ORIGINAL ARTICLE

A Survey on Temporal Changes of Drinking Water Quality in Urban Areas Using Iran Resources Water Quality Index and Statistical Analysis: A Case Study of Shiraz, Iran, 2011-2015

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Abstract

Background: Monitoring the water quality and analyzing its changes over time is an important aspect of sustainable management and development of water resources. The purpose of the present study was to analyze the trend of temporal variations in the quality of drinking water supplied from groundwater sources in Shiraz, using IRWQI (Iran Water Quality Index) as well as statistical analysis.

Methods: This study was conducted on groundwater resources in Shiraz, Iran from 2011 to 2015. 10 water quality parameters were used in this index including NO_3, Fecal Coliform, EC, TH, SAR, BOD_5, PO_4, COD, pH, and DO, with their own weights. Repeated measure test was used in order to analyze the differences between IRWQI values between the study years.

Results: The results showed that IRWQI varied between 89/96 (very good quality) and 49/51 (average quality) in the study years. The main causes of water quality decline were average to relatively high levels of hardness and nitrate. The general pattern of the changes in water quality has been accompanied by an increase and decrease, so that the water quality has improved from 2011 to 2013 but then declined until the end of the study.

Conclusion: Regarding the necessity of clarifying the water quality condition and its changes and the importance of using IRWQI as an emerging national indicator, water quality analysis in different parts of the country, taking advantage of this indicator and statistical analyses will help the country promote and accelerate the integrated management of water resources quality.

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Introduction

Water is essential for all life and human activities and access to freshwater in sufficient quantity and appropriate quality is required for sustainable development of any society.[1, 2] In recent years, the water crisis and water pollution by wastewater and agricultural activities in arid areas have become particularly prominent, so that providing sufficient and healthy drinking water has become a human challenge.[3-5] It is anticipated that the quantitative and qualitative water crisis will play an important role in future tensions and contradictions in the countries of West Asia and the Middle East.[6, 7] Lack of rainfall and water resources and rapid population growth in Iran, as one of those countries, have long existed. The quantity and quality of water are associated with each other and have a coherent and meaningful relationship with each other and in the case of drinking water, it can be claimed that water quality, if not more important than water quantity, has equal importance with it. Therefore, it is necessary to determine and continuously monitor the quality of water before it is used, a very small change in the amount of each of the parameters can change the water quality class.[8-12] On the other hand, when water sources become contaminated, it will be very difficult to restore the water quality. Therefore, it is very important that ways of assessment and prediction of the quality of water be available to protect these resources, which itself clearly shows the need for using tools to monitor the water quality.[13, 14]

Water quality index is a good way to summarize large amounts of data and express it as a single, understandable number and facilitate judgments about water quality.[15, 16] These indicators are a kind of water quality modeling tool with a logical and ideal approach to assessing the physical, chemical and biological changes of water over time, and they are able to demonstrate the process of water quality changing over time and in different locations. This has led to considering a special place for Water Quality Indices in water resources planning and management, especially in the drinking sector.[17-20] So far, a variety of indicators have been developed around the world for assessing the water quality with various approaches and computational methods. The most important of these indicators are National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment (CCMEWQI), British Columbia Water Quality Index (BCWQI), Oregan Water Quality Index (OWQI), and Centre St Laurent (CSL).[21, 22] In Iran, Iran Water Quality Index (IRWQI) is being tested and evaluated as an emerging national indicator for assessing the quality of water resources. Following the advent of IRWQI in the field of water quality management in the country, this indicator has been used in different parts of Iran as case studies. Several studies have addressed the use of this index on surface water, such as qualitative and seasonal changes of water pollutants in the Sorkheh-Hesar area by Hamedi and others, 2015; the study of water quality in the Terval River in Kurdistan province and quality zoning based on the interpolation model IDW by Nairy and Zandi in 2015; review of the water quality on Zaringol River in Golestan province by Sadeghi and others. in 2015; the use of IRWQI for spatiotemporal multi-criteria optimization of reservoir; and the study of water pollution in Choghakhor wetland in 2016.[23-27] Studies conducted by Javid and others on the toxicity of groundwater resources in Semnan, and the study of Hajatipour and Moslehi which evaluated and delineated the groundwater of Masjed Soleiman plain are some examples of studies carried out with IRWQI on the groundwater resources.[28, 29] Also, this national index has been employed to evaluate the water quality of groundwater sources. As an example, Ramakrishnaiah and others, applied IRWQI on data from 269 locations of drinking consumption viewpoint in Tumkur Taluk, Karnataka State, India.[30]

Considering the necessity of clarifying the water quality condition in the country's water resources and the importance of using IRWQI in water quality monitoring at the national level, the present study surveyed the drinking water quality changes being supplied from wells in Shiraz, Iran using IRWQI and statistical analysis in a five-year period.

Methods

Study Area

This study was conducted on drinking water wells located in the northwest of Shiraz. The geographical coordinates of this city are 29 degrees and 36 minutes north and 52 degrees and 32 minutes east, and its height from the sea level varies between about 1500 to 1700 meters in different parts of the city. The city is located in the Zagros Mountains and has a moderate climate. The population of this city in 2015 was just over 1,500,000.

In this study, 45 points of groundwater resource were surveyed. The sampling points are located in 4 areas in four different geographical directions (north, west, Southwest, and east). The location of the area and the sampling water wells are shown in Figure 1.

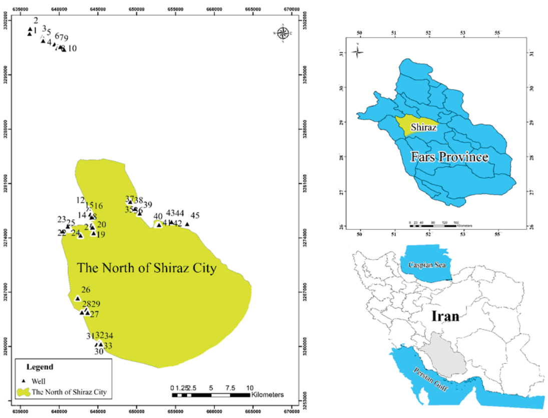

Figure 1: Location of sampling points of drinking water supply, Shiraz, Iran

IRWQI

This indicator was introduced by Iranian Environmental Protection Agency in 2014 as a national indicator for surface water and groundwater quality assessment. The title is general and includes 4 more subspecialty subsets, including the indicators of conventional parameters of surface water quality ($IRWQI_{SC}$), conventional parameters of groundwater quality ($IRWQI_{GC}$), toxic parameters of surface water quality ($IRWQI_{ST}$), and toxicparameters of the groundwater quality ($IRWQI_{GT}$).[31] In this study, the $IRWQI_{GC}$ index was used.

IRWQI calculation follows these steps:

- Selection of parameters according to Table 1.
- Converting the Dissolved Oxygen concentration from *mg/l* into saturation percentage.
- Determining the weight of each parameter using Table 1.
- Matching the measurement units of parameters (normalizing the data) and obtaining the subindex value for each parameter using the functional curves (Figure 2).
- Calculating the index value using Equation(1) and (2):

$$IRWQI_{GC} = \left[\prod_{i=1}^{n} I_i^{W_i}\right]^{\frac{1}{\gamma}} \quad (1)$$

Where

$$\gamma = \sum_{i=1}^{n} W_i \quad (2)$$

W_i is the ith parameter's weight, n is the number of parameters, and Ii is the index value of parameter i, which is extracted from the functional curve.

- Determining the linguistic classification equal to the calculated index using Table 2.

Data Collection and Analysis

Water qualitative data for a five-year period from 2011 to 2015 were collected annually and assessed by laboratory methods in accordance with the Standard Methods for Examination of Water and Wastewater.[32] Therefore, for each water quality parameter 5 numbers were reached. After determining the concentration of the 10 parameters, they were converted to sunindex values according to Figure 2. The subindex for each water quality parameter was an actual number between zero and 100. In the next step, the subindices were used to calculate the annual $IRWQ_{GC}$ values for each well according to the steps explained in section 2.2. Lastly, the anuual IRWQIs were compared to find the water quality trends in the study period. In order to analyze the changes in water quality during the study, the repeated measure test, as one of the ANOVA groups, was used.

Table 2: Linguistic terms for the interpretation of water quality based on $IRWQI_{GC}$[31]

Linguistic description	Index value
Very Bad	<15
Bad	15-29.9
Moderately Bad	30-44.9
Medium	45-55
Moderately Good	55.1-70
Good	70.1-85
Very Good	>85

Results

In this case study, the trends of water quality were explored in Shiraz, as a metropolis, within 5 years. As shown in Table 3, for the wells under investigation, the highest values of $IRWQI_{GC}$ (the best water quality) were observed in well No. 10 in 2011, 13 in 2012, 25 in 2013, 13 in 2014, and 25 in 2015 with index values of 84.90, 88.25, 89.5, 87.71 and 89.96, respectively. Water quality in these wells was pronounced as Very Good. The lowest values (The worst water quality) were found in well No. 45 in 2011, 44 in 2012 and 43 in the last three years with values

Table 1: $IRWQI_{GC}$ parameters and their weights[31]

No	Parameter	Weight	Unit
1	*NO_3*	0.151	mg/l
2	*Fecal Coliform*	0.134	$MPN/100\,ml$
3	*EC*[1]	0.129	$\mu s/cm$
4	*TH*[2]	0.103	mg/l as $CaCO_3$
5	*SAR*[3]	0.089	Dimensionless
6	*BOD_5*[4]	0.088	mg/l
7	*PO_4*	0.085	mg/l
8	*COD*[5]	0.080	mg/l
9	*pH*	0.074	Dimensionless
10	*DO*[6]	0.067	% Saturation

1 Electrical Conductivity *4 Biological Oxygen Demanding*
2 Total Hardness *5 Chemical Oxygen Demanding*
3 Sodium Absorption Rate *6 Dissolved Oxygen*

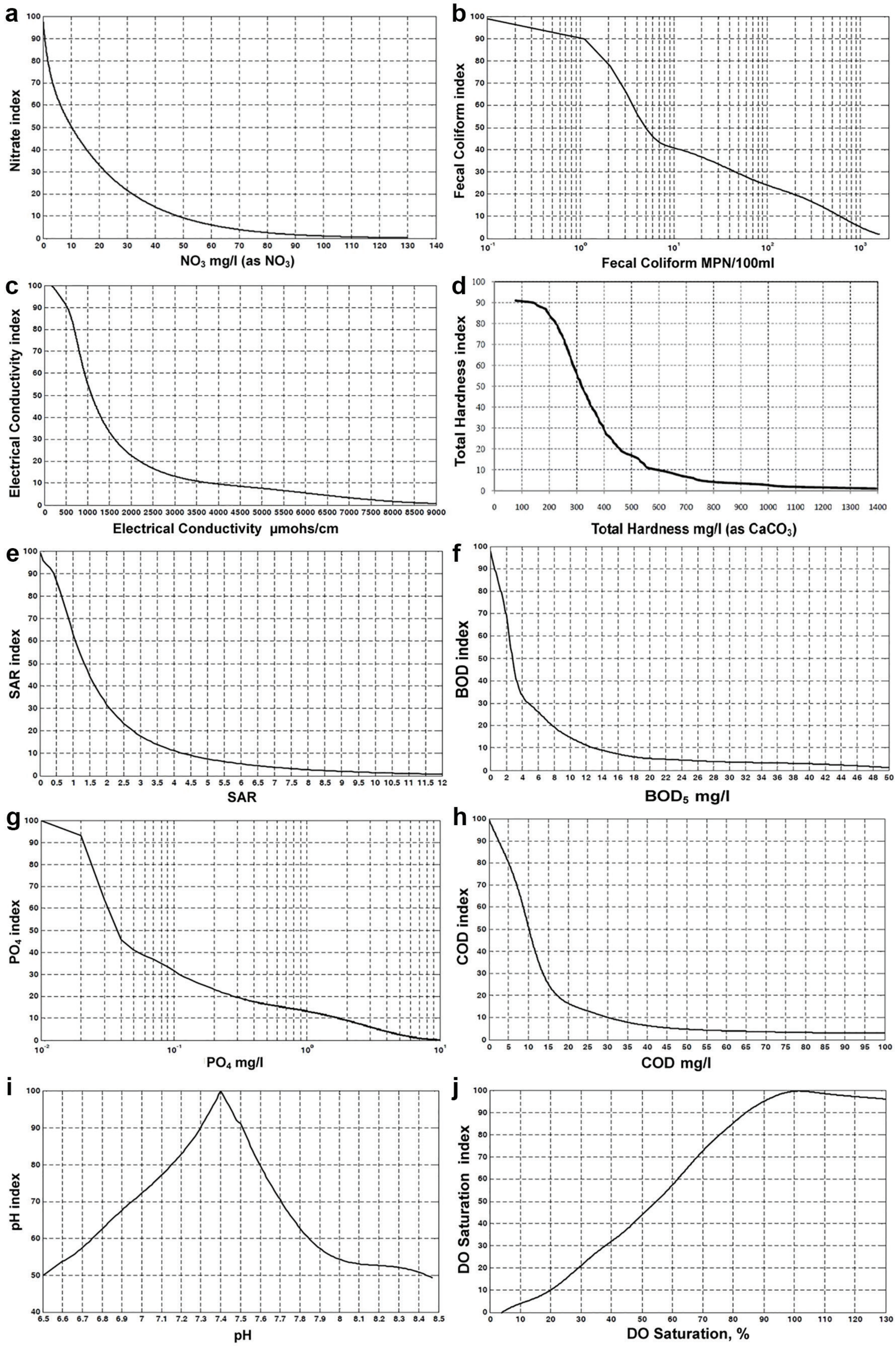

Figure 2: Functional curves used in $IRWQI_{GC}$: a) NO_3 , b) Fecal Coliform, c) EC, d) Total Hardness, e) SAR, f) BOD_5 , g) PO_4, h) COD, i) pH, j) DO.[31]

Table 3: Annual $IRWQI_{GC}$ values for drinking water in the studied wells in Shiraz, Iran (2011-2015)

Well No	Zone	$IRWQI_{GC}$				
		2011	2012	2013	2014	2015
1	North	82.89	80.94	83.16	81.3	82.06
2		77.76	81.99	83.36	80.47	80.89
3		74.94	82.51	83.61	82.76	79.72
4		76.68	79.44	83.83	83.79	77.31
5		79.53	79.41	83.83	83.82	80.87
6		80.15	80.11	81.91	84.95	80.52
7		77.63	82.8	82.2	77.43	78.28
8		76.86	81.82	82.15	81.5	78.91
9		82.61	75.71	83.65	79.03	81.09
10		84.9	84.97	83.79	79.41	83.11
11	West	84.54	80.7	82.69	81.66	82.19
12		80.35	82.38	87.91	83.87	83.34
13		82.68	88.25	85.51	87.71	85.13
14		79.96	79.36	82.4	84.66	79.91
15		74.98	83.19	82.88	80.1	79.36
16		70.68	74.26	75.22	75.69	76.71
17		65.6	66.33	64.39	66.27	64.20
18		80.63	85.75	86.06	83.726	82.56
19		74.78	70.34	69.41	69.697	63.55
20		65.93	62.06	66.26	66.221	68.41
21		66.4	73.24	75.57	66.992	69.36
22		58.83	70.94	79	70.187	62.78
23		84.09	77.37	85.94	82.05	83.23
24		78.73	82.35	88.21	80.853	81.99
25		83.06	84.46	89.5	86.12	89.96
26	Southwest	61.44	63.56	65.46	62.089	62.52
27		58.78	62.56	62.05	59.223	58.78
28		60.7	66.99	66.9	66.636	64.41
29		62.21	65.92	65.71	62.68	62.31
30		67.14	68.83	68.21	67.34	62.65
31		65.43	63.31	66.33	67.63	65.76
32		62.89	67.11	65.95	66.01	64.47
33		71.76	73.1	73.57	69.36	70.06
34		62.63	65.57	62.16	60.96	62.75
35	East	68.09	66.73	69.3	63.99	66.34
36		66.42	66.58	68.21	68.8	66.03
37		66.21	64.46	69.58	66.17	65.19
38		66.66	68.83	71.67	69.08	68.77
39		68.93	70.25	68.6	65.59	66.22
40		60.68	62.84	66.22	65.06	64.91
41		64.06	62.88	66.77	56.96	65.33
42		63.08	63.83	59.7	56.77	58.49
43		53.51	52.05	53.88	51.58	53.01
44		53.67	49.51	56.77	52.102	56.81
45		52.12	55.18	58.38	51.91	54.89

of 52.12, 49.51, 53.88, 51.58 and 53.01, respectively. Water quality in these wells was grouped as Medium.

Water quality trend in the five-year study period is displayed in Figure 3. It represents an increasing pattern during 2011 to 2013 and a decreasing from 2013 up to the end of the study afterwards. However, the slope of these changes was too insignificant to be considered as constant.

Water quality linguistic trend was classified and illustrated in Figure. 4, as a line chart. As this figure shows overall, water quality improved from the beginning year of the study to the middle in 2013, while after this year up to the end of the year 2015 water quality decreased.

The effect of the time on water quality changes was evaluated by analyzing the association between IRWQI in different study years from 2011 to 2015 through repeated measure test. The results of the pairwise comparison between the study years in terms of water quality changes are reported in Table 4.

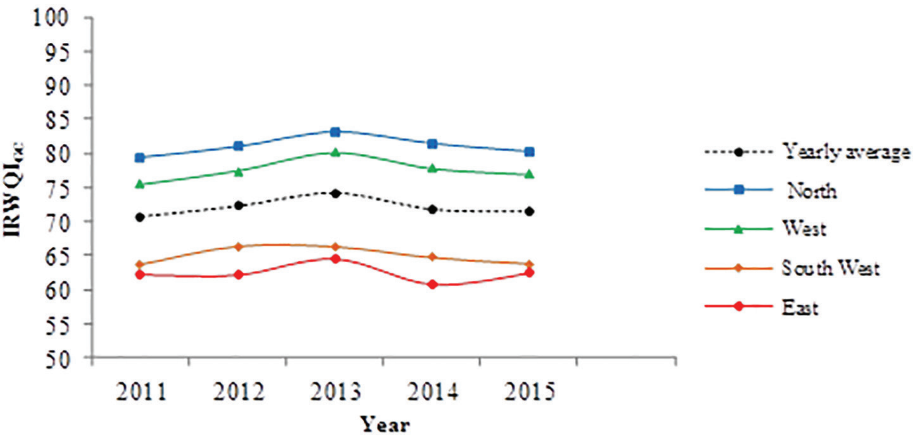

Figure 3: Trend of water quality changes in the studied areas, Shiraz, Iran (2011-2015)

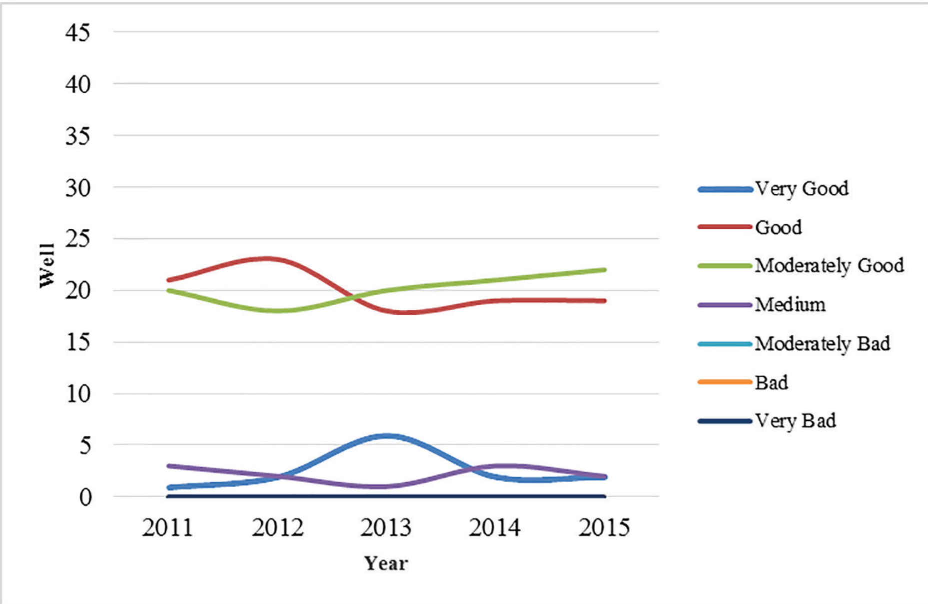

Figure 4: Changes of linguistic water quality groups in the studied wells, Shiraz, Iran (2011-2015)

Table 4: Analysis of the association between IRWQI values in the study years by repeated measure test

AV[1]±SD[1]					P value
2011	2012	2013	2014	2015	
70.707±1.397[a]	72.246±1.427[b]	74.180±1.479	71.786±1.548[a,]	71.452±1.447[a,]	0.001

Dissimilar values (superscripts a, b, c) are significantly different
All results are presented by AV±SD through repeated measure test
1. Average; 2. Standard Deviation

Discussion

Regarding the importance of water resources management and water quality monitoring in health protection, the necessity of a precise tool to survey the changes and fluctuations in the quality of water has become more obvious. Introducing IRWQI as a national index can confirm it. Also, other researchers such as Pourshahabi and others (2018) has confirmed IRWQI as a reliable index.[27]

Comparison of different areas showed the lowest water quality in Eastside and the highest in North and West side zones. There was a significant maximum difference between index values (40.45) in the East and West areas during the study.

According to the analysis of the effective parameters, the reason for low water quality in Eastside may be related to medium to a moderately high amount of hardness and nitrate. Surprisingly, even the amount of hardness and nitrate was less than the minimum limit in the index (often less than 22). The first issue to consider is the relatively high weight of NO_3 and TH that are respectively ranked the first and fourth in IRWQIGC index, respectively.

Therefore, these two parameters were responsible for water quality decline. It seems that quality dip, due to these quality parameters, was related to two factors: first, the karstic soil texture which is dominant in the study area, and second, the lack of the wastewater collection networks in almost half of the city. Therefore, the present study has clearly shown the relationship between human activity and water quality. Regarding the important role of Nitrate in water quality changes, different studies have been carried out on the effect of this parameter on water quality, showing the same results as the present study. Ramakrishnaiah and others found low quality water in more than 50 percent of samples that were due to exceeding amount of Nitrate and several parameters. They assumed the probable anthropogenic pollution sources for high Nitrate amount.[30] Also, another study that has analyzed IRWQI for Tarval River in Kordestan, Iran has confirmed the relationship between human activity and water quality changes.[26] Based on the evidence, such different patterns of water quality trends among these four areas may be due to the differences in locations, soil texture and human phenomena. Generally, similar to what was discussed by Javid and others. In 2015, there was no concern about the water quality and it was identified as appropriate for drinking.

Figure 3 shows the arrangement of water quality in the studied areas in a way that North, West, Southwest, and East sides were respectively ranked as the first, second, third, and fourth zones with respect to their water quality conditions. North and West sides had a similar water quality trend so that a partial enhancement was found from the beginning of the study to 2013 and following the reversed pattern up to the end of the study. Water quality trend in Southwest sides showed a little ascending, constant, and descending pattern in 2012, 2013, and 2013 to 2015, respectively.

East area has shown a different trend. In a way that no change was seen in the first year, but a fast increase was started which reached the peak in 2013 following by a plummet in the next year and stayed at its minimum index value in 2014 afterwards. Finally, the trend was ended by its second increase in 2015.

As Figure 4 shows, during the study period, a significant shifting from medium and moderately good quality to good and very good quality has occurred simultaneously.

In contrast to Hamedi's report, the quality of the whole water wells in Shiraz plain was higher than medium. Also, the calculated values of IRWQI were higher than those of their study.[21]

As Sadeghi discovered, according to IRWQI index, water quality of Zaringol River was set in the moderately good category.[25] In another study, Hajatpoor evaluated the quality groundwater sources of Golgir Plain in Masjedsoleiman, using IRWQI.[28] They found that the quality level was in the range of good and very good. The present study indicated the same linguistic classification as their study.

Generally, repeated measure test showed a significant difference in IRWQI values occurring over time ($P<0.001$). According to this Table, water quality changes between 2011 and 2012; 2011 and 2013; 2012 and 2013; 2013 and 2014; and finally 2013 and 2015 were statistically significant. Therefore, this statistical analysis indicated obvious changes in water quality which, as shown in Figure 4, reveals that the water wells under evaluation had an increasing and then decreasing trends in their water quality between 2011 and 2015 regarding IRWQI. Figure 4 indicates that all the studied wells obtained index values from the range of Medium to Very Good quality. It is implied from Figure 3 that most of the observed quality groups were good and moderately good in every year.

Conclusion

The purpose of the present research was to survey the changes in drinking water quality being supplied from groundwater resources in Shiraz, Iran by calculating IRWQI and statistical analysis in a five-year period. Overall, it was discovered that water quality was in the good category and was suitable for drinking over the study years. Most of the wells followed an ascending trend up to 2013. But increase in the amount of hardness and Nitrate has led to a decrease in the quality trend in several wells. Although the measured concentrations of these parameters were less than the maximum permitted level, these significant differences in the two final years were considered as a warning for declining water quality in the near future for this city. Using IRWQI coupled with suitable statistical methods would accelerate performing the homogeneous schemes of drinking water quality monitoring and future planning in urban areas in Iran.

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