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Determination of Van Basin Groundwater Potential by GIS Based, AHP and Fuzzy-AHP Methods

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ABSTRACT

Global warming and climate change put excessive pressure on the use of groundwater resources. As the demand for water consumption in fields such as agriculture and industry increases worldwide, the need for the modeling and evaluation of groundwater potential and quality efficiency increases accordingly. Nowadays, methods based on multi-criteria decision-making techniques such as geographic information systems (GIS), analytical hierarchy process (AHP), fuzzy analytical hierarchy process (F-AHP) and ELECTRE have begun to be used rapidly in the field of groundwater. These methods are of great importance because they reveal information faster. They are also a tool for the communication and meaning of information. In the light of this information, this study was carried out in order to model and evaluate the groundwater potential and quality of Van, Türkiye. In order to evaluate the groundwater potential of the Van province basin, remote sensing data with AHP and Fuzzy AHP methods, which are GIS-based MCDM programs, were used. Eight thematic maps such as precipitation, slope, soil texture, land use/land cover, geology, geomorphology, drainage density, drainage density and fault density were created. These thematic parameters were graded and weighted in the AHP method according to their effects on the groundwater potential. Then, five different groundwater recharge potential regions were classified as very good (8%), good (17%), moderate (43.37%), poor (23.03%) and very poor (9.6%). The evidence obtained by validating the results is in line with flow calculation studies showing that groundwater flows from the south to the northeast, middle and north to the southwest of the basin. The evidence obtained by validating the results is consistent with the flow calculation values showing that the groundwater basin flows from south to northeast, center and north to southwest of the study area. The validation shows that the method applied for the study area gives a meaningful and reliable result.

Keywords: AHP, Fuzzy-AHP, GIS, Groundwater Potential, MCDM

1. Introduction

Groundwater, one of nature's most valuable resources, is found in underground rocks, sediments, cracks and pore spaces. This groundwater plays an important role in economic growth as well as human welfare and maintaining the ecological balance (Zekai 2008; Naghibi et al. 2015). About 30% of the fresh water in the world is groundwater, of which only 0.3% is surface water, lakes, marshes, reservoirs and rivers (Senanayake et al. 2016). Rainwater seeping into the aquifer through soil pores and snowmelt are the two main sources of groundwater. The consumption of groundwater is more dependable and fresher than that of surface waters since it is more practical and less prone to pollution. Groundwater, which is more reliable and pure than surface water, has emerged as a global concern in the last century as the demand for fresh water increased with rapid industrialization and population growth (Manap et al. 2014). For this reason, groundwater extraction is crucial for water management and planning, particularly in rural areas (Das & Pardeshi 2018). In order to build a large irrigation system that uses sustainable resources, it is crucial to identify any possible groundwater locations. Groundwater formation in the region might be referred to as prospective groundwater in terms of groundwater exploration (Pathak 2017).

Although there is not enough groundwater in the world, excessive consumption and uncontrolled water use cause a further decrease in groundwater. Remedial procedures at the national, regional, and local levels should therefore be identified in advance and then used in order to ensure the sustainability and protection of groundwater and surface waters.

Groundwater movement; Lithological variation is defined by topographic condition, slope, geology, precipitation patterns, soil texture, etc., through soil pores (Mallick et al. 2014). This knowledge is an important link between the conservation and management of regional, national and international biodiversity, and the extensive exploration of local water resources. The use of Remote Sensing (RS) and Geographıcal Informatıon System (GIS), which are powerful tools, is very valuable in determining possible groundwater potential regions of arid and semi-arid regions (Rahmati et al. 2015). Analytical Hierarchy Process (AHP), which is one of the multi-criteria decision-making methods in various fields such as water, natural resources method, environmental impact analysis and regional planning, is widely used as well as being applied effectively (Rahaman et al. 2015).

In multiple data set analysis, the geometric mean of the parameters and the comparison matrix AHP technique is used in normalized weight calculation (Chowdhury et al. 2010).

The Van basin depends on groundwater, which is a reliable and vital natural water source. Currently, groundwater constitutes the majority of the city's annual water demand for agricultural, domestic and industrial needs. In addition to the rapid population growth, the excessive water demand of sectors such as agriculture, industry, and tourism poses a significant problem for the city of Van (DSI (State Hydraulic Works) 2015).

There are not many studies on the determination of potential groundwater resources in Van province. Therefore, this study provides a broader view of the potential groundwater distribution of the basin by using multi-criteria decision analysis (MCDA) and other variables in the evaluation of groundwater potential regions (Aslan & Celik 2021).

AHP, one of the multi-criteria decision making techniques, has been widely used by Saaty in the field of water resources engineering. In various water resource management studies, the AHP method has been successfully applied by integrating it with MCDA, RS and GIS techniques (Machiwal et al. 2011; Pinto et al. 2017).

For this reason, GIS supported AHP and Fuzzy-AHP methods were used to evaluate the groundwater potential resources of the Van basin and to integrate parameters such as hydrogeology, geology, geomorphology, soil texture, drainage density, and LU/LC. In addition to ensuring optimum and sustainable development and management of this critical groundwater resource, the purpose of designing potential sites is to develop a guide map for prospective groundwater exploration/operation (Das & Pardeshi 2018). Technologies such as remote sensing and GIS supported, AHP, TOPSIS, Fuzzy - AHP methods can be used with relatively accurate results in determining groundwater regions to solve the problems (whether there is groundwater or not). With these methods, it is possible to determine the boundaries of high potential regions in accessible areas.

2. Material and Methodology

2.1 Location and hydro-meteorology of the study area

The drainage area (17861.2 km^2) of Lake Van basin (The study area is located between 42° 40' and 44° 30 East longitudes and 37° 43' and 39° 26' North latitudes) was calculated using GIS. The land surface area of the basin excluding the lakes is 14101.4 km^2 (Ozler 2005). In the Van basin, transitional climate characteristics are observed between the continental climate of the Central Anatolia and Southeastern Anatolia regions and the Mediterranean climate. In terms of temperature, the degraded type of the Mediterranean climate is dominant. The main factor of this climate change (humidity and precipitation) is Lake Van. According to the Thiessen Polygons Method, the annual average precipitation in the basin is 447.29 mm (Konyar et al. 2019). Van basin location map is shown in Figure 1.

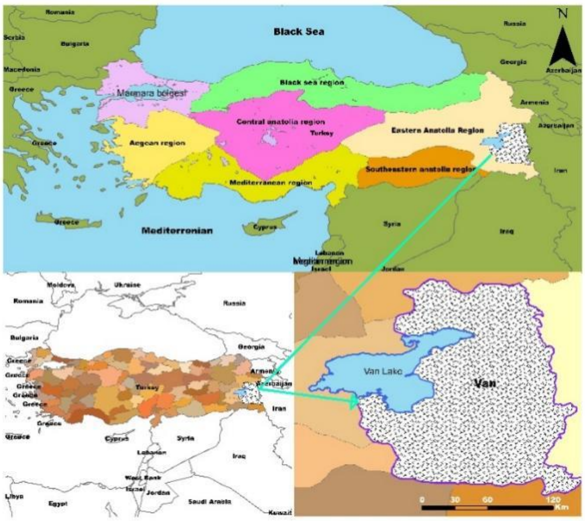

Figure 1- Van Basin Location Map

There are sedimentary, magmatic and metamorphic rocks formed from the earliest times to the present in the study area. Generally, metamorphic rocks belonging to the Bitlis Massif in the south of the basin, volcanic and volcanic rubber rocks that are the products of the young Nemrut and Suphan Mountains in the west and north, volcanic rocks belonging to the Yuksekova Complex and ophiolite components, current fluvial and lacustrine fragments and carbonates crop out in the east (Erdogan 2017).

2.2 Establishment of geographical data for the groundwater potential assessment of the basin

In the study, the Fuzzy Analytical Hierarchy Process (F-AHP) and Remote Sensing supported GWPI region mapping method were used along with ArcMap 10.2 program software (Jesiya & Gopinath 2020).

In the Van basin study, hydrological, anthropogenic and geological factors were taken into account, as well as expert opinions, field observations and literature reviews in evaluating the groundwater potential. Factors such as slope, geology, and geomorphology are considered geological elements. Data such as fault density, drainage density, land use/land cover, topsak class, current aquifer status and proximity to water bodies were evaluated as anthropogenic features (Akter et al. 2020; Jesiya & Gopinath 2020). Thematic data such as geology, aquifer (hydrogeology) and soil type were obtained by digitizing in Arcmap 10.2 software. The 1:50,000 scale drainage density map of the Van Basin was taken from the 17th Regional Directorate of State Hydraulic Works. Linear density analysis was performed to prepare the lineament and drainage density in km2 (Kumar et al. 2016; Akter et al. 2020; Jesiya & Gopinath 2020). The map in Figure 2 was produced by Aslan & Çelik (2021), inspired by the groundwater potential mapping study with geographical information techniques for a sustainable environment in the Haliliye basin (Aslan & Çelik 2021). These 8 parameters considered in the ArcMap environment were first converted into raster thematic maps and then into reclassified maps. Finally, the groundwater potential index distribution map was produced (Figure 2).

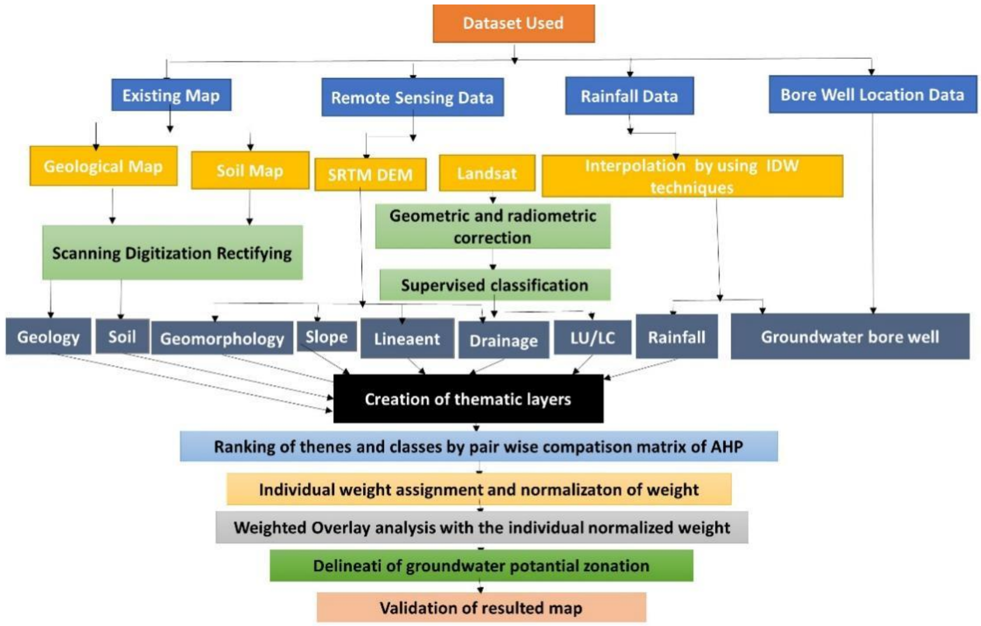

Figure 2- Hierarchical flow chart for groundwater potential area mapping of Van basin (Aslan & Celik 2021)

2.3 AHP method

The AHP method is an approach that evaluates Saaty's criteria in a certain order (according to the effects of parameters on groundwater), evaluates the weights of these criteria, compares the alternatives according to the criteria and provides ranking (Ozder et al. 2021; Munier & Hontoria 2021). The AHP method, which is based on three basic principles such as problem solving process decomposition, comparative judgments and synthesis of priorities, is a systematic approach that determines and represents the priority status of its multi-criteria elements in an order (Parameters or criteria) (Fedrizzi et al. 2018; Ly et al. 2018). Based on expert opinion through pairwise comparisons, the AHP method is widely used in situations such as setting priorities, reducing problem complexity, simplifying and planning decisions, choosing the best alternative, allocating resources, and conflict resolution (Samuel et al. 2017; Fattahi & Khalilzadeh 2018; Ozder et al. 2021). In pairwise comparison matrices, when comparing two criteria in relation to each other and each binary alternative according to any criteria, questions such as which one is more important and how important it is are asked (Di Bona et al. 2017). The implementation stages of AHP can be listed as follows (Pinto et al. 2017; Xingfeng 2017; Patra et al. 2018; Wang 2020);

Stage 1: Establishment of the Model and Formation of the Problem: In the AHP approach, quantitative and qualitative factors affecting the decision process are determined by conducting a survey or consulting expert opinions. As a result of the information obtained, a hierarchical structure is created by determining the criteria, sub-criteria and alternatives (Ozder et al. 2021).

Stage 2: Creating the Pairwise Comparisons Matrix: After the hierarchical structure is created, the data are collected using the pairwise comparisons scale in Table 1 and the paired comparisons matrix is obtained (Ozder et al. 2021).

Table 1- Importance level scale (Ozder et al. 2021)

Importance level	*Definition*
1	Equally important
3	Moderately important
5	Strongly important
7	Very strongly important
9	Definitely important

Stage 3: Determination of Criterion Weights and Scores of Alternatives: using pairwise comparison matrices, the weight of each decision alternative is calculated and accordingly, the matrix is normalized by dividing each column in the comparison matrix by the total column with its value. In the normalized matrix, the total value of each column is 1 and the eigen vectors are obtained by finding the average of the values in the row (Table 1).

Stage 4: Calculating Consistency Ratio: The following formulas were used to calculate the Eligibility Ratio (CI).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad \textbf{(1)}$$

In the formula, the CI Conformity Index is the largest eigenvalue in the λ_{max} matrix, where n is the number of elements in each matrix.

The Conformity Ratio (CR) is obtained by dividing the consistency index by the Random Index (RI) corresponding to the matrix of the same size;

$$CR = \frac{CI}{RI} \quad \textbf{(2)}$$

The random index table made for matrices of different sizes is in Table 2 (Saaty 2000).

Table 2- Randomness indexes (Saaty 2000)

N	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
RI	0.00	0.00	0.60	1.00	1.10	1.20	1.30	1.40	1.50	1.50	1.50	1.60	1.60	1.60	1.59

2.4 Fuzzy AHP

The Fuzzy AHP method is an effective tool that combines the fuzzy logic approach with the AHP method, and with this aspect, it cannot be digitized with precise data, and is an effective tool in decision-making processes where uncertainty and relativity are high. The decision maker is asked to verbalize his personal evaluation while determining of criterion weights. With this aspect, it is a more realistic evaluation method (Tu et al. 2020; Chaudhry et al. 2021). The ranking of alternatives is accomplished by means of linguistic variables. Each linguistic variable has a corresponding fuzzy logic. Equivalents of these expressions are triangular membership functions. There are 3 parameters that define the triangular membership function. If these parameters are taken as l, m, u, the components and shape of the triangular membership function are given below (Figure 1);

$$\mu_a(x; l, m, u) = \begin{cases} 1 \leq x \leq m \quad \text{if} & \frac{(x-1)}{(m-1} \\ m \leq x \leq u \quad \text{if} & \frac{(u-x)}{(u-m)} \\ x > u \text{ or } x < 1 \text{ if} & 0 \end{cases} \quad \textbf{(3)}$$

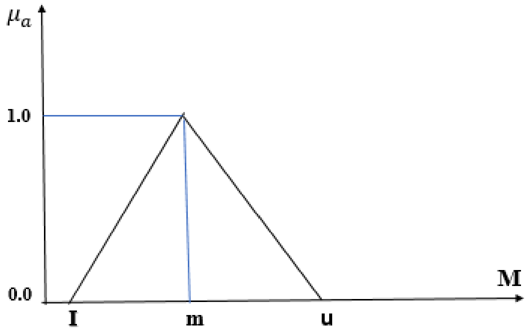

Figure 1- Triangle Membership Function (Ahirwar et al. 2021)

A triangular fuzzy number with A=1 is defined as the vertex m, and m need not be the midpoint between l and u (Mallick et al. 2019; Ahirwar et al. 2021; Singh et al. 2021). Fuzzy AHP steps (Sener et al. 2018; Tiri at al. 2018);

Step 1: The verbal comparison matrix between the criteria is obtained by using the fuzzy numbers given in Table 3 (Equation 4). At this stage, for a problem where k decision makers evaluate n criteria, the fuzzy comparison matrix for each k decision maker is defined as follows (Chai & Wei 2001).

Table 3- Verbal expressions and fuzzy triangular number equivalents in fuzzy AHP (Kaplan & Arikan 2012)

Language scale in order of 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)*

In this comparison matrix, the expression $d_{ij}^{\tilde{k}}$ is the i of the decision maker k. criterion j. is the fuzzy triangular number corresponding to the verbal pairwise comparison with the criterion.

$$A^{\tilde{k}} = \begin{bmatrix} \tilde{d}_{11}^{k} & \tilde{d}_{12}^{k} & \cdots & \tilde{d}_{1n}^{k} \\ \tilde{d}_{21}^{k} & \cdots & \cdots & \tilde{d}_{2n}^{k} \\ \cdots & \cdots & \cdots & \cdots \\ \tilde{d}_{n1}^{k} & \tilde{d}_{n2}^{k} & \cdots & \tilde{d}_{nn}^{k} \end{bmatrix} \qquad \textbf{(4)}$$

Step 2: If the number of decision makers is K, these values are averaged. According to this;

$$d_{ij}^{\sim} = \frac{\sum_{k=1}^{K} d_{ij}^{\tilde{k}}}{K} \qquad \textbf{(5)}$$

The averaged matching matrix can be represented as follows.

$$A = \begin{bmatrix} d_{11}^{\sim} & \cdots & d_{1n}^{\sim} \\ \vdots & \ddots & \vdots \\ d_{n1}^{\sim} & \cdots & d_{nn}^{\sim} \end{bmatrix} \qquad \textbf{(6)}$$

Step 3: The geometric mean of the fuzzy triangle numbers given for each criterion is found (Li, & Li 2009; Das 2017).

$$r_i^{\sim} = \left(\Pi_{j=1}^{n} d_{ij}^{\sim}\right)^{\frac{1}{n}}, \quad i = 1, 2, 3, \cdots, n \qquad \textbf{(7)}$$

Step 4: The value of each criterion, whose fuzzy weights are given, is calculated as follows (Senko 2018).

$$\tilde{W_i} = \oplus (\tilde{r_1} \oplus \tilde{r_2} \quad \oplus \tilde{r_n})^{-1} = (lw_i, mw_i, uw_i) \quad \textbf{(8)}$$

Step 5: The fuzzy $\tilde{w}_i$ values are clarified with the help of the formula below.

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \quad \textbf{(9)}$$

Step 6: In the last step, the Mi value is normalized (Hossain & Thakur 2020).

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \quad \textbf{(10)}$$

3. Results

3.1 Generating Raster and Classification Lines with GIS Program

Firstly, raster maps of the parameters of precipitation, slope, soil texture, land use/land cover, geology, geomorphology, drainage density, drainage density and fault density to be used in the study were produced. Later these maps have been reclassified.

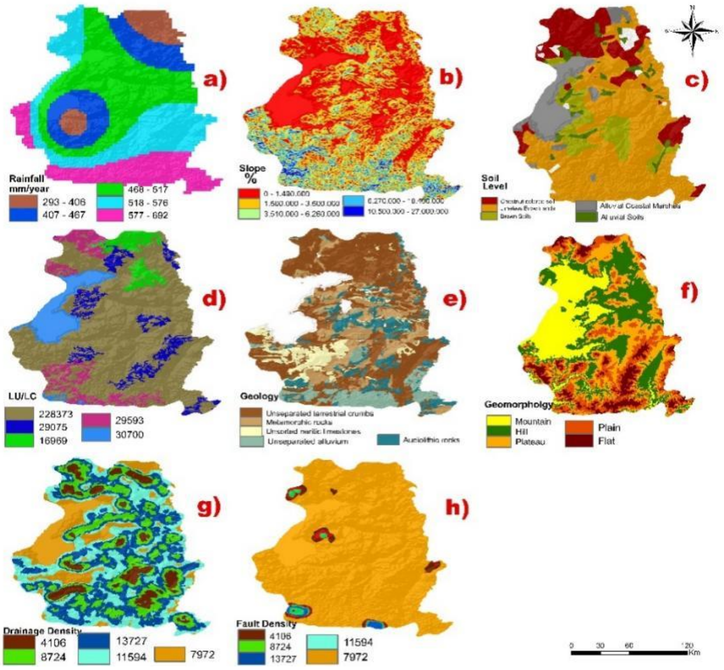

Figure 3- Groundwater thematic (a. Rainfall, b. Slope, c. Soil, d. Land Use/Land Cover, e. Geology, f. Geomorphology, g. Drainage Density, h. Fault Density) maps of the Van province basin

Rainfall: the most important parameter that ensures groundwater formation by filtration of the soil. As seen in Figure 3a, 41.23% of the Van basin has a maximum precipitation rate of 468-517 mm/year and approximately 21% has a maximum precipitation rate of 577-698 mm/year. Only 6% of the area has a precipitation rate of 293-408 mm/year (Figure 3a).

Slope: an effective parameter in obtaining the groundwater potential. In the parts where the slope is low, the flow of precipitation waters to the surface will be low and the underground infiltration will be high. This is an effective parameter in obtaining the groundwater potential. In places where the slope is low, the flow of precipitation waters to the surface will be low and underground infiltration will be high. Figure 3b shows that in about 35% of the basin the slope is 15% and close to 30% is above 30% (Figure 3b)(Batelaan & De Smedt 2001).

Soil Texture: like other parameters, soil also allows precipitation to infiltrate underground, and the rate and amount of infiltration varies according to the grain structure (groundwater infiltration is more in coarse-grained porous structures, infiltration is slower and less in fine-grained soils such as clay), and porosity in groundwater movement and recovery. The parameter in which permeability plays an important role is soil. Approximately 10% of the Van basin is chestnut colored soil, 52% limeless brown lands, 9% brown lands, 12% alluvial coastal marshes and 3% alluvial soils soil (Figure 3c).

Land Use: an important parameter for groundwater formation and is directly related to the infiltration of precipitation into the soil. Due to urbanization, low leakage and high surface flow rate, and wetlands and water bodies are considered to have the highest evaluation scores. Irrigated farmland also has high infiltration of water into the soil, and there is a high rate of seepage in plant areas, partly in the form of land, because the runoff is blocked by the fields.

Geology: an important parameter and seen in Figure 3e, is important in terms of reflecting the aquifer status showing the storage of groundwater. The proportion of unweathered terrestrial clastics in the basin is approximately 41%, and metamorphic rocks are at the highest level with 24%. The water holding capacity in these formations is not very high. Unsorted neritic limestones in the region are 21% and their water holding capacity is quite high (Figure 3e).

Geomorphology: (Figure 3f) the geomorphology map is the map describing the mountains, hills, plateaus, plains and plains in the basin. It states that the flat part of the basin has the highest groundwater potential and the lowest part of the groundwater is in the mountainous areas. The flat part of the field is approximately 39%, the plain 30%, the plateau 17%, the hill 10%, and the mountainous area 4% (Figure 3f) (Celik 2019).

Drainage Density: Affects groundwater potential and quality. It is also the reason for the decrease in the flow rate of water (Singh et al. 2018). For this reason, the performance coefficient of the ratios with low drainage density was taken as a higher value and the drainage density is mostly seen as low in the Van province basin (Figure 3g).

Fault Density: has a geological feature that shows the effect of precipitation on the ground. Feeding is more common in underground fractured areas. Although the cracked areas create discontinuity between the regions, they allow the precipitation to be fed to the underground aquifers in a shorter time. In areas with high lineament density, groundwater recharge is greater; in regions with low density, groundwater recharge is low (Magowe 1999). There is fault density in almost all of Van province (Figure 3h).

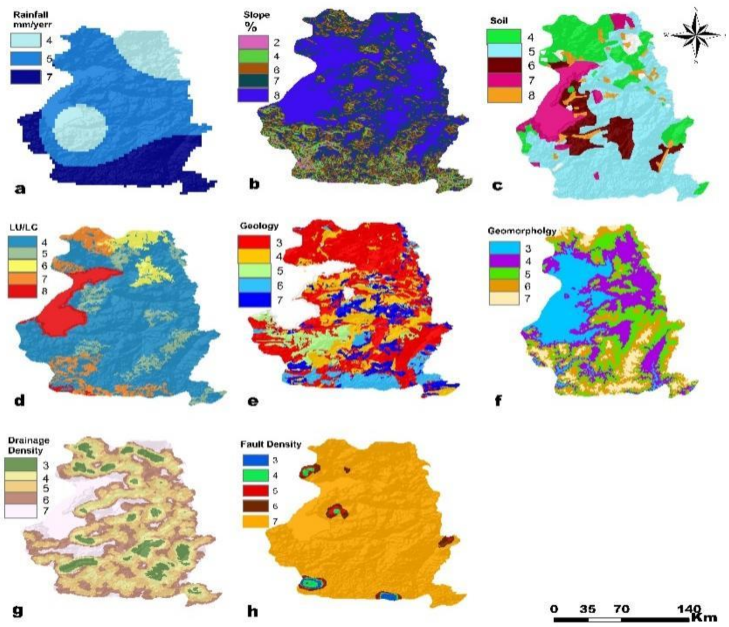

Figure 4- Van province basin groundwater classified (a. Rainfall, b. Slope, c. Soil, d. Land Use/Land Cover, e. Geology, f. Geomorphology, g. Drainage Density, h. Fault Density) maps

Rainfall (precipitation): in the Reclassify environment, the precipitation parameter is divided into 3 classes. Here, the best region is the area that scored 7 points and covers the south of the basin. The weakest part of the basin, rated as 4, is the north-eastern part of the city, which corresponds to the Siverek district (Figure 4a).

Slope: slope data is divided into 5 classes in ArcToolbox →Spatial Analyst Tools → Reclass →Reclassify table due to both visuality and ease of calculation. The lowest value obtained in this table received 1 point and the highest value received 5 points (Figure 4b).

Soil Texture: in this classification, the best area of the basin in terms of soil is the orange- colored areas (5), the weakest region of the basin, which was evaluated with 8 points, was the northern part, which received 4 points (Figure 4c).

Land Use/Land Cover: This parameter is divided into 5 classes in the reclassification table. According to the result in the basin, it is the red colored area in the western region, which received 8 points. The weakest area is the 4-dot blue areas (Figure 4d).

Geology: this parameter is also divided into 5 classes, and the parts evaluated with dark blue and evaluated with 7 points. The weakest part is the red area, which is evaluated with 3 points (Figure 4e).

Geomorphology: is divided into 5 classes in Spatial Analyst Tools → Reclassify →Reclassify environment. In the classification, burgundy-colored (4) and almost the middle part of the basin is the most productive (in terms of groundwater) area. The yellow-colored (7) is weak in the southern parts of the basin, and the weakest part is the blue part in the west of the basin (Figure 4f).

Drainage Density: This parameter is divided into 5 classes. The most valuable part of the basin in terms of drainage density receives 7 points, while the weakest part is the region with 3 points (Figure 4f).

Fault Density: Like other parameters, this parameter is divided into 5 classes. While the yellow area in the basin, which has 7 points and covers almost the entire region, is the weakest region, the region with 3 points is the best region in terms of high groundwater potential (Figure 4h).

3.2 Application of the AHP method

After these 8 parameters used in the AHP method were graded according to their effects on the groundwater potential and quality, the application of the AHP method could begin.

The precipitation used in the study was accepted as the most important parameter and was weighted with 9 points from the values from 1 to 9 in Table 1. When the slope is low, it is easier and more for precipitation waters to seep into the ground (In other words, in areas with low slope, the soil allows rainwater to seep underground). The higher the slope, the easier it is for precipitation water to disperse and the harder it is for the water to seep into the ground. Therefore, the slope parameter was scored as 7 (at 1-9) from the values given in Table 1. The remaining 5 parameters were graded according to their impact on groundwater and used in the AHP method (Saaty 2000).

In line with Saaty's suggestions in the AHP method, 8 parameters to be used in the study were graded according to their effects on groundwater potential and quality and implemented (Table 4).

Table 4- Pairwise comparison matrix table of eight thematic data selected in the study

Criteria	*Assigned Weight*	*Rainfall*	*Slope*	*Soil Type*	*LU/LC*	*Geology*	*Geomorphology*	*Drainage Density*	*Fault Density*
k_1	**9**	**1.000**	1.125	1.286	1.286	1.600	1.600	1.800	2.250
k_2	**8**	0.940	**1.000**	1.143	1.143	1.333	1.333	1.600	2.000
k_3	**7**	0.880	0.875	**1.000**	1.000	1.167	1.167	1.400	1.750
k_4	**7**	0.760	0.875	1.143	**1.000**	1.167	1.167	1.400	1.750
k_5	**6**	0.710	0.750	0.857	0.857	**1.000**	1.000	1.200	1.200
k_6	**6**	0.650	0.750	0.857	0.857	1.000	**1.000**	1.200	1.200
k_7	**5**	0.530	0.625	0.714	0.714	0.833	0.833	**1.000**	1.000
8_8	**4**	0.410	0.500	0.571	0.571	0.667	0.667	0.800	**1.000**
Total		**5.880**	**6.500**	**7.571**	**7.428**	**8.867**	**8.867**	**10.40**	**12.40**

Table 5 contains the criteria ranges according to Table 4. For example; In the process performed here, the first and second.... eighth columns are completed by dividing the first weight by the total weight, then dividing the second weight by the total weight, starting from the first column.

"Then the values in the rows are summed to calculate the normalized weight. The Geometric Average is also obtained by dividing each of these summed values by eight (total number of parameters)."

Table 5- Normalizing and geometric averaging of selected layers

Criteria	*Rainfall*	*Slope*	*Soil Type*	*LU/LC*	*Geology*	*Geomorphology*	*Drainage Density*	*Fault Density*	*Geometric Mean*	*Normalized weight*
k_1	0.170	0.154	0.169	0.173	0.180	0.180	0.173	0.181	0.1725	1.380
k_2	0.159	0.145	0.151	0.154	0.150	0.150	0.154	0.162	0.1531	1.223
k_3	0.149	0.135	0.132	0.135	0.132	0.132	0.135	0.141	0.1364	1.091
k_4	0.129	0.117	0.151	0.135	0.132	0.132	0.135	0.141	0.1340	1.072
k_5	0.121	0.109	0.113	0.115	0.113	0.113	0.115	0.097	0.1120	0.896
k_6	0.111	0.100	0.113	0.115	0.113	0.113	0.115	0.097	0.1096	0.877
k_7	0.090	0.092	0.094	0.096	0.094	0.094	0.096	0.081	0.0921	0.737
8_8	0.069	0.077	0.075	0.077	0.075	0.075	0.077	0.081	0.0664	0.531

Finally, the following values are obtained by following the formulas in the AHP method.

$$\text{Average } \lambda_{\max} = \frac{\Sigma(\text{Normalized weight})/(\text{Geometric Mean})}{8} = 8.12$$

In the last step, the CR value is calculated as follows. The fact that the value of CR is less than 0.1 in AHP applications shows that the application is consistent, otherwise the process should be reviewed again (Saaty 2000).

$$\text{Consistency Index (CI)} = \frac{8.12 - 8}{7} = 0.01714$$

$$\text{CR} = \frac{\text{CI (Consistency Index)}}{\text{Randomness Indicator}} = \frac{0.01714}{7} = 0.01224 < 0.1$$

Since the result is < 0.1, it is within the limits of agreement.

Table 6 was created after the raster thematic map of eight parameters was created in the GIS environment. Aslan and Celik (2021) examined the groundwater of the Harran Plain basin and mapped their modeling with the GIS supported AHP method. In addition, they created a groundwater database with the maps they obtained. Table 6 was created by considering this study (Aslan & Celik 2021).

Table 6- Details of layer properties and ordering properties and normalized weights

Sequence	*Layer*	*Weighting*	*Normalized total weight*	*Sub-Feature*	*Field Cover*	*Groundwater Potential zone*	*Evaluation*	*Sum of normalized weight of soil is not 100*
1	Rainfall	9	3411	Brown field	257	Very very poor	3	%08
				Dark blue field	577	Very poor	4	%17
				Green field	1139	Very poor	4	%33
				Blue field	846	Poor	5	%24
				Purple field	592	Moderate	6	%18
2	Slope	8	129795	The slope is too low	1931	Very good	7	%01
				The slope is low	8557	Good	6	%07
				Moderate slope	21525	Moderate	5	%17
				High slope	42802	Poor	4	%33
				The slope is too high	54980	Very poor	2	%42
3	Soil	7	120442	Chestnut colored soil	60297	Very poor	3	%5
				Limeless Brown lands	5097	Poor	4	%04
				Brown Soils	35934	Poor	5	%30
				Alluvial Coastal Marshes	228	Moderate	6	%02
				Alluvial Soils	18886	Good	7	%16
4	LU/LC	7	334710	Blue field	228373	Good	7	%68
				Green field	29075	Good	6	%8
				Red field	16969	Moderate	5	%5
				Purple field	29593	Poor	4	%9
				Brown field	30700	Very poor	3	%10
5	Geology	6	38652	Unseparated terrestrial crumbs	519	Poor	2	%1
				Metamorphic rocks	4698	Poor	3	%12
				Unsorted neritic limestones	6954	Moderate	5	%18
				Unseparated alluvium	7080	Good	7	%19
				Audiolithic rocks	19401	Very good	9	%50
				Mountain	26742	Poor	3	%21
				Hill	36088	Poor	4	%28
6	Geomorphology	6	129765	Plate	32908	Moderate	5	%25
				Plain	23057	Good	6	%18
				Flat	10970	Good	6	%8
				Brown area	4106	Very poor	3	%9
				Green area	8724	Poor	4	%19
7	Drainage Density	5	46123	Blue area	13727	Moderate	5	%30
				Turquoise area	11594	Good	6	%25
				Light brown area	7972	Very good	7	%17
8	Fault Density	4	42468	Blue area	455	Poor	7	%1
				Green area	447	Poor	6	%1
				Red area	794	Moderate	5	%2
				Brown area	2788	Very good	4	%7
				Orange area	37984	Good	3	%89

3.3 Distribution of the groundwater potential evaluation map of the region

Groundwater potential index distribution map was produced in the ArcMap environment with 8 parameters (precipitation, slope, soil, land use/land cover, geology, geomorphology, drainage density, fault density). As seen in Figure 5, these data were classified and weighted according to the values obtained in the AHP method and a precise map of the groundwater potential zone (GWPZ) was created (Dilekoglu & Aslan 2022).

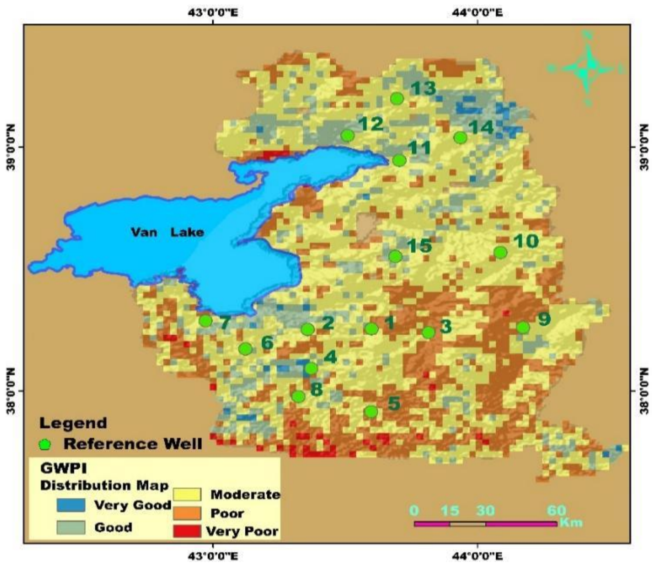

Figure 5- Groundwater Potential Area Distribution Map (GWPI_Zone)

As seen in Figure 5, the distribution values of the Groundwater Potential are between 406 and 683. According to the figure, it can be said that the groundwater potential is at a good level towards the center and partly to the south of the basin. The classification ranges of these GWPZ values and the total ratio of the basin are shown in table 7 (Aslan & Celik 2021).

Table 7- Classification of Van Basin according to Groundwater Potential GWPI Values

GWPZ value	*Explanation*	*Rate (%)*	*Covered area (km^2)*
406 - 461	Very Good	8.000	1128.08
462 - 517	Good	17.00	2397.17
518 - 572	Moderate	43.37	6115.37
573 - 628	Poor	22.03	3102.22
629 - 683	Very Poor	9.600	1353.70

3.4 Validity (Verification)

The Groundwater Potential Index map obtained from 15 observation water wells in Figure 5 represents both the water well locations and the groundwater study area. The groundwater potential of the pump wells drilled for irrigation purposes was evaluated with the degrees of very good, good, moderate, poor, very poor. Only one of the reference wells is partially compatible, and 14 of the data are compatible (Table 8).

Table 8- Groundwater Potential Index and Well Data

R.N.	*Town*	*X*	*Y*	*Depth (m)*	*SWL (m)*	*DWL (m)*	*Yield m3/day*	*GWPI*	*Evaluation*	*Notifications*
0	Kavuncular	383685	4265203	80	13.21	41.14	0.00	406	Poor	Compatible
1	Ercek	386375	4279150	75	8.95	32.73	0.00	417	Poor	Compatible
2	Cedel-ova	368366	4273846	100	15.92	68.00	0.42	420	Good	Compatible
3	Mollahasan	404724	4279217	178.2	1	8.15	1.40	426	Poor	Compatible
4	Taskonak	366200	4249080	132	13.13	51.08	0.85	428	Good	Compatible
5	S. Cavus hamlet	383875	4216966	100	60	90.00	0.05	430	Poor	P.Compatible
6	Elmalik	353125	4253075	56	49	54.00	0.32	438	Poor	Compatible
7	UI. Tunal	330892	4241674	77	6.57	38.12	0.22	509	Good	Compatible
8	Kusdagi Koyu	362500	4234750	141	56.13	51.00	0.00	515	Good	Compatible
9	Saray	427683	4279296	136	11.53	17.01	9.35	577	Good	Compatible
10	Kilimli K.	413243	4317686	119.5	4.7	15.29	3.27	419	Poor	Compatible
11	Kosk Koyu	389414	4310080	36.5	12.25	12.42	0.19	556	Good	Compatible
12	Unseli	379250	4316000	90	0.91	46.47	0.17	586	Poor	Compatible
13	Partak yolu	349570	4318439	200	30	37.0	0.20	622	Moderate	Compatible
14	Kockopru	355882	4331627	70	23.68	40.68	0.59	683	Moderate	Compatible

*: Where, Partially Compatible is P. Compatible, References Number are R.N., Urpinar Irrigation Tunnel is UI. Tunal

3.5 Fuzzy AHP

In this method, named Chang's Fuzzy AHP Method, each object is taken and a degree analysis is applied for each purpose in order.

Table 9- Comparison matrix and significance weighting values of eight parameters

Criteria	*Rainfall*	*Slope*	*Soil Type*	*LU/LC*	*Geology*	*Geomorp-hology*	*Drainage Density*	*Fault Density*	*Fuzzy Geometric mean value*
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)	1.56,1.85,2.06
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)	1.33,1.59,1.89
ST	(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)	1.04,1.31,1.56
LU/LC	(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)	0.90,1.10,1.32
G	(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)	0.78,0.85,1.13
GM	(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)	0.64,0.76,0.92
DD	(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)	0.63,0.64,0.90
FD	(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)*	0.62,0.67,0.86

Note; Abbreviations used in Table 9 and Table 10 GWPI: Groundwater Potential Index, R: Precipitation, S: Slope, ST: Soil Type, LU/LC: Land Use and Land Cover, G: Geology, GM: Geomorphology, DD: Drainage Density and FD: Fault Density, FGM: Fuzzy is the geometric mean value. In addition, FwW_1: W_i are fuzzy weights, and the subscripts r and w: denote the degree and weight of the parameter, respectively. In addition, Weights are indicated by W_i, W_i and Normalized weight NW

$r_1 = (1*1*3/2*3/2*2*5/2*5/2*3)^{\frac{1}{10}}.(1*3/2*2*2*5/2*3*3*7/2)^{\frac{1}{10}}.(1*2*5/2*5/2*3*7/2*7/2*9/2)^{\frac{1}{10}}$= (2.08, 2.38, 2.89)

Table 10- Weighting of thematic layers using the fuzzy-AHP method

	R	**S**	**ST**	**LU/LC**	**G**	**GM**
R	***(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)**
S	**(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)**
ST	**(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)**
LU/LC	**(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)**
G	**(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)**
GM	**(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)***
DD	**(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)**
FD	**(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)**

Table 10 (Continue)- Weighting of thematic layers using the fuzzy-AHP method

	DD	**FD**	**FGM**	**FwW_1**	**W_i**	**NW**
R	**(5/2,3,7/2)**	**(3,7/2,9/2)**	**1.56,1.85,2.06**	**0.20,0.21,0.19**	**0.200**	**0.204**
S	**(5/2,3,7/2)**	**(3,7/2,9/2)**	**1.33,1.59,1.89**	**0.18,0.18,0.18**	**0.180**	**0.184**
ST	**(2,5/2,3)**	**(5/2,3,7/2)**	**1.04,1.31,1.56**	**0.14,0.15,0.15**	**0.146**	**0.149**
LU/LC	**(3/2,2,5/2)**	**(2,5/2,3)**	**0.90,1.10,1.32**	**0.12,0.13,0.12**	**0.123**	**0.126**
G	**(3/2,2,5/2)**	**(2,5/2,3)**	**0.78,0.85,1.13**	**0.10,0.10,0.11**	**0.103**	**0.105**
GM	**(1, 3/2, 2)**	**(3/2,2,5/2)**	**0.64,0.76,0.92**	**0.11,0.09,0.09**	**0.097**	**0.099**
DD	***(1 ,1, 1)***	**(1, 3/2, 2)**	**0.63,0.64,0.90**	**0.06,0.07,0.08**	**0.063**	**0.064**
FD	**(1/2,2/3,1)**	***(1 ,1, 1)***	**0.62,0.67,0.86**	**0.05,0.08,0.07**	**0.067**	**0.068**
Total					**0.979**	**0.999**

Weights are indicated by Wi and Normalized weight NW.

Kaplan & Arikan (2012) studied the subject of Evaluation of Equipment Investment Projects in the Air Defense Sector with Fuzzy Analytical Hierarchy Process and Fuzzy AHP method (Kaplan & Arikan 2012). Table 10 was produced by making use of the literature and the studies of experts.

4. Conclusions and Recommendation

In this produced map, very weak areas (GWPZ value: 629 - 683) are found in clayey, calcareous soils, and rocky areas. Areas classified as moderate in terms of GWPZ (518 and 572) constitute a significant portion of the basin, approximately 43.37% of the total basin area (as it includes some agricultural and barren lands, it has a wide catchment area). The improvement of this area classified as moderate offers broader opportunities for the implementation of groundwater resources development programs compared to the weak GWPZ category. Improvement in this moderately moderate category requires less effort compared to the weak GWPZ category.

Areas identified as good level (462 – 517), corresponding to about 17% of the basin, not only offer productivity from an agricultural perspective but also present good opportunities for the improvement of irrigation facilities. Furthermore, this region, which is at a good level in terms of groundwater potential, provides a great opportunity for current research efforts, irrigation possibilities, and increased agricultural productivity.

The part of the basin with the best GWPZ level (629 – 683) provides the best opportunities for research activities, irrigation and increasing agricultural productivity. In short, for the groundwater potential of the Van Basin, there is a need for rigorous and appropriate planning and management studies by state institutions, albeit partially.

The well data obtained in order to determine the groundwater potential and quality of Van province with geographic information system supported AHP and Fuzzy AHP methods were updated in accordance with the purpose of the study. In this study, maps of selected wells representing the border regions of the basin and data on well yields were used and classifications were made accordingly. Then, thematic maps were created using GIS, IDW methods and other techniques in order to determine the formation of groundwater in the basin boundaries, where and in what proportion the groundwater is located, and usage possibilities. The thematic maps produced were applied by making the ratings suggested by Thomas L. Saaty to be used in AHP and Fuzzy AHP methods according to the potential effects of groundwater. The values obtained as a result of the application are given to the parameters suggested by Thomas L. Saaty (1, 2, 3, 4, 5, 6, 7, 8, 9). Since the result obtained in Table 9 is smaller than the value of 0.1 suggested by Saaty, a suitable solution was obtained according to the AHP method. Then, groundwater potential and quality analysis distribution map were created in ArcMap 10.2 environment. As a result of the application of the F-AHP method, the ideal order of the parameters was found.

The thematic maps created with the aim of understanding the groundwater potential of the Van basin, and the possibilities of using groundwater effectively and the selection of the well location to be drilled can be used to give a better diea for those who work in related fields of study. In the future, if water needs cannot be met from alternative water sources, the need for the drilling of new wells may emerge. In this eventuality, the thematic maps created will be useful in determining suitable well locations.

Limited surface and underground fresh water resources should be effectively protected with long-term programs for rapidly increasing urban drinking water, industrial and agricultural water needs. In order to protect and develop groundwater in accordance with different usage purposes, information about its potential status should be obtained from reliable units, institutions and organizations in a timely manner. Necessary plans should be made and implemented for the measures to be taken in case of negative effects on the work (such as excessive water withdrawal, illegal use, drought).

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