Identification of Suitable Site-specific Recharge Areas using Fuzzy Analytic Hierarchy Process (FAHP) Technique: A Case Study of Iranshahr Basin (Iran)

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ABSTRACT: Iranshahr Basin is located in the Sistan and Baluchistan province, subject to severe drought and excessive groundwater utilization. Over-reliance on groundwater resources in this area has led to aquifer drawdowns and socio-economic problems. The present study aimed to identify appropriate sites for Artificial Recharge Groundwater (ARG) in a single platform by applying GIS fuzzy logic spatial modeling. Three stages were performed. In stage one, nine factors affecting ARG were collected based on the literature review. In stage two, geology, soil, and land-use layers were digitized from the existing maps. Some layers such as rainfall, unsaturated thickness, water quality, and transmissivity data were imported to ArcGIS environments, and their surface maps were made by Ordinary Kriging (OK) method. In stage three, the parameters were standardized with the fuzzy membership functions, and the GAMMA 0.5 fuzzy overlay model was applied for aggregation parameters. Results showed that 72.8%, 16.7%, 7.7%, 2.5% of the areas were classified as unsuitable, moderate, suitable, and perfectly suitable sites for planning a groundwater recharge site. Subsequently, the minimum area required regarding the possible errors based on the literature review determined six sites (A–E) as areas with higher priority. Then, the recommended unsuitable/suitable sites were validated and omitted by using some more detailed views. Finally, two sites (E and F) were omitted, and four sites (A, B, C, D) were recommended for future artificial recharge planning.

KEYWORDS: Artificial recharge, Iranshahr plain, GIS, FAHP fuzzy logic model

TYPE: Original Research

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Introduction

As an essential water source, groundwater plays a significant role in maintaining ecological balance, environmental stability, human welfare, and economic development (Arefin, 2020; Green et al., 2011). Given the growing population and its demand for more food and irrigated cultivated areas, insufficient attention has been paid to the importance of groundwater environmental balance (Basirpour et al., 2016; Nhamo et al., 2020; Zhang et al., 2019). Groundwater is one of the key water sources in arid/semi-arid areas of Iran for farming, especially in central parts, which uses about 92% of water in Iran, 52% of which is supplied by groundwater resources (Nabavi, 2018). According to a recent study by Dalin et al. (2017), Iran ranked second in the world after India in terms of groundwater depletion embedded (at around 100 Bm^3) over the last two decades. The shortage of groundwater has unfortunately created a threat to the local inhabitants' lives. Thus, it is highly essential to identify and assess critical parameters for restoring aquifers. The restoration of aquifers using infiltration channels or land surfaces is common to recharge damaged aquifers artificially (Peters, 2020). Since groundwater is a spatial or spatiotemporal phenomenon, redevelopment of sources by surface infiltration systems requires in-depth studies. Hence, researchers have considered many effective criteria for artificial recharge zoning: distance from surface permeability, transmissivity, water source and well distance, geology, unsaturated aquifer thickness, land use, water quality, and land slope. Numerous means can be adapted to renovate groundwater resources, while the accurate findings of appropriate sites for artificial recharge by traditional methods may be impossible (Sprenger et al., 2017) or difficult (Mahdavi et al., 2013). Several techniques have been used for artificial groundwater recharge zoning: Geographic Information System (GIS), Remote Sensing (R.S), mathematical models, heuristic algorithms, multiple different criteria decision-making methods (analytical hierarchy process (AHP), fuzzy analytical hierarchy process (FAHP), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). GIS is a digital database management system designed to manage large scale and spatially distributed data from various sources (Torabi-Kaveh et al., 2016), which is ideal for advanced site-selection studies since it can efficiently retrieve, analyze, and display information according to user-defined specifications (Olatona & Nduka, 2017; Shamshiry et al., 2011; Wang et al., 2009). Therefore, GIS has been widely used by many researchers to achieve artificial groundwater recharge zoning across the world (Abdolazimi et al., 2014; Ahani Amineh et al., 2017; Das & Pal, 2019; Diamond & Melesse, 2016; Hohne et al., 2021; Lee et al., 2018; Machiwal & Singh, 2015;

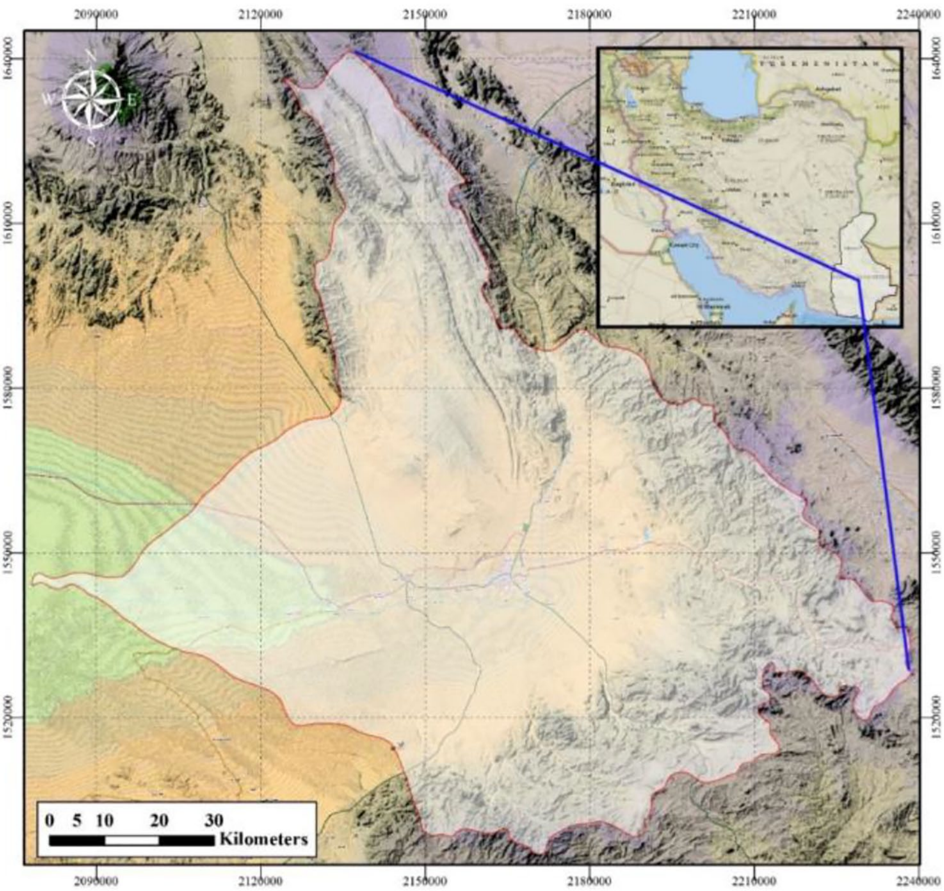

Figure 1. Location of Sistan and Baluchistan Province and Iranshahr Plain.

Mokarram et al., 2020; Rahmati et al., 2015; Rajasekhar et al., 2019; Singh et al., 2017; Tahmassebipoor et al., 2016; Vinay, 2019). Saaty (1980b) is a decision-making technique used to analyze and support decisions with multiple and even competing objectives (Li et al., 2020). Assessing land suitability for restoring aquifers and weight criteria are usually expressed in linguistic terms, while fuzzy logic is a more natural approach to this problem (Önüt et al., 2010). Hence, many researchers have attempted to use multiple fuzzy criteria decision-making methods like FAHP for groundwater restoration and management (Arianpour & Jamali, 2014; Eghbali Lord, 2018; Ilunga, 2012; Jebraeili & Zarei, 2018; Luo et al., 2020; Mahmoudi, 2016; Monjezi et al., 2013; Roozbahani et al., 2018; Shao et al., 2020; Thungngern et al., 2015; Zghibi et al., 2020). It is noteworthy that the classical AHP is preferable to the FAHP when the researcher is entirely sure about the validity of the obtained data and information; otherwise, the FAHP method is preferable. In this paper, the FAHP method reduces the number of suitable sites by eliminating those with scores (or weights) smaller than a predetermined constant value obtained under certain circumstances into a case study or the groundwater recharge guidelines. This study aimed to identify appropriate sites for artificial recharge in the arid area of Iranshahr Plain based on GIS-FAHP integration by using GIS and improved FAHP to rehabilitate better and restore the aquifer. The geology, climate, vegetation, aquifer properties, and topography data were used.

The study area

Iranshahr County is located in Sistan and Baluchistan Province in the southeast of Iran. The capital of this county is Iranshahr (Figure 1). Iranshahr is 41,730 km^2 in size and has six districts, two cities, 21 rural districts, and 181 villages. The population of Iranshahr was 254,314 in 2016 census (Statistical Center of Iran, 2016). This county is one of the hottest cities in Iran, with a slight increase in rainfall from east to west and an evident rise in humidity in its southern areas. This region is subjected to seasonal winds from different directions, the most important of which are the 120-day winds (Teimourian et al., 2020).

The annual average precipitation and evaporation were about 99.09 mm/year and 3242.2 (mm) in the recording period of 1996 to 2009, respectively. However, this region is considered an arid or low rainfall area in Iran due to a climatology viewpoint (Golchin et al., 2011). Thus, population growth and change in consumption patterns caused surface water resources not to be adequate in which groundwater can be indiscriminately extracted in many parts (Masoumi, 2015).

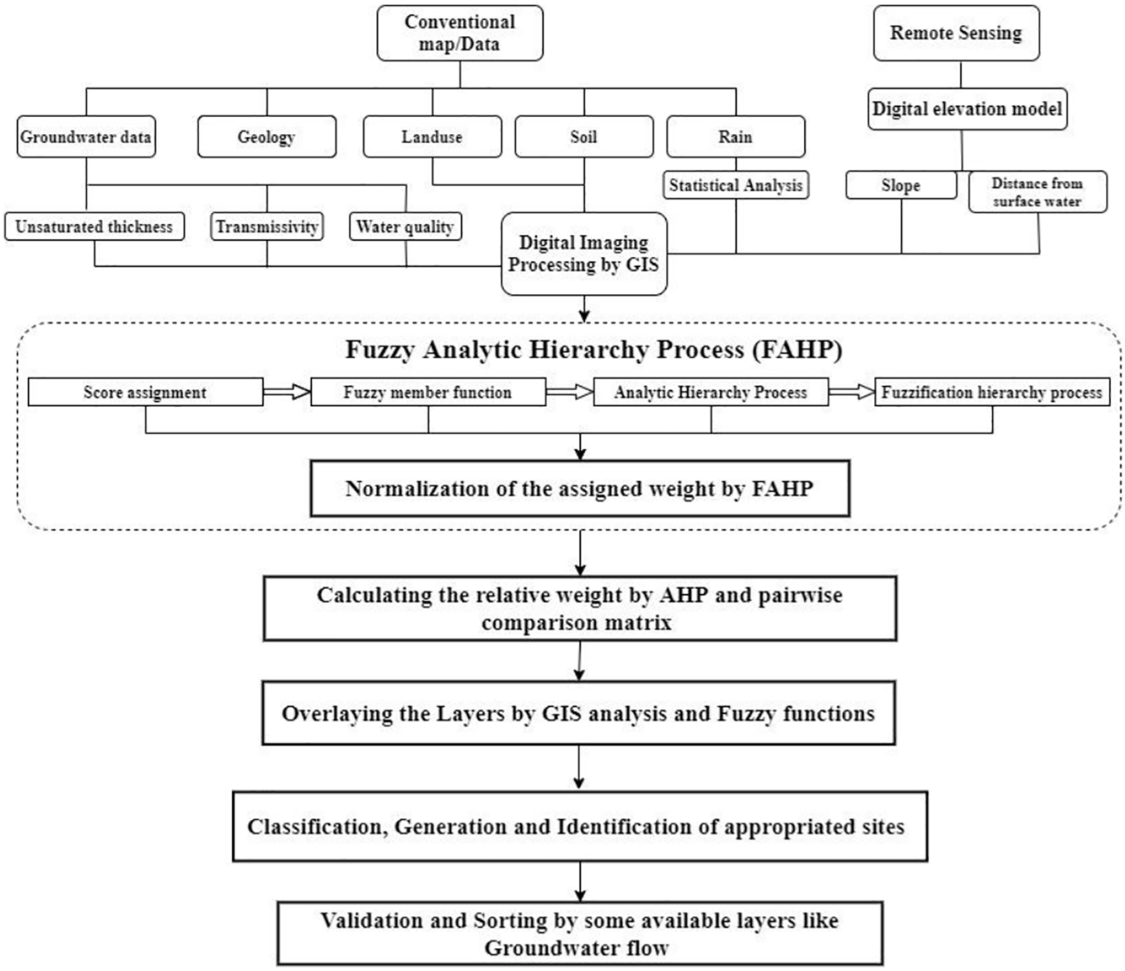

Figure 2. Decision tree developed for the artificial recharge site selection problem in Iranshahr County, including goals, four groups, and sub-criteria.

Methodology

In this study, the process of site selection was performed in two stages. All effective factors were evaluated concerning the theoretical and empirical literature in the first stage. Then, in the second stage, all influential factors were analyzed, and proper sites for groundwater restoration were identified by combining GIS and FAHP methods. Figure 2 shows the nine criteria used in the site selection process.

Calculating criterion weights by FAHP

The AHP shows how to use judgment and experience to analyze a complex decision problem (eg, groundwater restoration) by combining qualitative and quantitative aspects in a single framework and generating a set of priorities for alternatives (D'Apuzzo et al., 2009). Despite the popularity of the AHP, many researchers have expressed their concerns over certain issues in AHP, such as ambiguity associated with the judgment, standardization of non-commensurate criteria (ie, criteria which are not compatible in size, type, or scale), and personal assessments. They can enormously affect the AHP results (Karthikeyan et al., 2016; Lin & Wang, 2019; Musumba & Wario, 2019; Pourebrahim et al., 2014; Smith & von Winterfeldt, 2004). Thus, FAHP is developed to address these problems and overcome the defects (Mikhailov & Tsvetinov, 2004).

FAHP was applied to evaluate weight criteria related to the artificial recharge site selection. The criteria selected in the site selection process were classified into four main classes. A fuzzy set is a class of objects with a continuum of membership grades and is characterized by a membership (characteristic) function, which assigns a membership grade (0–1) to each object (Içtenbaş & Rouyendegh, 2012; Kahraman et al., 2004).

(Mohebbi Tafreshi et al., 2018, 2021) explained the general approach as follows. The first step in fuzzy models is parameter standardization with fuzzy membership function. Fuzzy values were assigned by converting raw input values to a membership scale from 0 to 1 based on a transformation function defined by expert opinion. Values approaching 1 are more suitable for the expected goal, and those approaching 0 are less suitable. Several fuzzy membership functions are available in the fuzzy logic extension of ArcGIS software (version 10), producing the sigmoid shape of membership in many fuzzy logic applications (Raines

Table 1. Saaty's 1 to 9 Scale of Relative Importance (Saaty, 1980a, 1980b).

INTENSITY OF IMPORTANCE	INTERPRETATION
1	Equal importance
3	Moderate importance
5	Essential
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between adjacent scale values

et al., 2010). The application of these functions is performed according to the midpoint and spread factors. The function for fuzzification was selected based on each criterion's identity, importance, and relationship with the goal. For standardizing the factors in this preliminary analysis, two fuzzy membership functions were employed as follows:

Fuzzy Linear: This function is defined by the user who establishes a linear relationship between the minimum and maximum values (Raines et al., 2010). The values lower than the minimum value are given 0, while those higher than the maximum value are given 1 (equation (1)).

$$\begin{aligned}\mu(x) &= 0 \; if \;\; x < \min,\; \mu(X) \\ &= 1 \; if \;\; x > \max \, otherwise \;\; \mu(X) \\ &= \frac{(x - min)}{(max - min)}\end{aligned} \tag{1}$$

Min and max are user inputs in this equation.

Fuzzy Gaussian: This function is obtained through a Gaussian or normal distribution around a user-specified midpoint (maximum value) with a defined spread decreasing to zero (equation (2)).

$$\mu(x) = e^{-f1*(x-f2)^2} \tag{2}$$

Where the user input f1 is the spread, and f2 denotes the midpoint. Increasing the spread makes the fuzzy membership curve steeper (Raines et al., 2010)

Aggregation of standardized factors by fuzzy overlay operations

After standardization, all the relevant factors should be combined. Researchers have proposed many fuzzy combination rules. There are five operators: fuzzy OR, fuzzy AND, fuzzy PRODUCT, fuzzy SUM, and fuzzy Gamma. In addition, choosing a fuzzy operator is important. The use of fuzzy AND as well as PRODUCT operators could have the lowest risk for defining appropriate sites, whereas fuzzy OR and SUM operators could lead to the maximum risk. The fuzzy gamma operator is defined in terms of the fuzzy algebraic product and the fuzzy algebraic sum. Thus, the risk of defining sites is in the middle. In this equation, γ is the power of gamma and input by the user.

It should be noted that when gamma power tends to one, it is closer to the "Fuzzy SUM" However, when gamma tends to zero, it is closer to the "Fuzzy PRODUCT" (Lewis et al., 2014; Mohebbi Tafreshi et al., 2018). The default value is 0.9.

$$\mu(x) = (\text{FuzzySum})^{\gamma} * \text{FuzzyProduct}^{1-\gamma}$$

It is suggested to have more probable sites since it is necessary to perform fieldwork to validate the inlet data and more detailed investigations like its social impact. Therefore, the fuzzy gamma operator with 0.5 gamma power is selected for the next step.

Selection of the effective factors, AHP, and pairwise comparison matrix

Regarding the standard guidelines (APA, 2001; Central Ground Water Board-India, 2007; Iranian Ministry of Energy, 2013), the relative importance of the parameters in selecting potential groundwater recharge sites in this case study is shown in Figure 2. Consequently, the relative importance of each of the parameters was estimated by using a pairwise comparison matrix constructed (9*9) according to the input factors, AHP technique obtained by (Saaty, 1977) and Saaty's scale (Table 1). It is noteworthy that inconsistencies in pairwise comparisons increase by increasing the number of comparisons (Saaty, 1980b). Therefore, AHP incorporates the consistency index (CI) to evaluate the matrix and the calculated weight. If C.R. is less than 10%, the weight would be acceptable. The results are shown in Table 2. Furthermore, due to the nature of some layers like land use, a pairwise comparison matrix was made to calculate the relative weight for each subgroup. Next, the calculated weights were normalized to have the same scale to compare other layers with a scale between 0 and 1 for integrating the weighted map layers (Tables 3 and 4).

Description and application of the criterion

A total of nine input layers, including lithology, bedrock depth, land use, distance from road (main roads), distance from the river (main rivers), elevation, and slope, were applied to evaluate appropriate sites in Iranshahr County (Figure 3). The criteria are explained in detail as follows.

Geology. Hema et al. (2017) reported that groundwater occurrence and flow could highly influence the porous and permeable hydrogeological zone. Thus, the artificial aquifer restoration is generally performed in quaternary deposits, which almost

Table 2. Pairwise Comparison Matrix for Standardizing Factor Scores.

THEMATIC LAYERS	GEO.	SOIL	SLOP	RAIN	UN.THI.	W.Q.	TRANS.	S.W. DIS.	LAND USE	SCORE
Geo.	1	2	1/2	1/3	1/2	1.2	2	1/2	1/2	0.144
Soil		1	2	2	2	2	1	3	2	0.188
Slop			1	2	5/4	2	1/2	2	2	0.111
Rain				1	1/2	3/2	3	2	5/4	0.54
Unsaturated thickness (Un.Thi.)					1	1/2	2	1/2	1/2	0.105
Water quality						1	3	1/2	1/2	0.081
Transmissivity							1	1/3	1/2	0.195
Surface Water distance								1	1/2	0.069
Land use									1	0.061
C.R	0.3%									

Table 3. Geological Classification and Calculated Scores.

GEOLOGY	Q^{AL}	Q^{M}	Q^{S}	QFT^{2}	QFT^{1}	OC	OTHER LITHOLOGY	SCORE NORMALIZED
Q^{Al}	1	1/2	3	2	3	4	5	0.9
Q^{m}		1	2	3/2	3	4	5	1
Q^{S}			1	2/3	2	2	3	0.44
Qft^{2}				1	2	2	3	0.54
Qft^{1}					1	2	2	0.31
Oc						1	2	0.23
Other lithology							1	0.15
C.R = 2%								

Table 4. Land Use Classification and Scores.

LAND USE	AGRICULTURE	WASE LAND	FLOOD PASSING	LOW-DENSITY LAND	CLIFF	SANDY DUNE	URBAN AREA	FOREST MEADOWS	SALTMARSH	SCORE NORMALIZED
Agricultural land	1	1/2	1/3	1/2	2	0.5	2	1/2	2	0.27
Wasteland		1	1/3	1/2	2	2	2	2	2	0.44
Flood passing			1	3	4	2	4	3	4	1
Low-density land				1	3	3	3	2	3	0.61
Cliff					1	1	1	1/2	1	0.18
Sandy dune						1/2	1/2	2	1/2	0.31
Urban area							1	1/2	1	0.18
Forest meadows								1	2	0.38
Saltmarsh									1	0.18
C.R = 2%										

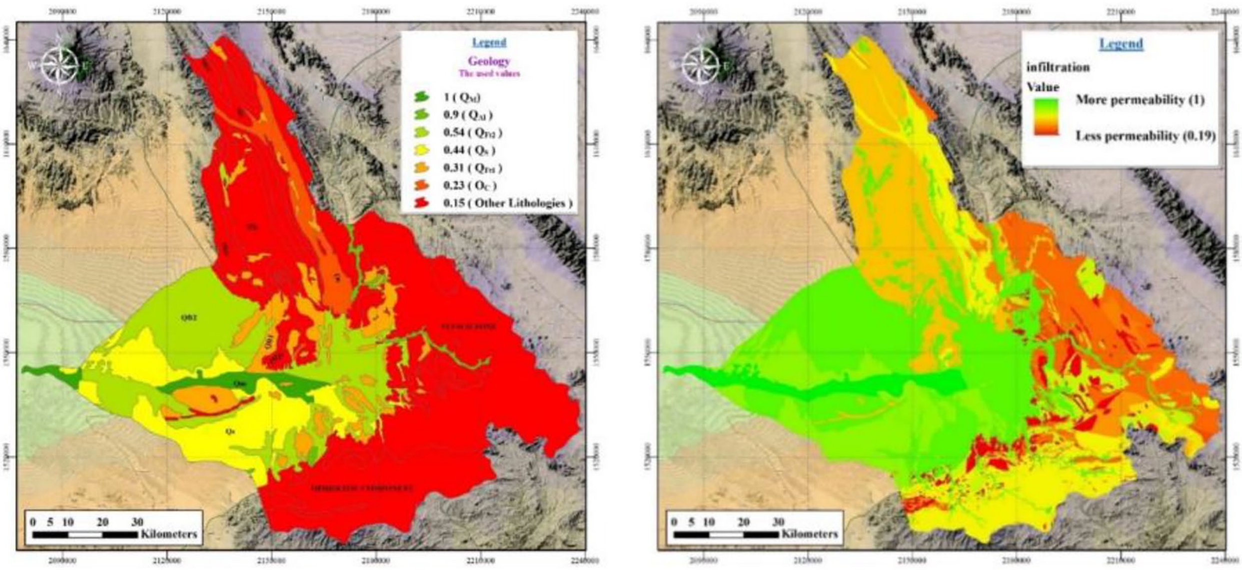

Figure 3. Geology (a) and Soil maps (b) integrated for groundwater recharge zoning.

have this property. Consequently, the quaternary units of Iranshahr Plain (Q_{Al}: sediments of the main rivers, buried channels, and flood plains, Q_m: Uniform floodplains and lake sediments, $Q_{S.}$: Sand dune, Q_{ft2}: Young alluvial Fan, Q_{ft1}: Old alluvial fan, and $O_{.C.}$: Coarse-grained conglomerate) were assigned with the highest scores due to their high permeability while lower permeability units received fewer weights/scores.

Further, the weights were calculated by comparing each subgroup of the quaternary units with other lithologies, including consolidated conglomerate and clay, Flysch zone, Ophiolite, Andesite, and Lava flows using the AHP method and then were normalized. The obtained results and the final map are shown in Table 3 and Figure 3a, respectively.

Soil/Surface permeability. The soil zone manages the entry of the surface water into the subsurface aquifer system and determines the percolation and hydraulic conductivity (Arivalagan et al., 2014). The main chemical and physical properties of soils are influenced by geological, climatic, vegetation, and land use conditions. Eight major soils types were identified in Iranshahr Basin, such as Alluvial sediment, debris, and sandy dunes as the highest permeability ratio and mass rocks (limestone, sandstone, siltstone, and igneous, and metamorphic) as the lowest permeability ratio. The relative surface permeability values were obtained from the Sistan and Baluchistan regional water authority to study water penetration into the soil in the study area. These values were ranked and standardized by using a linear fuzzy function (Figure 3b).

Slope. The areas with steep slopes have low groundwater levels since the bulk of rainfall is lost due to high runoff. Thus, the slope is an important factor that can control the infiltration of groundwater. A standard guideline published by the Ministry of Energy of Iran (2013) proved that the most appropriate slope for groundwater restoration is 2% to 3%, while slopes less than 1% are less valuable due to the precipitation of small participles like clay and reduction of permeability, which makes them unsuitable. The slope map of the basin was prepared from DEM derived from SRTM data of 30 m resolution. The slope varies between 0 in the central part and 86% in the eastern part of the catchment.

Consequently, using the decreasing fuzzy linear membership, the category with a slope between 2% and 3% was assigned the highest weight, whereas the class with a slope of more than 10% was given the lowest weight (0). It is noteworthy that slopes less than 1% were manually rated as 0.1 using a fuzzy comment. The results are shown in Figure 4a.

Rainfall. The rainfall distribution map of the Iranshahr Basin was prepared based on the data collected by Sistan and Baluchistan meteorological administrations. The infiltration rate of water directly impacts the rainfall occurrence along with the slope and land use. Moreover, elevated rainfall is related to strong groundwater potential (Chen, 2019), which can directly control groundwater. Although there are three synoptic stations, including Iranshahr, Bam Pour dam, and Daman, their number and geographical distribution are inadequate. Relations between rainfall and the altitude of the terrain is another proper method for rainfall-runoff studies in hydrology and accurately predicts the distribution of rainfall (Wang et al., 2018). So, the mean annual precipitation data of 13 meteorological stations covering the study area and surrounding were used with AW3D (ALOS Global Digital Surface Model) data of 30 m resolution for altitudinal trend analysis. The linear regression model results showed a good relationship between the precipitation and elevation ($y = 0.071x + 92.6$ and $R^2 = .75$). However, using the increasing fuzzy linear membership, the area with maximum estimated precipitation (247 mm) obtained

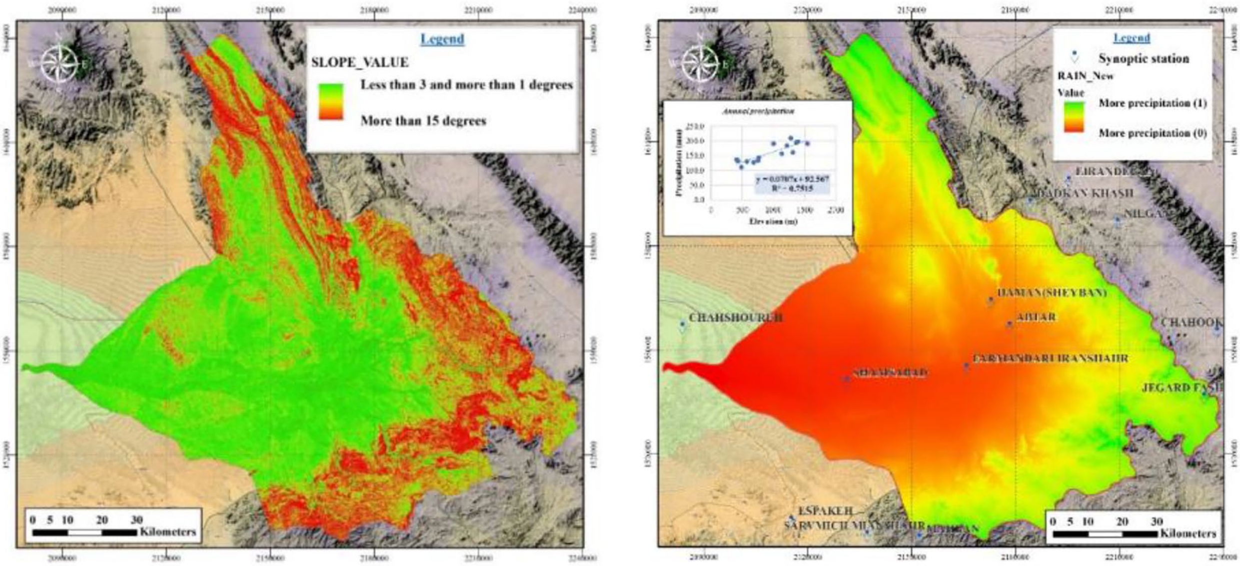

Figure 4. Slop (a) and Rainfall precipitation maps (b) integrated for groundwater recharge zoning.

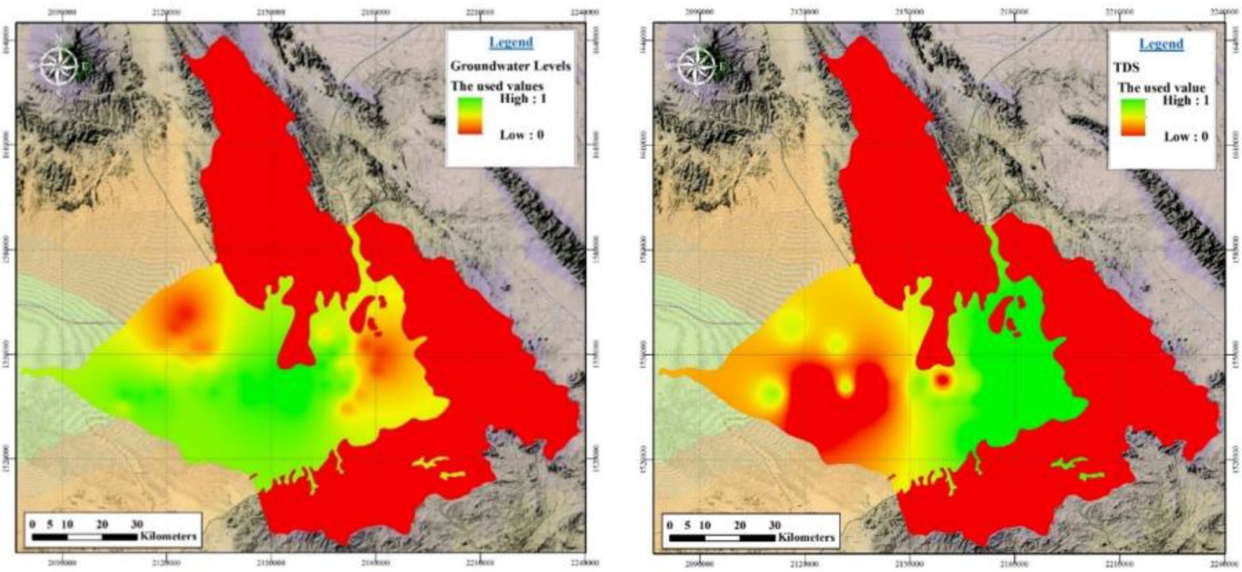

Figure 5. Unsaturated thickness (a) and TDS distribution maps(b) integrated for groundwater recharge zoning.

the maximum score while the minimum precipitation estimated for this area (12.2 mm) obtained the minimum score (0). The results are shown in Figure 4b.

Unsaturated thickness. The unsaturated zone plays an important role between groundwater and surface water. In addition, it is very important to consider the lag time between the water penetrating from the surface and reaching the saturated zone. The Iranian Ministry of Energy (Iran) in 2013 through Standard guidelines for artificial recharge of groundwater neither less than 5 m due to the water loss through evaporation nor more than 40 m due to maintaining a major part of the injected water can be suitable. Consequently, using the decreasing fuzzy linear membership, the thickness close to 10 m was assigned the highest weight while the weight given gradually drops off to 0 with increasing depths up to 40 m. It is worth pointing out that the unsaturated thickness less than 5 m were manually weighed as 0 using a fuzzy comment. The results are shown in Figure 5a.

Water quality. The quality of underground water is an effective parameter for finding a suitable site since poor groundwater quality is not valuable to be charged by the high quality of rain or surface water. The minimum Total Dissolved Solids (TDS) as a groundwater quality indicator in the study area was

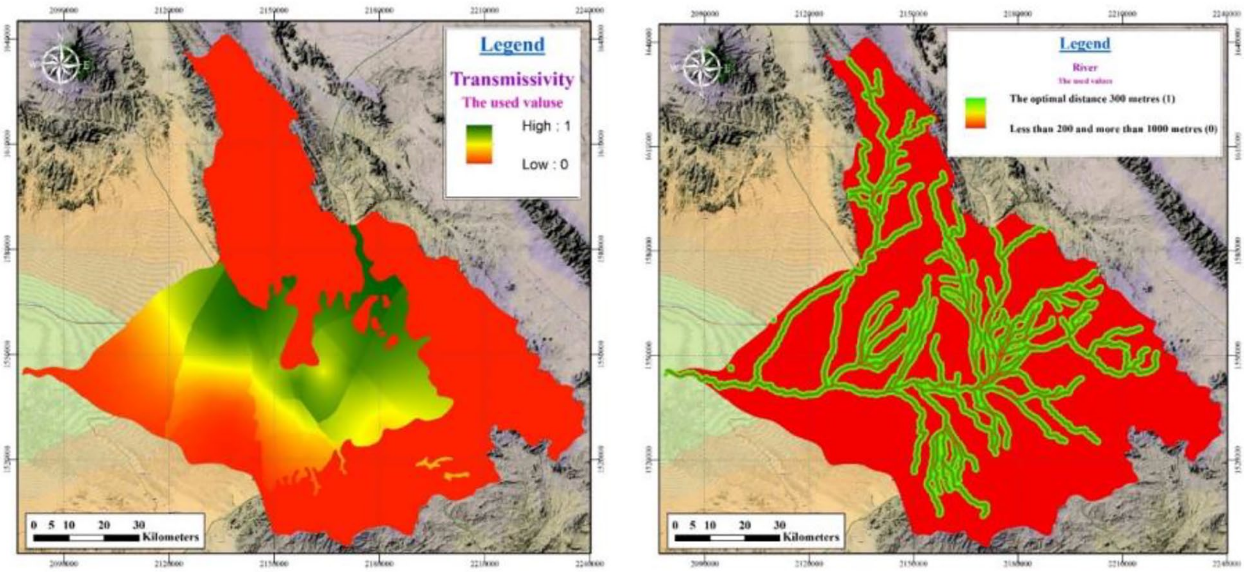

Figure 6. Transmissivity distribution (a) and distance from surface water maps (b) integrated for groundwater recharge zoning.

479 mg/l in the central part, while its maximum value was 4970 mg/l in the eastern and western part of the catchment. Consequently, using the decreasing fuzzy linear membership, TDS being close to 479 m is assigned as the highest weight, while the weight is given gradually drops off to 0 by increasing the TDS content up to 4970 mg/l. The results are displayed in Figure 5b.

Transmissivity. There is a direct relationship between the type of aquifer and transmissivity. The alluvial and aeolian deposits as sufficient aquifers have a bigger transmissivity for unconsolidated aquifers, while clay and shale deposits are rarely considered as appropriate aquifers. Furthermore, transmissivity as an indicator of the ability of soils to transmit water through the entire saturated thickness (Campos Pinto et al., 2016) can shed light on what is going on in the subsurface layer. Hence, areas with high transmissivity values have a high potential to be recharged. Sistan and Baluchistan Regional Water Authority prepared the transmissivity value. The results showed that transmissivity reduced from the northern part to the south part of the Iranshahr Basin (800–3000 m^2/day). Consequently, the highest transmissivity areas got a higher score using the increasing fuzzy linear membership, while other areas got a lower score. The results are shown in Figure 6a.

Distance from surface water. Access to a reliable surface water source and higher annual precipitation is highly important for implementing an artificial recharge plan. A river is required to implement an artificial recharge plan in the usual way, such as flood spreading, while it could have a direct role in designing the storage capacity of the structure (Central Ground Water Board-India, 2007). Previous studies identified that classes with a higher annual water supply volume are the same as higher-class waterways. Therefore, the third-order stream network using the Stranhler method was prepared in the GIS software. While the areas located at or close to 300 m from these waterways were given the highest score, the areas at intervals of more than 1 km were assigned the lowest score (0) due to the non-economic transfer of water and distances of less than 200 m, which could be because of probable damage from seasonal floods to existing installations at artificial recharge places. It is nothing that the weight gradually decreased to 0 by increasing the distance up to 1000 m. The final map prepared with the Fuzzy Gussan membership is shown in Figure 6b.

Land use/Landcover. Land use/land cover is a significant parameter in hydrogeological studies since agricultural lands, flood passing, sandy dunes, forests, and meadows play a positive role while cliff, urban areas, salt marsh play a negative role. However, it imparts a major indication of the extent of groundwater necessity and usage (He & Wu, 2019). Furthermore, Chowdary et al. (2008) reported that land with vegetation or fallow land and lands with water bodies were suitable sites for investigating groundwater.

As shown in Table 4, after normalizing the weight using a raster calculator, the residential regions, rocks, and salt marshes get the lowest weight due to high costs and limitations in implementing artificial recharge plans. In contrast, river routes and low vegetation lands are given higher priority in terms of economic issues. The map related to the final weights of land use after corrections is shown in Figure 7.

Discussion

Synthesis of information layers

The fuzzy overlapping index model was used for integrating and overlapping the layers in this study. This model includes a numerical classification system consisting of weights,

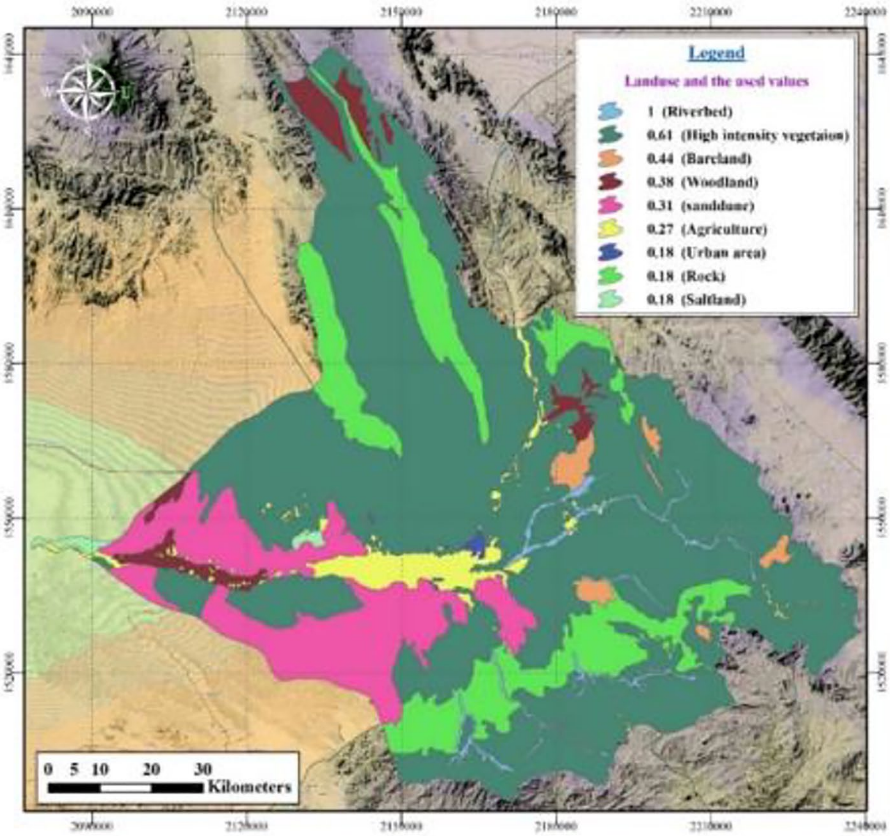

Figure 7. Landuse map integrated for groundwater recharge zoning.

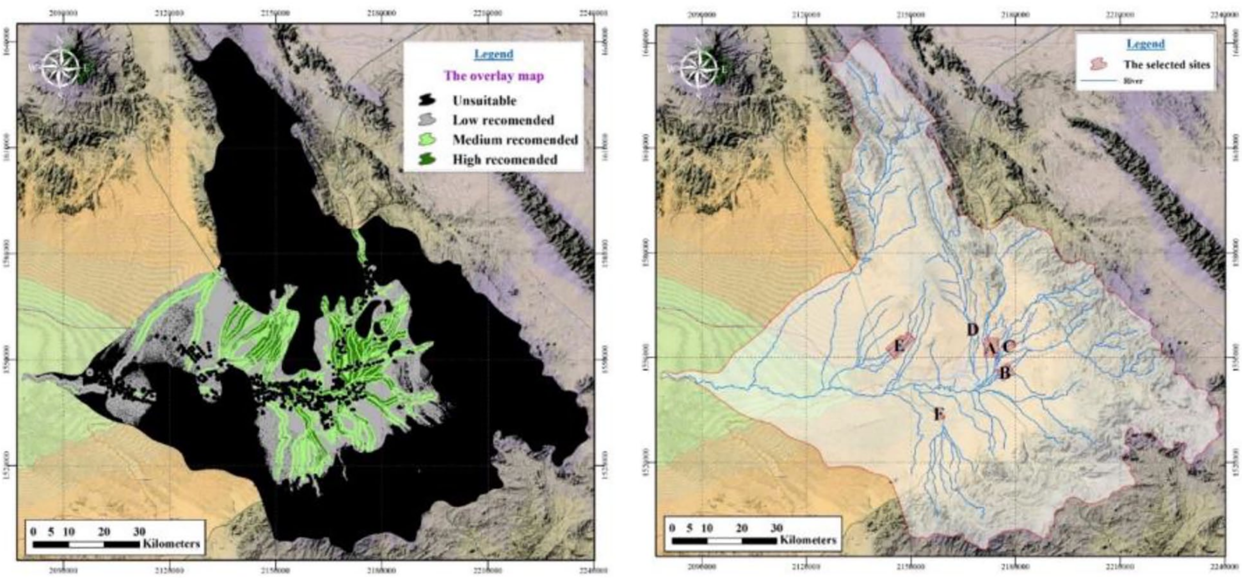

Figure 8. The final map (a) and the candidate sites for artificial recharge (b).

intervals, and scores (ArcGIS tutorials Ver: 10.5, 2020). First, each parameter was evaluated and weighed in comparison to the parameters mentioned above. After determining the relative weights of the parameters, the weights obtained in the previous step were used to combine all the parameters using the Raster Calculator command for each corresponding parameter. Therefore, given the increasing or decreasing effects of parameters in previous studies (Coburn, 2000; Gesim & Okazaki, 2018; Ghayoumian et al., 2007; Sema et al., 2017; Sprenger et al., 2017), the fuzzy GAMMA operator was used to create the final map. The final map of the proper sites for artificial recharge is shown in Figure 8a. Six sites were determined (A–E) based on this map and less distance to the nearest city (Iranshahr) for designing an artificial recharge site. Considering their probable errors, these sites were reassessed as follows.

Assessment of potential errors

Inputting data error (type 1) and processing data error (type 2) were considered two important error sources, although there may be other errors.

Inaccurate, unverifiable, or outdated data can cause a type 1 error, while overlay functions, calculating the relative weights, or even selecting an inappropriate fuzzy membership can be tagged by the type 2 error. The users do not have any role in the creation of the second type of error. However, these errors can be partially solved using updated data or having smaller and additional scale layers to validate or omit the unsuitable/suitable sites. The unsuitable sites were eliminated and then ranked the rest sites since there was no option to use the better data. The reasons to remove some of the considered sites are as follows:

Site E: This site was omitted since the injected water did not immediately reach after penetrating the groundwater. Thus, a proper site should be upstream groundwater flow. In addition, since agriculture was densely populated at the bottom, it was better to provide the farmers with rain-fed floods to reduce their social sensitivity.

Site F: Although this site is located on the main waterway, it is immediately placed after merging several freshwater streams. As a result, suspended sediment load could be high and reduce the lifetime of the project. Additionally, TDS concentration as a groundwater quality indicator in this area was between medium to bad. Hence, the implementation of artificial recharge schemes would be cost-effective.

Finally, four sites (sites A, B, C, and D) were prioritized compared to other areas. This systematic study led to better delineation of areas suitable for artificial by using several effective factors. However, the study sites should be examined more thoroughly through hydrogeological and geophysical investigations and analyses such as socio-economic and financial appraisal.

Conclusion

The most appropriate sites for artificial recharge could be determined using all available and effective parameters and combining GIS and FAHP methods as powerful decision-makers. On the other hand, proper scientific investigations can assess the need and feasibility of an area for artificial recharge. Thus, this or other similar methods could be considered as the necessary prerequisites for planning and implementation. However, the final maps showed that alluvial plains were suitable areas while we considered other effective parameters. The results showed that transmissivity, surface permeability, structural geology, and slop had the highest effect on selecting appropriate sites. Further, about 72.8 % of the total study area was determined as "unsuitable," 16.7% as "moderate," 7.7% as "suitable," and 2.5% as "perfectly suitable" areas, which can be a good indication for future artificial recharge planning and potential drilling of boreholes.

Author Contribution

The authors confirm contribution to the paper as follows: MZ, ME, study conception and design. GRS, MA, IA data collection. MZ, RD analysis and interpretation of results. MZ, RD draft manuscript preparation. All authors reviewed the results and approved the final version of the manuscript.

Declaration of conflicting interests

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