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ASSESSING AND MAPPING THE VULNERABILITY OF KARSTIC AQUIFER USING GIS AND COP MODEL

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ABSTRACT
Vulnerability assessment and production of the risk map of the contamination is considered as a managerial significant technique in the conservation of Karstic water resources. Karst aquifers in semi-arid regions of the West of Iran with respect to the region's natural conditions are prone to contamination. The present paper aims to estimate the value of vulnerability and to produce the map of the Karst aquifer of Gilan-e-Gharb in the West of Iran against the pollution diffusion, using COP model. The model estimates the vulnerability of the Karst's water resources against the contamination using three parameters: overlying layer (O), density of current (C), precipitation regime (P). The results show that 0.25% of the region's area is located in a very low vulnerability domain, and 25.5% of the region's area is in a low vulnerability domain, which represents a low vulnerability of this Karst aquifer against pollution. Most regions with a low and moderate vulnerability - in the dominion of developed Karsts of the Asmari limestone formation - are located in the high lands. The dominant vegetation of the region is mostly covered by forest and dense pastures, and its total amount of precipitation is more than 600mm. In general, C, P and O parameters play the most significant role in reducing the value of the vulnerability over the area of study, respectively. The C factor plays the most important role in lessening the vulnerability of the region due to the little area of developed Karsts, high district of non-Karst regions, and lack of suitable vegetation. On the other hand, the region's precipitation is relatively low which results in a decrease in the amount of contamination permeation. The map of (O) factor shows a high and very high vulnerability of the region, which represents the expansion of permeable structures in the region. The high vulnerability value of this factor is adjusted by other two factors, and on the whole, the vulnerability amount of region is kept down through these factors.

KEYWORDS: Vulnerability, GIS, COP Model, Karstic Aquifer.

INTRODUCTION

Precautionary demand for water security is now widely accepted throughout the world in order to eliminate the human population's problems and natural ecosystems (Münch and Conrad, 2007; Krause *et al.*, 2007, Gondwe *et al.*, 2011). In arid and semi-arid regions, water plays a significant role in the promising development of future (de Wit and Stankiewicz, 2006; de Jong *et al*., 2008). The potable underground water resources are mostly overused by humans (Andreo *et al.*, 2006). The underground water management is a crucial issue for the current and future generations. Administration of the underground water resources requires a quantitative and qualitative management of the subterranean water resources (Gaur *et al.*, 2011). Conservation of Karstic water resources is one of the most important actions in the management of the Karsts' water resources because of itsvulnerability and high sensitivity to the pollution (Afrasiabian, 2007). Karstic aquifers vary from other aquifers due to the distinct hydrologic traits (White, 1988; European Commission, 1995; Bakalowicz, 1995, Ford and Williams, 2007; Mudarra and Andreo, 2011).Karstic aquifers are affected by contamination. This is because of a quick transition as well as a poor reservation capacity in the penetration system. As a result, the effect of natural processes such as absorption, demolition, and filtration is reduced (Mudarra and Andreo, 2011). The contamination sources of Karstic waters are divided into two major kinds: 1- widespread and extensive pollution resources, 2- spot (limited) pollution resources (de Jong *et al.*, 2008). The expression of groundwater vulnerability includes both the common (natural) and special vulnerability. The natural vulnerability is based ona condition that the physical surroundings are made based on a special stage of conservation and on the basis of the region's hydrological and geomorphologic features. But the special vulnerability considers a specific pollutant (Vrba and Zaporozec, 1994).The European commission has given out the procedure of COST 620 in order to assess the vulnerability of karstic aquifer and produce the risk map of Karstic water resources. In general two factors are taken into account by the Pan - European method, namely the pollution movement from source to the target, and reduction of itsdensity throughout the route (Andreo *et al.*, 2006). The COP method was improved by COST Action 620 (Zwahlen, 2004), and was tested in two Karst aquifers of South Spain with various climatic and hydrologic characteristics, and then boosted. The COP method was applied by Kiros and Zhou (2006) in Ethiopia; Ducci (2007) in Italy; Ravbar (2007) in Slovenia; Dimitriou *et al.* (2008) in Greece; Leyland (2008) in South-Africa; and Plan *et al.* (2009) in Australia. In the COP model the three following factors are used to estimate the amount of vulnerability: the current density (C), the overlying layer (O), and precipitation (P). This method is widely being used to protect the underground water resources in the Karstic regions. And it is possible to produce the vulnerability map of the Karst aquifers for managerial purposes and keep them safe from harm based on the aforesaid method. The vulnerability map of aquifers is mostly considered as an efficient procedure to manage and conserve the underground water resources (Zwahlen, 2004; Vías *et al.*, 2010). The production of the vulnerability map of the underground waters is a kind of scientific approach to save the underground water resources presented in the late 1960s for the first time (Adams and Foster, 1992). This procedure has been considerably used over the past decades due tothelarge progress in hydrological models and GIS (Kattaa *et al.*, 2010).Throughout the several past decades in the semi-arid regions of Iran, the Karsts' water resources – as the main source of water supply for the local communities –have been severely affected by some factors such as over-utilization, pollution related to the human activities, and several droughts. With regard to the region's Karst geomorphologic characteristics, these major and important water resources for the region are in danger of contamination resulting from human industrial and agricultural activities. Gilan-e-Gharb's Karst aquifer is located in the West of Iran. Karst possesses invaluable resources of underground waters with respect to the limestone, the past and present climatic conditions, and the tectonic and geomorphologic characteristics. The annual discharge volume of the Karst aquifer of the Gilan-e-Gharb is around 28.918 million cubic meters, which has been recognized as the main source of water supply for drinking and agricultural purposes in the city of Gilan-e-Gharb and 50 suburb villages. It seems, therefore, necessary to investigate the vulnerability and also present some well-qualified approaches in order to protect the Karstic aquifers from the contamination. The objective of the present research is to apply a COP model through utilizing the Geographic Information System (GIS) as an effective procedure in contamination risk assessment of the Karsts' water resources, and finally, produce the vulnerability maps for the Karst aquifer of Gilan-e-Gharb.

CASE STUDY

The aquifer under study is located in the Zagrus zone in the southwest of Kermanshah province in western half of Iran (Figure 1).The highest region's elevation is about 2100 m and an area of 388 square kilometers with the direction of northwest-southeast between latitudes to N, and longitudes to E. In the light of stratigraphy, features of stones in the upper Cretaceous to Pliocene-Quaternary eras in the region under investigation can be observed, which include: Gurpy, Pabdeh, Asmari, Aghajary, Bakhtiary conglomerates and quaternary's sediments containing old and new traces, and old alluvial cones (Figure 7). Figure 2 represents the geologic profile of the study area. The structures of Gurpy, Pabdeh and Gachsaran located in the core eroded synclines. Asmari structure covers the surface of anticlines and the traces and old alluvial cones have expanded throughout the flat plains and hilly places. The region, on the basis of geology, is located in the undulated Zagrus zone. The region's plains are those kinds of synclinal ones and based on the structural features, it is an asymmetrical and reversed anticline, which recognized tectonics because of a high fault. Mirshokraei (1997) believes that the region's structural condition is justified with the pattern of the dextral sectorial zones. The region's faults possess the components of over thrust, tensile, resection and ordinary. The region's Karst has features like those of Holokarst, and their formation is made of paleo-karst through time, and belongs to the cold eras of quaternary. The important factors to develop the Karst in the region includes: lithology, Asmarian lime-layers, being tectonically or structure of the region, climate, slope and elevation. The Karsts' formations of the region consist of sinkholes, doline, poljecaves, Lapiaz, deep valleys of Karst, Karst flat fields and Karens (Bagheri, 2008). The average annual precipitation of the region is around 610mm and the average annual temperature is approximately 130C. The region under study holds a semi-arid climate due to existence of dry spells for 4-5 months.

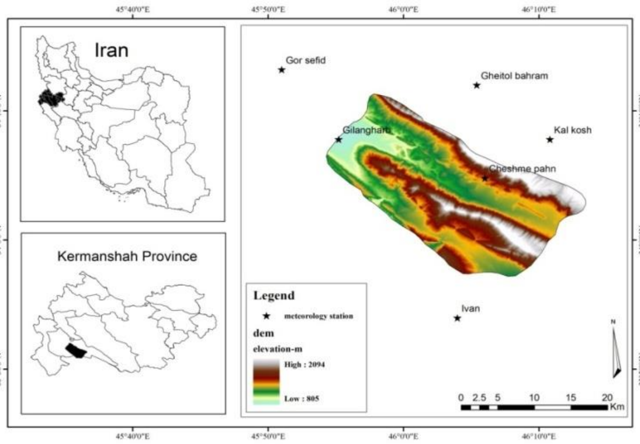

Figure 1. The geographic map of the studied area

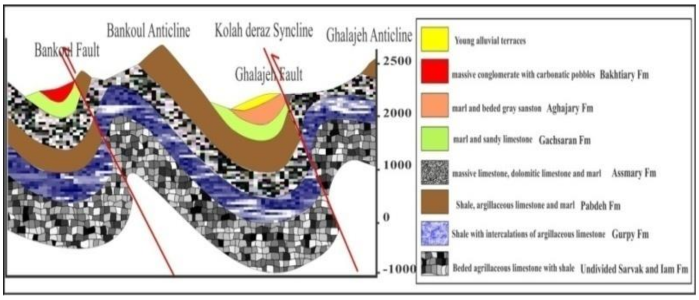

Figure 2. The geologic profile of the studied area

METHODS

The present research is a kind of practical research based on the theoretical and experimental methods and COP model. The topographic maps of 1:50000; geologic maps of 1:100000; soil map of 1:250000; aerial map of 1:50000 and IRS satellite images of 2002; and the records of precipitation and temperature data of the region's weather stations were used as the main data of the research. GIS was used as the main tool of the research in order to dothe final analysis and produce the vulnerability map. They were used ENVI 4.3 and Corel x4 for observational explanation and to prepare the satellite images as well as the profile (Side View). At first, the surroundings of the studied area were determined using topographic maps, and the topographic and geologic output data were transferred to the ArcGIS as the base data and then digitized. In the next step, the digital elevation model was provided in order to prepare the elevation and slope layers. The region's Karst landforms were identified during the operation of field investigation, and the geomorphology of the region's Karst was analyzed as well. In order to produce the precipitation map and evaluate the P.Q. index, the Kriging method was applied to interpolate the data. For this purpose, 7 rain-gage stations – with an appropriate distribution over the region - were used, while 2 out of 7 stations are located inside the study area. The region's precipitation holds a positive correlation with the elevation, but the distribution of the stations represents lack of stations over the high lands. Thus, the relationship between elevation and precipitation was estimated and then applied in the precipitation by using SPSS and multiple regressions technique. The correlation of precipitation and elevation over the region shows an increase of 280mm precipitation per 1000 meters. The relevant equation is Y=204.15+X (0.285), where x stands for the elevation. In COP model, the vulnerability is evaluated based on three factors of C, O and P. The O factor is used to investigate the preservation of the non-saturated sections of the aquifer against the occurrence of a pollutant agent, and C and P factors are utilized in order to amend the protection degree (O factor) (Andreo *et al.*, 2006). In this method, (O) stands for overlying layer; (C) indicates the current density and (P) shows precipitation regime. The O factor describes the protection provided for the groundwater by the layers above the saturated zone with the use of thickness, porosity and permeability properties of the soil and each lithological layer of the unsaturated zone (Daly *et al.,* 2002). The C factor is evaluated based on the Karsts' geomorphology, vegetation and the slope of topography. Table 1 illustrates how the COP method is estimated. The P factor includes the amount of precipitation and its time distribution (intensity), and it determines the power of the water to convey the pollutants on the surface into the aquifers. GIS has been used in order to compute the relevant indexes. The map of the required factors for each index was provided from the scientific authentic centers and then digitized. Afterwards, the value of C, O and P indexes over the region was estimated through using functions of the geoprocessing like intersect and dissolve. In the long run, the related layers were overlaid by using function of the spatial analyst and the final value of vulnerability was obtained. Finally COP vulnerability classes have been rated according to the values of Table 2. The range of this parameter varies between 10 (maximum value) and 1 (minimum value) and has reclassified in five equal classes.

Table 1. A flowchart for estimation of the COP index
(Vías *et al.*, 2006; 2010)

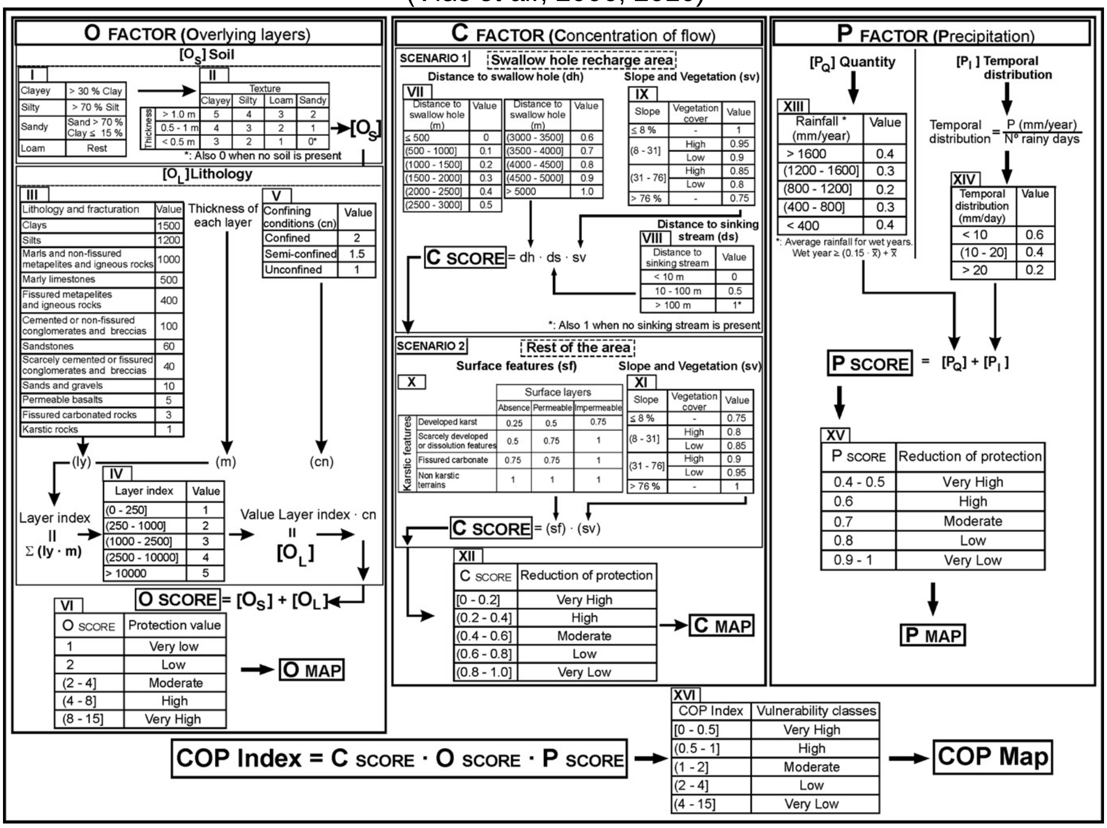

Table 2. Values for COP vulnerability classes

COP vulnerability classes	Class values
Very high	9-10
High	7-8
Moderate	5-6
Low	3-4
Very low	1-2

RESULTS

C index computation

The scenario 2 from the Table 1 was applied to compute the C index. First, surface features (sf) were estimated based on the geomorphologic characteristics of the region's Karst. And then (SV) index evaluated based on the slope and vegetation map of the region. Table 3 shows the ranking of the indexes. The development of the Karst is one of the important criteria in the penetration value of pollution, which the permeation process is more and uncomplicated in the holoKarst and as a result, the pollution might be transferred more quickly into the Karsts' aquifer. , The field observations were used to give the value to the slope and vegetation (sv) factor from the analysis of the region's Karst geomorphology. The upper sections of the heights contain a developed Karst and Karsts' landforms such as sinkholes, polje. The middle sections of the anticline that has been made of lime formation are scarcely developed. The lower heights with a sharp slope in the topography belong to the fissured carbonate regions, and are also a part of Marl formations and quaternary deposits, and the Karst morphology has not formed on it (Figure 3). The region has a sharp slope due to being mountainous in which the high steep lays over the anticline and the less steep lay down over the plains, Karsts' flat lands and on the top of the anticlines (Figure 4).The region's heights contain forest vegetation. Hillsides and some parts of the uplands hold a grassland flora and the surface of the plain are also covered with agricultural lands (Figure 5).

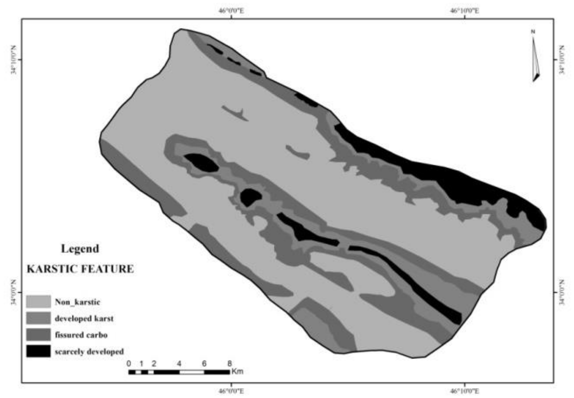

Figure 3. Karst map of the region

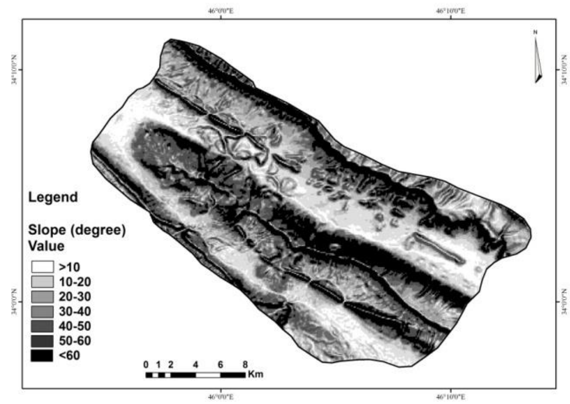

Figure 4. Slope map of the area of study

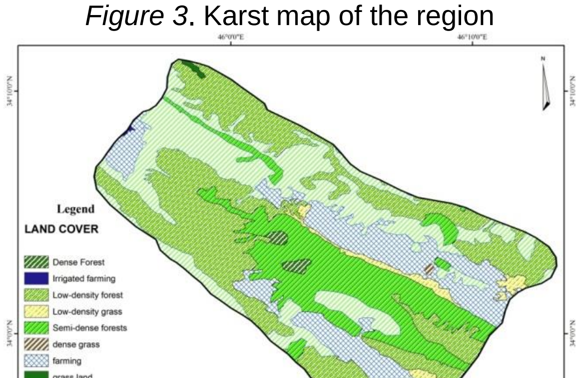

Figure 5. Vegetation map of the region

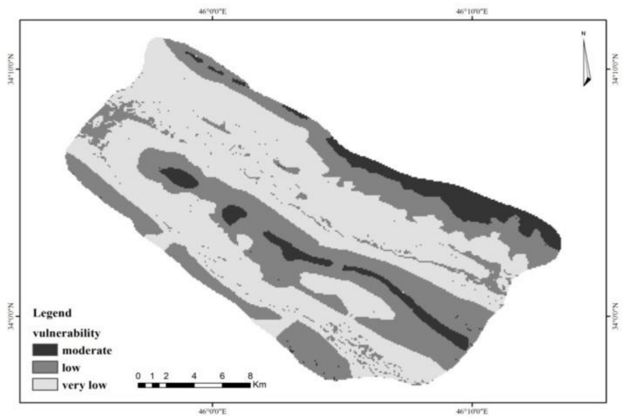

Figure 6. Interpolation map of C factor

The regionalization map of the C factor has been illustrated in Figure 6.The final value of the factor is between 0.375 and 1. In this map, the area with average risk is located over the high area of the region holding the metamorphosed Karst, low slope and thick to semi-thick vegetations. The area with low risk over the region consists of scarcely developed, fissured carbonate, semi-thick vegetation and high slope. The areas with lower risk are those regions that possess clay formations and quaternary alluvial deposit in the form of terrace and alluvial fan. These regions, are used for agricultural purposes as well, and have a relatively low slope. In the map of C factor, Karst geomorphology, slope and vegetation have the largest effect on the value of C factor respectively. Most parts of the region are placed within the area of low vulnerability, which is due to the expansion of the quaternary deposits.

The computation of O index

The O factor is evaluated based on thickness, porosity, the attributes of soil's permeation, and depth and type of the layers of lithology. Table 3 shows how to give values to each sub-factors of this index. The formations of Gurpy, Pabdeh and Gachsaran are made of Marl and lime. The Asmari formation has been made of lime and the formation of Bakhtiari is a mass conglomerate accompanied by carbonated stones with an appropriate rounding and a fragile combining. The old and new alluvial fans and terraces have been made of alluvial deposits of the small and big grain-like formations with a high percentage of sand and gravel. The geologic and soil maps of the region were used in order to assign values to the O factor (Figures 7 and 8).

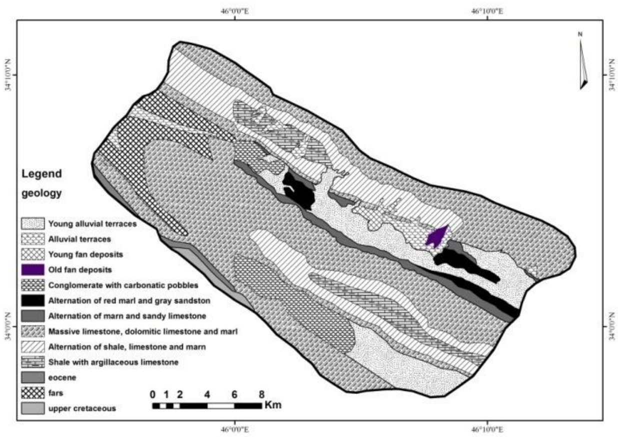

Figure 7. Geology map of the area of study

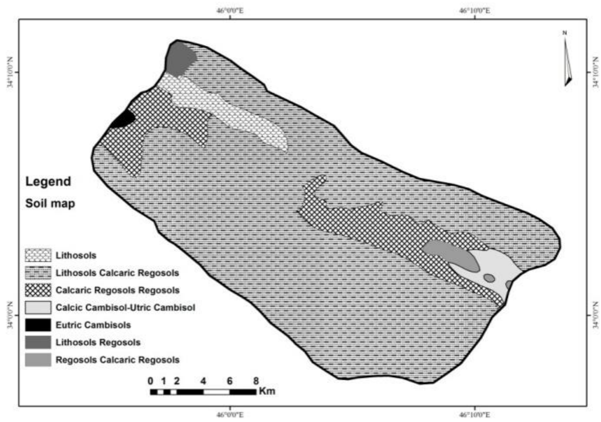

Figure 8. Soil map of the area of study

Interpolation map of the O factor is shown in Figure 9; the final value for this factor is between 5 and 12. In this map, most part of the area is occupied with high risk domain. The highlands of the region which is covered by Asmari formation and the surface of region's plains which is covered by quaternary alluvial deposits are located in a domain with high vulnerability. The regions which are situated in the domain of the very high vulnerability are surrounded by the formations of the Pabdeh, Gurpy and Gachsaran, and they mostly possess a sandy soil with a thickness less than 0.5 meter. In the map of O factor, the formation's thickness, type of the formations and soil play the most significant roles respectively. Almost the whole region is placed in the domain of large and very large vulnerability, which is formed due to theexpansion of lime formations and quaternary deposits which contain sand and stone.

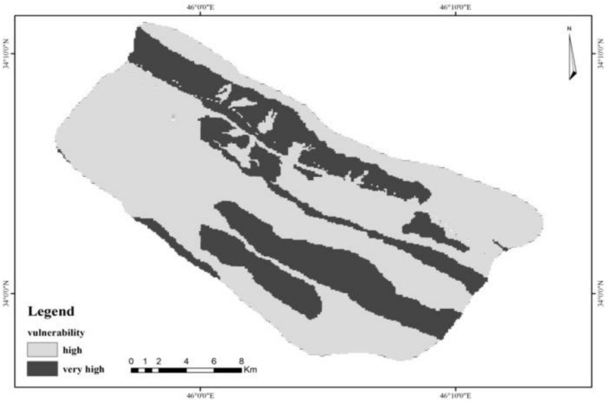

Figure 9. Interpolation map of O factor

Table 3. Values for COP factors and variables in the aquifer of Gilan-e-Gharb

Factor	Sub factor	Variable	Values
C	Scenario B: Karstic features	Developed Karst	0.5
		Scarcely developed	0.75
		Fissured carbonate	0.75
		Non Karstic	1
	Slope and vegetation	0–8%	0.75
		8–31% high vegetation	0.8
		8–31% low vegetation	0.85
		31–76% high vegetation	0.9
		31–76% low vegetation	0.95
		<76%	1
O	Soils Texture and thickness	sandy and >1m	2
		10m and > 1m	3
		Clayey and= 1m	4
		Loam and < 50	1
	Lithology [OL] Lithology and fracture	Marl	1000
		Conglomerates	100
		Sandstone	60
		Sands and Gravels	10
		Semi-confined	1.5
P	Quantity [PQ]	Average precipitation for wet years 400-800	0.3
	Intensity [PI]	Precipitation and number of days <10	0.6
		10-20	0.4

Computation of P index

The average precipitation of the region is between 430 – 800 mm. Over the lowlands of the region the precipitation amount is less than 500mm and in the highlands particularly over the mountainous regions the precipitation increases to approximately 800 mm yearly (Figure 10). The mean frequencies of rainy days are about 60-days per year. Figure 11 presents the interpolation map of the P factor in which the final value of this factor is between 0.7 and 0.9. In this map, the most areas belong to the low vulnerability domain and there is only an average risk domain over the eastern heights of the region.

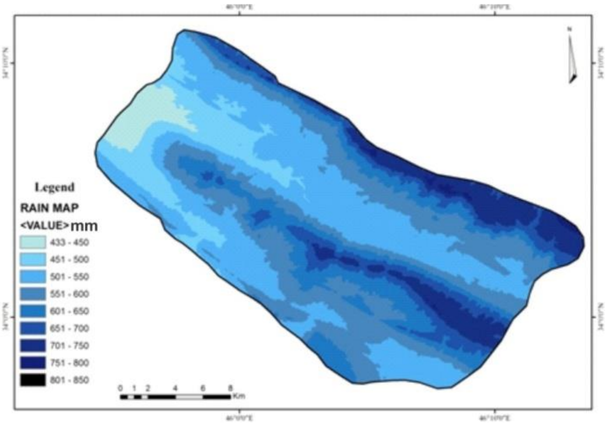

Figure 10. The map of annual precipitation for the region in millimeters

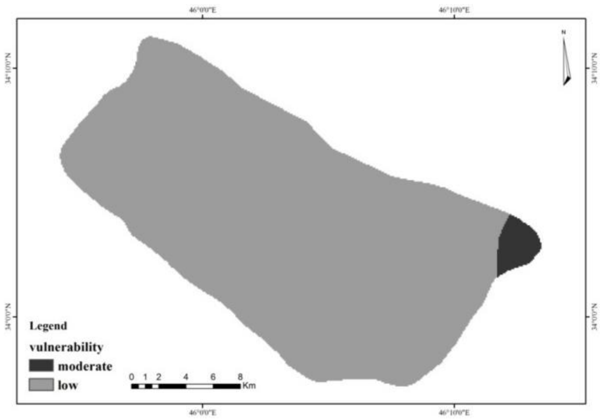

Figure 11. The interpolation map of P factor

Computation of COP model

Having computed the three factors of C, O and P and producing their vulnerability map, these layers were computed using spatial analysis function and then the final map of the region's vulnerability was computed (Fig. 12). The values of the region's vulnerability were measured between 1 and 10 and they were classified into five equal classes of very low, low, moderate, high and very high. Table 4 illustrates the area and the percentage of each area for these five classes in the area of study.

Table 4. Area and the percentage of area for each three classes in the study area

Percent	Area (km^2)	Vulnerability classes	COP index
0.25%	1	very low	1-2
25.2%	96.5	Low	3-4
47.61%	182.3	moderate	5-6
17.87%	68.4	high	7-8
9.07%	34.7	very high	9-10

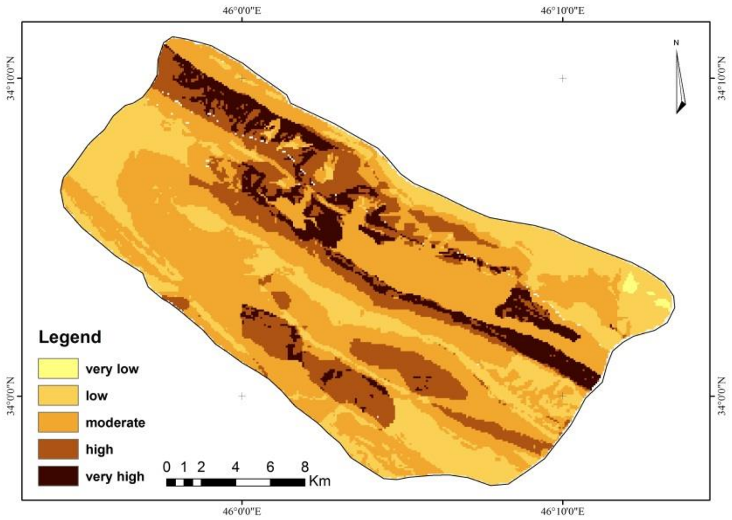

Figure 12. Map of the region's vulnerability based on COP model

CONCLUSIONS

In order to assess and produce the vulnerability map of the Karst aquifer of Gilan-e-Gharb the COP model which consists of three C, O and P parameters has been applied. After giving the value to each three factors and changing them into the raster layers, the layers were multiplied by each other through using spatial analyst function, and the value of COP index was computed between 1 and 10. The vulnerability was classified into five very low, low, moderate, high and very high classes (Table 4).The spatial distribution of vulnerability classes of the final map (Figure 12) shows that 0.25% out of the region's area is located in the very low domain, 25.2% in the domain of low and 47.61% in the domain of moderate and only 26.94% of the region located in the high and very high domain which depicts a low vulnerability of the present Karstic aquifer to the contamination. The moderate vulnerability domain is 182.3 km^2 which covers the most area in vulnerability classes. This domain has both spread out over the highlands and on the surface of plains in the region, and in the view of lithology, the region was surrounded mostly by Assmary and young alluvial terraces formations. These regions mainly consist of sandy, loam and clay soils. Regarding vegetation, the area is mostly covered by agricultural lands, semi dense and sparse forests. The highlands here have a sharp slope. The geomorphology of the region is fissured carbonate and most of its area includes non-Karst. The precipitation over the region is less than 600mm. The area of the domain with very low vulnerability is around 1km^2. The area of the domain with low vulnerability is around 96.5 km^{2}of which the greatest part is situated in the mountainous regions. This domain in the mountainous regions is located over the developed Karst in the Asmari lime formation, and over the Fars and quaternary alluvial deposits with less than 100 meters depth. The vegetation of the mountainous domain is mostly forest and there are agricultural lands and moderate pastures on the surface of plains. The slope value is less than 10 degrees on the surface of plains,but over the mountainous districts; the slope value varies between0-50 degrees due to the fact that the regionsare located in the Karstic flat regions. These districts have a precipitation more than 650mm over the highlands, but less than 500mm precipitation occurs on the surface of the plains.The area of the domains with high and very high vulnerability is around 103.1 km^2. This domain is located over the non-karst in the Pabdeh, Aghajari and Gurpy formation. The forest and pasture are the main type of vegetation in this domain. Slope is less than 30 degree and precipitation is less than 600 mm. In general, over the whole region, the factors of C, P and O play the most important role in the value of the region's vulnerability respectively. The vulnerability maps acquired by the three factors reveal that C factor plays the main role in reduction of the value of the region's vulnerability because of the low area of developed Karst, the large area of the non-Karst, sharp slope and poor vegetation of the region. On the other hand, the precipitation of the region is relatively negligible and this factor reduces the amount of contamination's penetration and as a result the value of vulnerability will be decreased. The map of O factor represents the vulnerability between high and very high over the region, which shows expansion of the permeable formations of sandy-Gravely out in the region. The value of high vulnerability of this factor was obtained by two other factors. All of these factors resulted in holding a low vulnerability value in the region. This model possesses a suitable effectiveness in the vulnerability assessment of the Karstic aquifers.

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