ORIGINAL PAPER

Estimation of groundwater recharge level in karstic aquifers using modified APLIS model

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Abstract

Considering the geographical location of Iran in the arid and semi-arid belt of the Earth and the low average annual precipitation, the groundwater resources, especially the karstic aquifers, are one of the most important water resources. The Golin karstic aquifer in the Alvand river basin of Kermanshah plays a vital role in supplying drinking and agricultural water to the surrounding local communities. The purpose of this study is to estimate the amount of water recharge into the Golin karstic aquifer in southwest of Kermanshah province. In this study, it is tried to consider the joints and fractures as an effective factor in karst aquifer recharge. For this purpose, the APLIS model is used with slope, lithology, soil, fractures and faults, geology, and altitude parameters in GIS environment. Using the APLIS model and taking into account the maximum weight for the related parameters, it was found that the recharge coefficient from precipitation into the related aquifer was calculated as 30%, while the water balance indicates the recharge level of about 50%. Studies show that the APLIS model ignores the role of joints and fissures which play an important role in the recharge of karstic aquifers. This study tries to consider the joints and fractures as an effective factor in recharge in the APLIS model and it was calibrated by applying some weights in the model based on the situation of the area. The results of this study show that the average water recharge to the karstic resources in this study area was 54.4% ranging from 18.8 to 90%, which corresponds with the water balance of the area.

Keywords Karst · Recharge · APLIS · Model · Weighting method · Golin

Introduction

The global demand for water supply to meet the needs of human societies and natural ecosystems has increasingly been recognized (Münch and Conrad 2007; Krause et al. 2007; Gondwe et al. 2011, 24). About one-fifth of the Earth's surface is covered by carbonate formations (Lamoreux 1991, 215). The karst formations constitute nearly 11% of total area of

Iran and about 90% of the Zagros heights (Afrasiabian 2007, 1). The water resources of karst aquifers have become increasingly important around the world, with approximately 25% of the world's population, particularly in Asia, Mediterranean region, and the USA supplying their water from the karst aquifers (Van Beynen et al. 2012, 868). Karst is, in fact, the geomorphic specific feature in carbonate and dissolvable rocks that is created by the function of hydrological processes and provides the basis for the formation of karst aquifers. The modern management of water resources requires constant update to surface–subsurface hydrological interactions. Karst aquifers act as large natural reservoirs of rainfall, and spring discharges reflect periods of poor or abundant rainfall, as well as long-term climate change (Chen et al. 2004). As groundwater recharge cannot be measured directly, it is estimated by using various methods. Depending on the available data, groundwater recharge can be calculated with a simple water balance model using precipitations and potential evapotranspiration, or with more complex and data-demanding hydrological models (e.g., Rushton and Ward 1979; Besbes and De Marsily 1984; Korkmaz 1990; Sophocleous 1991; Wu et al.
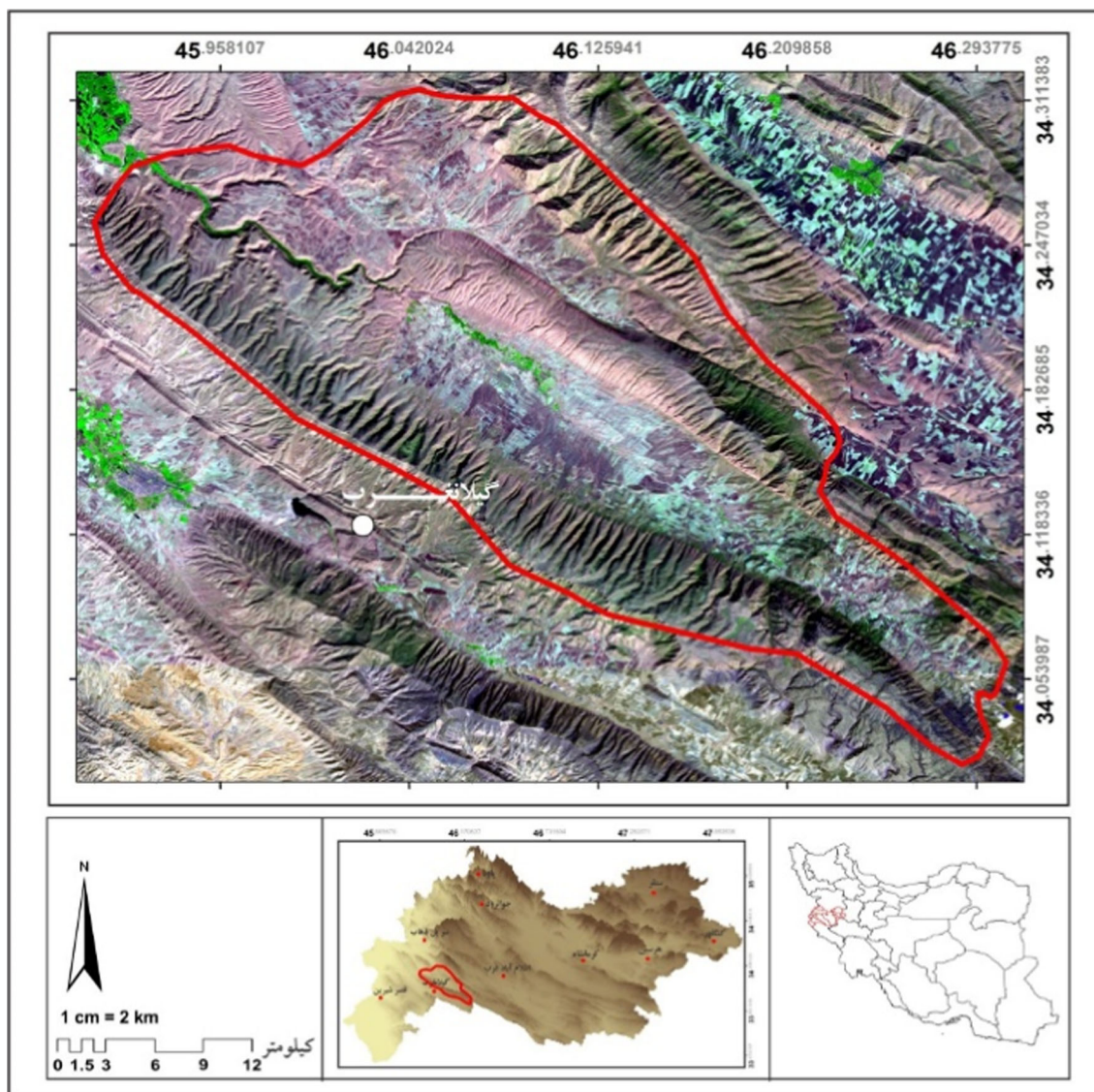

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Fig. 1 Geographical coordinates of the study area

1996, 1997; Avery et al. 1999; Ketchum et al. 2000). The other widely used technique is the Water Table Fluctuation (WTF) method (Healy and Cook 2002). It has been infrequently applied to karst aquifers, perhaps because the water table is generally too deep for convenient monitoring. The other one of methods that can estimate the ground water recharge level indirectly is APLIS. Several studies have been conducted on the recharge of karst aquifers. Andreo et al. (2008) used the APLIS method in a study to estimate the level of surface recharge and presented the results as a spatial distribution map for recharge. Espinoza et al. (2014) compared the APLIS and modified APLIS methods in the study area of La Florida on the eastern slope of the Andes with the altitude of about 2500 m and annual rainfall of about 1500 mm. It was concluded that the APLIS model used to estimate the recharge of karst aquifers is suitable for the Mediterranean region and the modified APLIS model is

suitable for the study area located in Peru. Martos-Rosillo et al. (2015) used the APLIS model in a study to investigate the recharge of carbonate formations, including the direct recharge through the fissures or even shallow pits, as well as the indirect annual recharge of the aquifers by groundwater resources. Lara Kirn et al. (2017) examined the aquifer recharge in both wet and dry years in the karst area of Andalusia, Spain, simulated the future climate changes using the soil moisture and evaporation parameters, and plotted the recharge maps of the coming years to 2099. Zarei and Pirbazari (2018) studied the karstic region of Javanroud, Kermanshah, and matched the final map with the maps of the springs and faults in the region and considered the high recharge regions, high discharge springs, and long faults suitable for geophysical operations. Using the APLIS model, Alem et al. (2017) studied the northern Khorasan aquifers, with the lowest level of water recharge into the aquifer is in the low altitude areas and in the
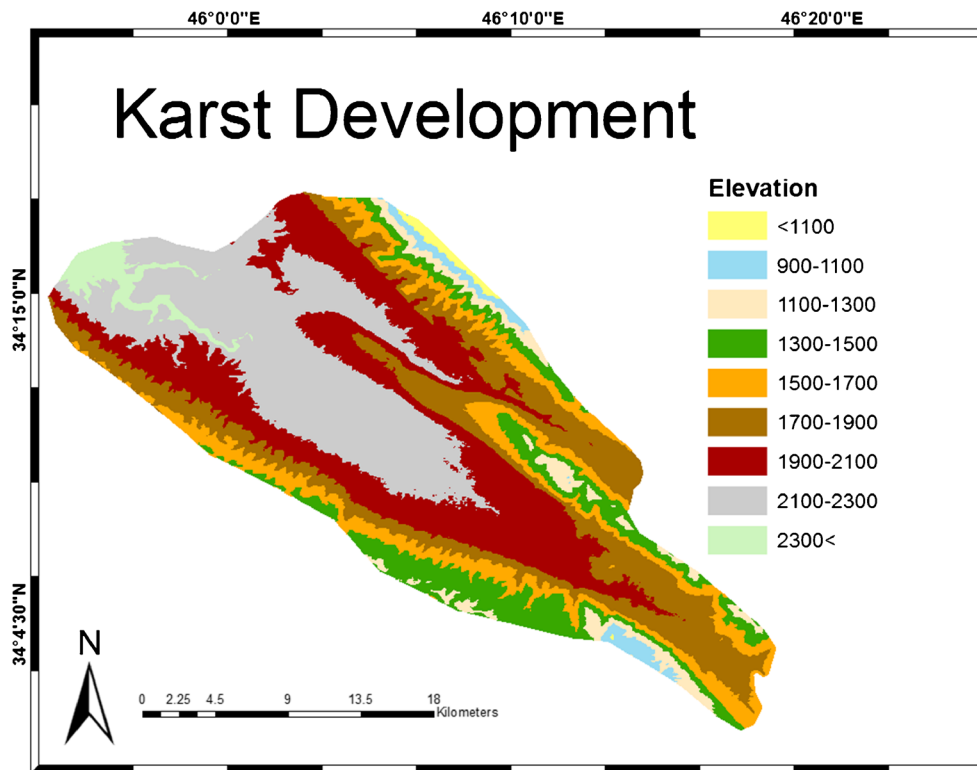
Fig. 2 Altitude map of the Golin aquifer

formations with the least amount of lime and dolomite, and the overall average aquifer recharge potential of 83% was estimated.

The present study aims to introduce the areas with the highest potential for water reservoirs using the APLIS model and by assessing the potential for water recharge
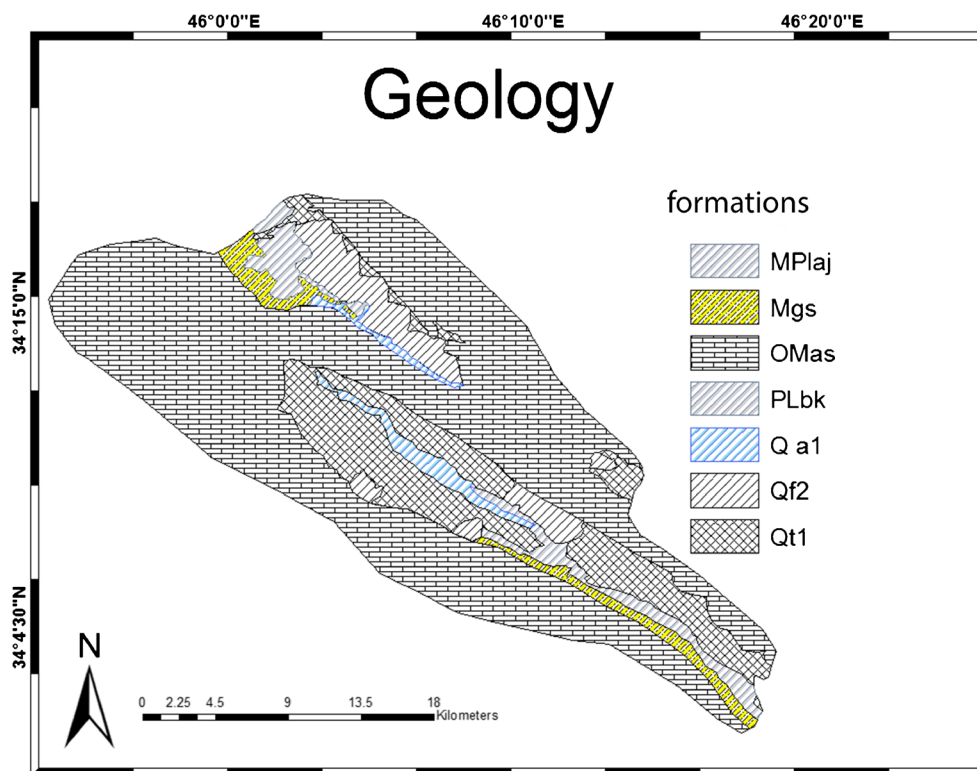

Fig. 3 Lithology map of the study area

Table 1 The altitude variable and scoring

Value	2	3	4	5	6	7	8	9	10
Elevation (m)	< 900	900–1100	1100–1300	1300–1500	1500–1700	1700–1900	1900–2100	2100–2300	< 2300

in the study area. One of the most important factors which has not been considered in the former versions of the model is fractures factor. So, in this research, this important factor, which considerably facilitates the infiltration, is added to the APLIS model and the modified APLIS model has been presented.

Methodology and results

The considered aquifer, Golin karst aquifer, is located in the folded Zagros zone in western Iran and southwest of Kermanshah province (Figs. 1 and 2). The maximum altitude of the area is 2467 m, and the area is 522.8 km², striking northwest-southeast from 34° to 34° 20′ north latitudes and from 45° 53′ to 46° 20′ east longitudes. In terms of stratigraphy in the study area, there are some outcrops seen from Eocene to Plio-Quaternary rocks that are in order from the old to the new ones: Asmari-Shahbazan, Asmari, Gachsaran, Aghajari, Bakhtiari conglomerate, and quaternary deposits including the new and old terraces and the old and new fans and river sediments (Fig. 3). The dolomite Asmari-Shahbazan and limestone Asmari formations cover the anticlines. Alternations of marl, claystone, and gypsum of Gachsaran formation; sandstone and claystone of Aghajari formation; and conglomerate of Bakhtiari formations have expanded in the form of hills in the plains and foothills, and the quaternary formations have expanded as terraces and fans into the plains and foothills of the region. The area is geologically located in the Zagros folded zone and is highly tectonized due to high faulting. The structure of the region is justified by the pattern of the right-lateral shear zones (Mirshokraei 1997, 91). The region faults have thrust components and the tensile, shear, and normal strike slips. The karstic forms of the area are of the holokarst type and are paleokarst based on the formation time. The karstic forms of the area are sinkholes, closed and smooth karstic pits, dolines, caves, lapies, deep karstic valleys, flat karstic zones, and karrens (Bagheri 2008, 56). The average annual rainfall is 600 mm and the average annual temperature is 13 °C. The region is semi-arid due to a dry period of ()5 months.

In this study, the APLIS model was used to estimate the recharge coefficient of the Golin karstic aquifer. The APLIS model was first proposed by Andreo et al. (2008) as a suitable model for locating areas with a high potential for creating the karstic aquifers. In this method, the parameters of slope (P), altitude (A), soil (S), geology of area (G), land cover or

lithology (P), and infiltration (I) are analyzed in the GIS software environment. The parameter (R), recharge rate for aquifers, will be the result of this study.

After preparing the required data layers and examining the significance and impact of each layer, these parts are given a score from one to ten and, then, the final map is produced by the following equation:

$$R = (A + P + (3 \times L) + (2 \times I) + S)/0.9 \qquad (1)$$

As shown in this equation, the infiltration (I) and lithology (L) parameters are two and three times more important than the rest of the parameters, respectively.

In order to estimate the recharge coefficient (R) of each aquifer, there are ten rankings for each parameter which assign the scores 1 (as the lowest impact level) to 10 (as the highest impact level) to the different parts of the parameter proportional to the impact level on the aquifer recharge.

Using the 10 m DEM, the altitude map was prepared at the intervals of 200 m and the highest score was assigned to the areas with the highest altitude. Table 1 shows the altitude levels and scores of the studied area.

Lithology

In this area, there are six major rock units including the quaternary formation and debris, which are assigned appropriate scores using the standard APLIS table (Table 2). The Gurpi and Gachsaran formations are composed of alternation of marl and thinly layers of lime and gypsum. The Asmari and Asmari-Shahbazan formations are composed of lime and the Bakhtiari formation consists of massive conglomerate with carbonate pebbles of good rounding and poor sorting. The old and new terraces and fans are composed of coarse- to

Table 2 The lithology variable and scoring of this variable

Value	Lithology variable
10	Limestone
5	Limestone, marl, and gypsum
3	Marl, sand, and gravel
3	Conglomerate
3	Alluvial fan
1	Quaternary depositions

Table 3 The soil variable and scoring of this variable

Soil variable	Lithosols calcaric	Calcic cambisol-utric cambisol	Calcic cambisols
Value	10	3	3

medium-grained alluvia with a large percentage of sand and gravel.

Soil

Soil type and thickness is one of the important factors in this process. In the territory of the Gachsaran formation, the combisol calcrete is less than 0.5 m thick and the ultra-combisol calcrete is located on the alluvial and quaternary deposits which assigned a score of 3, and the lithosol calcrete zone is matched with the highlands and has the highest area of the region (63%), and these areas are covered by Asmari and Asmari-Shahbazan formations which have the highest score given the characteristics and high permeability (Table 3) (Fig. 4).
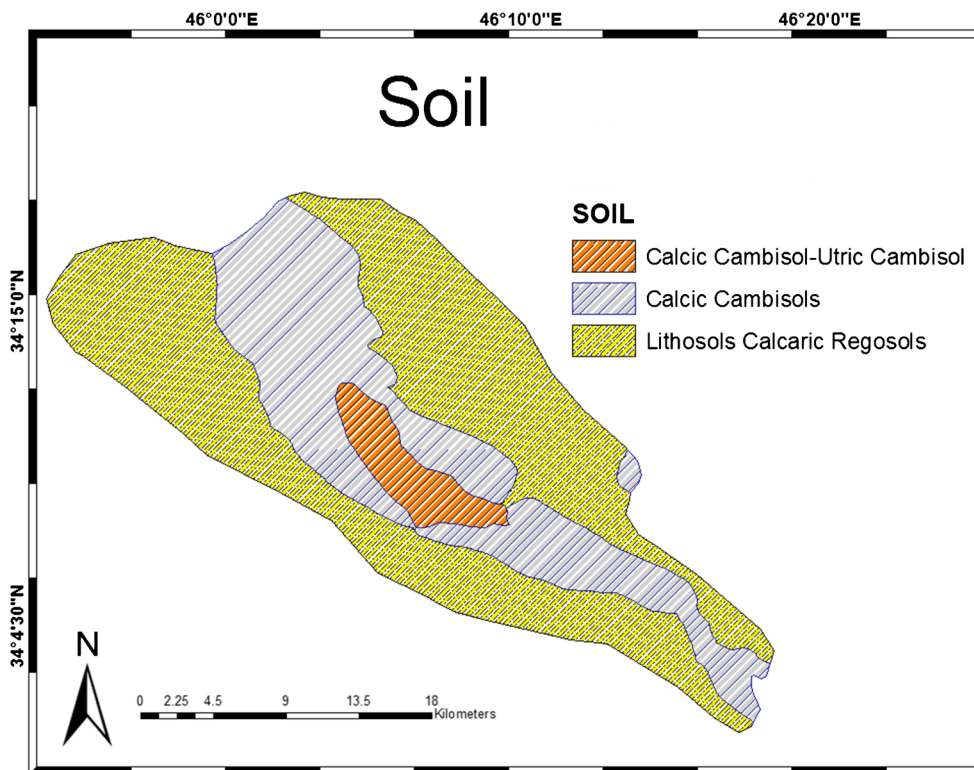
Preferential infiltration

The slope map produced in the GIS environment is also classified into 9 categories and, according to Andreo et al.

(2008), the score 7 will be eliminated from the scores assigned to the slope. In this part, due to the fact that in areas with lower slope, the opportunity for water infiltration is higher, the areas with the slope below 3% have the highest score, and the areas with the slope above 100% have the lowest score (Figs. 5, 6, 7). Table 4 shows the slope classification and the assigned scores. According to Eq. (2), the parameter (I) is resulted from the combination of this layer with the lithological layers and the distance from the faults.

$$I = C + F + S \qquad (2)$$

In fact, by increasing the gradient, the preferential infiltration is increased and the level of preferential infiltration is decreased by increasing the distance from the lineaments and fractures. In the case of the lithology variable, the karstic formations are given the score one and the rest of the areas without karstic lithology are given the score of 0 (Table 4). Finally, by taking into account the mean value for the three layers, the amount of preferential infiltration was determined for different parts of the region
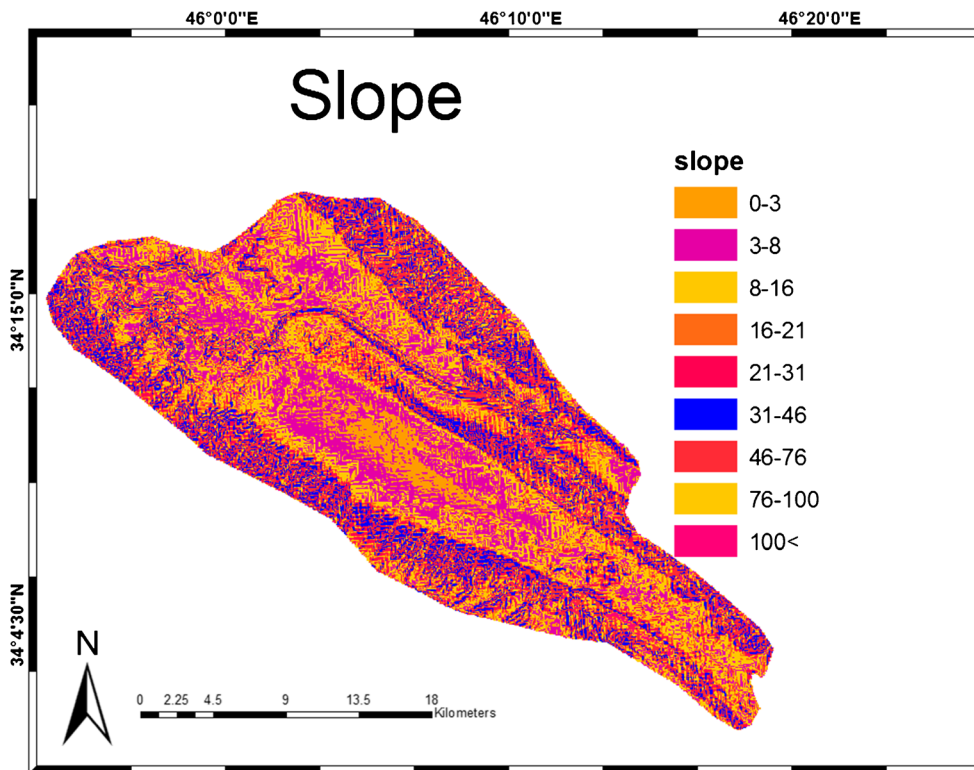

Fig. 4 Soil map of the study area

Fig. 5 Slope map

(Fig. 8). Accordingly, the preferential infiltration is often higher in slopes made from limestone which are considered karstic areas.

According to the preferential infiltration map, the infiltration ranges from 3 to 14 and these areas have the highest infiltration, which corresponds with the areas having less than
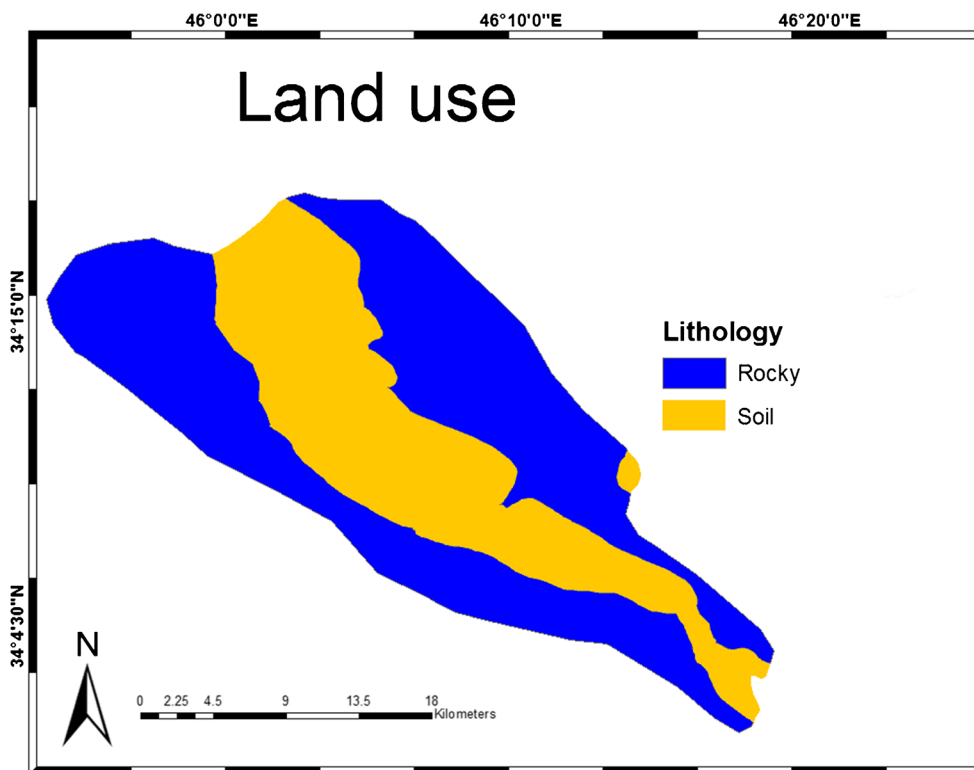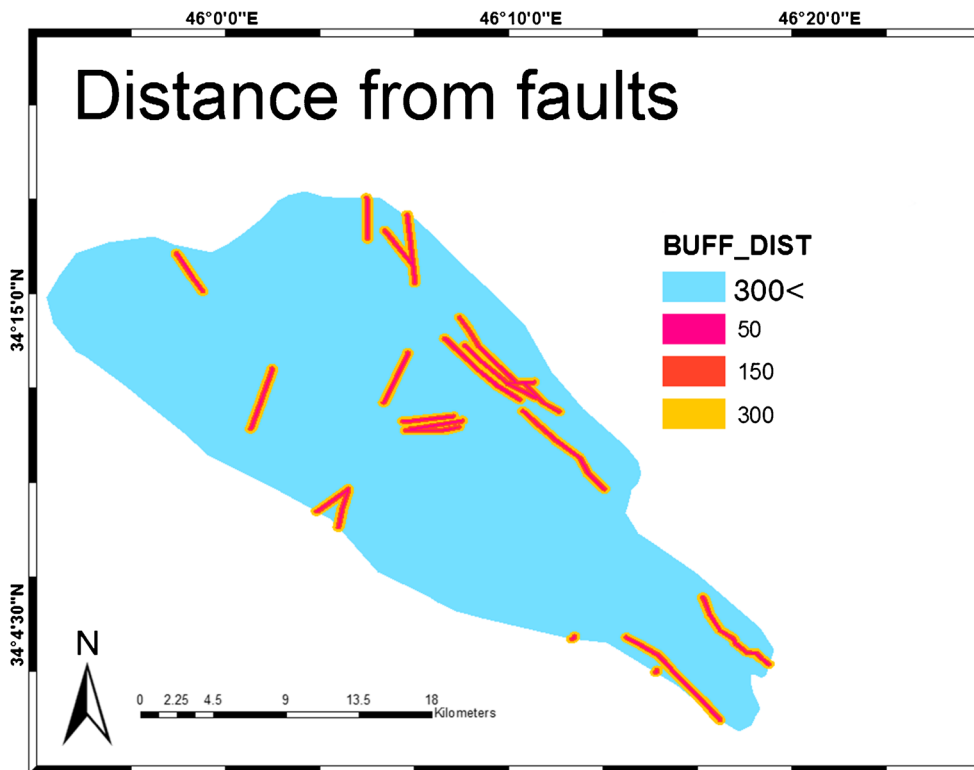

Fig. 6 Land use map

Fig. 7 Distance from faults

31% slope, calcareous and rocky lands, as well as areas close to fractures and faults.

After producing the preferential infiltration map, the final APLIS model was prepared according to Eq. (1) in the GIS environment (Fig. 9).

According to the APLIS model, the average recharge coefficient from the rainfall in aquifer is estimated 36%, but what should be noted here is that the amount of aquifer recharge data also has been presented by Kermanshah water organization (2017) and this coefficient is estimated as 52% by establishing the balance between the aquifer inputs and outputs. Therefore, using the field study and the APLIS model, it is concluded that the role of the observed joints and fissures (Fig. 10) in the area, which are of great importance, is ignored in this model. For this reason, in order to approach the percentage of recharge to the balance level of the area, the role of fractures and joints in the aquifer recharge is considered.

After preparing the fracture maps (Fig. 11) of the region resulting from field visits and reviewing the existing maps,

any area was given a score based on the level of fragmentation and fracture of the region (Table 5), in which the highest score was for the areas with the highest level of fragmentation and fissures.

Considering the significance of this factor, it was given a coefficient equal to the geological coefficient. As a result, Fig. 12 was produced by modifying Eq. (1) and calculating the recharge level using Eq. (3).

$$R = (A + P + (3 \times L) + (2 \times I) + (3 \times F) + S)/0.9 \quad (3)$$

In the modified APLIS model in this study, the parameters of slope (P), altitude (A), soil (S), geology of area (G), land cover or lithology (P), infiltration (I), and fissure (F) per unit area are analyzed in the GIS environment to obtain the parameter (R), aquifer recharge (Fig. 13).

The result obtained in this study is 54% according to the modified APLIS model (this model is modified by adding

Table 4 The preferential infiltration variable and scoring of this variable

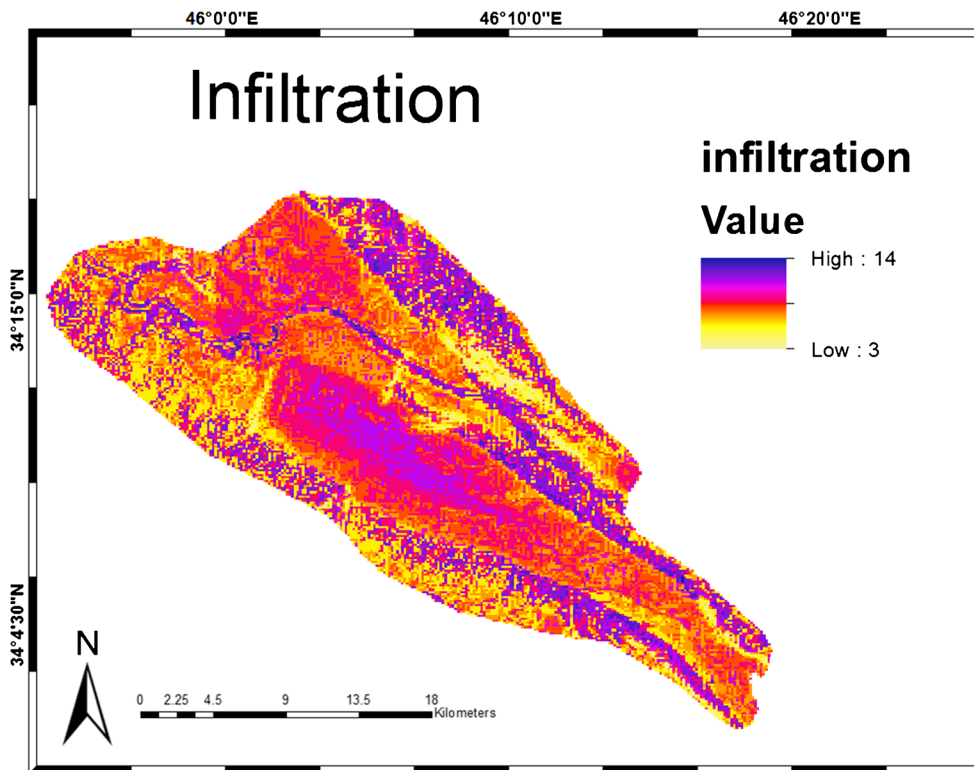| Value	1	2	3	4	5	6	8	9	10
Slope (%)	< 100	76–100	46–76	()46	()31	()21	()16	()8	≥ 3
Distance from the main fracture	≤ 50	50–150		150–300		**Lithology**		Soil areas	Rocky areas
Value	10	6		2		**Value**		0	1

Fig. 8 Preferential infiltration

fractures map in this study), which is closer to the result obtained by the water balance method and it can be concluded that it is more consistent with the reality of the region.

Map 13 shows the degree of karst evolution in different locations of the study area. According to this map, the altitudes of the area have a developed karst, in which existence of
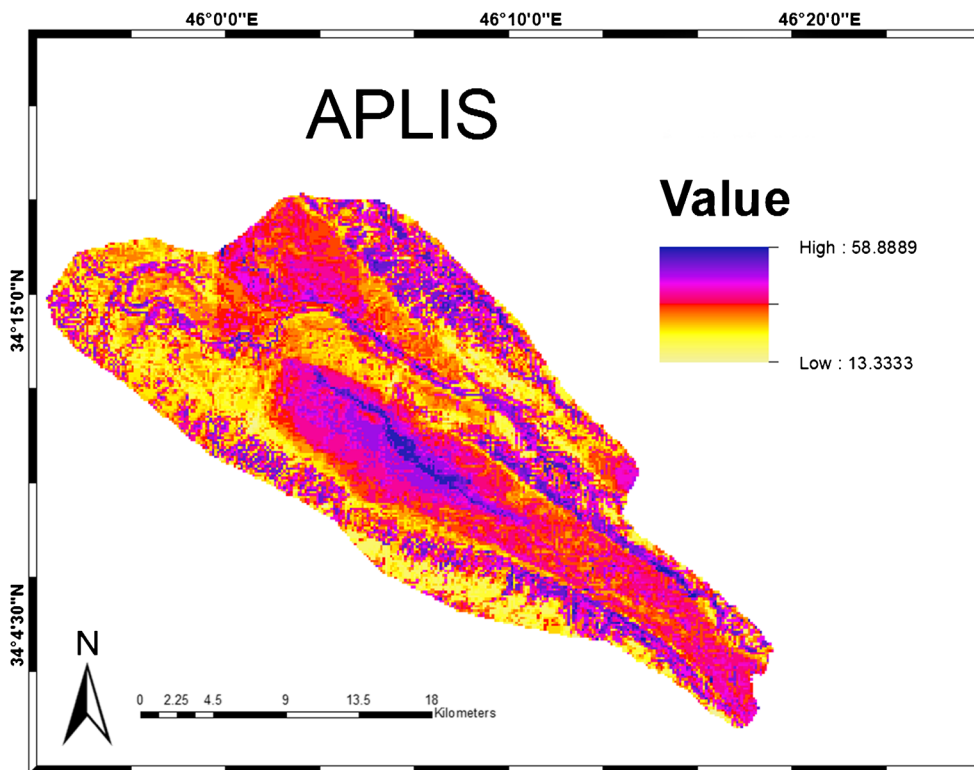

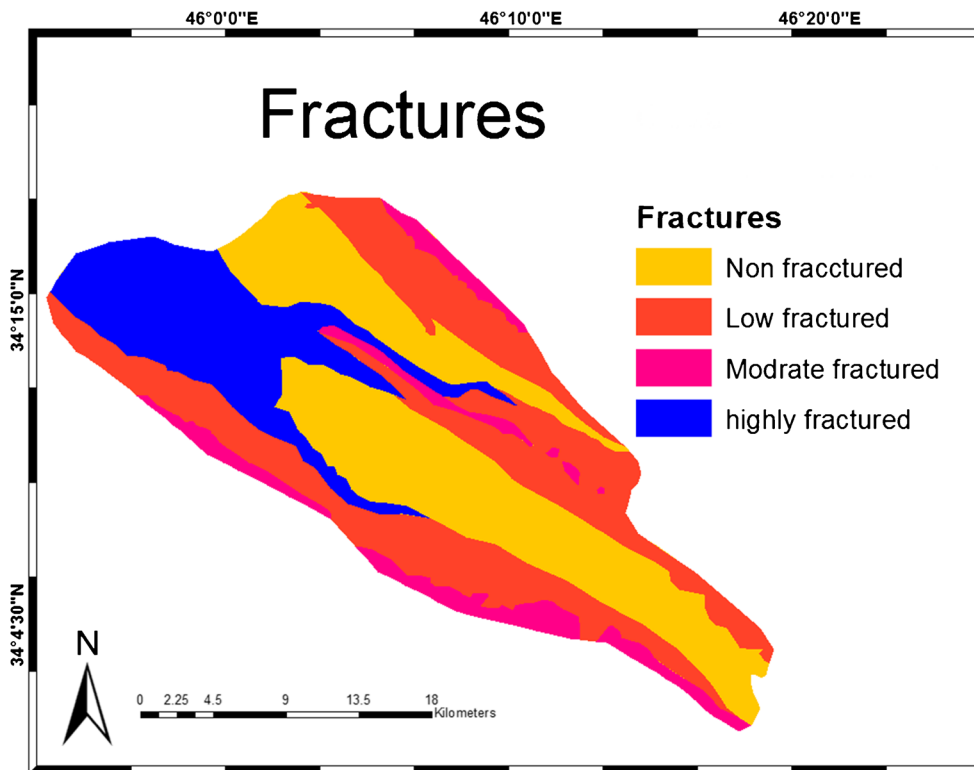**Fig. 9** Approximate recharge rate in APLIS in the study area

Fig. 10 Fractures of the area study area

karst landforms such as sinkholes and closed karstic pits and ponors confirm this subject. The middle part of the anticline composed of calcareous formations has a less-evolved karst, and the lower altitude and higher slope areas contain the low karstification calcareous formations, and also in the outcrop of marl formations and quaternary deposits, the karst morphology is not formed. In general, the region is characterized by high slope as being located in a mountainous region, with the high-slope areas corresponding to the anticline hillside and the low-slope areas corresponding to the surface of the plains. The karstic flat lands are also at the apex of the anticlines.

Figure 14 is an annual rainfall map of the area. The average rainfall of the area ranges from 425 to 825 mm and in the lower parts of the area, the rainfall is less than 500 mm. The rainfall is increased in the high altitudes, especially the mountainous regions, and reaches about 800 mm per year, which has precisely the highest rainfall in the most evolved karstic region (Fig. 14). The average number of days with rainfall in the area is also 68 days a year. The average annual rainfall of Iran is 250 mm and the average rainfall of the study area shows that this area is classified as the middle rainfall regions.

Conclusion

According to calculations using APLIS model, the average recharge coefficient from rainfall into the karst water resources in the Golin aquifer located in Kermanshah province, Iran is 36% which varies from 13 to 58%, but according to water balance method, by balancing the aquifer inputs (including rainfall, surface inputs of rivers, and
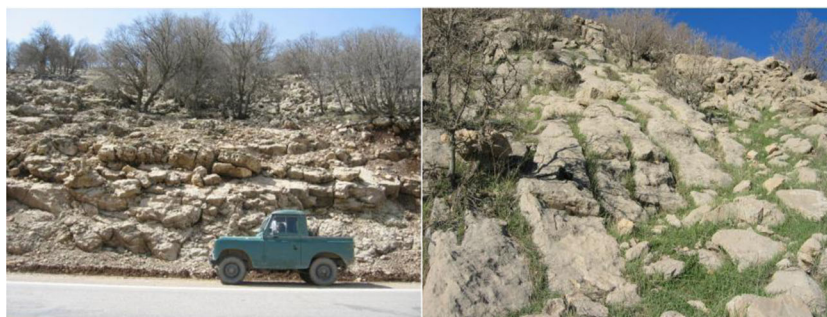

Fig. 11 Fractures of the study area (Photo by H. Karimi)

Table 5   The fracture variable and scoring of this variable

Fractures	Highly fractured	Moderate fractured	Low fractured	Non-fractured
Value	10	8	4	1

underground inputs) and outputs (including output from the spring, discharge to surface water, and underground discharge to adjacent karstic and alluvial aquifers) (Karimi 2002, Kermanshah water organization 2017), the percentage of rainfall infiltrating into the aquifer is estimated about 50%. The other thing that should be noted here is that the amount of aquifer recharge also has been calculated by Kermanshah water organization (2017) and this coefficient is estimated as 52% by establishing the balance between the aquifer inputs and outputs. By examining the model and what was observed in the field study, it was concluded that the role of joints and fissures in this model was neglected and this can justify the difference in the obtained results in estimating the recharge coefficient in two methods. Therefore, by modifying the model and considering the significance of the joints and fractures, the recharge coefficient of the aquifer was about 54%, which is closer to the result of the water balance method. The results obtained in the APLIS map are precisely opposite the result of the modified APLIS map in this study, so that, in the APLIS map, the lowlands without fracture,

without karstic evolution, and precisely the less-important areas in terms of lithology are among those that have the greatest impact on the aquifer recharge, but in a map that is derived from the modified APLIS model, the areas with the greatest impact on the recharge of aquifers are at highlands and anticlines and have a low and gentle slope, very large and modest fractures, and highest importance in terms of lithology. What should be noted here is that according to what is evident in the map of the karst evolution of the region corresponding to the final map of the modified APLIS model, the areas in which the most recharge occurs are consistent with the evolved karstic areas and relatively evolved fragmented carbonate formations. Regarding the rainfall factor, it should also be noted that the highest annual rainfall is in accordance with developed and relatively developed karstic regions, which can be considered as a positive factor in the recharge of karstic resources in the region. Based on the result of this research, it is recommended that the fractures factor should be considered as an important factor in recharge coefficient estimation in hard rock and karst aquifers.
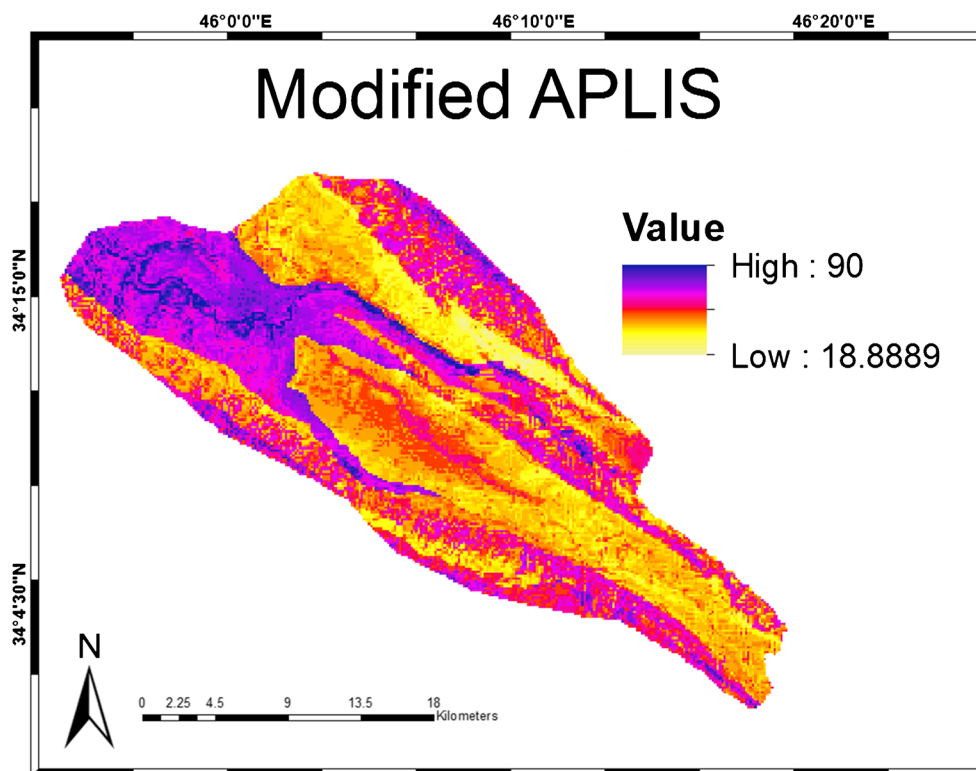
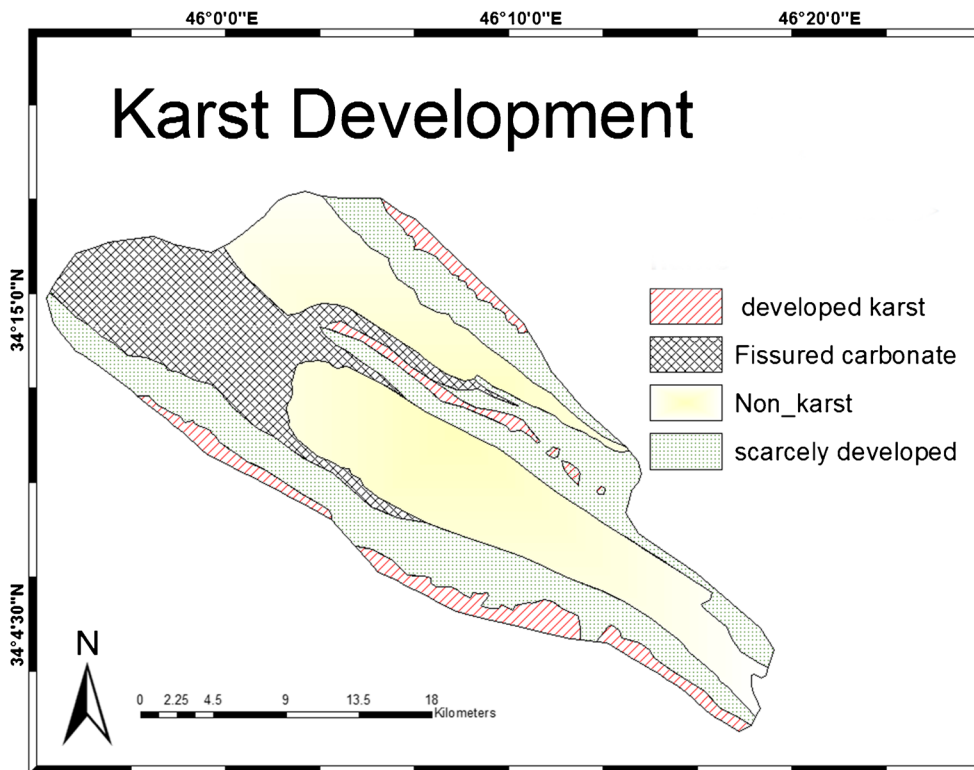**Fig. 12** Approximate recharge rate by modified APLIS in the study area
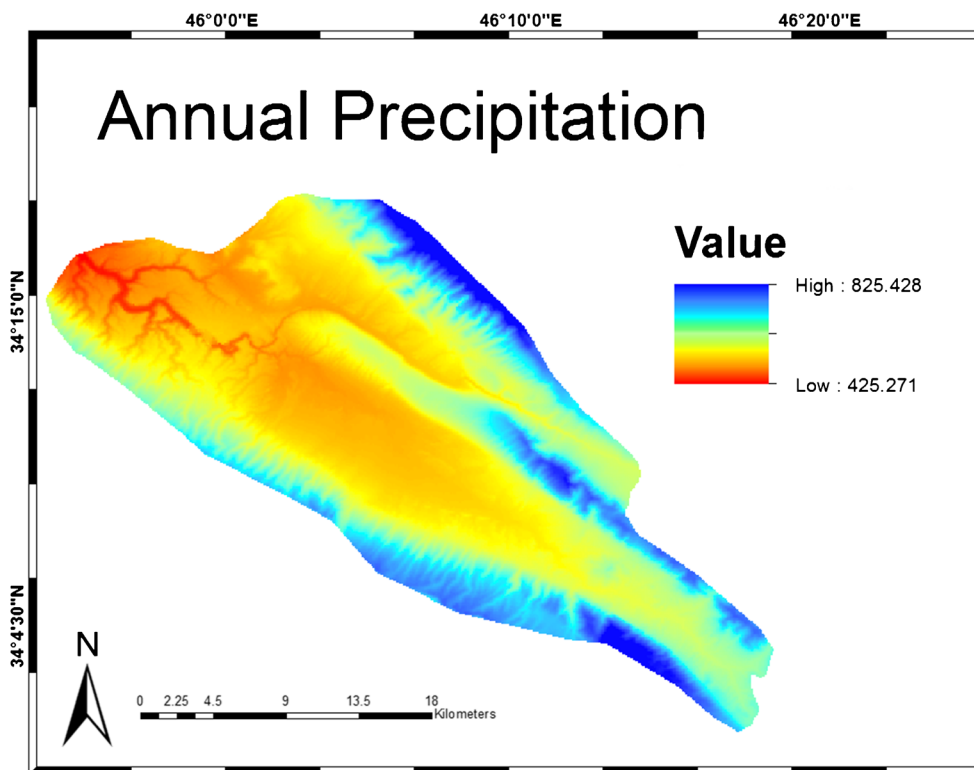
Fig. 13 Karst development map

Fig. 14 Annual precipitation map

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