Original Article

The Zoning of Groundwater Quality for Drinking Purpose Using SchullerModel and Geographic Information System (GIS)

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Abstract

Introduction: Determining the quality of water is particularly important in water resources management, and monitoring and zoning it are considered as a significant principle to be taken into account in planning. Schuller method is the commonest way to determine the quality of water. The present study was conducted in order to determine the quality of drinking water using Schuller modeling with the help of Kriging interpolation method in GIS environment.

Materials & Methods: In the present study, Schuller modeling and Kriging interpolation method were utilized Geographic Information System (GIS) environment in order to determine the quality of water during the statistical period of 2005 to 2014. In so doing, chemical analyzed samples retrieved from the wells and aqueducts of Yazd-Ardakan plain were used. To determine the quality of water, Schuller diagram was utilized in order to classify the quality of drinking water.

Results: The results of the study indicated that the quality of drinking water reduces as we move from the southwest to the northeast of the plain. Approximately 30% of the studied area was in good and acceptable condition in regard with the quality of drinking water. Also, about 57% of the study area had poor quality drinking water, i.e. water with inappropriate and totally unpleasant quality and 13% of the map of drinking water quality is devoted to average quality, which is located in the central area.

Conclusion: Only principled way to prevent dangerous consequences of the water table decline is the correct and systematic use of water.

Keywords: Geographic Information System (GIS); Drinking Water; Schuller Diagram; Interpolation; Zonation.

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Introduction

A source of clean water should be able to provide the given community with sufficient clean water. This goal can be met if the health authorities regularly monitor and control the resources in order to take action in case of any possible contaminants [1, 2].

The chemical quality of water us related to the presence of hardness ions especially water-soluble cations and anions. Specific standard amount and the maximum acceptable levels of these agents have been determined. Hardness ions of water are the most important and abundant agents that human body is not sensitive to them. Among cations and anions that are soluble in water in order of importance are cations like magnesium, calcium, strontium, iron, aluminum, manganese, and copper and anions like carbonate, bicarbonate, chloride, sulfate, silicate, and nitrate[2, 3].

Accurate identification and selection of water resources play a highly important and effective role in reducing occurrence of water-related problems and diseases. A water resource that has healthier quality and provides the consumer with water at less cost has priority over other water resources[4, 5].

High density of minerals in water is one of the causes of groundwater contamination, which has been taking and increasing trend in recent years due to population growth, an increase in wastewater production, and a decrease in the level of groundwater. If the density of minerals in drinking water exceeds an acceptable limit, it can cause health hazards[6, 7]. Therefore, the present study was aimed at zoning the quality of water in terms of its quality in Taft County and indentifying appropriate and inappropriate regions for exploitation of its groundwater resources.

Schuller method is the commonest way to determine the quality of water [4, 8]. In determining the quality of water using this method, the first step is to select an appropriate model to zone and interpolate the data. Many studies have been conducted on spatial analyses and interpolation and zonation methods by researchers like Laslett et al (1987) [9] and Weber and Englund (1992) [10]. The results of these studies indicated the high accuracy of Kriging interpolation methods.

As an appropriate tool, Geographic Information System (GIS) due to its ability and advantages in solving different problems can help the researchers in investigating different methods of interpolation [11]. The present study was conducted in order to determine the quality of drinking water using Schuller modeling with the help of Kriging interpolation method in GIS environment in the statistical period of 2005 to 2014.

Materials and Methods

Yazd-Ardakan plain with an area of 8050 km^2 is located between longitude 53 degrees and 46 minutes and latitude 31 degrees and 55 minutes in the center of Yazd Province. It borders SiahKooh desert to the north, sub-basin of Kharanaq to the east, ShirKooh Mountain to the south, and sub-basin of Taqestan and Nadushan to the west. The highest point of the area is the peak of ShirKooh (4075 m) and the deepest spot is 970 m. The average height of the area is 1565 m above sea level. Entrance of groundwater to the area is located in ShirKooh Mountain and the plain outlet is located in the north at the border of sub-basin of

SiahKooh[7]. The general direction of groundwater is from south toward north (Fig.1).

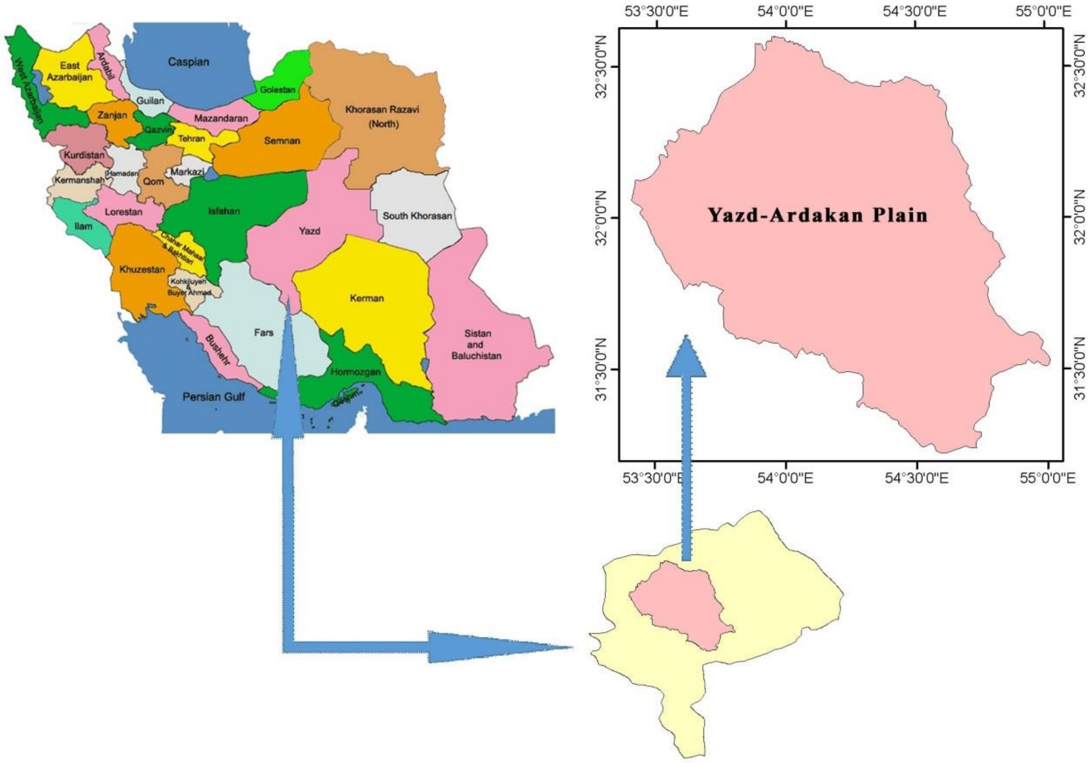

Fig. 1. The location of Yazd-Ardakan Plain in the country and Yazd Province

Data collection

In this study, the samples of 88water resources provided by Regional Water Organization were used. To assess the changes of groundwater quality, the TDS, TH, Na, Cl and SO_4 in 88water resources were calculated according to Schuller model in GIS environment during 2005 to 2014. Finally, WHO standards were used to compare and investigate the quality status of water.

In the present study, the results of chemical analysis of 88 water resources including wells, springs, and aqueducts in the region were utilized. Interpolation was carried out by Kriging method. The zonation method of determining the quality of water was conducted using Schuller model. In this Classification presented in Table 1, five parameters of levels of sulfate, chloride, sodium, total hardness, and total dissolved solids were taken into consideration. Therefore, the quality of water was classified into 5 groups of good, acceptable, average, inappropriate, totally unpleasant, and undrinkable .

Table 1. Classification of the quality of water according to Schuller method [6, 12]

Category	TDS	TH	Na	Cl	SO_4	Score
Good	<500	<250	<115	<175	<140	1
Acceptable	500-1000	250-500	115-230	175-350	140-280	2
Average	1000-2000	500-1000	230-460	350-700	280-560	3
Inappropriate	2000-4000	1000-2000	460-920	700-1400	560-1120	4
Totally Unpleasant	4000-8000	2000-4000	920-1840	1400-2800	1120-2240	5
Undrinkable	>8000	>4000	>1840	>2800	>2240	6

The method of measurement or spatial data collection is to form natural phenomena in GIS environment. When phenomena are collected as points, different methods can be utilized to construct layers out of them, this process is called interpolation. Interpolation methods employ a set of different mathematical and statistical models to predict unknown values. What is certain is the similarity of unknown points to the nearest known points or the principle of the nearest neighbor is the basis of interpolation methods. How this principle can be utilized depends on the selected model whose details are explained [11, 12].

Interpolation Concepts

In GIS analysis methods, spatial data are classified into two types whose understanding is particularly important. These types are called discrete and discontinuous, which are generally called categorical absolute data. That is, the borderline between these data in the nature can accurately be defined and stored in both forms of raster and vector, such as lake, a building, a road, etc. However, continuous data have integrity in nature and any position on the surface of the ground has a measure of them. For example, temperature is a continuous type of data and can be measured in any point. Gradient direction of features is another type of continuous data that can be measured using directions of north, south, etc. Liquid matters like runoff are also continuous data which can be measured and has direction [11, 13].

Continuous data cannot be measured at all levels because of their continuity; therefore, they are retrieved through samples. Measuring the continuous variable in areas that are not sampled in the area that point observations are distributed is called interpolation. Interpolation in fact shows spatial variations of a continuous variable. In other words, interpolation is to measure the value of the phenomena in locations that are not sampled using the known data of the neighbor pints. Neighbor points may be distributed in a regular or irregular pattern in the area. Therefore, in continuous phenomena, interpolation is utilized to convert the data of the observed points. The output of interpolation can be utilized as a map or layer in GIS analysis [11, 13, 14].

The accuracy extent of the interpolation results depends on spatial accuracy, the number and distribution of the known points, and the selected model. Best results can be achieved when the behavior of the mathematical function is similar to that of the given phenomenon. On the other hand, since interpolation is the descriptive value of unknown points in a region according to some known points, the sampling method is chosen in accordance with the target phenomenon. Most continuous data in nature are directional and their concentration is not equal.

Data Process using Kriging Model

This method is the most important and extensive method of interpolation, which is based on statistical models and relations. The raster layer constructed by this method shows a highly accurate surface (This method produces the best and most accurate output in mountainous areas). Unlike other methods, Kriging method is a global method. That is, in this method all observations of the target area are utilized. Kriging-based Interpolation methods provide more rational results compared to typical methods. At the same time, due to the special nature dominating the soil and random expansion and formation of earth layers, selecting the most appropriate method should be based on conformity of the data and the obtained results with the real data. Therefore, final decision requires conformity between the data and the number of local sampling [11, 13, 15].

Results

In order to examine and determine the quality of groundwater in the present study, Schuller modeling and Kriging interpolation technique were used to prepare the map of the parameters of this model. In so doing, an interpolation map was prepared for any of the 5 parameters of the model in the target region. Afterwards, the maps were classified according to Table 1 (Fig. 2). The obtained results and statistics of the model parameters are presented in Table 2.

Table 2. Information of parameters of Schuller model [12]

Quality of Water	Area (Hectare)				
	Cl	Na	SO_4	TDS	TH
Good	529665	395258	365747	156948	2755
Acceptable	173403	272088	371895	489961	817734
Average	253501	239093	436373	311602	546430
Inappropriate	393459	637649	729634	688453	952865
Totally Unpleasant	771731	573027	423121	679806	6986
Undrinkable	205011	209655	0	0	0

Through examining the changes of Schoeller model parameters during the statistical period of 2005 to 2014, it was found that the components of Cl, TDS and TH which are the main parameters of Schoelle rmodel[15] have a lot of changes in the study area and their increasing makes a significant role in the quality of drinking groundwater. In 2005, in the study area, the level of TDS was 3 times more than the permissible level and was equal to 1488 mg/l. In 2014, its level was 2794 mg l which is 6 times more than the permissible level. Therefore, it affects and reduces the water quality in the region. In 2014, in the study area, the level of TH was equal to 496 mg l. In 2014, its level was 915 mg l which is 2 times more than the permissible level. This increase reflects the hardness of groundwater and its low quality in the study area.

The amount of chloride in the region has an upward trend. This makes the region has the highest level of chlorine belonging to a quite unpleasant class. Water in arid and semi-arid regions contains a large amount of chlorine. By using such water, a large amount of chloride is compacted in agricultural soils. The excessive increase of chloride in the soil makes the plants toxic and prevents their biological activity. In this way, it plays an important role in land destruction. During the statistical period, the components of SO_4 and Na have downward trend and have the lowest effect on groundwater quality in the region. Table 3 shows the minimum, maximum and the average level of groundwater quality components in Yazd-Ardakanplain. In order to prepare the final map of zonation, the sum of the 5 parameters of Schuller model was used to construct the initial map, and then by classifying it, the final zonation map was prepared. (Fig. 2). Through investigating the maps obtained by Schuller model, the move from the western part of the region toward its eastern part shows a decrease in groundwater quality. The results related to groundwater quality zoning map of the study area, using Schuler, is summarized in (table 4).

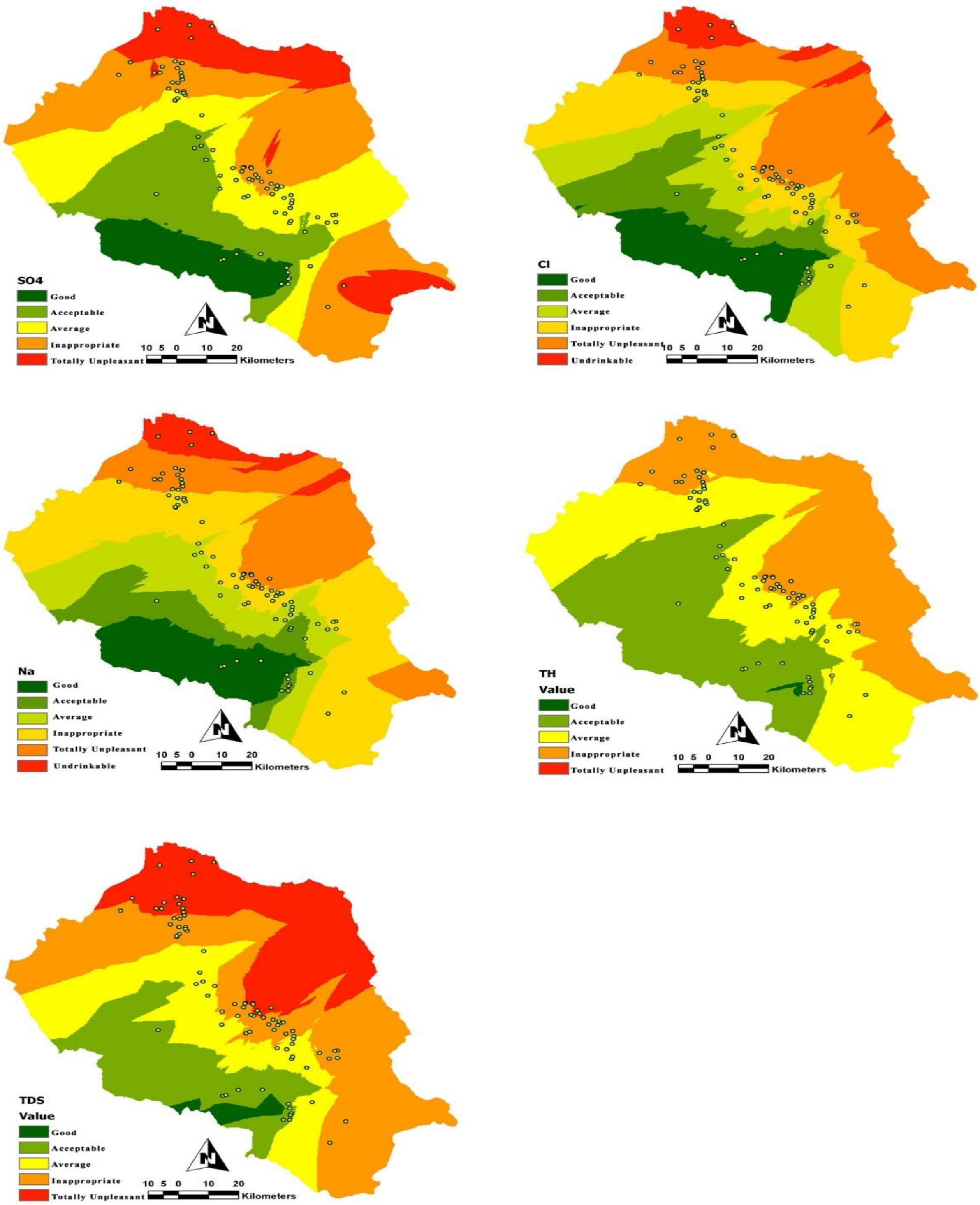

Fig. 2. The map of 5 parameters of Schuller model

Table (3). The minimum, maximum and average level of groundwater quality parameters in Yazd-Ardakan plain

Year	Level	TH (mg/l)	Na (mg/l)	SO_4 (mg/l)	Cl (mg/l)	TDS (mg/l)	Year	Level	TH (mg/l)	Na (mg/l)	SO_4 (mg/l)	Cl (mg/l)	TDS (mg/l)
2005	Min	14660.	4	0.76	2	251.67	**2010**	Min	232.58	4.06	1.11	3.72	551.05
	Max	1747.18	130.12	30.74	94.36	7393.41		Max	1524.04	105.87	26.92	69.82	5734.91
	Average	496.29	48.22	6.25	14.32	1488.80		Average	750.32	48.43	7.21	15.21	2256.65
2006	Min	170.15	3	0.13	2.54	267.78	**2011**	Min	349.72	2.41	2	3.54	220.41
	Max	9163.33	115.19	29.04	146.08	1828.54		Max	9592.34	122.79	35.09	119.72	2358.31
	Average	1756.16	18.18	6.63	51.53	501.52		Average	2976.87	38.36	13.12	53.87	863.68
2007	Min	343.26	1	1.39	3.92	221.71	**2012**	Min	526.56	4	1.37	4.88	268.30
	Max	6021.81	72.73	31.91	147.86	1451.81		Max	5771.70	126.93	28.15	150.68	1266.93
	Average	1949.19	12.23	7.71	59.59	516.54		Average	2365.21	32.54	9.1	22.36	640.99
2008	Min	638.73	3.70	2.59	1.19	240.28	**2013**	Min	341.02	1.5	2	1.42	206.14
	Max	5068.49	64.01	21.48	10.66	1581.7		Max	6824.18	90.45	25.11	81.01	2193.74
	Average	1822.7	11.34	8.18	7.65	515.55		Average	2649.92	14.28	11.22	25.09	881.51
2009	Min	810.96	6.36	3.21	2	389.63	**2014**	Min	396.01	1.68	1.37	2.45	203.60
	Max	5987.39	72.88	31.45	36.86	1700.19		Max	6548	74.20	28.12	63.09	2274.08
	Average	2134.12	13.12	8.42	21.22	754.54		Average	2794.46	29.44	9.97	24.87	915.77

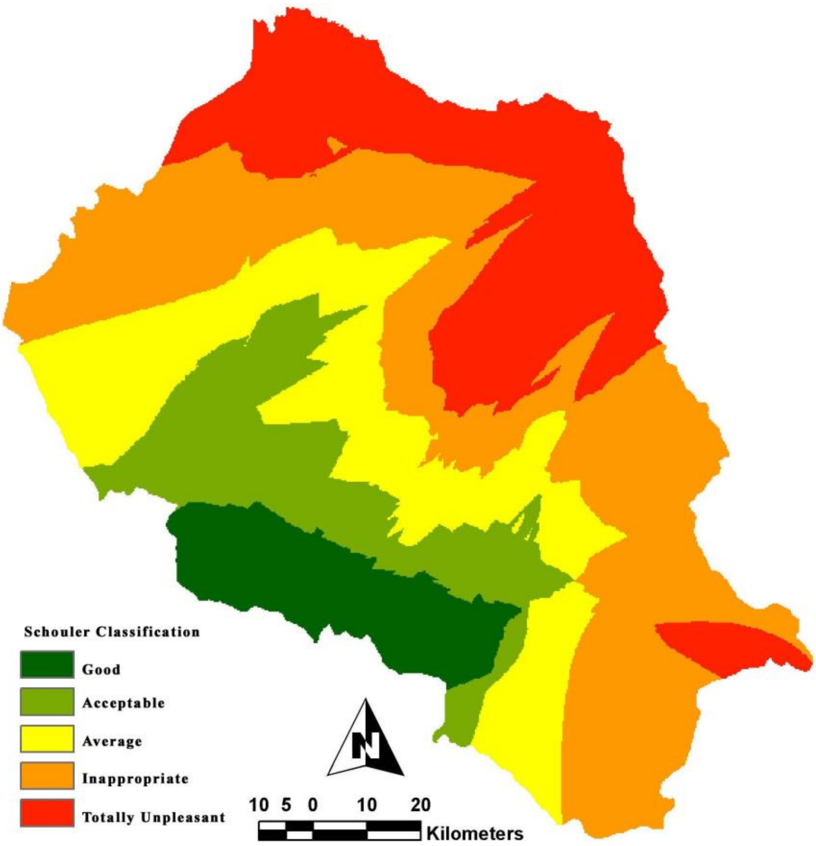

Fig. 3. Zonation map of groundwater quality based on Schuller model

Table 4. The information of the final map of drinkable water quality according to Schuller model

Row	Area (Hectare)	Area (%)	Water Quality
1	357605	15.4	Good
2	323928	13.9	Acceptable
3	309075	13.3	Average
4	645939	27.8	Inappropriate
5	690223	29.7	Totally Unpleasant

Discussion

According to the zonation map of water quality based on Schuller model, it can be concluded that:

1. Approximately 30% of the studied area was in good and acceptable condition in regard with the quality of drinking water. These regions are located in mountainous areas of PishKooh and MiyanKooh which are parts of ShirKooh. Geographical component of this region is mostly composed of Taft lime stone. This issue is also confirmed by ground truth because the best quality water can be found in this region.

2. About 57% of the study area had poor quality drinking water, i.e. water with inappropriate and totally unpleasant quality. These regions are located north, east, and northeast. The poor quality of drinking water in these regions and an increase in the minerals can be attributed to the regions' geographical components which are shale and sandstone. Presence of brine and saline water springs in the region is a proof for this issue.

3. About 13% of the map of drinking water quality is devoted to average quality, which is located in the central area. This section of the region is composed of neogene and alluvial components, and most wells of drinking tap water are located in this section. Presence of drinking water with relatively low levels of minerals proves the accurate zonation of the map.

The results obtained from the model parameters show that the components of Na, SO_4, TDS and TH contain the largest area in inappropriate class and the component of Cl contains the largest area in quite unpleasant class.

Machiwal and his colleagues [13] have evaluated the groundwater quality of Rajasthan located in West India using GIS and Kriging interpolation method. According to the results and the sensitivity analysis, it was found that the water quality index is more sensitive to water hardness and TDS [13].

It can be due to the existence of Neogene manufacturers. These parameters have a high weight and Schuller model is more sensitive to them. In fact, these components in Yazd-Ardakan plain groundwater have more effects on Schuller model. Therefore, they should be more carefully evaluated and monitored. In an assessment of groundwater quality changes in Yazd-Ardakan plain, during the statistical period of 2000 to 2009, Ekrami et al. have introduced TH and EC as the most important parameters affecting the groundwater quality of the study area [16]. In Rajasthan, India, it was found that TH has a high weight[13].The results are consistent with the studies conducted by Farajollahi[17] and Ekrami et al. [16] the recurrent drought and the sharp drop in the groundwater aquifer can be the main reasons for the increase of parameters (Cl, TH and TDS) affecting the groundwater quality. To evaluate and analyze the extent of groundwater salinity and nitrate in Neyriz Plain (Fars), Shabani and his colleagues have investigated some different geostatistical methods such as kriging, inverse distance, radial function and position and general estimator. According to this research results, the Kriging method was selected as the most appropriate method[18].

Conclusions

The Schoeller method is among the traditional methods to evaluate the quality of drinking water. It checks the parameters separately and determines the final quality based on the worst available one. Based on the results of the study of changes in rainfall in the period of 2005 to 2014, it was found that the drought phenomenon dominated the wetness in Yazd-Ardakan plain. The drought uptrend is particularly evident in the last decade. The results of changes in groundwater level in last four decades suggest its downward trend. The average decline of the water table is about 0.5 meters per year.

The results indicate that, by increasing the frequency of drought and severe decline of aquifer, the groundwater quality is greatly reduced. The reason of groundwater poor quality in the eastern part of the region can be the existance of Neogene manufacturers. Being in the morphology unit of the Epandage pediment and erosional pediment is the reason of groundwater appropriate quality in the western part of the region. According to the obtained results, TDS component has the upward trend. Their amount is several times more than the extent permitted by the World Health Organization (WHO).

Therefore, it should be evaluated and monitored more carefully. Through the investigation of the changes trend of groundwater quality in Yazd-Ardakan plain during the statistical period of 2000 to 2009, Ekrami and his colleagues have introduced the components of TH and EC as the most important parameters affecting the groundwater quality of region.

According to the results, it can be said that the only principled way to prevent dangerous consequences of the water table decline and reduction of groundwater resources quantity and quality is the correct and systematic use of water and avoiding uncontrolled groundwater withdrawal.

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