

GROUNDWATER RECHARGE ASSESSMENT IN THE KARST AQUIFERS OF NORTH KHORASAN, IRAN USING APLIS METHOD

OCENJEVANJE NAPAJANJA PODZEMNE VODE V KRAŠKIH VODONOSNIKIH V SEVERNEM HORASANU, V IRANU, Z UPORABO METODE APLIS

Hossein ALEM^{1*}, Akbar Esmailzadeh SOUDEJANI² & Saba Nahas FARMANIEH³

Abstract

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Hossein Alem, Akbar Esmailzadeh Soudejani & Saba Nahas Farmanieh: Groundwater Recharge Assessment in the Karst Aquifers of North Khorasan, Iran Using APLIS Method

In order to optimize consumption, maintenance and control of underground water, an estimation of the groundwater recharge is highly important. Therefore, this research investigates the aquifers in North Khorasan province using APLIS (Applied Physics Laboratory Ice Station) based on a GIS. For this purpose, several significant hydrogeological parameters affecting groundwater recharge including altitude, slope, lithology, soil type and infiltration are considered. Therefore, corresponding layers for these parameters were provided and prioritized. In the end and after integrating the data, the recharge rate was measured qualitatively and different regions were mapped accordingly. The results indicate that the annual average values on a 30-year timescale in karst formations of the North Khorasan vary between 103 mm and 362 mm, with the mean value of 192 mm. Minimum, maximum and mean recharge rates of aquifer in the study area are 42 %, 73 % and 54 %, respectively. Also, aquifer recharge potential in 83 % of the karst formations is moderate while it is high for the remaining. Low recharge regions correlate to lower karst limestone and dolostone areas in the lower altitudes while high recharge regions represent upper karst limestone and dolostone areas, especially in the high altitudes.

Key words: Groundwater resource management, Recharge, APLIS, GIS, karst, North Khorasan.

Izvleček

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Hossein Alem, Akbar Esmailzadeh Soudejani & Saba Nahas Farmanieh: Ocenjevanje napajanja podzemne vode v kraških vodonosnikih v severnem Horasanu, v Iranu, z uporabo metode APLIS

Za optimizacijo porabe, vzdrževanja in nadzora nivoja podzemne vode je ocena napajanja vodonosnika zelo pomembna. Zato raziskava z uporabo metode APLIS, ki temelji na GIS, raziskuje vodonosnike v provinci Severni Horasan v Iranu. Pri tem smo upoštevali več pomembnih hidrogeoloških parametrov, ki vplivajo na napajanje vodonosnika, vključno z nadmorsko višino, naklonom, litologijo, tipom tal in infiltracijo. Za vsakega od parametrov smo pripravili informacije v ustreznih oblikah. Po obdelavi in integraciji podatkov smo izračunali hitrost polnjenja vodonosnika. Različne regije smo ustrezno ovrednotili. Rezultati kažejo, da se v kraških formacijah Severnega Horasana letne povprečne vrednosti v 30-letnem časovnem obdobju gibljejo med 103 mm in 362 mm, s povprečno vrednostjo 192 mm. Najmanjše, najvišje in povprečne stopnje polnjenja vodonosnika v študijskem območju so 42-, 73- in 54-odstotne. Tudi potencial polnjenja vodonosnika je v 83-odstotnih kraških formacij ocenjen kot zmeren, za preostale predele je ocenjen kot visok. Območja z nizkim potencialom polnjenja so povezana z nižje ležečimi zakraselimi apnenci in dolomiti, višje ležeča območja predstavljajo apnenci in dolomiti z višjim potencialom polnjenja.

Ključne besede: upravljanje podzemnih vodnih virov, napajanje, APLIS, GIS, kras, Severni Horasan.

¹ Department of Earth Sciences, College of Sciences, Shiraz University, Shiraz, Iran, e-mail: hosseinalem22@gmail.com

² Department of Earth Sciences, College of Sciences, Shiraz University, Shiraz, Iran, e-mail: akbar.esmailzadeh@gmail.com

³ Department of Mathematics, Faculty of Sciences, University of Shiraz, Shiraz, Iran, e-mail: sabafarmanieh@chmail.ir

* Corresponding Author

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INTRODUCTION

The increasing population and considerable agricultural and industrial activities, which play a prominent role in the intense decline of aquifer levels, have increased the demand for fresh water. Since the resources are limited, proper maintenance and control on the one hand and appropriate consumption on the other hand require a comprehensive management (Esmaeili & Moore 2012; Nematollahi *et al.* 2016). The study and management of karst formations are significant due to their profusion and potential in the creating underground aquifers. The recharge rate is one of the basic parameters in consumption management and maintenance of these resources (Hartmann *et al.* 2014). Recharge of an aquifer can be defined as the annual average volume that is usually in the form of resources or the average annual input as well as a percentage of precipitation commonly known as 'rate of recharge' or 'effective infiltration' (Mejías *et al.* 2012; Andreo *et al.* 2008).

The measured time series of groundwater levels have often been used to quantify the recharge against time (Scanlon *et al.* 2002) but the heterogeneity of karst rocks in karst areas makes this method insufficient (Bakalowicz 2005).

Methods based on GIS, which utilize geographic attributes of parameters such as geology, altitude, slope, soil type, vegetation and mean annual precipitation, are often applied in order to determine the spatio-temporal distribution of recharge of karst formation (Andreo *et al.* 2008; Allocca *et al.* 2014). In this regard, calculation of recharge through conventional methods (evapotranspiration, natural, chemical or synthetic isotopic tracing, and calculation of precipitation against time) or through numerical models has limitations such as lack of access to accurate and periodic data (Radulovic *et al.* 2012). In the area under study, due to the lack of periodic assessment of the discharge of large springs, such methods produce limitations and problems in calculation of recharge (Guardiola-Albert *et al.* 2015). Recent years showed significant improvements in assessment methods which are in direct relation to GIS software and many researchers have used these methods (Jyrkama & Sykes 2007; Scibek & Allen 2006; Marechal *et al.* 2006; Lee *et al.* 2006; Samper *et al.* 2005; Conrad *et al.* 2004; Tapia Silva & Mora Flores 2004; Peña & Arcos 2004; Bouraoui *et al.* 1998; Burke 1995). These methods make the calculation of groundwater recharge easier through a quicker and more concise analysis (Peña & Arcos 2004). In this context and in order to overcome the problems and achieve a more realistic estimation of recharge in karst environment, based on indigenous variables of the aquifer, the Geological Survey of Spain

(IGME) has used a new technique called APLIS (Altitude, Pendant or Slope, Lithology, Infiltration, Soil) (Andreo *et al.* 2008). Comparatively better than previous models, this method does not require accurate and periodic data and therefore significantly decreases the costs of water resource management (López-Geta *et al.* 2004). Also, this method allows for the mapping of the spatial distribution of spontaneous recharge of the aquifers in the area (Espinoza *et al.* 2015). On the other hand, the precise study of autogenic recharge in carbonate rocks (including direct recharge, local and centralized recharge through shallow pits, and even indirect recharge through the substrate of surface water), as well as determination of the annual recharge of groundwater in karst formations are the advantages of APLIS method (Martos-Rosillo 2015). This method can be considered a new branch of recharge calculation study with mathematical expressions and can be called the technique for aquifer recharge calculation using remote testing and GIS (Andreo *et al.* 2008). This method doesn't have the problems common in conventional methods because the infiltration is studied by attending to the inherent properties of a karst aquifer (such as altitude, slope, lithology, infiltration and soil type). The APLIS index has specifically been used in eight aquifers in Spain where the results were consistent with the standard recharge rate (Andreo *et al.* 2015). However, this method has been applied in other carbonate aquifers around the world such as Southeast Spain (Touhami *et al.* 2013; Aguilera & Murillo 2009), Greece (Zagana *et al.* 2011), Cuba (Farfán *et al.* 2010), northeastern Oman (Germer *et al.* 2012), the Mediterranean (Hartmann *et al.* 2014), Southern Spain (Martos-Rosillo *et al.* 2008) and has achieved successful results.

Given the extent of upper Jurassic and lower Cretaceous Limestone in the cities of Shirvan, Bojnord, Faruj, Safiabab and Moshkan and the expansion of karst in these areas, potential aquifers with abundant fractures and fissures have been created in hard carbonate formations. The discharge of local springs has significantly decreased in recent years and a comprehensive study in these karst zones seems necessary, given their significant role in provision of water used for drinking and agriculture in North Khorasan, especially Shirvan – Asfrayn area. Given the significance of the recharge amount and diversity in discharge of water resources in the area, this study aimed to estimate the annual recharge rate of groundwater in karst formations, including those within cities of Shirvan, Bojnord, Faruj, Safiabab and Moshkan on a scale of 1:100000.

GEOLOGICAL AND GEOGRAPHICAL SETTING

GENERAL CHARACTERISTICS
OF THE AREA

The area under study is located between eastern latitudes $56^{\circ} 56'$ to $58^{\circ} 30'$ and northern longitudes $36^{\circ} 51'$ to $37^{\circ} 30'$ (Fig. 1). Morphologically, this area includes both plains and mountains, with the lowest point at an altitude of about 928 meters. The height points of the area include a wider range from the north-west to south-east, with a maximum altitude of 3026 meters above the sea level. With an altitude of 1095 meters above the sea level, Shirvan city is located at the center of the area under study. In terms of weather, the northern half of the area has mild and relatively humid summers and relatively cold winters while summer heat does not exceed 40°C . Due to proximity to Esfaraïen plain, the southern half of the area has relatively warm and dry summers, so that during summer the heat reaches to 45°C . The mean annual precipitation is 275 mm. Average temperatures in April and May 2015 have been reported 10.3°C and 18.2°C , respectively, which, compared to the previous year, are cooler although compared to a long-term statistical period, they're warmer. Based on different methods and classifications, the area under study is semi-arid, with cold winters.

GEOLOGICAL AND STRUCTURAL FEATURES OF
THE AREA

Structurally, the area under study belongs to Kopet Dag and Binalud structural zones, except for a small section in the southeast corner of the area that is located in central Iran. Due to a compression stress, this area stretches over a north-northeast and south-southwest direction. That stress is first visible in shortening and folding, creating thrust faults in some areas as pressure rises (Shabaniyan *et al.* 2010). Most of these faults are strike-slip faults with dumping and sometimes normal components; however, a number of thrust faults have been identified with wrinkling and much older than strike-slip faults (Ramazani Oomali *et al.* 2008).

The geological formations of the area (Fig. 2; Tab. 1) date back to the second period, the Neogene period in tertiary, and the Quaternary (i.e. Kopet Dag zone). From the various lime sets, karst springs such as Golian, Khosravieh, Garmab, Zoeram, Chehel Cheshme, Beshori, Vali Beik, Samand Devin Solocheshme and Starkhi have have outcropped. Deposition of the Paleozoic and Triassic is found in the southern half of the plate in the Binalood zone but the deposition at both Kopet Dag and Binalud continued steadily since the development of the Jurassic

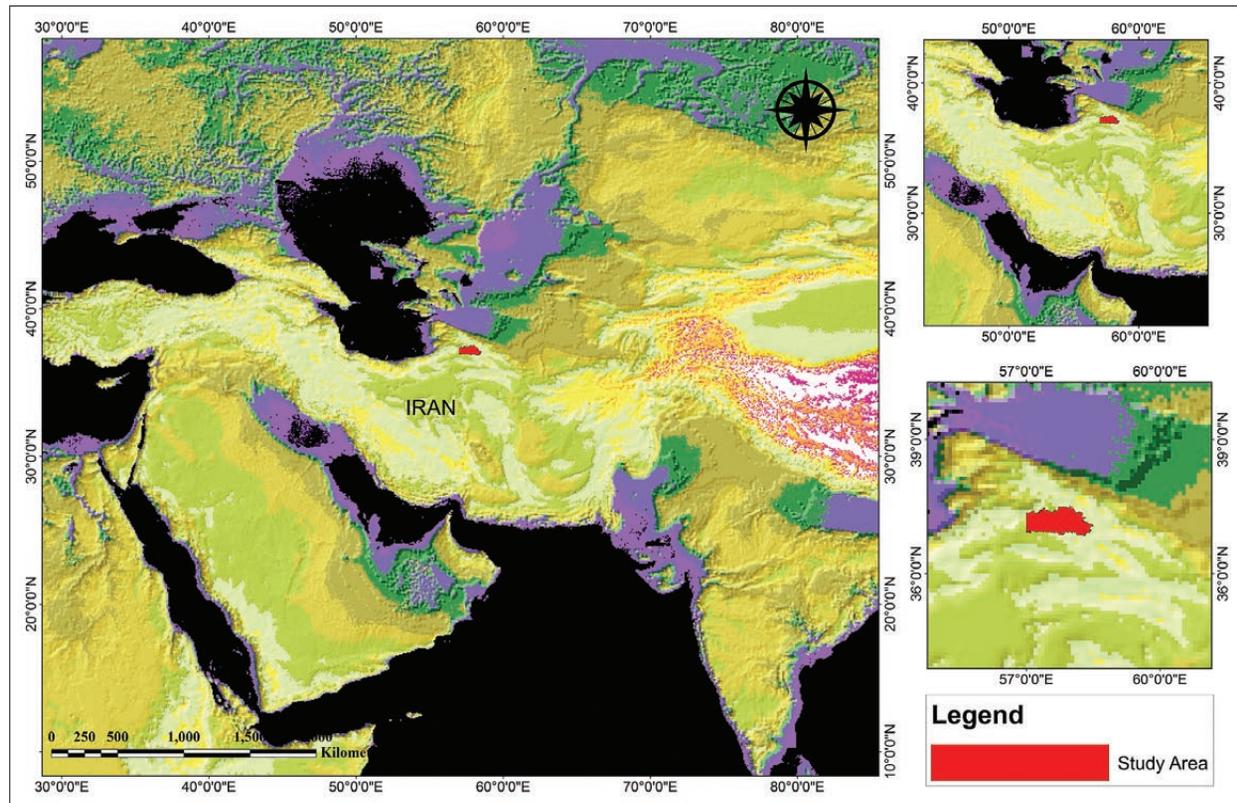


Fig. 1: Geographical location of the study area.

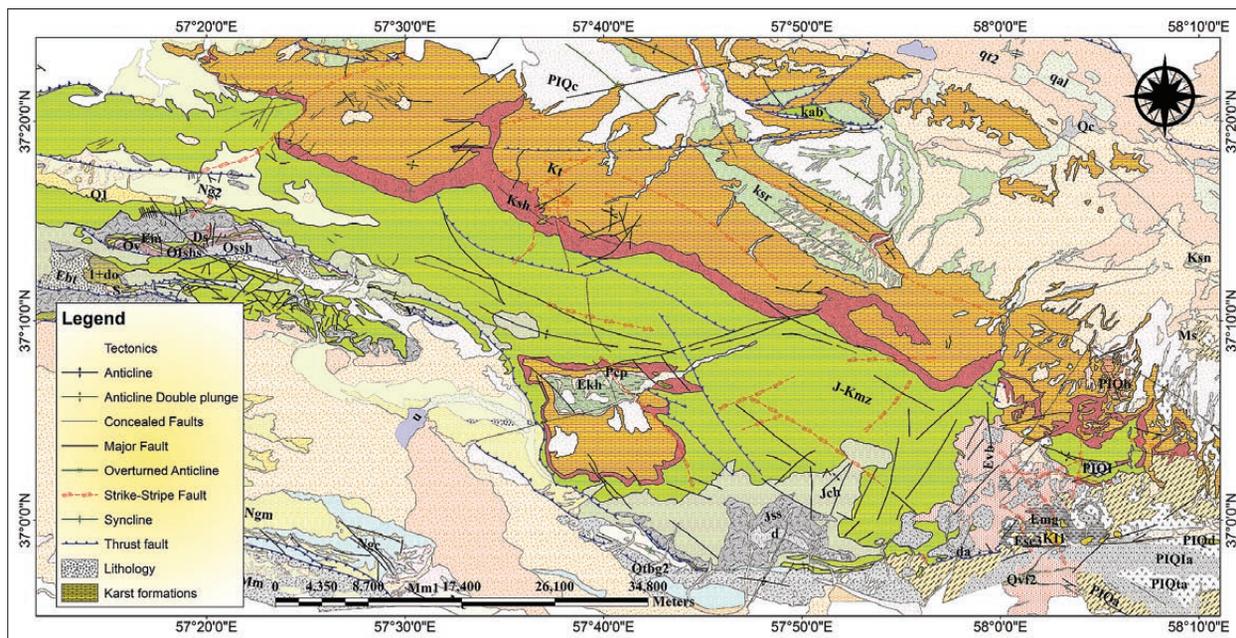


Fig. 2: Geological map of North Khorasan on a scale of 1:100000 (based on geological map of Shirvan, Bojnord, Faruj, Safiabad and Moshkan on a scale of 1: 100,000 at the National Geological Institution of Iran).

Tab. 1: The altitude variable and scoring.

Value	5	6	7	8	9	10
Elevation (m)	900–1200	1200–1800	1800–2100	2100–2400	2400–2700	2700–3100

Sea up until the end of Cretaceous. Therefore no considerable difference between depositions related to the Jurassic and Cretaceous on the Kopet Dag and Binalud can be observed (Moussavi-Harami & Brenner 1992), so much so that field observations suggest that outcropped formations of Binalud Paleozoic stretch under Kopet Dag as well. What follows is a brief account of the characteristics of lithology units in the area under study.

HYDRO-GEOLOGICAL FEATURES OF THE AREA

The karst zone of the area under study is located east of the North Khorasan. The relatively good precipitation, potential carbonate formations such as Tiregan, Mozdvaran, Tizkuh, Mila, Khosheyilagh and Abderaz, and active tectonics responsible for plenty of fissures and fractures, have been effective in creating the large aquifers of the area. Calcareous zones have covered an area of 1810 square kilometers. Karst springs such as Starkhy, Beshori, Khosravieh, Zoeram, Solocheshme, Garmab, Vali Beik, Golian, Samand Devin and Chehel cheshme have outcropped of these karst zones. According to existing statistics (2003–2014), the average discharge of the 6 karst springs that originate from these calcareous zones is 49.0 m³/s while Starkhy and Solocheshme, the

largest springs of this karst zone, emit 179.0 m³/s and 108.0 m³/s, respectively. In the area under study, Barzoo River is the main source of groundwater recharge. The river flows from northern heights of Shirvan and through Shirvan city to unite with Atrak River. Thus, this river plays an essential role in recharging underground aquifers in Shirvan plain. The other river is Atrak which originates from the Hezar-masjed, Aladagh and Binalud mountains and lies northwest to the area. The present underground aquifers includes Esfarayen aquifer (which covers large parts in southwest of the area under study and is hydraulically connected with Cal Shour and Cal Jelogir rivers), the southern Safiabad aquifer (which is located in south of the study area and has a hydraulic connection with Cal Shour), the north Safiabad aquifer (which is located in south of the area under study and is hydraulically connected with Esfarayen aquifer, as well as Ab Karane, Cal Shoon and Ab Haragh rivers), and finally, the Quchan aquifer in Shirvan (which is located in the northeastern of the area under study and is hydraulically connected with Atrak and Chery rivers). The aquifer in Shirvan city through the eastern end of the plain has a relatively good quality for irrigation and is of sodium sulfate type.

METHODS

The APLIS method has been applied to estimate the mean infiltration into the carbonate aquifer of precipitation for 30 years and to study the geographical distribution and expansion of karst developments. This method requires a mathematical statement that could stand for a hybrid or superposition layer (Syn depositional) in terms of the main variables of infiltration, since recharge is a result of the physical characteristics of the aquifer. These variables do not have the same weight or importance in recharge. Therefore, the information layers of each variable have been valued according to the ranking system of APLIS and have been combined by using the method equation of APLIS (Andreo *et al.* 2008) to determine the weight of each variable. Various multidisciplinary approaches including regression analysis (least squares linear fitting), ideal spot analysis, and linear weighted sum method have been used to determine the weight of each variable. The recharge rate can be calculated by combining the inherent variables of each aquifer such as the altitude above the sea level, slope, lithology, infiltration, and type of soil.

The total mean recharge rate of an aquifer can be calculated by entering information layers of each variable into GIS software environment using Equation 1 below, also known as APLIS index of recharge (Andreo *et al.* 2008).

$$R=(A+P+3\times L+2\times I+S)/0.9 \quad (\text{Eq. 1})$$

In this equation (Eq. 1), R represents the mean rate recharge, A: altitude, P: Pendant or Slope, L: Lithology, I: Preferential infiltration, and S: Soil type. The weight of each variable in the equation demonstrates their importance in determining the recharge rate (Duran *et al.* 2004). So, the lithology variable is three times more effective than the altitude (above the sea level), slope and soil whereas the variable of preferential infiltration in the areas is twice more effective than the mentioned variables. When divided by 0.9, the recharge rate from the precipitation on the surface of aquifer is about 8.88 to 88.8 %. In other words, recharge happens all the time, although this amount never reaches 100 % of precipitation.

RESULTS AND DISCUSSION

The mean recharge rate (R) for every aquifer is the average values of R corresponding to spatial units in the recharge map. In this scheme, there are ten rankings for each variable while each ranking is scored in an arithmetic progression of 1 to 10 (Andreo *et al.* 2008). Points 1 and 10 indicate minimum and maximum effective infiltration, respectively. In the following, the generated layers in this method are described.

INFORMATIONAL VARIABLES

Altitude variable

The 5m-DEM of area was produced in GIS Software using data from AutoCAD (such as altitude points, canals, elevation points and fracture of the area under study). Then this map was introduced to software and after the operation, the altitude map was extracted as output. The altitude variable was classified in ten sequences at intervals of 300 m (Tab. 1) and scores of 1 to 10 assigned to each ranking (Andreo *et al.* 2008). Given the minimum altitude of the area under study (919.4 m), this variable was ranked in 6 sequences (scores from 5 to 10). Given that a major portion of the area is located at high altitude, high points represent them so that point 10, for example, is prevailing in the area under study (Fig. 3). The produced layer for this variable and scores of each sequence

show that with larger altitude, the precipitation increases, leading to greater aquifer recharge. Also, difference between recharge amounts of altitude higher than 3,100 AMSL is not significant.

Slope variable

The map of slopes in the area under study was produced in GIS software using the existing slope data obtained from the National Geological Institution of Iran with scale of 1:100000 and then was ranked in 9 different sequences (Tab. 2). In the scoring system, point 7 was removed. Rating of slope at irregular intervals was done in accordance with the classification used in Andalusia Environmental Information System, where the slope is divided into 9 categories and point 7 is deleted from the slope table (Andreo *et al.* 2008). The scores assigned to the slope parameters decrease as slope gets steeper which means that increase in slope leads to decrease in groundwater recharge (Fig. 3). Therefore, low areas with a minimum slope get the highest scores (i.e. score 10). At heights, the slope is mainly between 3, 4 and 5 and rarely larger than this.

Lithology variable

Based on field observations and stratigraphic studies for the lithology variable, calcareous formations of Mozdu-

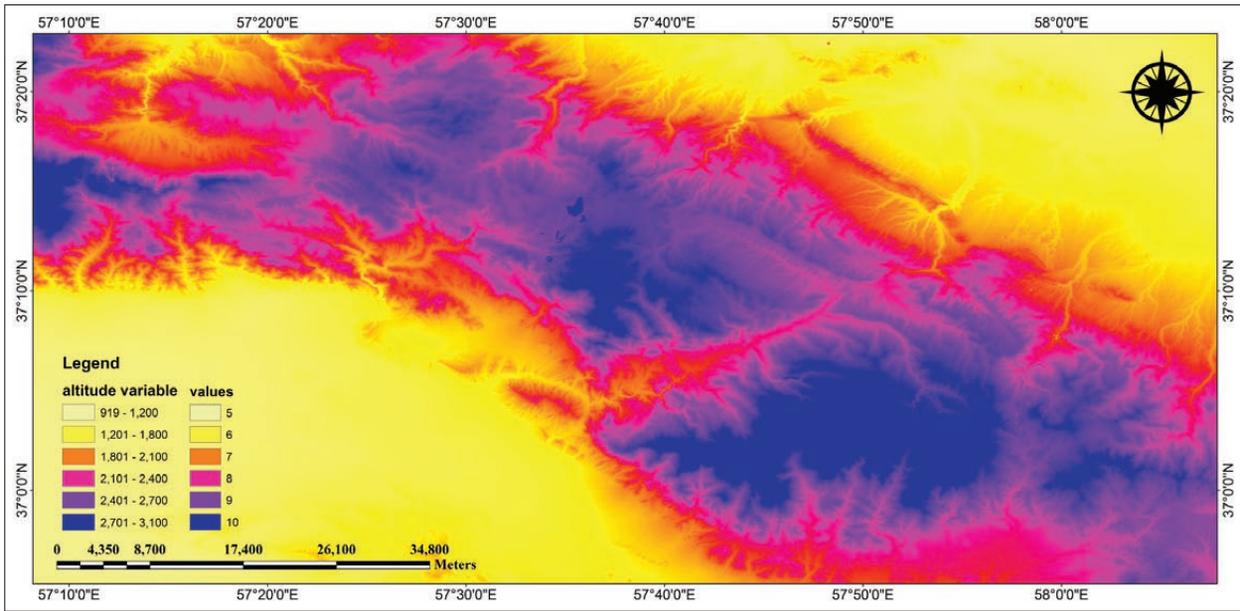


Fig. 3: The altitude map and values of the layers.

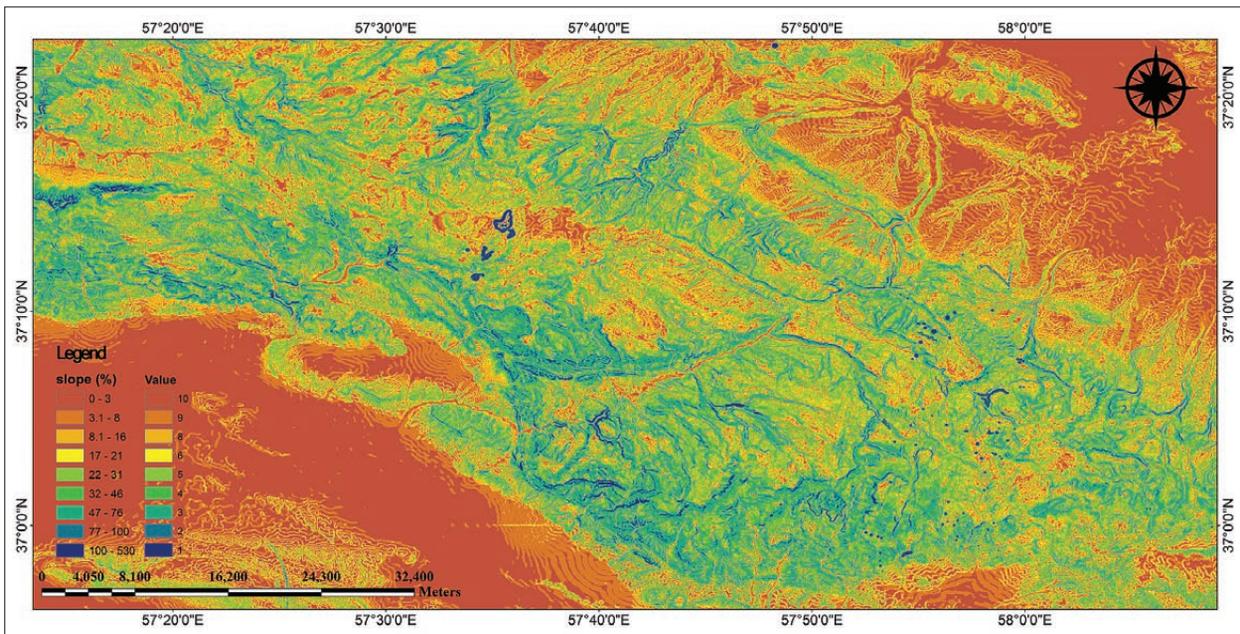


Fig. 4: The slope map and the slope values.

Tab. 2: The slope variable and scoring.

Value	1	2	3	4	5	6	8	9	10
Slope (%)	100<	76-100	46-76	31-46	21-31	16-21	8-16	3-8	3≥

aran, Lar and Tiregan (the original lime formations in the area) are made of bright pink lime, dolomitic lime, brown orbitolina lime and reef lime with marl interlayer that are distinguished by having many fissures. Accordingly and taking into account these observations, point

8 was determined for the areas covered with limestone. Therefore, as shown below (Tab. 3) limestone and fissured, fractured and partly karsted dolomite will be considered as the dominant rock formations in the area.

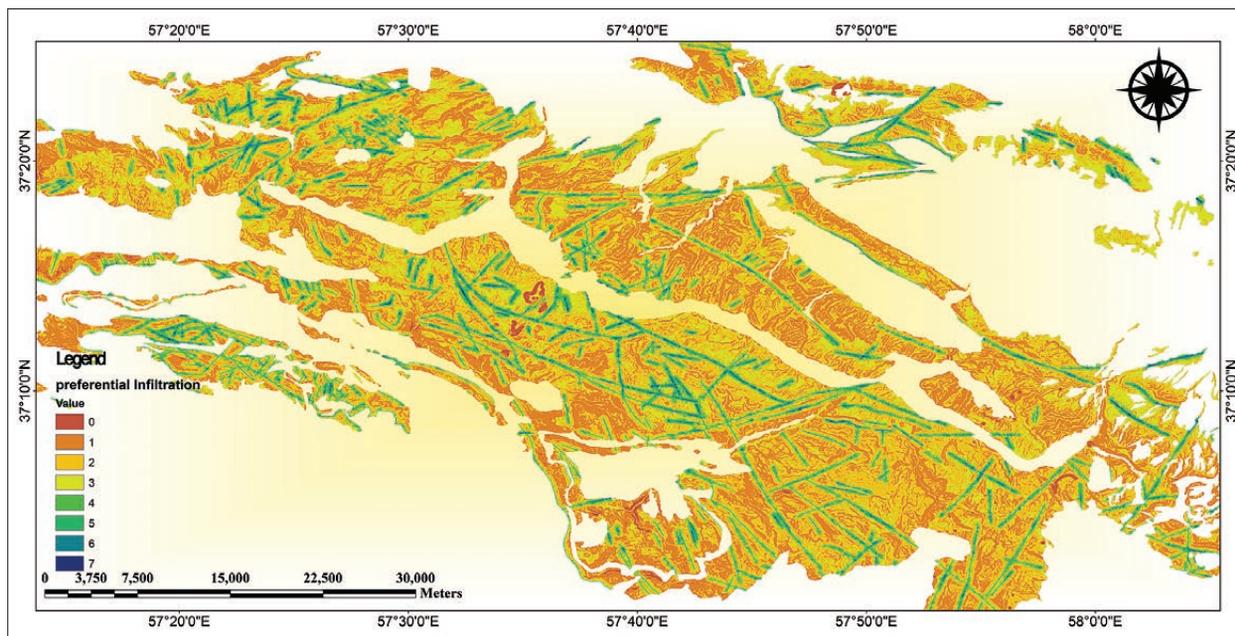


Fig. 5: Map of preferential Infiltration of areas.

Tab. 3: The lithology variable and scoring of this variable.

Value	Lithology variable
9-10	Limestone and karst dolomite
7-8	Limestone and fissured and fractured and partly karst dolomite
5-6	Limestone and fissured and fractured dolomite
4	Sand and Gravel
3	Conglomerate
2	Intrusive and metamorphic rocks
1	Shale, silt, sand

Soil variable

The classification of different soil types and rating system for these variables are presented in Table 4. Based on field studies, soil in the area is mainly calcareous regosols and fluvisols. Therefore, the point 8 was assigned to the layer of this variable. This type of soil is formed with very low thickness on hard formations and classified as poorly evolved soils. The thickness of this kind of soil is less than 50 cm.

Preferential infiltration variable

Ten rankings ranging from 1 to 10 were assigned to Preferential Infiltration variable. Points 1 and 10 are awarded to areas with minimum and maximum Preferential In-

Tab. 4: The soil variable and scoring of this variable.

Soil variable	Leptosols	Arenosols and xerosols	Calcareous regosols and fluvisols	Euthric regosols and solonchaks	Cambisols	Euthric cambisols	Histosols and luvisols	Chromic luvisols	Planosols	Vertisols
Value	10	9	8	7	6	5	4	3	2	1

filtration, respectively. As mentioned above, this layer is the outcome of three layers: slope, fault and rock type. According to the instruction of APLIS method 10 intervals are considered for the slope variable. That is as it was said; the variable 7 has been deleted. In fact, by increasing the gradient, the Preferential Infiltration variable has increased. Also, three intervals are considered for the fracture variable. Naturally, with increasing distance from junction and fault zones, the level of Preferential Infiltration decreases. In the case of Lithology variable; due to the unitary lithology of karst formations of the region Score 1 will be awarded (Tab. 5). Finally, according to the mean amount found for three layers, preferential infiltration rate was determined for different areas (Fig. 5). Accordingly, the preferential infiltration often occurs in low-slope areas which are made of limestone and normally are characterized by their potential to become karst.

CALCULATION OF THE RECHARGE RATE

Qualitative calculation of the recharge rate

In order to estimate the mean rate of aquifer recharge in the area under study, information layers were combined according to the APLIS equation in the GIS environment

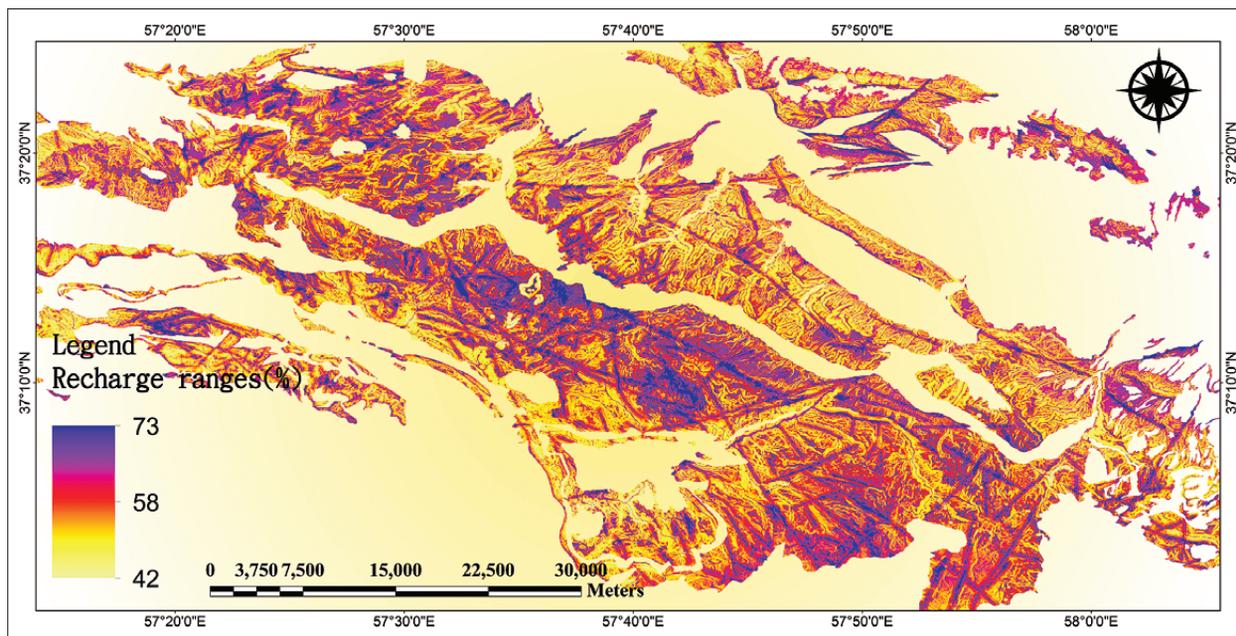


Fig. 6: Map of the recharge rate estimation using the APLIS method in the study area.

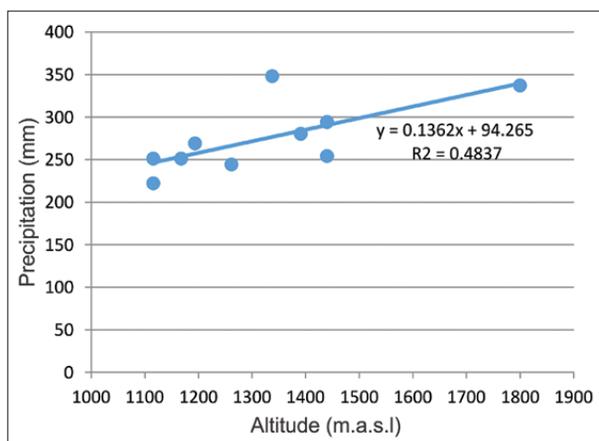


Fig. 7: The altitude-precipitation relationship in the area under study.

42 %, 73 % and 54 %, respectively. Spatially, the mean recharge rate obtained from APLIS in this study (54 %) is in compliance with other studies in different regions with a recharge rate of 32 % – 54 % (Andreo *et al.* 2008).

The results show that 83 % of karst formations in North Khorasan have moderate recharge and remaining 17 % shows high recharge (Tab. 6).

Low-recharge areas have a very good correlation with the areas at lower altitudes that have no karst formations in limestones. Areas with sufficient recharge associated with karst in the limestone and dolomite are shown below. Also, areas with high recharge are located in the vicinity of the main springs of Shirvan. In these areas, recharge rate increases in proportion to altitude. Such an association seems logical since higher areas have less soil thickness and therefore have more diverse vegetation. Therefore, less water is lost to evaporation and transpiration (evapotranspiration). Equally important is the water from sinkholes that plays an important role in

(Fig. 6). Based on the calculations, minimum, maximum and mean recharge rate in aquifers under study were

Tab. 5: The preferential infiltration variable and scoring of this variable.

Variable	≤3	8-3	8-16	21-16	31-21	46-31	76-46	100-76	100<	Distance from the main fracture (m)	≤ 50	150-50	300-150	Lithology
slope (%)										Value	10	6	2	1
Value	10	9	8	6	5	4	3	2	1					

Tab. 6: Different recharge ranges used to draw the map of spatial distribution of recharge.

Different recharge ranges (%)	≤ 20	20-40	40-60	60-80	≥80
Recharge	very low	low	moderate	high	very high

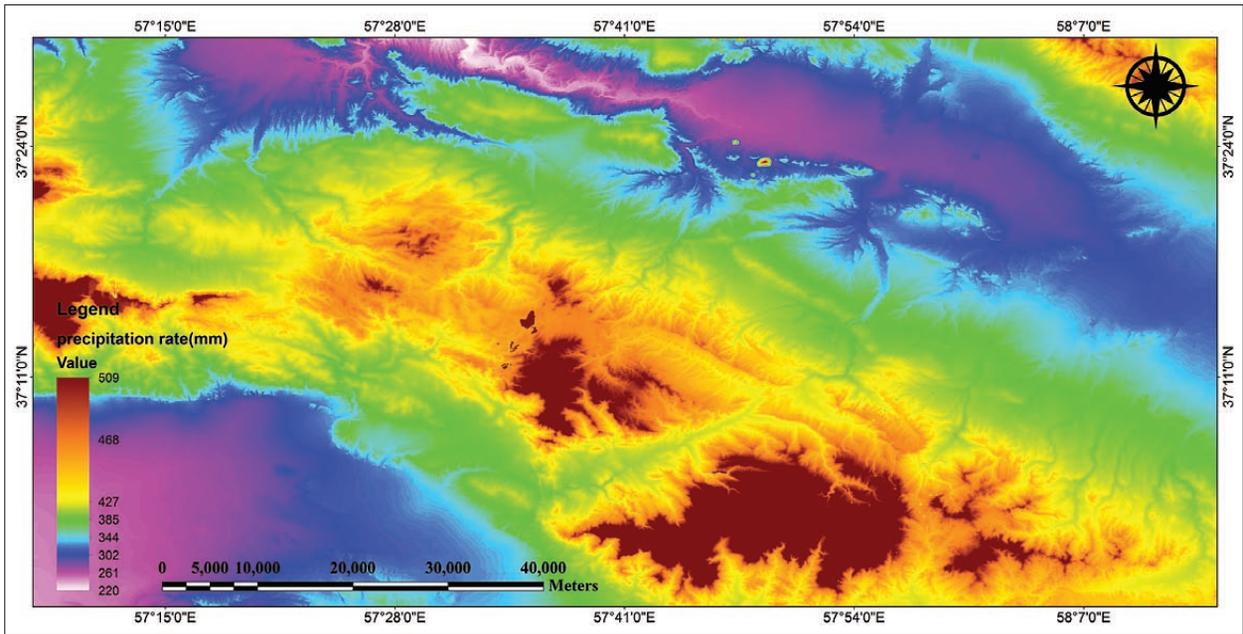


Fig. 8: Map of precipitation rate of area under study.

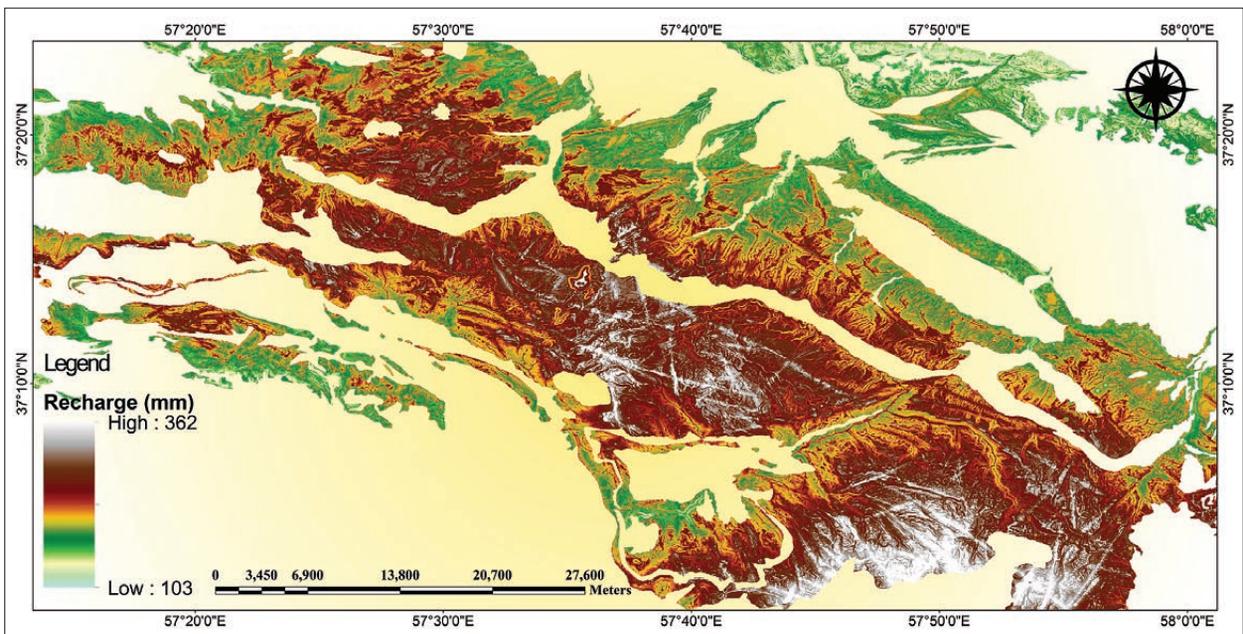


Fig. 9: Map of the mean annual recharge rate in the karst formations in a 30-year period.

recharge rate in low areas. So, the presence of water of sinkholes in low-altitude areas may be responsible for altitude-specific differences in recharge.

Quantitative calculation of the recharge rate

Based on the mean precipitation over a span of 30 years from rain-gauging stations in the area (Tab. 7) and on the altitude of each station, Precipitation-Altitude Graph

was plotted (Fig. 7). Equation 2 is obtained from the fit of these points.

$$Y=0.1349 X+96.028 \quad (\text{Eq. 2})$$

In this regard, X stands for altitude variable, and Y stands for the precipitation variable based on the altitude. After putting the equation in GIS software and introducing variable X as altitude DEM, variable Y was given as

Tab. 7: Information from Rain-Gauging Stations of North Khorasan.

Station name	River name	Y	X	Elevation	Precipitation rate(mm)
Chery	Chery	371037	580909	1338	348
Seiek ab shirvan	Atrak	372451	575556	4401	254
Asadly	Atrak	371731	572134	1800	337
Beshghardash	Atrak	372440	571706	1116	251
Farug	Atrak	371410	581310	1194	269
Shurak	Shurak	372233	574143	1168	251
Bidovaz esfaraieen	Esfaraieen	370403	573034	1262	244
Rubin araghi	Araghi	371115	572522	1391	280
Khosh esfaraieen	Calshur jajrom	370747	572026	1116	222
Nushirvan	Bidovaz	370437	573622	1440	294

DEM output for precipitation rate in the area with accuracy of 5 meters (Fig. 8). Then using the precipitation DEM and the recharge rate for karst formations in area under study (using APLIS), mean input of precipitation in North Khorasan for 30-year period was obtained in GIS software (Fig. 9). Accordingly, the mean annual

recharge rate in the karst formations of Northern Khorasan over a 30-year period is between 103 to 362 mm with an mean rate of 192 mm that has a good correlation with increase in altitude. In this way, the mean annual recharge rate is maximum in high karst areas with plenty of fissures and fractures and low-slope.

CONCLUSION

The APLIS method is applied on a regional scale. The spatial distribution of recharge is determined and main advantage in comparison with conventional methods. But since the recharge map is on a regional scale, it is not realistic to expect a high accuracy and the map should be used cautiously for detailed analyses on a local scale.

Using APLIS method, in this study the spatial distribution of recharge of the karst areas of Shirvan Plain- Esfarayen in North Khorasan was assessed. In this method, which is based on spatial information and positioning, the map of mean recharge rate was based on information layers of altitude, slope, lithology, soil and preferential infiltration zones was developed in GIS software.

The results indicate that the limestone and fissured, fractured and partly karsted dolomite should be considered as the dominant rock formations in the area particularly in low-slope altitudes and areas. The results show that minimum recharge rate in the area under study is 42 %, mainly located in karst areas. Low-recharge areas are in a very close correlation with the zones free of karst at lower altitudes. Recharge rate in karst highlands with low slopes and abundant fissures has been determined

to be around 73 %, a maximum rate. Also, 83 % of karst formations in North Khorasan have moderate recharge while 17 % has a high recharge level. The annual rate of recharge in the karst formations of Northern Khorasan over a 30-year period is between 103 mm to 362 mm with a mean rate of 192 mm.

Taking into account the recharge rate in different area of zoning, the proper management measures can be planned in order to conserve and consumption management of water resources. In this way, using water resources in the region would be strictly controlled by the recharge rate of precipitation and especially where recharge rate is low using water resources should be controlled. Proper performance with regard to consumption management is possible with regular supervision of water levels and consumption restrictions with respect to the recharge rate as the sole incoming component in the aquifer. The authors of this study strongly suggest that future studies consider management methods of restricted use considering recharge rate, especially in areas with low recharge.

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