# Application of water quality index to assessment of groundwater quality

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DOI: https://doi.org/10.47372/uajnas.2017.n1.a13

## Abstract

The main objective of this study was to: assess groundwater quality in rural areas of Zabid, Hodeidah, for drinking purpose using water quality index (WQI). Forty groundwater samples were collected from the study area. The water quality index (WQI) is a mathematical method used to facilitate water quality explanation. The WQI calculations required several physiochemical water parameters, including pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), $Cl^-$, $SO_4^{2-}$, $HCO_3^-$, $NO_3^-$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$ and $K^+$. The values of WQI indicated that 75% of groundwater in the study area was good for drinking (class II), 25 % Poor water (class III), and the WQIs ranged from 76 and 98; 101 and 126, respectively. It can be said, from this assessment, that groundwater in the study area was generally in Good-Poor water quality status**.** The reasons for the high WQI values of some study areas were due to the anthropogenic activities, as well as domestic and agricultural wastes.

**Keywords**: Ground Water, Water Quality Parameters, Water Quality Index.

## Introduction

Water quality index (WQI) is one of the most effective tools to express water quality that offers a simple, stable, reproducible unit of measure and communicate information of water quality to the policy makers and concerned citizens [11;26;41]. The purpose of the WQI is to provide a simple and concise method for assessing water quality for drinking usage. WQI provides a single value that expresses water quality by integrating different water quality variables [40;46;47]. WQI indicates a single number like a grade that expresses the overall water quality at a certain area and time based on several water quality parameters. WQI reflects a composite influence of contributing factors on the quality of water for any water system [23]. Water quality of different sources has been communicated on the basis of calculated water quality indices [44;49].

The traditional approaches for assessing water quality are based on the comparison of experimentally determined parameters with local or international standards. Although these approaches allow a proper identification of contamination sources, and may be essential for checking legal compliance, they do not readily give a global vision of the spatial and temporal trends in the overall water quality[14]. Numerous studies have proposed the use of a WQI for water quality assessment [10;12;21;22;24;26;29;38;40], and different methods for the calculation of the WQI have been developed, considering similar physical and chemical parameters in the way the parameter values are statistically integrated and interpreted [3;4;5;17;18;19;25;27;28;34;36;39;46;54]. The main objective of this study was the Application of water quality index to assess suitability of groundwater quality for drinking purposes in rural areas of Zabid, Hodeidah.

## Materials and Methods

### Study area

The study area comprises the middle part of Wadi Zabid, Al-Hodiedah Governorate. This area is located in the southern part of Tehama plain between longitude 297,000 - 335,000 UTM-E and latitude 1558000-1570000 UTM-N. Wadi Zabid is located on a distance about 100 km southeast of Al-Hodiedah port. Zabid water resources management district is an arid district typical of the Tihama region. It receives small amounts of rainfall during summer, with higher temperatures prevailing throughout the year. Rainfall increases east ward due to the geographic effect of the mountainous areas. The rain fall patterns are influenced by both the Red Sea convergence zone effect and the inter tropical convergences zone effect, which produce main rainfall periods, one from March to May and the other from July to September. Mean annual rain fall amount varies from < 100 mm in the western coastal areas to about 500 mm in the eastern foothills areas [35]. Zabid district is an arid district with high air temperature. The air temperatures vary according to the months of the year and the altitude. During the months from May to August, the temperature is very high where the maximum air temperature may reach $40^o$ C, while the temperature from September to April becomes moderate , about $18^o$C. The annual average of air temperature is $29.6^o$C. Humidity varies throughout the year. The mean monthly humidity is 60-75% [35]. The subsurface geology forms basically a continue which can be divided into two broad faces based on grain size, which decreases west-wards as a factor both of degree combination of sediment transport capacity, as the Wadi spate is dissipated on route to the sea. Altogether, four main physiographic units can be recognized within the land for the coastal plain: Alluvial fan, Alluvial plain (Coarse to medium subsurface deposits), Alluvial sand deposits and Alluvial marine platform (medium to fine subsurface deposits). Zabid water resources management district is underlained by an extensive alluvial aquifer which ranges in depth from 0-50 m in the east, adjacent to the foothills to 200-300 m at the coast.

**Sample collection and physico-chemical analysis**

In this study, Forty groundwater samples were collected from the rural areas of Zabid, during the first quarter of the year 2015, from nine zones including: Al-Hema; Al-Quraiah; Mahal Al-shaikh; Al-Morshedia; Mahal Al-Mubarak; Al-Shabariq; Belad Al-Requod; Al-Toraibah and Al-Zareebah (Table 1). Water samples from wells were collected in precleaned two liter polythene bottles and were analyzed for 12 parameters, viz., Electrical Conductivity (EC), pH, Total Dissolved Solids (TDS), Total Hardness (TH), Calcium ($Ca^{2+}$), Magnesium ($Mg^{2+}$), Sodium ($Na^+$), Potassium ($K^+$), Chloride ($Cl^-$), Bicarbonate ($HCO_3^-$), Sulphate ($SO_4^{2-}$), and Nitrate ($NO_3^-$). The physico-chemical analysis was carried out as per the standard methods [7].

**Water quality index calculation**

Computing WQI, three steps were followed [3;4;5;8;16;19;22;24;25;26;37;39;40;50;53]. In the first step, each of the 12 parameters (pH, EC, TDS, TH, $Cl^-$, $SO_4^{2-}$, $HCO_3^-$, $NO_3^-$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$ and $K^+$) has been assigned a weight ($w_i$) based on their perceived effects on primary health (Table 2). The maximum weight of 5 was assigned to parameters, such as nitrate and total dissolved solids, due to their major importance in water quality assessment [24;45]. Other parameters were assigned a weight between 1 and 5 depending on their importance in the overall quality of water for drinking purposes [5;25;19].

The second step, is the ‘relative weight calculation'. The relative weight (*Wi*) is computed by the following equation (1):

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \quad \text{………….. (1)}$$

where, *wi* is the weight of each parameter, n is the number of parameters and *Wi* is the relative weight. The weight (w*i*), the calculated relative weight (W*i*) values and the WHO standards for each parameter were given in Table 2.

In the third step, quality rating scale (q*i*) was calculated for each parameter using Eq. (2):

$$qi = \frac{Ci}{Si} \times 100 \quad \text{……………. (2)}$$

where, q*i* is the quality rating, C*i* is the concentration of each physo-chemical parameter in each water sample in mg/l and S*i* is the WHO standard for each chemical parameter in mg/l. Finally, the Wi and qi were used to calculate the SI*i* for each chemical parameter, and then the WQI was calculated from the following equations:

$$SIi = Wi \times qi \quad ………… (3)$$

$$Wi = \sum_{i=1}^{n} SIi \quad ………… (4)$$

where, SI$i$ is the sub-index of $i^{th}$ parameter, $q_i$ is the rating based on concentration of $i$ parameter and $n$ is the number of parameters.

**Statistical analysis**

Statistical analysis was carried out using the complete statistical software package for Minitab version 14. The statistical tests applied were basic statistics (maximum, minimum, mean, standard deviation) and Spearman's correlation matrix (assuming $p<0.05$).

## Results and discussion

In this study, the introduced indices of the groundwater quality are derived based on cation and anion contents of groundwater. These indices can only express the quality level of potable water in underground resources of the study area. In the phase of "selection" 12 different parameters including pH, EC, TDS, TH, $Cl^-$, $SO_4^{2-}$, $HCO_3^-$, $NO_3^-$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$ and $K^+$ as the important components of clean drinking water (physco-chemical parameters), are selected to be involved in the index. Table 2 shows the parameters and their standard values according to the drinking water quality standards of WHO.

**Water Quality Index (WQI)**

Water Quality Index (WQI) was used to determine the suitability of the groundwater for drinking purposes [9;30;33;42;43;48;49]. Water Quality Index (WQI) is a very useful tool for communicating the information on the overall quality of water [1;2;37]. The standards for purposes of drinking have been considered for the calculation of WQI as recommended by WHO [52]. Computed WQI values are usually classified into five categories (Table 3): excellent, good, poor, very poor and unfit for human consumption [24;38;42].

Calculation of WQI for individual samples is represented in Figure 1. The estimated water quality index revealed that the range of 64 to 126, with 75 % of groundwater in the study area fell in Good water category (class II), and 25 % Poor water categories (class III). The ten wells 15, 20, 23, 27, 32-34, 37, 39 and 40 were class (III) "poor water". The other wells were considered as good water. The reasons for the high WQI values, obtained for this study, area werete h high values of TDS, EC, TH, $SO_4^{2-}$, $Cl^-$, $Ca^{2+}$, $Mg^{2+}$, and $NO_3^-$. High correlation coefficients between these values were also reported by [5;6;15;20;31;51]. It can be said from this assessment that the groundwater in the study area was generally in Good-Poor water quality status.

**Assessment of Groundwater quality using WQI in study area**

The distribution of population and household numbers of study area, range, mean and their standard deviation values of the WQI of groundwater samples for nine zones were summarized in **Table 4**. The values of WQI indicate that all samples of groundwater in Al-Hema, Al-Quraiah, Mahal Al-shaikh, Al-Morshedia, Mahal Al-Mubarak and Al-Shabariq zones were good for drinking (class II), and the WQIs ranged from 76 and 98; moreover, also the WQI values in the other zones indicate that the 75%, 70% and 50% of groundwater samples, in Belad Al-Requod, Al-Toraibah and Al-Zareebah zones, respectively, were good for drinking (class II). On the other hand, the remaining water samples were classified as a poor water source for drinking (class III). The reasons for the high WQI values of some study areas were due to the anthropogenic activities, as well as domestic and agriculture wastes.

**Correlation matrix**

***Correlation analysis of water quality parameters and WQI of groundwater***

The degree of a linear association between water quality parameters and WQI has been measured by the simple correlation coefficient (r) (Table 5). Correlation analysis measures the closeness of the relationship between chosen variables; if the correlation coefficient is nearer to +1 or −1, the linear relationship between the two variables is perfected [3]. The calculated WQI showed the highly significant interrelation between its values and TDS (r=0.92), EC (r=0.90), TH (r=0.77), $SO_4^{2-}$ and $Cl^-$ (r=0.75), $Ca^{2+}$ and $Mg^{2+}$ (r=0.68), $Na^+$ (r=0.50), and $NO_3^-$ (r=0.22), while the negative relationship was by only pH (r=-0.03), and $K^+$(r=-0.04).

**Correlation analysis of water quality parameters, WQI and population numbers**

A strong positive correlation was between population numbers with $K^+$, $Mg^{2+}$, pH, $Na^+$, $Cl^-$, $NO_3^-$ and WQI. The concentration of nitrate in the groundwater was significantly derived from anthropogenic processes [25]. The concentration of nitrate does not exceed 10 mg/l in water under natural conditions [13]. Ammonium is transferred to nitrate by the nitrification process in the presence of oxygen ($5O_2 + 2NH_4^+ = 2NO_3^- + 4H_2O$). The possible sources of nitrates are poultry farms, animal wastages and septic tank leakages in the urban area. Nitrate leaching is enhanced by high infiltration of soil layer and low runoff potential. The presence of high nitrate concentration in the drinking water increases the incidence of gastric cancer and other potential hazards to infants and pregnant women [32].

## Conclusions

In the present study, WQI has been computed to assess the suitability of groundwater for drinking water purposes in Rural Areas of Zabid Directorate, Hodiedah, Yemen. After the analysis of various physico-chemical parameters, we observed the range of WQI from 64 to 126. The result showed that approximately 75% of the groundwater samples fall in class II " Good water for drinking", the remaining waters fall in class III "poor water". The high value of the WQI at this study area is mainly due to the higher values of total dissolved solids, electrical conductivity, total hardness, sulphate, chloride and nitrate in the groundwater.

**Table 1**. Location of sampling sites with their latitude and longitude

| Wells no. | Location | Latitude | Longitude |
|---|---|---|---|
| 1 | Al-Hema | 1570863 | 322013 |
| 2 | | 1571074 | 323086 |
| 3 | | 1573000 | 322184 |
| 4 | Al-Quraiah | 1569801 | 323554 |
| 5 | | 1568202 | 323953 |
| 6 | Mahal Al-shaikh | 1566601 | 329377 |
| 7 | | 1567163 | 330495 |
| 8 | Al-Morshedia | 1568063 | 332923 |
| 9 | | 1568397 | 332831 |
| 10 | Mahal Al-Mubarak | 1569442 | 331334 |
| 11 | | 1569353 | 329506 |
| 12 | | 1572456 | 330987 |
| 13 | Al-Shabariq | 1571254 | 332358 |
| 14 | | 1582491 | 336400 |
| 15 | Belad Al-Requod | 1578366 | 331797 |
| 16 | | 1583012 | 332681 |
| 17 | Belad Al-Requod | 1581390 | 336723 |
| 18 | | 1581027 | 333849 |
| 19 | Al-Toraibah | 1568493 | 324486 |
| 20 | | 1569248 | 329000 |

| | | | |
|---|---|---|---|
| 21 | | 1569478 | 328092 |
| 22 | | 1568667 | 327768 |
| 23 | | 1568271 | 326601 |
| 24 | | 1567665 | 329039 |
| 25 | | 1569144 | 331659 |
| 26 | | 1567697 | 329556 |
| 27 | | 1567914 | 328392 |
| 28 | | 1574067 | 325528 |
| 29 | Al-Zareebah | 1568445 | 325692 |
| 30 | | 1568165 | 325646 |
| 31 | | 1568105 | 326103 |
| 32 | | 1568772 | 326653 |
| 33 | | 1568439 | 326745 |
| 34 | | 1568559 | 328906 |
| 35 | | 1568116 | 328909 |
| 36 | | 1568049 | 328625 |
| 37 | | 1567857 | 328162 |
| 38 | | 1567670 | 327938 |
| 39 | | 1567691 | 327682 |
| 40 | | 1569178 | 327842 |

**Table 2**. Relative weight for parameters [24;26;38]

| Parameters | WHO Standards | Weight ($w_i$) | Relative Weight ($W_i$) $Wi = \frac{wi}{\sum_{i=1}^{12} wi}$ |
|---|---|---|---|
| pH | 8.5 | 4 | 0.11 |
| EC | 500 | 4 | 0.11 |
| TDS | 600 | **5** | 0.14 |
| TH | 500 | 2 | 0.05 |
| $NO_3^-$ | 45 | 5 | 0.14 |
| $SO_4^{--}$ | 250 | 4 | 0.11 |
| $HCO_3^-$ | 500 | 3 | 0.08 |
| $Cl^-$ | 600 | 3 | 0.08 |
| $Na^+$ | 200 | 2 | 0.05 |
| $Ca^{++}$ | 200 | 2 | 0.05 |
| $Mg^{++}$ | 50 | 2 | 0.05 |
| $K^+$ | 12 | 1 | 0.03 |
| | | $=37\sum_{i=1}^{n=12} Wi$ | $=1\sum_{i=1}^{n=12} Wi$ |

pH on scale; EC in µs/cm; ions, TH and TDS in mg/l

**Table 3**. Water quality classification based on WQI value [24;26;38]

| WQI Range | Class | Type of water |
|---|---|---|
| <50 | I | Excellent water |
| 50.1–100 | II | Good water |
| 100.1–200 | III | Poor water |
| 200.1–300 | IV | Very poor water |
| >300 | V | Water unsuitable for drinking |

**Table 4**. Population affecting groundwater quality and WQI indices in the study area

| Zones | *n* | Households No | Population (person) | WQI | | | Description |
|---|---|---|---|---|---|---|---|
| | | | | Mean | SD | Range | |
| Al-Hema | *3* | 515 | 2878 | 80 | 9 | 76-90 | Good |
| Al-Quraiah | *2* | 595 | 3414 | 89 | 10 | 81-96 | Good |
| MahalAl-shaikh | *2* | 625 | 3725 | 82 | 2 | 81-83 | Good |
| Al-Morshedia | *2* | 308 | 1978 | 87 | 9 | 81-94 | Good |
| Mahal Al-Mubarak | *3* | 530 | 3225 | 85 | 11 | 78-98 | Good |
| Al-Shabariq | *2* | 772 | 5151 | 80 | 6 | 76-84 | Good |
| Belad Al-Requod | *4* | 1844 | 9963 | 85 | 26 | 64-121 | 75%Good;25%Poor |
| Al-Toraibah | *10* | 3893 | 21946 | 88 | 21 | 64-126 | 70%Good;30%Poor |
| Al-Zareebah | *12* | 1509 | 8227 | 97 | 9 | 82-110 | 50%Good;50%Poor |

**Table 5.** Correlation coefficient matrix of parameters, Population number (Pop) and WQI

| | **pH** | **EC** | **TDS** | **$Ca^{2+}$** | **$Mg^{2+}$** | **$NO_3^-$** | **$SO_4^{2-}$** | **$HCO_3^-$** | **$Cl^-$** | **TH** | **$K^+$** | **$Na^+$** | **Pop** | **WQI** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **pH** | 1.00 | | | | | | | | | | | | | |
| **EC** | 0.26 | 1.00 | | | | | | | | | | | | |
| **TDS** | 0.17 | 0.99 | 1.00 | | | | | | | | | | | |
| **$Ca^{2+}$** | 0.25 | 0.82 | 0.81 | 1.00 | | | | | | | | | | |
| **$Mg^{2+}$** | -0.25 | 0.41 | 0.44 | 0.12 | 1.00 | | | | | | | | | |
| **$NO_3^-$** | -0.53 | -0.04 | 0.02 | -0.03 | 0.11 | 1.00 | | | | | | | | |
| **$SO_4^{2-}$** | -0.07 | 0.55 | 0.58 | 0.31 | 0.68 | 0.02 | 1.00 | | | | | | | |
| **$HCO_3^-$** | -0.62 | -0.16 | -0.09 | -0.09 | 0.27 | 0.20 | 0.11 | 1.00 | | | | | | |
| **$Cl^-$** | 0.04 | 0.60 | 0.62 | 0.28 | 0.56 | 0.22 | 0.59 | -0.17 | 1.00 | | | | | |
| **TH** | -0.07 | 0.53 | 0.84 | 0.76 | 0.74 | 0.05 | 0.66 | 0.11 | 0.55 | 1.00 | | | | |
| **$K^+$** | -0.84 | -0.35 | -0.25 | -0.32 | 0.14 | 0.42 | 0.15 | 0.65 | -0.08 | -0.12 | 1.00 | | | |
| **$Na^+$** | -0.45 | 0.31 | 0.37 | 0.25 | 0.43 | 0.11 | 0.63 | 0.26 | 0.34 | 0.45 | 0.45 | 1.00 | | |
| **Pop** | 0.91 | -0.70 | -0.76 | -0.52 | 0.91 | 0.88 | -0.75 | -0.81 | 0.91 | -0.66 | 0.90 | 0.90 | 1.00 | |
| **WQI** | -0.03 | 0.90 | 0.92 | 0.68 | 0.68 | 0.22 | 0.75 | 0.06 | 0.75 | 0.77 | -0.04 | 0.50 | 0.29 | 1.00 |

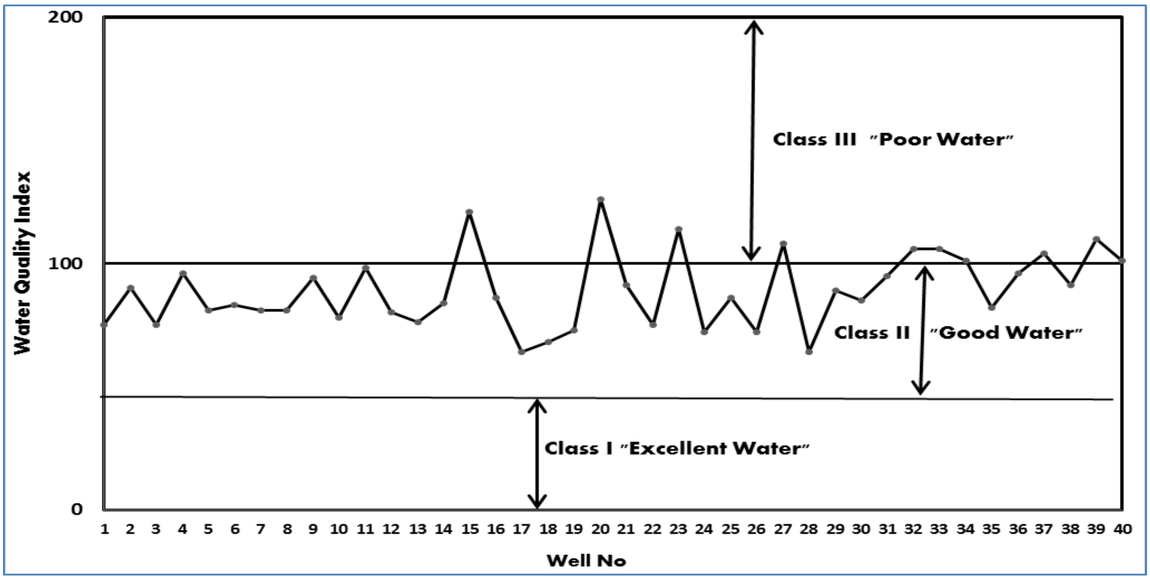


**Figure** 1: Values of WQI of studied samples

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# تطبيق دليل جودة المياه لتقييم نوعية المياه الجوفية

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DOI: https://doi.org/10.47372/uajnas.2017.n1.a13

## الملخص

الهدف الرئيسي من هذه الدراسة هو تقييم جودة المياه الجوفية في المناطق الريفية لمديرية زبيد – الحديدة لاستعمالها للشرب باستخدام دليل جودة المياه (WQI). تم جمع أربعون عينة من المياه الجوفية من منطقة الدراسة. مؤشر جودة المياه هو طريقة رياضية تستخدم لتسهيل تقييم نوعية المياه. تطلب حسابات دليل جودة المياه قياس العديد من المتغيرات الفيزيائية والكيميائية منها الرقم الهيدروجيني (pH)، الموصلية الكهربائية (EC)، الأملاح الذائبة الكلية (TDS)، العسرة الكلية (TH)، والأيونات السالبة (الكلوريد، الكبريتات، البيكربونات، والنترات)، والأيونات الموجبة (الكالسيوم، والمغنسيوم، الصوديوم، والبوتاسيوم). تشير قيم دليل جودة المياه (WQI) على أنَّ 75% من المياه الجوفية في منطقة الدراسة جيدة لاستخدام الشرب (الصنف الثاني)، و 25% مياه سيئة (الصنف الثالث)، وتراوحت قيم دليل جودة المياه بين 76 و 98؛ 101 و 126 على التوالي. وبناءً على هذا التقييم فإنَّ المياه الجوفية في منطقة الدراسة بشكل عام ذات جوده من الجيدة الى السيئة. وتعزى أسباب ارتفاع قيم دليل جودة المياه (WQI) في بعض مناطق الدراسة إلى النشاطات البشرية والنفايات المنزلية والزراعية.

**الكلمات المفتاحية:** المياه الجوفية، مقاييس جودة المياه، دليل جودة المياه..