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RESEARCH ARTICLE

EVALUATION OF WATER QUALITY BY USING CORRELATION COEFFICIENT AND WATER QUALITY INDEX IN SHARURAH GOVERNORATE, SAUDI ARABIA

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Abstract

This study is the first to be conducted in Sharurah governorate, Saudi Arabia, on groundwater. In this study, correlation analysis and water quality index WQI were used to analyze thirty data points of groundwater in some fields (15wells) in Sharurah city and its outskirts. The correlation analysis utilized the correlation coefficient to study the relationship between different physicochemical parameters such as Hydrogen ion concentration (pH), electrical conductivity (EC), turbidity ($Turb$), total dissolved solids (TDS), total hardness (TH), chloride (Cl^-), sulfate (SO_4^{2-}), fluoride (F^-), total iron (Fe) nitrite (NO_2^-) and nitrate (NO_3^-), of groundwater at studied wells for Sharurah city. On the other hand, water quality index provides a useful tool for monitoring of water quality, it uses the values of different water parameters in a mathematical equation to produce a value that rates water quality, and determines the suitability of water for drinking. The study came out with the results that there are several statistically significant correlations between water parameters. Whereas water quality index WQI result reflects that 80% of the samples are of excellent and good quality.

Keywords: Water quality parameters, Correlation coefficient, Water quality index, Sharurah governorate, Saudi Arabia.

1. Introduction

Water is a chemical substance that is composed of hydrogen and oxygen and is a ubiquitous in life [1]. Approximately 71% of the Earth's surface is covered by water, mostly in seas and oceans [2]. Seas and oceans hold about 97 % of surface water, groundwater 1.7%, glaciers and the ice caps 1.7 %, and other land surface water such as rivers, lakes and ponds 0.6% [3]. Water resources are limited and non-renewable in Saudi Arabia, which is an arid, and the largest country in the Middle East. Most of the people worldwide use groundwater for various purposes such as agriculture, household, industrial, recreational and environmental activities [4]. Water is the most important natural resource because it is renewable but not replaceable [4, 5].

The sedimentary rock formations that store water in the Kingdom are classified into major reservoirs (Al-Saq, Tabuk, Al-Wajid, Al-Manjoor, Al-Bayyadh, Al-Wasee', Umm Radhuma, Dammam, and Al-Nyujin). Al-Wajid Formation is located in the center of the south of the Kingdom, and its exposure appears on the surface of the earth at a distance of 300 km south of Wadi Al-Dawasir, and its width does not exceed 100 km. Its eastern borders are unknown, but it is believed that it is located under the Empty Quarter Basin, and its confined part extends to the south, as it is located in the dug wells in Sharurah and Al-Wadi'ah in the south of the Empty Quarter [6].

Several studies were conducted on water quality in Saudi Arabia as [7-13].

In this study, correlation analysis will be used to investigate the groundwater of Sharurah Governorate – Saudi Arabia based on different water quality parameters.

1.1 Water Quality Index WQI

Water Quality Index WQI is defined as a reflection of composite influence of water quality parameters [14-16]. The objective of WQI is to transform the large and complex information of water quality data into a simplified and useable information by the public and legislative decision makers [17, 18]. Water quality monitoring has become a central issue of many national and international environmental organizations in different countries; to identify whether waters meet designated uses, and to identify specific pollutants and sources of pollution [19, 20]. Many studies have used various indices to predict the water quality of different regions for drinking and other uses [18, 21-26]. [27] have proposed a simple effective method to summarize the overall characters (physicochemical and biological) of water to produce a simple, stable, consistent, and repeatable index that could be used to assess water quality [28, 29].

2. Materials and Methods

2.1 Groundwater quality data

Sharurah is a city in Najran province, southern Saudi Arabia, approximately 200 miles east of the city of Najran (Figure 1). and the population of Sharurah is 170,000, based on 2022 Census.

Fig. 1: Sharurah Location in Saudi Arabia (https://www.nationsonline.org/oneworld/map/saudi-arabia-map.htm).

Sharurah is a desert region located in the southern part of Saudi Arabia. Groundwater in this region is the only source of drinking water. So, its suitability for drinking and household uses is of public and scientific concern. These samples of groundwater were collected from 15 wells with a depth exceed 1000 meters (two samples from each well at 6 months interval) from March 2016 to December 2017; and were analyzed at Najran water laboratories, Ministry of Water.

Water quality correlation analysis is one of the most effective tools for monitoring water quality. Little work has been done on assessing groundwater quality in Saudi Arabia, particularly in Najran. Therefore, this method is used for the first time to assess the quality of water in Sharurah which is called the Bride of the Desert of the Empty Quarter.

In this study, the samples were analyzed for eleven physicochemical parameters such as Hydrogen ion concentration (pH), electrical conductivity(EC), turbidity ($Turb$), total dissolved solids (TDS), total hardness (TH), chloride (Cl^-), sulfate(SO_4^{2-}), fluoride (F^-), total iron (Fe), nitrite (NO_2^-) and nitrate (NO_3^-).

2.2 Statistical and Correlation Analysis

Water quality data was summarized in table and graphical form using Microsoft Excel, and SPSS. Moreover, a comparison of groundwater quality with Saudi Arabia standards for groundwater was performed.

Correlation coefficient is a single summary number that measure how strong a relationship is between two variables. To obtain the relationship between two parameters x and y , the Karl Pearson's correlation coefficient R is calculated using the following equation [30-32]:

$$R = \frac{n\sum_{i=1}^{n}(x_i y_i) - (\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{\sqrt{\left[n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2\right]\left[n\sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2\right]}} \quad (1)$$

where n is the number of data points. If R is found between -1 and 1, this indicates a good correlation coefficient. If the value of correlation coefficient R between $x$and y is close to ±1, this means that these two variables are highly correlated. In such cases, it is suitable to use the linear equation shown below [31,32]:

$$y = ax + b \quad (2)$$

where 'a' is the slope and 'b' is the intercept. a and b are to be determined by fitting the experimental data on the variables x and y to equation (2). The values of the constants 'a' and 'b' are calculated from the following relations:

" a" is the slope and " b" is the intercept.

$$a = \frac{n\sum(xy) - \sum x \sum y}{n\sum(x^2) - (\sum x)^2} \quad (3)$$

and

$$b = \frac{\sum y - a\sum x}{n} \quad (4)$$

2.3 WQI Calculation

This study used the index proposed by [27] to assess the quality of the groundwater. Although, this method has been widely used by many researchers, it is considered to apply for the first time in studying the quality of groundwater in Sharurah Governorate – Saudi Arabia.

Relying on several water quality parameters, we can obtain a single number, which characterizes the overall quality of the water. To calculate the , eleven parameters such as: pH , EC , $Turb$, TDS , TH , Cl^- , SO_4^{2-} , F^- , Fe , NO_2^- and NO_3^- have been used. WQI was computed by using the following three steps [23, 24, 33-35]:

First step: quality rating Q_i of i^{th} parameter for a total of n water quality parameters is computed for each of the parameters by using the following expression:

$$Q_i = \frac{M_i - I_i}{S_i - I_i} \times 100 \quad (5)$$

where:

M_i is the monitored value of the water quality parameter obtained from laboratory analysis.

I_i is the ideal value of that water quality parameter, I_i for pH is 7 but for other parameters equals zero.

V_{standard} is the standard of the water quality parameters.

Second step: the relative (unit) weight W_i for each water quality parameter was determined by using the following formula:

$$W_i = \frac{K}{S_i} \quad (6)$$

where $S_i V_{\text{actual}}$ is the standard permissible value for nth parameter, K is the proportionality constant, which can be calculated by using the following formula:

$$K = \frac{1}{\sum\left(\frac{1}{S_i}\right)} \quad (7)$$

Here the value of K is considered 1 [36].

In the final step, the overall Water Quality index WQI calculated by using the following formula:

$$WQI = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i} \quad (8)$$

3. Results and Discussions

3.1 Statistical analysis

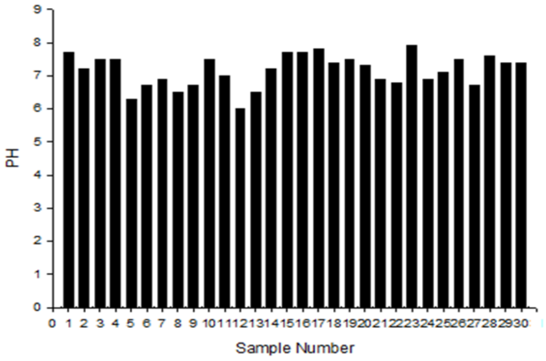
Descriptive statistics of the physicochemical parameters for the collected groundwater samples were presented in Table 1, where the parameters were compared to the Saudi groundwater standards [37, 38]. Figure 2, represents a line plot for the studied groundwater samples, with a dotted line representing the desirable limits. The results showed that all samples have complied with the standards for electrical conductivityEC, total dissolved solids TDS, Total Hardness TH, Sulfate SO_4^{2-} , Fluoride F^-, Nitrite NO_2^-, and Nitrate NO_3^-.

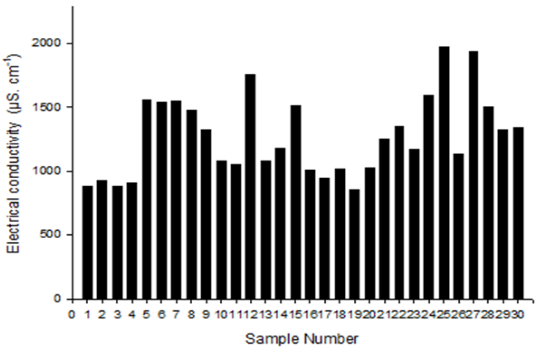
The pH value of groundwater samples indicated their slightly acidic to moderately alkaline nature (pH ranged from 6 to 7.9), with 93.3% of the sample fell within the desirable limits. Total dissolved solids TDS indicated the salinity behavior of groundwater. TDS values of the studied samples varied from 427 to $880 mg.L^{-1}$, and fell within the desirable limits. However, with a mean value of $625 mg.L^{-1}$, Figure 2(d) showed that most of the studied samples exceeded the desirable limit for drinking water supplies (<500 $mg.L^{-1}$) cited by [39].

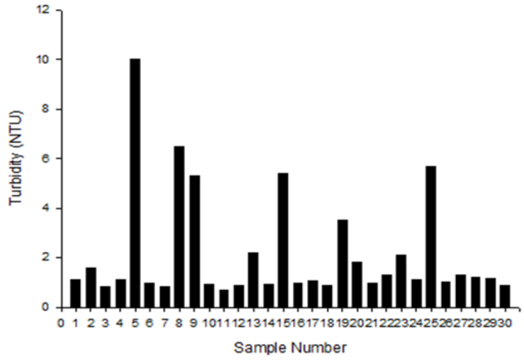
Chlorides are common constituents of all natural water. The measurable concentrations of Cl^- were in the range of $100 - 300 mg.L^{-1}$, and about 7% of samples exceeded the maximum limits as per [37]. Turbidity is the measure of relative clarity of a liquid, ranged from 0.7 to 10 NTU with almost 17% of the studied ground water samples exceeding the maximum limit recommended by [37]. High levels of iron in groundwater can serious problems to human health and affect water's taste. Iron concentration ranged from 0.04 to $0.3 mg.L^{-1}$, where more than 33% of the studied samples contained Fe concentration that exceeded the Saudi Arabian Standards Organization [37].

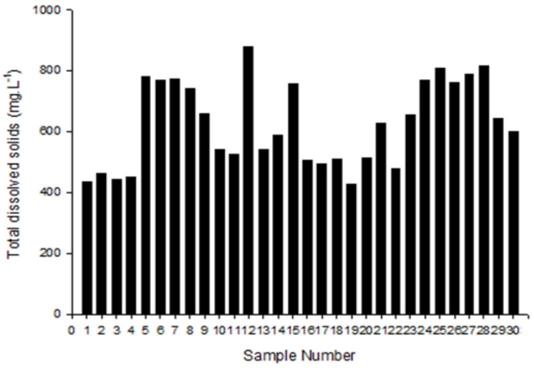
Table 1: Descriptive statistics and comparison of groundwater quality with Saudi Arabia groundwater standards [33, 34]

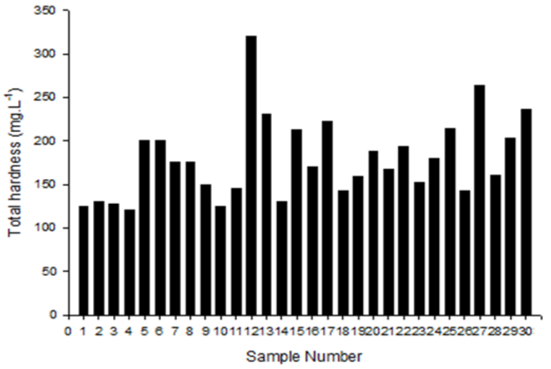
Parameter	Min.	Max.	Mean	SD	Maximum Permissible Value [33, 34]	Compliance Percent
pH	6	7.9	7.16	0.48	6.5-8.5	93.3 %
$Turb\ (NTU)$	0.7	10	2.14	2.22	5	83.3 %
$EC\ (\mu S\ \ cm^{-1})$	854	1977	1271.83	315.09	2500	100 %
$TDS\ (mg.L^{-1})$	427	880	625	141	1000	100 %
$TH\ (mg.L^{-1})$	120	320	178.67	46.31	500	100 %
$Cl^-\ (mg.L^{-1})$	100	300	178	53	250	93.3 %
$SO_4^{2-}\ (mg.L^{-1})$	45	198	111.43	45.45	250	100 %
$F^-\ (mg.L^{-1})$	0	0.72	0.23	0.20	1.5	100 %
$Fe\ (mg.L^{-1})$	0.04	1.53	0.32	0.33	0.3	66.7 %
$NO_2^-\ (mg.L^{-1})$	0	0.08	0.02	0.02	3	100 %
$NO_3^-\ (mg.L^{-1})$	0.1	7	3.25	1.58	50	100 %

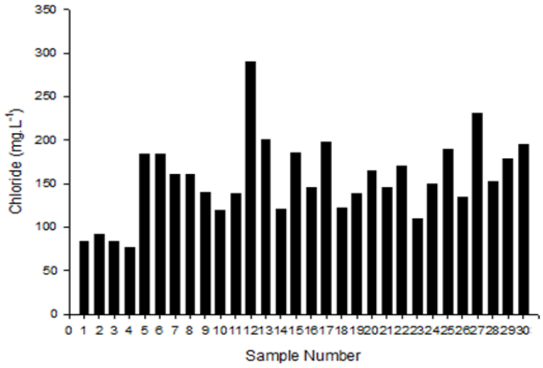

PH
Sample Number
(a)

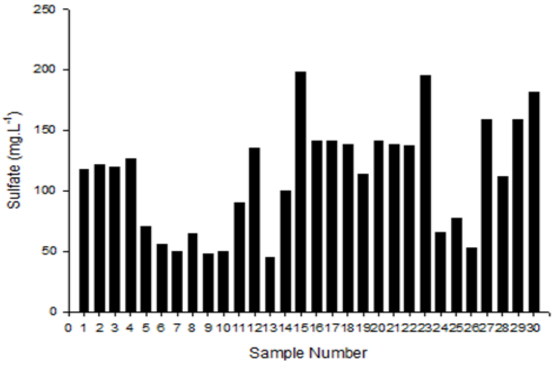

Electrical conductivity (µS. cm-1)
Sample Number
(b)

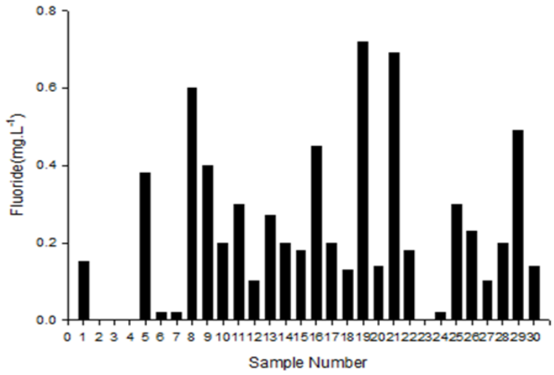

Turbidity (NTU)
Sample Number
(c)

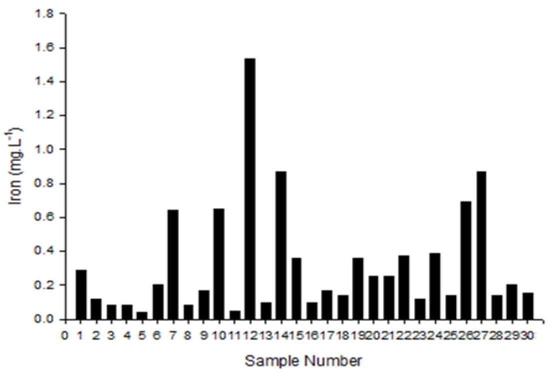

Total dissolved solids (mg.L-1)
Sample Number
(d)


Total hardness (mg.L-1)
Sample Number
(e)

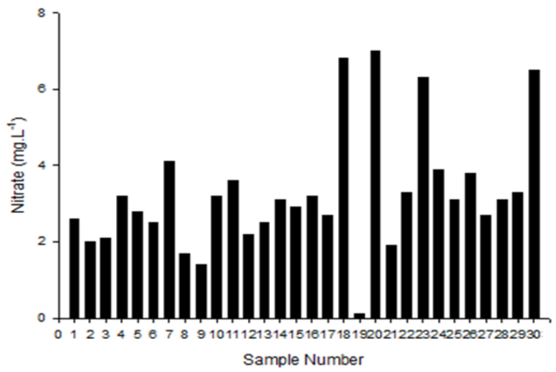

Chloride (mg.L-1)
Sample Number
(f)


Sulfate (mg.L-1)
Sample Number
(g)

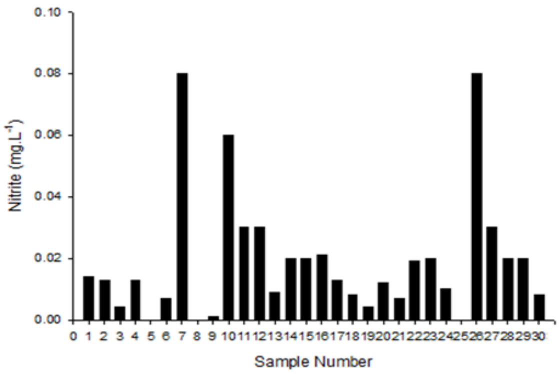

Fluoride(mg.L-1)
Sample Number
(h)



(i)



(k)



(j)

Fig. 2: Variation of (a) pH, (b) electrical conductivity, (c) turbidity, (d) total dissolved solids, (e) total hardness, (f) chloride, (g) sulfate, (h) fluoride, (i) total iron, (j) nitrite and (k) nitrate with groundwater samples.

Table 2: Pearson's Correlation Coefficient among groundwater parameters using SPSS (version 19).

Parameter	pH	$Turb$	EC	TDS	TH	Cl^-	SO_4^{2-}	F^-	Fe	NO_2^-	NO_3^-
pH	1										
$Turb$	-0.328	1									
EC	-0.557*	0.338	1								
TDS	-0.47*	0.324	0.888*	1							
TH	-0.508*	0.121	0.644*	0.52*	1						
Cl^-	-0.531*	0.351	0.792*	0.92*	0.48*	1					
SO_4^{2-}	0.452*	-0.206	-0.096	-0.2	0.224	-0.264	1				
F^-	-0.12	0.394*	-0.0493	-0.0435	-0.000516	0.0431	-0.102	1			
Fe	-0.324	-0.269	0.365*	0.395*	0.416*	0.463*	-0.0177	-0.182	1		
NO_2^-	0.114	-0.385*	0.0389	0.215	-0.0843	0.241	-0.218	-0.244	0.523*	1	
NO_3^-	0.296	-0.264	-0.0398	-0.0198	-0.00867	-0.0891	0.34	-0.444*	-0.108	0.16	1

* Correlation is significant at the 0.05 level

Correlation analysis of water parameters shows number of statistically significant correlations between several parameters. The strongest positive ($R = 0.92$) is observed between total dissolved solids TDS and ChlorideCl^- (Figure 3), and $R = 0.888$ between electrical conductivity EC and TDS (Figure 4), therefore high conductivity values of all samples reflect the amount of total dissolved solids TDSin groundwater. Moreover, a positive correlation was found $R = 0.792$ between EC and Cl^- (Figure 5), which indicates the strong relation between these three physiochemical groundwater parameters. The correlation coefficient between each pair of the studied parameters can be found in Table 2.

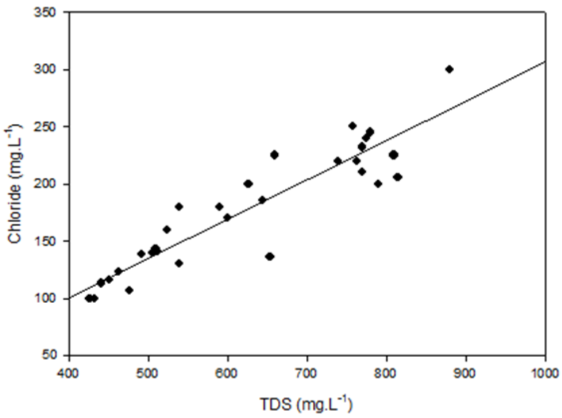


Fig. 3: Correlation between TDS and Cl^-

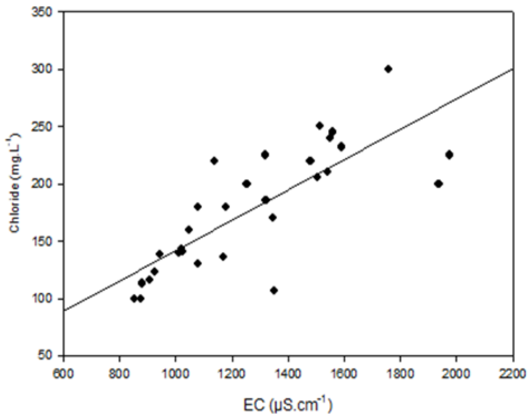


Fig. 5: Correlation between $EC$and Cl^-

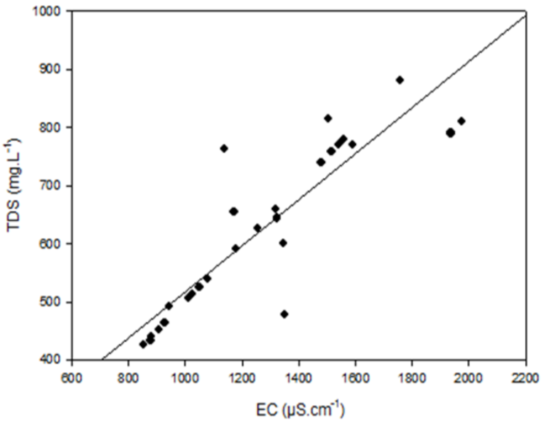


Fig. 4: Correlation between EC and TDS

3.2 Water Quality Index WQI

The water quality index of all samples taken was calculated according to the procedure explained previously in materials and methods (eq.5, eq.6 and eq.8). Values of *WQI* obtained for groundwater in the different 15 wells (30 samples) are shown in Table 3.

Figure 6 shows the statistical summary for water quality index WQI of groundwater samples. It can be seen that WQI values varied from 15.5to 366.75. The minimum value has been recorded from sample no. 11 while the maximum has been recorded from sample no. 12. The computed WQI values (Figure 7) are classified into five types "excellent water" to "water unsuitable for drinking" according to [24, 40] as shown in Table 4. The results show that more than half of water samples (53.33%) are excellent,26.67%are good water, and only 3.33% are unsuitable for drinking.

Table 3: Obtained *WQI* values of groundwater samples

Parameters	Observed Value V_{actual}	Standard value $V_{standard}$	Unit Weight W_i	Quality Rating Q_i	Q_iW_i
pH	7.5	8.5	0.1176	33.33	3.92
$Turb\ (NTU)$	0.85	5	0.2	17	3.40
$EC\ (\mu S\ cm^{-1})$	880	2500	0.0004	35.2	0.01
$TDS\ (mg.L^{-1})$	441	1000	0.001	44.1	0.04
$TH\ (mg.L^{-1})$	128	500	0.002	25.6	0.05
$Cl^-\ (mg.L^{-1})$	113	250	0.004	45.2	0.18
$SO_4^{2-}\ (mg.L^{-1})$	120	250	0.004	48	0.19
$F^-\ (mg.L^{-1})$	0	1.5	0.67	0	0
$Fe\ (mg.L^{-1})$	0.08	0.3	3.33	26.67	88.89
$NO_2^-\ (mg.L^{-1})$	0.004	3	0.33	0.13	0.04
$NO_3^-\ (mg.L^{-1})$	2.1	50	0.02	4.2	0.08
			$\sum_{i=1}^{n} W_i$=4.682		$\sum_{i=1}^{n} Q_iW_i$=96.82
Overall Water Quality Index WQI = $\frac{\sum_{i=1}^{n} Q_iW_i}{\sum_{i=1}^{n} W_i}$= 20.68					

It is observed that the majority of groundwater samples are good quality water, indicating that groundwater can be used for drinking purpose. Only six samples have poor water quality. The highest value of WQI obtained is due to the presence of iron in groundwater.

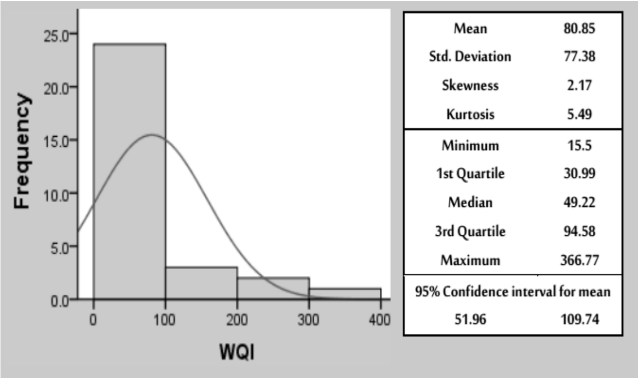


Fig. 6: Statistical summary for WQI of groundwater samples

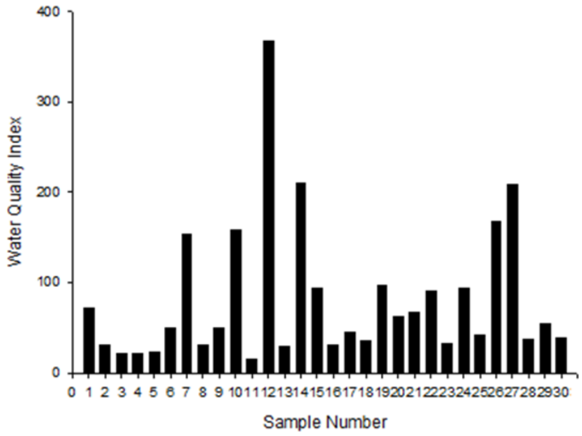


Fig. 7: Variation of water quality index in groundwater samples.

Table 4: Water quality classification based on WQI values (2016-2017)

Water Quality Index Level	Description	No. of samples	Percentage
< 50	Excellent	16	53.33 %
50 – 100	Good water	8	26.67 %
100 - 200	Poor water	3	10 %
200 - 300	Very poor (bad) water	2	6.67 %
> 300	Unsuitable (unfit) for drinking	1	3.33 %

Table 5 shows the correlation coefficient between water quality index WQI, and characteristics of groundwater. Results showed highly significant positive correlations between WQI and a total Iron (R = 0.999) which indicates that Fe concentration has the strongest effect on Sharurah groundwater quality. On the other hand, the correlation coefficient between WQI and the parameters, namely, Hydrogen ion concentrationpH, turbidity$Turb$, indicates a rather weak negative relationship, while a very weak negative relationship between WQI and sulfate SO_4^{2-}, fluoride F^- and nitrate NO_3^-. A low positive correlation values was observed between WQI and electrical conductivityEC, total dissolved solids TDS, total hardness TH, chloride Cl^- and nitrite NO_2^- . These results can be summarized by saying that a total Iron has a strong influence on the value of WQI. In other words, a total Iron is the most important parameter that specify water quality in our samples. Figure 8 shows the positive strongest correlation between WQI and a total Iron Fe graphically. This result is confirmed by the study [41] which showed that a total iron has a significant effect on WQI.

Table 5: Correlation between WQI and selected parameters of groundwater using SPSS.

Parameter	Correlation coefficient (R) with WQI
pH	−0.337
$Turb$	−0.236
EC	0.375
TDS	0.406
TH	0.424
Cl^-	0.477
SO_4^{2-}	-0.023
F^-	-0.149
Fe	0.999
NO_2^-	0.513
NO_3^-	-0.126

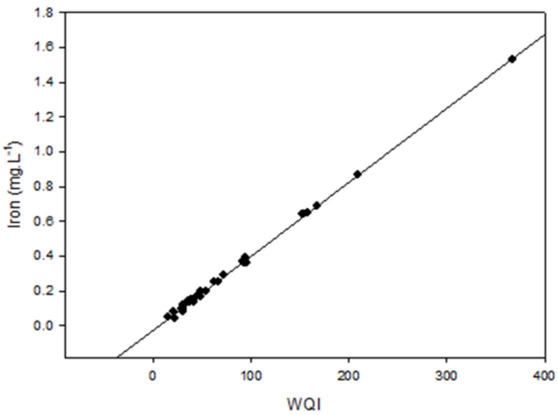


Fig. 8: Correlation between WQI and $Total\ Iron$

The current study shows that all the selected parameters are well in a compliance and agreement within water quality standards given by [33]. Therefore, we can say that it is fit for drinking purpose. As the importance of water quality for human consumptions, it should be monitored and checked continuously.

4. Conclusions and Recommendations

From correlation analysis, it is concluded that there is a strong relation between the three physiochemical groundwater parameters TDS, EC and Cl^-, while there is a weak and moderate relations between the other parameters, which means the correlation analysis technique has been proven to be a very useful tool for monitoring groundwater and has a good accuracy, this leads to invest these results to reduce the costs of some analytical instruments by predicting the parameters EC and Cl^{-} in terms of parameter TDS by establishing a suitable regression equations.

The overall WQI values computed for the samples of groundwater at some fields (15 wells) for Sharurah city and its outskirts lies between class I (‘Excellent water’(53.33%)) and class II (Good water’ (26.67%) (Table 1), which indicates that the groundwater water quality is good and suitable for drinking and other domestic purposes. The variations of index values are due to variation in physicochemical parameters of groundwater. Application of WQI in this study is useful in assessing the overall water quality. This method is systematic and gives comparative evaluation of the water quality in different wells. It is also helpful for public to understand the water quality as well as being a useful tool in many ways in the field of water quality management.

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مقالة بحثية

تقييم جودة المياه باستخدام معامل الارتباط ومؤشر جودة المياه في محافظة شرورة بالمملكة العربية السعودية

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المُلخّص

هذه الدراسة هي الأولى التي أجريت في محافظة شرورة بالمملكة العربية السعودية على المياه الجوفية، وفيها تم استخدام تحليل الارتباط، ومؤشر جودة المياه لتحليل ثلاثين نقطة بيانات للمياه الجوفية في بعض الحقول (15 بئر) في مدينة شرورة وضواحيها. استخدم تحليل الارتباط معامل الارتباط لدراسة العلاقة بين المعلمات الفيزيائية والكيميائية المختلفة مثل الرقم الهيدروجيني (pH)، الموصلية الكهربائية (EC)، العكارة (Turb)، المواد الصلبة الذائبة الكلية (TDS)، العسر الكلي (TH)، الكلوريد (Cl^-)، الكبريتات (SO_4^{2-})، الفلوريد (F^-)، الحديد الكلي (Fe)، النتريت (NO_2^-)، والنترات (NO_3^-) من المياه الجوفية في الآبار موضع الدراسة في مدينة شرورة. من ناحية أخرى وفر مؤشر جودة المياه أداة مفيدة لمراقبة جودة المياه، فهو يستخدم قيم معلمات المياه المختلفة في معادلة رياضية لإنتاج قيمة تحدد جودة المياه، وتحدد مدى ملاءمة المياه للشرب. توصلت الدراسة إلى وجود عدة ارتباطات ذات دلالة إحصائية بين معلمات المياه. بينما تعكس نتيجة مؤشر جودة المياه أن 80% من العينات ذات نوعية ممتازة وجيدة.

الكلمات المفتاحية: معلمات جودة المياه، معامل الارتباط، مؤشر جودة المياه، محافظة شرورة، المملكة العربية السعودية.

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