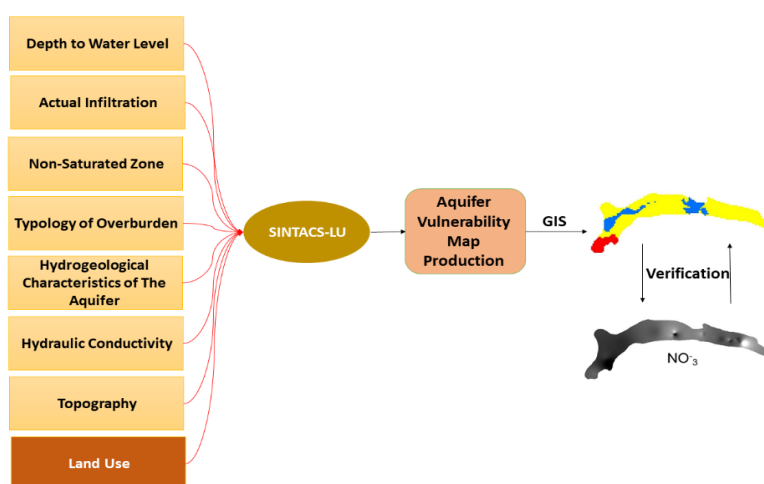


Original paper

Evaluation of the SINTACS-LU model capability in the analysis of aquifer vulnerability potential in semi-arid regions

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GRAPHICAL ABSTRACT



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ABSTRACT

Detection of aquifer vulnerable areas can highlight preventive actions for groundwater contamination. Different models have been presented for the evaluation of vulnerability that one of the most regular and well-known models of the overlapping index as the SINTACS-LU (Soggiacence, actual infiltration, non saturated zone, typology of overburden, hydrogeological characteristics of the aquifer, hydraulic conductivity, topographic Slope) model was considered in this research. In fact, this model has been extended based on the impact of land use parameters in the vulnerability evaluation. Purpose of this study is the qualitative evaluation of Birjand plain aquifer vulnerability using the SINTACS-LU model. For this, the Birjand plain aquifer in the statistical periods of 2013-2018 has been evaluated. According to the results of this assessment, the SINTACS-LU vulnerability zoning map reveals that 15 percent of the studied region has the vulnerability of medium to high, 75 percent of the area has a high vulnerability, and 10 percent has the too high vulnerability. In order to the verification of the SINTACS-LU model, the relationship between the vulnerability index and the obtained nitrate concentration values from 21 groundwater samples were assessed. The correlation coefficient between the SINTACS-LU vulnerability index and the nitrate concentration was 75 percent, which indicates the appropriate correlation of this model with the nitrate concentration as the indicator of the groundwater contamination.

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1. Introduction

Nowadays, overuse of natural resources and abundant production of waste in modernized societies have threatened groundwater

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resources and caused extreme contamination. Natural and anthropogenic pollution processes have caused a rapid decline in the water quality globally and mostly in developing countries (Fatemi, 2015). Today, water quality surveys have become widespread and

include issues related to surface water and groundwater pollution (Kasmaei et al. 2017). Groundwater contamination due to the emission of contaminants is considered as a bioenvironmental issue, which creates economic and health problems (Yang and Wang. 2010). Once an aquifer is contaminated, the contamination becomes persistent as a result of high capacity, longer persistence time, and lack of physical accessibility (Wang et al. 2012). On the other hand, decontamination which struggles to improve the groundwater quality, is a complicated process which needs time and financial resources. Hence, groundwater contamination control or reduction is one of the important principles in groundwater resource management (Huan et al. 2012). The concept of vulnerability was first introduced in France in 1960. Vulnerability is a type of relative attribute, without smell and non-measurable, and depends on the aquifer properties of the geological and hydrogeological environment (Antonakos et al. 2007). Various methods have been presented in order to evaluate the vulnerability including the Processing Methods, Overlapping Methods, and Statistical Methods (Tesoriero et al. 1998). The processing methods use simulation models to estimate contaminant movement. The statistical methods use the correlation between spatial variables and the quantity of the contaminants in groundwater. Also, overlapping methods integrate the controller parameters of contaminant movement from the ground surface into the saturation zone and determine an index called the vulnerability index in different parts of a territory (Tesoriero et al. 1998). One of the most conventional and well-known methods of the overlapping index is the SINTACS model (Civita. 1994), which includes the parameters of soggiacence, actual infiltration, non-saturated zone, typology of overburden, hydrogeological characteristics of the aquifer, hydraulic conductivity, and slope of the topographic. This model is an overlapping method in which the obtained data from the various parameters are analyzed in combination and then processed by the geographic information system (GIS) (Civita. 1994). In this study, by modifying the SINTACS model through adding the land use parameter to the model maps, in addition to identifying the vulnerability of the Birjand plain aquifer; necessary study is done about the most effective parameters affecting the aquifer vulnerability in order to manage the groundwater resources. Among different existing ranking methods such as groundwater hydraulic confinement/overlying strata/depth to groundwater table (GODS), aquifer vulnerability index (AVI), depth to water, net recharge, aquifer media, topography and land use (SI), flow concentration, overlying layers and precipitation (COP) and depth to groundwater, net recharge, aquifer media, soil media, topography, impact of the vadose zone and hydraulic conductivity (DRASTIC), the SINTACS-LU model has been selected for the evaluation of Birjand plain aquifer qualitative vulnerability. One of the main advantages of the SINTACS-LU model is the vulnerability evaluation using several numbers of informational layers, which limits the effect of errors or unpredictable problems on the final output. Moreover, the suggested model has the layer of Land Use more than the basic SINTACS one. Pisciotta et al. (2015) used two models of the SINTACS and DRASTIC in order to evaluate the intrinsic vulnerability against nitrate contamination damage in ground water and to compare the environmental effect of excessive agricultural development in Sicily, the Mediterranean region of Italy. The obtained nitrate concentration values were compared with the values of the SINTACS and DRASTIC by Pearson correlation method and the results demonstrated that the SINTACS model has a further correlation with nitrate values. using the SINTACS model, Qadir et al. (2016) examined vulnerability of Sulaymaniyah plain aquifer (located in Kurdistan province in Iraq). The results of this model, based on the data from 96 drinkable water wells located in the plain, demonstrate the high correlation between the mentioned model and nitrate content in Sulaymaniyah plain. Ewusi et al. (2017) evaluated Torka city aquifer vulnerability located in Ghana, using the SINTACS model. Results of this experiment suggested that, concerning the presence of mine and industrial activities in the studied aquifer, over 50 percent of the aquifer area had high vulnerability, and also by the analysis of sensitivity of the existing parameters in the aquifer, depth of water table and coefficient of hydrolytic conductivity had a significant effect on the aquifer vulnerability. Mastrocicco et al. (2017) provided the Company Plain vulnerability map, located in the south of Italy, using the SINTACS model. The results indicated that due to the vast agricultural lands and excessive use of nitrogenous fertilizers to achieve a higher productivity of crops, the vulnerability was in most parts of the region, and it is necessary to find a solution to control the use of chemical fertilizers by the farmers. The vulnerability evaluation maps which are prepared based on the indexes overlapping methods, are one of the decision-making tools in order to the qualitative management of groundwater resources. Primastuti and Kusratmoko

(2018) determined areas of vulnerability to contamination with SINTACS and SINTACS-LU in Taman Rahayu. Results indicated that the SINTACS-LU model had a higher correlation (about 80%) with nitrate concentration than SINTACS (about 70%). In a study by Baihaqi et al. (2019), vulnerability of the Ci Deres area in Indonesia has been evaluated using two models of SINTACS-LU and DRASTIC-LU. Based on their evaluation, the SINTACS-LU model has better accuracy than the DRASTIC-LU model. Asghari Moghaddam et al. (2018) carried out a research for considering the intrinsic vulnerability of Oshnavieh plain aquifer using from DRASTIC and SINTACS models. Based on their results, corrected DRASTIC and SINTACS models showed 76.3 and 67.56 percent correlation with nitrate values respectively. Utami et al. (2019) used Modified SINTACS by LU parameter to analyze the Opak plain vulnerability. Their model validation experiment with Nitrate concentration of drinking water wells showed a 57% correlation. Also, Rufino et al. (2019) assessed groundwater quality for drinking and irrigation use by groundwater quality index (GQI) and, in parallel, standard SINTACS was applied to evaluate the intrinsic vulnerability of the aquifer. Nitrate concentrations and sodium absorption ratio (SAR) in groundwater samples were used to verify the reliability of vulnerability data. Results showed positive correlation with nitrate ($r = 0.63$) and SAR ($r = 0.64$) contents, thus pointing to combined SINTACS-GQI as a more reliable approach than standard methodologies.

Assessment of previous works showed that SINTACS model is suitable to assess vulnerability. Considering land use parameter, the SINTACS-LU has been chosen for the purpose of this study as against other overlapping methods, it has more hydrogeological parameters. In other hand, none of the researches have evaluated the vulnerability assessment of Birjand plain with SINTACS-LU model which is located in semi-arid region and has not evaluated the efficiency of this model. In addition, previous research has not investigated the sensitivity analysis, prioritization and importance of parameters on the issue of aquifer vulnerability. Due to the fact that Birjand plain aquifer is located in a semi-arid region, and is the lone water source in the center of Southern Khorasan province and in recent years with the growth of population and reduced rainfall is exposed to high vulnerability. In this study, by modifying the SINTACS model (adding land use maps to model maps), in addition to recognizing the vulnerability of Birjand plain aquifer to pollution, the most effective parameters affecting the aquifer vulnerability to manage groundwater resources are also considered.

2. Material and methods

Birjand is the region where the experiment was conducted, and it is located in the northern part of the Bagheran highlands at the longitude of 59°13' and the latitude of 32°53'. This plain is rectangular and is limited to Moli highlands and Markooh in the north, Bagheran highlands and Rach Mountain in the south, Bandar Mountain and Amin Abad in the east, and Korang and Chang highlands in the west, as well as the alluvial aquifer which has been formed in its central zone (Figure 1). The total area of Birjand plain aquifer basin is about 3425 km² of which 980 km² is plain and the rest is occupied by highlands. The average precipitation has been 170 millimeter per year, and the maximum and minimum of Birjand plain altitude is 1491 and 1295 respectively. The region land use includes the dryland, abandoned lands, farmlands, and residential areas. In total, Birjand aquifer is almost rectangular in shape, which its average length is 55 km and its width is 5 km (Eftekhari et al. 2019).

2.1. SINTACS-LU model

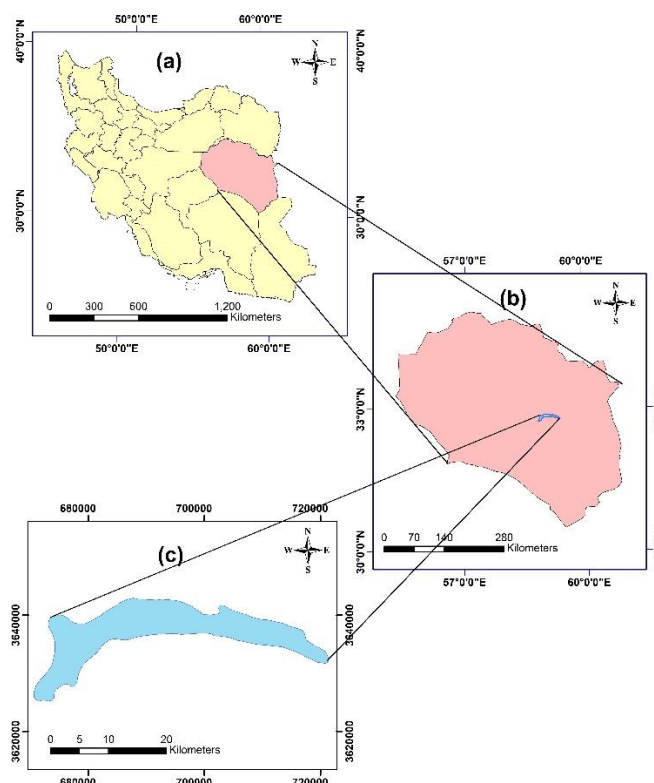
This model has been used by Civita (1994) in order to evaluate the capability of groundwater relative contamination vulnerability, using seven hydrogeological parameters.

$$\text{SINTACS-Index} = (S_o \times S_w) + (I_r \times I_w) + (N_r \times N_w) + (T_r \times T_w) + (A_r \times A_w) + (C_r \times C_w) + (S_v \times S_v_w) + (LU_r \times LU_w) \quad (1)$$

where, S_o is soggiacence, I is actual infiltration, N is non-saturated zone, T is typology of overburden, A is hydrogeological characteristics of the aquifer, C is hydraulic conductivity, S_v is slope of the topographic, LU is land use, w is weight, and r is the relevant rank of every model parameter. In Table 1, the weights and ranks related to the SINTACS-LU model have been represented. Likewise, the current effective weights and ranks on the mapping of Birjand plain aquifer qualitative vulnerability based on the SINTACS-LU model have been illustrated in Fig. 2.

Table 1. The weights and ranks related to the SINTACS-LU model (Ahmadi Far et al. 2017).

Parameter		Parameter	
Depth to water, m (weight 5)	Rank	Hydraulic conductivity, m/d (weight 3)	Rank
0-3	9	0.07-0.1	3
3-5	8	0.1-0.864	4
5-7	7	0.864-4.32	5
7-10	6	4.32-8.64	6
10-13	5	8.64-43.2	7
13-20	4	43.2-86.4	8
20-30	3	86.4-366.39	9
30-36	2		
36<	1		
Aquifer saturated zone (weight 3)		Slope of the topographic % (weight 2)	
Sand and gravel	9	0-3	10
Sand and gravel along with some Silt and clay	7	3-5	9
Clay and silt	3	5-7	8
		7-10.5	7
Actual Infiltration (weight 4)		10.5-13.5	6
0-50	1	13.5-16.5	5
50-100	3	16.5-19.5	4
100-175	6	19.5-23	3
175-250	8	23-27.5	2
250<	9	27.5<	1
Semi saturated environment (weight 5)		Typology of Overburden (Weight 4)	
Fine alluvial sediments		loam	6
Such as clay and silt	5	Sandy loam	5
Sand	7	Fine sand	9
Coarse alluvial sediments		sand	10
Such as sand and gravel	9		
Clay and silt	2	Land Use (weight 5)	
		Lands which have not been cultivated temporarily	5
		Wet lands agronomic crops	8
		Dryland and wasteland	4
		Residential area	5

**Fig. 1.** The general position of Birjand's plain (a) Iran (b) South Khorasan province c) Birjand plain aquifer.

This model has been evolved from the American DRASTIC model, but the difference is that the ranking process in this model is more adjustable. This model has been constituted from the combination of 7 measurable hydrogeological parameters, which are effective on the transfer of contaminants into groundwater, and comprising the soggiacence, actual infiltration, hydrogeological characteristics of the aquifer, typology of overburden, slope of the topographic, unsaturated components and hydraulic conductivity. At the present research, the Land Use layer has been added to enhance the accuracy of the model as mentioned earlier. In this method, the vulnerability index results from the product of the weight multiplication by the eighth rank of the

mentioned parameter, based on Eq.1. Classification and evaluation of the different classes concerned with every one of the parameters were carried out in GIS environment. The relative weight of 1 to 5 accrues to every one of the specifications with regard to their share in the contamination of groundwater which is a representative of each attribute's relative impact on the contamination transport into groundwater (Civita. 1994). Also, in this model, a rank of 1 to 10 is given to the range of every hydrologic specification according to their efficacy on the vulnerability. This provides for the user the possibility of using the SINTACS model according to the area of study (Civita. 1994).

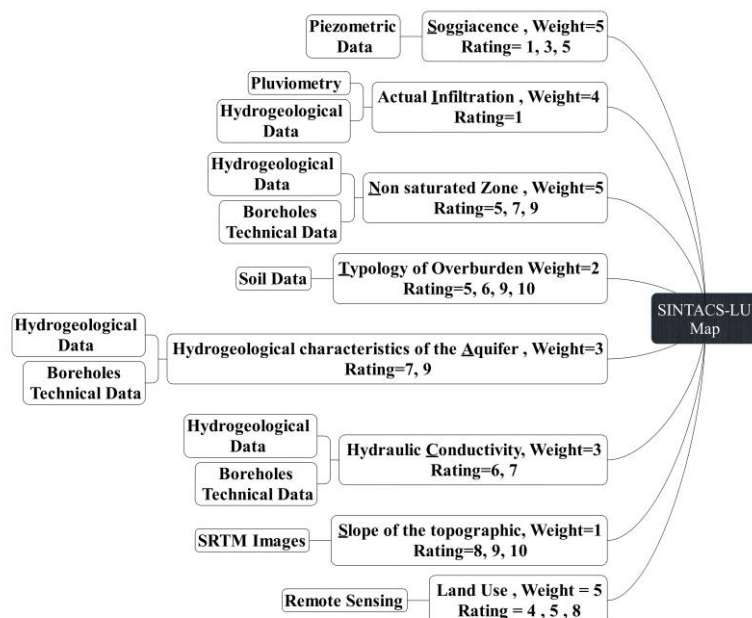


Fig. 2. The existing weights and ranks effective on the mapping of Birjand plain aquifer qualitative vulnerability by the SINTACS-LU model.

2.1.1. Soggiacence

The distance between the land surface and the water table is called soggiacence. In other words, this parameter indicates the depth that a contaminant must pass through to reach groundwater (Bartazs et al. 2015). In order to have the layer of depth in the water table, the water level information in piezometers including piezometers name, piezometers position in terms of UTM, and water level depth were used. The required information for the arrangement of this layer was provided from the geographical position of the water table level and the Piezometer height of 15 located in the plain which has been collected by the Regional Water Department of South Khorasan Province (Table 2). For the groundwater depth zoning, the ordinary kriging method has been used since this method has the minimum error (Fig. 3a).

$$\text{Actual Infiltration} = \text{soil permeability} + \text{precipitation value} + \text{slope percentage} \quad (2)$$

2.1.2. Actual infiltration

Actual infiltration is the amount of water that penetrates from the ground surface and reaches into a water table. Furthermore, through the increase of actual infiltration value in a region, the contamination potential of groundwater will rise in that region. In order to attain the actual infiltration layer, first, it was classified according to the criteria of table 3. Next, Pisco equation (Eq. 2) was used to calculate the potential of Actual Infiltration in the region (Fig. 3b).

2.1.3. Non-saturated zone

The non-saturated zone comprises the zone between the water table and the unsaturated soil environment. This zone is unsaturated or saturated discontinuously and controls the contaminant passing and its dilution. For the preparation of unsaturated space layer, log 19 of observational and exploitable well existing in Birjand plain aquifer was used by the cooperation of Regional Water Department of South Khorasan province, and it was analyzed using Techlog software, and to assure the minimum error, zoning was performed by inverse distance weighted method (Fig. 3c).

Table 2. The position of the piezometers situated in aquifer.

Row	UTM - X	UTM - Y	Row	UTM - X	UTM - Y
1	701534	3638970	9	675795	3634528
2	695940	3639273	10	705106	3636548
3	687790	3640119	11	688058	3637542
4	674499	3638383	12	711013	3635581
5	673802	3629361	13	694239	3641144
6	680949	3638227	14	681450	3638570
7	712800	3638300	15	6758004	3629934
8	684773	3637695	-	-	-

2.1.4. Typology of overburden

This is the area above the non-saturated zone and approaches the zone where plant roots penetrate in, or the activity of microorganisms exist. Aquifer vulnerability potential depends upon soil characteristics such as permeability, texture, and soil organic materials percentage

(Kim and Hamm. 1999). To determine the soil texture, the extracted map with a scale of 1:50000 from the Agricultural Department of South Khorasan Province was applied and later for the raster mapping, the primarily scanned georeferencing was used and then was digitalized (Fig. 3d).

2.1.5. Hydrogeological characteristics of the aquifer

This section is associated with the component characteristics of the saturated zone, such as the porosity rate, particle types and size (Brahim et al. 2012). In order to have the hydrogeological characteristics of the aquifer layer, log 19 of observational and exploitable well existing in the region was used with cooperation of Regional Water Department of South Khorasan province, and it was analyzed using Techlog software, and the zoning was done by inverse distance weighted method due to its minimum error (Fig. 3e).

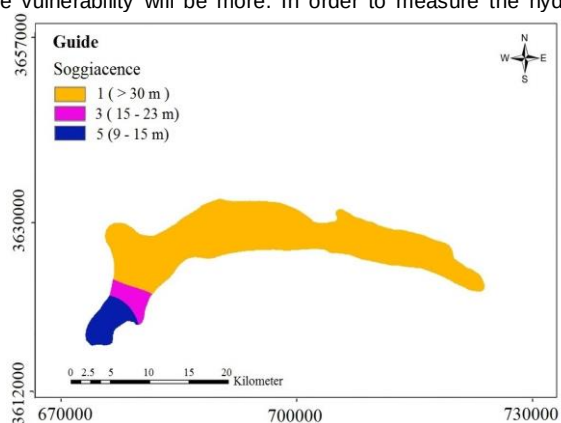
2.1.6. Hydraulic conductivity

The capability of the hydrogeological characteristics of the aquifer in water transferring and associated contaminants is called hydraulic conductivity. This parameter controls the transport and distribution of contaminants from the injection point inside the saturated zone (Mahmoodzadeh et al. 2013). The further the hydraulic conductivity is the more will be the possibility of contaminants flowing in the aquifer, so the vulnerability will be more. In order to measure the hydraulic

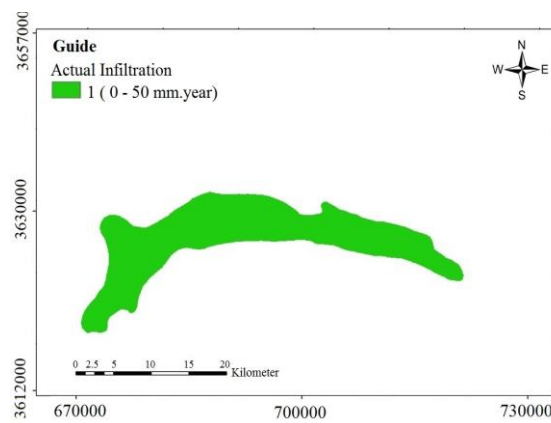
conductivity layer, first, the pumping test data that has been conducted by the Regional Water Department of South Khorasan Province were analyzed using the GWW software, then, with the application of the obtained transmission coefficient layer and division of this layer by the aquifer saturated thickness, the hydraulic conductivity layer was gained. The zoning was accomplished using inverse distance weighted method due to the minimum error (Fig. 3f).

2.1.7. The slope of the topographic

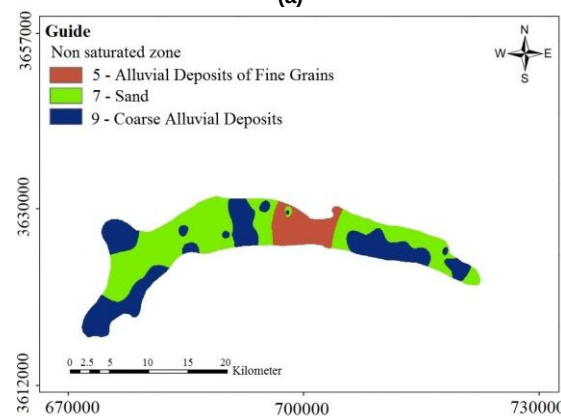
This parameter is the slope of the land surface. The land surface slope affects the movement and penetration of contaminants. The less the land slope is, the more will be the contact of a contaminant with the land surface, and subsequently, the more likely will be its penetration into the land. Hence through the decrease of land surface slope, the possibility of aquifer vulnerability increases (Fadaei Nobandeghani. 2014). The topographic map was provided using a digital elevation model (DEM) with a spatial resolution of 15m by the ARC GIS software (Fig. 3g).



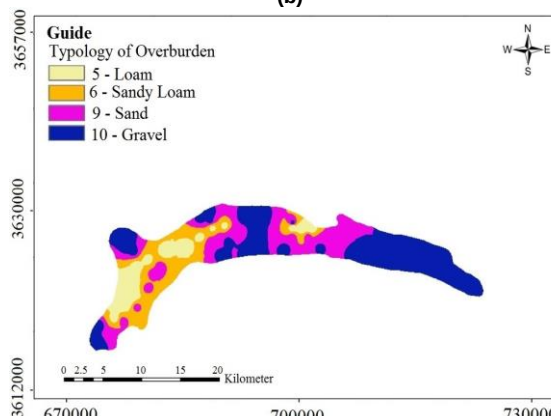
(a)



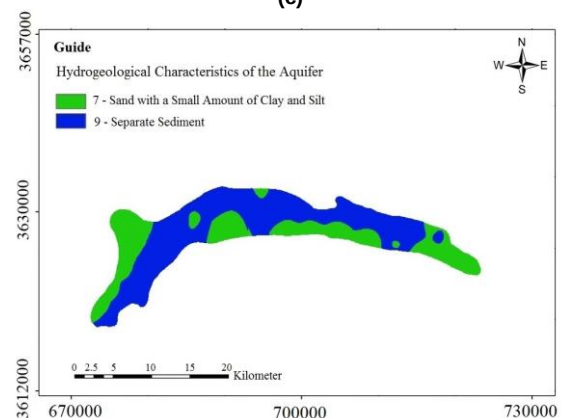
(b)



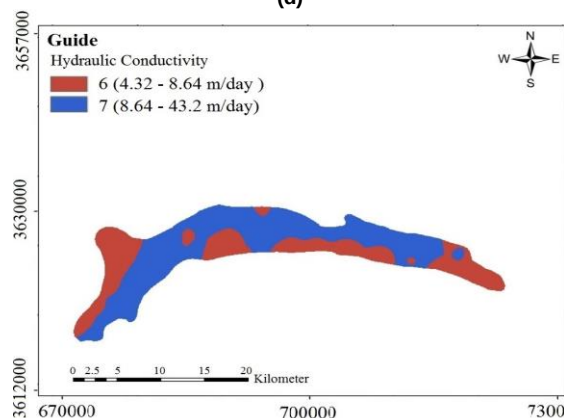
(c)



(d)



(e)



(f)

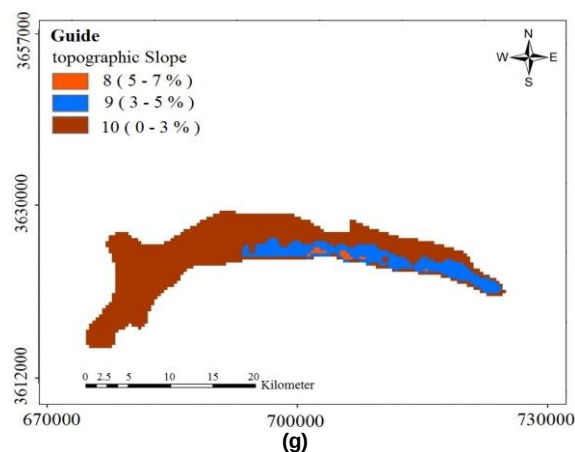


Fig. 3. SINTACS model parameters of Birjand aquifer; (a) water depth level; (b) Net recharge; (c) non-saturated zone; (d) Typology of overburden; (e) hydrogeological characteristics; (f) hydraulic conductivity; (g) topographic zoning.

2.2. Land use

Population growth, agricultural, industrial and urban activities and thereupon increasing the land-use change and the usage of groundwater resources, not only has diminished but also has degraded the quality of these valuable resources. In this research, land use as an extension parameter to SINTACS model has been considered. Actually, due to the increased amount of agricultural and industrial

activities in the research case study, it seems that land use has an essential impact on water resource pollutions. Then, this parameter has been integrated into the SINTACS model. For the preparation of this map, the images of Landsat Satellite 8 in the Google earth engine environment that have been photographed in 2017 were utilized and then the images analysis was performed to zone the lands. In this plain, farming with a sophisticated irrigation system, dry farming, wastelands, and residential areas are visible (Fig. 4).

Table 3. Classification of actual infiltration.

Actual infiltration		Soil permeability		Precipitation (mm)		Slope (percentage)	
Factor	Range	Factor	Range	Factor	Range	Factor	Range
10	11 to 13	1	Too low	1	500<	4	2<
8	11 to 6	2	Low	2	500 to 700	3	2 to 10
5	6 to 7	3	Medium	3	700 to 850	2	10 to 30
3	7 to 5	4	High	4	850>	1	33>
1	5 to 3	5	Too high	-	-	-	-

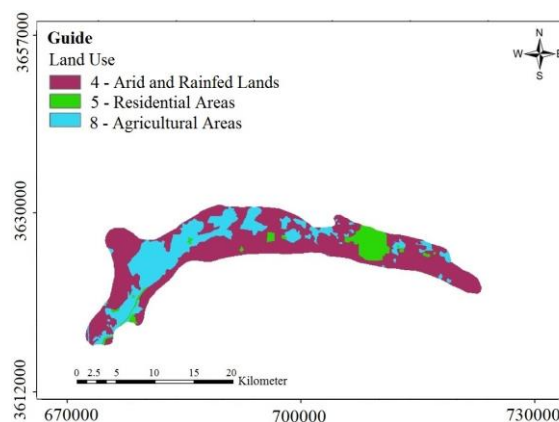


Fig. 4. The map of land use zoning.

2.3. Aquifer risk-taking

Land use differs in every region, and based on land use, the efficacy of contaminants varies in different sections. The combination of land use type to every location vulnerability generates the modified vulnerability. Ahmadi Far et al. (2017) defines the value of a modified vulnerability as the risk value. Determination of risk value means to designate the degree of harm of the entry of contaminants into the region, in keeping with the land use. The risk map is calculated based on equation 3 (Remesan and Panda. 2008).

$$MDI = DI + (L_r \times L_w) \quad (3)$$

In this equation, MDI is the risk value or the modified vulnerability, DI, the value of vulnerability, L_r , the related rate associated with the type of use and L_w is the weight related to the Land Use. Table 1 was used for the weighting and ranking of the land use parameter and next through the combination of the land use layer with the vulnerability index, equation 4 SINTACS of the aquifer vulnerability map called the SINTACS-LU was arranged and classified as Table 4.

2.4. Nitrate

Since nitrate does not naturally exist in groundwater in natural conditions, it is considered as a contaminant movement index from the land surface into groundwater in particular in agricultural lands, and it has been recommended as a quality measure of groundwater (Huan et al. 2012). In this experiment, the nitrate contents of 21 wells located in Birjand plain aquifer based on the data from the water quality lab of the Water and wastewater department of Birjand city have been used. The applied data is an average of nitrate concentration during five years from 2013-2018. The position of the wells located in the aquifer has been illustrated in figure 5-a and to show the nitrate concentrations all over the Birjand aquifer; a kriging interpolation has been used (Fig. 5b).

3. Results and discussion

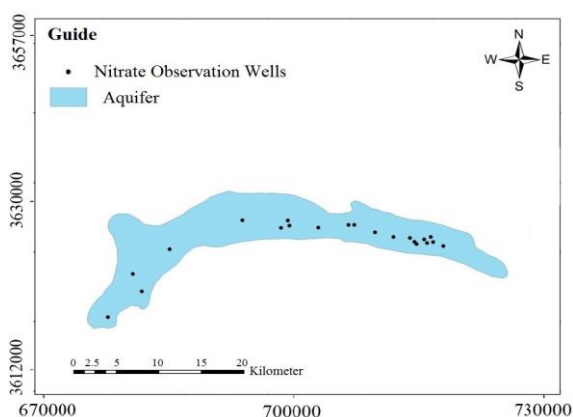
By the combination of 8 standard applied maps in the SINTACS-LU model in the GIS environment of the overlapping index method, the final intrinsic vulnerability of the studied aquifer was calculated. According to this, the final index of the intrinsic vulnerability in the

SINTACS-LU model was between 120 up to 180 (Fig. 6). Likewise, in this experiment, the correlation coefficient was first calculated between the parameters of the SINTACS model which according to the results of the correlation test shows a strong relationship between the type of

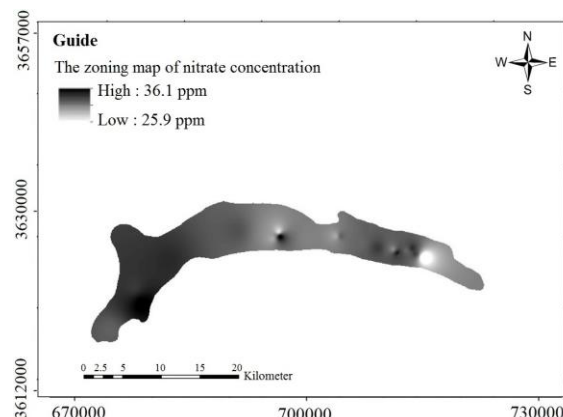
hydrogeological characteristics of the aquifer, land use, typology of over burden and hydraulic conductivity coefficient which is due to the direct influence of these parameters altogether.

Table 4. The classification of the SINTACS-LU vulnerability (Ahmadi Far et al. 2017).

Vulnerability	The range of vulnerability
63>	Without contamination
64-77	Too low
78-99	Low
100-119	Low to medium
120-139	Medium to high
140-159	High
160-179	Too high
180<	Quite prone to contamination



(a)



(b)

Fig. 5. (a) The nitrate observed wells position, (b) The zoning map of nitrate concentration.

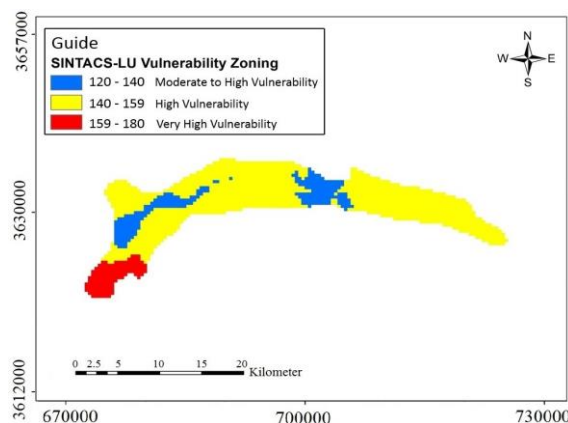


Fig. 6. Map of Birjand plain aquifer vulnerability in SINTACS-LU.

3.1. Analysis of map removal sensitivity

The analysis of sensitivity was introduced by Lodwick et al. (1990). In this method, the change of vulnerability index is calculated by the removal of one or a few informational layers (Eq. 4). In this equation, S is the sensitivity rate, V and V' are unchanged and changed vulnerability indexes, respectively, N and n are the number of used layers for the calculation of V and V'. In fact, the unchanged vulnerability index is calculated using all 8 parameters, and the changed vulnerability index is calculated using a fewer number of parameters.

$$S = \left(\frac{|V - V'|}{n} \right) \times 100 \quad (4)$$

3.2. Analysis of single parameter sensitivity

The actual or effective weight of each parameter was measured by equation 5 in this method, and then compared with the theoretical weight, that in this equation W is the effective weight of each parameter. P_r and P_w are the weights and related rates of the parameter, respectively, and V is the total vulnerability index in that region.

$$W = \left(\frac{P_r \times P_w}{V} \right) \times 100 \quad (5)$$

In order to evaluate the model and obtain useful information of the devoted rank and weight values of input parameters of the SINTACS-LU model, as well as the model reaction to the conducted changes, analysis of sensitivity contributes a lot to the sensitivity evaluation of every model parameter. So, evaluation of the model parameters sensitivity was accomplished in two general ways of layers removal and unit parameter sensitivity analysis. In the sensitivity analysis by two methods of removing single parameter and the single layer, results demonstrate that effective parameters such as aquifer type have the maximum influence in the contamination of Birjand's plain aquifer, as more than 60 % of the saturated zone lithology is constituted of large particles. (Fig. 3e). The land use parameter is situated in the second position, which because of the residential areas and release of urban, agricultural, and rural sewages in the plain, it shows the importance of this parameter in the determination of groundwater vulnerability (Fig. 4). Likewise, the depth of water table parameter has a considerable impact on the transport and distribution of the contaminants into groundwater, since the zoning of water depth has represented that the west and southwest areas of the aquifer have a higher water table so these areas have further potential in the contamination of aquifer on the vulnerability map (Fig. 3a). On the other hand, in the analysis of the sensitivities, it can be found that the parameter of the net feeding has

the minimum effect on the transport of the contaminants into groundwater, because according to Fig. 3b, it can be deduced that due to the poor precipitations and deficiency of net feeding, it has had the minimum theoretical weight during the experiment. In the present research, the zoning of Birjand's plain vulnerability was conducted in the GIS environment, using nitrate ion as the indicator of the contamination which resulted from urban sewage and agricultural waste. Next, through the application of the SINTACS-LU model, the vulnerability index of the region was calculated. The vulnerability index of the SINTACS-LU model was between 120 up to 180. In order to gain a better perception and indication of the intrinsic vulnerability of the region, the final acquired index was classified into three different categories. Fig. 6 illustrates that 15 percent of the region has a vulnerability in the range of medium to high, 75 percent of the area has a high vulnerability, and the remaining 10 percent has a too high vulnerability. For the verification of the SINTACS-LU model, the relationship between the vulnerability index and the values of obtained nitrate from 21 samples of groundwater was assessed. In order to determine the correlation between the nitrated layer and the SINTACS-LU index layers, the correlation has been measured in MATLAB software. The resulted correlation coefficient between the vulnerability indices of the SINTACS-LU and nitrate concentration was 75 percent, and this correlation value suggests that the SINTACS-LU model has a proper correlation with nitrate concentration. The investigation of Tables 5 and 6 indicates that firstly, application of different methods of the map elimination sensitivity analysis and the analysis of the single parameter sensitivity have roughly represented similar results, and the parameters sensitivity trends are the same in the model. Secondly, based on this investigation, the parameter of the aquifer water table has the maximum efficacy and the slope of the topographic and actual infiltration of the region has the minimum impact. Reviewing similar research regarding the aquifer vulnerability also confirms these consequents. Primastuti and Kusramtoko (2018) evaluated the aquifer vulnerability in Taman Rahayu area in a research titled: the spatial pattern of groundwater vulnerability using the SINTACS model. They compared two SINTACS and SINTACS-LU models and their results confirmed 70 % accuracy of the SINTACS model and 80% accuracy of the SINTACS-LU (Primastuti and Kusramtoko. 2018). Rahimzadeh Kivi et al. (2015), in a research titled as "the determination of Birjand's plain groundwater qualitative vulnerability" using the DRASTIC model, applied the hierarchical analysis method which showed that the results of this weighting were similar to the sensitivity analysis results of the present research (Rahimzade Kivi et al. 2015).

Table 5. Sensitivity analysis of the SINTACS-LU model map removal.

The index of vulnerability changes	Removed layer							
	S	I	N	T	A	C	S	LU
Minimum	0.906	1.23×10^{-4}	0.141	1.185×10^{-3}	3.067×10^{-4}	1.125×10^{-5}	6.9×10^{-5}	0.092
Maximum	1.092	0.537	2.371	1.13	1.99	1.016	0.895	2.196
Average	0.99	0.268	1.256	0.565	0.995	0.508	0.447	1.144
Standard deviation	0.027	0.099	0.245	0.183	0.311	0.225	0.173	0.539

Table 6. Sensitivity analysis of the SINTACS-LU model single parameter removal.

The index of vulnerability changes	Removed parameter							
	S	I	N	T	A	C	S	LU
Minimum	2.256	1.728	9.372	5.61	8.59	3.31	3.384	10.023
Maximum	12.884	3.029	23.33	13.215	17.29	11.4	7.57	24.757
Average	7.57	2.378	16.351	9.412	12.94	7.355	5.477	17.39
Standard deviation	2.184	0.196	2.18	1.581	1.29	1.38	1.29	3.777

4. Conclusion and future works

Regarding the fact that the western and southwestern parts of the aquifer have the nitrate concentration more than 36 ppm and based on The World Health Organization's standards, the maximum allowed nitrate concentration for potable water is 50 PPM (WHO. 1996), in the case of groundwater lack of qualitative management, the regions which are prone to the contamination will be entirely contaminated in the future, and this leads to the irretrievable difficulties. Besides keeping with the region climate, deficiency of precipitation, recent droughts, population growth, growth of urbanization, increase of agricultural and industrial activities and consequently the enhancement of contaminations which resulted from the urban sewage as well as agricultural and industrial wastewaters, and in contrast the increasing need for water in order to supply drinkable water, all these issues will only be resolved with the cooperation of people in charge, experts and managers.

Likewise, Hassanpour and Khozayemhnezhad (2018) in a research titled as "the locating of infiltration wells for the artificial infiltration and quality improvement of Birjand's plain aquifer using the refined wastewater", measured parameters weighting by the ANP method and the obtained results indicated the maximum weight of hydraulic conductivity parameter, and its comparison with this research sensitivity analysis also reveals the great impact and significance of hydraulic conductivity in the aquifer vulnerability which confirms the consequence of the present experiment (Hassanpour and Khozayemhnezhad. 2018). The zoning of the absorbing well drilling localities by Hassanpour and Khozayemhnezhad (2018), with the approach of Birjand's plain aquifer quality improvement, represented that the regions are considered poor in terms of priority, the same as the results of the present experiment, and as it has been demonstrated in figure 6, they have extreme vulnerability. Keshavarz et al. (2015) in another research titled as "the proper locating of drinkable water extraction using fuzzy hierarchical analysis in Birjand's plain aquifer", provided a map of extraction potential of potable water extraction in Birjand aquifer using 5 categories from "weak" to "very good" (Keshavarz et al. 2015). Based on the results, the western and southern areas of the aquifer are categorized into the weak class and the eastern areas are grouped into the very good class which in comparison to the SINTACS model vulnerability zoning, results demonstrated that the poor regions are more exposed to the vulnerability in terms of drinkable water extraction. Shiekhvanloo (2007) prepared Birjand plain aquifer vulnerability map in the three classes of low vulnerability, medium vulnerability, and high vulnerability in research entitled as "the evaluation of Birjand plain aquifer qualitative vulnerability based on the GODS model". According to this map, the eastern and central areas of the aquifer have low to medium vulnerability and the western and southwestern areas of the aquifer have a high vulnerability which indicates the appropriate efficiency of the SINTACS-LU model in Birjand plain aquifer qualitative zoning. In comparison to two models of GODS and SINTACS-LU, the correlation consequents towards the nitrate concentration represent that the SINTACS-LU model has a greater correlation than the GODS model and the reason is the presence of more parameters in the transition and distribution of the SINTACS-LU model contamination. Likewise, as the research of Rahimzade Kivi et al. (2015) demonstrated, results of the vulnerability model in the DRASTIC method has indicated that the western and southwestern areas of the aquifer have the moderate to high vulnerability and the central areas have moderate and low vulnerabilities which are consistent with the results of this research.

For future works, we propose a more extended statistical period and, if possible, more sampling wells can help building and evaluating the model better. Optimization of the model parameters through optimization models (such as artificial intelligence) can lead to higher correlation coefficients in the results. Since the improvement of the SINTACS model with land use parameter has led to better results in the semi-arid region studied, further improvements of the model in combination with other new indices are suggested.

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