

Evaluation of Groundwater Quality Using Groundwater Quality Index (GWQI) in Sharjah, UAE

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Abstract. The rapid growth in the world population resulted in an increase of the freshwater needs in many sectors. Groundwater is the most important freshwater source specially for arid and semi-arid regions due to lack of surface water sources and low precipitation rates in those regions. In this study, monthly groundwater quality data were collected from eleven well fields in Sharjah over the period of 2004-2017. Water quality parameters including bicarbonate, calcium, chloride, fluoride, magnesium, sodium and sulphate were selected for the analysis. In the study, water quality index (WQI) process is used to develop groundwater quality index (GWQI) for Sharjah using above mentioned water quality parameters. Mann-Kendall and Spearman's Rho tests were adopted as non-parametric trend tests for temporal (trend) analysis of GWQI, whereas inverse distance weighting interpolation was used in GWQI spatial trend analysis. Temporal trend analysis results showed significant trends in 8 out of 11 well fields. Spatial analysis showed the highest values for salinity ions in the well fields closest to the northern region, whereas the lowest values were detected in the southern region.

1 Introduction

The rapid growth in the world population resulted in an increase of the freshwater needs in many sectors [1]. Groundwater is the most important freshwater source specially for arid and semi-arid regions due to lack of surface water sources and low precipitation rates in those regions. Around 25% to 40% of the drinking water in the world is extracted from groundwater [2].

Groundwater is a renewable source that can be recharged naturally by precipitation [3]. It is more desired choice for many purposes compared to surface water due to the existence of dissolved minerals in groundwater combined with some of its special characteristics [4]. Groundwater is in general in good quality and less prone to seasonal variations [5].

Groundwater can be affected by many factors such as the increase of the irrigation activities, industrialization and urbanization [6]. Due to increase of industrial freshwater needs along with the use of synthetic fertilizers, pesticides and insecticides for agriculture production can cause serious concerns regarding the groundwater contaminations [7]. In addition, lack of management of the groundwater use that can lead issues such as sea water intrusion [8], human health and plant growth problems [9]. It also effects the economic development and social prosperity [2]. In many cases, groundwater contamination is irreversible and stopping the source of pollutants will not restore its quality [10]. In many countries, bad drinking water quality can lead to serious and dangerous illness that would be major cause of death [1].

Considering above-explained importance of the groundwater, it is important to have an effective and sustainable groundwater management to keep groundwater sufficient (in terms of quality and quantity) for the present use and the future [11]. Groundwater monitoring is an essential component of effective groundwater management. In groundwater monitoring, water quality index (WQI) is widely used. The WQI is outcome of a rating process to provide an overall representation of the groundwater quality using water quality parameters. This technique is used to decrease the large amount of water quality parameters in a single numerical value to assess groundwater quality status [12].

The WQI is a method to explain the water quality in a single dimensionless number and it can be established by aggregating the measurements of a selected water quality parameters [13]. The WQI studies started in 1965 [14]. After that, many researchers and organizations started to develop and modify WQIs (e.g., [15-18]). WQI has become significant and widely used method for water quality monitoring to assess the water quality for different purposes due to its simplicity. WQI transforms all the selected water quality parameters into a single numerical number that can represent the overall quality of different water bodies while taking into consideration the contribution of each parameter. A WQI can be adopted to compare the water quality of different locations and water bodies without referring to statistical assessment for water quality data [17,19]. It is very useful tool for decision making for the water authorities [20-22]. Due to its several advantages, the WQI has been adopted by many

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organizations and agencies throughout the world (e.g., [5, 15, 17, 18, 23, 24]).

Several studies developed WQIs for different purposes over different geographical locations. However, there is no study in the literature for a WQI to assess groundwater quality in UAE. Therefore, this research aims to develop a groundwater quality index (GWQI) for Sharjah, UAE to assess the groundwater quality for domestic use. In this study, The GWQI is developed and applied spatially around the study area, and critical points in terms of groundwater quality are identified.

2 Study Area

The study area, Emirate of Sharjah, UAE is located along the northern coast of the Persian Gulf on the Arabian Peninsula with a central coordinate of 25.3° N 55.5° E, approximately 166 km Northeast of the city of Abu Dhabi. Sharjah covers an area of about 2,590 km². Sharjah is considered as an arid region where the average annual rainfall is about 100 mm/year. The average daily capacity and production of groundwater is 21.5 and 15.46 million gallons respectively. Most of the extracted groundwater is used for irrigation purposes [25].

There are 11 well fields that have been taken into consideration for this study (Sadia, Tawi Awaid, Badai, Falah, Ghoreefa, Hamdah, Madam, Mohadab, Seih Aqareb, Seih Harmal and Wahoosh) which are displayed in the Figure 1. The well fields are approximately evenly distributed between the coastline and the mountainous region of Sharjah. Monthly groundwater quality data from the well-fields over the period of 2004-2017 were employed in this study.

Based on availability of data and number of samples from the well fields, water quality parameters including bicarbonate (HCO₃⁻), calcium (Ca), chloride (Cl⁻), fluoride (F), magnesium (Mg), sodium (Na) and sulphate (SO₄⁻) were selected for analysis.

3 Methodology

3.1 Temporal trend analysis

3.1.1 Mann-Kendall (MK)

The MK test is a non-parametric test and used in several trend analysis studies [26-34]. The z-statistics for this test can be calculated by:

$$z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases} \quad (1)$$

The S value can be computed by:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \quad (2)$$

where $x_j - x_k$ are the sequential data values, and n is the number of data. sgn can be found by:

$$\text{sgn}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases} \quad (3)$$

The Var(S) can be calculated using:

$$\text{Var}(S) = \frac{n(n-1)(2n+5)}{18} \quad (4)$$

In this test, the positive test statistic shows that there is an increasing trend, whereas the negative test statistic shows that there is decreasing trend. The null hypothesis (H₀) of the MK test is “There is no trend”. If the calculated z statistics is larger than critical values that are derived from normal distribution tables at specific significance levels (i.e., 0.1, 0.05, 0.01 significance levels), then H₀ is rejected, and the alternative hypothesis H_A, which is “there is a trend”, is accepted [31].

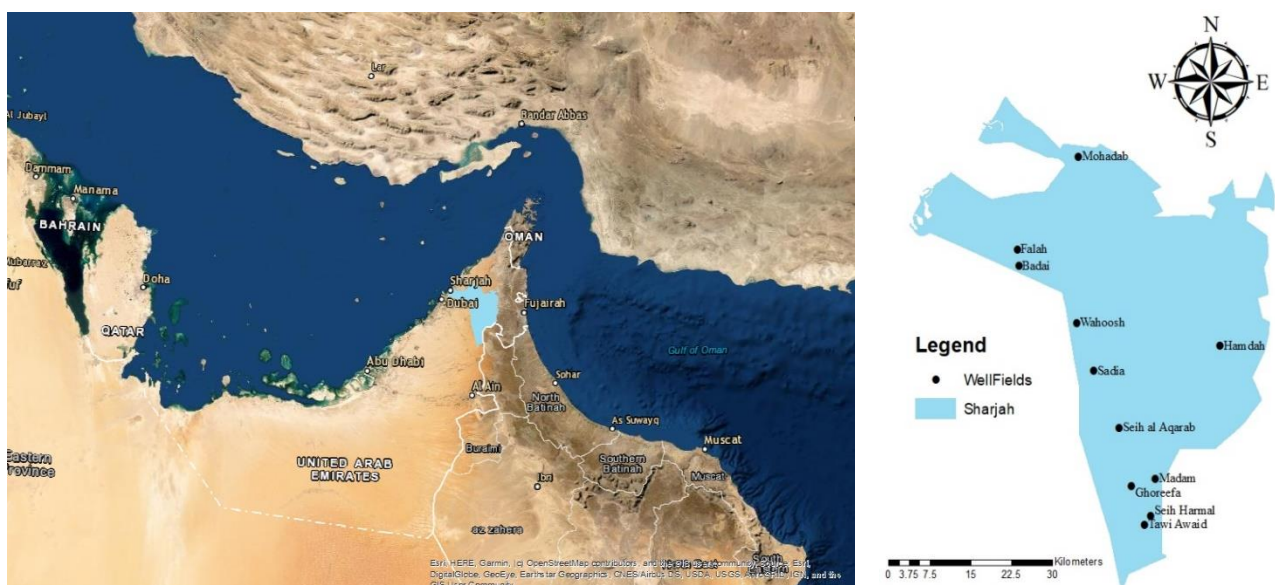


Fig. 1. Study area and location of the wellfields.

3.1.2 Spearman's Rho (SR)

The SR test is a rank-based test that is used to find the correlation between two variables is significant. One variable is considered as the time itself in the SR test, while the other variable is the equivalent time series data. The time series values are replaced with their ranks, and the SR test statistic ρ_s is calculated as shown:

$$\rho_s = \frac{s_{xy}}{(s_x s_y)^{0.5}} \quad (5)$$

Where:

$$s_x = \sum_{i=1}^n (X_i - \bar{X})^2 \quad (6)$$

$$s_y = \sum_{i=1}^n (Y_i - \bar{Y})^2 \quad (7)$$

$$s_{xy} = \sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y}) \quad (8)$$

The z statistic can be computed by:

$$z = \rho_s (n - 1)^{0.5} \quad (9)$$

In these equations, X_i corresponds to the time, Y_i is the variable of interest, \bar{X} and \bar{Y} refer to the average values of X_i and Y_i . Null and alternative hypothesis of the SR test are the same as the MK test, furthermore the procedure of the SR test to determine whether there is a trend is same as that of the MK test [31].

3.2 Spatial analysis

Spatial analysis is the analysis of data over an area. The Inverse Distance Weighting interpolation (IDW) method is used for spatial analysis [32]. The IDW is simple and easy to use. It basically assumes the unknown value in a certain point by approximating a weighted average of values at point within a certain limit of distance. The math behind IDW is that the weights are inversely proportional to a power of distance. Eq. 10 represents the calculation for IDW.

$$X_p = \frac{\sum_{i=1}^n \left(\frac{X_i}{d_i^p} \right)}{\sum_{i=1}^n \left(\frac{1}{d_i^p} \right)} \quad (10)$$

Where X_p is the unknown value point, X_i the value of a close point, d_i is the distance between the unknown and known point and p is a parameter that represents the power.

3.3 Groundwater quality index

Water quality index (WQI) process is used to develop groundwater quality index (GWQI) for Sharjah. GWQI is outcome of a rating process to provide an overall representation of the groundwater quality using water quality parameters. This technique is used to decrease the large amount of water quality parameters in a single numerical value to assess groundwater quality status. This

method has been used in many groundwater analysis studies [35-40] In general, there are 3 main steps required to develop the WQI. These steps are assigning weights, calculating rating scale and aggregation of sub-indices to produce the final index. Details of the steps are explained in the following sections.

3.3.1 Establishing weights

In this step, weights for each parameter will be assigned depending on their importance and significance on the final index. Weights in general can be equal and unequal. Equal weights are assigned to the parameters when the parameters have equal importance. Whereas unequal weights are assigned to parameters when the parameters have more or less importance than others. It is worth to mention that equal weights are used when the index developers have doubts in the subjectivity of the experts' opinions in reaching convergence. Furthermore, using different weights can show sensitivity in the final index towards heavily weighted parameter. This application is very important in some specific uses such as the aquatic life. In this study, weights are assigned to the selected parameters according to importance on the groundwater quality for domestic use. The relative weight W_i can be found by the following equation:

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i} \quad (11)$$

Where W_i is the relative weight for each parameter, w_i is the weight assigned for each parameter and n is the number of parameters selected.

3.3.2 Rating scale

The second step in the water quality index is calculating the rating scale. The objective of this step is to transform all the selected parameters into common scale since the parameters in general have different units. Furthermore, the ranges of the parameters can differ from one to another from the same unit. Due to these reasons, this step is very important to proceed in establishing the water quality index. In this study, the rating scale was calculated depending on the permissible limits from a legal standard from the Abu Dhabi Water Quality Regulations (ADWQR). The use water quality standards facilitate subdivision of rating scale values which gives more information to the users (House, 1986). In this method, the critical points which are used to develop the rating scale can be found by using the permissible limits for domestic use. The following equation is used to develop the sub-index value in this method:

$$R_i = \left(\frac{x_i}{x_{pl}} \right) \times 100 \quad (12)$$

Where R_i is the rating scale value, x_i is the actual parameter value and x_{pl} is the permissible limit value.

3.3.3 Aggregation of sub-index

After assigning weights and calculating the rating scales of every parameter, aggregation of sub-indices with their weights is the final step to generate the final GWQI. In this study, arithmetic with un-equal weights approach has been used for sub-index aggregation. This method is simple and commonly used among the WQIs developers. The final index value can be calculated by the following equations:

$$SI_i = W_i R_i \quad (13)$$

$$GWQI = \sum SI_i \quad (14)$$

Where SI_i is the sub-index value and W_i is the relative weight of each parameter and the total weights for all the parameter is equal to 1. The sub-index interpretation will be divided into different classification which are shown in Table 1.

Table 1. Water quality classifications as determined by the final aggregated index.

Final aggregated GWQI	Water quality classification
< 50	Excellent
50-100	Good
100-200	Poor
200-300	Very poor
> 300	Water unsuitable for domestic purpose

As shown in Table 1, low GWQI values represent good groundwater quality, whereas high GWQI values represent bad groundwater quality.

4 RESULTS and discussion

Table 2 shows simple statistics (average, maximum and minimum) for all the selected parameters along with their ADWQR permissible limits and relative weights.

It can be seen from Table 2 that bicarbonate values ranged between 78 and 196 mg/L with an average of 116 mg/L, the permissible limit for bicarbonate is 300 mg/L. The weight assigned for bicarbonate was 3 and the relative weight was found to be 0.12. Calcium values ranged between 14 and 131 mg/L with an average of 50 mg/L, the permissible limit for calcium is 80 mg/L. The weight assigned for calcium was 2 and the relative weight was found to be 0.08. Chloride values ranged between 100 and 1258 mg/L with an average of 506 mg/L, the permissible limit for chloride is 250 mg/L. The weight assigned for chloride was 5 and the relative weight was found to be 0.19. Fluoride values ranged between 0.1 and 1.1 mg/L with an average of 0.5 mg/L, the permissible limit for fluoride is 1.5 mg/L. The weight assigned for fluoride was 5 and the relative weight was found to be 0.19. Magnesium values ranged between 17. and 135 mg/L with an average of 53 mg/L, the permissible limit for magnesium is 30 mg/L. The weight assigned for magnesium was 2 and the relative weight was found to be 0.08. Sodium values ranged between 80 and 804 mg/L with an average of 346 mg/L, the permissible limit for sodium is 150 mg/L. The weight assigned for sodium was 4 and the relative weight was found to be 0.15. Sulphate values ranged between 58 and 1103 mg/L with an average of 277 mg/L, the permissible limit for sulphate is 250 mg/L. The weight assigned for sulphate was 5 and the relative weight was found to be 0.19.

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Table 2. Descriptive statistics and permissible limits of water quality parameters.

	Avg	Max	Min	ADWQ R	Wei ght	Relati ve weight
Bicarbonate (mg/L)	116.9	196.5	78.5	300	3	0.12
Calcium (mg/L)	50.4	131.2	14.0	80	2	0.08
Chloride (mg/L)	506.3	1258.0	99.6	250	5	0.19
Fluoride (mg/L)	0.5	1.1	0.1	1.5	5	0.19
Magnesium (mg/L)	53.6	135.6	17.1	30	2	0.08
Sodium (mg/L)	346.3	804.9	80.5	150	4	0.15
Sulphate (mg/L)	277.0	1103.3	58.3	250	5	0.19
					26	1

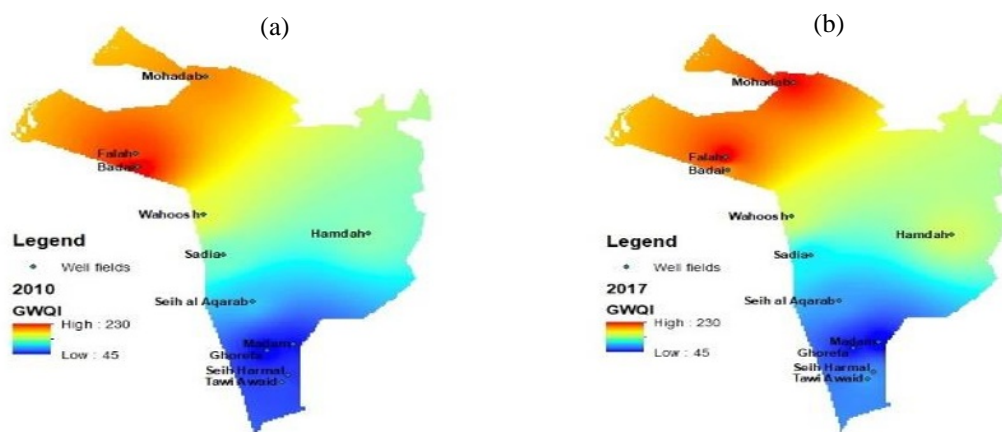


Fig. 2. GWQI Map (a) in 2010 (b) in 2017

4.1 Temporal trend analysis

Table 3 showed GWQI trend analysis results for MK and SR tests. Significance level of the trends (if there is a statistically significant trend) are shown in parentheses.

Table 3. MK and SR results

	MK	SR
Badai	-2.351 (0.05)	-2.4 (0.05)
Falah	-1.675 (0.05)	-1.971 (0.05)
Ghoreefa	4.003 (0.01)	3.782 (0.01)
Hamdah	0.356	0.051
Madam	-0.616	-0.518
Mohadab	-0.755	-0.807
Sadia	-2.452 (0.05)	-2.819 (0.01)
Seih Aqarab	-3.545 (0.01)	-3.48 (0.01)
Seih Harmal	1.97 (0.05)	1.945 (0.10)
Tawi Awaid	3.211 (0.01)	3.008 (0.01)
Wahoosh	-3.433 (0.01)	-3.305 (0.01)

As can be seen from Table 3, there are increasing GWQI trends in Ghoreefa, Hamdah, Seih Harmal and Tawi Awaid well fields. Among those, increasing trends in Ghoreefa, Seih Harmal and Tawi Awaid are statistically significant. Decreasing GWQI trends were detected in Badai, Falah, Madam, Mohadab, Sadia, Seih Aqarab and Wahoosh well fields. Among these trends, decreasing trends in Badai, Falah, Seih Aqarab, Wahoosh and Sadia showed statistically significant trends as shown in Table 3.

4.2 Spatial analysis

It can be seen from Figure 2 that the GWQI values show large variation over the region. There is a clear pattern change from south to north. Figure 2 indicates that the southern part of the study has the best GWQI results. In the southern region, GWQI went up to 45 corresponding to excellent quality. The GWQI values increase towards the northern part of the study area showing the worst values at the far northern side. In Figure 2, part (a) shows values of GWQI in 2010 and part (b) shows values of GWQI in 2017. There is a slight change in the GWQI over 2010-2017 based on comparison of Figure 2 (a) and (b). The change can be recognized mainly in the southern part of the study area indicating a slight increase in the overall GWQI. Since the selected parameters are all related to salinity, it can be stated that the main problem in northern part of the study area is groundwater salinity.

5 Conclusion

In this study, seven water quality parameters taken from eleven wellfields were used to develop a GWQI. Trend analysis of GWQI was conducted using MK and SR tests. Spatial analysis was carried out using inversed distance weighting method and different groundwater quality

index maps were generated. The followings are major conclusions of this study:

- Significant increasing GWQI trends were found in Ghoreefa, Seih Harmal and Tawi al Awaid meaning deterioration of groundwater quality.
- Significant decreasing GWQI trends were found in Badai, Falah, Sadia, Seih Aqarab and Wahoosh.
- Generated GWQI map showed that the best groundwater quality (lower GWQI values) was found in the southern side of the study area. On the other hand, the worst groundwater quality (higher GWQI values) was identified in the northern part of the study area.
- Spatial analysis of the GWQI showed that GWQI values has increased over time which means the quality of groundwater is decreasing.
- The groundwater aquifer is mostly facing the issue of salinity.
- It is important to mention that in the southern part of the study area, trend analysis showed an increasing trend in GWQI (which means that the groundwater quality is getting worse) in most of the well fields, but in spatial analysis, the southern part showed the best GWQI values. For the northern part, trend analysis showed decreasing trend in GWQI (which means that the groundwater quality is getting better) in most of the well fields, but in spatial analysis it showed the worst values.

This study is expected to provide useful information for the decision makers of groundwater management authorities. It is shown in this study that groundwater salinity is an important problem in Sharjah requiring a quick and effective action.

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