Original Article

Proposing an Index to Evaluate the Groundwater Quality Using "Multi-Criteria Decision Making" Approach and Analyzing the Spatial Distribution of it in Tajan Plain, Northern Iran

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Abstract

Background and purpose: In many regions especially in the north of Iran groundwater is the most important resource for drinking supply. A present study was carried out in the Tajan plain in northern Iran. The aim of this study was to evaluate the quality of groundwater.

Materials and Methods: In order to constructing the groundwater quality index (GWQI) 3 main levels were composed; selection, standardization, and aggregation. The analytical hierarchy process (AHP) as a powerful multi-criteria decision-making approach was used to select the indicator parameter and determining the weights, the national drinking water standard of Iran was considered for standardization level, finally the quality index values in each well were calculated by aggregating the sub-index of entire parameters. For analyzing the spatial distribution of GWQI the geographic information system were applied, the status of groundwater quality in Tajan plain was interpolated on a map.

Results: The results showed that the "GWQI" values varied between 0.145 and 0.450, according to this range four quality classes were determined on interpolated map. Analyses showed that 27.8% of the study area has very good quality aquifer, 57.8% has good quality, 10.9% of Tajan aquifer has moderate quality, and 3.5% is poor. It is considerable that the quality of groundwater around the urban zone is poor.

Conclusion: It was concluded in present study that the "AHP" is a reasonable method for selection of the most appropriate parameters also suitable technique for calculation of the weights for determining the GWQI.

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Key words: Groundwater Quality Index, Analytical Hierarchy Process, Spatial Distribution, Tajan Plain

1. Introduction

Water resources are the most vital natural resources around the world so maintaining the qualitative health of these valuable resources is very essential. Nowadays, these resources including surface and ground water are at the risk of pollution because of intensive human activities like land use changes, solid-waste disposal, industrial activities, and others.

Water contamination consists of physical, chemical, or biological changes in water in a way that the water is not potable for human or usable for other purposes anymore (1).

Between different usages of water, drinking water resources due to their relation with human health are especially considerable. In many communities, groundwater is the most important resource for drinking supply, in such areas, evaluating the quality of groundwater is very important. It is noteworthy that in all Caspian countries as well as north of Iran, groundwater is the most drinking supply in the coastal zone (2). The present study was done in Tajan plain in the north of Iran, province of Mazandaran.

Groundwater, a renewable and finite natural resource, vital for man's life, social, and economic development and a valuable component of the ecosystem, is vulnerable to natural and human impacts (3). There are different methods for water quality assessment; one of the old methods is Schuler diagram, this method provides a drinking-water assessment with regard to chemical parameters individually and in a point of aquifer (4); it is almost an old method but still many researchers use it for related studies (5,6). The other method for assessing the groundwater quality is Groundwater Quality Index (GWQI). This index was presented by Babiker et al. in which six parameters [total dissolved solids (TDS), CL^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+] were combined with each other and the spatial distribution was analyzed (7). GWQI is commonly used method in different researches (8-10).

Sine groundwater resources are affected by different pollutants in different areas; suitable parameters should be select as indicators to assess the status of water quality in different aquifers. The main objective of present study was proposing multi-criteria decision-making (MCDM) approach as a logical way for selecting and weighting the parameters for creating a water quality index in Tajan plain. Given the complexity of the decision process, the focus of MCDM approaches is to enhance the ability to make sound decisions for water resources management, in particular for river basin planning (11), hydropower operation (12), groundwater planning (13), and irrigation (14). MCDM finds the best options among the feasible alternatives in the presence of multiple, usually conflicting, and decision criteria.

In this study analytical hierarchy process (AHP) was used, AHP is known as a powerful and effective MCDM method for ranking and prioritizing (15). In many cases, allocating the relative weights for the different criteria involved in making a decision is very difficult (16), AHP is a suitable way to calculate the weights of evaluation criteria.

This method was used in two steps of constructing groundwater quality index in Tajan plain; first for selecting the indicator parameters and second for calculating the weights of parameters.

Geographical information system (GIS) was used to analyze the spatial distribution of groundwater quality index in the study area. GIS is a power tool for collecting, storing, transforming the spatial information, and arriving decision from the real world for particular set of purpose in real time, where the stored information are geo-references or geocoded (17). Since the 1980s, GIS was developing very fast in water resources management and had achieved remarkable results in regional water resources planning and development and utilization of application (18). Creating a GIS-based data bank of water quality for continues monitoring of the change in water quality, improvement and filtration of some sources, and replacement with the sources of better quality are essential (19). GIS is very applicable in groundwater quality and vulnerability studies (20,21).

2. Materials and Methods

2.1. Study area and sampling points

Tajan plain (the study area) is located in the north of Iran - the province of Mazandaran, in the northern Alborz range. Tajan plain geographically lies between 3979233-4076712 N latitude and 673657-705004 E longitude. Tajan plain with an area of 631.1 km^2 is one of the 5 sub-watersheds of Tajan basin; this plain is located in the northern part of the basin. Geographic location of the case study is shown in figure 1. Tajan River with about 170 km long passed the Tajan basin and drains into the Caspian Sea (22).

Since the objective of this study was determining the quality index of drinking groundwater, so the drinking wells of the study area were considered as sampling points. The US Geological Survey suggested that at least 30 sampling points should be considered for groundwater studies (23). A 65 wells in the area of study were selected as sampling points.

2.2. Providing the water quality index

The way of calculating GWQI is almost same in different researches, but the indicator parameters and the weight of parameters are not the same. Stigter et al. (24) have described the method of constructing GWQI in 3 main levels: (1) selection, (2) standardization, and (3) aggregation. In this study, water quality index was calculated via equation 1 (25) for each of 65 sampling wells.

$$\mathbf{GWQI} = \sum_{i=1}^{n} W_i \frac{C_i}{Cs_i} \quad (1)$$

Where,

GWQI = Groundwater quality index

W_i = The relative weight of ith water quality parameter

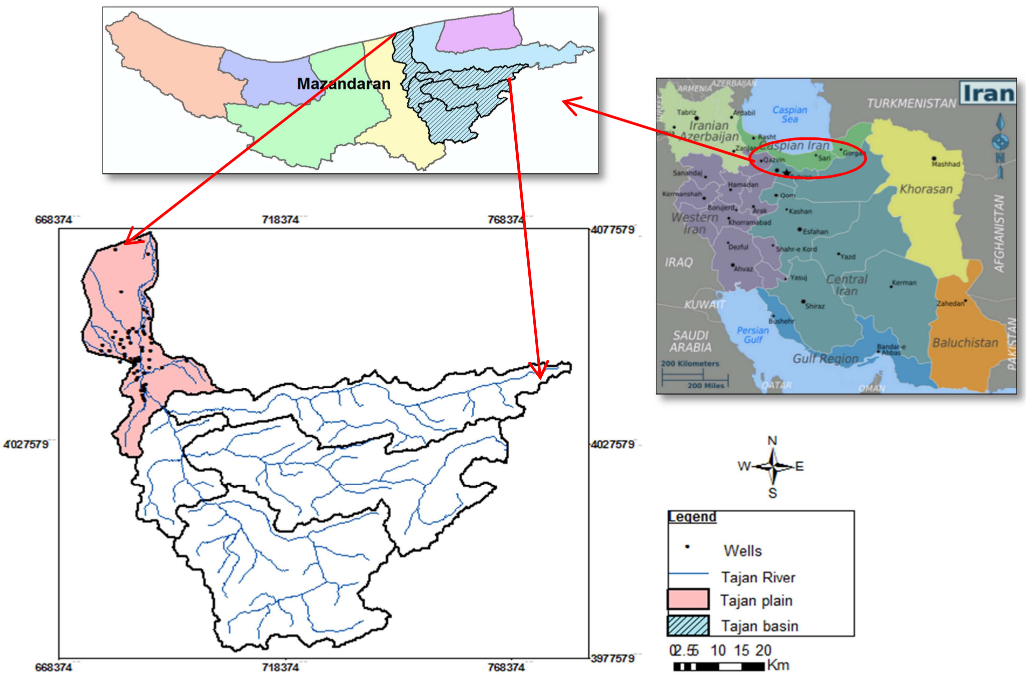

Figure 1. Geographic location of the case study (Tajan plain)

C_i = The observed concentration of the i^th^ parameter

Cs_i = The concentration limit value (Allowable concentration in national drinking water standard of Iran) of the i^th^ parameter

2.2.1. Selecting and weighting the water quality parameters

To calculate the GWQI in the case study, at first, the indicator parameters were selected via AHP technique. The first step in this technique is decomposing the problem into a hierarchy. The hierarchy of present study consists of three main levels; the goal (selecting the most appropriate quality parameters as the indicators), criteria (groups of the parameters) and sub-criteria (different quality parameters). Figure 2 shows the hierarchy of the research (Figure 2).

The AHP method uses pairwise comparison for obtaining the relative weights of criteria and sub-criteria (26). The basis of this technique is expert opinion; thus, 20 experts were identified as a group for advising in different steps, they were familiar with the study area and were expert in the knowledge of drinking groundwater quality.

A questionnaire was designed in the form of paired comparison tables and all experts were compared the parameters with the scores between 1 and 9 (1 means tow parameters have the same importance, and 9 shows the highest preference of one parameter over the other) (27). Expert opinions were combined for calculating the final weights of parameters. At last parameters were ranked and prioritized according to the final weights. According to an expert group opinion first quarter of parameters (the first 6 parameters) were selected as indicator parameters.

Different steps of selecting the indicator parameters by AHP are shown in figure 3. Expert Choice software was used in this study to accelerate the analysis (steps 4, 5, 6, and 7 in figure 3); this software is a specialized program to AHP (28).

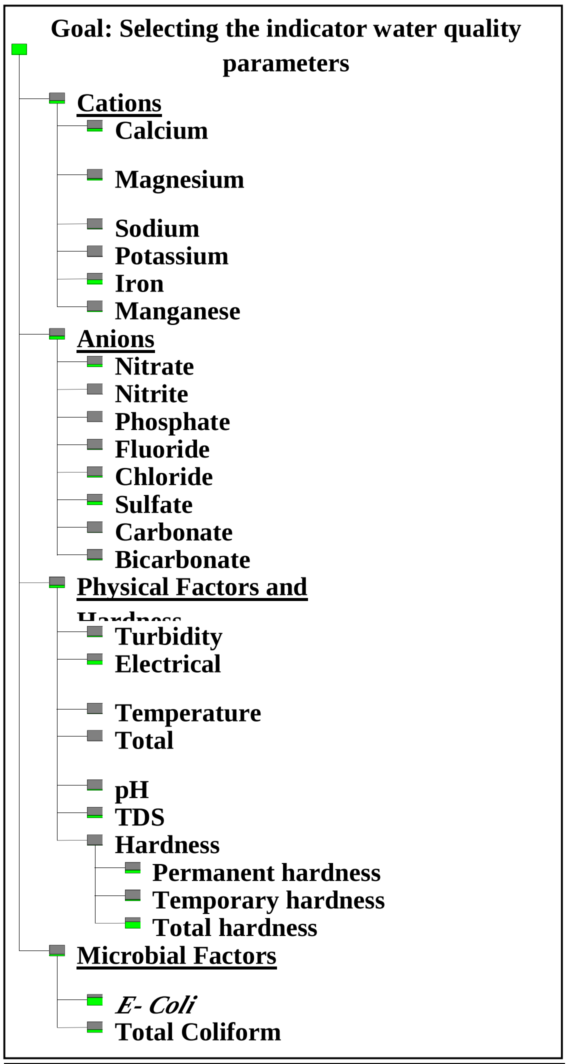

Figure 2. The hierarchy of the research

To calculate, the participation weight of each parameter in the GWQI, the final weights of indicator parameter were normalized and the normalized weights (Table 1) were used in the index as participation weight (W_i in Equation 1).

2.2.2. Standardization, aggregation and calculating the GWQI value

In the second stage, the sub-index of each indicator parameter was calculated. Sub-index means C_i/Cs_i (Equation 1).

The average of the water quality data in a 10 years period (2004-2013) was calculated for each parameter in each well to determine the observed concentration (C_i). The related data were obtained from two companies in

Mazandaran (Mazandaran Water and Wastewater Company and Mazandaran Company of rural water and sewer).

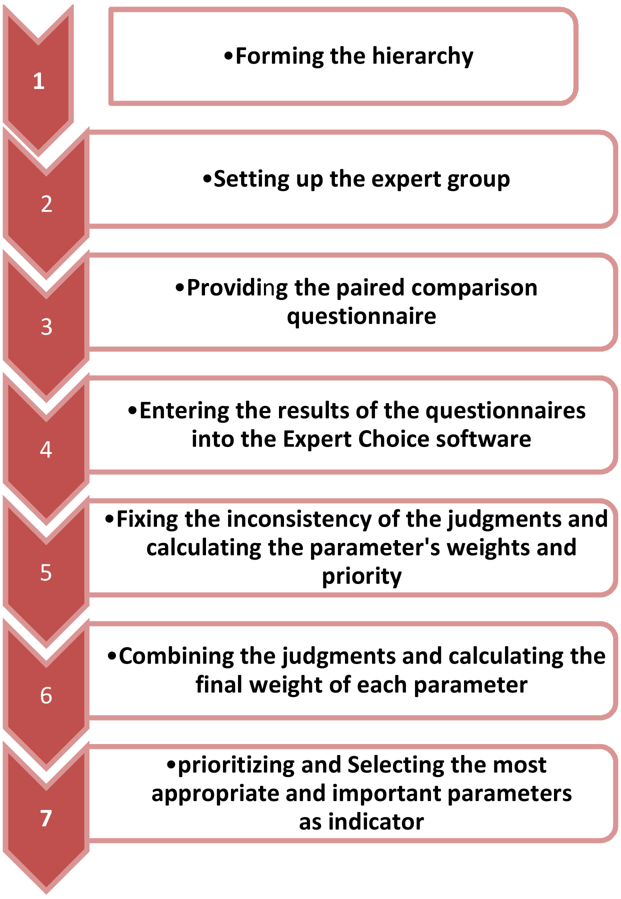

Figure 3. The process of selecting indicator water quality parameters by analytical hierarchy process

The concentration limited value of indicator parameters were extracted from national drinking water standard of Iran (29); standard values are shown in table 1. The calculated Sub-index value was multiplied to the related weight (W_i* C_i/Cs_i in Equation 1) for each indicator parameter. Finally, GWQI was determined by aggregating the values of all 6 parameters (Equation 1) for each sampling wells in the study area.

2.3. Spatial analysis of GWQI

The map of GWQI was generated using interpolating approach in GIS. Kriging method was used in this study between different interpolating methods. Kriging method considers the spatial correlation between the sample points and is mostly used for mapping spatial variability (30). Kriging method is reported by many researchers around the world, this method is a known and acceptable method for spatial analysis of groundwater quality (31,32).

3. Results

As previously mentioned at the first level of constructing GWQI, the indicator parameters were chosen by AHP technique. After completion of all weighting analyses the ranking graph of all criteria were plotted by Expert Choice program. Furthermore, the final graph of sub-criteria (water quality parameters) was plotted (Figure 4); in this graph the parameters were ranked and prioritized according to their final weights. The first 6 parameters mean the high priority ones [Sulfate-Iron-Nitrate-Electrical conductivity-Calcium-TDS] were considered as indicator parameters. The overall inconsistency was 0.02, which shows a high degree of homogeneity in the opinions and synthesis. The < 0.1 inconsistency ratio is acceptable in AHP; the closer the inconsistency ratio to zero shows the greater consistency (33).

To determine the participant proportion of each indicator parameters following steps were performed; first the extracted weights of 6 indicator parameters were aggregate to be 0.541, then individual weights of parameters divided by the total weight (0.541). With this operation the normalized weights were calculated, normalized values were determined as the weight of each parameter (Table 1).

Allowable concentration of quality parameters are shown in table 1, the values were obtained from national drinking water standard of Iran, this limit values were used in the level of standardization for determining the sub-index of each parameter.

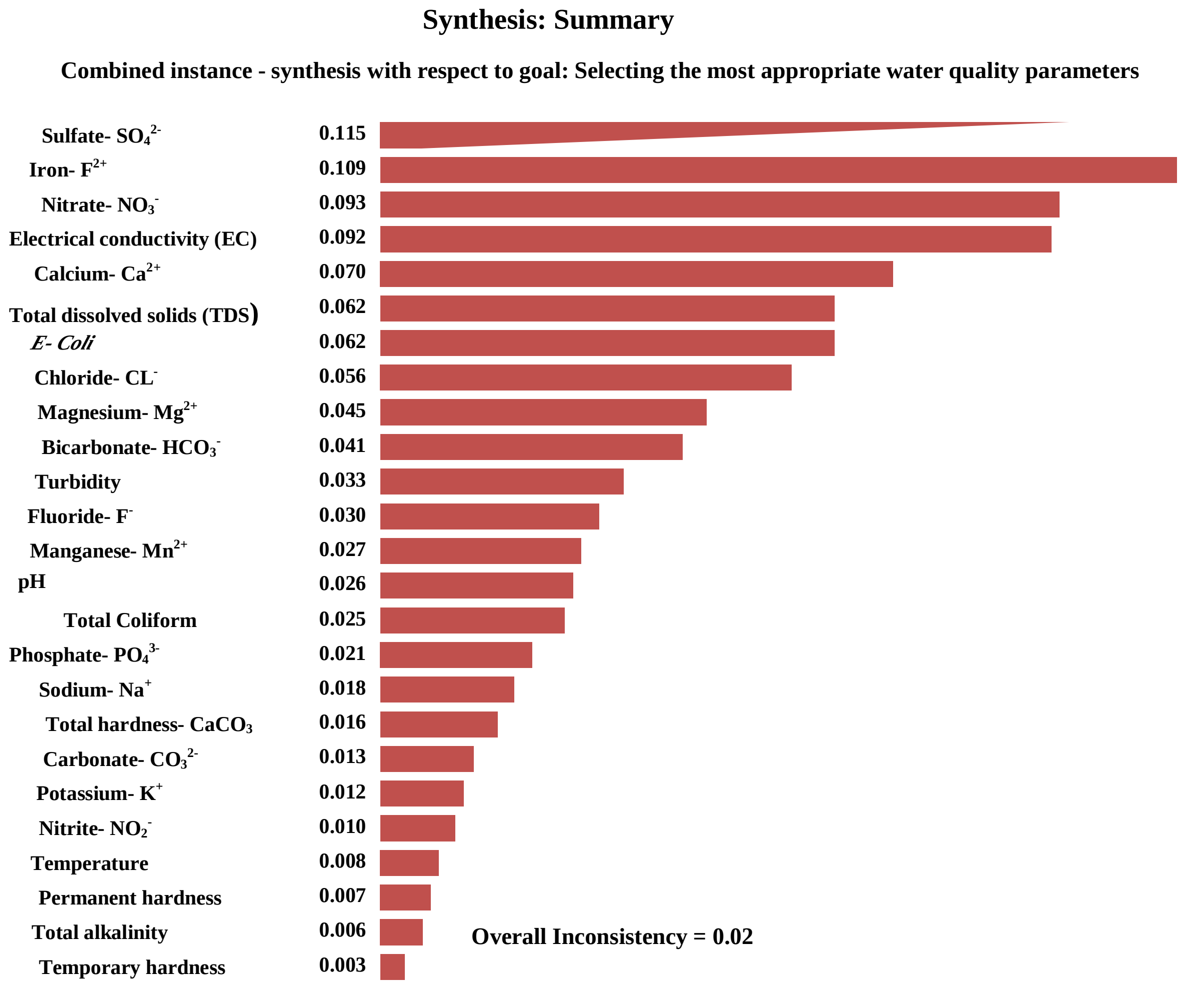

Figure 4. Ranking graph of all the water quality parameters of the study

Table 1. Relative weights and allowable limits of water quality parameters

Parameters	The obtained weight from AHP	Normalized weight	Allowable limit
Sulfate	0.115	0.21	400 mg/l
Iron	0.109	0.23	1 mg/l
Nitrate	0.093	0.17	50 mg/l
EC	0.092	0.17	1800 µmhos/cm
Calcium	0.070	0.13	300 mg/l
TDS	0.062	0.11	1500 mg/l
Sum	0.541	1.00	-

AHP: Analytical hierarchy process; TDS: Total dissolved solids; EC: Electrical conductivity

Based on the above steps and using equation 1, the GWQI was determined for all sampling wells of the study area. Table 2 shows the GWQI values of all sampling wells with more details.

GWQI map is derived from 6 indicator parameters. The data of all wells were interred and processed in GIS environment to get the output map (water quality index map) as shown in figure 5. The water quality index was reclassified into four classes that describe the quality of groundwater in the studied region. These four classes are: very good, good, moderate, and poor. The ranges and classes of the GWQI are given in table 3.

Table 2. The groundwater quality index (GWQI) values for sampling wells in Tajan plain

Wells	Sulfate	Iron	Nitrate	EC	Calcium	TDS	GWQI
1	57.43	0.13	9.46	775.89	109.55	429.64	0.243
2	38.08	0.09	8.27	695.50	114.97	448.00	0.216
3	46.00	0.14	7.32	608.25	116.57	445.43	0.220
4	72.17	0.06	8.07	710.00	118.71	438.71	0.230
5	88.76	0.11	7.09	647.86	105.36	426.00	0.233
6	80.00	0.11	9.45	869.17	122.13	627.25	0.280
7	63.78	0.18	9.75	714.25	114.47	370.00	0.249
8	82.83	0.09	9.93	679.90	105.34	378.29	0.235
9	65.80	0.15	5.17	752.13	119.80	395.14	0.236
10	36.25	0.16	11.37	830.25	132.05	529.75	0.266
11	30.10	0.05	5.98	686.13	113.74	434.00	0.194
12	80.88	0.10	2.49	905.00	85.14	517.25	0.233
13	84.73	0.15	7.33	836.00	106.63	467.92	0.261
14	78.27	0.17	5.17	883.88	106.58	537.00	0.264
15	90.80	0.11	16.91	740.80	106.12	451.8	0.279
16	67.40	1.12	5.00	634.83	95.75	411.00	0.411
17	92.00	0.05	26.14	1027.00	137.00	616.00	0.352
18	107.03	0.10	9.97	1089.83	141.00	795.00	0.336
19	75.43	0.05	11.1	710.67	101.10	455.20	0.234
20	64.75	0.99	10.63	631.50	81.80	402.50	0.396
21	75.33	0.17	7.53	770.00	101.36	440.00	0.250
22	80.20	0.10	6.47	810.83	90.55	493.00	0.238
23	66.27	0.45	6.65	806.67	84.40	513.00	0.301
24	83.10	0.31	9.52	764.60	103.30	505.40	0.295
25	64.33	0.19	6.92	714.11	98.42	486.86	0.243
26	28.93	0.33	5.53	576.60	73.10	361.25	0.214
27	33.53	0.33	7.53	656.14	83.20	379.63	0.237
28	36.25	0.28	5.75	641.75	65.80	378.50	0.213
29	68.50	0.62	2.88	682.50	79.80	443.50	0.304
30	73.00	0.21	1.40	897.50	101.20	539.00	0.256
31	124.30	0.02	19.48	1036.03	151.23	695.79	0.353
32	111.22	0.02	19.20	1438.72	125.84	921.97	0.390
33	127.42	0.02	14.96	944.41	108.03	619.27	0.306
34	114.47	0.02	12.36	946.97	97.06	619.20	0.286
35	113.84	0.02	22.91	1237.17	125.25	836.62	0.378
36	120.69	0.01	23.29	1139.14	119.44	779.53	0.365
37	124.33	0.02	14.39	982.11	112.30	640.94	0.310
38	126.82	0.03	14.61	964.69	111.09	610.57	0.309
39	118.64	0.02	14.08	1376.50	136.33	926.60	0.375
40	118.13	0.01	11.76	945.44	105.95	624.50	0.288
41	108.28	0.05	25.00	1223.97	124.97	817.66	0.386
42	130.11	0.02	10.92	936.14	112.25	618.60	0.295
43	116.38	0.02	12.58	930.14	104.90	621.14	0.290
44	112.26	0.04	17.30	1045.97	112.85	709.63	0.329
45	111.16	0.02	23.99	1187.12	128.48	795.66	0.374
46	128.11	0.03	11.12	948.44	108.59	644.44	0.298
47	124.99	0.02	12.01	973.71	105.95	647.53	0.299
48	126.94	0.02	8.95	906.42	104.40	606.67	0.279
49	138.54	0.03	17.3	1760.44	118.76	1218.49	0.450
50	45.11	0.08	1.20	511.56	65.70	315.67	0.145
51	50.12	0.09	1.10	575.34	63.40	328.00	0.155
52	54.70	0.03	8.40	720.25	83.57	479.75	0.205
53	55.63	0.25	7.50	622.13	78.10	375.14	0.227
54	98.12	0.04	18.40	786.97	112.23	519.20	0.286
55	88.33	0.03	12.23	751.85	107.55	526.43	0.253
56	78.14	0.03	8.10	676.13	78.76	424.00	0.206
57	49.21	0.06	7.90	642.13	65.87	414.00	0.186

Table 2. The groundwater quality index (GWQI) values for sampling wells in Tajan plain (Continue)

Wells	Sulfate	Iron	Nitrate	EC	Calcium	TDS	GWQI
58	33.40	0.02	12.50	591.40	114.87	387.30	0.200
59	58.38	0.02	9.50	649.81	71.35	421.90	0.192
60	56.53	0.04	10.30	643.70	96.70	414.60	0.208
61	62.11	0.02	15.15	789.43	109.88	520.10	0.251
62	63.12	0.04	12.50	750.70	108.88	497.40	0.240
63	42.80	0.49	11.00	660.00	65.20	402.20	0.280
64	67.31	0.05	11.65	738.50	101.20	466.76	0.235
65	52.12	0.10	4.50	590.83	76.91	381.56	0.181
Maximum	138.54	1.12	26.14	1760.44	151.23	1218.49	0.450
Minimum	28.93	0.01	1.10	511.56	63.40	315.67	0.145
Mean	80.98	0.14	10.84	836.52	103.52	537.61	0.270
SD	30.83	0.21	5.76	230.44	19.96	168.46	0.070

TDS: Total dissolved solids, EC: Electrical conductivity, GWQI: Groundwater quality index, SD: Standard deviation

Table 3. Groundwater quality classes in Tajan plain

GWQI classes	Range of the classes	Area km^2	Area percent
Very good	0.15-0.23	175.3	27.8
Good	0.23-0.27	364.4	57.8
Moderate	0.27-0.31	68.7	10.9
Poor	0.31-0.45	22.6	3.5

GWQI: Groundwater quality index

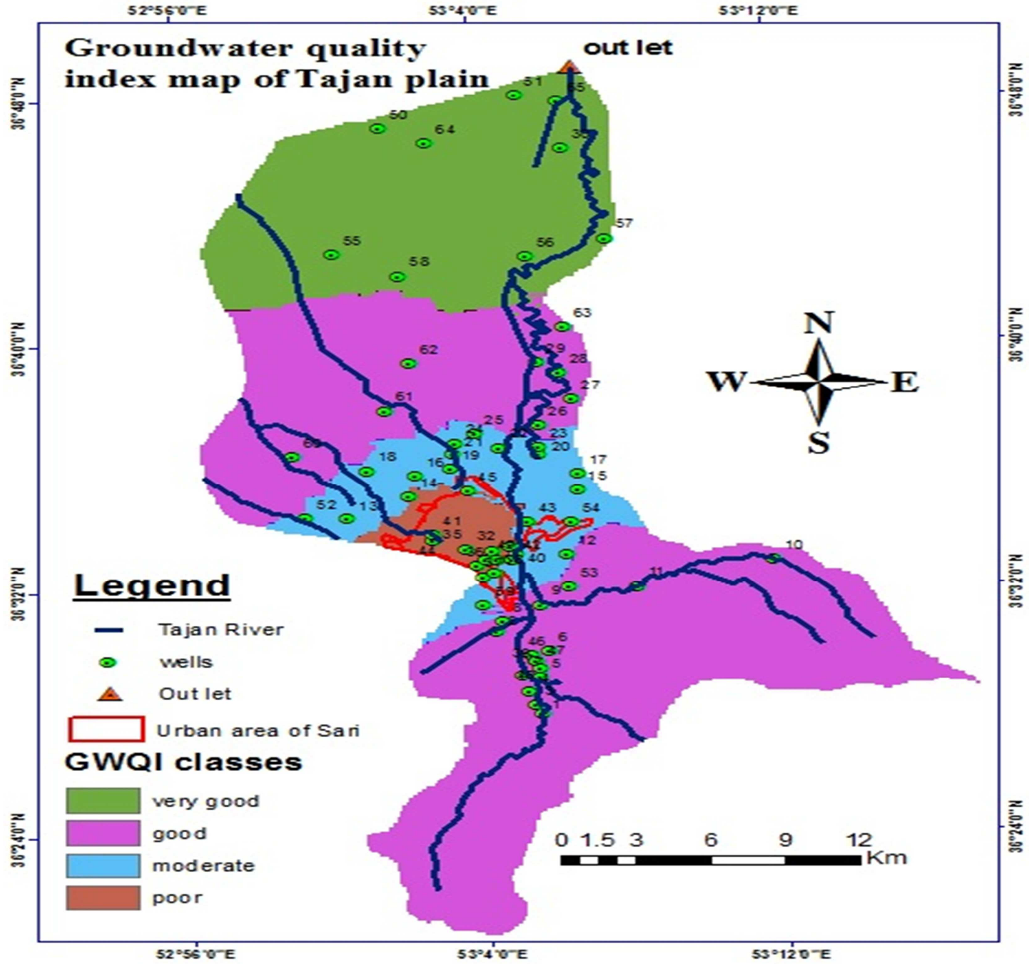

Figure 5. Spatial distribution of groundwater quality index in Tajan plain

4. Discussion

Since the environmental and social specifications of different geographical regions are not the same, using a fixed group of parameters is not favorable to evaluate the groundwater quality in all areas. Because of the noted reason, a logical way was proposed to select a special set of parameters for the study area.

It was concluded in present study that a MCDM approach, especially the AHP method is a reasonable method for selection of the most appropriate parameters, also this technique is a suitable way for calculation of the weights for determining the GWQI values. One of the most important conclusions that obtained from this level of study was that: the background of pollution is an essential issue that should be considered in selecting parameters. For example, expert opinion stated that microbial agents are rarely observed in wells in Tajan plain; thus, despite the importance of this factor, it is not a priority for analysis. Furthermore, despite the importance of nitrate, sulfate was the most serious anion in this plain.

According to points mentioned; three main results were obtained from the first step of this study means Analytical Hierarch Process: First, the weighting of each parameter determines its importance ratio; second, the priority of the parameters and third, selecting the most important ones in Tajan plain.

In this study, GWQI was calculated for 65 studied wells, the index was varied between 0.14 and 0.45. This range indicates that the groundwater quality in the study area can be classified in different levels, so the status of groundwater quality in Tajan plain was interpolated with kriging method and divided into four types of zones: Poor water quality (0.31-0.45), Moderate water quality (100.1-136), Good water quality (0.23-0.27), and very good water quality (0.14-0.23). The location of quality classes were shown on the map and the ranges and percentage area of classes was interred in table 3.

Table 3 shows that 57.9% of the area has groundwater with good quality, 27% of Tajan plain has very good quality of groundwater, 10.9% has moderate groundwater quality and 3.5% has poor one.

According to the results, the highest area is allocated to the second class, means good groundwater quality. However, the map shows that the quality of groundwater around the urban area is poor. This results show that the concentrations of population and industrial activities have inappropriate impacts on aquifers, so it is concluded that the most important variable that affected the groundwater quality is concentration of population. It is worth noting that the quality ranges are comparative in the study area, means the poor class in Tajan plain can be a good quality class in other plains.

Based on GWQI map the area near the outlet (Caspian sea) has very good groundwater quality class, this is because of the low concentration of population and residential areas in this zone. In the southern area of Tajan plain the quality of groundwater is good; this is due to the low amount of agricultural land in the area because forests are the dominant land cover in this zone. In the central region of plain with a little distance from dense urban area the Groundwater quality is moderate, population in this area is lower than the urban sector but the amount of agricultural land in this zone is high.

According to the results, it can be concluded that population, residential areas, and agricultural land are the main causes of groundwater pollution in the area of study.

One of the advantages of the proposed approaches is flexibility; according to pollutant factors in different regions the indicator parameter and the importance weights of them can be varied. Furthermore, the interpolated index can reclassify into other ranges by Kriging technique.

Conflict of Interests

If this article be published in your journal, an amount will be paid as reward to authors by Islamic Azad University, Science and Research Branch.

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