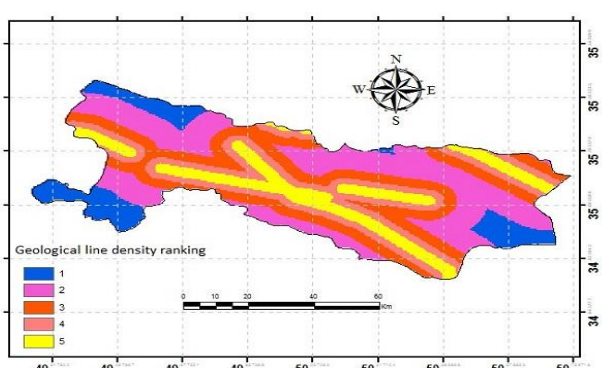

Figure 9. Ranking of Geological Line density map

Topographic data: The topographic data is another important factor in the potential of groundwater resources, as it influences runoff coefficient and permeability. This data plays an important role in groundwater movement and aquifer location. In other words, as altitude increases, water infiltration into the ground decreases and runoff increases, reducing groundwater potential (Rahimi & Mousavi, 2013). The topographic status of the area was prepared into five elevation classes in this study, with the highest altitudes having the lowest weight and the lowest altitudes having the highest weight. Slope data: Low-sloped areas retain water for a long time, allowing more water to penetrate. High-sloped areas, on the other hand, have a lot of runoff and very little infiltration (Carrara, 1988). In other words, the amount of water that penetrates the earth is affected by the topography and height of the earth's surface. In other words, water penetrates the ground less and runs off more at high altitudes. As a result, increasing altitude has an inverse effect on groundwater potential. The direction and speed of surface runoff movement are determined by surface topography. It can play an important role in groundwater dispersion.

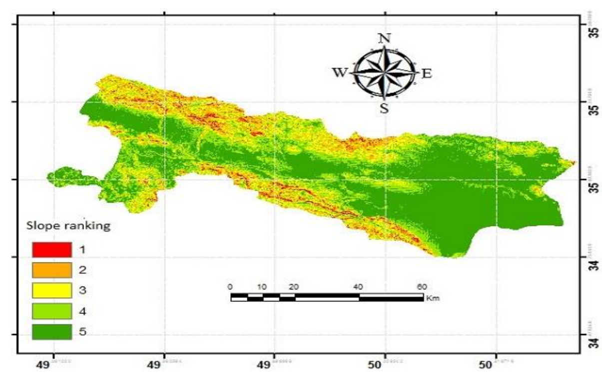

Figure 10. Ranking of slope map

In low slope areas, runoff velocity is low. Because of the slow runoff speed, more water penetrates the ground. In contrast, the infiltration rate of water is greatly reduced in steep areas, resulting in large amounts of runoff (Sander, Chesley, & Minor, 1996). The presence or displacement of groundwater aquifers is heavily influenced by slope and topography. Aspect data: The value of each pixel at the slope layer's output, extracted as a raster from the DEM, indicates the direction of the pixel's slope.

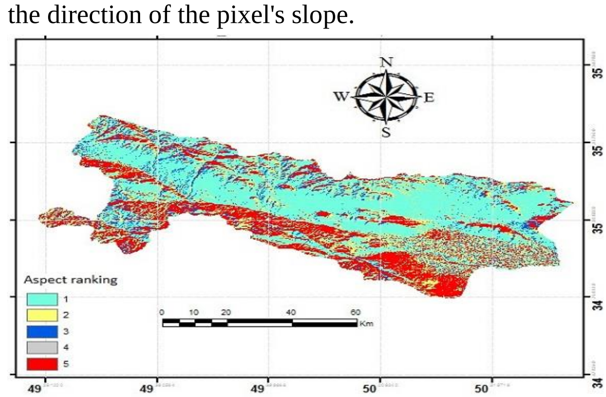

Figure 11. Ranking of aspect map

In this research, the final aspect map was divided into five classes, with the northern slopes receiving the most weight and the southern slopes receiving the least. Figure 11 shows that ranking number 1 is assigned to locations that are flat and do not have a slope.

Land surface temperature (LST): Today, an increase in surface temperature is observed as a result of changes in the conversion of vegetation surfaces to impermeable surfaces. These changes affect solar radiation absorption, surface temperature, evaporation rate, thermal management, and wind turbulence, and can have a significant impact on atmospheric conditions near the surface. As a result, there is little or no vegetation in areas with high surface temperatures. In order to estimate the LST (Figure 12), the surface emissivity was first calculated using the method based on the NDVI-based method. The LST was then calculated using the Subrino single-band algorithm (Jiménez-Muñoz & Sobrino, 2003).

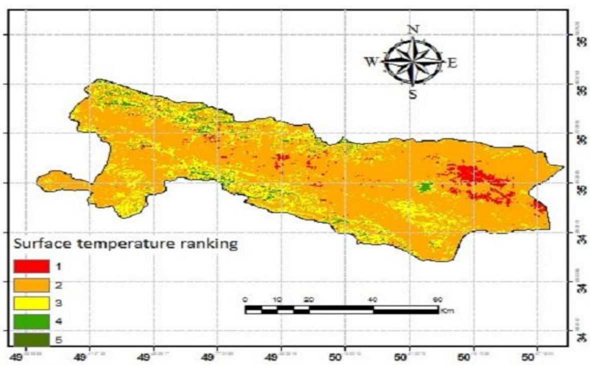

Figure 12. Ranking of LST map

4.1. Weighing to Criteria and Integration

Before integrating the relevant components and maps, it is necessary to evaluate the relative relevance of the effective variables in groundwater and the suitable weight for each of them. For weighting, the desired criteria are presented to the experts in these methods, and they are asked to weigh each of the criteria based on their knowledge, experience, and skills. There are several ways to obtain expert opinions and give them weight. Methods for ranking, grading, and numbering are simple, inexpensive, and quick. When compared to other methods, the hierarchical analysis method used in this study has greater accuracy and stronger theoretical foundations (Babaei.M, Gari.H, & Golanezhad.J, 2010). One of the most effective MCDM techniques is AHP analysis. This method is based on pairwise factor comparisons and allows for the investigation of various quantitative and qualitative decision-making criteria. As previously stated, three different hierarchical analysis methods were used for weighting in this study, including the nine-degree hierarchical analysis method, the fuzzy hierarchical analysis method, and the structured hierarchical analysis method. The results of determining the weight of criteria for one case are shown in Table 4.

Table 4. Weight of criteria

Criteria	**Lithology**	**Rainfall**	**Drainage Density**	**Land Use**	**Geological line Density**
Weight	0.290	0.214	0.154	0.120	0.076
Criteria	Topography	Slope	Aspect	Temperature	
Weight	0.055	0.040	0.031	0.022	

The approach of integrating and merging groundwater data was employed as a weighted spatial overlap method using Equation 1.

$$GWP = \sum_{i=1}^{n} (W_i \times X_i) \qquad (1)$$

where GWP corresponds to the value of each pixel of groundwater potential in the study area; Wi equals the weight of each map; and Xi represents the value of each pixel in the data map based on its ranking.

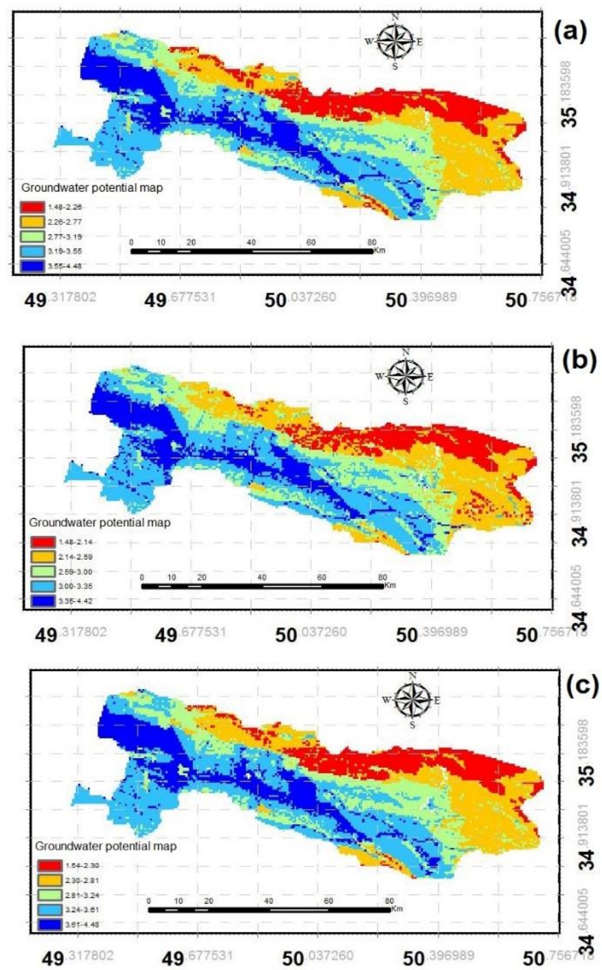

Figure 13. Map the potential of water resources in three different weighing modes

As a result, the map of vulnerable areas in each case was classified into five classes: very appropriate, appropriate, moderate, poor, and inappropriate. In addition, the weight and importance of different data were changed using three different weighting methods, and in three different cases, the groundwater resources potential map, as shown in Figures 13a, b, and c. These figures show that areas closer to blue have higher groundwater potentials, while areas closer to red have lower potentials. The results show that all three output maps with different weights are not significantly different from one another, indicating that the comprehensiveness and completeness of the information data used are well compatible despite the different methods and weights.

The final map was created by taking the average of the three previous maps. In the final map, Figure 13, 14.50% of the area has a very low potential, 7.50% has a low potential, 21% has medium potential, 34.50% has good potential, and 22.50% has very good potential for groundwater.

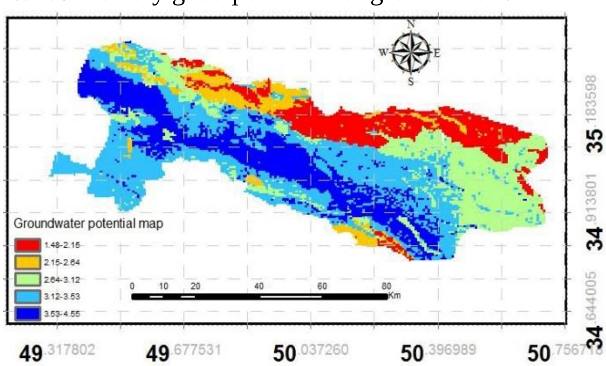

Figure 14. The final map of groundwater resources potential of the average of the three weighing methods.

4.2. Validation of results

To assess the accuracy of the results, the location of wells in the study area, as shown in Figure 15, was used and compared to the groundwater potential map.

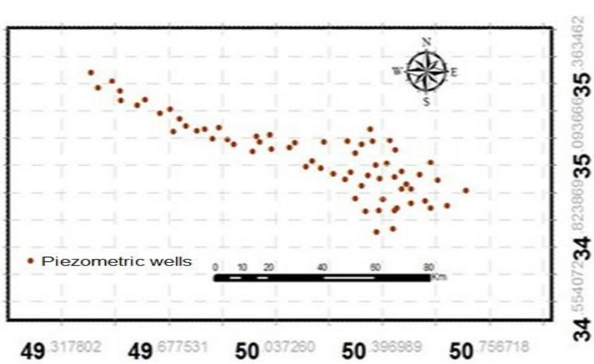

Figure 15. Wells map to validate the results

It is necessary to explain, First and foremost, this research is the first in the study of groundwater in the northwestern portion of Iran's central province, and it was nearly impossible to compare directly with the results of earlier research due to the lack of groundwater research in this area in previous research. As a consequence, 62 piezometer wells received from the Central Province Water and Sewage Company were geo-referenced, mapped, and investigated in this research to determine the accuracy of the results. The validation findings revealed that the groundwater potential zone classes had a high degree of overlap with the well location and number of groundwater wells in the given area. For that purpose, the locations of these 62 piezometer wells were compared to the groundwater potential map and overlapped with the potential map developed from this research. The bulk of the wells, as indicated in Figure 16, are in high-potential locations. For example, a 74% accuracy indicated the placement of wells in regions with high potential by comparing the final map with the distribution of these wells, demonstrating the method's accuracy in this study. As shown in Figure 16, the majority of the wells are in high-potential areas. For example, by comparing the final map and the distribution of these wells, 74 % accuracy revealed the location of wells in areas with high potential, confirming the method's accuracy in this study. However, some of them are in various areas. This might be because of the steep slope in those places, as well as the direction of the soil data in the basement and along the faults and fractures that expose the water in those locations, and their power supply is located in high-potential areas.

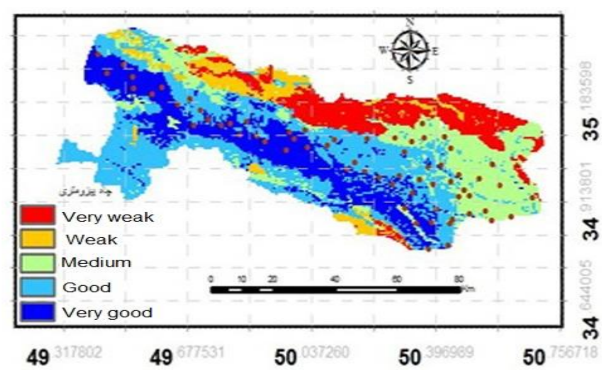

Figure 16. Combining it with the resulting groundwater potential map

5. Conclusion and Suggestions

This research integrated satellite imagery and geological data to investigate a potential groundwater zone in Iran's central province's northwestern region. To that end, the weight and rank of the thematic layer were determined using MCDA. Nine-degree hierarchical analysis, fuzzy hierarchical analysis, and structured hierarchical analysis were used to explore the weighting of effective data in groundwater-prone locations. In addition, the application of Landsat 8 reflective and thermal imagery in groundwater investigations has been examined and reviewed, with the results validated using well piezometric well ground truth data. Finally, the final groundwater potential map is generated by averaging the three previously stated scenarios with the least amount of error.

With increased population, urbanization, and agricultural development, there has been a strong focus on surface and groundwater management. There has been no study to identify groundwater potential in the study area, which is located in the northwestern part of Iran's central province. As a consequence, this study identified and mapped groundwater vulnerable areas in the research area by integrating terrestrial, environmental, geological, and satellite images. The distinction between this research and previous studies can be expressed in three ways. Each previous study applied different data of information to a specific area. Furthermore, for the first time in this study, the weighting of effective data in groundwater susceptible areas in three modes was used to minimize the opinion of experts in allocating the basic knowledge of information layer weights used in the research. Nine-degree hierarchical analysis, fuzzy hierarchical analysis, and structured hierarchical analysis were used to investigate various methods, and the final map was obtained by taking the average of the three cases with the least amount of error. Besides that, in this study, the potential of reflective and thermal images from Landsat 8 in groundwater studies was investigated and evaluated.

As an outcome, the information data used in these three methods were weighed using the hierarchical analysis process based on their importance and impact on groundwater, and a potential map of groundwater susceptible areas was created. According to the final findings, 14.50% of the area has very low groundwater potential, 7.50% has low, 21% has medium, 34.50% has good, and 22.50% has very good groundwater potential. The results also revealed that groundwater expansion in the study area is mostly concentrated in the west, southwest, southeast, and center, with low potential areas visible in the north and northeast. Furthermore, the evaluation of the results based on the type of geological and environmental data revealed that areas with high groundwater potential have good rainfall and land cover of the types of river alluvium, clonglomera, and sandstone. Areas with low rainfall, high altitude, and hard ground, on the other hand, have low groundwater potential. The groundwater potential is in good and very good areas according to the validation of the results, with the position of 62 piezometer wells, except for a limited number of wells in the area with low groundwater potential. This may be due to the fact that these areas are lower in elevation than their upstream counterparts, as well as the slope of the area being west to east and north to south, which may be the direction of the soil layer in the basement, as they have caused water to overflow in those areas, whereas their power supply is in higher areas with good potential. Finally, groundwater potential mapping employing GIS, RS, and the integration of diverse geological, environmental, satellite, and terrestrial data may be regarded as one of the most efficient ways to save time and money while also being cost-effective.

Due to the absence of access to water depth in piezometric wells in this study, it is proposed that future research examine the depth and level of subsurface water. In addition, future studies should consider combining radar satellite data from Sentinel and Landsat to extract more moisture and soil property parameters. It is advised to employ knowledge-based approaches if there are enough layers of information and effective variables in subterranean water, as well as information on the kind of soil, soil moisture, and other soil characteristics.

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