Evaluation of Groundwater Potential by GIS-Based Multicriteria Decision Making as a Spatial Prediction Tool: Case Study in the Tigris River Batman-Hasankeyf Sub-Basin, Turkey

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Abstract: The Tigris River Batman-Hasankeyf region sub-basin drainage area is in the Upper Tigris basin and lies between the area where the Batman stream joins the river and the Yanarsu stream flows into the river. Intensive agricultural activities are carried out in this region, and irrigation is generally obtained from groundwater just as it moves away from the riverfront. The study area is a valuable basin for both Turkey and the Middle East. In this study, the effectiveness of the Geographic Information System (GIS)-based multicriteria decision-making (MCDM) analytic hierarchy process (AHP) as a spatial prediction tool was utilized in exploring the groundwater potential of the drainage area. In the analysis, eight hydrological and hydrogeological criteria were considered as influencing factors, namely, geomorphology, geology, rainfall, drainage density, slope, lineament density, land use, and soil properties. The weights of these criteria were determined through the AHP method; the Arc GIS 10.2.2 program and its submodules were used. The major findings of the study were that groundwater-potential index values of the basin were derived. Groundwater-potential-zone evaluation of the basin was obtained as follows: very poor (19%), poor (17%), moderate (34%), good (17%), very good (13%); and groundwater potential zone (GWPZ) maps of the sub-basin were created.

Keywords: groundwater-potential zone; multicriteria decision making; GIS; analytic hierarchy process (AHP); Upper Tigris sub-basin

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1. Introduction

Groundwater is an important alternative water resource for the development of urban and rural areas with increasing needs. Demand for fresh water is increasing due to factors such as population growth, irrigated agricultural activities, and climate change [1]. Climate change and the threat of droughts, surface-water potential, and the risk of pollution of surface waters caused by human activities such as agriculture and industrialization [2,3] necessitate the identification of alternative water resources. Being less polluted than surface water makes groundwater a valuable essential resource. Groundwater is also an essential water source during alternative-surface-water shortages, especially in regions with a semiarid climate such as the Tigris Basin. However, unplanned groundwater use disrupts the natural feeding balance of aquifers. Excessive use of aquifers could have adverse consequences on the environment, ecology, and economy of the region [4,5]. For this reason, groundwater-discharge zones need to be determined with a focus on appropriate water management. While it is always possible to identify groundwater potential with observation-purpose water wells, it is uneconomical in extensive areas.

Several techniques have been adopted by various researchers that do not require fieldwork, e.g., the decision-tree model [6], principal component analysis (PCA) [7], and the logistic-regression

model [8]. Most of these methods are based on multivariate statistical techniques [9]. In contrast, the analytical hierarchy process (AHP) is considered to be a simple, effective, transparent, and reliable technique [10]. The AHP method is easy to identify in a useful way by integrating geographic information system (GIS) and remote sensing (RS) data. Groundwater parameters such as precipitation, aquifers, land use, and soil type can easily be defined as spatial data in a GIS environment. Thus, the method is very useful for identifying potential groundwater areas and is well-suited for the useful identification of groundwater-potential regions [11–13]. AHP is an approach that was developed by Thomas L. Saaty in the early 1980s [14]. It was developed with planned criteria according to a certain stage, evaluating the weights of these criteria, and comparing the criteria with other similar studies [15,16]. It is possible and preferable to determine hydrological and hydrogeological parameters that influence groundwater formation and their effects on groundwater formation and generate potential groundwater maps with GIS-based Multicriteria Decision-Making (MCDM) techniques. GIS-based multicriteria decision analysis (MCDA) has been extensively used in the field of hydrological and water resources [16,17]. It has gained popularity in the last decade as it provides GIS-based mapping [18].

Most current studies [19–22] widely applied RS- and GIS-based AHP–MCDM techniques for the assessment of Groundwater Potential Zones (GWPZs) with effective results. When these studies were examined, it was found that land use (LU), geomorphology (GM), geology (G), recharge rate (RR), drainage density (DD), DEM, rainfall (RF), slope (SL), surface water body (SW), lineament density (LD), lithology (LI), and water table depth (WTD) parameters were used in almost all studies. groundwater potential index (GWPI) values of the basins were conditioned by overlaying all those criteria weights with AHP methods [23–26]. These GWPI values were then classified, and GWPZ maps of different global regions were created [27–30]. However, the thematic layers used to identify GWPZs differ according to studies and regions, and the selection of qualitative layers is arbitrary. In almost all studies, the LU, Soil, GM, DD, SL parameters were mainly used. Murthy (2000) added RF in GWPZ studies of the semiarid Andhra Pradesh region [29]. İbrahim Bathis and Ahmed (2016) [30] also added the RF and LD parameters. Sikdar et al. (2004) [31], Prasad et al. (2007) [32], Madrucci et al. (2008) [33], Chowdhury et al. (2009) [34], Senanayake et al. (2016) [13], Zaidi et al. (2015) [35] also took into account the G parameter. Jha et al. (2010) [36] considered SW even though it is a substrate of Land Use. Machiwal et al. (2011) [10] utilized SW, RR, and WTD. Senanayake et al. (2016), and Agarwal and Garg (2016) [37] added the DEM criterion. In pre-2012 studies, LI was also taken into account (Jaiswal et al., 2003 [38] by Srivastava and Bhattacharya in 2006 [39] and Magesh et al. in 2012 [40]).

In this study, the GIS-based MCDM AHP method was used to produce groundwater-potential maps of the Tigris River Batman-Hasankeyf drainage area using meteorological, hydrological, and hydrogeological characteristics without drilling water wells (test drilling) in the area. In this study, the ArcInfo 10.2.2 GIS program and extensions such as spatial analyst and arc hydro were used to define groundwater potential. Eight criteria that affect groundwater discharge, namely, land use, slope, geology, geomorphology, soil map, drainage density, fault density, and precipitation were taken into account. The relative weights of each criterion were determined by the AHP–MCDM method in a GIS environment. GWPZ maps of the basin were obtained as a result of this study. The acquired potential-groundwater-discharge maps properly represent a significant source that helps water-resource managers to make accurate management plans and much better use of groundwater resources.

2. Materials and Methods

2.1. Study Area

The Tigris river is an important source of water that originates within the borders of Turkey and discharges into the Persian Gulf. The total length of the Tigris River is 1750 km, about 500 km of which is within the borders of Turkey. The primary source of the river is in the southeast of Turkey, from Hazar lake and Hazarbaba mountain (2290 m). Within the borders of Turkey, after crossing the

Diyarbakir plain and south of the Batman city center, the river passes through Gercüş and historical Hasankeyf districts. This area is also upstream of the Ilısu dam, which is under the Southeastern Anatolia Project (GAP). The total discharge area of the sub-basin is 1140 km^2 (Figure 1). The Tigris Batman Discharge area is geographically at between 41°01′–41°38′ East longitude and 37°51′–37°32′ North latitude.

Tigris River is an important resource that is used for potable and utility water, as well as agricultural irrigation, with dams constructed in the regions of the river basin. The river has significant agricultural potential in the drainage area, which is why humans have been living in these basins for 10,000 years [41,42]. The study area comprises the ancient Hasankeyf settlement (which is located southeast of Turkey) and Tigris valleys. Although some regions along the river basin have rich surface-water resources, it is solely operated for groundwater use in agricultural irrigation due to incomplete irrigation projects [43]. Although the study area is a valuable basin for Turkey and the Middle East, the assessment of water resources has transcended locality and has reached significant value on a global scale, just like oil and other natural resources.
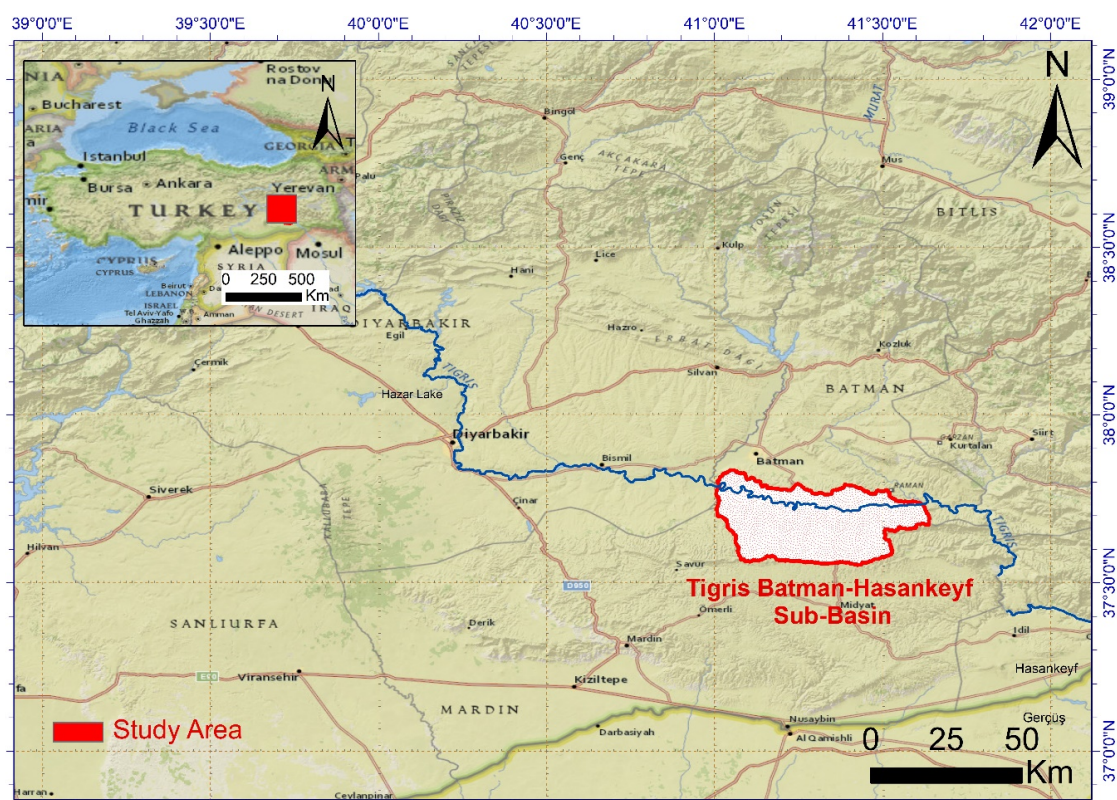
Figure 1. Tigris River Batman-Hasankeyf sub-drainage basin (study area) and its location.

2.2. Method

The GIS–MCDM combination is an excellent evaluation tool that analyzes multiple-criteria methodologies under a GIS environment [44,45]. It simplifies solving problems and improves the use of multiple criteria [46]; the Spatial Analyst extension of the Arc GIS program is perfectly suitable to implement this model. The analysis process was performed with the Spatial Analysis and Overlay tools taking into account the relative values, and grading and interpolating the final thematic maps. To determine the groundwater potential of the region, 8parameters were taken into account: GM, LU, G, LD, DD, S, R, and ST. The relative weight of each parameter was determined by the AHP method. The binary comparison matrices of these parameters are indicated in Table 1, and the weights of each parameter obtained as a result of the normalized values of these parameters are indicated in Table 2. Finally, thematic maps of the groundwater potential of the Upper Tigris Basin Batman subdrainage

area were acquired with the Arc GIS spatial analyst overlay method. The methodology flowchart of the entire study is shown in Figure 2.

To obtain groundwater-potential maps of the Batman subdrainage area, 1/25,000 M45 and M46 topographic maps with 5 X 5 m resolution were first digitized; then, DEM maps of the region were produced (Figure 3a). Hydrological land characteristics were extracted by using drainage-density maps. Drainage density, as shown in Equation (1), was acquired by dividing the length of the stream by the drainage area. DD was prepared with DEM data by using the Arc Hydro program. A flow direction (Fdr) map was obtained (Figure 3b); then, the drainage-density map was extracted by dividing thematic river maps that were derived from a flow accumulation (Fac) and stream definition (Figure 3c) operation in the basin area.

$$DD = L/A \tag{1}$$

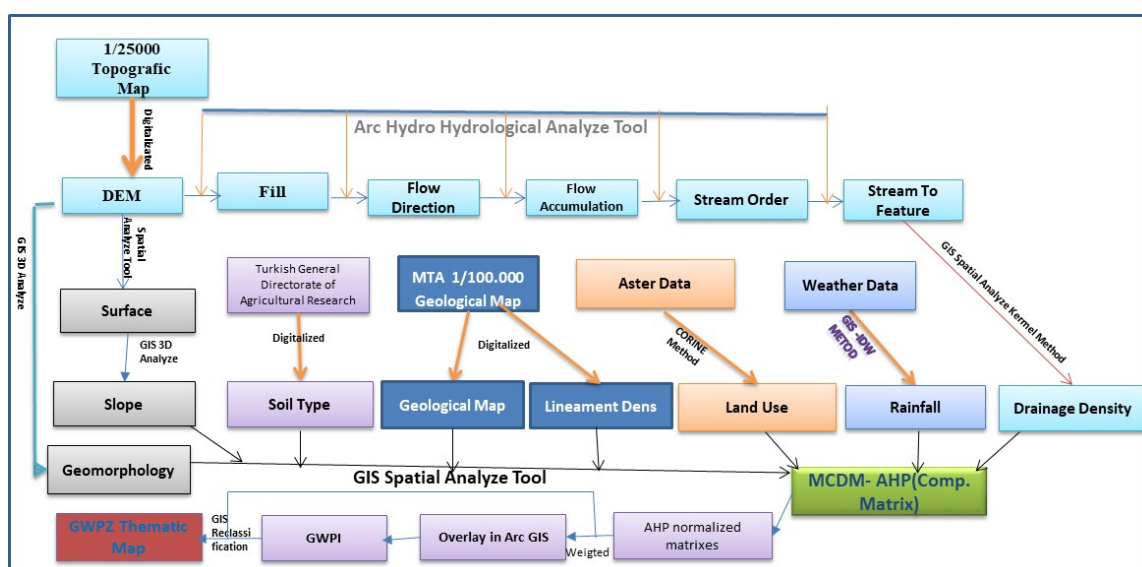where DD is Drainage Density, L is drainage length, and A is per-unit area [47].

Figure 2. Study methodology flowchart.

From DEM maps, geomorphological maps were produced with the Arc GIS program Spatial Analyst, and S maps were created with the 3D Analysis program. First, geological maps and lineament (fault) lines were converted into kml (Google Earth) format, then into shp format by using the Data Interoperability command via the Turkish General Directorate of Mineral Research and Exploration website [48]. Geological formations were converted into raster format with the related representation, and the geological status of the region was analyzed. Lineament (fault) density (LL) was calculated as per Equation (2) [49]:

$$LL = \sum_{i=1}^{n} Li/A \tag{2}$$

where LL is lineament density, *Li* is lineament length, *i* is lineament number, and *A* is area.

Precipitation (rainfall) data were acquired from the Diyarbakır regional office of the Turkish State Meteorological Service. The average annual-precipitation figures of the last 30 years, observed by meteorological stations at the Diyarbakır–Batman regions, were analyzed by the Spatial Analyst Inverse Distance Weighting IDW interpolation method; then, precipitation maps were formed.

The soil-type study was derived from the Turkish General Directorate of Agricultural Research and Policies. LU data were extracted from the Global Land Cover Facility site as Erdas images. These data were classified with the Coordination of Information on the Environment (CORINE) method. CORINE are land-cover-/use data generated by the computer-assisted visual-interpretation method over satellite imagery and RS data according to land-cover-/use classifications set by the European Environment

Agency [50]. CORINE is employed to utilize the terrain-classification degree of RS data in a GIS environment [51]. In satellite imagery, the coordinates of each pixel were defined according to the coordinates of the ground control points (rectification).
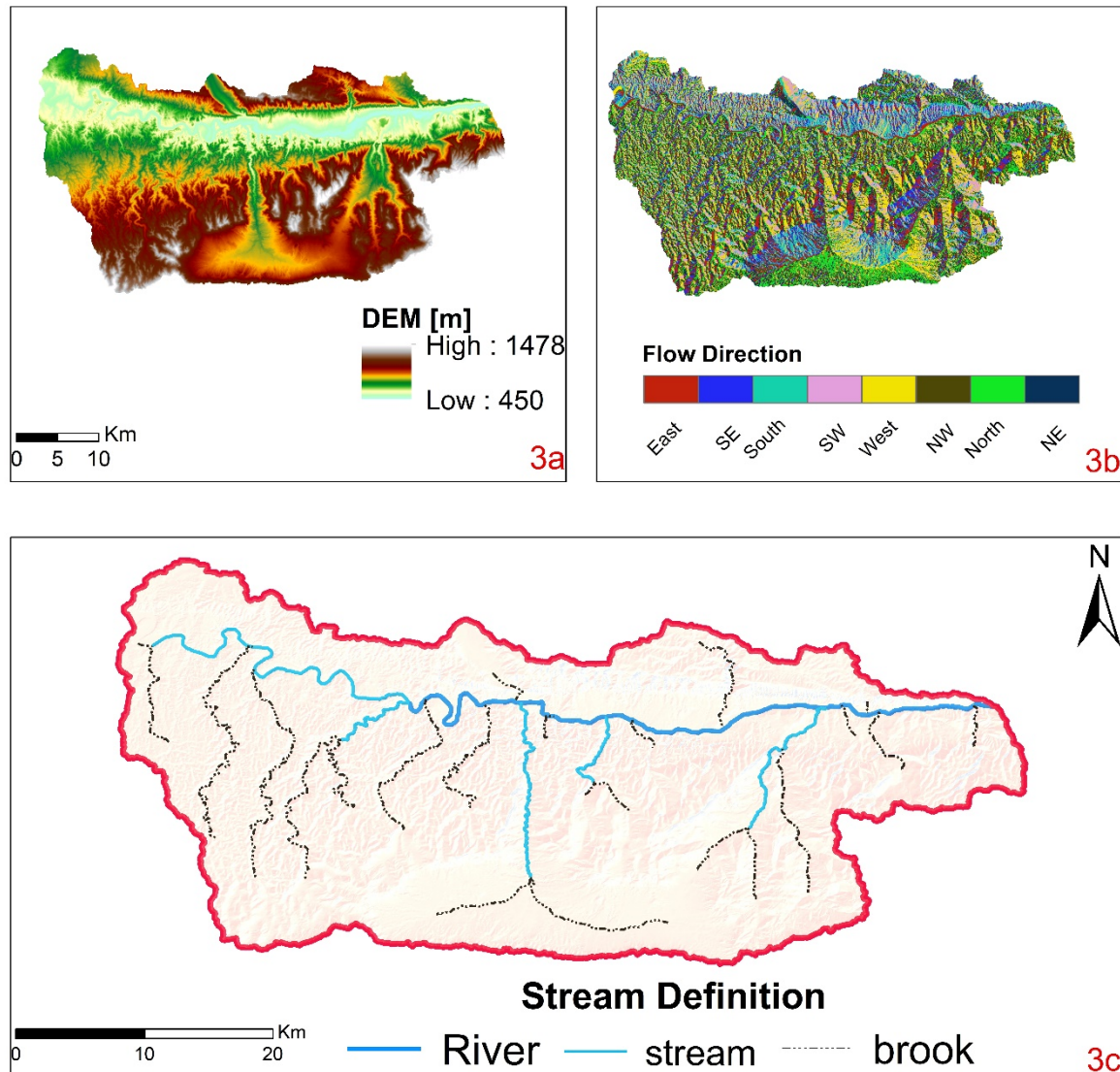
Figure 3. Drainage-density creation process; 3 (**a**): DEM map, 3 (**b**): Flow Direction (Fdr) map; 3 (**c**): Stream Definition.

GWPI is a dimensionless magnitude formed by the sum of the relative weights of the parameters affecting groundwater potential. This coefficient was obtained by calculating the weights of the criteria that made up the groundwater potential by the AHP and GIS-based MCDM method as shown in Equation (3) [52]. This indicator gives information about groundwater potential in different regions [53].

It is calculated according to the AHP method as follows:

$$\text{GWPI} = \text{Sr.Sw} + \text{LDr.LDw} + \text{Gr.Gw} + \text{GMr.GMw} + \text{LUr.LUw} + \text{STr.STw} + \text{Rr.Rw} + \text{DDr.DDw} \quad (3)$$

where GWPI is groundwater potential index, S is Slope, LD is lineament density, G is geology, GM is geomorphology, LU is land use, ST is soil type, R is rainfall, and DD is drainage density. In addition, subscripts r and w refer to the rating and weight of the parameter, respectively.

2.3. GIS-Based AHP Method

The AHP is one of the most widely used MCDM methods. It was developed by Thomas L. Saaty in 1980, and it is an approach created by planned criteria (identification of selection criteria) at a certain stage that involves evaluating criteria weights (relative importance), comparing the alternatives for each criterion, and determining an overall ranking of the alternatives. The AHP is widely used in areas such as reducing confusion/complexity in problems, facilitating decisions, finding priorities by applying expert provisions with comparisons [54], distinguishing resources and solving complexities/confusion, uncovering best options, and planning [55]. Here, the AHP method was applied in rating the selected factors. In order to determine the relative importance of selection factors and weight formation, the AHP methodology was applied, and objective weight assessment was carried out. There had to be at least 2 criteria and 2 alternatives to the technique [56]. Relative importance was given to these criteria, so information and experience are particularly important for accurate assessment and analysis. Criteria could be qualitative and quantitative [57,58]. The GIS-based MCDM as an expert-knowledge-based approach that is very useful for solving complex problems.

The application of the GIS technique and multicriteria decision analysis provides more flexible solutions for the prediction of groundwater-potential zones.

Accordingly, a decision matrix was formed on the basis of 1–9 scaling for parameters affecting a decision. The criteria in the scoring scale were as follows: (1) extremely unimportant, (2) very unimportant, (3) unimportant, (4) moderately unimportant, (5) equally important, (6) moderately important, (7) more important, (8) very important, (9) extremely important [59].

In this study, the weighting of various criteria was carried out through field experiences and literature review. The basic steps for determining the system's normalized weight and consistency ratio (CR) were as follows:

Step 1. Establishment of judgment matrices (*p*) by pairwise comparison:

$$\mathbf{p} = \begin{vmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{vmatrix} \tag{4}$$

where p_n displays the *n* th indicator unit and p_{nn} is the judgment matrix element.

Step 2. Calculation of normalized weight:

$$Wn = GMn / \sum_{n=1}^{N} GMn \tag{5}$$

where *W* is weight vector (column) and *GMn* is the geometric mean of the *i* th row of the judgment.

Step 3. *CR* calculation to verify the coherence of the judgements:

$$CR = CI / RCI \tag{6}$$

Consistency index (*CI*) is denoted as follows:

$$CI = \frac{\lambda \text{max} - N}{N - 1} \tag{7}$$

where λ is the eigenvalue of judgment matrix and it is calculated as follows:

$$\lambda = \frac{\sum\limits_{i=1}^{n} (P_i W)n}{N.W} \tag{8}$$

Random consistency index (RCI) could be obtained from standard tables [60]. The *CR* value had to be about 0.10 or less to be accepted.

3. Results and Discussion

In this study, slope, lineament-density, geology, geomorphology, land-use, soil, rainfall, and drainage-density criteria were taken into consideration. The pairwise comparison matrix is depicted in Table 1. The relative normalized weight (W) of the criteria was then calculated and is shown in Table 2. RCI was calculated as 0.011. Hence, the weight criteria within the criteria were quite consistent. The distribution in the basin and relative weights of these thematic maps are shown in Table 3. In order to determine the groundwater-potential zones in the Tigris River Batman drainage area, the derived parameters of the thematic map are shown in Figure 4. These maps are GM, G, LD, S, R, ST, and LU. As a result, the GWPZ map extracted by the weights of these parameters is shown in Figure 5.

Table 1. Analytic hierarchy process (AHP) pairwise comparison matrix.

Parameters	Slope	Lineament Density	Geology	Geomorphology	Land Use	Soil	Rainfall	Drainage Density
Slope	1.00	1.80	1.29	1.13	1.50	1.29	1.00	1.29
Lineament dens	0.56	1.00	0.71	0.63	0.83	0.71	0.56	0.71
Geology	0.78	1.40	1.00	0.88	1.17	1.00	0.78	1.00
Geomorphology	0.89	1.60	1.14	1.00	1.33	1.14	0.89	1.14
Land use	0.56	1.20	0.86	0.75	1.00	0.86	0.67	0.86
Soil	0.78	1.40	1.00	0.88	1.17	1.00	0.78	1.00
Rainfall	0.89	1.80	1.29	1.13	1.50	1.29	1.00	1.29
Drainage dens	0.49	1.40	1.00	0.88	1.17	1.00	0.78	1.00

Table 2. Normalized AHP matrix.

Parameters	Slope	Lineament Density	Geology	Geomorphology	Land Use	Soil	Rainfall	Drainage Density	Normalized Weight
Slope	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Lineament dens	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.12
Geology	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
Geomorphology	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13
Land use	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.12
Soil	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
Rainfall	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.14
Drainage Dens	0.08	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.13

λ_{max} = 8.12, CI = 0.02, RCI = 1.41, CR = 0.011 < 0.1: acceptable.

3.1. Geomorphology

Geomorphology maps (Figure 4A) are topographic maps showing mountainous, lowland, hilly, and alluvial regions of the region. Alluvial regions have the highest groundwater potential, while mountainous regions have the lowest. The geomorphological distribution of the study area is as follows: mountainous areas (23%), hilly areas (21%), alluvial areas (1%), plains (43%), and plateaus (12%).

3.2. Geology

The geological parameter is one of the most important parameters in terms of groundwater potential. Geological characteristics are important in terms of reflecting aquifer status, which shows groundwater storage. The geological thematic map of the basin is shown in Figure 4B. Limestone, and sandstone and conglomerate ratios were the highest in the basin with 43% and 17%, respectively. Water-retention capacity is higher in these formations. Evaporite rocks and moraine formations are at 22% in the region. The percentage of other formations is shown in Table 3.

Table 3. Summarized AHP assessment of parameter sub-properties.

Weight	Criteria	Sub-Feature	Area Cover (%)	Sub-Rank
7	Geomorphology	Alluvion	1	9
		Plain	43	7
		Plateau	12	5
		Hill	21	3
		Mountain	23	1
7	Geology	Shale	10.9	1
		Sandstone–conglomerate	17.1	7
		Evaporites/moraine	21.7	3
		Clayey limestone/basalt/quartz	0.6	5
		Pebble–sandstone–conglomerate	5.0	7
		Limestone	43.7	8
		Alluvion	1.0	9
5	Lineament density (%)	0–0.01	93.7	1
		0.01–1.5	1.4	3
		1.5–3.5	2.6	5
		3.5–6.50	2.3	7
9	Slope (%)	0–2	9	9
		2–4	6	7
		4–8	12	5
		8–15	25	3
		>15	48	1
7	Rainfall (mm/year)	448–478	43.57	5
		479–508	32.16	6
		509–548	17.08	7
		549–592	7.18	8
6	Soil	Alluvial soil	0.10	9
		Brown forestry soil	56.90	6
		Brown Soil	41.30	4
		Reddish-brown soil	1.70	3
5	Drainage density (%)	0–0.01	55.5	1
		0.1–2	4.1	7
		2–4.06	40.5	9
		Bare rock	7.23	1
		Discrete rural building	0.13	3
		Non-irrigated agricultural field/vineyards	28.92	4
		Agricultural areas with natural vegetation/non-irrigated orchard	12.32	5
		Sparse plant areas	30.23	6
		Grassland	19.79	7
		Irrigated area	0.17	8
		Water bodies	1.21	9

3.3. Lineament Density

Lineament density is an important geological feature that shows rainfall penetration into the ground [61]. Feeding is more common in underground fractured areas. Although fractured areas create discontinuity between regions, they enable rainfall to be fed to underground aquifers in less time. In areas where lineament density is high, groundwater feeding is higher; in areas where density is low, groundwater feeding is less.

Results of the lineament-density map of the basin (Figure 4C) are summarized in Table 3. Accordingly, there is no fault density in 94% of the basin. The area covered by a density of <1.5 part in the basin is 1%, with a density 1.5–3.5 is 3%, and with a density of 3.5–6.5 is 2%.

3.4. Slope

Precipitation infiltration (leakage) is an effective hydrological parameter in obtaining groundwater potential [62]. In low-slope locations, infiltration into the ground is more common as surface flow will be less. As slope ratio increases, surface flow increases, and infiltration into the ground is less. As seen in Figure 4D, the slope is greater than 15% in 48% of the basin. The slope at 25% of the study area is between 8%–15%. Areas having the ideal slope rate (less than 2%) for groundwater formation are 9%. A further 2%–4% of the slope rate areas are 6% in the basin.

3.5. Rainfall

Rainfall (precipitation) is one of the most important groundwater parameters. Groundwater is formed by rainfall infiltrating the ground. Accordingly, 43.57% of the basin has a rainfall rate of 448–478 mm/year and 32.16% has 479–508 mm/year. Only 7% of the basin has a rainfall rate of 549–592 mm/year (Figure 4E).

3.6. Soil

Soil is an important parameter that influences rainfall infiltration into the ground. The rate and amount of infiltration vary depending on grain structure. In coarse-grained porous structures, groundwater infiltration is higher. In fine-grained soils such as clay, infiltration is slower and less. Porosity and permeability both play an important role in groundwater movement and recovery. In the soil map of the study area (Figure 4F), we can see that, in the basin, alluvial soil: 0.10%, brown forestry soil: 56.90%, brown soil: 41.30%, and reddish-brown soil: 1.70% (Table 3).
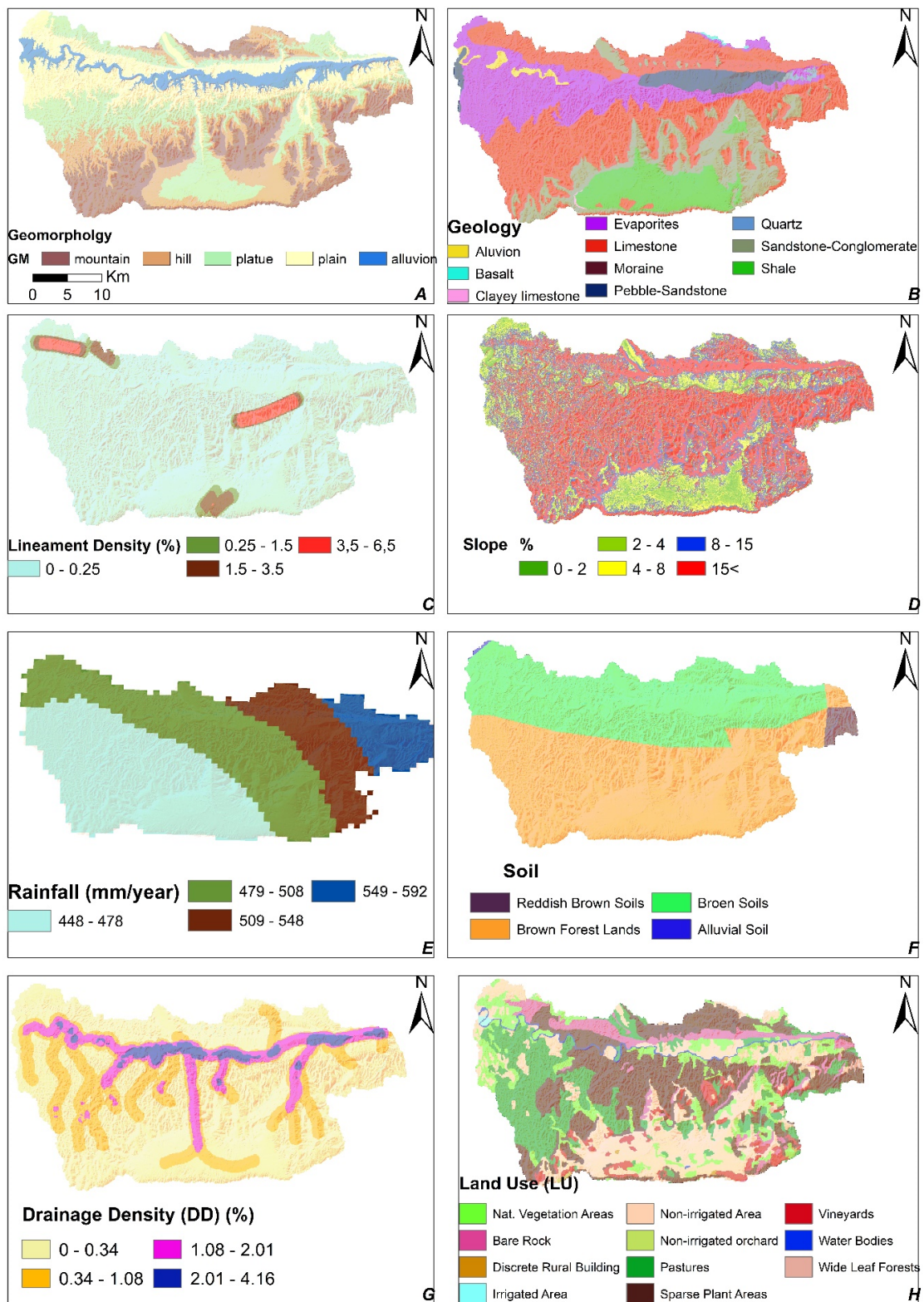
3.7. Drainage Density

Drainage density is one of the parameters affecting the groundwater-potential index. In river flows, drainage density is low in areas with low infiltration [63]. Where drainage density is small, infiltration occurs at a higher speed because the flow is slow. Hence, the performance coefficient of ratios with low drainage density was taken as a higher value. Drainage density is generally low in the basin (Figure 4G).

3.8. Land Use

Land use is directly related to rainfall leaking into the ground. It is therefore an important criterion for groundwater formation. Due to urbanization in construction sites, leakage is rare and surface flow rate is therefore higher. Wetlands and water bodies are considered to have the highest evaluation score. Similarly, in rivers, alluvial deposits have a high leakage rate. In addition, irrigated agricultural areas' water infiltration into the ground is also high. In a similar way, there is a high rate of leakage in plant zones, partly in land form, because surface flow is prevented by plantations. Land-use rate and utilization classification are shown in Table 4. As depicted in the table, water mass and irrigated areas in the Batman discharge area are very small. By majority, there are non-irrigated agricultural areas (28%), pastures (19%), and areas with different vegetation.

Table 4. Tigris Batman drainage field GWPZ evaluation.

| Evaluation	km^2	%
Very poor	262.45	19
Poor	241.71	17
Moderate	484.22	34
Good	234.53	17
Very good	177.09	13

Figure 4. Main criteria affecting reclassified Groundwater Potential Index (GWPI) raster maps (**A**): Geomorphology, (**B**): Geology, (**C**): Lineament Density, (**D**): Slope, (**E**): Rainfall, (**F**): Soil, (**G**): Drainage Density, (**H**): Land Use map.

3.9. GWPZ Delination

GWPI is a coefficient showing the groundwater potential of the region. This coefficient is defined on the probability of obtaining groundwater resources for that area. The GWPI of an area varies

according to the variability of properties that make up groundwater potential and, predominantly, the coefficient of significance. This final map shows the low–medium–high rate GW discharge regions for potential.

The GWPZ map was derived by periodic GWPI classification, shown in Figure 5. Accordingly, the GWPZ evaluation of the basin is summarized in Table 4 as follows: very poor (262.45 km^2; 19%), poor (241.71 km^2; 17%), moderate (484.22 km^2; 34%), good (234.53 km^2; 17%), and very good (177.09 km^2; 13%). As depicted, the maximum weight of the basin is 34% moderate GWPZ.
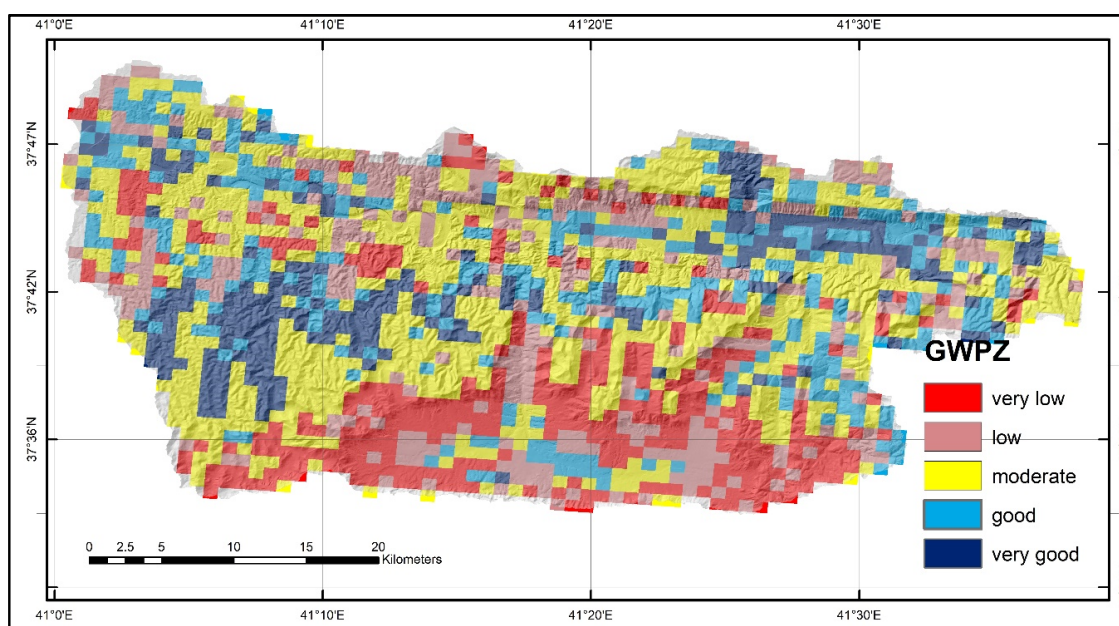
Figure 5. Tigris Batman-Hasankeyf drainage field Groundwater Potential Zone (GWPZ) map.

3.10. Discussion

GIS-based multicriteria decision analysis is a flexible tool that supports decision makers in identifying groundwater potential. Therefore, a major challenge in the proposed GIS-based multicriteria decision analysis is the selection of criteria for groundwater-potential-zone mapping. Criteria selection requires good knowledge of the site and watershed data, the accurate weighting of criteria by hydrogeologist experts, and accurate cooperation between selected factors. One of the most important stages of the decision-making process is the determination of the criteria weight, in other words, their importance. Weights given to the criteria directly affect the outcome of the decision analysis. Analysis accuracy depends on the determination of the weights with sufficient accuracy. There are several methods for determining criteria weights, and since these methods differ from each other in terms of accuracy, ease of use, clarity, and theoretical structure, which method to use in determining weights varies according to the priorities of the decision maker. Although ranking and scoring methods are easier to use, binary comparison and preference priority analysis methods give more accurate results.

The GIS-based MCDM method is a good alternative in this research area. MCDM techniques are used very effectively to solve problems in various and different areas [64–66]. Despite the many methods used in MCDM applications, the most common is AHP. In the selection of the appropriate areas, considering the relative impact of the various criteria in relation to each other [67] gives useful results in groundwater-discharge assessment [68–71]. The model used in this study allowed us to identify areas with high, medium, and low potential for groundwater charging zones. The presence of the thematic data obtained with this approach requires that accuracy is checked on the field. This is not always an economical and fast method, but it is possible to compare the water budgets of the basins

with the field test. However, results achieved by this approach play an important role in this type of groundwater-management study.

In this study, it was concluded that places with the highest groundwater potential are in river crossings and the alluvial zone near the Tigris river. Findings showed that this method is suitable for the Batman-Hasankeyf sub-basin. Another feature of this region is that the slope is very low. Similar studies using the same method in different regions had varying results. In an Indian study, the Indian Hooghly district was classified into three groundwater-potential zones, 'good', 'moderate', and 'poor', covering 71%, 23%, and 6%, respectively. 'Good' GWPZ indicated that the alluvial plain has excellent groundwater potential [22]. Madrucci et al. studied groundwater-favorability mapping on a fractured terrain in the eastern portion of the state of São Paulo, Brazil [33]. They determined a "moderate favorability" GW potential level in almost half of the basin. Results obtained from the study are acceptable when compared with well logs on the field. GWPZs were calculated by a similar method in the Yamuna basin, another basin of India, and it was found that about half of the basin had good–very good value, and 24% had weak potential [25]. In a study on the Manuba aquifers in NE Tunisia with the GIS-based MCDM method [66], it was found that only 24% of the basin had a low GW potential. GWPZ values of a region vary according to hydrological and hydrogeological conditions. However, it is crucial to evaluate the GW potential of a basin by correctly using these variables.

4. Conclusions

In this study, groundwater potential was explored in the Tigris river Batman region sub-basin drainage area by integrating spatial-analyzer tools with MCDM. The MCDM–AHP technique was successfully applied to the normalized weight and rank of each parameter and its sub-properties affecting the groundwater potential of the basin. In total, eight layers were used in system integration. As a result of the overlay of these maps, GWPI values of the basin were extracted. These GWPI values were reclassified into five classes: very poor, poor, moderate, good, and very good. By utilizing this method, local GWPZ maps of the basin were derived.

The final maps showed that 34% of the basin has moderate groundwater potential. However, 36% of the basin demonstrated poor potential, while 30% of the basin has good potential. This GWPZ map should be taken into account in watershed planning by managers. On the basis of the findings, controlled groundwater use should be made in the poor-potential areas of the basin. In these regions, groundwater should only be used as potable water. The use of groundwater can be realized in agricultural areas at moderate-potential zones, but large-scale agricultural irrigation should be prevented. In areas with good potential, groundwater can be used in agricultural irrigation. However, water-well drillings must be properly controlled and opened at wide intervals on the field.

It is more accurate to learn the groundwater potential of a narrow area by drilling several observation wells. However, in large-scale basins, this is both expensive and time-consuming. It is purely logical and valuable to preferably discover the groundwater potential of large-scale basins in the macroplan with the MCDM method. Hydrological and hydrogeological data are now easier and relatively cheaper to obtain with RS and satellite methods. This method could be applied not only to the upstream Tigris basin but to anywhere else in the world as well. The most important topic to consider is that specific hydrological and meteorological criteria that affect groundwater and their weight might change depending on each region's condition.

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References

1. Okello, C.; Tomasello, B.; Greggio, N.; Wambiji, N.; Antonellini, M. Impact of population growth and climate change on the freshwater resources of Lamu Island, Kenya. *Water* **2015**, *7*, 1264–1290. [CrossRef]
2. Diamantino, C.; Henriques, M.J.; Oliveira, M.M.; Ferreira, J.P.L. Methodologies for pollution risk assessment of water resources systems. *IAHS Publ.* **2007**, *310*, 298.
3. Alessa, L.; Kliskey, A.; Lammers, R.; Arp, C.; White, D.; Hinzman, L.; Busey, R. The arctic water resource vulnerability index: An integrated assessment tool for community resilience and vulnerability with respect to freshwater. *Environ. Manag.* **2008**, *42*, 523. [CrossRef] [PubMed]
4. Danielopol, D.L.; Griebler, C.; Gunatilaka, A.; Notenboom, J. Present state and future prospects for groundwater ecosystems. *Environ. Conserv.* **2003**, *30*, 104–130. [CrossRef]
5. De Stefano, L.; Lopez-Gunn, E. Unauthorized groundwater use: Institutional, social and ethical considerations. *Water Policy* **2012**, *14*, 147–160. [CrossRef]
6. Lee, S.; Lee, C.W. Application of decision-tree model to groundwater productivity-potential mapping. *Sustainability* **2015**, *7*, 13416–13432. [CrossRef]
7. Helena, B.; Pardo, R.; Vega, M.; Barrado, E.; Fernandez, J.M.; Fernandez, L. Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga River, Spain) by principal component analysis. *Water Res.* **2000**, *34*, 807–816. [CrossRef]
8. Pourtaghi, Z.S.; Pourghasemi, H.R. GIS-based groundwater spring potential assessment and mapping in the Birjand Township, southern Khorasan Province, Iran. *Hydrogeol. J.* **2014**, *22*, 643–662. [CrossRef]
9. Thapa, R.; Gupta, S.; Guin, S.; Kaur, H. Assessment of groundwater potential zones using multi-influencing factor (MIF) and GIS: A case study from Birbhum district, West Bengal. *Appl. Water Sci.* **2017**, *7*, 4117–4131. [CrossRef]
10. Machiwal, D.; Jha, M.K.; Mal, B.C. Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. *Water Resour. Manag.* **2011**, *25*, 1359–1386. [CrossRef]
11. Yin, H.; Shi, Y.; Niu, H.; Xie, D.; Wei, J.; Lefticariu, L.; Xu, S. A GIS-based model of potential groundwater yield zonation for a sandstone aquifer in the Juye Coalfield, Shangdong, China. *J. Hydrol.* **2018**, *557*, 434–447. [CrossRef]
12. Elbeih, S.F. An overview of integrated remote sensing and GIS for groundwater mapping in Egypt. *Ain Shams Eng. J.* **2015**, *6*, 1–15. [CrossRef]
13. Senanayake, I.P.; Dissanayake, D.M.D.O.K.; Mayadunna, B.B.; Weerasekera, W.L. An approach to delineate groundwater recharge potential sites in Ambalantota, Sri Lanka using GIS techniques. *Geosci. Front.* **2016**, *7*, 115–124. [CrossRef]
14. Saaty, T.L. *The Analytic Hierarchy Process*; McGrawHill: New York, NY, USA, 1980.
15. Saaty, T.L. *Fundamentals of Decision Making and Priority Theory*; RWS Publications: Pittsburgh, PA, USA, 2000.
16. Guo, J.-Y.; Zhang, Z.-B.; Sun, Q.-Y. Applications of AHP method in safety science. *J. Saf. Sci. Technol.* **2008**, *2*, 69–73.
17. Wang, Y.; Li, Z.; Tang, Z.; Zeng, G. A GIS-based spatial multi-criteria approach for flood risk assessment in the Dongting Lake Region, Hunan, Central China. *Water Resour. Manag.* **2011**, *25*, 3465–3484. [CrossRef]
18. Tang, Z.; Zhang, H.; Yi, S.; Xiao, Y. Assessment of flood susceptible areas using spatially explicit, probabilistic multi-criteria decision analysis. *J. Hydrol.* **2018**, *558*, 144–158. [CrossRef]
19. Chen, H.; Wood, M.D.; Linstead, C.; Maltby, E. Uncertainty analysis in a GIS-based multi-criteria analysis tool for river catchment management. *Environ. Model. Softw.* **2011**, *26*, 395–405. [CrossRef]
20. Nair, N.C.; Srinivas, Y.; Magesh, N.S.; Kaliraj, S. Assessment of groundwater potential zones in Chittar basin, Southern India using GIS based AHP technique. *Remote Sens. Appl. Soc. Environ.* **2019**, *15*, 100248. [CrossRef]
21. Abrams, W.; Ghoneim, E.; Shew, R.; LaMaskin, T.; Al-Bloushi, K.; Hussein, S.; AbuBakr, M.; Al-Mulla, E.; Al-Awar, M.; El-Baz, F. Delineation of groundwater potential (GWP) in the northern United Arab Emirates and Oman using geospatial technologies in conjunction with Simple Additive Weight (SAW), Analytical Hierarchy Process (AHP), and Probabilistic Frequency Ratio (PFR) techniques. *J. Arid Environ.* **2018**, *157*, 77–96. [CrossRef]
22. Patra, S.; Mishra, P.; Mahapatra, S.C. Delineation of groundwater potential zone for sustainable development: A case study from Ganga Alluvial Plain covering Hooghly district of India using remote sensing, geographic information system and analytic hierarchy process. *J. Clean. Prod.* **2018**, *172*, 2485–2502. [CrossRef]

23. Gdoura, K.; Anane, M.; Jellali, S. Geospatial and AHP-multicriteria analyses to locate and rank suitable sites for groundwater recharge with reclaimed water. *Resour. Conserv. Recycl.* **2015**, *104*, 19–30. [CrossRef]

24. Saidi, S.; Hosni, S.; Mannai, H.; Jelassi, F.; Bouri, S.; Anselme, B. GIS-based multi-criteria analysis and vulnerability method for the potential groundwater recharge delineation, case study of Manouba phreatic aquifer, NE Tunisia. *Environ. Earth Sci.* **2017**, *76*, 511. [CrossRef]

25. Kaur, L.; Rishi, M.S.; Singh, G.; Thakur, S.N. Groundwater potential assessment of an alluvial aquifer in Yamuna sub-basin (Panipat region) using remote sensing and GIS techniques in conjunction with analytical hierarchy process (AHP) and catastrophe theory (CT). *Ecol. Indic.* **2020**, *110*, 105850. [CrossRef]

26. Gupta, M.; Srivastava, P.K. Integrating GIS and remote sensing for identification of groundwater potential zones in the hilly terrain of Pavagarh, Gujarat, India. *Water Int.* **2010**, *35*, 233–245. [CrossRef]

27. Rahmati, O.; Samani, A.N.; Mahdavi, M.; Pourghasemi, H.R.; Zeinivand, H. Groundwater potential mapping at Kurdistan region of Iran using analytic hierarchy process and GIS. *Arab. J. Geosci.* **2015**, *8*, 7059–7071. [CrossRef]

28. Pinto, D.; Shrestha, S.; Babel, M.S.; Ninsawat, S. Delineation of groundwater potential zones in the Comoro watershed, Timor Leste using GIS, remote sensing and analytic hierarchy process (AHP) technique. *Appl. Water Sci.* **2017**, *7*, 503–519. [CrossRef]

29. Murthy, K.S.R. Ground water potential in a semi-arid region of Andhra Pradesh—A geographical information system approach. *Int. J. Remote Sens.* **2000**, *21*, 1867–1884. [CrossRef]

30. Ibrahim-Bathis, K.; Ahmed, S.A. Geospatial technology for delineating groundwater potential zones in Doddahalla watershed of Chitradurga district, India. *Egypt. J. Remote Sens. Space Sci.* **2016**, *19*, 223–234. [CrossRef]

31. Sikdar, P.K.; Chakraborty, S.; Adhya, E.; Paul, P.K. Land use/Land cover changes and groundwater potential zoning in and around Raniganj coal mining area, Bardhaman District, West Bengal—A GIS and Remote Sensing Approach. *J. Spat. Hydrol.* **2004**, *4*, 1–24.

32. Prasad, R.K.; Mondal, N.C.; Banerjee, P.; Nandakumar, M.V.; Singh, V.S. Deciphering potential groundwater zone in hard rock through the application of GIS. *Environ. Geol.* **2007**, *55*, 467–475. [CrossRef]

33. Madrucci, V.; Taioli, F.; De Araújo, C.C. Groundwater favorability map using GIS multicriteria data analysis on crystalline terrain, Sao Paulo State, Brazil. *J. Hydrol.* **2008**, *357*, 153–173. [CrossRef]

34. Chowdhury, A.; Jha, M.K.; Chowdary, V.M.; Mal, B.C. Integrated remote sensing and GIS-based approach for assessing groundwater potential in West Medinipur district, West Bengal, India. *Int. J. Remote Sens.* **2009**, *30*, 231–250. [CrossRef]

35. Zaidi, F.K.; Nazzal, Y.; Ahmed, I.; Naeem, M.; Jafri, M.K. Identification of potential artificial groundwater recharge zones in Northwestern Saudi Arabia using GIS and Boolean logic. *J. Afr. Earth Sci.* **2015**, *111*, 156–169. [CrossRef]

36. Jha, M.K.; Chowdary, V.M.; Chowdhury, A. Groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques. *Hydrogeol. J.* **2010**, *18*, 1713–1728. [CrossRef]

37. Agarwal, R.; Garg, P.K. Remote sensing and GIS based groundwater potential and recharge zones mapping using multi-criteria decision making technique. *Water Resour. Manag.* **2016**, *30*, 243–260. [CrossRef]

38. Jaiswal, R.K.; Mukherjee, S.; Krishnamurthy, J.; Saxena, R. Role of remote sensing and GIS techniques or generation of groundwater prospect zones towards rural developmentean approach. *Int. J. Remote Sens.* **2003**, *24*, 993–1008. [CrossRef]

39. Srivastava, P.K.; Bhattacharya, A.K. Groundwater assessment through an integrated approach using remote sensing, GIS and resistivity techniques: A case study from a hard rock terrain. *Int. J. Remote Sens.* **2006**, *27*, 4599–4620. [CrossRef]

40. Magesh, N.S.; Chandrasekar, N.; Soundranayagam, J.P. Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. *Geosci. Front.* **2012**, *3*, 189–196. [CrossRef]

41. Ahunbay, Z.; Balkiz, Ö. Outstanding universal value of Hasankeyf and the Tigris valley. *Doğa Deneği.* **2009**, *22*. Available online: https://goo.gl/qZ9tqX (accessed on 10 August 2019).

42. Miyake, Y.; Maeda, O.; Tanno, K.; Hongo, H.; Gündem, C.Y. New excavations at Hasankeyf Höyük: A 10th millennium cal. BC site on the upper Tigris, southeast Anatolia. *Neo Lithics* **2012**, *1*, 3–7.

43. Çelik, R. Temporal changes in the groundwater level in the Upper Tigris Basin, Turkey, determined by a GIS technique. *J. Afr. Earth Sci.* **2015**, *107*, 134–143. [CrossRef]

44. Rikalovic, A.; Cosic, I.; Lazarevic, D. GIS based multi-criteria analysis for industrial site selection. *Procedia Eng.* **2014**, *69*, 1054–1063. [CrossRef]

45. Mahmoud, S.H. Delineation of potential sites for groundwater recharge using a GIS-based decision support system. *Environ. Earth Sci.* **2014**, *72*, 3429–3442. [CrossRef]

46. Chenini, I.; Mammou, A.B.; El May, M. Groundwater recharge zone mapping using GIS-based multi-criteria analysis: A case study in Central Tunisia (Maknassy Basin). *Water Resour. Manag.* **2010**, *24*, 921–939. [CrossRef]

47. Tarboton, D.G.; Bras, R.L.; Rodriguez-Iturbe, I. A physical basis for drainage density. *Geomorphology* **1992**, *5*, 59–76. [CrossRef]

48. General Directorate of Mineral Research on Exploration. Available online: http://yerbilimleri.mta.gov.tr/anasayfa.aspx (accessed on 8 August 2019).

49. Mandal, U.; Sahoo, S.; Munusamy, S.B.; Dhar, A.; Panda, S.N.; Kar, A.; Mishra, P.K. Delineation of groundwater potential zones of coastal groundwater basin using multi-criteria decision making technique. *Water Resour. Manag.* **2016**, *30*, 4293–4310. [CrossRef]

50. Gallego, F.J.; Batista, F.; Rocha, C.; Mubareka, S. Disaggregating population density of the European Union with CORINE land cover. *Int. J. Geogr. Inf. Sci.* **2011**, *25*, 2051–2069. [CrossRef]

51. Ateşoğlu, A. Havza çalışmalarında kullanılan CORINE 2006 arazi sınıflandırma verilerinin doğruluğunun araştırılması. *İstanb. Üniv. Orman Fakültesi Derg.* **2016**, *66*, 173–183. [CrossRef]

52. Rao, B.V.; Briz-Kishore, B.H. A methodology for locating potential aquifers in a typical semi-arid region in India using resistivity and hydrogeologic parameters. *Geoexploration* **1991**, *27*, 55–64.

53. Shekhar, S.; Pandey, A.C. Delineation of groundwater potential zone in hard rock terrain of India using remote sensing, geographical information system (GIS) and analytic hierarchy process (AHP) techniques. *Geocarto Int.* **2015**, *30*, 402–421. [CrossRef]

54. Punniyamoorty, M.; Ponnusamy, M.; Lakshmi, G. A combined application of structural equation modeling (SEM) and analytic hierarchy process (AHP) in supplier selection. *Benchmarking Int. J.* **2012**, *19*, 70–92. [CrossRef]

55. Kannan, V. Benchmarking the service quality of ocean container carriers using AHP. *Benchmarking Int. J.* **2010**, *17*, 637–656. [CrossRef]

56. Greene, R.; Devillers, R.; Luther, J.E.; Eddy, B.G. GIS-based multiple-criteria decision analysis. *Geogr. Compass* **2011**, *5*, 412–432. [CrossRef]

57. Triantaphyllou, E.; Sanchez, A. A sensitivity analysis approach for some deterministic multi-criteria decision making methods. *Decis. Sci.* **1997**, *28*, 151–194. [CrossRef]

58. Ho, W.; Xu, X.; Dey, P.K. Multi-criteria decision making approaches for supplier valuation and selection: A literature review. *Eur. J. Oper. Res.* **2010**, *202*, 16–24. [CrossRef]

59. Saaty, T.L. Decision-making with the AHP: Why is the principal eigenvector necessary. *Eur. J. Oper. Res.* **2003**, *145*, 85–91. [CrossRef]

60. Alonso, J.A.; Lamata, M.T. Consistency in the analytic hierarchy process: A new approach. *Int. J. Uncertain. Fuzziness Knowl. Based Syst.* **2006**, *14*, 445–459. [CrossRef]

61. Magowe, M.; Carr, J.R. Relationship between lineaments and ground water occurrence in western Botswana. *Groundwater* **1999**, *37*, 282–286. [CrossRef]

62. Batelaan, O.; De Smedt, F. Wet Spass: A flexible, GIS based, distributed recharge methodology for regional groundwater modelling. *IAHS Publ.* **2001**, *269*, 11–18.

63. Tucker, G.E.; Bras, R.L. Hillslope processes, drainage density, and landscape morphology. *Water Resour. Res.* **1998**, *34*, 2751–2764. [CrossRef]

64. Mendoza, G.A.; Martins, H. Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. *For. Ecol. Manag.* **2006**, *230*, 1–22. [CrossRef]

65. Makropoulos, C.K.; Butler, D. Spatial ordered weighted averaging: Incorporating spatially variable attitude towards risk in spatial multi-criteria decision-making. *Environ. Model. Softw.* **2016**, *21*, 69–84. [CrossRef]

66. Karnatak, H.C.; Saran, S.; Bhatia, K.; Roy, P.S. Multicriteria spatial decision analysis in web GIS environment. *Geoinformatica* **2017**, *11*, 407–429. [CrossRef]

67. Adiat, K.A.N.; Nawawi, M.N.M.; Abdullah, K. Assessing the accuracy of GIS-based elementary multicriteria decision analysis as a spatial prediction tool—A case of predicting potential zones of sustainable groundwater resources. *J. Hydrol.* **2012**, *440*, 75–89. [CrossRef]

68. Azimi, S.; Moghaddam, M.A.; Monfared, S.A.H. Spatial assessment of the potential of groundwater quality using fuzzy AHP in GIS. *Arab. J. Geosci.* **2018**, *11*, 142. [CrossRef]

69. Singh, P.K.; Dahiphale, P.; Yadav, K.K.; Singh, M. Delineation of groundwater potential zones in Jaisamand Basin of Udaipur District. In *Groundwater*; Springer: Singapore, 2018; pp. 3–20.

70. Gnanachandrasamy, G.; Zhou, Y.; Bagyaraj, M.; Venkatramanan, S.; Ramkumar, T.; Wang, S. Remote sensing and GIS based groundwater potential zone mapping in Ariyalur District, Tamil Nadu. *J. Geol. Soc. India* **2018**, *92*, 484–490. [CrossRef]

71. Souissi, D.; Msaddek, M.H.; Zouhri, L.; Chenini, I.; El May, M.; Dlala, M. Mapping groundwater recharge potential zones in arid region using GIS and Landsat approaches, southeast Tunisia. *Hydrol. Sci. J.* **2018**, *63*, 251–268. [CrossRef]