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Spatial Prediction of Groundwater Potential of Upper Tigris Basin Mapping in Türkiye with GIS-Based Multicriteria Decision Making (MCDM) Method

Recep ÇELIK[1]

ABSTRACT

The Upper Tigris region in the Middle East is in Turkey and this study shows it to be an area with significant water resources that enable agricultural activities in the region. Since the GAP irrigation project, yet to be completed, there is an extensive use of groundwater for irrigation. This situation threatens the groundwater potential of the basin. Therefore, determination of groundwater potential should be evaluated properly instead of relying assessment of the groundwater potential of the region with observation wells, which is a more costly method. In this study, the groundwater potential of the basin was determined by the GIS-based Multi-Criteria Decision Making (MCDM) method; the GIS-based-AHP method is used for identifying the groundwater potential zones of the Upper Tigris Basin as an alternative to expensive and time-consuming method of well drilling. There are 8 key criteria considered; Geomorphology (GM), Geology(G), Line Density (LD), Slope (SL), Drainage Density (DD), Land Use (LU), Rainfall (R), and Soil Type (ST) and the individual weight of each criterion was evaluated by the AHP technique and utilized by the "Spatial Analysis Overlay Weighted Method" obtaining the "Groundwater Potential Index (GWPI)". The GWPI values obtained is used to classify the Upper Tigris Basin into five categories as follows: 319 km^2 of the basin has very poor potential (3.8%); 2217 km^2 has poor potential (26.7%); 2800 km^2 has moderate potential (33.7%); 2200 km^2 has good potential (26.5%); and finally, 763 km^2 has very good potential (9.2%).

Keywords: Diyarbakır basin, groundwater potential, the AHP Multi-Cretia Decision Making (MCDM) Method, GIS.

1. INTRODUCTION

The Upper Tigris Basin is significant for surface water potential. However, due to the incomplete projects in the basin, groundwater is widely used as an alternative irrigation method (Çelik 2015). The advantage of the groundwater compared to surface water is the

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1 Dicle University, Department of Civil Engineering, Diyarbakır, Türkiye
recep.celik@dicle.edu.tr - https://orcid.org/0000-0002-0739-6146

fact that the risk of contamination for the groundwater is substantially lower than that for the surface water. In this regard, the groundwater potential of the basin must be figured out. In partially arid zones, when surface water reaches to minimum flow level, groundwater is also a significant alternative for agriculture and irrigation and also for other intended uses (Çelik 2015).

Determination of groundwater potentials by wells is not always economically feasible. Under these circumstances, among several other methods, GIS and MCDM methods have been properly and successfully employed (Rahman et al 2012; Nag et al., 2012; Lee et al., 2012; Pradhan 2013; Feizizadeh et al., 2014) to determine aquifer parameters and their impacts on groundwater sources and supplies.

Multi-Criteria Decision Making (MCDM) techniques, which requires at least two criteria and two alternatives (Diakoulaki et al., 1995), have been utilized successfully for the solution of similar problems in various areas (Makropoulos and Butler, 2006; Mendoza and Martins, 2006; Karnatak et al., 2007; Greene et al., 2011). Since relative importance is attached to each variable based on qualitative and quantitative criteria, not only the numerical data but also the previous experience of expert users is important (Triantaphyllou and Sanchez, 1997; Malczewski, 1999; Ho and Dey, 2010). For the assignment of the relative importance, among many methods available, the most common alternative is the Analytical Hierarchical Method (AHP) method (Saaty, 1980, 1989, 2000). It has been in use for the selection of the suitable area by counting the co-efficiency rates of the comparative importance of multiple criteria in relation with each other (Abdalla, 2012) and recharges assessment (Zaidi et al., 2015; Senanayake et al., 2016; Hermann et al., 2016, Verma & Patel, 2021). The AHP -MCDM techniques have become very common in positional planning and management. Comparative studies were conducted in a number of research studies through multivariate statistical analyses with GIS methods (Althuwaynee et al., 2014; Haghizadeh et al., 2017; Çelik, 2019; Doke et al, 2021). Furthermore, similar works were also conducted by the fuzzy-AHP method in some of the above-mentioned research activities (Nobre et al., 2007; Iqbal et al., 2015; Mallick et al., 2019; Mahammad & Islam, 2021).

Diyarbakır Basin is a sub-basin of the upper Tigris basin known for its relatively rich surface water potential. Since irrigation projects of the GAP Project has not yet been completed in the basin, agricultural activities along the riverbank are based on surface water consumption and in other places, water is obtained from the groundwater storages through the wells. Thus, it is necessary to figure out the quality and quantity potential of the groundwater in this region. This study aims to define suitable maps of the upper Tigris sub-basin groundwater potential zones owing to the GIS-based MCDM method. The borders of the basin are marked using the ArcMap Spatial Analysis based on Dem maps. There are eight key parameters considered; Geomorphology (GM), Geology (G), Drainage Density (DD), Line Density (LD), Land Use (LU), Slope (SL), Rainfall (R), and Soil Type (ST). Weights of all criteria are determined with the AHP technique. The ultimate results were compared with the records of the 61 wells drilled within the basin. After comparing the well log data with the ultimate map studies, the results are consistent at 80% accuracy.

2. MATERIALS AND METHODS

2.1. Study Area

The total length of the Tigris River is 1750 km, and only 500 km flows within Turkish borders (Isaev and Mikhailova, 2009). It arises from the joint point of the Hazar Baba Mountain (2290 m) and Hazar Lake in the southeast of the Elazığ province. Its drainage area is about 10550 km^2, starting from the upstream of the Tigris River and covering Batman in the west and the northern parts of Mardin Savur region in the south (Figure 1).

Upper Tigris basin is located between eastern longitudes at 40 º -44º and northern latitudes at 37 º -55º, around the Diyarbakır province. North of this basin is surrounded by mountains (GAP Development Plan 2002).

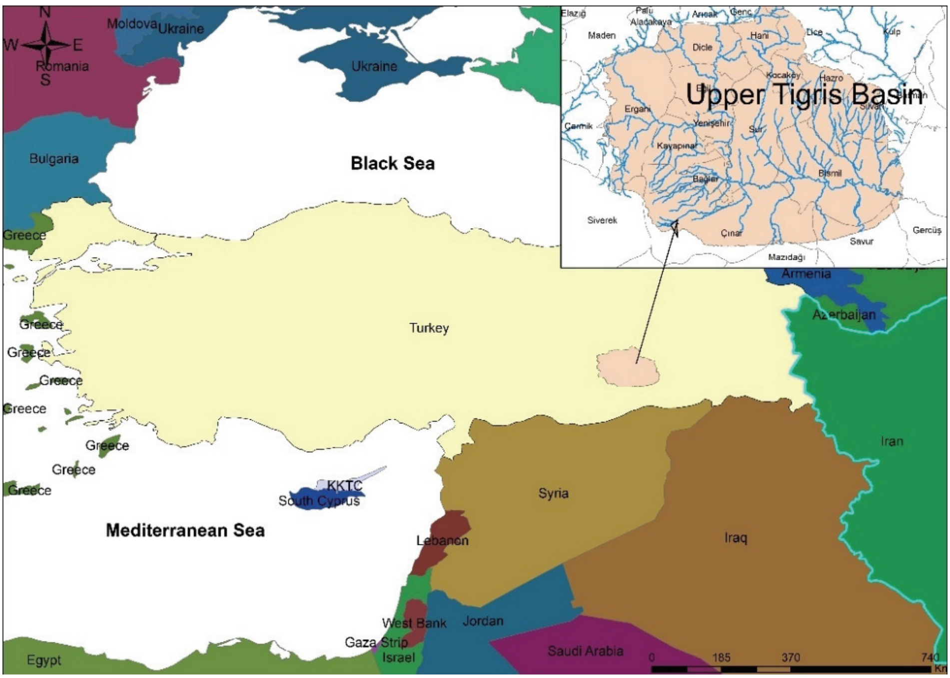

Figure 1 - Upper Tigris Basin location map

2.2. Methodology

As mentioned before, there are eight parameters taken into consideration; these are Geomorphology (GM), Land Use (LU), Geology (G), Line Density (LD), Drainage Density (DD), Slope(S), Rainfall (R), and Soil Type (ST). Each parameter weight is assessed via the AHP technique.

Initially, DEM (Digital Elevation Model) maps are obtained from General Directorate of Spatial Planning's M43, M44, M45, M46's layouts where 1/100 000 topographic maps of the region (mpgm.csb.gov.tr) were digitized using (35 × 35) m^2 resolution. With these DEM data; slope, geomorphologic and drainage density maps are produced via the Spatial Analysis and Arc Hydro extensions of the Arc GIS 10.2.1 program.

The necessary information about the active and energetic fault lines, which are published both by the General Directorate of Mineral Research and Exploration (MTA) (Emre et al., 2013) and on its website online data system, are digitized and turned into kml format and the fault is converted to shp. format by the Data Interoperability extension. Land use is obtained in Erdas image format from Global Land Cover Facility site and converted in accordance with the CORINE method. Average annual rainfall values between 1971-2017 are taken from the Turkish State Meteorology website, and the precipitation maps of the entire region are obtained by using the ARC GIS Inverse Distance Weight (IDW) method. Moreover, soil type is obtained by processing the data from Özden (2001) and the official website of the Ministry of Agriculture. The study flow chart is shown in Figure 2.

Firstly, all criteria maps are converted to raster maps, and then they are reclassified via spatial analyses "reclassification" modules considering all sub-ranks as shown in Table 4. All thematic maps are then reclassified in accordance with the weight ratio determined via the AHP method (Tables 1 and 2). Ultimately, the Groundwater Potential Index (GWPI) is constructed considering the relative weights of each parameter by using the Overlay Sum method.

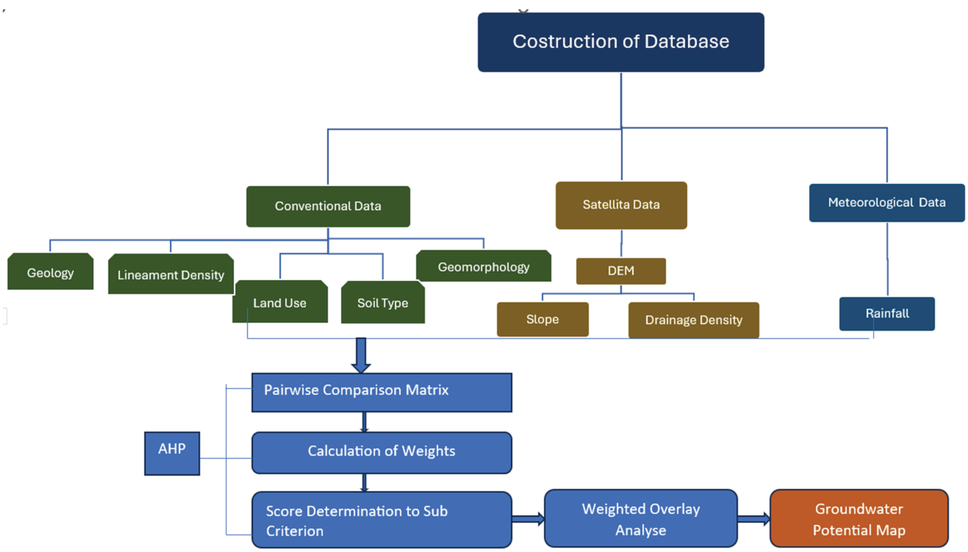

Figure 2 - The study methodology flow chart

2.2.1. The AHP Methods

The AHP is the common method of MCDA, which is set on three principles: extrication, relative decision, and integration the preferences (Saaty, 2000). In the AHP method, all quantitative and qualitative factors affecting the decision process are determined by consulting the opinions of experts on this subject. Afterward, as a result of the information obtained, a hierarchical structure is created by determining the purpose, criteria and alternatives. AHP is comprised of four stages as follows:

- **The** First **Stage:** The objective, criteria, and alternatives of the problem are determined. The hierarchical Structure is formed (Table 1).

Table 1 - All criteria AHP Comparison Matrix

	GM	G	LD	SL	R	ST	DD	LU
GM	1.00	1.00	1.40	0.78	1.00	1.17	1.40	1.17
G	1.00	1.00	1.40	0.78	1.00	1.17	1.40	1.17
LD	0.71	0.71	1.00	0.56	0.71	0.83	1.00	0.83
SL	1.29	1.29	1.80	1.00	1.29	1.50	1.80	1.50
R	1.00	1.00	1.40	0.78	1.00	1.17	1.40	1.17
ST	0.86	0.86	1.20	0.67	0.86	1.00	1.20	1.00
DD	0.71	0.71	1.00	0.56	0.71	0.83	1.00	0.83
LU	0.86	0.86	1.20	0.67	0.86	1.00	1.20	1.00

GM: Geomorphology, G: Geology, LD: Line Density, SL: Slope,
DD: Drainage Density, LU: Land Use, R: Rainfall, ST: Soil Type

- **The Second Stage:** At this stage, the comparison of the relative weights of each criterion with one another and alternative is performed. The comparisons demonstrate which criterion is more significant and are managed according to the 1-9 scale (Table 2) determined by Saaty (2000). In this study, the scores of all the main and sub-criteria are shown in Table 4.

Table 2 - Pairwise comparison scale

scale	• **Explain**
1	• Equal
3	• Slightly superior
5	• Much superior
7	• too much superior
9	• Absolute superiority
2,4,6,8	• Intermediate compromise values

- **The Third Stage:** The vector of the weights (W) is determined through the priority vectors and comparison matrices (Table 3). Initially, the paired comparison matrix is normalized through A·w = λmax. Subsequently, the weights are determined. The normalization is determined via division of all a_{ij} matrix elements by the column total.

Weight calculation:

$$W_i = \sum_{i=1}^{n} a_{ij} \ /n \tag{1}$$

Table 3 - AHP Normalized Matrix and Significance Weighting Values of Using Parameters

	GM	G	LD	SL	R	S	DD	LU	W
GM	0.11	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
G	0.11	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
LD	0.08	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09
SL	0.15	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
R	0.11	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
S	0.08	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
DD	0.15	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11
LU	0.20	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.14

λ_{max}: 8.23; CI: 0.03; CR: 0.023<0.1: all are acceptable (Saaty, 2000).

- **The Fourth Stage:** The calculation of consistency ratio and the CR coefficient are conducted after the calculation of consistency index (CI). In the paired comparison of the decision matrices, it is accepted as consistent if CR is lower than 10%. The primary matrix of topics and their linked sub-themes have been reviewed in a methodical manner via AHP branch of information. The coherence ratio of precedence matrix can be made feasible with the aid of this technique (Saaty, 2000).

The AHP table (Table 2) indicates the highest weight criteria is the Slope with 17%, followed by Land Use 14%, Rainfall, Geology and Geomorphology 13%. The lowest weight parameter is Lineament Density with 9%.

3. RESULTS

In order to define the potential groundwater recharge zones in any basin, the primary parameters are mapped in Figure 3 as: Slope (S), Lineament Density (LD), Geology (G), Geomorphology (GM), Land Use (LU), Soil Type, Rainfall (R) and they are summarized in Table 4. The scores of the criteria were determined by examining studies in the literature (Adiat et al., 2012; Althuwaynee et al., 2014; Doke et al., 2021, etc.) and considering the effect rates of the parameters on groundwater formation. In the table, areas with high groundwater potential are ranked with high ranking. For example, for the slope parameter, % 0-2 is ranked as 9 because it is high in terms of groundwater potential. Finally, Groundwater potential index (GWPI) is mapped in Figure 4. Both series of maps depicted in Figures 3 and 4 are constructed by the author based on scientific data and findings.

3.1. Geomorphology

Geomorphology represents an important criterion describing the plain, mountainous, hilly and alluvium districts of the topographic map. It is a criterion showing the gathering of groundwater potential in the basin area. Most effective areas are flatness (30.1 %), plains (27.7%) and hills (27.3 %). The alluvium portion is 9.4% while the rate of the mountains is 5.5%.

3.2. Geology

Geologic features are considered significant for determining the groundwater potential (Krishnamurthy et al., 2010). Besides, the geological structure is important for the location of an aquifer. Limestone and basalt structures are good aquifers. On the other hand, alluviums in the streambeds play an important role as well (Gale et al., 2002; Kresic 2010;). The basin is comprised of particularly Terrestrial clastic (35.1 %), Basalt (23.2 %), and Neritic limestone (16.7%).

3.3. Slope

The main source of the groundwater potential is the infiltration capacity of the rainfall. However, this infiltration is mostly occurred with high permeability soil types and low slope condition. The slope of the terrain has a very high value effect. Infiltration is higher where the slope is small since the surface flow is slow, whereas underground water supply is less where the slope is high since the surface flow is higher (Reid & Iverson, 1992). As shown in Table 4, slope of the significant portion of the land varies between 0-4 %. As it moves towards the north, the slope is increasing.

3.4. Land Use

Land Use is also a major parameter for groundwater capacity assessments (Eulenstein et al.,2016). Due to the urbanization, infiltration is scarce and thus the runoff rate is high. Wetlands are considered to be at the highest assessment level and, there is a high rate of infiltration in rivers and alluvial deposits. Another rating is followed up by wet agricultural areas. A major part of the water leaks into subsurface in the irrigation zones. Similarly, the planted zones have a high rate of infiltration, since surface runoff is mitigated by plantations. Rate and usage classification of land use are shown in Table 4.

3.5. Rainfall

Precipitation is the main source of groundwater formation. A portion of the precipitation runoff on surface feeds the surface water sources, and another portion infiltrates to underground and forms the groundwater reservoirs (Jan et al.,2007; Wang et al., 2015). In this study, the annual average precipitation data are used between 1975 and 2017 taken from the General Directorate of Meteorology. Through the interpolation of these data and ArcMap

Spatial Analysis IDW method, the average rainfall map of the region is obtained. It is classified in Table 4 and ranking coefficients are determined accordingly.

3.6. Soil

Soil classes are obtained from the class maps of the Ministry of Agriculture. Soil type class distribution of basin is revealed in Table 4. Soil type is a particularly essential criterion for groundwater because of its infiltration capacity for groundwater recharge to aquifers. The capacity of coarse-grained soils is high in the infiltration such as gravelly, sandy, and alluvial soils, this has a high-grade weight in the groundwater potential formation. Besides, soils of clay, sand or silt have low infiltration capacity. Thus, such soil classes are at a lower assessment class.

3.7. Drainage Density

Drainage Density (DD) is one of the criteria affecting the groundwater potential index (GWPI). In river channels infiltration is less in the regions with high drainage density (Tucker and Bras, 1992), whereas the infiltration gets at a higher proportion due to the surface flow; slow regions with low drainage density. Therefore, the output rate parameter is considered as a higher rank with low drainage density. Drainage density is obtained from DEM maps, with the practical help of GIS Arc-Hydro tool, in the order of, fill sinks – flow direction – flow accumulation – stream segmentation – stream definition are acquired by the accurate classification of the rivers through the hierarchical process. Drainage density (DD) is expressed as follows:

$$DD = L/A \tag{2}$$

where L is the total drainage length and A is area (Tarboton, 1992).

3.8. Lineament Density

The lineament density (LD) indicates an important geological feature for groundwater recharge (Magowe and Carr, 1999). The cracked areas generate discontinuities between the areas and cause groundwater recharge to aquifers in a short period of time. The areas with high fault intensity have a high rate of effect in terms of recharge and the areas with low fault intensity have a low rate of effect. The LD is calculated as follows (Mandal et al., 2016);

$$LD = \sum_{i=1}^{n} L_i / A \tag{3}$$

where L_i is lineaments length, and i indicates the number of lineaments and A is basin drainage area.

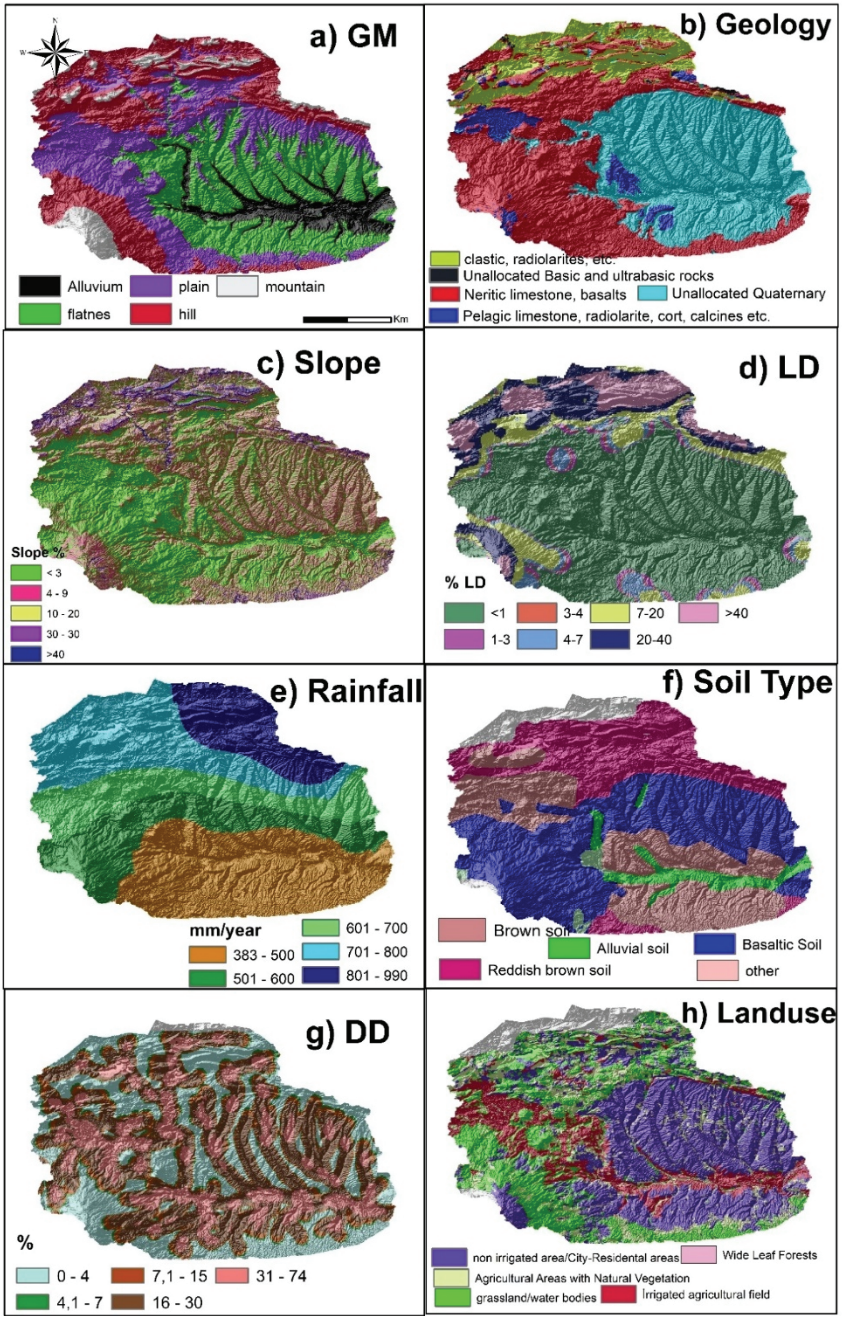

Figure 3 - Main parameters effect on Groundwater Potential Recharge Map (GM: Geomorphology, G: Geology, LD: Line Density, SL: Slope, DD: Drainage Density, LU: Land Use, R: Rainfall, ST: Soil Type

Table 4 - AHP Assessment Sub-Properties of Parameters Summarized Table

Feature Rank	Assigned Normalized Weight	Sub-Feature	Area Coverage (%)	Rank
7	Geomorphology map	Alluvium	9.4	9
		flatness	30.1	7
		plain	27.7	6
		hill	27.3	3
		mountain	5.5	1
7	Geology	Neritic limestone	16.7	7
		Terrestrial clastic	35.1	9
		Magmatic and Volcanic Rocks	4.1	6
		Unallocated Quaternary	3.6	9
		Pelagic limestones, clastic, radiolarites, etc.	0.6	5
		Basalt	23.2	6
		Soils and carbonates	11.4	5
		Unallocated Basic and ultrabasic rocks	0.3	5
		Pyroclastic rocks	0.4	5
		Unallocated terrestrial clastic	4.0	5
		Pelagic limestone, radiolarite, cort, calcines etc.	0.7	6
5	Lineament Density (km/km^2)	0-1	61.7	1
		1-3	2.4	2
		3-4	1.2	3
		4-7	4.5	5
		7-20	11.0	7
		20-40	11.2	8
		>40	8.1	9
9	Slope (%)	0-2	33.5	9
		2-4	21.4	7
		4-8	21.2	5
		8-15	14.7	3
		>15	9.2	1
7	Rainfall (mm/year)	383-500	32.5	4
		500-600	17.7	5
		600-700	8.7	6
		700-800	10.4	7
		800-900	19.3	8
		900-985	11.4	9

6	Soil	Aluvial soil	1.3	9
		Basaltic soil	39.9	8
		other	5.3	7
		Brown Forestry soil	0.1	6
		Brown Soil	24.0	5
		reddish brown soil	29.5	5
5	Drainage Density (km /km^2)	0-4	0.0	9
		4-7	0.0	7
		7-15	0.0	5
		15-30	0.0	3
		30-50	0.0	1
6	Land use	grassland	19.15	7
		Rocks	1.63	2
		Discrete Rural Building	0.68	5
		Agricultural Areas with Natural Vegetation	9.91	7
		Irrigated Area	13.63	8
		Non-irrigated agricultural area	43.16	5
		Natural Meadows	6.11	7
		Wide Leaf Forests	4.07	6
		Continuous City Structure	0.06	3
		Water bodies	1.01	9
		coastal, sandy	0.10	9
		Industrial or Commercial Areas	0.13	2
		marsh	0.12	9
		Construction sites/airport	0.12	3

3.9. Groundwater Potential Index (GWPI)

GWPI represent a dimensionless magnitude, which implies the groundwater potential in a region. It is obtained through the weights of various parameters. It provides information about groundwater potential in various locations (Rahmati et al., 2015; Shektar and Pandey, 2015). It is calculated via the AHP method as shown below (Lee et al., 2012, Rahmati et al., 2015, Çelik 2019:

$$GWPI = SL_r.SL_w + LD_r.LD_w + G_r.G_w + GM_r.GM_w + LU_r.LU_w + ST_r.ST_w + R_r.R_w + DD_r.DD_w \qquad (4)$$

where SL is the slope, LD is the lineament density, G is geology, GM is geomorphology, LU represents the land use, ST is the soil type, R is the rainfall, and DD is the drainage density. In addition, the subscripts “r” and “w” refer to the rating and weight of the parameter, respectively. The reclassification of GWPI index is given in Figure 4.

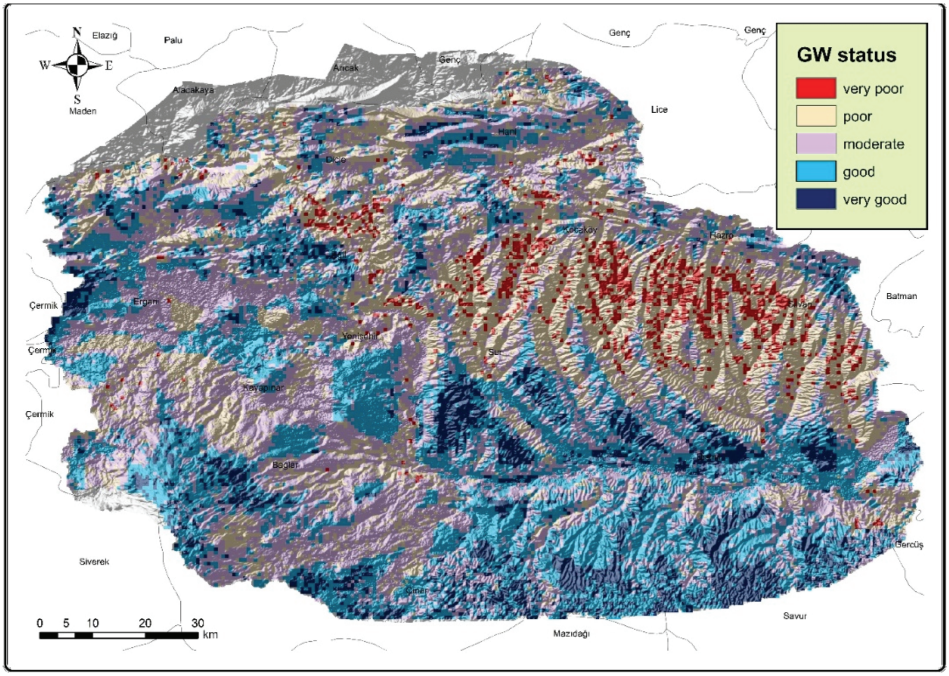

Figure 4 - Upper Tigris Basin groundwater potential recharge map

3.10. Determination of Groundwater Potential Zones

The ranking assigned for all thematic maps and a comprehensive description of their corresponding sub-features are shown in Table 4. In order to produce the GWPZ map efficiently, the sum of the weights criteria is used as determined by the AHP method. In Figure 4, the groundwater potential index of the basin is divided into five classes; very good potential, good potential, moderate potential, poor potential and very poor potential.

Table 5 - Upper Tigris Basin Groundwater Potential Status

Status	Percentage	Area (km^2)
very poor	3.8%	319
poor	26.7%	2217
moderate	33.7%	2800
good	26.5%	2200
very good	9.2%	763

Table 5 summarises the basin groundwater potential status; 319 km^2 (3.8%) portion of the basin is rated as very poor potential, 2217 km^2 (26.7%) portion of the basin is poor potential; 2800 km^2 (33.7%) portion of the basin is moderate potential; 2200 km^2 (26.5%) portion of the basin as good potential; 763 km^2 (9.2%) as very good potential. There is a major part of the basin with a moderate groundwater potential. In the northern part of the basin, GWPI index has a very poor potential. This is due to both the aquifer properties and the steep slopes in these regions.

3.11. Validation and Sensitivity Analysis

The results of this study are compared with 61 well-records over the basin in Table 7. Classification of the Yield Values are performed as follows: 0.00-2.00 as "very low"; 2.01-4.00 as "low"; 4.01-8.00 as "moderate"; 8.01-15.00 as "good"; and 15.01 and above as "very good". Each of the "Well GW Status" and "Obtained GWPI Status" are assigned 5 ranks in an increasing order as "very low", "low", "moderate", "good" and "very good". The evaluation is performed on the results compiled in Table 7 by assigning the corresponding "comparison score" from among a 5 point-scale, where the highest and lowest scores assigned are 5 and 1 respectively, as follows:

- If the Well GW Status and the Obtained GWPI Status match exactly, i.e., if they differ by no rank order, the comparison score assigned is 5 as shown in lines 1 through 5 in Table 6.
- If the Well GW Status and the Obtained GWPI Status differ by 1 rank order, the comparison score assigned is 4 as shown in lines 6 through 13 in Table 6.
- If the Well GW Status and the Obtained GWPI Status differ by 2 rank orders, the comparison score assigned is 3 as shown in lines 14 through 19 in Table 6.
- If the Well GW Status and the Obtained GWPI Status differ by 3 rank orders, the comparison score assigned is 2 as shown in lines 20 through 23 in Table 6.
- If the Well GW Status and the Obtained GWPI Status differ by 4 rank orders, the comparison score assigned is 1 as shown in lines 24 and 25 in Table 6.

After that, all comparison scores (the blue entries in Table 7) are summed up and the result is divided by the perfect matching scoring which is 61*5 = 305, i.e., the sum of the comparison scores for the hypothetical case when all "Well GW Status" and "Obtained GWPI Status" pairs match perfectly.

In this case, 80% validation rate is obtained for the 61 wells analysed. In this situation, GWPI index shows 100% compliance with the data from 23 wells, 80% compliance with the data from 19 wells and 60% compliance with the data from 15.

Table 6 - Comparison Score Assignment

Line Number	Well GW Status	Obtained GWPI Status	Rank Difference	Comparison Score
1	very low	very low	0	5
2	low	low	0	5
3	moderate	moderate	0	5
4	good	good	0	5

5	very good	very good	0	5
6	very low	low	1	4
7	low	very low	1	4
8	low	moderate	1	4
9	moderate	low	1	4
10	moderate	good	1	4
11	good	moderate	1	4
12	good	very good	1	4
13	very good	good	1	4
14	very low	moderate	2	3
15	low	good	2	3
16	moderate	very low	2	3
17	moderate	very good	2	3
18	good	low	2	3
19	very good	moderate	2	3
20	very low	good	3	2
21	low	very good	3	2
22	good	very low	3	2
23	very good	low	3	2
24	very low	very good	4	1
25	very good	very low	4	1

Table 7 - a Upper Tigris Basin Validation Well Information with GWPI results

Well Number	Y	X	Yield (sec/l)	Well GW Status	Obtained GWPI Status	Comparison Score
1	4234976	594798	1.00	very low	very low	5
2	4240605	641220	5.00	moderate	moderate	5
3	4170332	618940	60.00	very good	very good	5
4	4248630	619128	29.00	very good	good	4
5	4252657	627148	3.60	low	low	5
6	4185994	618632	18.00	very good	moderate	3
7	4175722	651710	28.00	very good	good	4
8	4254428	611381	7.00	moderate	very good	3
9	4187953	640152	10.00	good	moderate	4
10	4190264	649502	26.00	very good	very good	5
11	4251104	596420	5.00	moderate	moderate	5
12	4234587	567662	1.00	very low	good	2
13	4233371	650890	1.00	very low	very good	1
14	4162753	608983	17.00	very good	good	4

15	4175743	659607	15.00	good	good	5
16	4173275	666873	24.00	very good	moderate	3
17	4234982	659234	1.00	very low	moderate	3
18	4220954	569040	36.00	very good	moderate	3
19	4170605	624752	47.00	very good	very good	5
20	4223240	580608	2.00	low	low	5
21	4203377	667978	20.00	very good	low	2
22	4191198	633005	24.00	very good	good	4
23	4238558	630703	4.00	moderate	good	4
24	4174932	635793	38.00	very good	good	4
25	4181275	653577	5.00	moderate	moderate	5
26	4193562	607319	30.00	very good	moderate	3
27	4237944	560898	1.00	very low	moderate	3
28	4165449	640104	23.00	very good	good	4
29	4174411	612403	40.00	very good	moderate	3
30	4177651	669466	11.00	good	good	5
31	4181012	641897	40.00	very good	good	4
32	4236705	583757	3.00	low	good	3
33	4179984	605814	35.00	very good	moderate	3
34	4182577	632206	30.00	very good	good	4
35	4173824	642624	22.00	very good	good	4
36	4181645	625847	34.00	very good	very good	5
37	4174894	617440	14.00	good	good	5
38	4189429	623372	15.00	good	good	5
39	4185502	598971	3.00	low	moderate	4
40	4222567	621532	2.10	low	low	5
41	4231481	626618	3.30	low	very low	4
42	4217025	648300	3.00	low	low	5
43	4184591	608795	2.00	low	moderate	4
44	4222736	641586	1.60	very low	very low	5
45	4228009	599394	3.50	low	good	3
46	4236613	621107	2.80	low	very good	2
47	4177644	598191	4.00	moderate	moderate	5
48	4221388	603826	10.00	good	low	3
49	4214235	614259	1.30	very low	moderate	3
50	4220908	635885	3.00	low	low	5
51	4193657	615252	4.00	moderate	very good	3
52	4196175	591900	5.00	moderate	good	4
53	4208575	574553	2.00	low	low	5

54	4204265	606998	6.00	moderate	moderate	5
55	4202196	572525	5.00	moderate	moderate	5
56	4217281	598313	3.00	low	good	3
57	4203855	618848	20.00	very good	very good	5
58	4230751	613900	3.00	low	moderate	4
59	4210382	631105	5.00	moderate	low	4
60	4201907	587760	10.00	good	moderate	4
61	4199178	611842	2.00	low	moderate	4

GWPI: Groundwater Potential Index; Validation Rate: 243/(5*63) = 0.80 = 80% accuracy

4. DISCUSSION

In order to determine the groundwater potential of a region in the most accurate way, it is necessary to drill observation wells in the fields. However, this method is uneconomic and takes a long time in large basins. However, taking into account the RS data and the parameters affecting the groundwater with their weight, methods such as GIS based AHP methods give an idea about a basin's groundwater potential in a shorter time with great accuracy. In this study, it has been demonstrated that the use of this method is a viable one.

On the other hand, at a macro-level analysis performed over an expanded area the groundwater potential map is a significant tool that can be useful in basin-based hydrological studies and possibly for groundwater well digging operations in the future. As an added benefit of this study, for micro planning, more reliable assessment can also be conducted with the help of similar criteria and lower-scale maps. Especially geological factors, slope, geomorphological factors and the potential effects of the land use should be taken into consideration.

Finally, aquifer region risk and pollution analyses should be carried out regularly due to agricultural and other anthropological activities, and sustainable groundwater management should be provided properly at the local Governor and Municipality levels. Urbanization areas and their development axis and structures such as urban solid waste facilities should be projected by taking into account groundwater maps in the future.

5. CONCLUSION

The Analytical Hierarchical Process (AHP) integrated with Geospatial technology is presented as an accurate method for finding out the groundwater potential of a region as demonstrated in this study. Groundwater potential maps were obtained with an 80% accuracy for the North (Upper) Tigris Basin by utilizing this method. Moreover, It was determined that 3.8% of the basin area has very poor potential, 26.7% has poor potential, 33.7% has moderate potential, 26.5% has good potential, and 9.2 % of the basin shows very good potential.

Approximately 36% of the basin has good potential to very good potential. These key areas are predominantly in the plain part of the basin and are close to the Tigris River in Diyarbakır-Sur, Çınar, Bismil and Batman regions. In places with good and very good water potential, there are sufficient water resources for agricultural irrigation as well. Provided that the amount of groundwater recharge is taken into account, groundwater can be used for agricultural irrigation in these regions. Especially, north-northeast areas of the basin seem to have poor potential in terms of the groundwater. The reason for this is that the region has hilly and mountainous geomorphological characteristics, and the water supply is low. However, there is enough groundwater potential in these regions for domestic use/drinking water and small-scale agricultural irrigation.

The western and south-western parts of the basin generally have a moderate potential. There are also hills in these areas. However, the slope is not as high as it is in the northern regions. There is suitable groundwater potential in these regions both domestic use and moderate scale agricultural irrigation.

6. SUGGESTIONS FOR FURTHER STUDIES

GIS based AHP methods give an idea about a basin's groundwater potential in a shorter time with great accuracy instead of the time consuming and very expensive method of well drilling. The use of GIS based AHP methods, based on the implementation on the Upper Tigris Basin in Turkey as demonstrated in this study, seem to be a good alternative method to determine groundwater potential.

We suggest that this method should be used at different geographies both within and outside Turkey. The reason is simple; due to global warming, water is quickly becoming a rare resource for consumption as well as agriculture. Having groundwater potential maps readily constructed at local and national administrations, may prove to be valuable at times of mild or severe draught, in order to determine the water resources that can be tapped into.

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