Mathematical analysis study of physical parameters and water quality index for groundwater quality monitoring in coastal Hadhramout –Yemen

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Abstract

Groundwater wells are the major source of drinking water in Hadhramout-Yemen. The current study assessed the quality of fifty-five water wells data for coastal Hadhramout-Yemen. The samples were tested for physical parameters such as color, Hydrogen ion concentration **(**pH), electrical conductivity (EC), turbidity (Turb) and total dissolved solids (TDS). This assessment is based on comparing water quality of physical parameter values to the Yemeni standards, calculating the water quality index (WQI) for each well and the correlation coefficients (R) between each pair of the selected physical parameters. The correlation coefficient between (WQI), and the selected physical parameters was also calculated. The percentage of compliance to the Yemeni standards in water samples varies from 71.19 % for TDS to 100% for PH. The WQI reflects that most of the samples (forty-nine) are of good and excellent quality. A good relationship was found (simple linear regression) between the color and the turbidity. The current results show that all physical parameters of drinking water are more or less correlated with each other and the WQI, is a very useful and easy tool for monitoring drinking water.

Keywords: Water quality parameters, Regression equation, Correlation coefficient, water quality index, Hadhramout, Yemen

Introduction

Water quality is a term used to express the suitability of water to designated uses or processes. Any particular use will have certain requirements for the physical, chemical or biological characteristics of water [9].

Water quality is influenced by natural effects as well as by human activities. The most natural influences are geological, hydrological and climatic, since these affect the quantity and quality of water available. Their influence is generally greatest when the available quantities of water are low and limited resource must be used at maximum; for example, high salinity is a frequent problem in arid and coastal areas, while the influences of human activities on water quality are both widespread and varied in the degree to which they damage the ecosystem and/or limit the use of water [9].

Monitoring quality of groundwater is usually examined in four aspects which are:
(i) physical examination]; (ii) chemical examination; (iii) Toxins examination; and (iv) Bacteria examination [14]. It is possible to develop equation of best fit for the data input of electrical conductivity and other parameters by the systematic calculation and interpretation of the correlation coefficients. These equations could be effectively used for the prediction of water quality by making observation on electrical conductivity alone or any one of the other parameters. This enables the monitoring of water quality is an easy and quick method [1].

Water quality parameter correlation and regression analysis is one of the most effective tools or methods for water quality monitoring. A very little work has been done on assessing the quality of groundwater and treated water in Yemen. Therefore, this method is used for the first time for water quality assessment in coastal Hadhramout –Yemen.

Water Quality Index (WQI):

Water Quality Index (WQI) is the most effective tool to convey water quality information in the simplest form to the public and legislative decision makers [7]. WQI transforms the large and complexed information of raw water quality data into a simplified and logical form with different categories of water quality that reflects the overall water quality status [23]. It has become a central theme of many national and international environmental agencies in various countries to determine water quality status of any source for various uses and for comparative purposes between different stations [13,19]. Numerous studies have used the various indices to predict the water quality of different regions for drinking and other uses [23,1,18,6]. Brown et al. in 1972 [24] have proposed an unambiguous method for communicating this information to everyone concerned by using simple, stable, consistent, and reproducible unit of water quality index method.

Water quality indices have to be developed considering the local properties and pollution status of the ecosystems. Although few parameters are used for the modified water quality indices, they can give proximate results with indices that are using more parameters. Such an initiative would allow the managers, decision makers, or policy makers to appreciate the state of the water body very easily and propose suggestions for managing the water body very effectively [5].

Materials and Methods

Drinking water quality data

Coastal Hadramout is located on Arabia's southern region at the Arabian Sea, which extends 720 km between 49' 07' E and 50' 21' E, occupying the eastern part of the southern coast of Yemen (Figure 1).

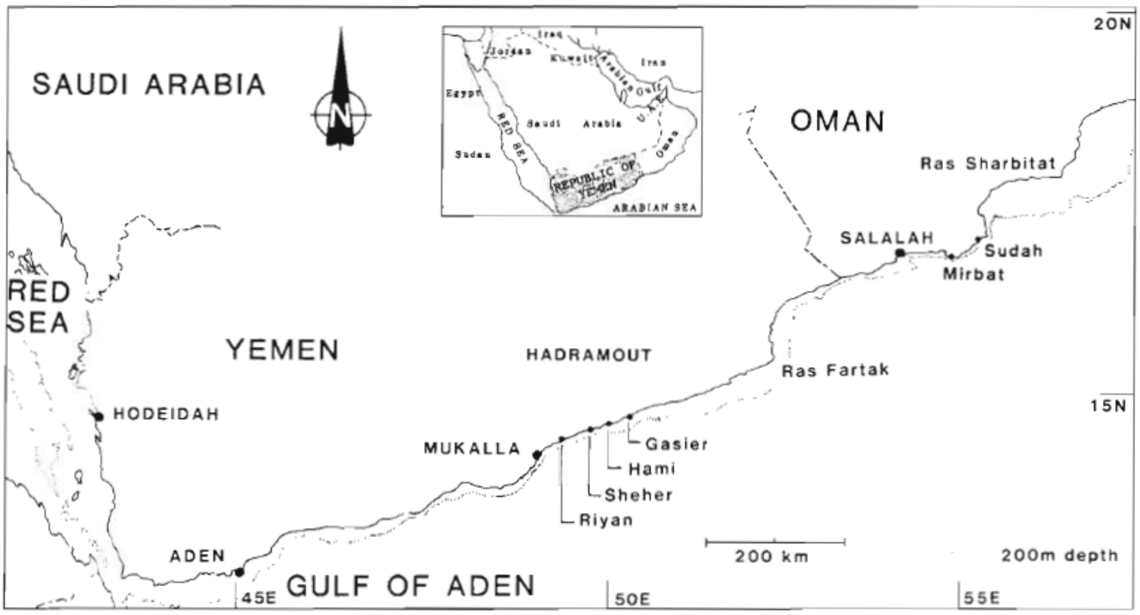


Figure 1: The eastern part of the southern coast of Yemen

During January - December 2010, drinking ground water samples were collected from different locations for the coastal Hadhramout towns, namely: Al-Mukalla, Alghail, Ash-Shihr and some regions (Al-Hami, Al-Maqued, Addees Sharegia, Arraidah). The water collected samples were analyzed at laboratories of the Local Corporation for Water Supply and Sanitation according to standard methods. In this study, the samples were analyzed for five principal physical parameters of groundwater quality, such as color, pH, electrical conductivity (EC), turbidity (Turb) and total dissolved solids (TDS), at the constant value of temperature (=25 °C for deeper groundwater temperature remains relatively constant).

Statistical and Correlation Analysis:

Water quality data were summarized in the table and graphical form using Microsoft Excel, and SPSS. Statistical measures, such as mean, standard deviation, variance, ... etc, were calculated. Moreover, a comparison of groundwater quality with Yemeni drinking water standards was performed.

Correlation coefficient is a single summary number that gives a good idea about how closely one variable is related to another variable. To obtain the relationship between two parameters x and y, the Karl Pearson's correlation coefficient R is calculated using the following equation [10,12,17,3,16,21,25,20]:

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

where n is the number of data points. For good correlation coefficient value of R it should be between - 1 < R < 1. If the values of correlation coefficient R between *x* and *y* are fairly large, it implies that these two variables are highly correlated. In such cases, it is feasible to try the following linear equation [3,21,25, 20]:

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

where x is the independent variable and y is the dependent variable, as 'a' is the slope of the line and '*b*' is the intercept on the Y-axis . *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:

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

and

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

Water Quality Index WQI Method

Relying on several water quality parameters, we can obtain a single number, which characterizes the overall quality of the water. To calculate the WQI different quality water parameters have been used depending on the physical parameters determined for each water sample.

The index classifies the water quality based on the purity of sample by using the measured physical water quality parameters. This index was computed by using the following steps [1,24,11]:

In the first step, for the calculation of WQI, five parameters; such as color, pH, EC, Turb, and TDS, have been used.

In the second step, quality rating Q_i of ith parameter for a total of n water quality parameters was computed for each of the parameter by using the given expression:

$$Q_i = \frac{V_{actual} - V_{ideal}}{V_{standard} - V_{ideal}} \times 100 \tag{5}$$

where:

V_{actual} is the actual value of the water quality parameter obtained from laboratory analysis

V_{ideal} is the ideal value of that water quality parameter, V_{ideal} for pH is 7 but for other parameters equal zero.

$V_{standard}$ is the recommended standard of the water quality parameter.

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

$$W_i = \frac{K}{S_i} \tag{6}$$

where S_i is the standard permissible value for nth parameter.

K is the proportionality constant, which can be calculated by using the formula:

$$K = \frac{1}{\sum (1/S_i)} \tag{7}$$

Here the value of K is considered 1 [4].

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

$$WQI = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i} \tag{8}$$

Results and Discussion:

Water Quality Parameters:

Color:

Color in water is primarily due to the presence of colored organic substances (primarily humic substances), metals such as *Fe, Mn* or highly industrial wastes (from pulp, paper and textile industries). In addition, slaughterhouse operations may add substantial coloration to water in receiving streams. Colored water does not cause so many health problems, but it is aesthetically unacceptable [2].

Color in groundwater samples varied from 1 to 129 Pt/Co with mean (17.6 Pt/Co), and standard deviation 26, which indicates a strong variation of Color values in the wells (Figure 2). In addition, An interesting result in Figure 3 is that the 1st quartile is 5 and the 3rd quartile is 16, which means that at least quarter (29% exactly) of the wells match the optimum Yemeni standards for color (5 Pt/Co) (Table 1), and 25% of the wells exceeds the maximum permissible limit (15 Pt/Co), respectively.

In spite of the fact that, in general, the results of Color in groundwater samples is not quite satisfying. Figure 3 shows that Al-Mukalla wells have the worst results when compared to Alghail and Ashshihr wells.

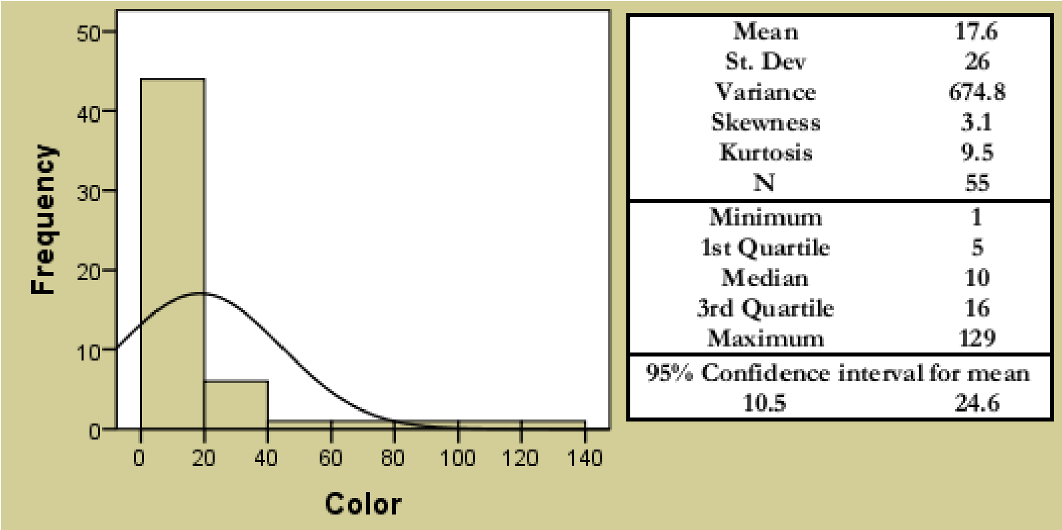


Fig. 2: Statistical summary for color in groundwater wells

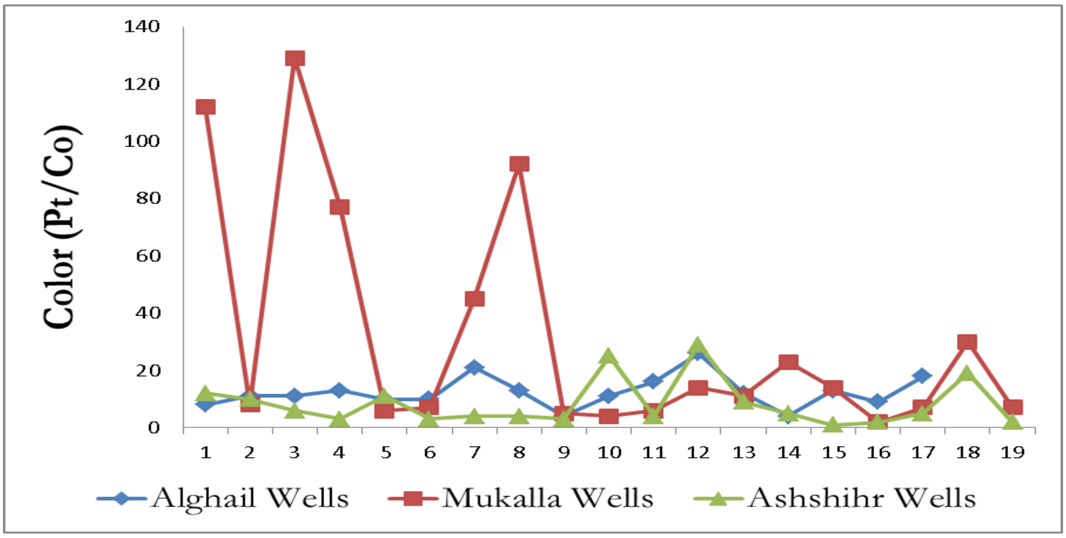


Fig. 3: Variation of Color in different wells

Table 1: Comparison of water quality parameters of groundwater wells in coastal Hadhramout with drinking water quality standard (Yemeni Standards)

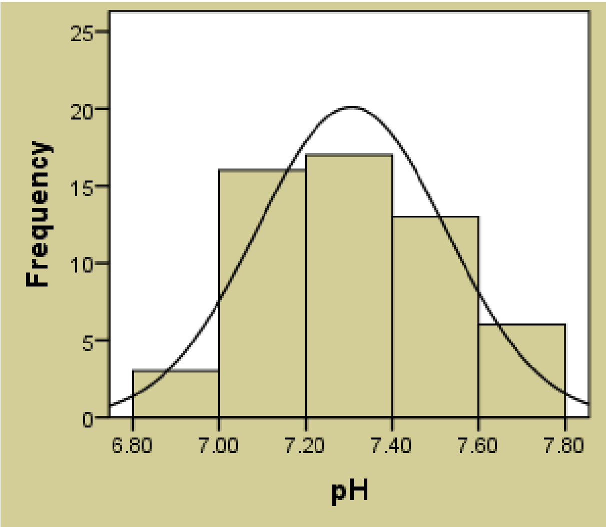
Parameters	**Observed Range of Samples**		**Yemeni Standards** [28]		**Compliance Percent**
	Minimum	**Maximum**	**Optimum limit**	**Maximum permissible limit**	
Color (Pt/Co)	1	129	5	15	74.55 %
pH	6.84	7.75	6.5 – 8.5	6.5 - 9	100%
EC (μm/cm)	1124	4443	450 - 1000	2500	80%
Turbidity (NTU)	0.46	25.6	1	5	85.45%
TDS (mg/l)	720	2844	650	1500	70.91%

pH:

The pH value is an important index of acidity or alkalinity and the concentration of hydrogen ion in groundwater [2].

Figure 4 shows the statistical summary for pH in groundwater samples. It can be seen that pH values varied from 6.84 to 7.75, which means that the sampling groundwater collected from the 55 different wells were within the optimum limit (6.5–8.5) of Yemeni standards for drinking water (Table 1). Figure 5 shows the variation of pH in groundwater samples according to the three districts Alghail, Al-Mukalla, and Ashshihr.

pH of solution is taken as negative logarithm of H_2 ions. Value range of pH from 7 to 14 is alkaline, from 0 to 7 is acidic and 7 is neutral. Mainly drinking water pH lies from 4.4 to 8.5. The pH scale commonly ranges from 0 to 14 [7].



Mean	7.31
St. Dev	0.22
Variance	0.05
Skewness	0.13
Kurtosis	-0.66
N	55
Minimum	6.84
1st Quartile	7.12
Median	7.34
3rd Quartile	7.46
Maximum	7.75
95% Confidence interval for mean	
7.25	7.37

Fig. 4 : Statistical summary for pH in groundwater wells

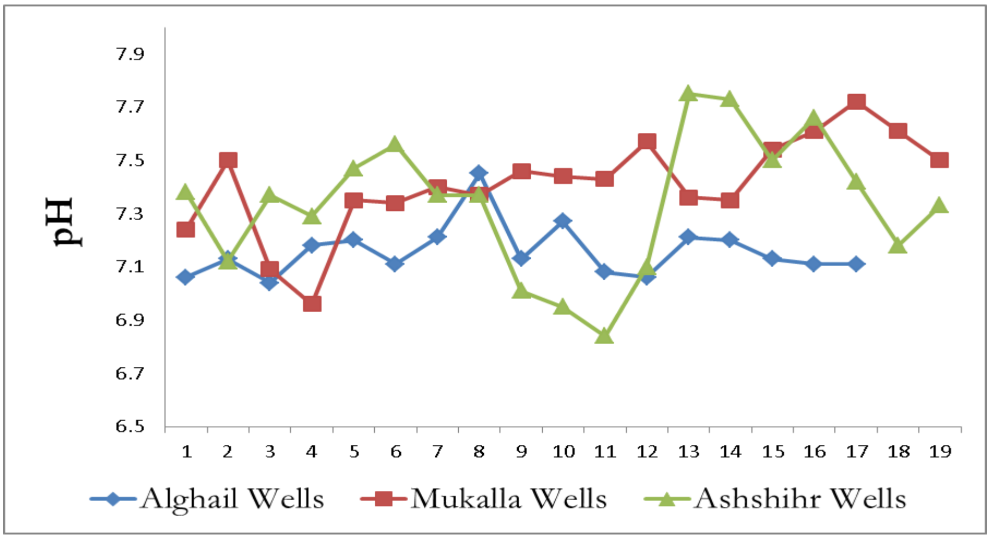


Fig. 5: Variation of PH in different wells

Electrical conductivity (EC):

The electrical conductivity value depends on the concentration and degree of dissociation of the ions as well as the temperature and migration velocity of the ion in the electric field. The electrical conductivity measures the concentration of ions in water. The concentration of ions depends on the environment, movement and sources water [27].

Figure 6 shows that the EC in groundwater samples vary from 1124 to 4443 µS/cm, with mean (2080 µS/cm) and standard deviation 624.7. Although none of the wells matches the optimum value of EC according to Yemeni standards for drinking water (450 - 1000 µS/cm) (Table 1), 80 % of the groundwater samples collected (44 out of 55 wells) does not exceed the maximum permissible limit (2500 µS/cm).

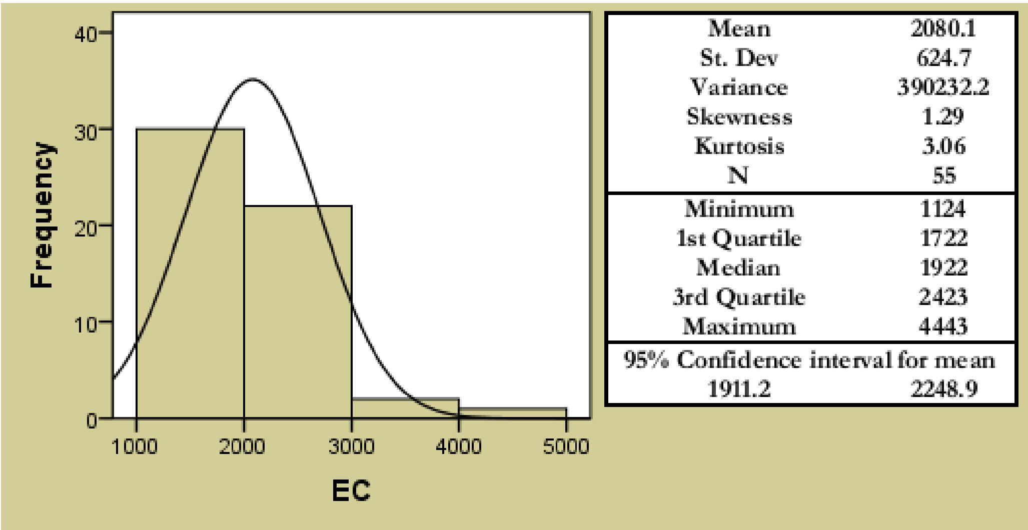


Fig. 6 : Statistical summary for EC of groundwater wells

Figure 7 shows the variation of EC in groundwater samples. It can easily be seen that Ashshihr wells have the highest values for EC followed by Alghail wells, then Al- Mukalla wells for most of the groundwater samples.

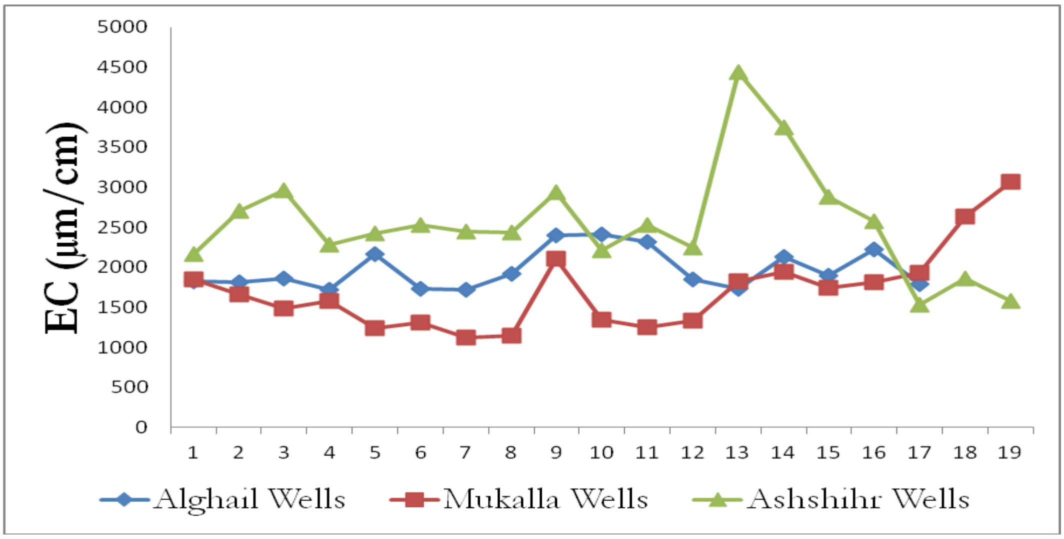
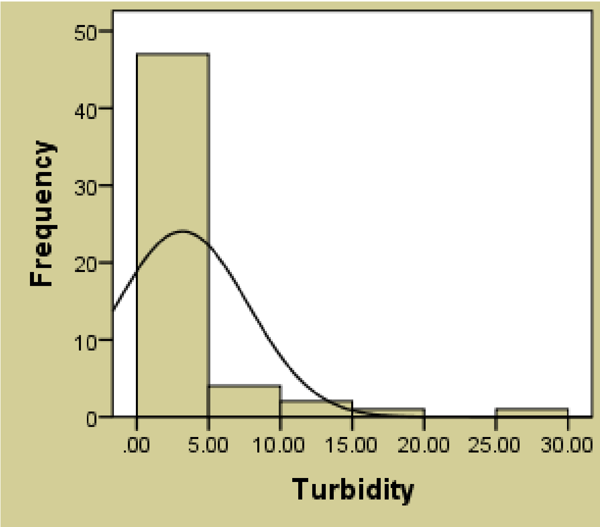


Fig. 7: Variation of EC in different wells

Turbidity:

Suspension of particles in water interfering with passage of light is called turbidity. Turbidity is caused by wide variety of suspended particles. Turbidity can be measured either by its effect on the transmission of light which is termed as Turbiditymetry or by its effect on the scattering of light which is termed as Nephelometry [7].

Figure 8 shows that the Turb in groundwater samples vary from 0.46 to 25.6 NTU, with mean 3.2 NTU and standard deviation 4.6. This indicates strong variation in Turbidity values. Also, the statistical summary shows good results for Turbidity values. It is seen that most of the groundwater samples collected (47 out of 55 wells) does not exceed the maximum permissible limit (5 NTU) of Yemeni standards for drinking water (Table 1). Figure 9 displays an indicator of the source of strong variation in Turbidity, as seen in the figure that there are four extreme values in Al-Mukalla wells.



Mean	3.2
St. Dev	4.6
Variance	20.83
Skewness	3.32
Kurtosis	12.19
N	55
Minimum	0.46
1st Quartile	0.77
Median	1.78
3rd Quartile	3.44
Maximum	25.6
95% Confidence interval for mean	
1.96	4.42

Fig. 8: Statistical summary for Turbidity of groundwater wells

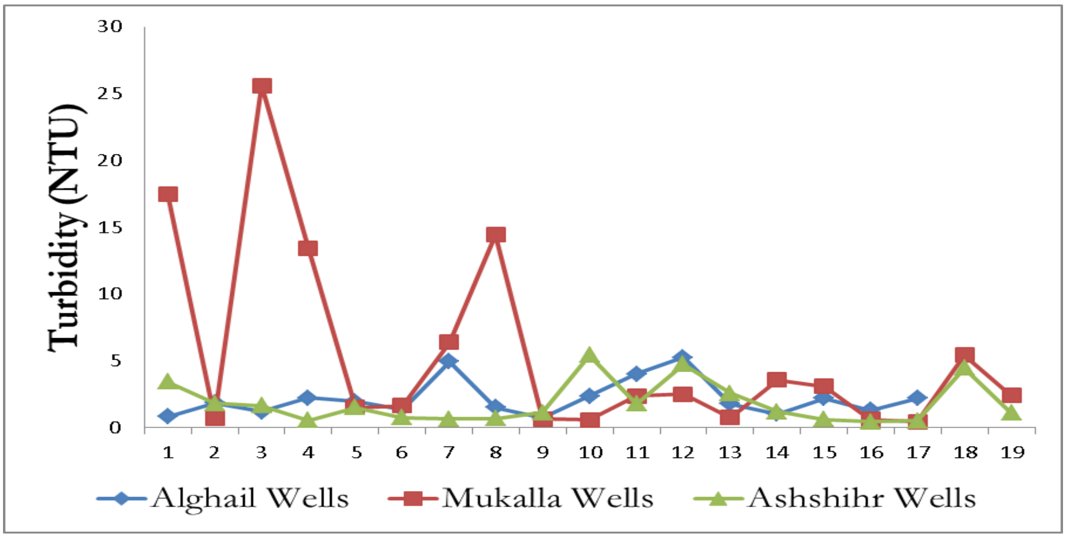
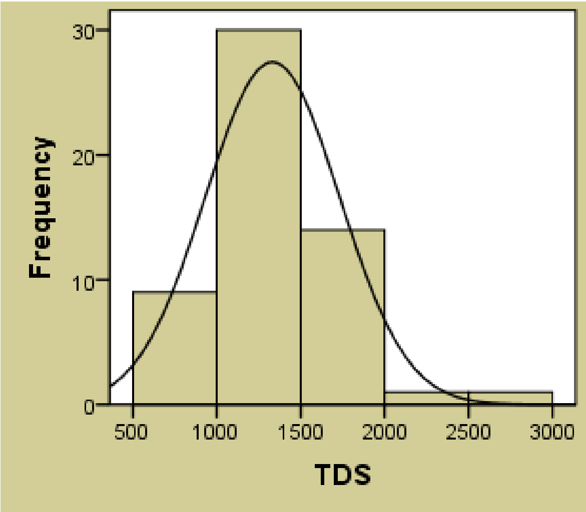


Fig. 9: Variation of Turbidity in different wells

Total Dissolved Solids (TDS):

TDS is a measure of all dissolved substances in water, including organic and suspended particles that can pass through a very small filter [8]. As being of coastal area, seawater intrusion is the main factor for the increased amount of TDS in GW, supported by a high value of sodium and chloride [7].

Figure 10 displays that TDS in groundwater samples varied from 720 to 2844 mg/l, with mean (1331.3 mg/l) and standard deviation 399.8. The results show that 3rd quartile is 1551 which means that most of the TDS values of groundwater samples (39 different wells out of total 55 wells) do not exceed the maximum permissible limit (1500 mg/l) of Yemeni standards for drinking water (Table 1). Figure 11 shows the variation of TDS in groundwater samples. It can be seen that Ashshihr wells have the highest values for TDS, followed by Alghail, then Al-Mukalla wells for most of the groundwater samples.



Mean	1331.3
St. Dev	399.8
Variance	159870.1
Skewness	1.293
Kurtosis	3.1
N	55
Minimum	720
1st Quartile	1102
Median	1230
3rd Quartile	1551
Maximum	2844
95% Confidence interval for mean	
1223.2	1439.4

Fig. 10: Statistical summary for TDS of groundwater wells

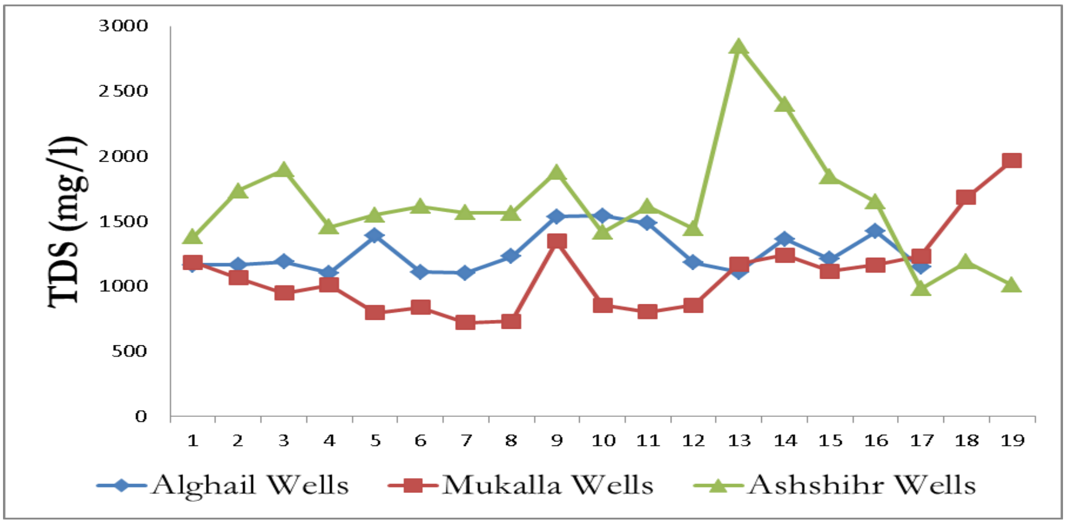


Fig. 11 : Variation of TDS in different wells

In table (1), water quality parameters for the fifty-five wells was compared with the Yemeni drinking water quality standard. It can be see that the percentage of compliance varies from 70.91% for TDS to 100% for pH.

In this study, the correlation analysis represented by correlation coefficient is a measure of relationship between every pair of water physicochemical parameters and regression equations also established by taking positive correlation coefficients (Table 2).

The highest positive correlation is observed between electrical conductivity (EC) and total dissolved solids (TDS), as shown in Fig. (12). There is also a strong positive correlation exists between color and turbidity, as shown in Fig. (13).

Table 2: Correlation Coefficient among water quality parameters.

Parameter	**Color**	**pH**	**EC**	**Turbidity**	**TDS**
Color	1				
pH	- 0.226	1			
EC	- 0.303	0.235	1		
Turbidity	0.982	- 0.244	- 0.256	1	
TDS	- 0.303	0.235	1	- 0.256	1

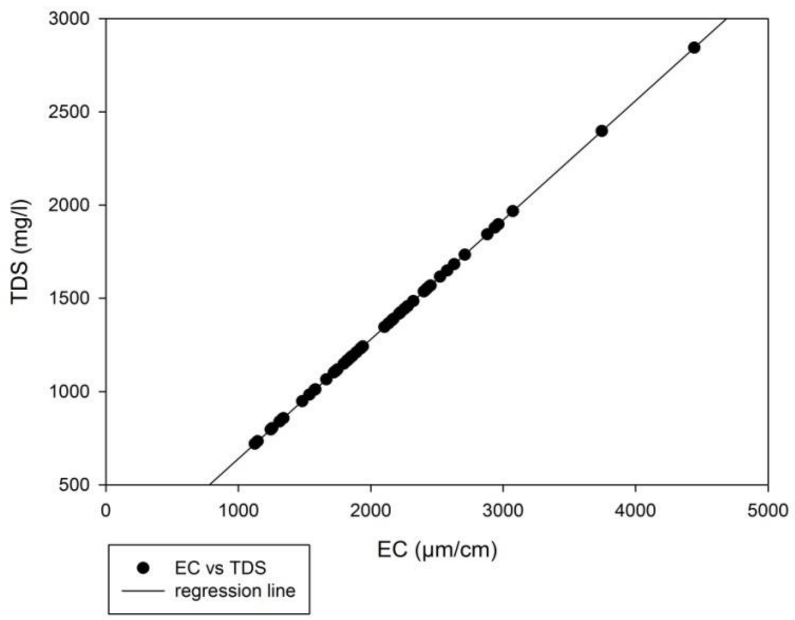


Fig. 12: Correlation between EC and TDS

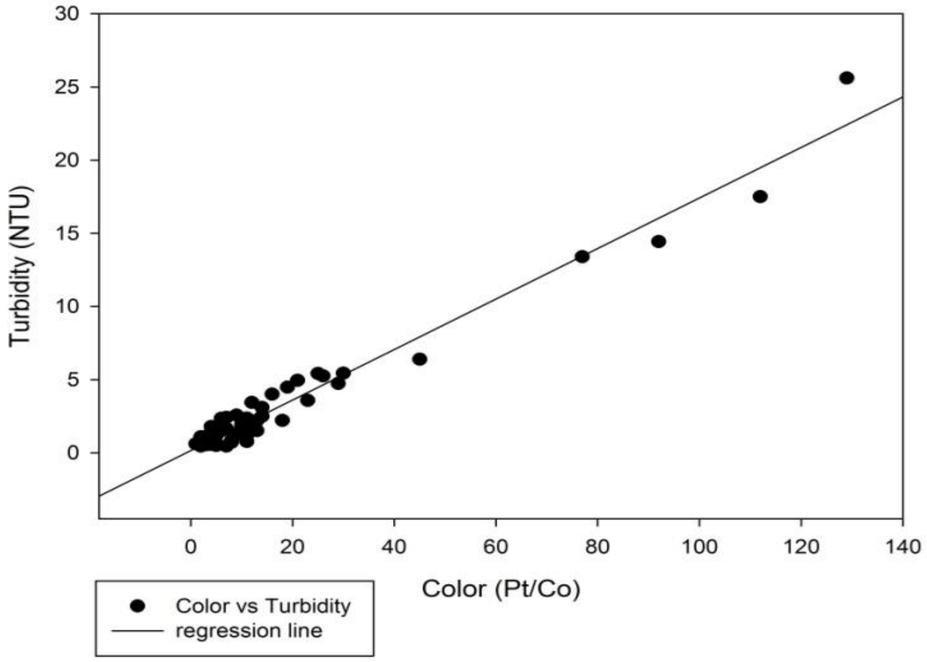


Fig. 13: Correlation between color and turbidity

Water Quality Index (WQI):

The water quality index of all samples taken was calculated according to the procedure explained previously in the materials and methods (eq.5, eq.6 and eq.8). Samples of WQI obtained for groundwater in the sites, namely Al- Mukalla, Alghail and Ash-Shihr are shown in Tables (3, 4 and 5).

Table 3: Sample calculations of WQI in Al-Mukalla wells

Parameters	Observed Value (V_{actual})	Standard value ($V_{standard}$)	Unit Weight (W_i)	Quality Rating (Q_i)	$Q_i W_i$
Electrical conductivity (EC) μm/cm	1664	2500	0.0004	66.56	0.027
Total Dissolved Solids (TDS) mg/l	1065	1500	0.0006667	71.00	0.047
PH	7.5	6.5 - 8.5	0.1176471	33.33	3.922
Turbidity NTU	0.71	5	0.2	14.20	2.840
Color Pt/Co	8	5 - 15	0.0666667	53.33	3.556
			$\sum_{i=1}^{n} W_i$ =0.3854	$\sum_{i=1}^{n} Q_i W_i$ =10.391	

Overall Water Quality Index $WQI = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i} = 26.96$

Table 4: Sample calculations of WQI in Alghail wells

Parameters	Observed Value (V_{actual})	Standard value $(V_{standard})$	Unit Weight (W_i)	Quality Rating (Q_i)	$Q_i W_i$
Electrical conductivity (EC) µm/cm	1821	2500	0.0004	72.84	0.029
Total Dissolved Solids (TDS) mg/l	1166	1500	0.0006667	77.73	0.052
PH	7.06	6.5 - 8.5	0.1176471	4.00	0.471
Turbidity NTU	0.83	5	0.2	16.60	3.320
Color Pt/Co	8	5 - 15	0.0666667	53.33	3.556
			$\sum_{i=1}^{n} W_i$ =0.3854	$\sum_{i=1}^{n} Q_i W_i$ =7.427	
Overall Water Quality Index WQI = $\frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i}$ = 19.27					

Table 5: Sample calculations of WQI in Ash-Shihr wells

Parameters	Observed Value (V_{actual})	Standard value $(V_{standard})$	Unit Weight (W_i)	Quality Rating (Q_i)	$Q_i W_i$
Electrical conductivity (EC) µm/cm	2160	2500	0.0004	86.40	0.035
Total Dissolved Solids (TDS) mg/l	1382	1500	0.0006667	92.13	0.061
PH	7.38	6.5 - 8.5	0.1176471	25.33	2.980
Turbidity NTU	3.44	5	0.2	68.80	13.760
Color Pt/Co	12	5 - 15	0.0666667	80.00	5.333
			$\sum_{i=1}^{n} W_i$ =0.3854	$\sum_{i=1}^{n} Q_i W_i$ =22.17	
Overall Water Quality Index WQI = $\frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i}$ = 57.53					

The correlation coefficient between WQI and the physical parameters (Table 6) and regression equations also established by taking strong correlation coefficients ($R \geq 0.900$). Regression equations established between WQI and selected parameters are used to estimate the value of one parameter if value of other is known without using any analytical techniques.

From Table 6 below, it can be seen that the highest correlation coefficient between WQI and the studied parameters was with Color (R = 0.992) and Turbidity (R = 0.995) which indicates a strong positive relationship between WQI with both Color and Turbidity. In the other hand, the correlation coefficient between WQI and the rest of the parameters, namely, pH, EC, and TDS indicates a rather weak negative relationship. These results can be summarized and is said that Color and Turbidity have a strong influence on the values of WQI. In other words, Color and Turbidity values are the most important parameters that specify water quality in our samples. Figures 14, and 15, respectively, show the strong relation between WQI and Color and Turbidity graphically.

Table 6: Correlation coefficient between water quality index (WQI), and physical parameters

Parameter (Units)	Correlation coefficient (R) with WQI
pH	-0.183
EC (µm/cm)	-0.264
TDS (mg/l)	-0.264
Color (Pt/Co)	0.992
Turbidity (NTU)	0.995

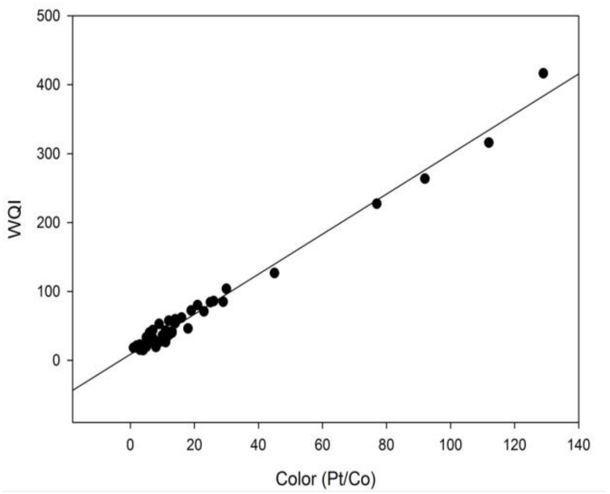


Fig. 14: Scatter diagram of WQI vs. color of ground water

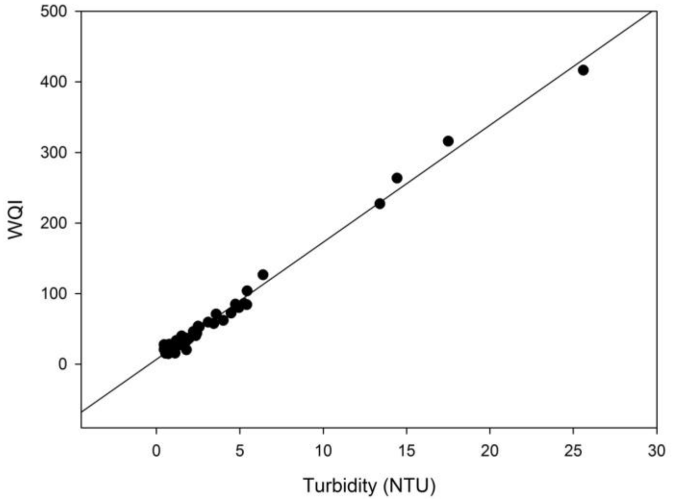


Fig. 15: Scatter diagram of WQI vs. Turb. of ground water

Classification of Water Samples according to their WQI:

The water quality ratings based on index value for this WQI are summarized according [1,26] in Table (7). These results are also compared with Yemeni Standard [28] recommended for drinking purpose.

Table 7: Water quality rating and index values

Water Quality Index Level	Description of water quality rating	No. of samples (wells)	Percentage
$<$ 50	Excellent water	38	69.09 %
50 - 100	Good water	11	20 %
100 - 200	Poor water	2	3.64 %
200 - 300	Very poor (bad) water	2	3.64 %
$>$ 300	Unsuitable (unfit) for drinking	2	3.64 %

Conclusion

Water Quality Index (WQI) reveals the 'Excellent water' (69.09%) and 'Good water' (20%) water quality during current study. The results of the study confirm the suitability of groundwater for drinking purposes. But, regular monitoring is required to determine the pollution load with follow up treatment of water to improve the water quality, which is being used for drinking purpose. The currents study showed that the WQI is a useful tool for water management, as it allows to appreciating the state of a water body easily and to making suggestions for a more efficient basin management.

Acknowledgments

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دراسة رياضية تحليلية للبارامترات الفيزيائية ومعامل نوعية المياه لمراقبة نوعيةِ المياه الجوفيّةِ في حضرموت الساحل-اليمن

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الملخص

تعد آبار المياه الجوفية المصدر الرئيسي لمياه الشرب في حضرموت الساحل -اليمن .وقد قيَّم البحث الحالي بيانات لنوعية مياه الشرب لخمس وخمسين بئراً في حضرموت الساحل -اليمن . تم اختبار العينات للبارامترات (للمعلمات) الفيزيائية كاللون (color)، تركيز أيون الهيدروجين (pH)، التوصيلية الكهربائية (EC)، العكارة (Turb)، المواد الصلبة الذائبة (TDS). يعتمد هذا التقييم على مقارنة قيم البارامترات الفيزيائية لنوعية المياه بالمعايير اليمنية، وحساب كل من معامل نوعية المياه (WQI) وقيم معاملات الارتباط (R) بين كل زوج من البارامترات الفيزيائية المحددة .و تم حساب معامل الارتباط بين معامل نوعية المياه (WQI) والبارامترات الفيزيائية المختارة قيد الدراسة. وقد تم التوصل إلى النسبة المئوية لعينات المياه استناداً للمعايير اليمنية تتراوح من 71.19% للبارامتر (TDS) الى 100% للبارامتر (pH). وتم تحديد المعادلات القياسية لنوعية المياه للبارامترات الفيزيائية لجودة المياه. و لُوحِظ انَ معامل نوعية المياه يعكس أنً معظم العينات (49 عينة) هي من نوعية جيدة وممتازة. اوضحت الدراسة الحالية علاقة جيدة (الانحدار الخطي البسيط) بين اللون والعكارة . وتبين النتائج الحالية أنُ جميع البارامترات الفيزيائية لمياه الشرب ترتبط ارتباطاً أو أكثر ببعضها بعضاً، وأنً معامل نوعية المياه (WQI) هو أداة مفيدة جدا وسهلة لمراقبة نوعية مياه الشرب.

الكلمات المفتاحية: بارامترات نوعية المياه، معادلة الانحدار، معامل الارتباط، معامل نوعية المياه، حضرموت، اليمن.