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Assessment of ground water vulnerability using the DRASTIC method (Case study from arid regions of Kermanshah and Ilam, west of Iran)

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Abstract

Ground water contamination has been a matter of concern in developing agricultural areas which is prone to pollution by fertilizers such as nitrates. In arid parts of Kermanshah and Ilam provinces due to the transference of water from Sirvan River by tunnel and channel, agricultural industry especially irrigation technology has been developed in a rush. Ground water is not easily contaminated, because many aquifer systems possess a natural capacity to attenuate and thereby mitigate the effects of pollution. Once this occurs, it will be difficult to remediate. The replacement cost of a failing local aquifer is generally high and its loss may influence other water resources. Further, in the developing countries, such remediation might practically be impossible. Thus it is important to identify which aquifer systems and settings are most vulnerable to degradation. The main aim of this research was to evaluate extend of ground water contamination in some agricultural plains in arid regions of Kermanshah and Ilam based on the DRASTIC model. The electrical conductivity (EC) values are assigned to verify some parts of the DRASTIC vulnerability map; largely this arises from the lack of adequate nitrate information. In all plains, EC is in agree with vulnerability map except for Somar, due to the presence of Gachsaran Formation which increase EC dramatically.

Key words: the DRASTIC map, water contamination, aquifer vulnerability, electrical conductivity.

1. Introduction

Ground water is vital to human life and economic development. It is a part of the hydrologic cycle and also a valuable renewable resource which occurs in permeable geologic formations known as aquifers (Rosin et al. 2013). One way to prevent the vulnerability of aquifers is to distinguish areas prone to contamination and then put forward a suitable managerial land use (Margat 1968). Many concepts have been proposed for vulnerability of aquifers by several researchers (Albinet & Margat 1970, Collin 1987, Foster 1987). Albinet & Margat (1970), the pioneers in this field, defined vulnerability as the possibility of contaminants migration from land surface into aquifers under natural conditions. Also Stigter et al. (2006) introduced it as a descriptive parameter which showed areas with the maximum possibility of contamination.

Vulnerability was classified into two types: intrinsic vulnerability and specific vulnerability which have been influenced by internal factors (e.g. geological, hydrological and hydrogeological properties) and by external factors (e.g. human activities,land uses and etc), respectively (Gogu & Dassargues 2000, Stigter et al. 2006).

Four vulnerability assessment methods have been developed and represented graphically as a map including hydrogeological setting methods, parametric methods, numerical and statistical methods (Vrba & Zoporozec 1994, Canter 1997). Although the reliability of the maps is doubtful, it could be confirmed by considering the overlapping results of different methods and contamination zones by specific pollutants such as nitrate (Dixon 2005, Andersen & Gosk 1997, Foster 1987, Stigter et al. 2006, Gogu & Dassargues 2000).

Of all these methods, the parametric method with Drastic model developed by Aller et al. (1987) seems to be more common and the most widely used model, owing to its application for the regional scale areas (i.e small scale maps), for the assessment of intrinsic vulnerability and for easily data acquisition (Ahmadi & Aberoumand 2009, Gemitzi et al. 2006, Guo et al. 2007, Musekiwa & Majola 2013, Stigter et al. 2006).

Now a day's many techniques exist for integration systems such as Fuzzy logic, neural networks and Analytical Hierarchy Process (AHP) (Fijani et al. 2013, Musekiwa & Majola 2013). For DRASTIC model, GIS technology has been used to integrate ratings and attributes of important parameters into aquifer vulnerability maps.

The study areas extend over a great area in the western part of Iran and cover an area of 20774 km2of dry-arid region. The agricultural practices aim to apply in the study areas, thus the aquifers obviously expose to agricultural-induced nitrate and other contaminations. Here, it is tried to assess aquifer vulnerability of twenty two plains based on agricultural land use and validate it by comparing it with the electrical conductivity (EC) map.

2. The study area's location and description

The study areas are agricultural plains and parts of a total arid region which is located between 45◦ 24'12" -47◦ 57'54"E longitudes and 31◦ 48'47"-34◦ 54'25"N latitudes, the westernmost of Kermanshah and Ilam provinces, in Iran (Fig. 1).

The rivers of this region originate from the high elevation areas of the Zagros Region and discharge to the Iraq border. Although the western arid regions have suitable land for agricultural practices, these areas encounter the lack of water supply and to some extent poor water quality. The other challenge in this area is the lack of water for urban, economical, industrial and environmental areas caused the migration of residents. Due to strategic position of these areas for border security status, it should be more vital to remove such principal issues. Therefore, the project of water transfer from Sirvan River basin in west of Iran, which is one of the large-scale projects in water resources management in Middle East, has been designed and it consists of a number of reservoirs and transfer systems. Besides, Daryan Dam is currently under construction near Daryan in Kermanshah province. The purpose of the dam is to divert a significant portion of the river to Southwestern Iran for irrigation through the 48 km long Nosoud Water conveyance tunnel and to produce hydroelectric power.

3. Geology of the study area

Evaluation the geological setting of the area aims to characterize the accurate input variables of DRASTIC model such as soil media, aquifer media, vadose zone media, and hydraulic conductivity. The study area is parts of Zagros Imbricate Zone of the Zagros Orogen which is situated in west of Zagros in Kermanshah and Ilam provinces (according to Alavi, 1994, 2004) (Fig. 2). The NW-SE trending arid zone is composed of high folded zone (internal Zagros), Zagros fold-thrust belt (external Zagros) and Khuzestan plain.

The oldest geological formations situated in the northern part of the study area are Khanehkat and Neyriz Formations which dominantly consist of dolomite, shale and limestone units. Cretaceous formations include Bangestan group which contains argillaceous limestone, shale, sandstone and conglomerate deposits. These formations mostly outcrop in Zahab and Jagiran plains in the northeast of the arid zone.

In Tertiary, most of the agricultural plains are composed of limestone-dolomite Asmari Formation which acts as the most important karstified formation among all plains. This formation is overlain by impermeable marl and gypsum Gachsaran Formations which is the main factor for increasing ground water salinisation (or sand and marl Aghajari Formation) and is underlain by shale and marly Pabdeh-Gurpi Formation.

Quaternary sediments are mainly composed of alluvial deposits that lie as overburden on older sediments. These sediments resulted from erosion of the bedrock or reworking of older fluvial and alluvial formations. Aquifer systems are predominantly built up in young fluvial and alluvial formations which have become coarse-grained toward northern plains.

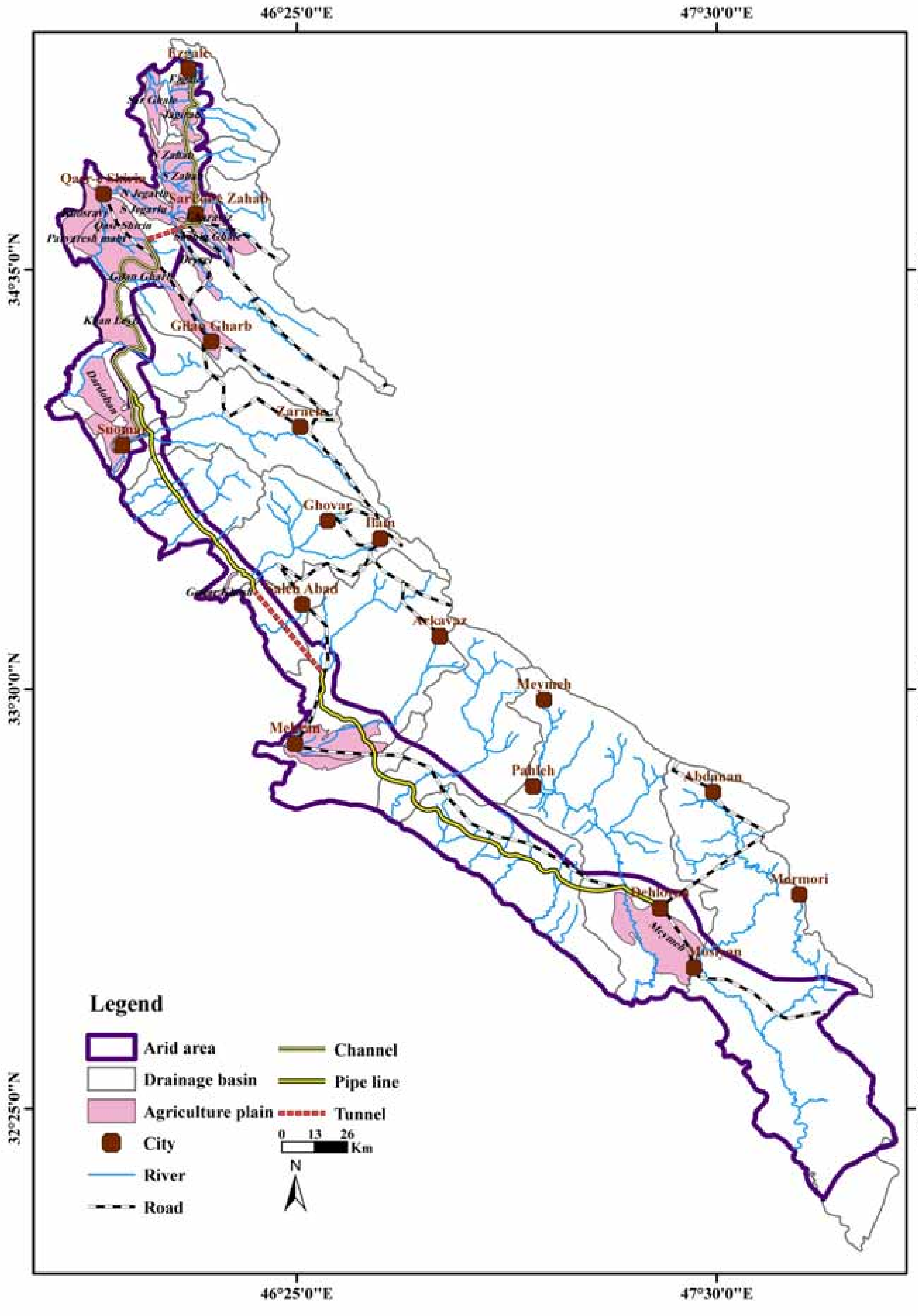


Fig. 1 Distribution of agricultural plains in arid zone

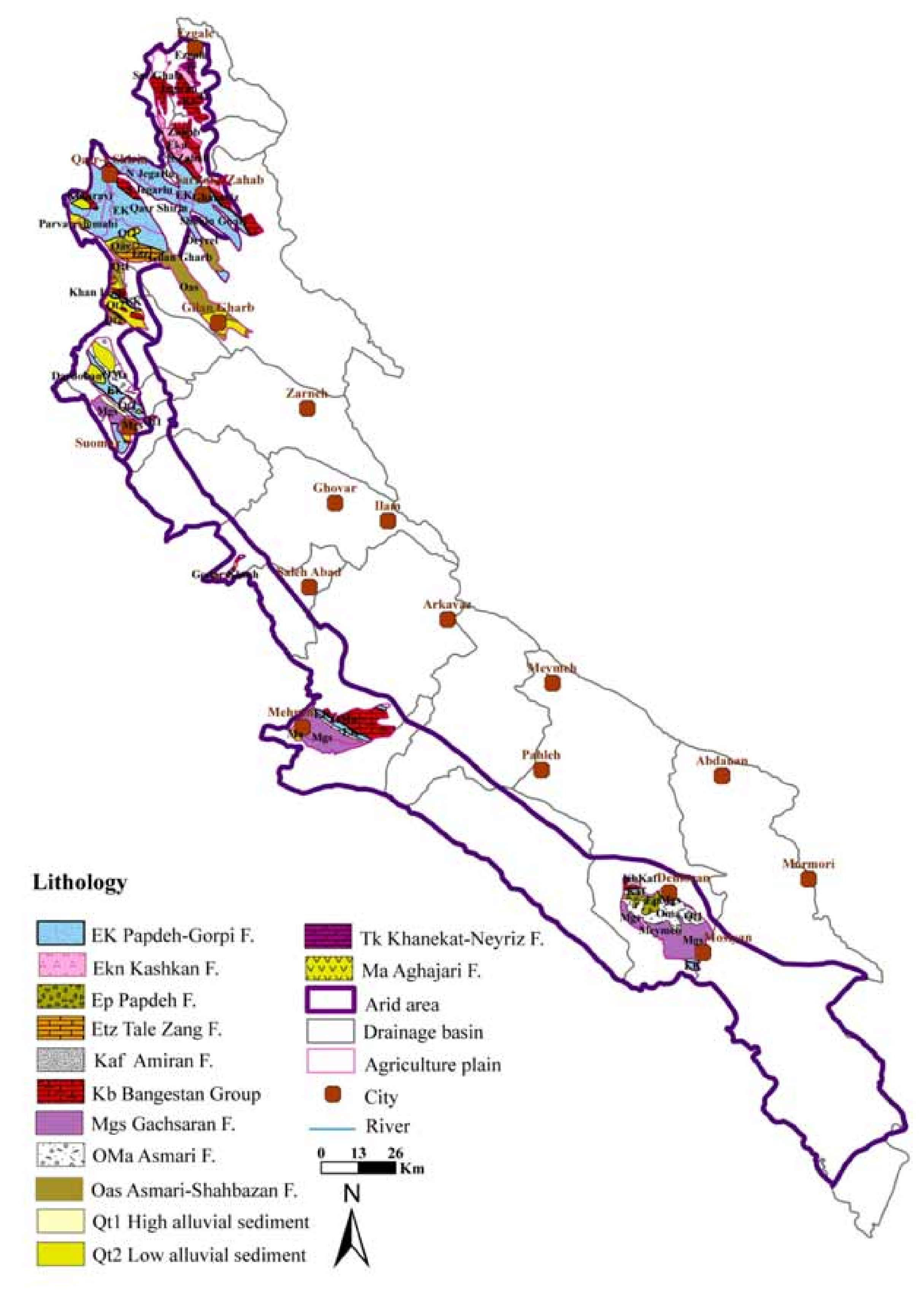


Fig. 2 Geological map of the agricultural plains in agricultural plains

4. DRASTIC model definition and methodology

Drastic is a parametric and overlay index method developed by Aller et al. (1987) for the US Environmental protection Agency to assess aquifer vulnerability to pollution for any types of aquifers and soil media.

This method is based upon attributing rating and ranging to the parameters, Viz., Depth to water table, Recharge (net), Aquifer media, Soil media, Topography, Impact of the vadose zone and Conductivity (hydraulic) (Table 1). The parameters are relatively rated between 1 and 10 according to the relative significance of each parameter to the pollution potential. Every increase in the rated attributes prevents from attenuation of the contaminant and intensifies its spreading (Stigter et al. 2006).

These ratings are based on qualitative methods and so some researchers believe that DRASTIC method is an inappropriate predictor and specially has little correspondence between the most vulnerable and the most contaminated areas (Rupert 2001). But this model can analyze vulnerability almost precious based on accurate and more number of dataset.

After mapping all parameters, to achieve a greater balance and to increase the importance of parameters, some weights were assigned to each map. Final DRASTIC index was calculated by adding up the parameters and overlaying the individual maps in a GIS environment (Eq. 1).

$$\text{DRASTIC Index} = 5 \times D + 4 \times R + 3 \times A + 2 \times S + T + 5 \times I + 3 \times C \qquad (1)$$

The DRASTIC index, used in this paper, ranges from 79 to 199 (Stigter et al. 2006). Some vulnerability classes have been proposed by some researchers to facilitate interpretation for final index such as: extremely low, very low, low, moderate to low, moderate to high, high, and very high potential (Corniello et al. 1997; Stigter et al. 2006).

The methodology structure of the study is illustrated in Figure 3. The DRASTIC system has four layers including:

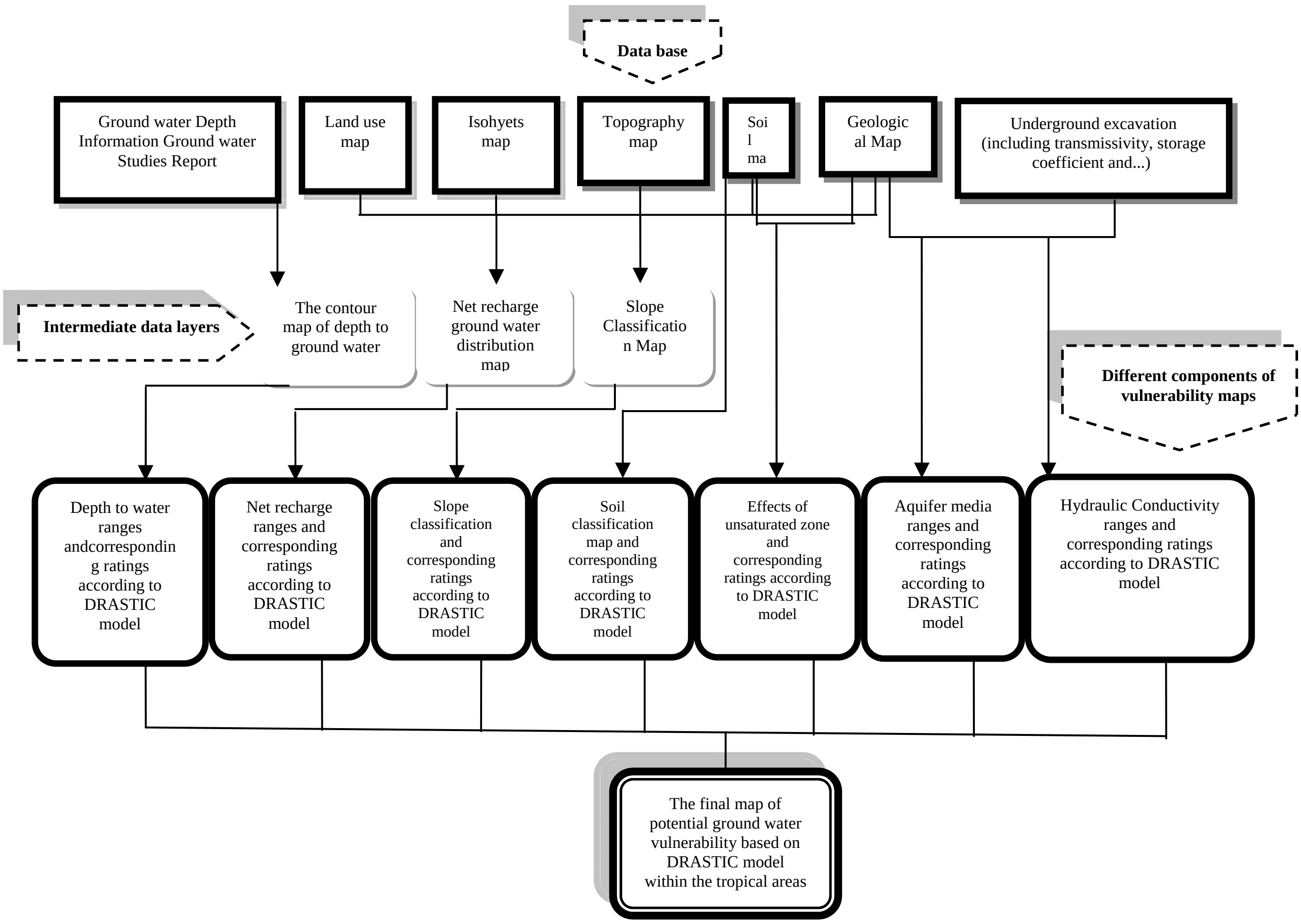


Fig. 3 The DRASTIC parameters rating method, from Aller (1987)

Table 1 Rating values of the seven attributes of DRASTIC model (The higher the value of the rating, the more the sensitivity to contamination) (Aller et al., 1987).

DRASTIC parameters		Rating and range indices										
SOIL Media	Rating	1	2	3	4	5	6	7	8	9	10	10
	Range	Not Shrinking Clay	Muck	Clay Loam	Silty Loam	Loam	Sandy Loam	Shrinking Clay	Peat	Sand	Gravel	Thin or Absent
Ingredients unsaturated zone	Rating	1	3	3	3	6	6	6	8	9	10	
	Range	Confining Layer	Silt/Clay	Shale	Limestone	Sandstone	Bedded Limestone, Sandstone	Sand and Gravel with Silt	Sand and Gravel	Basalt	Karst Limestone	
Aquifer Media	Rating	2	3	4	5	6	6	8	8	9	10	
	Range	Massive Shale	Metamorphic/Igneous	Weathered Meta-morphic Igneous	Glacial Till	Bedded Sandstone, Limestone	Massive Sandstone	Massive Limestone	Sand and Gravel	Basalt	Karst Limestone	
Hydraulic conductivity of the aquifer (m/day)	Rating	1	2	4	6	8						
	Range	0.04-4.1	4.1-12.3	12.3-28.7	28.7-41	41-82						
Topography (Slope Percent)	Rating	10	9	5	3	1						
	Range	0-2	2-6	6-12	12-18	18>						
Net recharge (mm)	Rating	1	3	6	8	9						
	Range	0-50.8	50.8-1-1.6	101.6-177.8	177.8-254	254>						
Depth to water (m)	Rating	1	2	3	5	7	9	10				
	Range	30.4>	22.8-30.8	15.2-22.8	9.1-15.2	4.6-9.1	1.5-4.6	0-1.5				

1. Dataset layer that should be analyzed and used for data mining to extract some base maps. Dataset considers the following data: Ground water depth information report (2010); geological map; land use map; isohyets map; soil map; underground excavation report including transmissivity, storage coefficient and etc.
2. Intermediate layer was extracted from Dataset information includes Net recharge GW distribution map; Topography zone; GW depth contour map.
3. DRASTIC model components include all 7 DRASTIC parameters.
4. Output layer includes DRASTIC vulnerability map.

5. Application to the study areas

5.1 Depth to ground water

The contaminants should pass through the unsaturated zone to the water table. By increasing the thickness of this zone, the effect of the purifying processes is significantly increased. It should be mentioned that the travel time depends on aquifer type such as confined aquifers surrounded by low permeability media can slow down contaminants migration as against phreatic aquifers (Hasiniaina et al., 2010). The water levels recorded in 2006-2009 were assigned to create a piezometric surface and GW depth contour map (Mahabghods GW report, 2009). As shown in Figure 4, this map was converted to the map of DRASTIC ratings on the basis of the defined ranges (Table 1). For areas with lack of information, kriging interpolation of contiguous data is applied to estimate GW depth.

Based on geological maps the upper aquifers in all study areas can be classified into three categories; namely, i. e., phreatic, confined and karstic (limestone) aquifers. The plains with Asmari-Shahbazan Formation and/or high alluvial thickness could have low Gw depth which increases GW vulnerability to pollution such as Khosravi, QasrShirin, GilanGharb and etc.… But plains especially with marl and sandstone such as Aghajari Formation usually have low permeability.

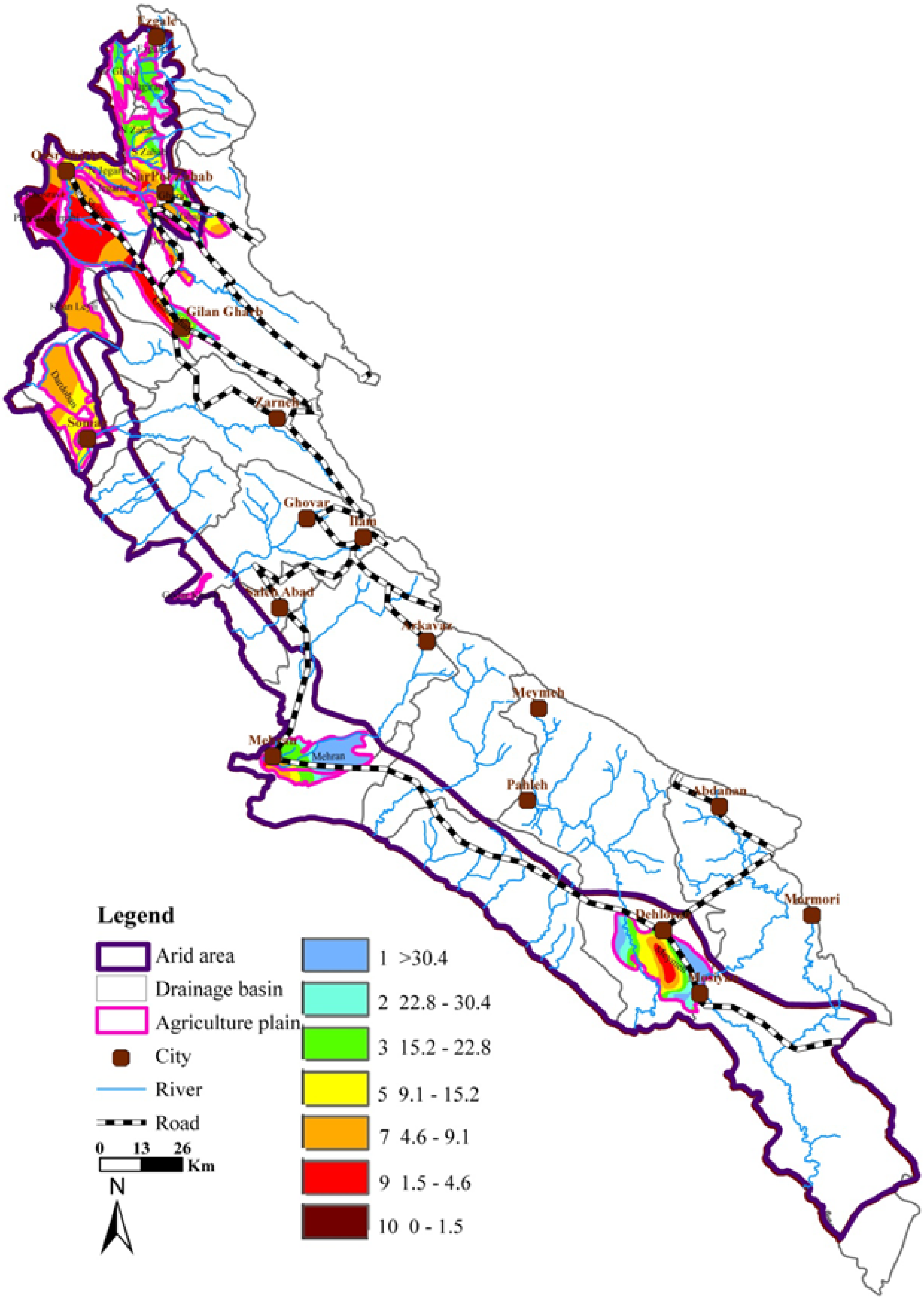


Fig. 4 Depth to water ranges and corresponding ratings according to DRASTIC model, in agricultural plains

5.2 Net recharges (R)

Net recharge is the fraction of rainfall which infiltrates through surface layers and reaches the aquifers. The rainfall passes through vadose area of soil and transports contaminant fluid vertically to aquifer media (Aller et al. 1987). Areas with higher capability of recharge are usually more vulnerable to pollution, due to convenient transferring process of contaminant from surface to depth. In this study net recharge was determined by subtracting the amount of rainfall from runoff as follows:

$$\mathbf{R = P - Runoff} \qquad (2)$$

$$\mathbf{Runoff = C * P} \qquad (3)$$

Where R is net recharge of aquifer (mm); P is average of annual rainfall (mm); Runoff is average of annual runoff (mm) and C is runoff coefficient. To determine the runoff coefficient some data layers have been used, such as soil media with 1:700,000 scale, land use with 1:100,000 scale and slope map with 1:700, 000 scale. Finally a spatial distribution of runoff coefficient was obtained and replaced in equation (2) which made spatial distribution of runoff. Then net recharge of aquifers was produced. As seen in Figure 5, most of the study areas have high net recharge capability; therefore they are classified in the 8 and 9 classes.

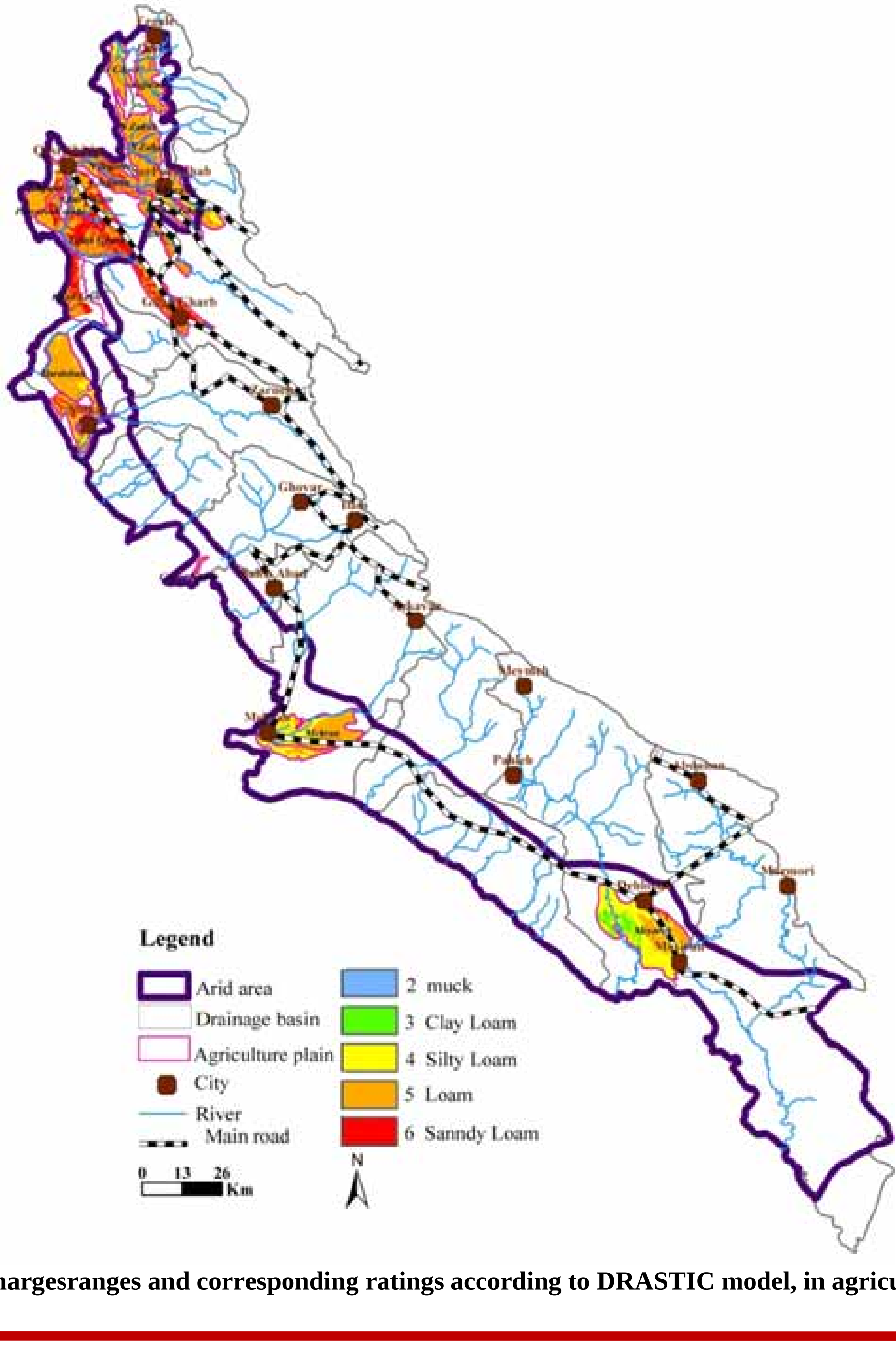


Fig. 5 Net rechargesranges and corresponding ratings according to DRASTIC model, in agricultural plains

5.3 Aquifer media

Aquifer media controls the attenuation characteristics of aquifer and contaminant movement in aquifer media. As mentioned above, the 1:700,000 scale geological map of the study areas gave an overview of the aquifers present in the study area. But for determining upper aquifer types is need to use hydraulic conductivity rather than geological map which is showed outcropping formation.

The study areas in arid zone cover the total area of approximately 20,774 Km2. Also, alluvial zones are about 4713 Km2, which is equivalent to 23% of the total area.

On the other hand, main reservoirs of the study areas were mostly formed in carbonate rocks and rarely in non-carbonate rocks such as sandstone. Carbonates rocks with considerable thickness and extent exist mostly in the northern plains of the arid zone. These rocks forms over 6542 km2 of the study areas including Azgale, Zahab, Sarpolzahab, Ghaleshahin, Deyreh, Mehran and Mosiyan.

Non-carbonate rocks such as Eocene conglomerate every now and then composed underground reservoirs such as Kashkan formation. The ratings used to each aquifer class are shown in Figure 6.

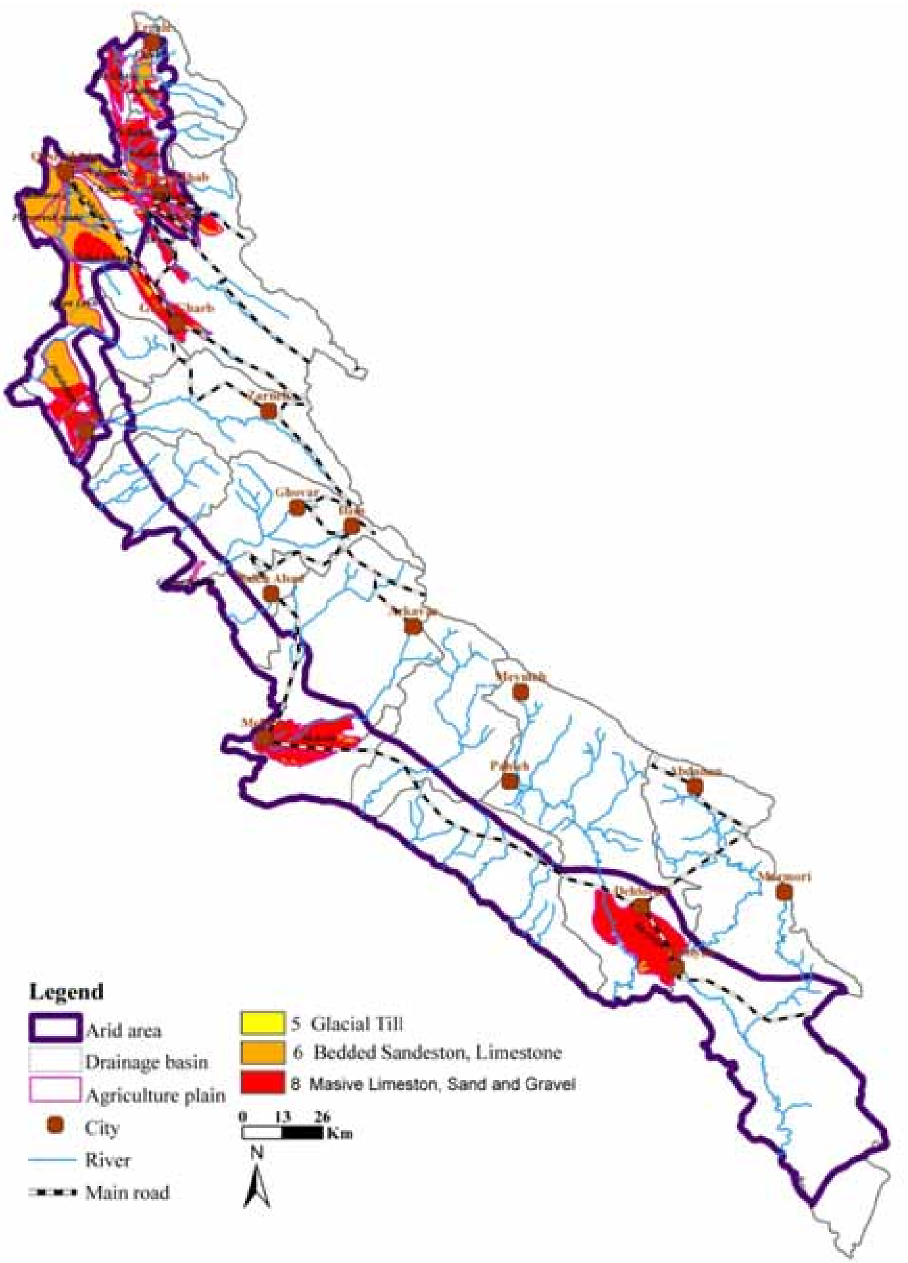


Fig. 6 Aquifer media ranges and corresponding ratings according to DRASTIC model, in agricultural plains

5.4 Soil media (S)

Soil map and hydrologic soil group map with scales of 1:700,000 from agriculture Jahad organization of Kermanshah were applied to determine the spatial distribution of the soil types in the study areas. The soil classes for the study areas with corresponding DRASTIC ratings (Table 1) are mapped in Figure 7. As can be seen in this Figure, approximately all kinds of soils can be found in the study areas; although clay loam (rating 3), loam (rating 5) and shrinkage clay (rating 7) are dominantly extended. Owing to the lack of soil information in some areas, it is tried to use other sources such as existing descriptive information and/or adjacent plain information. Therefore, appropriate classification has been assigned to these areas. Consequently, DRASTIC model in some areas are not reported.

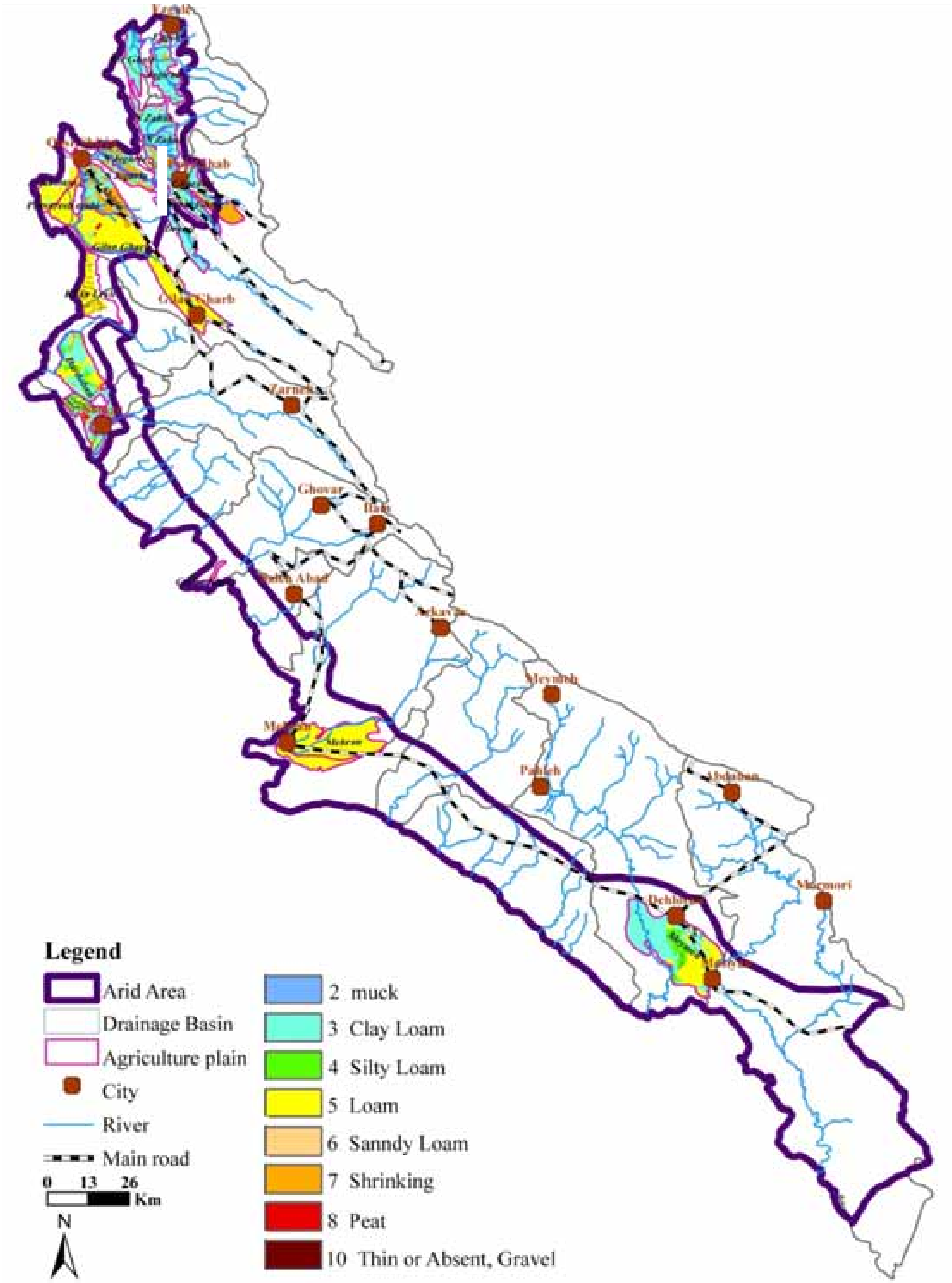


Fig. 7 Soil media ranges and corresponding ratings according to DRASTIC model, in agricultural plains

5.5 Topography (T)

Topography is a main factor controlled pollution infiltrating to aquifer, in other words, low slope causes low movement of pollution and increases infiltration chances. The Digital Elevation Model (DEM) map was used to determine the slope percentage of the land surface, indirectly. After that, the slope percentages were assigned ratings on the basis of the corresponding ranges defined by DRASTIC model (Fig. 8). Most of the northern plains in the study areas are classified in rating 2, as topography here is approximately flat (2-6%). On the other hand, the other dominant slope in the areas is rating 1 which is occupied by part of Zahab and Sarqale plains and all the southern plains.

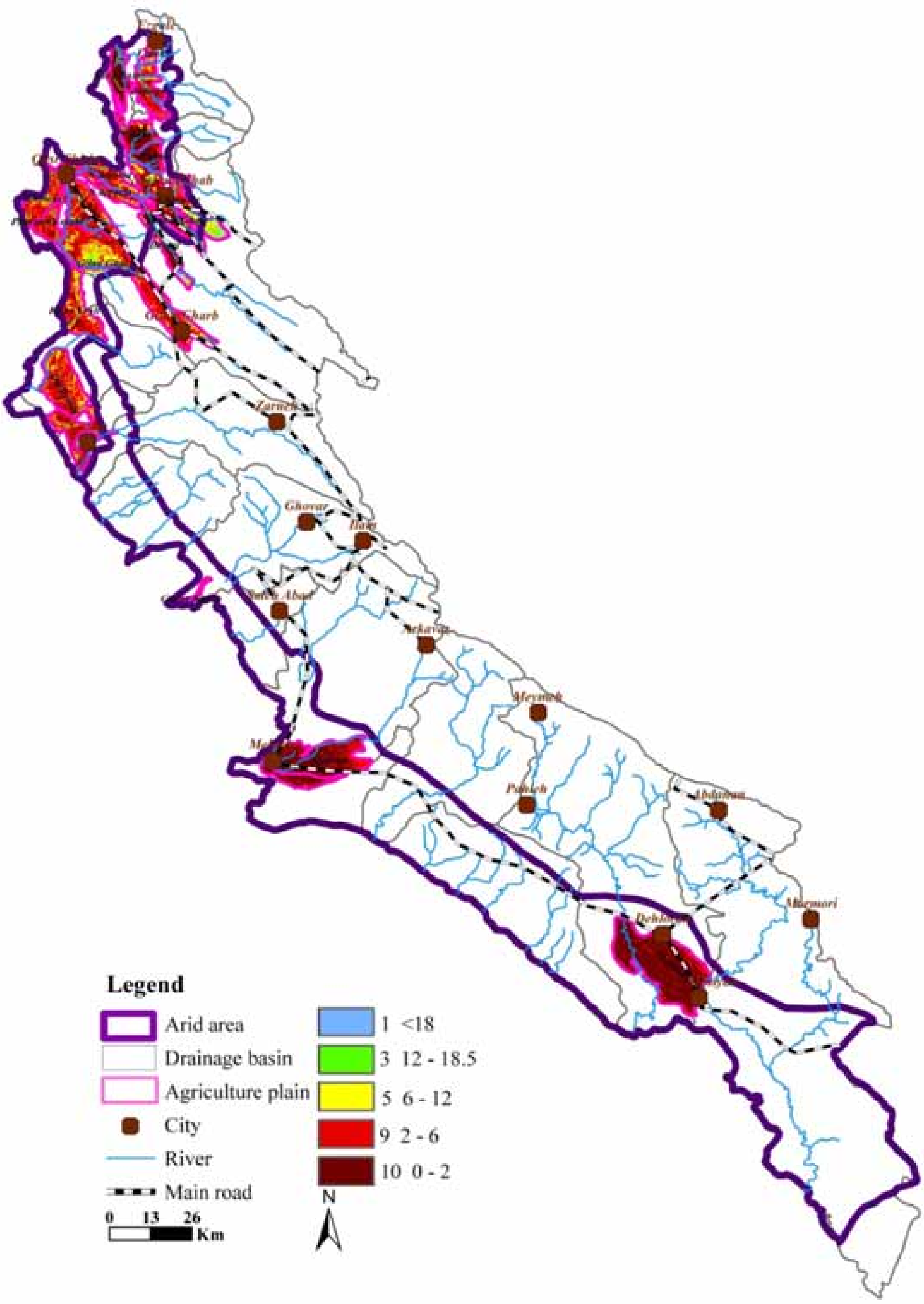


Fig. 8 Topography ranges and corresponding ratings according to DRASTIC model, in agricultural plains

5.6 Impact of the vadose zone media (I)

The vadose zone is a so-called unsaturated zone which is affected by upper layer formations or outcrops. Therefore, the geology map with the scale of 1:700,000 is a base map used for determining vadose zone media (Fig. 9). Although in some areas with negligible thickness of upper layers, deep formations should be considered for its media. As most parts of the study areas are covered by shale, limestone and sandstone such as upper Cretaceous to Miocene rocks, the vadose zone were classified in 3 classes but the majority were placed in classes 3 and 6. It should be mentioned that the study areas have karstified limestones but as they are not clearly distinguishable from the usual types, all limestone were classified with the same ratings.

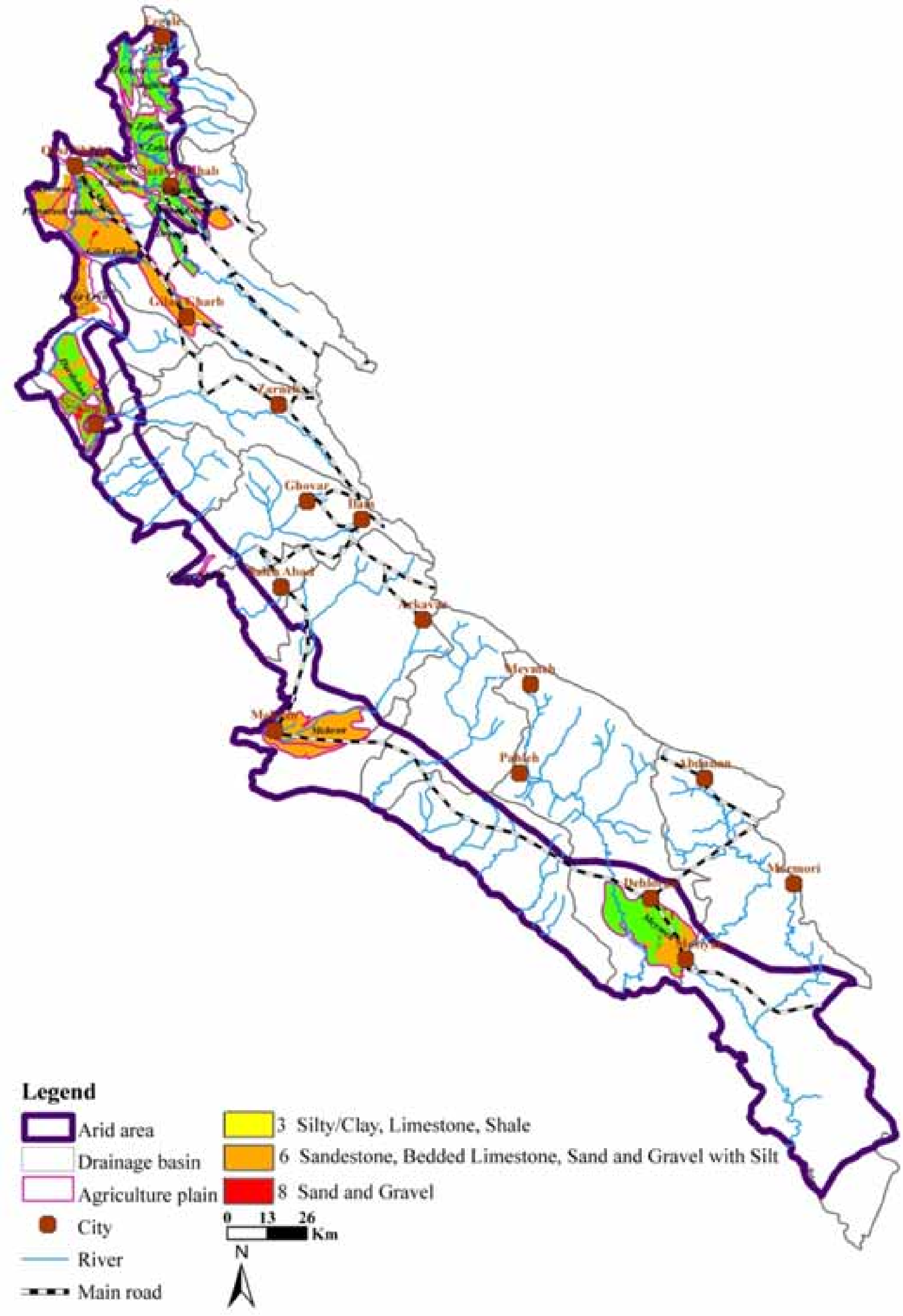


Fig. 9 The vadose zone media ranges and corresponding ratings according to DRASTIC model, in agricultural plains

5.7 Hydraulic Conductivity (C)

Exploratory excavations have been done including 83 wells and geophysical surveys with 1456 number of sondages. In order to determine the alluvium and aquifer thickness and to calculate the hydrodynamic factors, the exploratory wells were excavated. In these plains, the alluvial thickness from north to south increases. This excavation is done to represent the types of sediments, thickness and depth of alluvium and aquifer, type and depth of basement, and quality and quantity status of ground water. The maximum thickness of alluvium is 220 meters in Mehran plain. The depth to water range is from a maximum of 63 meters in Dehloran plain to a minimum of 1 meter in other plains (Table 2).

The higher the conductivity, the more easily the pollutants can percolate the aquifer media. Additionally, because many of the self-purification processes in the soil media (such as chemical and biological analysis) will take time, the more the contaminants have effusion, the less removal potential of contaminant will take place. Based on Hydraulic conductivity, the values of aquifer in most of the study area is 0.04 – 4.1 (m/day) (DRASTIC rating 1) and only for a small part of the study area the DRASTIC rating is estimated. The results indicated that an estimate was between 4.1 and 12.2 (m/day) (Fig. 10).

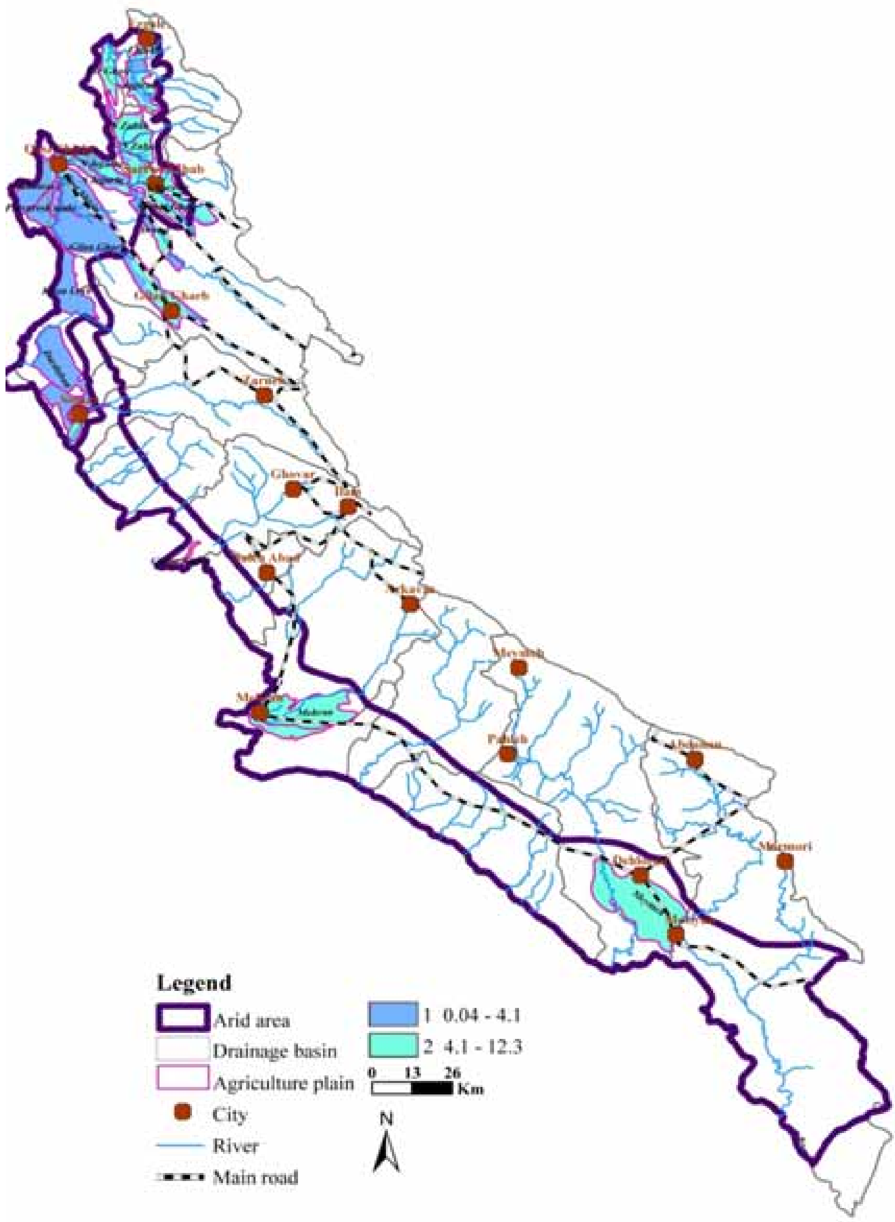


Fig. 10 Hydraulic Conductivity ranges and corresponding ratings according to DRASTIC model, in agricultural plains

Table 2 Transmissivity and storage coefficient from aquifer pumping tests.

No.	Agricultural plains	Area (Km^2)		Alluvial Thickness (m)		Transmissivity (m2/day)		Storage coefficient (%)
		Alluvial	Altitude	Max	Min	Max	Min	
1	Azgleh	121.2	581	150	30	---	---	5
2	Zahab	167.3	265	200	70	2502	674	7
3	GilanGharb	133	824	120	45	7000	833	3
4	QasrShirin	70	485	100	5	---	---	4
5	Deyre	214	633	100	25	800	---	5
6	SarPol-e- Zahab	194	456	120	35	2160	1100	3
7	Suomar	229	2926	100	15	256	11	3
8	Ilam	104	1088	70	15	---	---	3
9	Salehabad	82	196	100	15	---	---	7
10	Mehran	1021	4316	220	70	7600	592	5
11	Dehloran	658	1985	140	15	6114	120	5
12	Mosian	1543	1738	200	85	5633	700	5
13	GodarKhosh	173	559	150	65	700	198	5

6. Discussion

All DRASTIC parameters have been mapped as an individual vulnerability map in the previous sections. Afterwards they were all overlaid in the GIS software and the indices were calculated according to equation (1). This was to obtain the final DRASTIC map. This map is shown in Figure 11. The DRASTIC index is classified into eight grades which are attributed a qualitative degree of vulnerability ranging from “extremely low” to “extremely high”. Only six classes are shown, as the highest class (extremely vulnerable) for the study area is not present. Most of agricultural plains are placed in the Low to medium class and others are medium to high, only one of them has a very low vulnerability (Table 3). Some plains including Ezgle, Jagiran, Sarghale, N Zahab, S Zahab, Beshiveh, Godarkhosh and Meymeh have shown a very low and a low average aquifer vulnerability index. The main parameter which greatly affects the vulnerability index in these plains is depth to water which is relatively high. These plains mostly have limestones and alluvial aquifer media which have an adverse effect on aquifer pollution; however, it has a negligible impact in comparison to depth to water.

As mentioned above, the majority of the plains including N Jegarlu, S Jegarlu, Dardoban, GhaleShahin, Gharaviz, Deyreh, GilanGharb, Somar and Mehran demonstrated a low to medium average aquifer vulnerability index.

In these plains depth to water decreases and causes vulnerability index to increase. The presence of marl and sandstone along with limestone and alluvial sediments in N Jegarlu, S Jegarlu, Dardoban and GhaleShahin apparently has a great impact on the reduction of aquifer vulnerability to pollution. Among all plains, Gilan Gharb and Mehran have the most transmissivity values and consequently have a maximum hydraulic conductivity.

Although the presence of Gachsaran Formation in these plains especially in Mehran reduce permeability and enhance the concentration of soluble substances both salt and gypsum in aquifer. Other plains, i.e. Parvareshmahi; Khan leyli; Gandomban; Khosravi; QasrShirin, are categorized in the range of Medium to high aquifer vulnerability index.

As seen in DRASTIC maps in these plains soil media (loamy soil) and depth to water are dominantly the main parameters. The aquifer media and vadose zone media of these plains are generally composed of marl and sandstone.

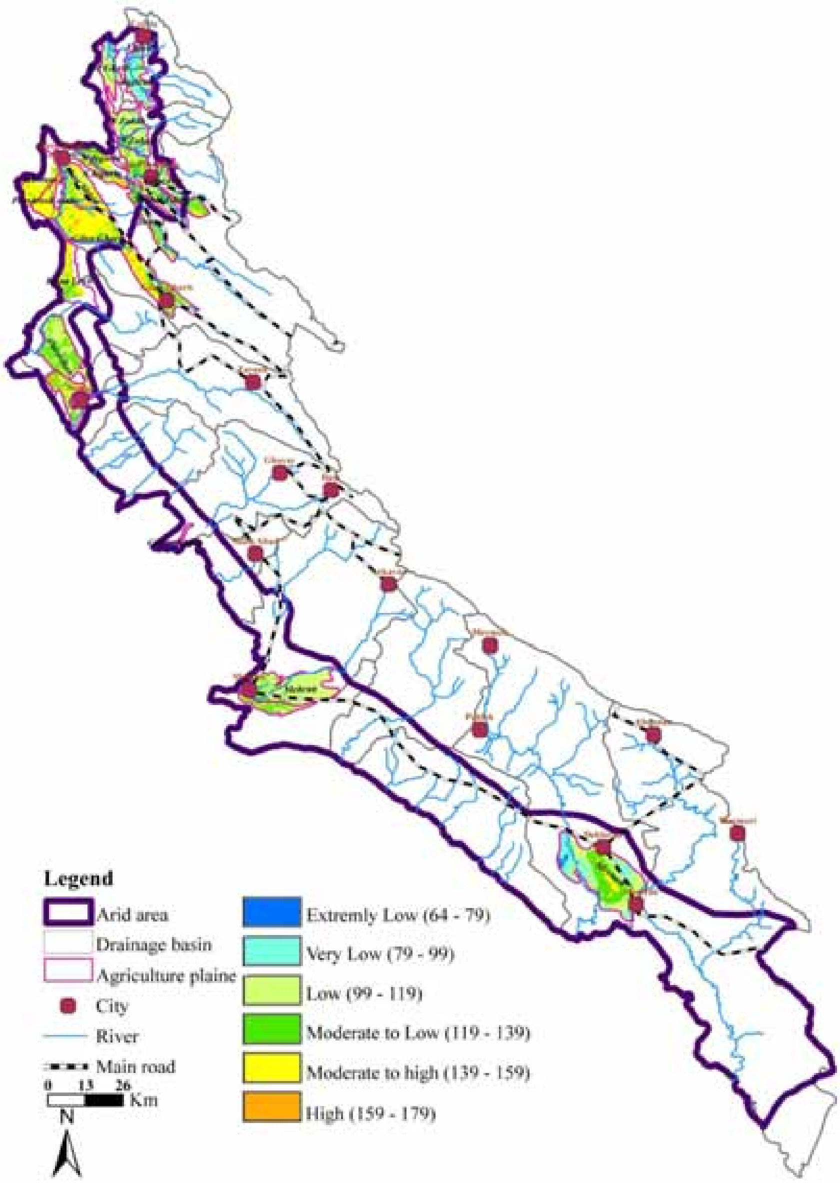


Fig. 11 DRASTIC map of agricultural plains in arid zone

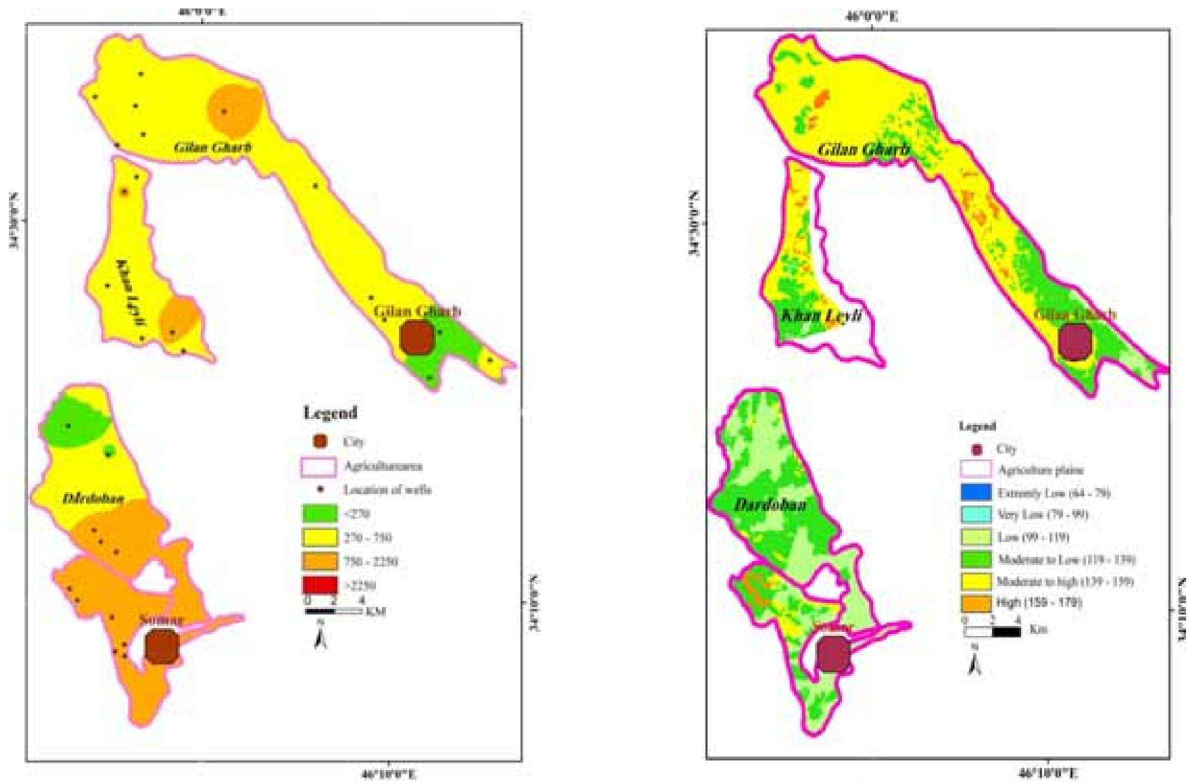
Table 3 Results of average vulnerability index and its occupying areas for agricultural plains

No.	Agricultural plains	Total area (ha)	Average vulnerability index	Description	No.	Agricultural plains	Total area (ha)	Average vulnerability index	Description
1	Ezgle	2006	92	Very low	12	GhaleShahin	7015	121	Low to medium
2	Jagiran	7837	102	Low	13	Gharaviz	5966	123	Low to medium
3	Sarghale	6526	106	Low	14	Parvareshmahi	5343	152	Medium to high
4	N Zahab	7583	110	Low	15	Deyreh	6467	120	Low to medium
5	S Zahab	5186	114	Low	16	GilanGharb	12766	138	Low to medium
6	Beshiveh	7783	117	Low	17	Khan leyli	12185	143	Medium to high
7	N Jegarlu	8830	127	Low to medium	18	Somar	8227	127	Low to medium
8	S Jegarlu	4133	132	Low to medium	19	Godarkhosh	1079	104	Low
9	QasrShirin	12100	141	Medium to high	20	Mehran	26025	121	Low to medium
10	Khosravi	8494	147	Medium to high	21	Meymeh	33030	110	Low
11	Dardoban	17557	123	Low to medium	22	Gandomban	18246	147	Medium to high

Comparison of Drastic model with the electrical conductivity(EC) map.

The study area is located in the border margin of Iran and has a very low population density. Therefore, for water supplies are rivers and natural sarabs like Ghilan Gharb sarabs and so no drinking water wells exist in these areas. In addition, the number of agricultural wells are limited to cover all plains, about 30 wells and no nitrate measurements have been done for these wells. Although, many researchers used nitrate concentration values to verify ground water vulnerability map, another approach is to correlate between ground water vulnerability and electrical conductivity (EC) (Musekiwa and Majola, 2013).

A similar method was followed in this study with the use of ground water electrical conductivity (EC) map to verify the accuracy of the ground water vulnerability result. Electrical conductivity (EC) values were classified based on Wilcox agricultural water classification (Wilcox, 1955). There are similarities between the ground water vulnerability map and the electrical conductivity map of GilanGharb, Khan Leyli, Somar and Dardoban plains (Fig. 12). The problem with the use of the electrical conductivity values for verification in western part of Iran is that there is a scarcity of data in some parts of the plains. This is the same problem even for the electrical conductivity values. Also, the existence of soluble formations such as Aghagari Formation raises EC in Somar plain dramatically.



(a) **(b)**

Fig. 12 Comparison of the ground water vulnerability map with EC map

6. Conclusion

Here, the DRASTIC model was used to assess the changes in the aquifer vulnerability to pollution under agriculture practices in the west of Kermanshah and Ilam provinces, and were then related to nitrate concentration in agricultural water wells. The major conclusions of this study are summarized as follows:

Limestone and alluvial deposits such as Asmari and Shahbazan Formation in the study area, increase the vulnerability of the aquifers, on the other had, marl and sandstone units such as Aghajary Formation reduce the permeability and attenuation capability of the ground.

The Depth to water parameter, among the other DRASTIC parameters, appears to have the greatest impact on aquifer vulnerability to pollution.

Despite the fact that aquifer media and geology characteristics are significant parameters in determining the aquifer vulnerability for

Parvareshmahi; Khan leyli; Gandomban; Khosravi and QasrShirin plains, soil media and depth to water parameters dominant influence than the other two parameters.

Due to locating of agricultural plains in border and deprived areas, access to privileged information such as nitrate concentration for modeling vulnerability maps is difficult.

Although EC map has shown a close similarity to vulnerability map but geology of the areas especially soluble formation affected EC and yielded diversionary values in comparison with vulnerability map.

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