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GIS – based groundwater potentiality mapping using AHP and FR models in central Antalya, Turkey

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Abstract: Groundwater is considered as one of the essential natural resources stored beneath the earth surface by infiltration through various rock layers. Groundwater potential supplies almost 30% of fresh water in the world, and in general, 65% of groundwater is used for agricultural irrigation, 25% as drinking water, and the remaining 10% is utilized as industrial water. The main aim of this study is to delineate groundwater potential zones in the central Antalya province, Turkey using the analytical hierarchy process (AHP) and frequency ratio (FR). Seven thematic layers including lithology, slope, drainage density, landcover/landuse, lineament density, rainfall, and soil depth were considered as influencing parameters to run these models. The preparation of all geospatial datasets was carried out in GIS environment and Google Earth Engine. Besides, some authorized relevant web portals were also tried for obtaining the required spatial data. The findings of analysis by AHP and FR models show that Muratpasa, Kepez, and eastern Dosemealti in the eastern part of study area are characterized by high potentiality of groundwater, while the regions in southern, western parts covered by igneous rocks and other less permeable sediments, also featured by high and steep slopes are followed by low or very low groundwater potential. Consequently, the results from both models were assessed using receiver operating curve (ROC) and area under curve (AUC) for validation. The validation in this study confirms the higher effectivity of results achieved by FR than the AHP model.

Keywords: GIS, groundwater, AHP, FR, potential, lithology

1. Introduction

Groundwater is considered as one of the vital elements of nature which is found in the voids of the earth and packs the pore space of soil beneath the water table [1–4]. Groundwater is proven as one of the most significant natural resources which is dependent as a source of water supply in all climatic regions of the world [5, 6]. Almost 30% of the world's fresh water is supplied by groundwater while only 0.3% is furnished by surface water including lakes, reservoirs, and rivers [4, 7]. The main sources of groundwater are rainwater and snowmelt which are leaching down through the soil pores into the aquifer [8].

At present time due to rapid growth of industrialization and population, demands on fresh water directly affected on groundwater has been increasing which is a worldwide concern, therefore exploitation of groundwater is considered as an essential part of water management and planning [4, 7]. The availability of groundwater resources depends on the diverse geological, morphological, biological and atmospheric characteristics factors including lithology, topographic condition, geologic structures, climate, soil type and many other, and the movement mainly depends on the porosity, permeability, transmissibility, and the storage capacity of the rocks [9–12].

There are several approaches for targeting groundwater potential by considering these factors. The applicable methods are geological, geophysical and remote sensing which have been examined by many scientists. The efficiency of methods are varied, some of them are more effective, accurate, time saving and with less cost, while the traditional methods are time consuming and require high expenses [13–15]. Furthermore, integration of GIS and remote sensing studies has the capability to analyse and store huge amounts of geospatial data and delineate groundwater potential using different methods [4, 15, 16].

Several studies have been carried out for groundwater management using various multi-criterial decision making and learning machines algorithms [12, 13, 17–19]. Diverse studies have been undertaken on groundwater potential mapping using Analytical Hierarchy Process (AHP), Frequency Ratio (FR), and Influencing Factor [4, 15, 20–26]. Some other researchers have examined logistic model tree, Dempster-Shafer model, certainty factor, logistic regression, random forest model, maximum entropy model, decision tree model, artificial neural network for delineation of groundwater potentiality [27–31].

Central Antalya is mostly covered by agricultural areas consuming groundwater reservoirs, also in some areas, groundwater is characterized by pollutants. Due to Mediterranean climate, the study area is characterized by hot and dry weather in summer and warm weather in winter, hence distinct groundwater management and planning is required to overcome the problems arising from drought. The initial planning is highlighting groundwater potential mapping. Therefore, this study aims to delineate the groundwater potential zones using AHP and FR models in a GIS environment. The findings of this study sufficiently contribute to further detailed groundwater related studies, agricultural irrigation planning, urban planning in Antalya province.Central Antalya is mostly covered by agricultural areas consuming groundwater reservoirs, also in some areas, groundwater is characterized by pollutants. Due to Mediterranean climate, the study area is characterized by hot and dry weather in summer and warm weather in winter, hence distinct groundwater management and planning is required to overcome the problems arising from drought. The initial planning is highlighting groundwater potential mapping. Therefore, this study aims to delineate the groundwater potential zones using AHP and FR models in a GIS environment. The findings of this study sufficiently contribute to further detailed groundwater related studies, agricultural irrigation planning, urban planning in Antalya province.

2. Study area

Central Antalya is located in the south western part of Turkey within the 29o44/ - 35o52/ longitudes and 36o41/ - 37o20/ latitudes over the Antalya Travertine Plateau. It contatins the area of almost 4060 km2 which covers the 5 districts; Korkuteli, Dosemealti, Kepez, Muratpasa, and Konyaalti. Regionally the study area is bordered with Sparta, Burdur, Denizli provinces and Toros Mountains in the the north and with the Mediterranean sea in the south east (Figure 1). The study area is characterized by Mediterranean climate which is hot and dry in summer and warm – rainy in winter seasons.

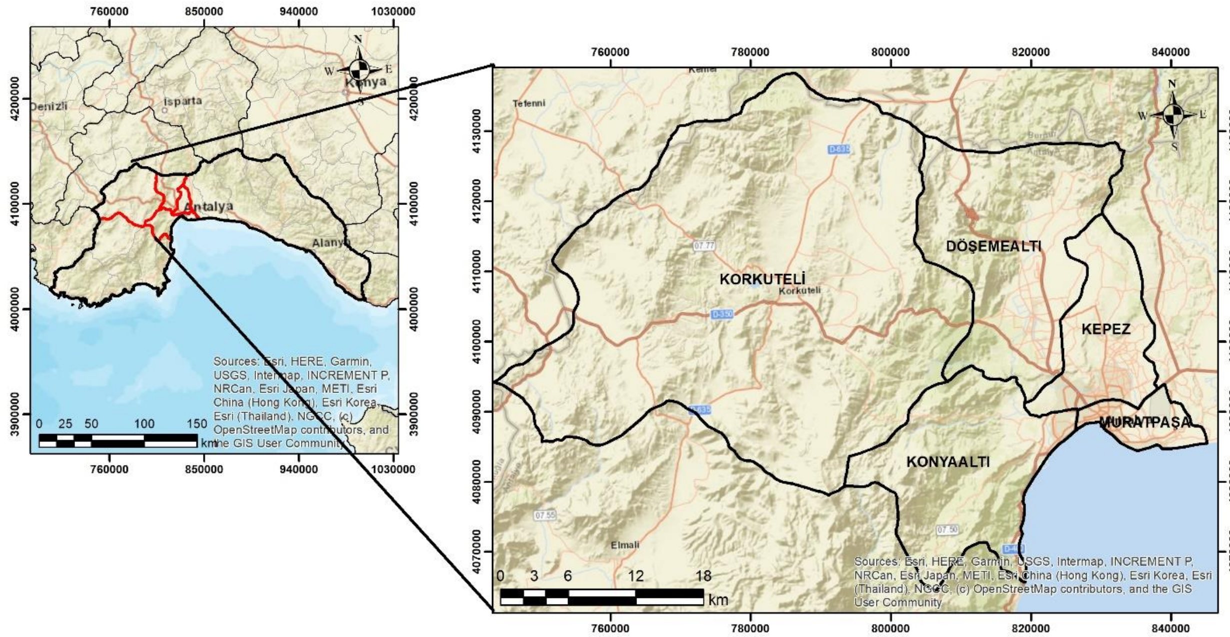

Figure 1. Location of study area

3. Material and Methods

Geographic Information System and remote sensing were used in this study to map groundwater potential zones by examining analytical hierarchy process and frequency ratio models. Totally seven thematic layers including lithology, slope, drainage density, landcover/landuse, lineament density, rainfall, and soil depth were generated and weighted considering the expert ideas and previous literature. The whole design of methodology is depicted in (Figure 2).

3.1. Generation of Geospatial Datasets

Remotely sensed, conventional, and climatic data were provided from different organizations and authorized websites to generate thematic layers influencing groundwater potential. Lithology of an area is the most critical factor while considering groundwater potential zones, as rock porosity and permeability have direct impact on groundwater movement and availability [4, 15, 32] . The lithological map of the study area in scale 1:25000 was extracted from the geological map of Turkey prepared by the General Directorate of Mineral Research and Exploration (MTA) of Turkey. The map was processed and reclassified for analysis using ArcGIS 10.5 (Figure 3A). Considering the influence of geology on groundwater potential, most of the study area is covered by sedimentary and metamorphic rocks, as one of the largest travertine plateaus of Turkey is situated in the eastern part including Kepez, Muratpasa, and south eastern part of Dosemealti districts. Moreover, central, western, and northern parts of the study area are covered by alluvium and sandstone formation which are good indicators of groundwater recharge. Based on the presence of igneous rocks within the south east and south west, it is judged that groundwater activities are less in these areas due to less permeability of rocks.

Several studies describe that slope and drainage density have significant roles in run off and penetration of water which control the groundwater. SRTM DEM was downloaded from the USGS website through scripting in Google Earth Engine and was processed in GIS environment. Both slope and drainage density thematic layers were classified into five classes. The areas with high slope pave the way for high runoff and erosion and less permeability, while the areas with gentle slope correspond to less runoff and high infiltration [15, 23, 33] (Figure 3B). It is seen that Kepez, Muratpasa, eastern Dosemealti, and central Korkuteli districts within the study area comprise gentle slopes (0 – 16 o), while the western part of Desemalti, and most of Konyaalti districts are characterized by moderate slopes of (32 – 48 o), only 3% of the study area accounts for steep slope (54 – 80o).

Drainage density has also significant influence on run off and groundwater infiltration as the high density of drainage indicates high runoff and less groundwater recharge whereas high groundwater infiltration and less runoff are characterized by less drainage density [4, 34, 35]. The drainage network of the study area was prepared and analyzed for density using ArcGIS, the resultant map was classified and resampled into five classes (Figure 3C). It is considered that drainage density within the study area is ranging between (0 – 2.87 km-1) corresponding to moderate interval. The classes of drainage density have almost equal distribution over the area except the last class which has limited extension.

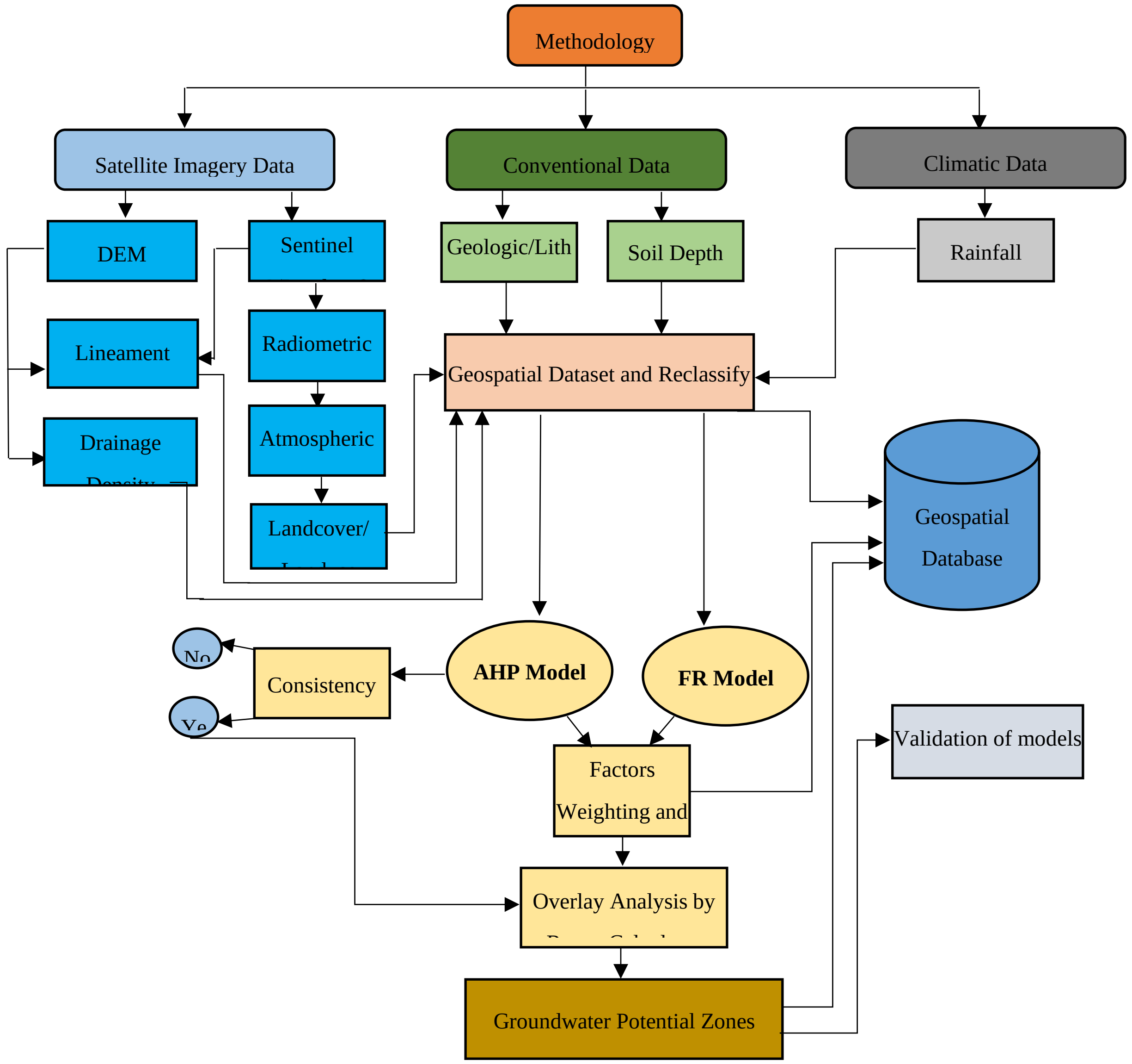

Figure 2. Flowchart describing the methodology

Land pattern and coverage play an essential role for development of groundwater activities as land covered by vegetation, forest and greening influence high infiltration of groundwater, while land covered by builtup areas decrease recharge and increase runoff flow. In this study, the landcover/landuse map was prepared by integration of Sentinel 2 MSI and CORINE Land Cover 2018 from the official website of Copernicus. The classification was carried out in Google Earth Engine, ENVI 5.7, and ArcGIS 10.5. The final landcover/landuse map is characterized by 9 classes: forest, sparse plants, natural grassland, agricultural areas, urban areas, mining extraction areas, waterbodies, bare soil, and bare rocks (Figure 3D). It declares that most of the area is covered by forests and agricultural areas, and limited sections in the south eastern part are dedicated to build up areas. The water body reservoirs have limited distribution over the study area. The forests, agricultural areas, grasslands, and sparse plants significantly help the process of groundwater activities and recharge.

Lineaments are defined as linear or curvilinear structures on the earth surface and are indicators of weaker zones of bed rocks. Lineament density has a fundamental role in groundwater potential indirectly as the high potential zones of groundwater are followed by high density of lineaments [23]. The lineament map was prepared using visual interpretation and automatic extraction in this study. SRTM DEM 30m and Landsat 8 were used to automatically extract lineaments using ArcGIS and PCI Geomatica software. Visual interpretation and elimination of all anthropogenic features such as roads, canals, rivers, etc. were conducted on the resultant map to achieve the final thematic layer. The final map was targeted to generate the lineament density map processed in the GIS environment (Figure 3E). The existence of lineaments on igneous rocks are effective for groundwater recharge, however in this study, lineaments with high density are found farther from igneous masses. The lineaments trend in NE-SW direction.

The rainfall factor is considered as one of the most significant hydrologic elements which crucially effect groundwater recharge [15, 36]. Rainfall data was downloaded from the official web portal of Center for Hydrometeorology and Remote Sensing (CHRS) with spatial resolution of 1km for 10 years between 2009 to 2020. An average annual rainfall map for the study area was generated and resampled as raster data in ArcGIS Desktop (Figure 3F). The rainfall map shows that coastal areas experience less annual precipitation than eastern and central parts. Rainfall is one of the main sources of groundwater within the study area which ranges between 401.42 – 549 mm annually.

Soil depth is another important control on groundwater potential as a region with higher depth of soil is a place for developing of higher potential of groundwater. The soil depth spatial map was prepared using well log data in GIS environment (Figure 3G). South western and northern parts are characterized by deep soil depth, whereas central and western parts have shallow and moderate soil coverage.

3.2. Analytical Hierarchy Process (AHP)

AHP is a multicriteria model for complex decision making through assessing multiple factors which was first introduced by [37]. The model stands for inputting influencing parameters which are accomplished by the opinions and knowledge of experts [15, 38]. Based on [39], the AHP model contains the definition of objectives, determination of required criteria, pairwise comparisons and matrices preparation, determining relative weights using eigenvalue techniques, calculating consistency ratio of model, and final decision-making steps.
The influence and importance of each factor are defined by making a pairwise matrix and the factors are valued on [37] scale from 1 (equal significance) to 9 (extreme significance) shown in (Table 1).

Table1. Pairwise comparison matrix between all factors for AHP model

	Factors						
Factors	Lithology	Slope	Drainage Density	Landcover/ Landuse	Lineament Density	Rainfall	Soil Depth
Lithology	1.00	3.00	4.00	5.00	5.00	7.00	6.00
Slope	1/3	1.00	2.00	2.00	4.00	5.00	6.00
Drainage Density	1/4	½	1.00	2.00	3.00	4.00	5.00
Landcover/Landuse	1/5	½	1/2	1.00	2.00	3.00	4.00
Lineament Density	1/5	¼	1/3	1/2	1.00	2.00	3.00
Rainfall	1/7	1/5	1/4	1/3	1/2	1.00	1.00
Soil Depth	1/6	1/6	1/5	1/4	1/3	1.00	1.00
Sum	2.29	5.61	8.28	11.08	15.83	23.00	26.00

The normalized pairwise comparison matrix is prepared by division of each cell by the total of each column, normalized weights are obtained for each factor by the average of each row shown in (Table 2.).

Table 2. Normalized pairwise comparison matrix and weights of each factor

Factors	Factors							
	Lithology	Slope	Drainage Density	Landcover/ Landuse	Lineament Density	Rainfall	Soil Depth	Weights
Lithology	0.4361	0.5341	0.4829	0.4511	0.3158	0.3043	0.2308	0.3936
Slope	0.1454	0.1780	0.2414	0.1805	0.2526	0.2174	0.2308	0.2066
Drainage Density	0.1090	0.0890	0.1207	0.1805	0.1895	0.1739	0.1923	0.1507
Landcover/Landuse	0.0872	0.0890	0.0604	0.0902	0.1263	0.1304	0.1538	0.1054
Lineament Density	0.0872	0.0445	0.0402	0.0451	0.0632	0.0870	0.1154	0.0689
Rainfall	0.0623	0.0356	0.0302	0.0301	0.0316	0.0435	0.0385	0.0388
Soil Depth	0.0727	0.0297	0.0241	0.0226	0.0211	0.0435	0.0385	0.0360
Sum	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Once the weights are assigned, it is required to calculate consistency of the matrix, it is judged by the Consistency Ratio following equation developed by [37].

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

Where, CR is consistency ratio, CI is consistency index, RI is random index which is taken from a table prepared by [37]. It depends on the number of criteria and in this study, it is equal to 1.32. CI is calculated using the following equation:

$$CI = \frac{\lambda \max - n}{n - 1}$$

Where, λmax is the principle eigenvalue of the matrix and is calculated from the matrix that comes to 7.3 in this study, n is the number of factors considered for groundwater potential which is 7. According to [37, 40], the CR obtained must be less than 0.1. If it comes greater than 0.1, then the pairwise comparison matrix should be readjusted by assigning different values to factors [41]. The CR of this study was found $0.0342 < 0.1$ which judges the consistency of matrix.

All the factors were classified into sub classes and were ranked based on their impact on groundwater activities. Finally the ranks of each sub class were normalized by division of each rank value into summation of all ranks as shown in (Table 3).

The groundwater potential zones (GPZ) were obtainen by application of the following equation carried out through raster calculator or ArcGIS.

$$GPZ = \sum_{i=1}^{n} AHP = Lt_W Lt_R + Sl_W Sl_R + DD_W DD_R + LC/LU_W LC/LU_R + LD_W LD_R + Rf_W Rf_R + SD_W SD_R$$

Where, GPZ is groundwater potential zone, AHP is Analytical Hierarchy Process, Lt is lithology, Sl is slop, DD is drainage density, LC/LU is landcover/landuse, LD is lineament density, Rf is rainfall, SD is soil depth, W is weighting, and R is rating.

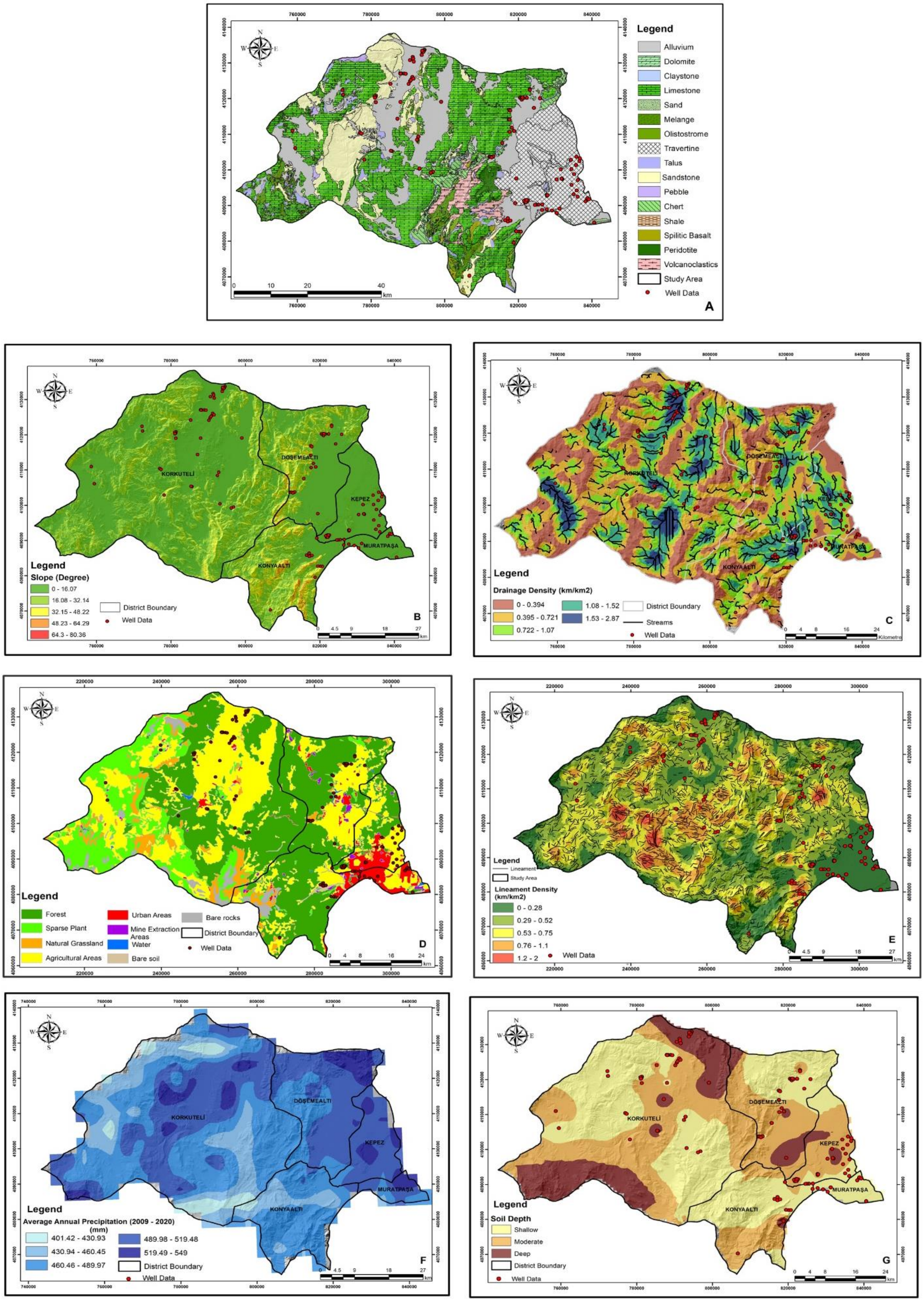

Figure 3. Thematic spatial maps of study area; A) lithology, B) Slope, C) Drainage Density, D) Landcover/Landuse, E) Lineament Density, F) Rainfall, and G) Soil Depth

Table 3. Assigned normalized weights and rates for all factors and sub – classes

No	Factors	Sub – Classes	Rating	Normalized Rates	Weights
1	Lithology	Alluvium	6	0.113	0.3936
		Dolomite	3	0.057	
		Claystone	1	0.019	
		Limestone	7	0.132	
		Sand	4	0.075	
		Melange	2	0.038	
		Olistostrome	2	0.038	
		Travertine	6	0.113	
		Talus	2	0.038	
		Sandstone	4	0.075	
		Pebble	3	0.057	
		Chert	6	0.113	
		Shale	1	0.019	
		Spilitic Basalt	2	0.038	
		Peridotite	2	0.038	
		Volkanoclastics	2	0.038	
2	Slope	< 16.07	5	0.333	0.2066
		16.08 – 32.14	4	0.267	
		32.15 – 48.22	3	0.200	
		48.23 – 64.29	2	0.133	
		> 64.3	1	0.067	
3	Drainage Density	< 0.394	5	0.333	0.1507
		0.395 – 0.721	4	0.267	
		0.722 – 1.07	3	0.200	
		1.08 – 1.52	2	0.133	
		> 1.53	1	0.067	
4	Landcover/Landuse	Bare Rocks	2	0.050	0.1054
		Mine Extraction areas	3	0.075	
		Natural Grasslands	4	0.100	
		Forests	7	0.175	
		Sparse Plants	5	0.125	
		Waterbodies	8	0.200	
		Agricultural areas	5	0.125	
		Bare soil	4	0.100	
		Urban areas	2	0.050	
5	Lineament Density	< 0.28	1	0.067	0.0689
		0.29 – 0.52	2	0.133	
		0.53 – 0.75	3	0.200	
		0.76 – 1.1	4	0.267	

		> 1.1	5	0.333	
6	Rainfall	< 430.93	1	0.067	0.0388
		430.94 – 460.45	2	0.133	
		460.46 – 489.97	3	0.200	
		489.98 – 519.48	4	0.267	
		> 519.49	5	0.333	
7	Soil Depth	Shallow	2	0.200	0.0360
		Moderate	3	0.300	
		Deep	5	0.500	

3.3. Frequency Ratio (FR)

Frequency ratio is a bivariate statistical model applied as an essential tool for geospatial assessment to determine the probabilistic relationship between dependent and independent variables or multi classified thematic layers [11, 15]. [42] asserted that FR is cosidered as the probability of occurrence of a certain factor. In groundwater potential mapping, it is applied based on the relationship between distribution of observational wells and parameters influencing groundwater potential [4]. Freuqncey ratio in this study was calculated using the following equation:

$$FR = \left[\frac{\left(\frac{P_{gw}}{T_{gw}}\right)}{\left(\frac{P_f}{T_f}\right)}\right] = \frac{\%\,wells}{\%\,pixels}$$

Where, FR stands for frequency ratio, P_gw is the number of pixels with groundwater well for each sub class of a factor, T_gw is total number of wells, P_f is the number of pixels in each sub class of a factor, T_f is the total number of pixels of a factor. In this study, a total of 141 well data with high yield were used, and the FR was calculated by the integration of FR of each sub class of factors in ArcGIS 10.5 using the following formula:

$$GPZ = \sum_{i=1}^{n} FR = Lt_{FR} + Sl_{FR} + DD_{FR} + LC/LU_{FR} + LD_{FR} + Rf_{FR} + SD_{FR}$$

Where, GPZ is the groundwater potential zone, FR is frequency ratio. The data considered in the above formula was calculated in Table 4.

Table 4. Spatial relationship between factors and wells with assigned FR for each sub-class

No	Factors	Sub – Classes	No of pixels	Percentage of sub class	No of wells	Percentage of wells	FR
1	Lithology	Alluvium	345076	21.25	69	48.94	2.303
		Dolomite	1028	0.06	0	0.00	0.000
		Claystone	2737	0.17	0	0.00	0.000
		Limestone	592052	36.46	12	8.51	0.233
		Sand	3532	0.22	3	2.13	9.783

		Melange	49510	3.05	0	0.00	0.000
		Olistostrome	16588	1.02	0	0.00	0.000
		Travertine	211013	12.99	48	34.04	2.620
		Talus	45655	2.81	1	0.71	0.252
		Sandstone	220921	13.60	7	4.96	0.365
		Pebble	11176	0.69	0	0.00	0.000
		Chert	52394	3.23	1	0.71	0.220
		Shale	234	0.01	0	0.00	0.000
		Spilitic Basalt	9309	0.57	0	0.00	0.000
		Peridotite	15059	0.93	0	0.00	0.000
		Volkanoclastics	47714	2.94	0	0.00	0.000
2	Slope	< 16.07	662532	40.80	111	78.72	1.930
		16.08 – 32.14	391247	24.09	16	11.35	0.471
		32.15 – 48.22	319286	19.66	4	2.84	0.144
		48.23 – 64.29	197243	12.15	7	4.96	0.409
		> 64.3	53571	3.30	3	2.13	0.645
3	Drainage Density	< 0.394	401889	24.84	17	12.06	0.485
		0.395 – 0.721	483391	29.87	25	17.73	0.593
		0.722 – 1.07	394551	24.38	33	23.40	0.960
		1.08 – 1.52	256027	15.82	41	29.08	1.838
		> 1.53	82206	5.08	25	17.73	3.490
4	Landcover/Land use	Bare Rocks	35418	2.18	0	0.00	0.000
		Mine Extraction areas	9376	0.58	0	0.00	0.000
		Natural Grasslands	82159	5.06	8	5.67	1.121
		Forests	668037	41.17	29	20.57	0.500
		Sparse Plants	219736	13.54	3	2.13	0.157
		Waterbodies	3168	0.20	0	0.00	0.000
		Agricultural areas	535478	33.00	70	49.65	1.504
		Bare soil	5256	0.32	0	0.00	0.000
		Urban areas	63977	3.94	31	21.99	5.576
5	Lineament Density	< 0.28	59630	14.71	51	36.17	2.460
		0.29 – 0.52	111176	27.42	35	24.82	0.905
		0.53 – 0.75	123274	30.40	37	26.24	0.863
		0.76 – 1.1	83001	20.47	10	7.09	0.346
		> 1.1	28416	7.01	8	5.67	0.810
6	Rainfall	< 430.93	53933	3.28	6	4.26	1.298
		430.94 – 460.45	234155	14.24	9	6.38	0.448
		460.46 – 489.97	674202	40.99	46	32.62	0.796
		489.98 – 519.48	566163	34.42	65	46.10	1.339
		> 519.49	116440	7.08	15	10.64	1.503

		Shallow	717956	44.23	72	51.06	1.155
7	Soil Depth	Moderate	648620	39.96	47	33.33	0.834
		Deep	256656	15.81	22	15.60	0.987

4. Results and Discussion

Considering the 7 most influential thematic layers on groundwater potential, the map deduced from AHP and FR calculation was prepared and classified into four classes based on the Jenk classification scheme in ArcGIS 10.5 ranging from very low, low, and moderate to high classes.

For AHP analysis which is a common multi criteria decision maker model for various geospatial investigation, all the considered thematic layers were classified differently, while most of them are into five classes. The factors, and sub – classes were weighted and ranked based on their importance and having the opinions of relevant experts. The overall CR was obtained 0.034 which show the high consistency of model application. The resultant map by AHP model (Figure 4a) shows that 24% and 39% of the total area of central Antalya province is characterized by moderate and high groundwater potential (Table 5). These areas have almost regular distribution over all the districts except for Konyalti. The land coverage shows that areas covered by travertine, alluvium and agricultural sites having moderate and high groundwater potential.

The very low and low potential are seen over areas covered by less greening or igneous rocks. Frequency ratio (FR) was applied to find the ratio between the percentage of wells availability within a certain class and area of each sub class of a factor [15]. As described in (Table 4), higher FR is found for sand sediments in which the lithology factor is 9.783.

In the slope factor, flat areas are followed about 79% of all well, hence the slope less than 16 degree is having the highest FR which is (1.93). In this study, the frequency ratio is getting high by increasing the drainage density as a density of more than 1.53 km-1 accounts for the highest FR of (3.49). The same trending of ratios is seen in other case studies as well by [4, 15]. Considering the landcover pattern, the higher number of wells are seen within agricultural and urban areas, which show the highest frequency ratios of 1.5 and 5.57. The largest number of wells are distributed within the lesser density of lineaments hence they have the highest FR of 2.46. The regions highlighted by the highest amount of annual precipitation are characterized by highest frequency ratio (1.5). Almost 50% of groundwater wells were drilled within the regions with shallow thickness of soil, therefore they have higher FR (1.15). The final resultant map by FR model was also classified into four classes according to Jenk Classification Scheme and showing that 48% of the study area is characterized by low and moderate groundwater potential while only 4% of the region contains high potential (Figure 4b..) (Table 5).

Table 5. The distribution of groundwater potential classes based on AHP and FR models.

Class	AHP Model			FR Model		
	Range	Area (km2)	Area (%)	Range	Area (km2)	Area (%)
Very Low	0.0743 – 0.1472	377.125	9.71	2.4140 – 5.6005	1807.733	46.54
Low	0.1473 – 0.1717	1068.54	27.51	5.6006 – 8.6277	853.6725	21.98
Moderate	0.1718 – 0.1922	1508.575	38.84	8.6278 – 12.7702	1066.238	27.45
High	0.1923 – 0.243	930.17	23.95	12.7703 – 22.7280	156.8275	4.04

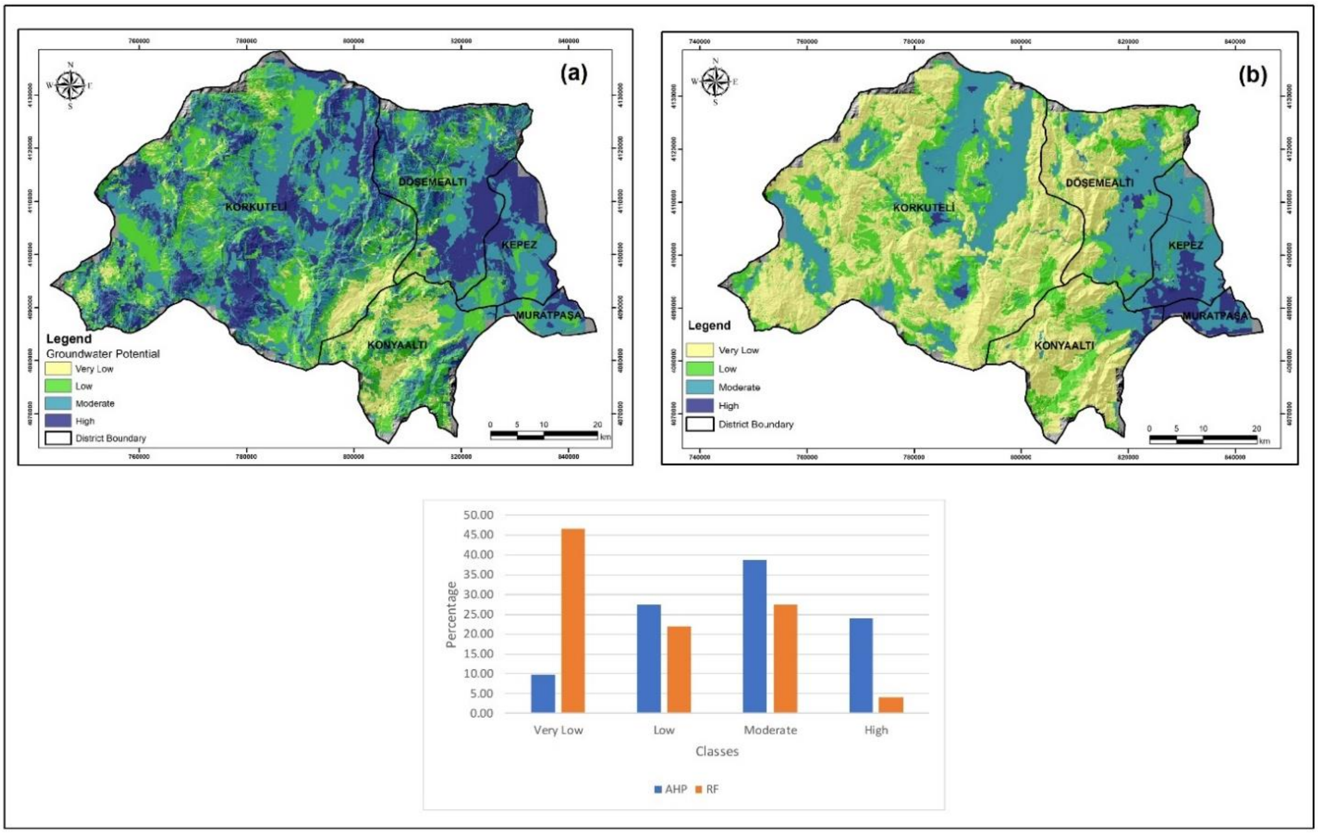

Figure 4. The groundwater potential maps for central Antalya, Turkey by a) AHP Model, b) FR Model.

4.1. Validation

Each model must be validated as [43] asserts that a model finds its significance when it is validated. There are several methods for checking the accuracy and validation of groundwater potential maps generated by AHP and FR models. The most usable validation techniques are reciver operating chacteristics (ROC) analysis and area under curve (AUC) which have been examined by several scholars [4, 6, 15, 20, 44]. In this study wells with high yield and a generated groundwater potential dataset were considered to analyse the ROC curve. The ROC curve was prepared by considering the percentage of groundwater potentential classes on the x axis and percentage of groundwater wells on the y axis.

Once the ROC was created, AUC was calculcated to find the accuracy of models and the correct occurrence or non-occurrence of pre-defined classes (Figure 5). The quantitative – qualitative of AUC for the AHP model was calculated 0.56 (or accuracy of 56%), while AUC for FR model shows 0.65 (accuracy of 65%). Based on [15, 45], the AUC values corresponding to prediction accuracy can be divided into: poor (0.5 – 0.6), average (0.6 – 0.7), good (0.7 – 0.8), very good (0.8, 0.9), and excellent(0.9 – 1). Calculation and plotting of AUC for both models shows that results from FR model are more efficient than AHP model in the study area.

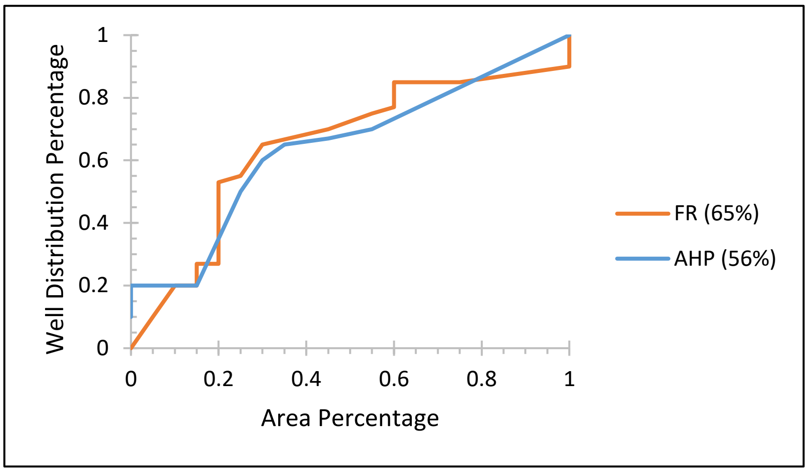

Figure 5. Chart showing the ROC curve and AUC for AHP and FR models

5. Conclusions

Groundwater potential mapping has been carried out using different traditional and remotely based approaches for decades. The use of remote sensing technology and GIS makes it easy and accessible for experts to conduct potential mapping with low effective costs and time consumed. Various spatial and non-spatial modelling using GIS environment are applied to demarcate groundwater potential in which their accuracy is different. In this study, analytical hierarchy process and frequency ratio models were applied by considering seven thematic layers: lithology, slope, drainage density, landcover/landuse, lineament density, rainfall, and soil depth.

By giving high importance to lithology of the region and less importance to the soil depth layer, Muratpasa, Kepez, and eastern Dosemealti districts are followed by the high potential of groundwater based on both models. The main reasons for high potential of these districts are existence of a huge travertine plateau which makes an environment for higher permeability of groundwater. The regions are characterized by steep slopes, also igneous rocks coverage is directed to low and very low groundwater potential due to huge amounts of run off on the surface. The regions covered by agricultural, forest areas and alluvium have moderate potential for groundwater.

The reliability of the AHP model for groundwater potential demarcation is directly dependent on the assignment of the weights and ranks to each class and sub-class. Therefore, deep study and knowledge on factors influencing the targeted object are required, also the geographical, geological, and hydrological characteristics of the study area are another point to be contemplated. Implementation of FR does not require more knowledge of users to set ranks or weights, while the model itself finds ratio of factors which gives more reliable results. The final resultants maps and validation confirm that groundwater potential mapped by FR is more reliable and efficient than the AHP model. The results from this study can be a hint for the responsible departments to have accurate future planning of groundwater in terms of distribution, planning, consumption, and artificial recharge. Moreover, the findings should be followed with further detailed field work and other relevant studies to accomplish accurate groundwater potential mapping at large scale over the small districts and villages.

Conflict of interest

The authors declare that there is not any potential conflict arising out of this paper. The paper is also not accompanied by any funding resources.

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