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Determination of groundwater potential distribution of Ceylanpinar Plain (Turkey) in Upper Mesopotamia by using geographical information techniques and Fuzzy-AHP with MCDM

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ABSTRACT

The Ceylanpinar Plain is an important part of Upper Mesopotamia and one of the largest plains of Turkey, is in danger of facing water scarcity due to global climate change. For this reason, the potential of groundwater resources is important. In this study, groundwater potential zones in the Ceylanpinar Plain basin were investigated utilizing a weighted overlay analysis method combined with fuzzy analytical hierarchy process (FAHP) multi-criteria decision-making (MCDM) approaches and geoinformation technologies. The groundwater potential zone map was created using 10 theme layers that were produced and processed in a geographic information system (GIS) environment (GPZM). After that, possible groundwater zones were identified and classified into five categories: very good, good, medium, poor, and very poor. By assessing the present open well distribution and yield data of selected wells within the research catchment, the predicted groundwater potential zones (GWPZ) was confirmed. As a result, 17% of the study area was found to be very good, 39% good, 20% moderate, 21.4% poor and 2.6% very poor. This study provides a key estimate and crucial information for regional water administrators and officials in southeast Turkey by giving a map of the groundwater potential region, in order to ensure sustainable groundwater management.

Key words: climate change, multi-criteria decision method, Sanliurfa, sustainability, water scarcity

HIGHLIGHTS

- The Ceylanpinar Plain, an important part of Upper Mesopotamia and one of the largest plains of Turkey, is in danger of facing water scarcity due to global climate change. For this reason, the potential of groundwater resources is important.
- The groundwater potential zone map was created using ten thematic layers that were produced and processed in a GIS environment (GPZM) and using Fuzzy-AHP with MCDA method.
- This study provides a key estimate and crucial information for regional water administrators and officials in southeast Turkey by giving a map of the groundwater potential region, in order to ensure sustainable groundwater management.

1. INTRODUCTION

Water is vital for life. Groundwater is a relatively abundant source of water in many parts of the world. Groundwater has a 30% share of fresh water resources worldwide (Ustun & Solmaz 2004; Ostad-Ali-Askari *et al.* 2019). Considering that approximately 70% of freshwater resources originate from polar glaciers and snow, the importance of efficient management of available groundwater is evident (Charbeneau 2000; Ostad-Ali-Askari *et al.* 2020). In Turkey, where the average precipitation is 643 mm, the water regime is irregular and the distribution of precipitation varies according to time and regions. When the data of many years is examined, the total usable water potential of Turkey is 110.0 billion m^3/year, of which 98 billion m^3/year is surface water and 12.0 billion m^3/year is groundwater potential (World Water Council 2003). While the total water consumption in the world was 1,000 km^3 in 1940, by 2040, worldwide water consumption is expected to exceed 4,350 billion m^3 in terms of outflow (Statista 2021). Water consumption per capita in the world averages around 850 m^3 per year. Considering that the world population is increasing by an average of 80 million people per year, it seems inevitable that the need for fresh water in the world will increase by 68 km^3 per year (Sen 2003).

In comparison to surface waters, groundwater is the second most important freshwater reservoir and the best option for human and commercial activity (Ostad-Ali-Askari *et al.* 2017; Arabameri *et al.* 2019). Therefore, predicting and managing groundwater is crucial to avoid serious water shortages in drought-prone semi-arid regions (Deshmukh & Aher 2016; Golian *et al.* 2020). The geological and geomorphological structure of a region governs its hydrological environment and groundwater development (Doke *et al.* 2018; Das & Pal 2019; Ostad-Ali-Askari & Shayannejad 2021); where flow, seepage, percolation rates are controlled by physiographic factors. Some researchers consider relief, slope, drainage lithology, geological structures, soil, linear features, geomorphology, land use/land cover (LU/LC), rainfall amount, distance from the river, etc. It took into account that potential groundwater zones are generally determined by landscape, climatic, and environmental parameters (Das *et al.* 2017; Ostad-Ali-Askari *et al.* 2018a; Parameswari & Padmini 2018; Pande *et al.* 2020). River flow and environmental flow affect groundwater formation, hence natural streams and groundwater have a link (Murmu *et al.* 2019; Derakhshannia *et al.* 2020). The availability of groundwater fluctuates dramatically throughout the year, and river flows have a significant impact on the recharge process (Mohamed & Elmahdy 2017; Ostad-Ali-Askari *et al.* 2018b). The quality of groundwater is also affected by stream flow (Singh *et al.* 2018).

Groundwater exploration, for example, is a very specific decision-making task since it involves a variety of characteristics that are evaluated using competitive and unequal criteria (Malczewski 1999). The combination of these criteria aids in the development of a trustworthy and credible forecast map for future groundwater use planning in the region. Multi-criteria decision analysis (MCDA) can be used to achieve this integration. MCDA is an experienced and understood, math-based technique that allows you to choose between two or more competing options. It also aids decision makers in making the right decision from a range of alternatives and competing variables (Kan 2013). The most popular MCDA method is the analytical hierarchy process (AHP). AHP has today realized use in a variety of sectors of geology, most notably in groundwater research, where it has performed well, particularly in determining groundwater potential zones (Kan 2013; Fashae *et al.* 2014; Mogaji *et al.* 2014).

AHP is a biased method for examining control variables for comparing options. AHP uses binary comparisons to anticipate the relative importance of criteria and alternatives at all levels of hierarchy. AHP has been successfully coupled with other tools such as multi-objective mathematical programming, in addition to being used as a stand-alone decision tool (Ho 2008). Because traditional AHP is based on certainty and uncertainty, it is unable to accurately portray human thought (Kahraman *et al.* 2003). Van Laarhoven & Pedrycz (1983) suggested fuzzy analytical hierarchy process (FAHP) to overcome this problem and make a more confident decision. The FAHP methodology can be thought of as a more advanced version of regular AHP. The ease with which AHP can handle both quantitative and qualitative criteria in multi-criteria decision-making situations based on decision makers' judgments, as well as the uncertainty and incomprehensibility that exists in many decision-making situations, can all contribute to decision makers' ambiguous judgments in traditional AHP approaches (Bouyssou *et al.* 2000). In FAHP, criterion weights are considered to be predominantly determined by field experts using pairwise comparisons and subjective assessments to calculate weight ratios. Second, it is described as a set of triangular fuzzy numbers, the spread of which reflects the environment or lack of trust in a certain judgment. In practice, the process places a greater emphasis on the domain expert's more confident judgements. The parameters' scores can be either quantitative or qualitative. Subjective judgments of experts are used similarly to weights to create scores that are normalized to aspects that are naturally difficult to measure (Tan *et al.* 2013). Based on expert judgments, the FAHP approach turns the exact value into fuzzy integers and membership functions. This method allows for a more logical weighting of the criteria and, as a result, the best choices (Aryafar *et al.* 2013).

In this study, physical and mathematical analysis of the current state of the groundwater body of the Ceylanpinar Plain, which is one of Turkey's most significant plains with its 1.635.928 hectares of land and sustains most of its agricultural production with groundwater. The potential of the basin has been revealed by using numerical models through the evaluation of aquifer parameters and the analysis of pressure factors. In this context, studies on determining the geological and hydrogeological characteristics of the aquifer system of the basin, researching and defining the relationships, and calculating the hydrogeological parameters will be carried out.

The Ceylanpinar Plain groundwater system has been defined and necessary data and maps have been provided and analyzed within the scope of the study that will serve to use it efficiently and effectively for the benefit of humanity. The hydrometeorological module of the program, which will be used to calculate and model the current and future potential of the Ceylanpinar groundwater aquifer, has been prepared.

The Ceylanpinar Plain is one of the largest plains in Turkey and forms an important part of the upper Mesopotamian plain. The sustainable agricultural potential of the plain is proportional to the potential of groundwater. For this reason, this study is also important.

2. MATERIALS AND METHODS

2.1. Study area

The study area, which is within the provincial borders of Şanlıurfa-Mardin, is between 360 40′ and 370 40′ north latitudes and 390 25′ and 400 40′ east longitudes according to Greenwich beginning. The average elevation of the plain is 500 m and the drainage area is 7,200 km^2. It is surrounded by ridges that form the topographic border with Karacadağ in the north, Tektek Mountains in the west, and the Kızıltepe Plain in the east. In this area, there is no other source other than Ceylanpinar source group, except for insignificant basalt covered springs and 0.5 m^3/sec. Hanik spring is at the drainage border in the north. The average annual temperature in the region is 19 °C and the average precipitation is between 300 and 600 mm from south to north. The topographic subsidence is 6% in the north–south direction, and the altitude, which is 750 m on the skirts of Karacadağ, decreases to 350 m in the south around the springs. Grain is cultivated on a large scale in the region, which is very poor in terms of vegetation. These dry streams are seen as Eocene strips in the Miocene and they cover a distance of 50–70 km, starting from the foothills of Karacadağ and reaching the Turkey–Syria border, more or less parallel to each other. The Ceylanpinar Plain is located in southeastern Anatolia and represents a transboundary groundwater basin. The surface area of the plain is about 2,000 km^2. The Ceylanpinar Plain is the plain with the widest agricultural and animal use area in Turkey. The Ceylanpinar Plain is located in the lower Euphrates Basin in southeastern Anatolia region. Eocene-aged limestone forms the foundation of the Ceylanpinar Plain. These were covered by Miocene limestone, gravelly clay and clayey sands with gypsum in places. As we go north, basalt cover is located on these series. The most important formation that carries groundwater, the Eocene limestones, is located below the basalts in the north and the Miocene in the south and east. The Miocene formation usually consists of clay, limestone, marl, as well as a mixture of gravel and sand levels. Although the Miocene old formation carries a small amount of water, it is of poor quality. The thickness of the Miocene decreases as it moves from south to north and from west to east. Basalts spread from north to south, forming a cover partly on the Miocene series and partly on the Eocene limestones.

In dry agricultural areas where irrigation cannot be done, wheat and lentils are grown, while in watery areas wheat, cotton, lentils, sunflowers, feed plants are grown and corn is planted as the second crop. The Ceylanpinar Plain location map is presented in Figure 1.

2.2. Data

In order to determine the distribution in the field of the main and sub-criteria planned to be used in the study, slope and elevation maps were created from the digital elevation model (DEM) obtained by digitizing the 1/25.000 scaled maps obtained from the Turkey State Hydraulic Works (SHW) XV Regional Directorate with the ArcGIS 10.2.1 program. With the help of the same program, drainage features, limiting soil features and land use capability subclass maps were prepared for the field by using the digital format soil map obtained from Şanlıurfa Provincial Directorate of Agriculture. Temperature and precipitation data were obtained from Şanlıurfa Regional Directorate of Meteorology using interpolation analysis and streams digitized from the plots were produced using proximity analysis. Likewise, geomorphology and hydrology maps obtained from Turkey SHW XV Regional Directorate were digitized and topographic maps were created. Then, a reclassification process was applied to standardize all maps. Then, the overlapping process between the layers was applied, considering the priority vector values and sub-criteria scores for all layers. Thus, a suitability map for the Ceylanpinar Plain groundwater potential was obtained. According to the same map classification system, areas without significant restrictions, areas with moderate intensity restrictions, and areas with severe restrictions that cannot be corrected can be overcome over time, but those with valid acceptable restrictions are classified as areas with severe limitations. These areas were named 'extremely suitable', 'moderately suitable', 'marginally suitable', or 'not suitable' respectively. The groundwater suitability map was created using the formula below (Eastman *et al.* 1995):

$$S = \sum_{n=1}^{n} w_i.x_i \tag{1}$$

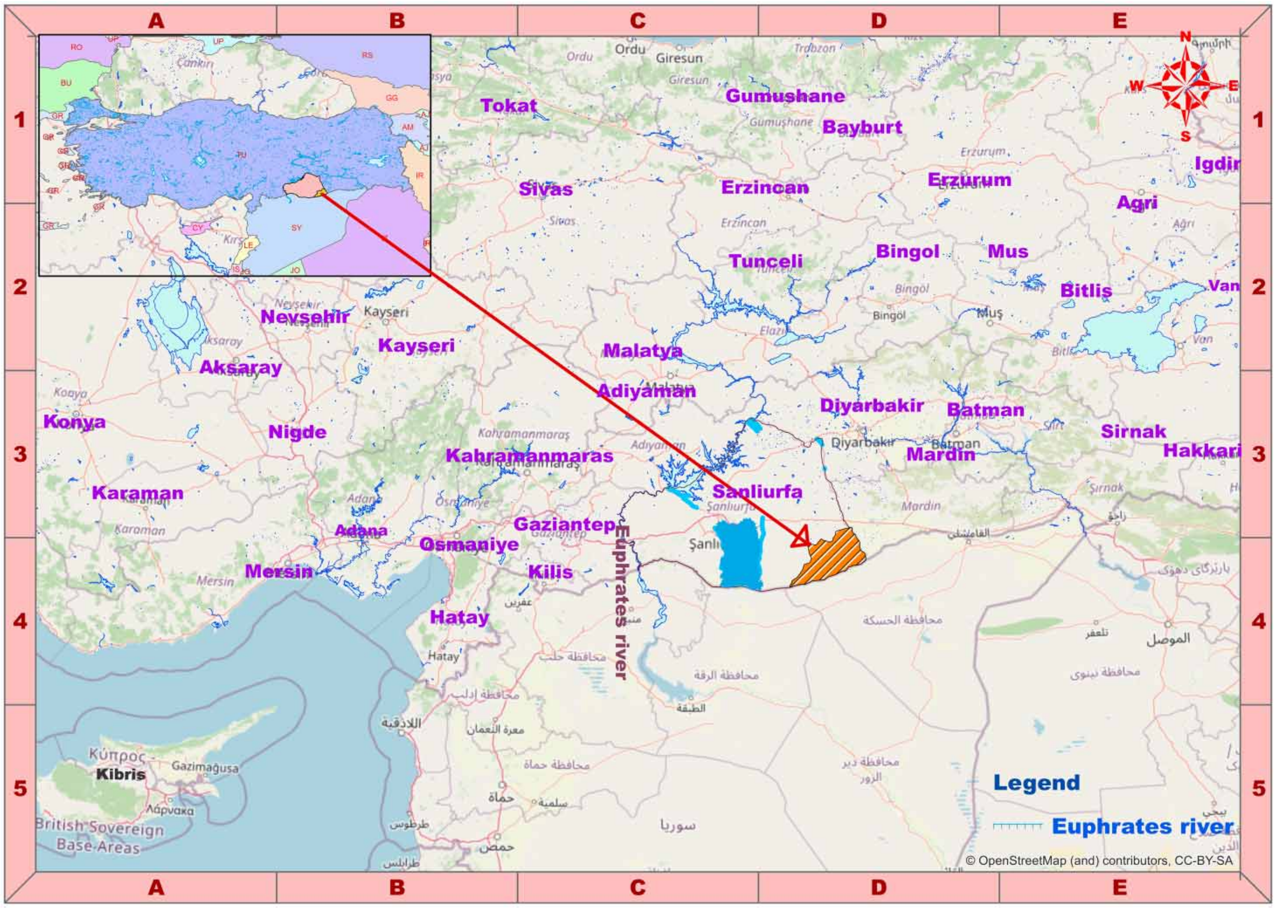

Figure 1 | The Ceylanpinar Plain location map.

In the equation, S represents the total groundwater suitability score, n represents the total number of groundwater suitability criteria, w_i represents the weight of the groundwater suitability criterion, and x_i represents the sub-criteria score of the groundwater suitability criterion.

2.3. Method

In this study, land suitability assessments, which express the assignment of values to alternatives over more than one dimension or criteria, were made by using the MCDM method, which is used to solve real-world problems with multiple dimensions. In land suitability assessments, MCDM techniques, which include many tasks, including data collection, structuring, spatial analysis, and calculation of criteria, and the use of GIS (Joerin *et al.* 2001), are considered to be the most useful decision support systems (Mohit & Ali 2006). There are numerous approaches, each under the umbrella of MCDM, which include processes of interpreting and using formal results in the context of decision making, each using different protocols and many algorithms to reveal their inputs (Huang *et al.* 2011). AHP and its extensions analytic network process (ANP), simple additive weighting (SAW), technique for order of preference by similarity to ideal solution (TOPSIS), elimination et choix traduisant la realite (ELECTRE), grey relation analysis (GIA), the decision making trial and evaluation laboratory method (DEMATEL) Visekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and multi-objective optimization on the basis of ratio analysis (MOORA) are included in MCDM (Ersoy 2019). In this study, the use of AHP and FAHP, which are among the MCDM methods, was chosen as the method.

In recent years, the AHP approach for MCDM has been actively used and successfully implemented in groundwater potential zone mapping (Kaliraj *et al.* 2014). However, despite the demand for AHP, the method is sometimes criticized for failing to adequately deal with the inherent uncertainties and uncertainties associated with matching a decision maker's perception to sharp numbers (Chen *et al.* 2011). In dry and semi-arid environments, the AHP approach for MCDM has also been employed for groundwater potential mapping (Machiwal *et al.* 2011; Mallick *et al.* 2015; Rahmati *et al.* 2015). Due to the flexibility of fuzzy membership functions, none of the research combining fuzzy set theory with MCDA and specifically FAHP would increase the accuracy of groundwater potential maps. In this regard, the current study used a combined technique of GIS and FAHP to build thematic data layers for defining the GWPZ in Turkey's Ceylanpinar Basin. The following are the key objectives:

- Proposing and showing a methodology for identifying and delineating groundwater potential regions in the Ceylanpinar Basin utilizing GIS methods and FAHP through a case study;
- Recognize the variables that influence the identification of possible groundwater regions;
- It demonstrates the capabilities of GIS technology in groundwater mapping.

This study, which used the FAHP MCDA technique, will be useful for identifying possible groundwater regions that might assist decision makers, policymakers, and water resource managers in making integrated and reliable groundwater resource use decisions.

This research took into account a total of 10 different theme layers. The flow factor and water storage in the region are predicted to be controlled by these 10 layers. The influence of these variables was weighted based on their response to groundwater formation and expert judgment. A layer with a high weight suggests a layer with a strong impact on groundwater potential, while a layer with a low weight indicates a layer with a modest impact. Each criterion's weight was assigned according to its relative relevance rating on the Saaty scale (1–9). In addition, weights are assigned based on previous studies and field experience. The Saaty's relative importance value scale is evaluated between 9 and 1 according to its importance decency. According to the classification, weights were given according to the importance of the thematic layers and their water holding capacity. As a result, in the pairwise comparison matrix, all theme layers were compared to one another. The criteria questioned as to how important one is over the other are compared in pairs with respect to the next-level member, based on the judgment of the decision maker to determine their relative importance. In this way, a decision matrix is formed. This matrix is used to calculate the priorities of the criteria. In this evaluation, Saaty (1990) verbal evaluation scale corresponding to numerical values is used (Table 1).

For weight assignment, subclasses of thematic layers were classified in the GIS platform using the natural refractive classification method. Each thematic layer sequence's subclasses were ranked on a scale of 0–9 in terms of their relative impact on groundwater development. Table 2 shows the assigned order and weights of the thematic layers.

To calculate the consistency ratio (CR), the basic original value (λ) was calculated using the Eigen vector technique, and the consistency index (CI) was determined with the help of Equation (2) given below:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

Table 1 | Saaty's dual comparison rating scale (Saaty 1990)

Importance density	Definition	Explanation
1	Equal importance	Both criteria contribute equally to the purpose
3	Lighter significance of one to the other	Experience and evaluation support one criterion against another
5	Important or strong significance	Experience and evaluation strongly support one criterion against another
7	Very strong importance	A criterion is strongly preferred and its dominance is demonstrated in practice
9	Extreme importance	Evidence is as high as possible, while one criterion is preferred over another
2, 4, 6, 8	Intermediate values between two close decisions	It is used when consensus is needed

Table 2 | Classification of the factors affecting the Groundwater Potential Regions

Sequence No.	Thematic layers	Rank	Subclasses	Land coverage area (km^2)	Area covered (%)	Groundwater view	Degree
1	Land use	6	Natural meadow	2,656	0.06	Very poor	3
			Mixed agricultural areas	14,284	0.30	Poor	4
			Pastures/natural vegetation	11,334	0.24	Moderate	5
			Non-irrigated arable land	13,170	0.28	Good	6
			Continuous irrigated area	6,106	0.13	Very good	7
2	Soil	7	Other areas	837	0.03	Moderate	6
			Reddish brown territory	33,115	0.97	Good	7
3	Geology	8	Neritic limestones	37,656	0.83	Poor	4
			Terrestrial crumbs	52	0.001	Moderate	5
			Basalt	960	0.02	Good	6
			Unseparated quaternary	6,293	0.14	Very good	7
4	Geomorphology	8	Flatness	19,092	0.12	Very poor	3
			Plain	28,110	0.17	Poor	4
			Plateau	44,197	0.27	Moderate	5
			Hill	49,340	0.30	Good	6
			Mountain	23,066	0.14	Very good	7
5	Aquifer (hydrogeology) (m)	8	405–436	113	0.025	Very poor	4
			386–405	181	0.040	Poor	5
			374– 386	1,806	0.401	Moderate	6
			372–374	2,130	0.473	Good	7
			368–372	269	0.060	Very good	8
6	Drainage density (km/km^2)	5	0–1	7	0.29	Poor	3
			2–4	8	0.33	Moderate	4
			5–7	9	0.38	Good	5
7	Rainfall (mm/year)	9	318–331	1,067	0.24	Good	3
			331–350	890	0.20	Moderate	4
			350–381	1,073	0.25	Poor	5
			381–397	1,411	0.32	Very poor	7
8	Slope (%)	8	0,001–0.739	2,705	0.016	Very good	9
			0.739–1.514	7,254	0.044	Very good	8
			1.515–2.658	23,446	0.142	Good	7
			2.659–4.466	54,499	0.330	Moderate	5
			4.467–9,411	75,901	0.461	Poor	3
9	Depth to groundwater (m)	4	150–196	10,444	0.144	Very good	7
			196–242	10,016	0.139	Good	6
			242–287	32,420	0.449	Moderate	4
			287–333	13,454	0.186	Poor	3
			333–379	5,946	0.082	Very poor	2
10	Terrain	6	I	26,443	0.654	Moderate	5
			II	3,795	0.094	Moderate	4
			III	7,249	0.179	Poor	3
			IV	2,337	0.058	Very poor	2
			VI	587	0.015	Very good	8

where n is the number of factors used in the analysis. Consistency ratio;

$$CR = \frac{CI}{RI} \tag{3}$$

It is defined as RI = random consistency index and its value is taken as 1.49 for $n = 10$ from the table given by Saaty (Yeh *et al.* 2009).

Saaty (1990) stated that a CR of 0.10 or less is acceptable to proceed with the analysis. If the CR value is 0, it means there is an excellent level of consistency in pairwise comparison.

2.3.1. Fuzzy AHP (FAHP)

In the FAHP method, $(n \cdot (n-1))/2$ comparisons are made in a matrix containing n elements. Since the comparison of a criterion with itself will be expressed as 1, all diagonal values of the matrix must be 1. After the completion of the binary comparisons, it is necessary to determine the relative importance of each element compared, i.e. its priority, which Saaty (1990) considers to be the 'synthesis' section. Saaty (1990) admitted that the priorities of the criteria can be estimated by finding the prime eigenvector of matrix A. Despite the fact that the AHP approach captures an expert's knowledge through perception or preference, it still falls short of properly reflecting human ideas with current numbers when compared to the FAHP method, due to the use of interval values rather than simple net numbers. To solve hierarchical fuzzy multi-criteria decision-making problems, the FAHP approach is used. The field experts' binary comparison of the decision factors is given using triangular fuzzy numbers in the FAHP approach.

The flow diagram for this study is given in Figure 2, and as shown in the figure, 10 hydrogeological parameters to evaluate the groundwater potential distribution, which are rainfall, soil class, land use, land cover, geology, geomorphology, hydrogeology, aquifer depth, slope, and drainage density maps were created. Table 1 shows the scale for pairwise comparison of one feature with the other in the FAHP method. Instead of using traditional numbers, the fuzzy weighting ratios of 2/3, 1, 3/2, 2, 5/2, 3, 7/2, 4, and 9/2 are utilized to represent the strength of preference of one element over another using interval numbers. The fuzzy scale was used to make pairwise comparisons of the parameters.

The processes of computing the relative weights of the criteria using FAHP were applied according to Chang (1996) measure analysis.

The value of the fuzzy synthetic coverage in relation to the object is defined in the first phase as follows:

$$S_i = \sum_{j=1}^{n} M_{gi}^{j} x \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \quad (4)$$

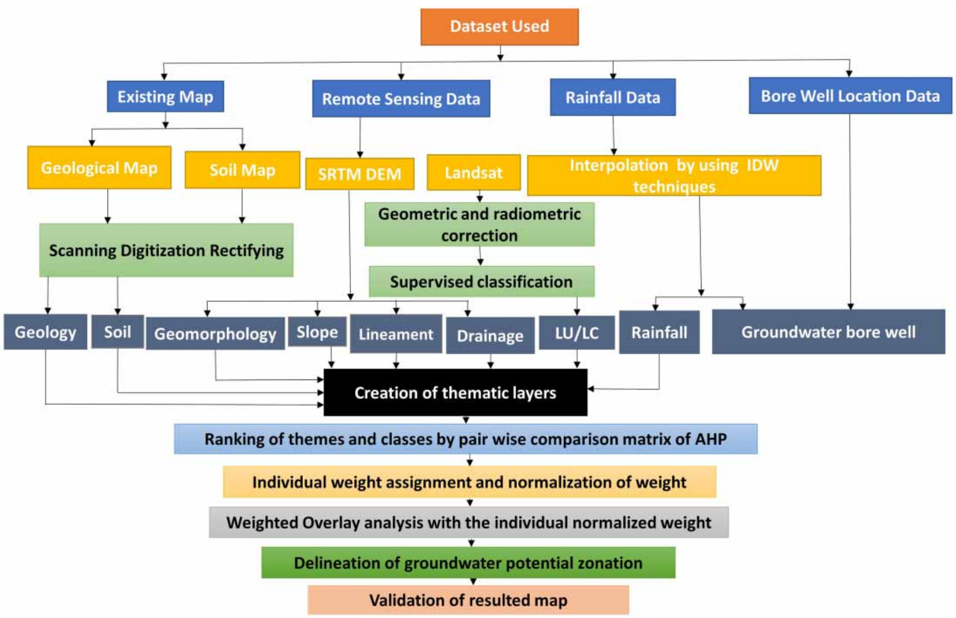

Figure 2 | Flow-chart methodology adapted for the present work.

To obtain the $\sum_{j=1}^{m} M_{gi}^{j}$ value in the formula, fuzzy addition is applied to the m order analysis value as seen in Equation (5):

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} I_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{5}$$

and $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$ to get the fuzzy addition values of $M_{gi}^{j} (j = 1, 2, 3, \cdots\cdots\cdots, m)$ were performed as follows:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} I_i \sum_{j=1}^{m} m_i \sum_{i=1}^{n} u_i \right) \tag{6}$$

And getting the inverse of the vector in Equation (6):

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_1}, \frac{1}{\sum_{i=1}^{n} m_1}, \frac{1}{\sum_{i=1}^{n} I_1} \right) \tag{7}$$

Second stage: $M_2 = (I_2, m_2, u_2) \geq M_1 = (I_1, m_1, u_1)$ probability degree is defined as:

$$V(M_2 \geq M_1 = \sup_y \geq [\min(\mu_{M1}(x), \mu_{M2}(y))] \tag{8}$$

and it can be equivalently expressed as:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M2}(d)$$

$$\begin{cases} 1, & \text{if } m_2 \geq m_1, \\ 0, & \text{if, } m_2 \geq m_1, \\ & \dfrac{I_1 - u_2}{(m_2 - u_2) - (m_1 - u_2)} \end{cases} \quad \text{otherwise,} \tag{9}$$

where d is the coordinate of D′ which is the highest intersection point between μ_{M1} ve μ_{M2} (Figure 3).

The values $V(M_1 \geq M_2)\ ve\ V(M_2 \geq M_1)$ are needed to compare M_1 and M_2.

Third stage: The probability of the degree of convex fuzzy number being greater than k convex fuzzy number $M_i (i = 1, 2, 3, \cdots\cdots\cdots, k)$, $V(M \geq M_1, M_2, M_3, \cdots\cdots\cdots, M_k)$, can be specified with the help of $V[(M \geq M_1)\ ile\ (M \geq M_2)\ ve\ (M \geq M_k)]$.

$$\min V(M \geq M_i), \quad i = 1, 2, 3, \cdots\cdots\cdots, k \tag{10}$$

let's admit

$$d^1(A_1) = \min V(S_1 \geq S_k) \tag{11}$$

The weight vector for $k = 1, 2, 3, \ldots\ldots\ldots\ldots, n;\ k \neq i$ can be given,

$$W' = (d'(A_1), d'(A_2), d'(A_3), \cdots\cdots\cdots d'(A_n))^T \tag{12}$$

where $A_i\ (i = 1, 2, 3, \ldots\ldots\ldots, n)$ is the n element.

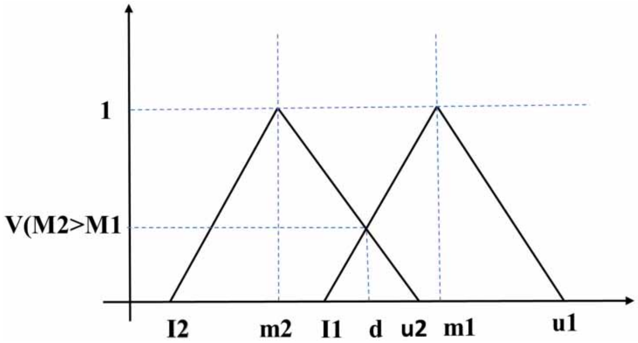

Figure 3 | The intersection between M1 and M2.

The final step with normalization is the normalized weight vectors,

$$W = (d(A_1),\ d(A_2),\ d(A_3),\ \ldots\ldots\ldots\ldots,\ d(A_n))^T \tag{13}$$

where W is a non-fuzzy number. Table 3 shows the FAHP scale we utilized in our research.

In order to create the groundwater potential region map of Ceylanpinar plain, all ten thematic layers were combined with a weighted thrust analysing method in geographic information system with this equation:

$$\mathrm{GWPZ} = \sum_{i}^{n} (X_A \times Y_B) \tag{14}$$

3. RESULTS AND DISCUSSIONS

In our study, we used the AHP and FAHP methodologies to give weight to each theme and its classes. Expert opinion, relevant literature, and field experience were used to generate comparison matrices as shown in Tables 4 and 5. Each subject in the comparison matrix was given equal weight in the comparison matrix. Precipitation and aquifers were given the most weight because they represent real groundwater recharging status. After that, there was soil class, slope, geology, geomorphology, drainage density, and land structure. The 10 thematic layers' consistency rates and the weights assigned to their features were in line with the expected outcomes. The slope played a significant part in the groundwater potential recharging area process in this semi-arid region. The most essential components of groundwater recharge for any region are precipitation, aquifer, and soil class. Statistical models based on AHP, FAHP, and GIS were used to determine relations between the site of borehole data and 10 groundwater potential parameters. Expert opinions, local hydrologist opinions and literature reviews were taken into account according to the selection of criteria. The GWPI was developed using a GIS-based

Table 3 | Fuzzy scale (Chang 1996)

Language scale for importance	Triangular fuzzy scale	Triangle fuzzy mutual scale
Just equal	(1, 1, 1)	(1, 1, 1)
Equally important	(1/2, 1, 3/2)	(2/3, 1, 2)
Weakly more important	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly more important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Much more strongly important	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Very much more strongly important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
Definitely more important	(3, 7/2, 9/2)	(2/9, 1/5, 1/3)

Table 4 | Pair wise comparison matrix table of 10 thematic layers chosen for the present study

Criteria	Assigned weight	Soil	Slope	Land Use	Rainfall	Aquifer	Geology	Geo-morphology	Terrain	Drainage density	Aquifer depth	Geometric mean	Normalized weight
ST	8	8/8	6/7	8/6	8/9	8/9	8/5	8/4	8/5	8/5	8/5	1.240	0.12
S	7	7/8	7/7	7/6	7/9	7/9	7/5	7/4	7/5	7/5	7/5	1.211	0.12
LU	6	6/8	6/7	6/6	6/9	6/9	6/5	6/4	6/5	6/5	6/5	1.257	0.13
R	9	9/8	9/7	9/6	9/9	9/9	9/5	9/4	9/5	9/5	9/5	1.463	0.14
A	9	9/8	9/7	9/6	9/9	9/9	9/5	9/4	9/5	9/5	9/5	1.463	0.14
G	5	5/8	5/7	5/6	5/9	5/9	5/5	5/4	5/5	5/5	5/5	0.811	0.08
GM	4	4/8	4/7	4/6	4/9	4/9	4/5	4/4	4/5	4/5	4/5	0.637	0.06
T	5	5/8	5/7	5/6	5/9	5/9	5/5	5/4	5/5	5/5	5/5	0.811	0.08
DD	5	5/8	5/7	5/6	5/9	5/9	5/5	5/4	5/5	5/5	5/5	0.811	0.08
AD	5	5/8	5/7	5/6	5/9	5/9	5/5	5/4	5/5	5/5	5/5	0.811	0.08

$CR = CI/RI = 0{,}024/1{,}49 = 0{,}016 < 0{,}1$ is within the limits of consistency.

Where: LU, Land use; ST, Soil type; GM, Geomorphology; G, Geology; AD, Aquifer depth to water table; A, Aquifer; DD, Drainage density; R, Rainfall; S, Slope and T, Terrain class; FGM, Fuzzy geometric mean value.

Table 5 | Compared matrix of the significance weighting values of thematic layers

	ST	R	A	AD	S	LU	LC	G	GM	DD	FGM
ST	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	2, 5/2, 3	5/2, 3, 7/2	5/2, 3, 7/2	3, 7/2, 9/2	3, 7/2, 9/2	3, 7/2, 9/2	2.08,2.38, 2.89
R	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	2, 5/2, 3	5/2, 3, 7/2	3, 7/2, 9/2	3, 7/2, 9/2	3,7 /2, 9/2	1.65, 2.49, 2.20
A	2/5, 1/2, 2/3	1/3, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	2, 5/2, 3	5/2, 3, 7/2	5/2, 3, 7/2	3, 7/2, 9/2	1.27, 1.57, 2.06
AD	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	2, 5/2, 3	2, 5/2, 3	5/2, 3, 7/2	1.06, 1.34, 1.68
S	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	2, 5/2, 3	2, 5/2, 3	5/2, 3, 7/2	0.91, 1.22, 1.59
LU	2/7, 1/3, 2/5	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	2, 5/2, 3	0.98, 0.70, 1.13
TC	2/7, 1/3,2/5	2/7, 1/3, 2/5	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	1, 3/2, 2	3/2, 2, 5/2	0.53, 0.73, 1.53
G	1/3, 2/5, 1/2	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	2/3, 1, 2	1/2, 2/3, 1	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	0.52, 0.75, 1.01
GM	1/3, 2/5, 1/2	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1/2, 2/3, 1	1/2, 2/3, 1	1/2, 2/3, 1	1, 1, 1	3/2, 2, 5/2	0.53, 0.57, 0.88
DD	2/7, 1/3, 2/5	2/7, 1/3, 2/5	1/3, 2/5, 1/2	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1/2, 2/3, 1	1, 1, 1	0.41, 0.50, 0.69

Table 6 | Weights for thematic layers using F-AHP

	ST	R	A	AD	ST	LU	LC	G	GM	DD	FGM	Fuzzy weights W_i	W_i	NW
ST	1, 1, 1	1, 3/2, 2	3/2, 2,5/2	3/2, 2, 5/2	2, 5/2, 3	5/2, 3, 7/2	5/2, 3, 7/2	3, 7/2, 9/2	3, 7/2, 9/2	3, 7/2, 9/2	2.08, 2.38, 2.89	0.21, 0.19, 0.18	0.193	0.193
R	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	2, 5/2, 3	5/2, 3, 7/2	3, 7/2, 9/2	3, 7/2, 9/2	3, 7/2, 9/2	1.65, 2.49, 2.20	0.17, 0.20, 0.14	0.170	0.170
A	2/5, 1/2, 2/3	1/3, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	2, 5/2, 3	5/2, 3, 7/2	(5/2, 3, 7/2)	3, 7/2, 9/2	1.27, 1.57, 2.06	0.13, 0.12, 0.13	0.127	0.127
AD	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	2, 5/2, 3	2, 5/2, 3	5/2, 3, 7/2	1.06, 1.34, 1.68	0.11, 0.10, 0.11	0.107	0.107
S	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	2, 5/2, 3	2, 5/2, 3	5/2, 3, 7/2	0.91, 1.22, 1.59	0.09, 0.10, 0.11	0.100	0.100
LU	2/7, 1/3, 2/5	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	2, 5/2, 3	0.98, 0.70, 1.13	0.10, 0.06, 0.09	0.083	0.083
TC	2/7, 1/3, 2/5	2/7, 1/3, 2/5	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	1, 3/2, 2	3/2, 2, 5/2	0.53, 0.73, 1.53	0.05, 0.06, 0.10	0.070	0.070
G	1/3, 2/5, 1/2	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	2/3, 1, 2	1/2, 2/3, 1	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	0.52, 0.75, 1.01	0.05, 0.06, 0.06	0.057	0.057
GM	1/3, 2/5, 1/2	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1/2, 2/3, 1	1/2, 2/3, 1	1/2, 2/3, 1	1, 1, 1	3/2, 2, 5/2	0.53, 0.57, 0.88	0.05, 0.04, 0.06	0.050	0.050
DD	2/7, 1/3, 2/5	2/7, 1/3, 2/5	1/3, 2/5, 1/2	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1/2, 2/3, 1	1, 1, 1	0.41, 0.50, 0.69	0.04. 0.04, 0.05	0.043	0.043
Total													1.000	1.000

groundwater potential mapping approach after theme harmonization of groundwater search criteria. In most environmental modeling applications, such as water resource assessments, the reliability of forecasting analytics has been a significant concern.

With the help of the results obtained from Tables 4 and 5, the results of the weighting (W) of the thematic layers applied to FAHP techniques and the normalized weights (NW) are given in Table 6.

According to the results obtained, the rational states and classified states of thematic maps are shown in Figures 4 and 5, respectively.

3.1. Distribution of groundwater potential regional map

Multi-criteria decision system 10 parameters with multiple evaluation process: soil class, slope, land use, rainfall, aquifer criteria, geology, geomorphology, drainage density, land structure, depth and GWPI values were obtained. By classifying this value, the groundwater potential region (GWPZ) final map was obtained (Figure 6).

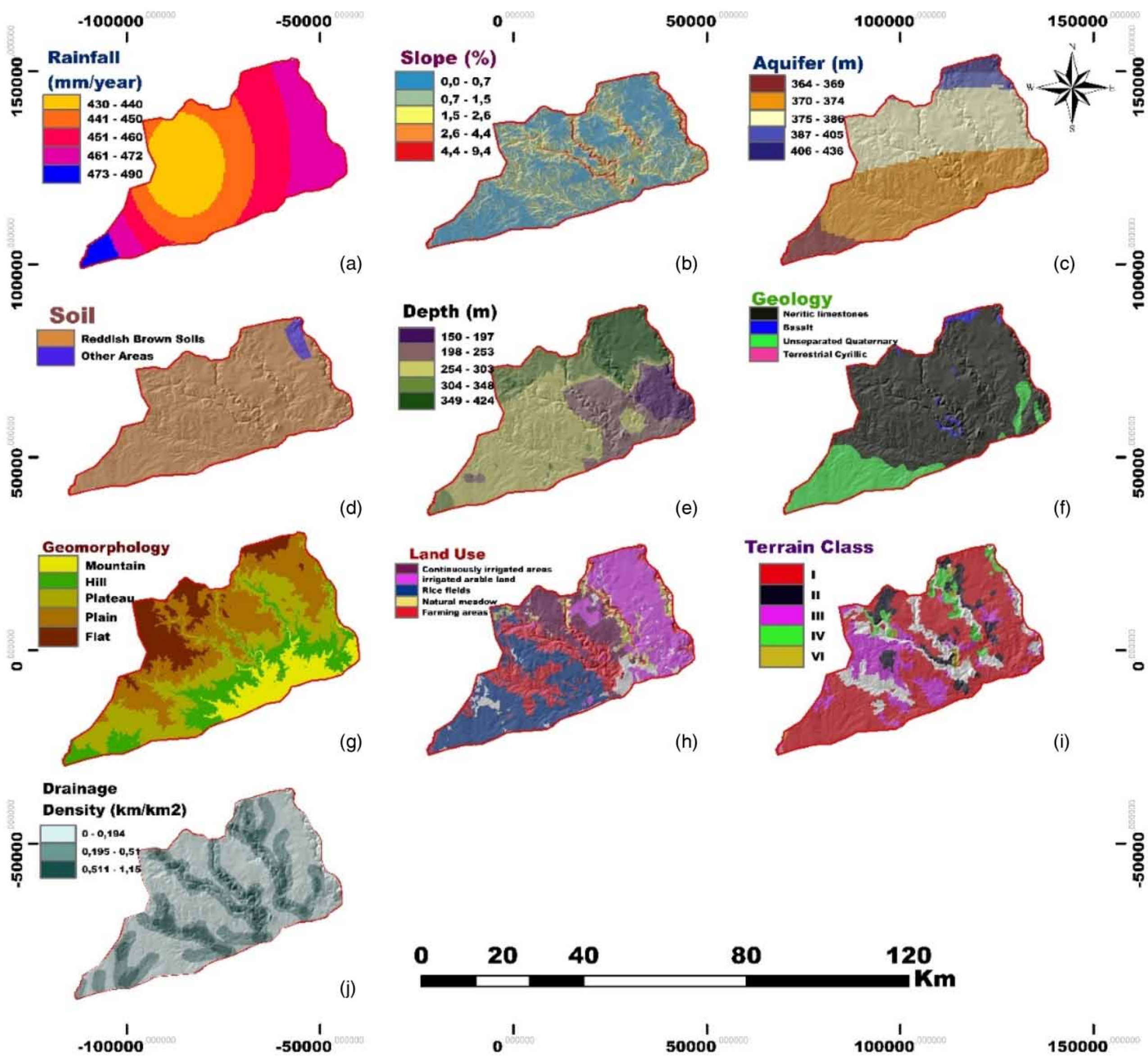

Figure 4 | Rational states of thematic maps.

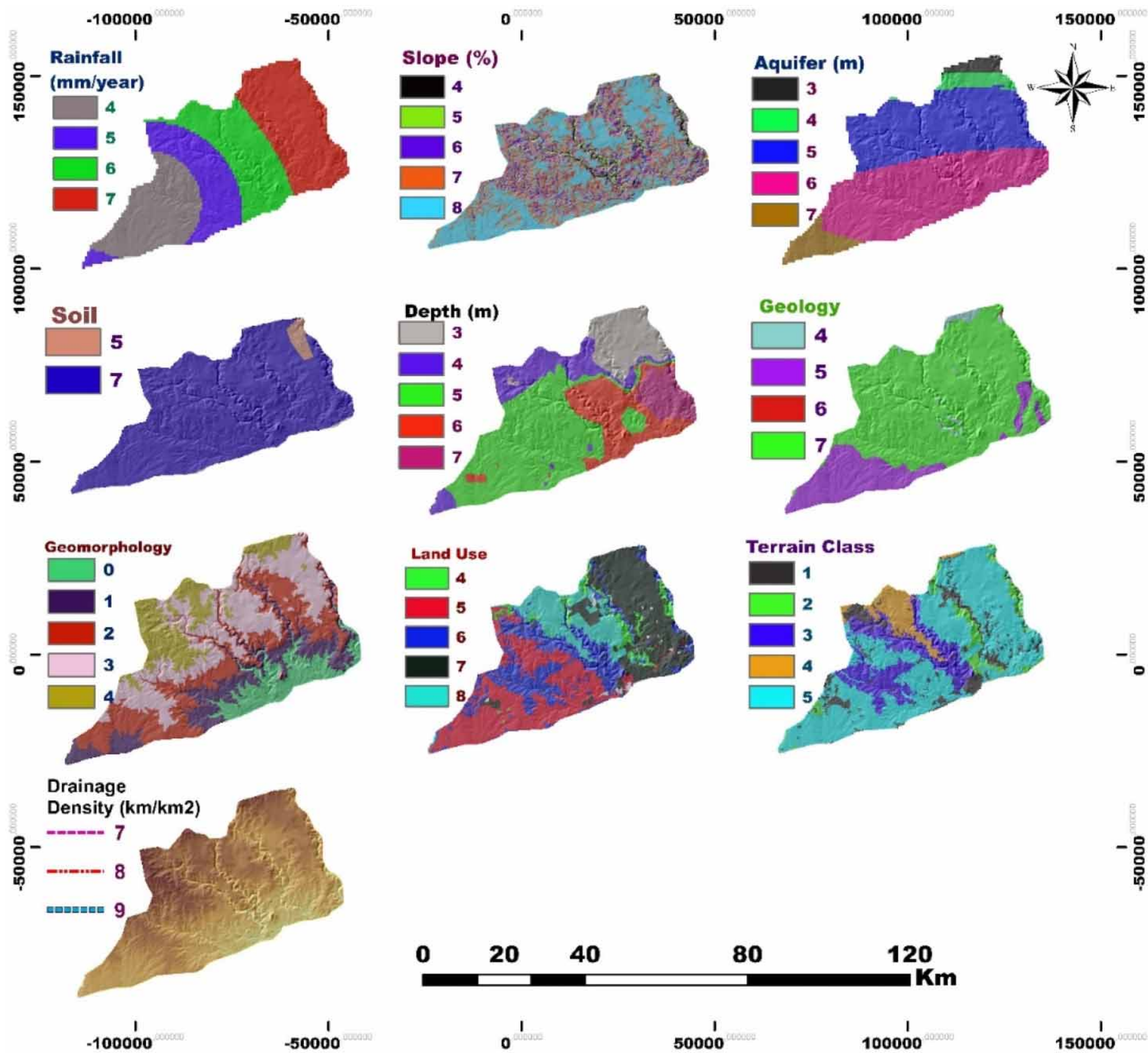

Figure 5 | Classified status of thematic maps.

In this thematic map, the GWPI value ranges between 370 and 617. It explains the classification ranges according to GWPZ values and the total ratio by basin in Table 7. As seen in Figure 4, groundwater potential is at a good level in the center of the Ceylanpinar Basin and partially towards the south. It is mostly moderate in the northern parts.

3.2. Validity (verification)

The groundwater area map was validated using data from 19 observation water wells located inside the basin limits. The GWPZ map represents the groundwater study area map with water well locations. In Figure 6. The groundwater potential of almost all existing pumping wells for irrigation purposes are rated as very weak, poor, medium, good, or very good for the area. As a result of this classification, three of the 19 reference well data were partially discordant. Of these, 16 are compatible with a one-to-one rating. This situation is summarized in Table 8.

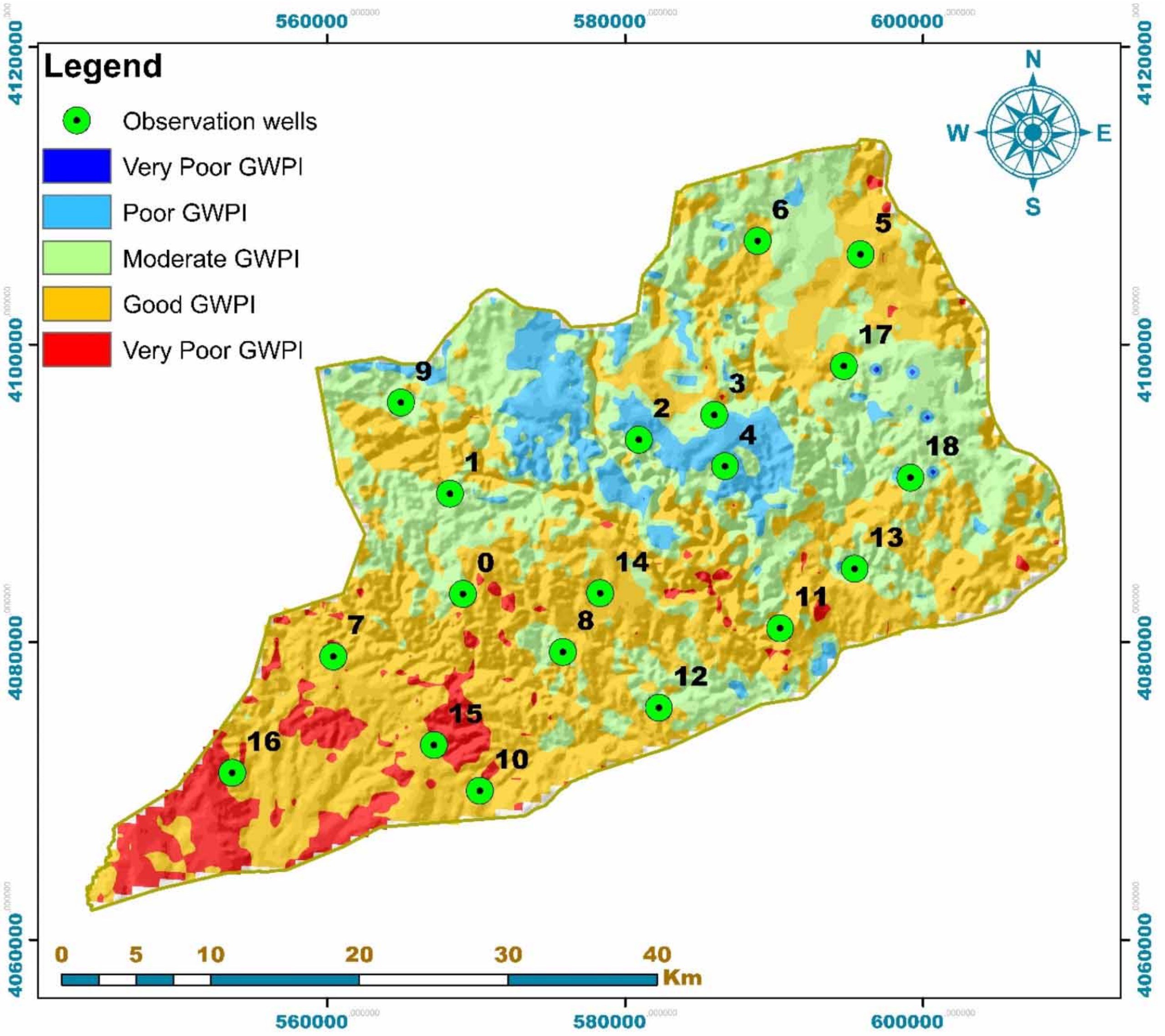

Figure 6 | GWPZ distribution map.

Table 7 | Classification according to Ceylanpinar Plain GWPI values

GWPI range	Definition	Rate (%)	Area (km^2)
618–656	Very poor	2.6	41.47
579–617	Poor	21.4	341.33
541–578	Moderate	20	319
502–540	Good	39	622.05
462–501	Very good	17	271.15

4. CONCLUSIONS

The Ceylanpinar Plain is part of the Mesopotamia, the most important region in history. It has been an area of agricultural activities since the beginning of civilization known in history. Agricultural lands in the region are very efficient and

Table 8 | Comparison of GWPI and well data

Wells	Coordinates X	Coordinates Y	Depth (m)	SWL (m)	DWL (m)	Yield (l/s)	GWPI	Evaluation	Compatibility
0	569100	4083243	295	150,3	169,9	10	478	Moderate	Compatible
1	568236	4089980	290	155,11	169,83	12	476	Good	Compatible
2	580913	4093609	230	121	159	9,7	474	Good	Compatible
3	585983	4095269	225	131,58	143,65	10,3	472	Poor	Compatible
4	586702	4091829	225	127,9	134,4	6,4	470	Good	Compatible
5	595802	4106060	400	134	147	12,4	468	Poor	Compatible
6	588895	4106960	390	112	136	15,7	466	Poor	Compatible
7	560397	4079043	275	145	148	8,9	462	Good	Compatible
8	575812	4079341	275	102	103	20	656	Good	Compatible
9	564938	4096108	345	143	153	13,2	648	Good	Compatible
10	570239	4070017	280	108	113	10,1	642	Poor	Compatible
11	590401	4080940	255	69	72	6,7	624	Good	Compatible
12	582259	4075595	230	56	56	9,3	620	Poor	Partially compatible
13	595410	4084934	270	61	63	7,4	616	Moderate	Compatible
14	578314	4083291	275	114	115	11	614	Moderate	Compatible
15	567155	4073090	275	126	128	13,3	612	Good	Compatible
16	553607	4071223	250	114	125,8	7,9	610	Moderate	Partially compatible
17	594684	4098556	150	70	80	5,4	608	Poor	Compatible
18	599157	4091057	150	70	80	5,4	606	Moderate	Partially compatible

SWL, Static water level; DWL, Dynamic water level.

the irrigation water supply is groundwater. The sustainability of agriculture and livestock in the region depends on the sustainability of these resources. On a regional basis, it is possible to create an underground water potential map by modeling the impact rates of large-scale water potential on groundwater. A parametric approach using the techniques of Rs, GIS, and AHP can reduce time, labor, and costs to minimum levels and thus make faster decisions for productive management of water resources. Despite the limitations of the criteria, such analysis is a valuable and practical tool for areas and areas (especially developing states) for the determination of water solutions due to data shortages. The sustainability of agriculture and livestock in the region depends on the sustainability of these resources. On a regional basis, it is possible to create an underground water potential map by modeling the impact rates of large-scale water potential on groundwater.

Exploration of groundwater resources is one of the most important research fields in arid and semi-arid climates. Due to the agricultural expansion of the site, it was necessary to analyze the groundwater potential. In this study, a weighted thrust evaluation method employing GIS-based AHP and FAHP techniques was utilized to explore groundwater potential regions in the basin. The ability to employ fewer validation data (such as well locations and yield data) and the thematic layers of hydro geomorphology while still retaining optimal mapping accuracy is a benefit of such a mapping methodology. Totally, 10 thematic layers, such as geology, slope, aquifer, precipitation, depth, drainage density, land use, land structure, geomorphology, and soil texture were defined and classified as thematic layers by integrating and analyzing them in the GIS environment. Potential groundwater locations were then identified and classified into five categories: very good potential, good potential, medium potential, poor potential, and very poor potential. As a result, approximately 30% (472.19 km^2) of the area has very bad potential; 23% (358.88 km^2) has bad potential. 19% (298.27 km^2): medium and 22% (350.9 km^2): good groundwater potential suitable for agriculture. The resulting map categories align well with the productivity and sustainability of already developed groundwater resources and can therefore be used with some confidence to identify additional areas for development.

Groundwater well recharge, groundwater depth level data, and cascade drop pumping well tests should be performed in various sections of the basin to evaluate the particular efficiency of groundwater wells at various GWPIs, as described in this article. In this approach, the study site's groundwater can be extracted in a sustainable manner. However, in the absence of rigorous validation of groundwater data, the proposed methodology can be used as the primary estimation of groundwater expectations and the potential sites identified for drilling water wells should be preferred.

This study should contribute significantly to the understanding of the potential of groundwater zones in the studied basin, as well as the possibility of being used as a starting point by engineers, hydrologists, decision makers, and regional planners for the regeneration of this vital life-sustaining resource. Because the study method is based on logical criteria, it might be applied to various semi-arid and arid parts of the world with minor alterations. In order to build successful policies and processes for the healthy use and exploration of groundwater resources, a unified strategy is also required, particularly by ministries, government agencies, non-governmental organizations, and individuals. Future studies may aim to explore groundwater potential with fuzzy subjects, neural networks and other advanced artificial intelligence methods. Also, to better comprehend groundwater potential, groundwater criteria should be included as a decision-making approach.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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