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ARTICLE

Use of GIS to Estimate Recharge and Identification of Potential Groundwater Recharge Zones in the Karstic Aquifers, West of Iran

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ARTICLE INFO

Article history
Received: 4 October 2022
Revised: 31 October 2022
Accepted: 5 November 2022
Published Online: 11 November 2022

Keywords:
Karstic aquifers
Remote sensing
GIS
AHP
Aquifer recharge coefficient
Iran

ABSTRACT

Estimating and studying groundwater recharge is necessary and important for the management of water resources. The main aim of this work is to estimate the value of the annual recharge in some parts of the Kermanshah and Kurdistan province located in the west of Iran. There are many approaches available for estimation of the recharge, but RS (remote sensing) and GIS (geographic information system) have provided and combined a lot of effective spatial and temporal data of large areas within a short time. For this purpose, nine information layers including the slope, aspect of slope, lithology, lineament density, drainage density, precipitation, vegetation density, soil cover, and karst features were prepared and imported to the ArcMap software. After preparing the information layers, they have to weigh based on their effects on the value of the recharge. In order to be weighted the different parameters, methods of judgment experts, reciprocal influences of parameters, and AHP were used. Using GIS, the results obtained from the final map indicated the average value for the recharge based on the average calculated coefficient of recharge. The annual recharge coefficient in the study area was estimated to be between 30% and 80%.

1. Introduction

Groundwater potential is dependent on recharge, its management and sustainability require the identification of the recharge coefficient. Recharge has an impact on the groundwater flow and transport models. It is the most important parameter for abstraction from a groundwater reservoir, especially in arid and semiarid regions, like Iran, because the extraction from groundwater should not be larger than the average recharge (in the long term).

The aquifer recharge can be determined by different methods. These methods can be put into several groups such as studies on surface water, unsaturated zone, saturated zone, and remote sensing. Each of these methods can be divided into subgroups. The techniques based on surface water studies have included the surface-water budget, hydrograph analysis, direct measurement [1-6], seepage meters [7], and natural and artificial tracers. The technics

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DOI: https://doi.org/10.30564/agger.v4i4.5122

based on unsaturated-zone studies contain methods of assessment of the soil moisture balance. Many authors have worked in this field [8-10].

Some methods have been used in both the saturated and unsaturated-zones such as water balance [11-13] and Darcy's low. The application of this method requires knowing the hydraulic conductivity and hydraulic head in the unsaturated zone. Natural tracers [14-17] and CMB (Chloride Mass Balance) have been used by many researchers for the estimation of recharge [18,19]. Water table fluctuation (WTF) is based on the measurement of the water level before and after precipitation, and with this measurement, the recharge has been estimated [19]. Modeling is another method for evaluation of the recharge [19,20]. The appropriate technique used for estimating the recharge in a saturated zone is the saturated volume fluctuation (SVF).

As is clear, there are many different ways to estimate the recharge, but because of the expanse of the study area, using the RS (remote sensing) and GIS (geographic information system) is the most beneficial way. Other methods are usable at the local scale, in which there is a lot of data and equipment. The RS and GIS are powerful and unique tools used for managing and evaluating vital groundwater recharge. These have provided and combined a lot of effective spatial and temporal data of large areas within a short time. The RS and GIS technics have been used for the evaluation and estimation of the recharge zone [21-29,13].

The study area covers an area of about 22000 km^2 situated in Kermanshah and Kurdistan province in the West of Iran (Figure 1). It is located between 46.48°-47.93°E longitude and 34.19°-35.36°N latitude. The study area has a Mediterranean climate. The temperature ranges between 6 °C and 21 °C, and the total annual rainfall is ranging from 350 mm to 750 mm. Based on the average precipitation and temperature in this area, by using the interpolation of weather station data in the study area, there are three different zones of precipitation. Zone A in the central and west has 385 mm, zone B with 700 mm in the northwest, and other parts have 515 mm. The population in the study area is more than 2 million people. Most of this area is covered by the mountainous region. The most geologic setting of the studied area is limestone and dolomite, and there are sandstone, shale, conglomerate, radiolarite, volcanic rocks consisting of andesite and gabbro in some parts, and also alluvium deposits of Quaternary age (this part has an agricultural plain). The major formations in the mountainous region are carbonate formations.

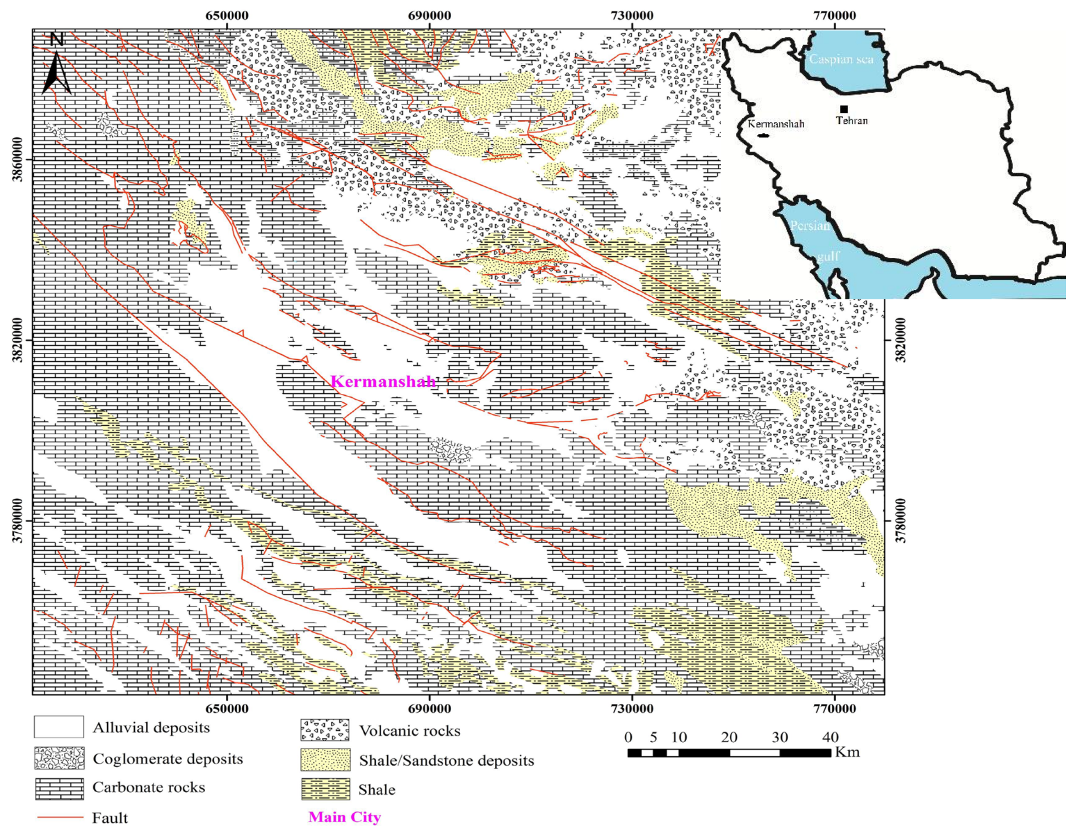


Figure 1. Geological map of the study area.

Figure 1 shows the geological map of the area. There are several important karstic aquifers in the study area. Because of the breadth of the study area, using RS and GIS is the most efficient way. The estimated recharge for the different geological settings is more complicated because this area has more heterogeneity, so GIS is a very convenient tool. The objection against GIS is the large number of expert comments it received. This problem has partly been solved using the methods applied in this paper.

The fundamental aims of this study are:

1) Estimating the annual recharge in the study area

2) Determining the important potential zone for the recharge

3) Introducing and comparing several different methods weighing in GIS to evaluate the recharge.

2. Materials and Methods

To achieve the above goals, GIS was applied. The mean coefficient of annual recharge for this area was calculated using three various methods for weighing, rating and comparing with others and the real discharge was measured. First, the layers of information corresponding to the recharge were introduced into GIS. For this work, ENVI 4.3, Google Earth, global mapper 13, and ArcGIS 10 were used. Finally, the layers were entered into ArcMap. For rating and weighing the prepared layers, three methods were used, which are explained below.

3. Results and Discussion

The estimation and evaluation of the groundwater recharge potential zones have been explored by analyzing the various parameters such as lithology, slope, aspect, Lineament density, drainage density, precipitation, karst feature, soil cover, and vegetation cover, it has been done by using 3 different weighting methods in ArcGIS. The most important information layers which affect the recharge into the study area's aquifers are as follows:

3.1 Lithology

Lithology and hydrographic networks influences the lineaments and drainage as a function of porosity (primary and secondary), and water percolation. The distribution of the lithological formation was taken from a geological map of 1:250000 scale for Kermanshah [30], as a base, but had to be combined with the fieldwork. Satellite images (Landsat 7 ETM+) and Google Earth were used for more exact matching. The area mainly has been covered by carbonate formation and in some part igneous rocks and shale, sandstone, whereas the surrounding mountains were covered by alluvial plains. This study aims to assess the recharge in Karstic aquifers, so, only carbonate formations has been considered (Figure 3a).

3.2 Slope

The slope is an influencing factor for the percolation resulting in the recharge. The slope information layer was created using the Digital Elevation Model (DEM) of the studied area. Then it was classified in ArcGIS by degree (Figure 3b).

In steep areas, the possibility of the presence of soil and vegetative on limestone is usually low. However, sinkholes and other solutional cavities are generally absent in the steep regions. Therefore, the flat regions with low slopes, particularly on the top of mountains, play an important role in karst aquifer recharges.

3.3 Aspect (Slope Direction)

The angle of the sunbeam varies in different slope directions. Such that the resistance time of snow in the North and North-East slopes is larger than in South and South-West directions. Therefore, this factor has a major impact on the recharge, especially in snowy areas. This layer was also produced by DEM and then reclassified in ArcGIS. The North-facing slopes gave more values (Figure 3c).

3.4 Lineament Density

The term lineament is commonly used for some geological linear features. The main lineament features are the fault, rift valleys, axial traces of folds, joints and fractures, vegetation along, dike, layering of stratification, rivers, and valleys.

The faults and joints provide the possibility of percolation. The dissolution causes a larger space for more infiltrating water. The most accurate method for providing a lineament map is the fieldwork but it is more expensive and has a limited spatial viewpoint. Thus, maps of lineament can be made using remote sensing. For this purpose, geological maps, satellite images (Panchromatic band of IRS), and Google Earth were used. A satellite image enters the ENVI software, and by using the appropriate filter, becomes an apparent lineament in the studied area. Google Earth was used to correct it. More values were devoted to a higher density of lineaments. The final map was produced by the ArcGIS software (Figure 3d).

3.5 Drainage Density

The stream is the drainage path for the passage of water from the highland to lowland regions. So, the drainage density can influence the recharge because water has more time to penetrate. Because the stream contains a large value of water for a long time, it becomes the most important in the top order. This layer was plotted by ArcGIS, and controlled by Google Earth (Figure 3e).

3.6 Precipitation

More amount of precipitation results in a greater value of recharged water (in the warm months which is the high evaporation, precipitation is very low or does not occur). This layer was prepared by the data available for 12 stations in the study area that had long-time data (a thirty-year period).

Generally, the precipitation occurs concentrated relatively, during the period in which evaporation is low, for example, according to the data of Kermanshah station, the total precipitation for the water year of 2015-2016 was 654 mm, 524 mm of this amount, has been recorded in 20 days (from the end of November until March and 1 day in May). This period had 67 days of frost days. Due to the presence of large development karst areas with wide karst features in the area, the rate of recharge in mountainous areas is relatively high (Figure 3f).

3.7 Karst Feature

Other parameters that can influence the value of recharging water are Karst features. In the areas with low slopes and low evaporation (due to high elevation), up to 90% of precipitation can be infiltrated [31]. In the carbonate formation, at several points in the study area, sinkholes were observed. Such karst features can be the most effective factor for recharge (Figure 3g).

3.8 Soil Cover

Most part of this area does not have run-off, precipitation infiltrated, or volatilize. In the karstic part of the study area, cracks are, observed in the soil. The area observed is related to subsurface drainage (cracks in epikarst, according to the studied area) (Figure 2).

The soil cover layer was extracted from the satellite images, and then it was inputted into the ArcGIS software (Figure 3h).

3.9 Vegetation Density

The last layer of information produced was the vegetation density layer. To achieve the above aim, satellite images of ETM^+ and the NDVI software were used. This index was created by subtracting bands 3 and 4 and dividing by the total of them. Its range was between –1 and +1. Devoid of vegetation gave-1 and increased with the vegetation cover (Figure 3i).

The effect of each factor on recharge relative to the others is different. In the next step and before overlapping layers, it is necessary to determine the relative importance of each layer to the other layers. The expert judgment is very impressive when weighing ArcGIS. In this work, three methods were used for weighing, and the effect of the expert judgment in them is getting less. Finally, the outputs of the different methods were compared.

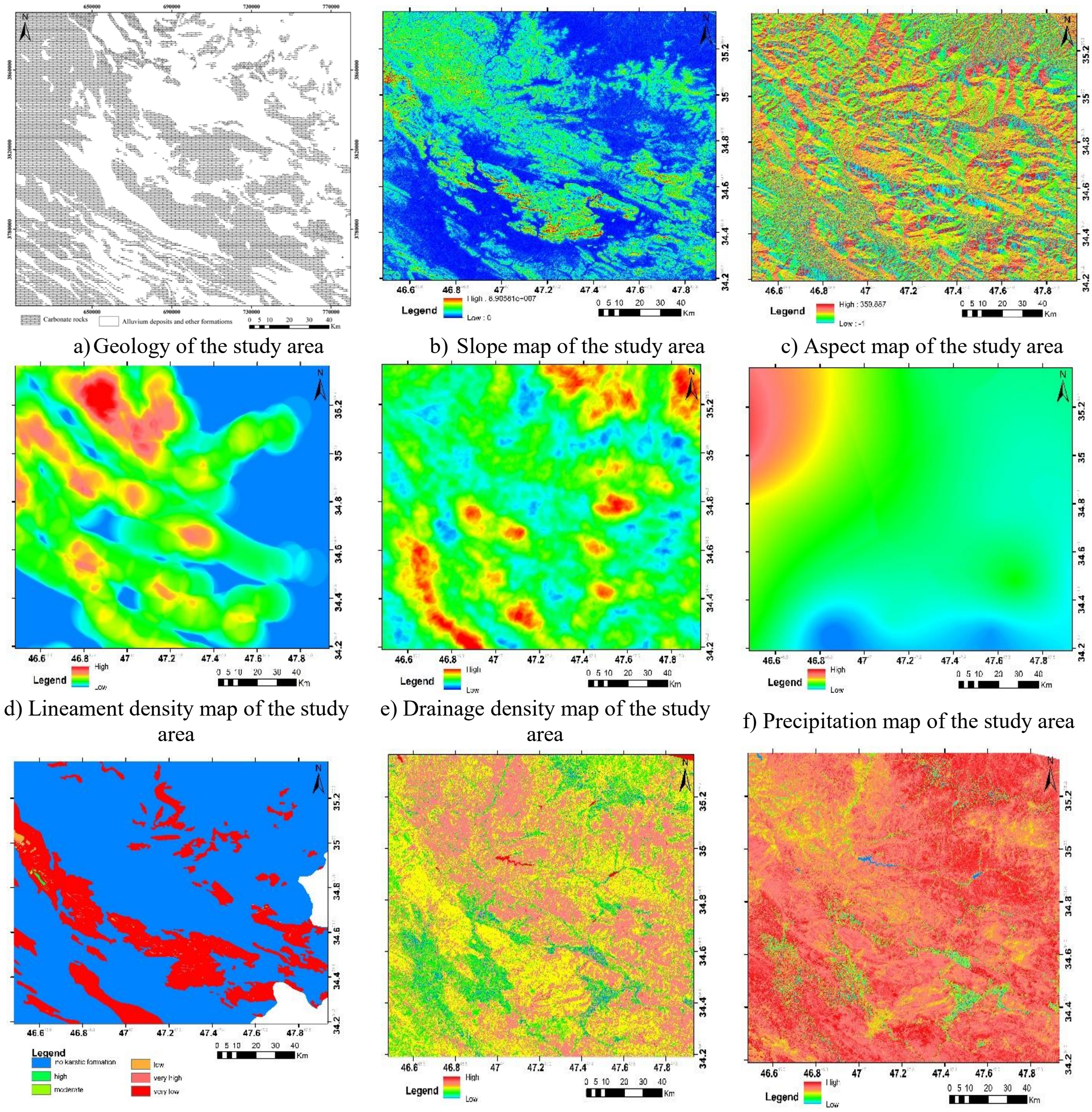
3.10 Expert Judgment

In this approach, determining the estimated weighed is based on the expert opinion that is at a specific scale, for example on a scale of 1 to 100. The 100 points were divided among the various criteria. A score of zero will be allocated to one parameter, and this parameter will be ignored. In the event that just one parameter takes 100 points, this has been considered only. The coefficients and weights for this method are presented in Table 1.

a

b

Figure 2. a) Cracks observed in the soil at the south of Ravansar, of the area, b) Epikarst observed on a mountain at north of Kermanshah.



a) Geology of the study area

b) Slope map of the study area

c) Aspect map of the study area

d) Lineament density map of the study area

e) Drainage density map of the study area

f) Precipitation map of the study area

g) Karst feature map of the study area

h) Soil cover in the study area

i) Vegetation map of the study area

Figure 3. Prepared effective layers on aquifer recharge.

3.11 Reciprocal Influences of Parameters Method

This method has been used by Shaban (2003) for the first time [21]. For this approach, the expert idea is effective only in the early stage (in the rating categories). Then each of the criteria had been evaluated and then divided into the effective major and minor parameters. One (1) point is allocated to the major effect and the minor effect gets half of the point. The sum of all points for each criterion produces its coefficient. The measured weight of each coefficient is multiplied by its initial coefficient. The final weight was obtained by summing the weights. Figure 4 shows the effect of parameters on each other.

The calculated effect for each influencing factor is expressed as follows:

Lithology: 2 minor + 4 majors = 0.5 × 2 + 1 × 4 = 5

Lineament density: 1 minor + 2 major = 0.5 × 1 + 1 × 2 = 2.5

Drainage density: 1 minor + 2 major = 0.5 × 1 + 1 × 2 = 2.5

Karst feature: 2 minor + 2 majors = 0.5 × 2 + 1 × 2 = 3

Precipitation: 4 majors = 1 × 4 = 4

Soil cover: 1 minor + 3 major = 0.5 × 1 + 1 × 3 = 3.5

Aspect: 3 minor + 1 majors = 0.5 × 3 + 1 × 1 = 2.5

Slope: 1 minor + 3 major = 0.5 × 1 + 1 × 3 = 3.5

Vegetation: 1 minor + 3 major = 0.5 × 1 + 1 × 3 = 3.5

To obtain the weight of each factor, the calculated effect and coefficient must be multiplied (Table 2). Finally,

Table 1. Categorization and weights of factors influencing recharge based on expert judgment.

Affecting factor	Classify	Rate	Weight	Affecting factor	Classify	Rate	Weight
Lineament density	< 30% 30-50% 50-65% 65-80% > 80%	3 4 6 8 9	10%	Drainage density	0-20% 20-30% 30-40% 40-55% 55-70% > 70%	2 4 5 6 7 8	14%
Soil cover	Very high High Moderate Low Without soil cover	–5 –3 –1 6 9	14%	Karst feature	Very high High Moderate Low Very low Without karst feature	9 7 6 4 3 2	15%
Vegetation	High Moderate Low Very low Without vegetation	7 6 4 2 1	10%	Aspect	N-NE SE-E NW-W SW-S ----	8 6 4 5 3	10%
precipitation(mm)	360-400 400-450 450-500 500-550 550-600 600-640 640-680 680-740 740-780	1 2 3 4 5 6 7 8 9	8%	Slope	0-1 1-5 5-7.5 7.5-12.5 12.5-22 22-33 > 33	9 7 6 5 4 3 2	14%
Lithology	Karst Alluvial Conglomerate Impure karst Shale-Sandstone Volcanic rocks	7 0 0 5 0 0	5%				

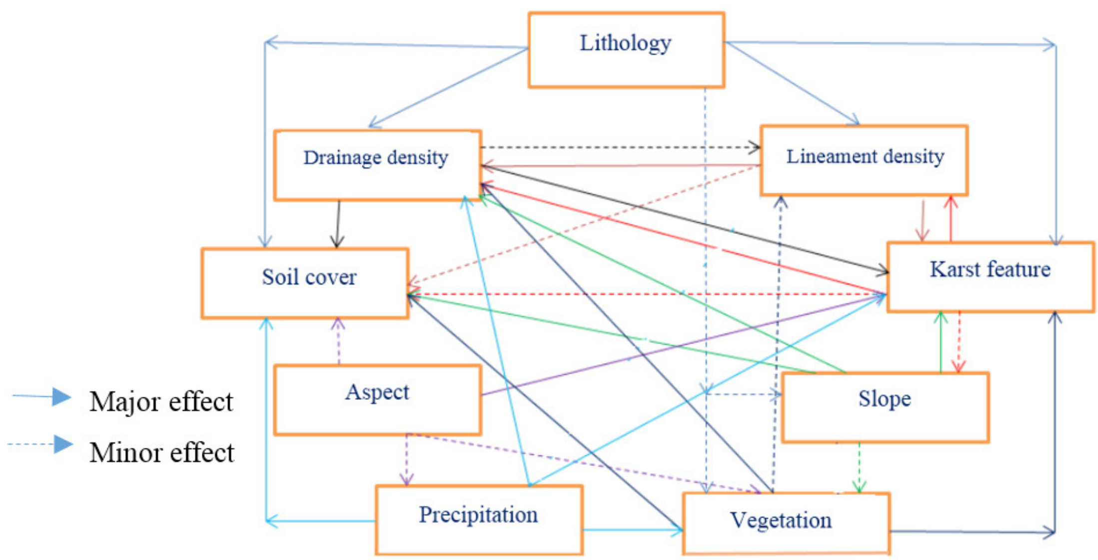


Figure 4. Schematic sketch showing affective parameters concerning aquifer recharge.

Table 2. Categorization and weight of selection factors influencing recharge, based on reciprocal influences of parameters method.

Factor	Classify	Rate (a)	The calculated effect (b)	Weight |a*b|	Sum	Total weight
Lithology	Shale-Sandstone Volcanic rocks shale-sandstone Karst-Impure karst Conglomerate alluvial	0 0 0 5 0	5	10 5 15 35 20	85	12
Lineament density	0-20% 20-30% 30-45% 45-70% > 70%	4 5 6 7 9	2.5	10 12.5 15 17.5 22.5	77.5	11
Drainage density	0-20% 20-30% 30-40% 40-55% 55-70% > 70%	2 4 5 6 7 8	2.5	5 10 15 17.5 20	67.5	10
Soil cover	Very high High Moderate Low Without soil cover	5 3 1 2 8	3.5	17.5 10.5 3.5 7 28	66.5	9
Slope	> 5 5-12.5 12-22 22-33 > 33	8 6 4 3 2	3.5	28 21 14 10.5 7	80.5	11
Aspect	N-NE SE-E NW-W SW-S -	8 6 4 5 3	2.5	20 15 10 12.5 7.5	65	9
Karst feature	Very high High Moderate Low Very low and Without karst feature	9 7 6 4 2	3	27 21 18 12 6	84	12
Vegetation	High Moderate Low Very low Without vegetation	7 6 4 2 1	3.5	24.5 21 14 7 3.5	70	10
precipitation(mm)	360-450 450-550 550-640 640-740 > 740	2 4 5 8 9	4	8 16 20 32 36	112	16

the weight of each factor must be integrated. The sum of the weights, in this case, was equal to:

$$85 + 84 + 80.5 + 65 + 77.5 + 112 + 67.5 + 70 + 66.5 = 708$$

The percentages of the factor affecting the recharge were as follows:

Lithology: (85/708) × 100 ≈ 12

Lineament density: (77.5/708) × 100 ≈ 11

Drainage density: (67.5/708) × 100 ≈ 10

Karst feature: (84/708) × 100 ≈ 12

Precipitation: (112/708) × 100 ≈ 16

Soil cover: (66.5/708) × 100 ≈ 9

Aspect: (65/708) × 100 ≈ 9

Slope: (80.5/708) × 100 ≈ 11

Vegetation: (70/708) × 100 ≈ 10

3.12 AHP Method

The Analytical Hierarchy Process (AHP) has been designed to solve multivariate problems by Saaty (1986) [32]. The values in this method are assigned from one to nine (Table 3). The AHP variable elements in each level are compared with the higher-level elements. The weights are called the relative weight and by using the integration of relative weights, the absolute weight is calculated (Figure 5). Using this method, the calculated weight for each factor varies between zero and one. The closer to one is the more important factor, and vice versa. Using the expertise and the extension of AHP in ArcMap software, the relative and absolute weights are calculated for each criterion (Table 4).

Using these methods, the coefficient of annual recharge is then calculated.

The maps obtained for each selection factor (in each method) were produced as layers. The ArcGIS software was applied to the overlaying of these layers with determined weights together. The resulting maps for each method are shown in Figure 6.

Table 3. Scale of relative importance for the AHP method (according to [32]).

Intensity of importance	Definition
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong importance
8	Very very strong importance
9	Extreme importance

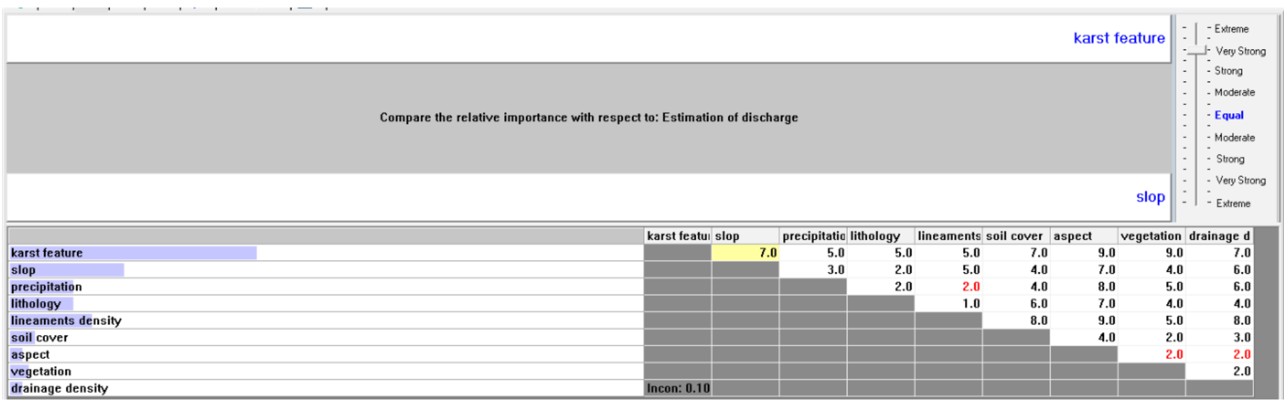


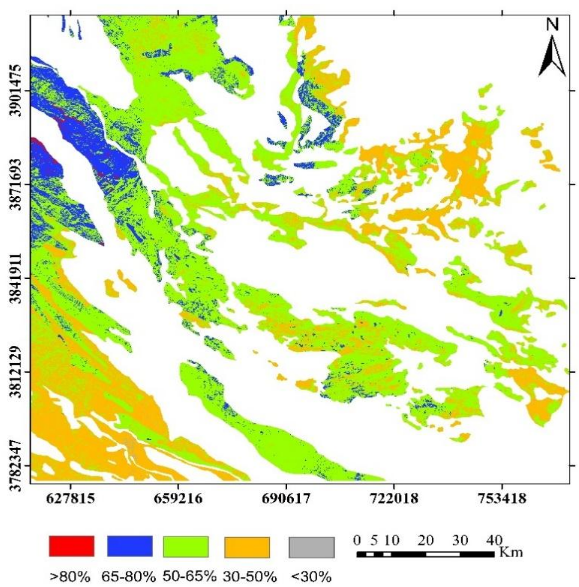
Figure 5. The matrix of the AHP method.

Table 4. Categorization and weight of factors influencing recharge based on the AHP method.

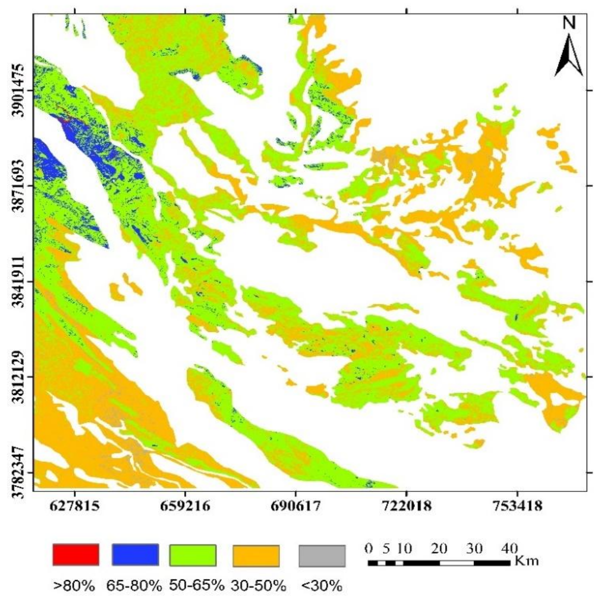
Factor	Categorize	Rate	Calculated weight by software	Factor	Categorize	Rate	Calculated weight by software
Lithology	Shale-Sandstone Volcanic rocks shale-sandstone Karst-Impure karst Conglomerate alluvial	6	0.094	Slope	> 5 5-12.5 12-22 22-33 > 33	7	0.181

Table 4 continued

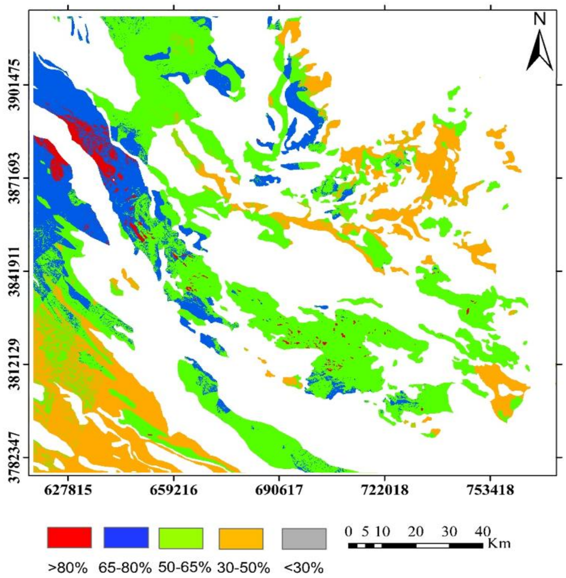
Factor	Categorize	Rate	Calculated weight by software	Factor	Categorize	Rate	Calculated weight by software
Lineament density	0-20% 20-30% 30-45% 45-70% > 70%	7	0.125	Aspect	N-NE SE-E NW-W SW-S -	4	0.016
Drainage density	0-20% 20-30% 30-40% 40-55% 55-70% > 70%	5	0.022	Karst feature	Very high High Moderate Low Very low and Without karst feature	9	0.397
Vegetation	High Moderate Low Very low Without vegetation	5	0.027	Soil cover	Very high High Moderate Low Without soil cover	6	0.037
				precipita-tion (mm)	360-450 450-550 550-640 640-740 > 740	7	0.101



a) Expert judgment method



b) reciprocal influences of parameters method



c) AHP method

Figure 6. Final recharge map of the study area, obtained by a) Expert judgment method, b) reciprocal influences of parameters method, c) AHP method.

4. Conclusions

In order to achieve the goal of this paper (to estimate the recharge in the study area), GIS was used. Although GIS was applied, the main disadvantage was the personal view intervention. To overcome this problem, the data obtained from 3 different methods were used. Although the degree of personal view intervention in them is different, the results are almost the same. The percent of their area was classified into five classes (Table 5). The recharge coefficient varied from about 30% to 80%. The maximum area and the mean recharge coefficient are shown in Table 5. In order to estimate the annual recharge, the first coefficient of recharge was calculated using Equation (1), then the value of the annual infiltration was estimated. Given that the average annual precipitation is around 473 mm, the values for the recharged water (W) for these methods Equation (1) are as follows:

Expert judgment: The average coefficient of recharge was 0.48, and the value for the infiltrate was about 2279 MCM.

Affecting parameters: The average coefficient recharge was 0.54, and the value for the infiltrate was about 2470 MCM.

AHP: The average coefficient recharge was 0.44, and the value for the infiltrate was about 2130 MCM.

$$R = \frac{\sum_1^n A_1R_1 + A_2R_2 + \ldots A_nR_n}{A_t} \quad (1)$$

$$W = PRA$$

where A is the area, R is the recharge coefficient, P is the precipitation, and W is the volume of water recharged into the aquifer.

Table 5. Results obtained for the different methods.

Method	Recharge percent	Area (km^2)	Average recharge coefficient	W (MCM)
Judgment expert	< 30% 30-50% 50-65% 65-80% > 80%	69.72 4732.10 4390.66 198.57 0.026	0.48	2279
Affecting parameters	< 30% 30-50% 50-65% 65-80% > 80%	8.33 2792.74 5444.42 1125.45 21.03	0.54	2470
AHP	< 30% 30-50% 50-65% 65-80% > 80%	5.25 7415.18 1760.55 201.53 10.37	0.44	2130

The final infiltrate map was derived by combining the obtained maps from the methods (Figure 7).

Based on Figure 7, the average water infiltrate was obtained to be 2249 MCM, and the recharge coefficient was calculated to be 0.50. The maximum coefficient is related to the areas with many karst features, which is consistent with the fieldwork evidence (Figure 7).

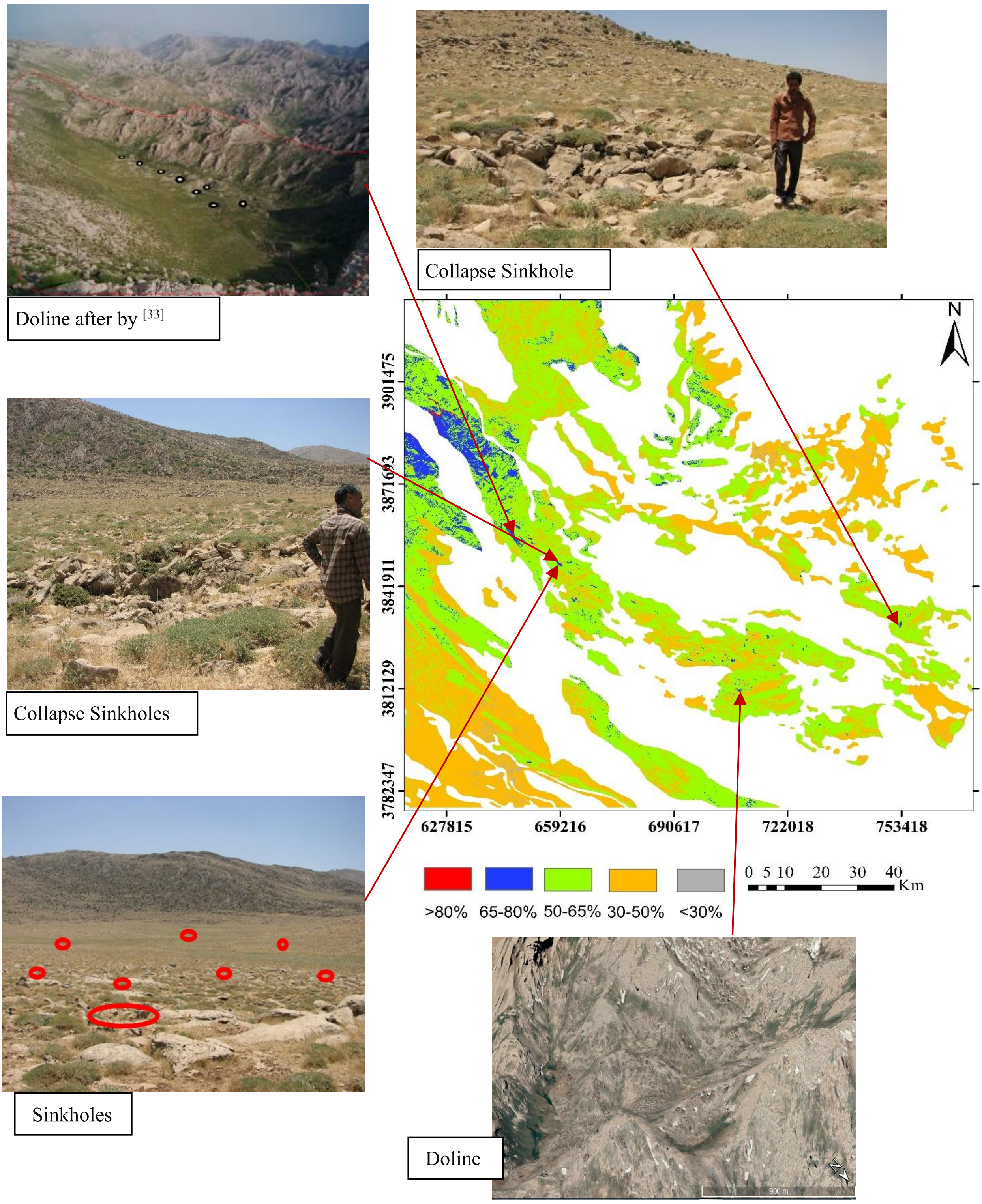


Figure 7. Final recharge map for karstic aquifer in the west of Iran, obtained by the combination of different methods, photographs of the high potential groundwater recharge zones area.

Author Contributions

Z. Najafi conceived the presented idea and investigated the analytical methods. G.H. Karami developed the theory and performed the computations and supervised the findings of this work. Both authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest in the publication of this article.

Funding

This research received no external funding.

Acknowledgment

This research has been supported by prof. Michel Schneider, we wish to express our sincere gratitude and appreciation to him for his enormous help and support.

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