Assessment of Groundwater Quality for Drinking Purposes Using Water Quality Index (WQI) in Shiraz, Iran (2011 to 2015)

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ABSTRACT
Drinking water quality monitoring is a prerequisite for macro planning of development programs in metropolitans, improvement in health, and water resources management. Since WQIs (Water Quality Index) are known as comprehensive tools for interpretation of water quality, this study benefitted from this tool to determine the drinking water quality trends in Shiraz, Iran in a five year period from 2011 to 2015 and figure out the factors affecting its changes in this city. For this aim, annual data of 9 water quality parameters including DO, Fecal Coliforms, pH, BOD_5, NO_3, PO_4, temperature deviation, turbidity, and TS were collected for 45 drinking water wells located in 4 zones (Dokuhak, Derak, Sabzpushan, and Chamran) to calculate the WQI. Pairwise comparison of years in terms of WQI values was analyzed statically using post-HOC analysis in Univariable repeated measure test. The results showed that the highest and the lowest water quality level both for annual and long term evaluations belonged to Derak and Chamran zones, respectively. All the studied wells in the five years were classified in "good" quality group. According to statistically analyze the highest significant change in water quality ($p\text{-value} < 0.001$) was found between the two years 2013 and 2015. In terminal years of the study, the increased concentration of TS and NO_3 caused a partial decrease in water quality in some sources. These significant differences can be considered as a warning for the soon future. Therefore, it makes sense to accelerate the development of sewer systems and manage uncontrolled population growth in this city to prevent further water pollution. Permanent monitoring of water quality using WQIs seems to be essential to figure out a perspective of water quality trends and proper decision-making for developments in urban areas.

Key words: Water quality, Drinking, NSFWQI, Shiraz

LIST of ABBREVIATIONS

WQI: Water Quality Index

NSF: National Sanitation Foundation

TS: Total Solids

SAR: Sodium Absorption Rate

INTRODUCTION
Accessing fresh water in an adequate amount and having proper quality is a prerequisite to achieve the sustainable metropolitans' development [1]. In recent decades, with the rapid population growth and industrial extensions, severe increase in the need for fresh water is obviously seen in all human societies [2]. Statistics show that in the last 40 years, water consumption rate has been doubled, and until 2025, at least 25% of the world's populations will live in countries dealing with water crisis [3]. Countries in the Middle East and North Africa, having 1% of fresh water resources, are considered as the most arid regions of the world [4]. Water shortage and rapid population growth are two characteristics of these countries, and this problem has a long history in Iran, as one of the countries located in this region. On the other hand, water quality and quantity is not separated, and they are strongly linked together [5]. With regard to the increased need for water in big cities, the amount of this natural resource is gradually decreasing and as a consequence water quality is affected. This issue has turned into an important problem in developing countries in recent years [6, 7]. Therefore, the significance of evaluating water quality in performing health programs and water resource management in Iran is clearly obvious.

Environmental collected data are mostly massive with special complexities. On the other hand, one of the difficulties that most environmental managers are facing to is how to present these bulky data in the form of simple and understandable information to the government and environmental managers and also to public in a lower level of specialty and knowledge

[8]. Therefore, many health or environmental legislator institutes have presented useful and practical WQIs. The advantage of these indices is that they are able to show the water quality status in a comprehensive way as one simple number which is judicable and facilitates interpreting water quality of each resource [9, 10]. National Sanitation Foundation Water Quality Index (NSFWQI) is known as a universal index to express and judge water quality condition. It was introduced in 1970 by the National Sanitation Foundation of USA. It is the most known due to ease of use, less complexity, and being accepted by most specialists, and also has been used in Iran in an extensive way [11-13]. For example, Shokuhi *et al*., [14], in 2012 used NSFWQI to evaluate the water quality in Aydughmush dam in Mianeh, Iran. They found that most measured samples had good quality according to NSFWQI classification. The result of their study showed that the quality of water in this lake is appropriate for being used as drinking. Yousefzadeh *et al*., [15], in 2013 used NSFWQI index to evaluate the quality of water in Khorram Rood River in Khorram Abad, Iran in 6 stations for a 6 months period. Their study showed that the best and the worst water quality conditions were classified in quality groups of good and bad, respectively.

Thereafter, this index has become a fundamental structure to develop many new WQIs [16]. For instance, a newly WQI namely IRWQI was proposed by the Department of Environmental Protection of Iran based on NSFWQI. Karimi and Sabouri, [17], 2016 evaluated the groundwater quality in Shiraz, Iran using IRWQI including 10 quality parameters (NO_3, Fecal Coliform, EC, Total Hardness, SAR, BOD_5, PO_4, COD, pH, and DO). Their findings showed that during this period, water quality was categorized in "very good" to "relatively bad" quality groups.

One of the advantages of using NSFWQI is to ease the interpretation of water quality trends in different times and places in a proper way. Therefore, they have found a special place in water resources planning and managing, especially for drinking purpose [18, 19]. Abba *et al*., [20], in 2015 evaluated the water quality trend in Yamuna River in India using NSFWQI for three years including 2000, 2005, and 2010. Their study showed a steady decreasing trend of water quality due to severe increase in anthropogenic activities.

In terms of using WQIS, the type of resource and the purpose of consumption have been always considered by the specialists. Beamonte, [21], believes that selecting the method for evaluation of water quality based on the type of consumption is much more effective than focusing on the type of supplementary resource. Therefore, many researchers have used NSFWQI to evaluate groundwater quality for drinking purposes. For example, Hassani *et al*., [22], in 2012 used NSFWQI for groundwater quality assessment in Yazd, Iran, and their results showed that although the measured concentration of parameters in samples were lower than the standard limits, the water quality was not proper for drinking. Yisa *et al*., [23] estimated groundwater quality in the Maikunkele region, Nigeria using NSFWQI. Their findings showed that water quality ranged from "bad" to "moderate" and were not suitable for dinking. Dhok *et al*., [24], used NSFWQI for groundwater quality evaluation in Baramati, India and they found that it was not suitable for drinking purposes.

With regard to the extensive use of NSFWQI, the aim of this study was to use NSFWQI to investigate the quality of drinking water in Shiraz, Iran being supplied from groundwater resources and analyze its trends toward the study period.

MATERIALS AND METHODS

NSFWQI

In the present study, NSFWQI was used to investigate the water quality status. This index has been designed by the National Sanitation Foundation (NSF (with Delphi technique. 9 water quality parameters are used in the index. These parameters and their specific weights are presented in Table 1. For each parameter, NSF has prepared a specific functional curve of which parameter's concentration is converted to a standardized sub- index value ranged from zero to 100.

Table 1: Water quality parameters and their weights in NSFWQI [25]

parameter	Weight
DO	0.17
Fecal Coliform	0.15
pH	0.12
BOD_5	0.10
NO_3	0.10
PO_4	0.10
Temperature Deviation	0.10
Turbidity	0.08
TS	0.08

Arithmetic sum is used to calculate WQI using sub-indices and exerting the parameters' weights, which is shown in the Eq. 1.

$$NSFWQI = \sum_{i=1}^{n} w_i I_i \qquad (1)$$

Where, w_i is the weight of i^{th} parameter, and I_i is the sub index value of i^{th} parameter.

In the present study, online NSFWQI calculator was used for calculating the index [26]. The index values can be described as linguistic classifications shown in Table 2.

Table 2: NSFWQI classification [25]

NSFWQI	Classification
0-25	Very bad
26- 50	Bad
51- 70	Medium
71- 90	Good
91- 100	Excellent

Study Area

Shiraz, the center of Fars province, is located in the southwest of Iran. The coordination of this city is 29° and 36`` N, 52° and 32`` E. Its elevation varies from 1480 to 1670 meters in different areas. It is located in the mountainous region of Zagros, and has mild weather. The mean annual temperature is 18 degree centigrade and annual rainfall is about 337.8 millimeters. The population was about 1700000 in 2015.

Data Collection and Analysis

The number of wells to be studied was calculated using eq. 2.

$$n = \frac{z^2 SD^2}{d^2} \quad (2)$$

Where, z is the confidence index. SD is the standard deviation, and d is the maximum acceptable difference. Considering the z value equal to 1.96, SD equal to 0.309, and d value equal to 0.06, minimum required well numbers were estimated to be 42. In this study, 45 water wells have been considered. These wells are located in 4 zones of the city indicated by letters A to D and having the names: Dokuhak, Derak, Sabzpushan, and Chamran, respectively. Study area and location of each water well are shown in Fig. 1. Data was collected for a 5 year periods from 2011 to 2015. All the parameters were measured according to Standard Methods for Examination of Water and Wastewater [27]. ANOVA test (Univariable repeated measure test) was first applied for statistical analysis of water quality trend in the 5-year period and after that pairwise comparison between each two years was run through post-hoc analysis using SPSS software ver.21.

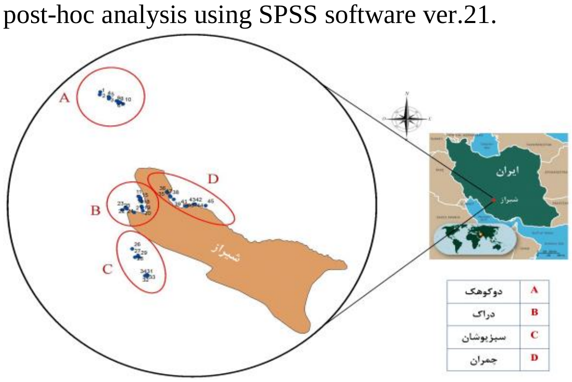

Fig. 1. Study area and drinking water wells' locations

RESULTS

The annual and long terms NSFWQI are provided in Table 3. As can be seen in this table, in 2011, 2012, 2013, 2014, and 2015, wells No. 25 (WQI= 87), 14 and 25 (WQI= 87), 25 (WQI= 89), 11 (WQI= 88), and 25 (WQI=88) had the highest WQI, respectively. In these years wells No. 45 (WQI=78), 43 and 45 (WQI= 78), 42 and 45 (WQI = 78), 41 (WQI = 77), and 42 and 45 (WQI = 78) had the lowest WQI values, respectively. For each well, long term (5-year) status of water quality determined by calculating the average of annual WQI values and results are shown in Table 3. The highest and the lowest long- term WQI (87.2 and 78) belonged to wells No. 25 and 45, respectively. Quality group trend through the study years is shown in Fig. 2.

Table 3: Annual and long- term NSFWQI in drinking water wells

Well No.	Zone	NSFWQI					
		2011	2012	2013	2014	2015	5- year average
1	A (Dokuhak)	85	85	85	85	85	85.0
2		83	83	83	83	83	83.0
3		83	83	83	83	83	83.0
4		83	83	83	83	83	83.0
5		84	85	84	84	84	84.2
6		84	83	84	83	84	83.6
7		83	83	83	83	83	83.0
8		83	83	83	82	83	82.6
9		83	84	84	83	83	83.6
10		86	85	85	85	86	85.4
11	B (Derak)	86	87	88	87	86	86.8
12		85	86	86	86	85	85.8
13		85	84	86	84	85	85.0
14		87	86	87	83	87	85.6
15		86	87	85	86	86	85.6
16		83	83	83	83	83	82.8
17		80	80	81	79	80	80.0
18		85	86	86	85	85	85.6
19		82	81	82	80	82	81.6
20		81	80	82	81	81	80.8
21		83	82	80	79	83	80.6
22		81	82	81	79	81	80.4
23		83	86	85	83	83	84.4
24		85	87	85	86	85	85.6
25		87	89	85	88	87	87.2
26	C (Sabzpushan)	82	82	81	81	82	81.6
27		81	80	80	80	81	80.4
28		82	82	82	82	82	82.0
29		83	84	83	83	83	83.2
30		82	82	83	81	82	82.0
31		82	82	82	82	82	82.0
32		83	83	81	83	83	82.6
33		81	83	82	81	81	81.6
34		83	82	86	82	83	83.2
35	D (Chamran)	81	80	82	80	81	80.8
36		82	82	86	81	82	82.6
37		82	82	87	82	82	83.0
38		82	81	81	81	82	81.2
39		80	79	79	79	80	79.6
40		80	80	85	80	80	81.0
41		81	79	77	80	81	79.4
42		81	78	78	78	81	79.0
43		78	80	80	79	78	79.2
44		80	80	78	80	80	79.4
45		78	78	78	78	78	78.0

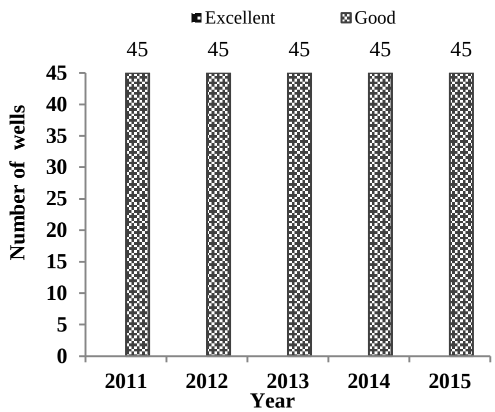

Fig. 2: Water quality classification trend in studied wells (2011-2015)

Table 4: Post-hoc analysis of annual changes in NSFWQI in ANOVA test

Year		Mean difference	SD	Sig
2011	2012	-0.178	0.150	p-value > 0.050
	2013	-0.222	0.185	p-value > 0.050
	2014	-0.400	0.249	p-value > 0.050
	2015	0.356	0.150	p-value < 0.050
2012	2011	0.178	0.150	p-value > 0.050
	2013	-0.044	0.171	p-value > 0.050
	2014	-0.222	0.271	p-value > 0.050
	2015	0.533	0.167	p-value < 0.020
2013	2011	0.222	0.185	p-value > 0.050
	2012	0.044	0.171	p-value > 0.050
	2014	-0.178	0.270	p-value > 0.050
	2015	0.578	0.144	p-value < 0.001
2014	2011	0.400	0249	p-value > 0.050
	2012	0.222	0.271	p-value > 0.050
	2013	0.178	0.270	p-value > 0.050
	2015	0.756	0.272	p-value < 0.020
2015	2011	-0.356	0.150	p-value < 0.050
	2012	-0.533	0.167	p-value < 0.020
	2013	-0.578	0.144	p-value < 0.001
	2014	-0.756	0.272	p-value < 0.020

DISCUSSION

According to the findings, the best annual water quality in 2011, 2012, 2013, 2014 and 2015 belonged to wells No. 25, 14 and 25, 25, 11, and 25, respectively. Since these two wells are located in Derak zone, this region had the best water quality compared to other zones. The lowest water quality belonged to wells No. 45, 43 and 45, 42 and 45, 41, 42 and 45, respectively. Since these wells are all located in Chamran zone, this region had the lowest water quality compared to other zones. In Chamran zone, NSFWQI was about 10 units lower compared to Derak zone. The pattern of quality change in individual wells were different in the way that in wells No. 1, 2, 3, 4, 7, 28, 31 and 45 the water quality remained completely unchanged, and in other ones simultaneous increase or decrease were seen. Yearly average of NSFWQI for all studied wells in 2011, 2012, 2013, 2014 and 2015 was 82.48, 82.66, 82.71, 82.88, and 82.13, respectively. Comparing the average WQI values in the four zones, they showed different patterns of changing so that, in zone A, B, and C almost constant trends have been observed while zone D fluctuated over the time in the way that it had minor decrease in 2012 and 2014 and minor increase in 2013 and 2015. According to the different location of wells and different kind of geological layers and the level of human activities, the effect of these factors on water quality changes in wells, were different compared to each other. Therefore, during a 5-year period, water quality changes were occurred in all four regions, but water quality changes of each well during this period were about 1 to 3 units. Despite 1-10 unit differences in annual NSFWQI, they did not cause any changes in quality classifications. According to Fig. 2 and Table 2, it can be seen that water quality of all wells was reported to be "good", and the factor of time does not create any change in the linguistic classification of water. Yisa *et al*., [23], in 2010 found that the quality of groundwater resources in the Maikunkele region in Nigeria using NSFWQI was in the range of "bad" to "moderate" and is not suitable for dinking. However, according to Fig. 2, all wells in the whole study years were classified in the "good" group and no change was seen. Therefore water quality classes were completely different from their study and groundwater quality in Shiraz is considered to be better than Maikunkele region for drinking purposes. Karimi and Sabouri, [17], 2016 using IRWQI for groundwater quality assessments in Shiraz, found that during the same period as present study (2011 to 2015), about half of the wells were rated as "very good" to "relatively good", and the remaining wells were rated as "relatively bad". The wells that were rated as "relatively bad" had a high level of Total Solids. The results of the two studies somehow are in agreement with each other in terms of the effective factors in water quality decrease, so that in both studies Total Solids is commonly considered as the factor causing spatial changes in water quality. However, the linguistic classification resulting from their study showed different qualitative ratings with that of the present study. This difference is mainly because of the structural differences of IRWQI and NSFWQI, such as weighting factors of parameters and their functional curves.

According to AVOVA test, in overall, NSFWQI showed a significant difference in water quality in the whole study period (p-value < 0.02). But each year, separately (Table 4), in 2012 and 2015, 2013 and 2015 (the most significant), and 2014 and 2015 water quality changes was statistically significant. Between the two years 2013 and 2015 the highest difference of WQI value was between well No. 25 in 2013 and well No. 45 in 2015 which was equal to 11 units. Investigating the concentration of parameters in these two years showed that NO_3, TS, PO_4, DO and temperature deviation caused these differences. Given that about 50% of Shiraz population hasn't been under coverage of sewer systems and those citizens are using cesspools, parameters causing these changes showed that during the last two years of the study, these wells were predominantly under the influence of human activities. Dhok *et al*., [24], in 2011 found that according to NSFWQI, water quality was influenced by anthropological activities. The reason for declining the groundwater quality was exactly the same in the current study and that of Dhok *et al*. But it should be noticed that among those parameters only the temperature deviation was higher than the standard level while others were observed in lower levels than the maximum standards.

Hassani *et al*., [22], in 2012 evaluated the groundwater quality in Yazd, Iran using NSFWQI. Their findings showed that the highest and the lowest values of NSFWQI in samples were 60 and 25, respectively. They found that although the measured concentration of parameters in samples were lower than the standard limits, the water quality was not proper for drinking. Investigating temporal changes of NSFWQI in their studies showed that the difference among the highest and lowest index values during the study period was 45 units which showed a very severe change. So the difference between maximum and minimum number of WQI was much more than that observed in the present study which was 11 units. Also the water quality condition in Shiraz city seems to be much better than in Yazd city and much more suitable for drinking.

Long term water quality evaluation showed that Derak and Chamran had the highest and the lowest water quality, respectively. Mean difference in 5 year indexes in these two wells was 9.2, but despite this difference, wells No. 25 and 45 were classified in "good" quality group.

CONCLUSION

This study investigated the drinking water quality trends in Shiraz, Iran by using NSFWQI as a well-known WQI. Water quality evaluation was conducted for 5 years, and the role of time in the water quality trend was analyzed, statistically. This study showed that groundwater quality in this city is suitable for drinking. But in terminal years of study, increased concentration of some parameters which are likely to be originated from anthropological activities led to a partial decrease in water quality in some wells. Although the measured concentrations of those parameters were all below the standard level and acceptable ranges, these significant differences are considered as a warning for the soon future. Therefore it makes sense to accelerate the development of sewer systems and manage uncontrolled population growth in the city to prevent further pollution of this valuable resource. To sum up, the results of this study can be used in the comprehensive monitoring program for drinking water quality management and making wright decisions in the way of future development of this city.

ETHICAL ISSUES

Ethical issues such as plagiarism have been considered by the authors.

CONFLICT OF INTEREST

There is no conflict of interest for any of the authors

AUTHORS' CONTRIBUTION

In this article M. A. Baghapour was the supervisor of the study and M. R. Shooshtarian collected and analyzed the data, prepared the article, and was the corresponding author.

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