2023, 20(6 Suppl.): 2395-2413
https://dx.doi.org/10.21123/bsj.2023.9348
P-ISSN: 2078-8665 - E-ISSN: 2411-7986

Baghdad Science Journal

A Novel Water Quality Index for Iraqi Surface Water

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Received 10/09/2023, Revised 18/10/2023, Accepted 18/10/2023, Published 05/12/2023

Abstract

The study aims to build a water quality index that fits the Iraqi aquatic systems and reflects the environmental reality of Iraqi water. The developed Iraqi Water Quality Index (IQWQI) includes physical and chemical components. To build the IQWQI, Delphi method was used to communicate with local and global experts in water quality indices for their opinion regarding the best and most important parameter we can use in building the index and the established weight of each parameter. From the data obtained in this study, 70% were used for building the model and 30% for evaluating the model. Multiple scenarios were applied to the model inputs to study the effects of increasing parameters. The model was built 4 by 4 until it reached 17 parameters for 10 sampling times. Obviously, with the increasing number of parameters, the value of the index will change. To minimize the effect of eclipse that arises in WQI and to solve the problem of overlapping quality and pollution, this study has created another index linked with IQWQI, which included both the quality and the degree of pollution. The second index is called the Environmental Risk Index (ERI), where only the variables that exceed the permissible environmental limits were included. Sensitivity Analysis was done to predicate IQWQI and to determine the most influential parameters in the IQWQI score; two types of models were chosen for the run of the sensitivity test, which are the Artificial Neural Network Regression (ANNR) and Backward Linear Regression (BLR). The results of IWOI and ERI for freshwater use during the dry season were very poor water quality with a high degree of risk. While in the wet season, both indices' values ranged from poor water quality to very poor water quality with a high degree of risk.

Keywords: ANNR, BLR, IQWQI, Iraq, Tigris River, Surface Water, Water Quality.

Introduction

When using WQIs to assess water quality monitoring data, results can be significantly interpreted, especially when pollutant concentrations are below the water quality criteria. In general, WQI can totally disregard the significance of sampling frequency in assessing water quality[1]. WQIs enable administrative decision-makers to evaluate the efficacy of regulatory programs and present information on water quality to the audience in an understandable and straightforward manner. They also assist professionals in separating monitoring data into a larger framework[2,3]. Indices were used for almost all monitoring programs, including environmental planning, water quality monitoring, assessment, treatment, and public awareness[4].

The establishment of a scientific approach for selecting a numerical index for identifying chemical water contamination was encouraged, according to a panel of the president's science consultative committee on environmental pollution[5]. The panel stated that different chemical contaminants must be detected by the method used. Its outcome is essentially proportionate to the harmful consequences that water pollution has on people or aquatic life. The index enabled many changes in water quality that followed. In response to this claim, Horton released the first water quality indicator (WQI) the same year[6]. Since then, WQIs have developed into a common and useful tool for evaluating the water quality of various water bodies all over the world[7-10]. Following Horton, Brown et al. [11] developed a WQI with a structure that is comparable to Horton's index[6]. Still, with much rigidity in selecting parameters, the National Sanitation Foundation (NSF) provided funding for the research conducted by Brown et al. [11]. Because of this, Brown's index is sometimes known as NSFWQI.

A WQI[12] was developed in 2020 by a team of Iraqi experts to assess the suitability of rivers for drinking. Using the Delphi method, a survey of 44 water quality management experts asked them to select and rate only 10 from 27 water quality parameters. According to the panel's recommendation, only six parameters were chosen for the index: TDS, COD, DO, Total Hardness, TC and Cl, and based on their opinions, weights were given for each parameter. The subindex for each parameter was taken by the average curve representing the variation in water quality level on a scale of 0-100. The next step included the aggregation of all subindices by weighted average. The final formula for the WQI is as follows: IraqiWQI= $[(-0.019\ TDS + 84.587) \times 0.2] + [(-0.006\ TC + 86.231) \times 0.2]+[10\ DO\times 0.2] + [(-0.119\ TH + 113.68) \times 0.15] + [-5.886\ COD+ 99.846) \times 0.1] + [(-0.12\ Cl + 106.58 \times 0.15]$. This index has a fixed system of parameters that cannot allow for a new parameter. Also, elements and toxic substances were not included and are restricted to only drinking water use.

Due to the depletion of water supplies, expansion of agriculture, an increase in drainage, and high temperatures, the quality of the water is declining toward the middle and southern regions of Iraq. As a result, there are more salts and pollutants in this water, which is seen in the areas' drinking water quality[13]. In light of these factors, it is essential to regularly evaluate the river's water quality in order to determine its suitability for various uses and to detect pollution as soon as possible so that the appropriate authorities can take the necessary action[14].

Because of the absence of water quality models that mimic the environmental reality of Iraqi water, this study aims to develop a water quality index that fits the Iraqi aquatic system consisting of physical and chemical factors.

Materials and Methods

Sites Description

Climate

The Iraqi climate is arid to semi-arid, with dry, hot summer and cold winter. Moreover, it has low humidity and low precipitation[7], and the mean annual rainfall is about 11.02 mm. Climate elements affect the hydrological characteristics of the river, as temperature affects the amount of evaporation. Temperature increases in summer, which leads to the evaporation of water and an increase in salinity in the surface water. The rise in water temperature affects aquatic organisms by, for example, decreasing oxygen, accelerating the organic dissolution of polluted organic materials, and increasing the toxicity of some chemical pollutants[15]. In addition, Intergovernmental Panel on Climate Change (IPCC) has identified Iraq as highly vulnerable to climate change[16]. According to the two main seasons (Wet and Dry) in Iraq are based on the relative humidity RH% Table 1, in which above 50 RH% is considered a wet season, while less than 50 RH% is considered a dry season[14].

Table 1. Climate rate during the study period (source; Ministry of Transport/Iraqi Meteorological and Seismology 2020-2021))

	Months									
	Ju. 2020	Au.2020	Se.2020	Oc.2020	No.2020	De.2020	Ja.2021	Fe.2021	Ma.2021	Ap.2021
RH%	21.0	24.0	27.0	34.0	60.0	69.0	55.0	59.0	41.0	31.0

Study site

Five sites were chosen for conducting the study along the Tigris River within Baghdad City during 2020-2021, starting from Al-Muthana Bridge (north of Baghdad) and ending before the confluence between the Tigris and Diyala Rivers to the south of Baghdad City (Fig. 1), Table 2, represents the Global Positioning System for the sites. The first site (Al-Muthanna Bridge) is located at the entrance of the Tigris River into Baghdad city, this site represents the northern part of the Tigris River, a natural area influenced mainly by fisheries and agricultural activity and didn't have industrial activities. The second site (Al-Greaat Area) is located under a floating Bridge for pedestrian crossing, this site is about 7.99 km away from the first site, the area's nature is agricultural and rich, with palm groves and submerged plants on both edges and people visit this place to relax and go to restaurants, therefore, a lot of food scraps and plastic waste can be found near the river in this site. Site three (Al-Sarrafia Bridge) has a lot of human activity like restaurants, fisheries, residential buildings, etc, the distance between this site and the second site is about 7.52 km and it is located in the middle of Baghdad city. The fourth site (Al-Jadriyah Bridge) is predominantly urban with little agricultural activity on the campus of the University of Baghdad, the western part of this area has been converted into an artificial pool (Al-Jadriyah Lake for tourism), where water is pumped from the Tigris River into this lake, the distance between the third and fourth site is about 7.99 km. The Fifth site (Al Za'franiya Area) is located southeast of Baghdad, before the mouth of the Diyala River, this site is influenced by many industrial activities which are located on the bank of the river, part of which belongs to the government sector and other parts to the private sector, like the vegetable oil plant under the Al-Dora Bridge and Al-Rasheed Power Station south of Baghdad (gas and thermal station) and various sources of water are brought to the river from these sectors, today this site is crowded with population due to urban development and an increase in municipal services.

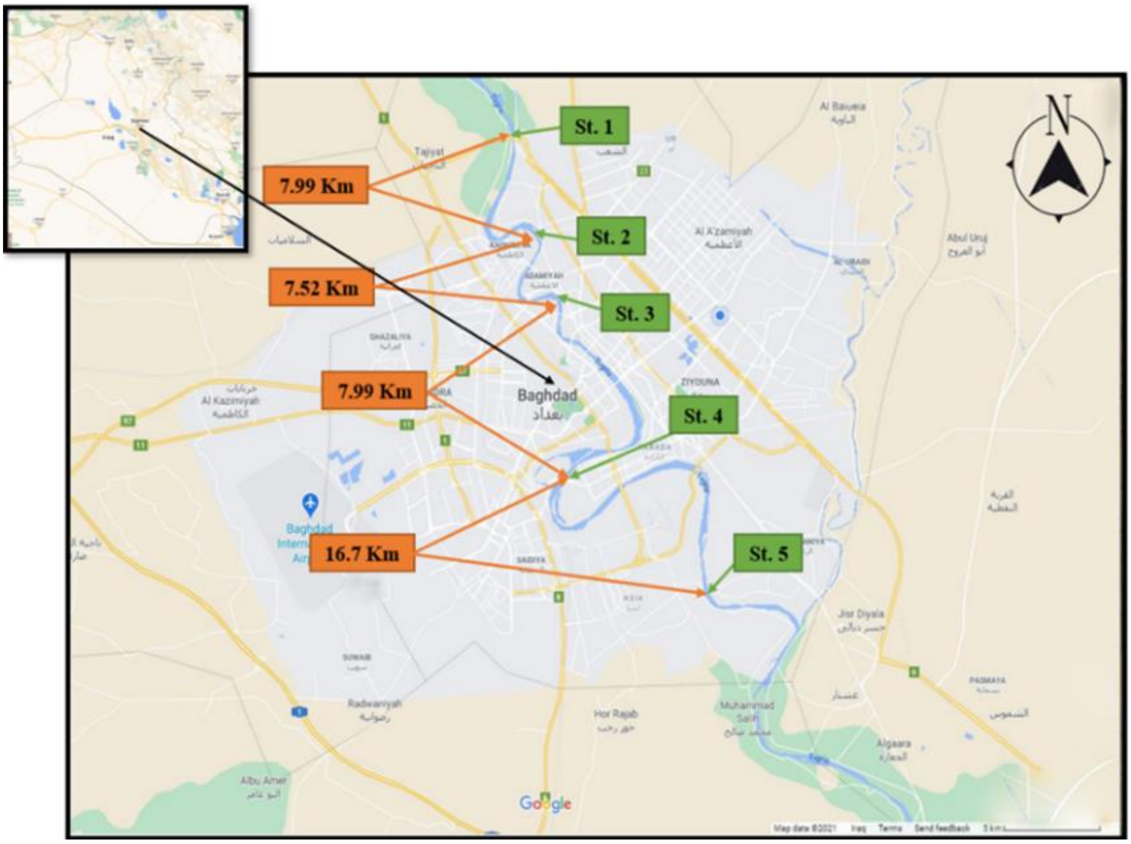

Figure 1. Sampling sites across Tigris River, Baghdad City (google earth, 2022) (green boxes represent the sites and the orange boxes represent the distance between each two sites).

2023, 20(6 Suppl.): 2395-2413
https://dx.doi.org/10.21123/bsj.2023.9348
P-ISSN: 2078-8665 - E-ISSN: 2411-7986
Baghdad Science Journal

Table 2. The geographical positions (GPS) of the study site

	Position	Longitude	Latitude
St. 1	Al-Fahamah area	44°20'43.30"E	33°25'42.19"N
St. 2	Al-Greaat area	44°20'55.54"E	33°23'26.41"N
St. 3	Al-Sarrafia Bridge	44°22'22.84"E	33°21'11.55"N
St. 4	Al-Jadriyah Area	44°22'27.69"E	33°17'1.39"N
St. 5	Al-Za'franiya Area	44°27'18.95"E	33°14'0.08"N

Water Samples

Three water samples were taken from each site: one from each bank of the River and one from the middle. The average sampling time was between 7:00 AM to 6:30 PM. Each sample was collected from the subsurface (about 20-30 cm below the surface) in clean stopper-fitted polyethylene bottles. Before filling the bottles with the required sample, they were rinsed in river water several times. The samples were preserved in an ice-cool box until they were taken to the laboratory and subjected to physical and chemical analyses. Laboratory measurements were conducted 24 hours after sampling at the Environmental Research Center-University of Technology-Iraq. Field and laboratory measurements represented in Table 3 were carried out according to APHA[17].

Iraqi WQI (IQWQI) Model Development Questionnaires

Delphi method was used to determine the final weight. Delphi technique can be defined as a communication method aimed at forming standards and guidelines and predicting trends[18]. A typical step was followed when using the Delphi method started with:

A- In developing the initial Delphi questionnaire, 55 parameters were selected for 4 water usages (freshwater, aquatic life protection, agriculture, and raw drinking water) to prepare the questionnaire, including the parameters plus reasons and justifications for including them in the WQI. In the questionnaire, the respondents were asked to choose the most important parameters from their point of view and experience to evaluate the uses referred to above, giving a weight value for each parameter (from 1 to 5) (unconditional Integers), where the weight value (1) represents the least important and the weight value (5) is the most important (Supplement 1).

B- Selecting the expert panel; 76 experts from academics and engineers with expertise in water quality management, starting with experts with Assistant Professor titles and above.

C- Distributing the questionnaire; it was sent to the experts to collect the information and their opinions; the questionnaire will help identify the most appropriate parameters used to develop the Iraqi Water Quality Indices and assign a weight for each parameter.

D- Collecting and analyzing the questionnaire, from the 76-expert panel, 32 responded, 4 refused to participate, and 40 did not respond. Eight respondents have been excluded from the 32 respondents due to a lack of information.

Parameters selection

Based on the purpose of the water uses, the parameters were chosen for the freshwater purposes for IQWQI, and the value of the standard for each parameter is shown in Table 3.

Table 3. Parameters chosen for calculation of WQI for Freshwater (Natural) uses with their guidelines arranged in descending order according to wights, Turbidity in NTU, other parameters in mg. L^{-1}

	Parameters	Observed Value				Standard value	Reference
		Dry		Wet			
		Mean ±SD	Min-Max	Mean ±SD	Min-Max		
1.	DO	6.4±0.2	6.1-6.5	8.1±0.2	7.8-8.3	5	19
2.	BOD_5	1.22±0.20	1.01-1.47	1.41±0.19	1.15-1.70	Less 5	19
3.	pH	7.9±0.0	7.9-8.0	8.1±0.1	8.1-8.3	6.5-8.5	19
4.	CN	0.024±0.003	0.020-0.030	0.016±0.001	0.014-0.017	0.02	19
5.	TDS	595.4±26.5	562.3-630	678.7±22.7	639.3-695	500	20
6.	PO_4	0.33±0.02	0.31-0.35	0.76±0.03	0.74-0.80	0.40	19
7.	Cr	0.058±0.022	0.020-0.070	0.0±0.0	0.0-0.0	0.05	19

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https://dx.doi.org/10.21123/bsj.2023.9348
P-ISSN: 2078-8665 - E-ISSN: 2411-7986
Baghdad Science Journal

8.	NO_3^-	5.92±0.97	4.30-6.55	5.34±1.04	3.99-6.25	15	19
9.	Ni	0.039±0.046	0.010-0.120	0.084±0.123	0.01-0.3	0.10	19
10.	Cl^-	185.5±18.9	163.2-207.2	193.4±5.5	184.1-198.5	200	19
11.	Pb	0.201±0.038	0.140-0.250	0.121±0.053	0.07-0.21	0.05	19
12.	SO_4^{-2}	192.8±6.7	184.4-201.5	232.7±19.7	202.3-252.2	200	19
13.	Zn	0.017±0.004	0.010-0.020	0.025±0.019	0.0-0.05	0.50	19
14.	Turb.	34.4±1.2	33.3-36.4	22.4±2.7	20.1-25.9	50	21
15.	Al	0.019±0.003	0.010-0.020	0.017±0.007	0.010-0.030	0.10	19
16.	Fe	0.212±0.079	0.130-0.310	0.077±0.03	0.04-0.12	0.30	19
17.	F^-	0.16±0.014	0.14-0.18	0.13±0.014	0.1-0.16	0.20	19

Weight Assignment

Parameter weighting help to assign relative importance to each parameter and illustrate interrelations between different parameters[22]. Based on the expert opinion, each parameter was assigned a weight (AW) from 1-5, and the main values of the weight were used. Then the temporary weight (tW) was calculated where a temporary weight of 5 was assigned to the parameter which gained the highest rating. All other temporary weights of the parameters were obtained by dividing the highest significance rating by the individual mean rating. Each temporary weight was then divided by the sum of all the temporary weights to arrive at the final weight, as shown in the following equation (Eq. 1).

$$final\ Wi = \sum \frac{t\,W}{\sum tW} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 1}$$

Where tW= temporary weight. It should be considered that the total final weight (the summation of all weights of parameters) is 1.0 for WQIs.

Sub-indices Formation and Aggregation of Functions

After assigning weights, index aggregation is performed to obtain the final index score. Aggregation occurs in sequential stages where the index aggregates sub-indices. The sub-index (SI) is determined for each parameter (Eq. 2), and the quality rating is calculated as in Eqs. 3 and 4. The additive (arithmetic) method reached the final index (Eq. 5).

$$SI_i = final\ wight \times Q_i \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 2}$$

$$Qi = \frac{C_i - C_{ideal}}{S_i - C_{ideal}} \times 100 \text{ for pH and DO} \ldots\ldots\ldots \text{Eq. 3}$$

$$Qi = \frac{C_i}{S_i} \times 100 \text{ for other parameters} \ldots\ldots\ldots\ldots \text{Eq. 4}$$

SI_i= the sub-index of ith parameter; Q_i= quality rating based on the concentration of ith parameter; C_i= is the observed value of the nth parameter; S_i= is the standard value of the nth parameter; C_{ideal} for DO= 14.6; C_{ideal} for pH=7; W*i*= final wight.

$$IraqiWQI = \sum SI_i / Wi \ldots\ldots\ldots \text{Eq. 5}$$

Water Quality Rating

According to Tyagi *et al.* [23], the best rating compatible with the Weighted Arithmetic Water Quality Index model is the NSFWQI model. It is given in Table 4, where WQI = 0 is the best value and WQI > 100 is unsuitable for use where the sub-indices qi are not restricted to the range 0 – 100. Consequently, it is possible that WQI > 100.

Table 4. Water quality rating as per weight arithmetic water quality index method[19]

WQI Value	Rating of Water Quality	
0 – 25	Excellent water quality	Blue
26- 50	Good water quality	Green
51 – 75	Poor water quality	Yellow
76 – 100	Very Poor water quality	Orange
> 100	Unsuitable	Red

Environmental Risk Index

WQI, raises the problem of the eclipse, which is a term used to describe how the final WQI score hides the effects of the parameters that exceed the allowed levels and eventually masks the true nature of WQ, this situation occurs while applying the mathematical formula[24], where lowly weighted sub-indices may be dominated by highly weighted sub-indices, or vice versa, putting the overall water quality rating in a questionable situation. Some

2023, 20(6 Suppl.): 2395-2413
https://dx.doi.org/10.21123/bsj.2023.9348
P-ISSN: 2078-8665 - E-ISSN: 2411-7986
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researchers mentioned the eclipsing problem[22]. Ott [25] was the first author that pointed to eclipsing and described it as "poor environmental quality exists for at least one pollutant variable, but the overall index does not reflect this" the problems of eclipsing worsen as the number of parameters increase. Swamee and Tyagi [26] and Smith [27] referred to the eclipsing problem as "the index score hides the parameter responsible for limiting that water's suitability for the particular use and the degree by which it does this". The eclipsing can occur by one of the following; (i) inappropriate sub-indexing, (ii) parameter weightings that do not accurately reflect the relative importance of the parameters (iii) aggregation functions that are not appropriate[28].

Example of eclipsing: in 4 virtual environmental parameters result, the observed value of one of them is beyond the permissible limit Table 5. The final index score might indicate good water quality, even though one of the parameters does not meet its permissible limit, so the parameter failure is hidden or eclipsed by the aggregation function.

Table 5. Example of eclipsing

Parameters (mg. L^{-1})	Nitrate	Cadmium	Phosphorus	Chromium
observed Value	7.1583	0.0001	0.344	**0.095**
Permissible limit	15	0.0005	0.4	0.05
Sub-index	16.626	1.0727	5.7109	3.9921
Final WQI	**85 = Good Water Quality**			

So, it was thought that there would be another index linked with the water quality index to be included in its calculation called Environmental Risk Index (ERI), where only the variables that exceed the permissible environmental limits are included.

The calculation depends on the concentration of each parameter that exceeded the permissible limit (Eqs. 6.1, 6.2.).

$$ERI = \sum_i^n R_d^i \text{ ....Eq. 6.1}$$

$$R_{id} = \frac{C_i}{S_i} \text{ .... Eq. 6.2}$$

Ci= is the observed value of the nth parameter
Si= is the standard value of the nth parameter

Based on the degree of contamination categories mentioned in[29], the ERI was built with some modifications to be compatible with this study Table 6.

Table 6. Categories of the Environmental Risk Index modified from[29]

Categories	**ERI classes**	
no risk	0	Blue
low degree of risk	0 - < 8	Green
medium degree of risk	8 ≤ Cd>16	Yellow
considerable degree of risk	16 ≤ Cd>32	Orange
high degree of risk	Cd ≥ 32	Red

The final calculation of the IQWQI was made by Microsoft Excel ver. 19, where the fixed cell contains the component of the WQI; parameter, mean of respondents, temporary weights, final weight, observed value, standard value, and sub-index. All these cells are linked with the final WQI equation to generate the final score.

Canadian Council of Ministers of the Environment Water quality index (CCMEWQI)

The Canadian WQI was calculated in this study to be compared with the results of IQWQI. The CCMEWQI is a mathematical approach for evaluating surface water for various purposes following specific criteria[30]. The index is computed by summing the three factors according to Eq. 7. As indicated in Table 7. The index is based on three factors.

$$CCMEWQI = 100 - \frac{\sqrt{f_1^2+f_2^2+f_3^2}}{1.732} \text{ .... Eq. 7}$$

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https://dx.doi.org/10.21123/bsj.2023.9348
P-ISSN: 2078-8665 - E-ISSN: 2411-7986
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Table 7. Calculation of the factors of CCMEWQI

Factors	Equations
F1 (Scope)	$f_1 = \frac{number\ of\ parameters\ that\ do\ not\ comply\ with\ standard\ or\ objective}{\text{total number of parameters}} \times 100$
F2 (Frequency)	$f_2 = \frac{number\ of\ \text{tests that do not meet objectives (failed tests)}}{\text{total number of parameters}} \times 100$
F3 (Amplitude)	$Excursion = \left(\frac{Failed\ test\ value\ i}{Objective\ i}\right) - 1.$ When the test value must not exceed the objective. $Excursion = \left(\frac{Objective\ i}{Failed\ test\ value\ i}\right) - 1.$ When the test value must not fall below the objective. $nse = (\sum Excursion)/(number\ of\ tests)$ $f3 = (nse/(0.01nse + 0.01))$

Statistical Analyses

Jeffrey's Amazing Statistics Program (JASP) for statistical analysis based on R programming language was used to conduct the sensitivity analysis for IQWQI for freshwater use (17 parameters). The dataset used in the calculations consisted of 108 values for each parameter. The data is split into 70% for training the network and 30% for testing.

Results and Discussion

IQWQI Calculation

Parameters selection

70% of the data obtained from this study was used for developing the model**.** Water quality parameters are chosen based on the most concerned and available standards Table 3. The parameters set are selected based on Iraqi and international water maintenance standards. The first set for building the IQWQI was for freshwater use. This set contains 17 parameters Table 3. These parameters were used to identify the overall health of the Tigris River.

Weight assignment

The Delphi process obtained the parameter weight values. The parameter weight values are estimated based on the relative importance of the water quality parameter and/or the appropriate water quality guidelines[24]. The subindices were calculated for each parameter (for four water uses based on the expert panel drift from the Delphi method, first of all, it must take the average rating returned by respondents and then transform each parameter to temporary weights by dividing the parameter with the highest rate by the other parameters Table 8, first red box, and the parameter with the highest rating is given a full rating value which is 5, then, to determine the final weight for each parameter included in the model each temporary weight is divided by the sum of all temporary weights of parameters example 1, individual parameter concentrations is transformed to the same scale. Weighting aims to assign relative importance to each parameter and elucidate interrelations between different parameters. To ensure that the final wights are correct, the sum of all final wights must be 1, as reported by[2], where the majority of WQI models applied unequal weighting techniques where the sum of all of the parameter weight values was equal to 1 Table 8, last red box.

Table 8. Weight Assignment for Studied Parameters

Parameters	mean of rating returned by respondents	tW= temporary wight	W_i=final weight	Qi=[Ci/S_i]*100	S_{ii}=RW*QI
DO	4.170	5.000	0.203	78.642	15.980
BOD^5	3.880	1.075	0.044	25.320	1.106
pH	3.880	1.075	0.044	200.053	8.738
CN^-	3.890	1.072	0.044	102.823	4.480
TDS	3.760	1.109	0.0451	124.738	5.622
PO_4^{3-}	3.700	1.127	0.046	58.442	2.677
Cr^+	3.680	1.133	0.046	64.490	2.970
NO_3^-	3.650	1.142	0.046	39.867	1.851
Ni^+	3.470	1.202	0.049	56.287	2.749
Cl^-	3.460	1.205	0.049	94.664	4.637

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https://dx.doi.org/10.21123/bsj.2023.9348
P-ISSN: 2078-8665 - E-ISSN: 2411-7986
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Pb^{+}	**3.380**	**1.234**	**0.050**	**325.144**	**16.303**
SO_4^{-2}	**3.260**	**1.279**	**0.052**	**103.527**	**5.382**
Zn^{+}	**3.220**	**1.295**	**0.053**	**3.946**	**0.208**
Turb.	**3.060**	**1.363**	**0.055**	**59.811**	**3.313**
Al^{3+}	**3.060**	**1.363**	**0.055**	**18.367**	**1.017**
Fe^{2+}	**2.980**	**1.399**	**0.057**	**63.943**	**3.636**
F^{-}	**2.720**	**1.533**	**0.062**	**73.257**	**4.564**
sum	**-**	**24.6059**	**1.00000**	**-**	**-**

A linear scaling function was applied to convert parameter values to the sub-index (equation), where sub-index values were assigned based on the pollution condition[2] (example 2). It can be noticed from Table 8 that DO, Pb. pH and SO_4 have a high value of sub-index, which correlates with the high the values of these parameters in the guidelines as previously explained and it must be kept in mind that the calculation of DO and pH differ from the rest where both of them must approach ideal values which are 14.6 for DO and 7 for pH. For a more detailed explanation of the calculation of IQWQI, see examples 1 and 2.

Example 1. Calculation of temporary weights.

parameter	mean of rating returned by respondents	temporary weights	
DO	4.170	5	5.000
BOD^5	3.880	=4.17/3.88	1.075
pH	3.880	=4.17/3.88	1.075
CN^{-}	3.890	=4.17/3.890	1.072
PO_4^{3-}	3.700	=4.17/3.70	1.127
Cr^{+}	3.680	=4.17/3.680	1.133
NO_3^{-}	3.650	=4.17/3.650	1.142
Ni^{+}	3.470	=4.17/3.470	1.202
Cl^{-}	3.460	=4.17/3.460	1.205
Pb^{+}	3.380	=4.17/3.380	1.234
SO_4^{-2}	3.260	=4.17/3.260	1.279
Zn^{+}	3.220	=4.17/3.220	1.295
Al^{3+}	3.060	=4.17/3.060	1.363
Fe^{2+}	2.980	=4.17/2.980	1.399
F^{-}	2.720	=4.17/2.720	1.533
TDS	3.760	=4.17/3.760	1.109
Turb.	3.060	=4.17/3.060	1.363
(Sum)			**24.6059**

Example 2. Final weight Wi and quality rating formation.

	Wi	**Result of Wi**	**Qi=[Ci/Si]*100**	**Result of Qi**
DO	=5.000/24.6059	0.203	=((7.05-14.6)/(5-14.6))*100	78.642
BOD^5	=1.075/24.6059	0.044	= (1.27/5) *100	25.320
pH	=1.075/24.6059	0.044	= ((8-7)/(7.5-7)) *100	200.053
CN^{-}	=1.072/24.6059	0.044	= (0.02/0.02) *100	102.823
PO_4^{3-}	=1.127/24.6059	0.046	= (0.23/0.4) *100	58.442
Cr^{+}	=1.133/24.6059	0.046	= (0.03/0.05) *100	64.490
NO_3^{-}	=1.142/24.6059	0.046	= (5.98/15) *100	39.867
Ni^{+}	=1.202/24.6059	0.049	= (0.06/0.1) *100	56.287
Cl^{-}	=1.205/24.6059	0.049	= (189.33/15) *100	94.664
Pb^{+}	=1.234/24.6059	0.050	= (0.16/0.05) *100	325.144
SO_4^{-2}	=1.279/24.6059	0.052	= (207.05/200) *100	103.527
Zn^{+}	=1.295/24.6059	0.053	= (0.02/0.5) *100	3.946
Al^{3+}	=1.363/24.6059	0.055	= (0.02/0.1) *100	18.367
Fe^{2+}	=1.399/24.6059	0.057	= (0.19/0.3) *100	63.943
F^{-}	=1.533/24.6059	0.062	= (0.15/0.2) *100	73.257

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https://dx.doi.org/10.21123/bsj.2023.9348
P-ISSN: 2078-8665 - E-ISSN: 2411-7986
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TDS	=1.109/24.6059	0.0451	= (623.69/500) *100	124.738
Turb.	=1.363/24.6059	0.055	= (29.91/50) *100	59.811
(Sum)		**1.00000**		

Aggregation

The aggregate parameters collection process consolidates all parameters' quality scores obtained from subindices into a single water quality index score. A simple additive aggregation function was used to aggregate sub-indices. This final step is essential to produce a single unitless number representing overall water quality relative to the chosen guideline (Example 3).

Example 3. Subindices Formation and Aggregation

	SI_i=RW*QI	Result of SI_i	IQWQI=∑SIi/ W_i	IQWQI
DO	=0.203*78.642	15.980	= [15.980 + 1.106 + 8.738 + 4.48 + 2.677 + 2.970 + 1.851 + 2.74 + 4.637 + 16.303 + 5.382 + 0.208 + 1.017 + 3.636 + 4.564 + 5.622 + 15.980]/ 1.0000	**85.23**
BOD^5	=0.044*25.320	1.106		
pH	=0.044*200.053	8.738		
CN^-	=0.044*102.823	4.480		
PO_4^{3-}	=0.046*58.442	2.677		
Cr^+	=0.046*64.490	2.970		
NO_3^-	=0.046*39.867	1.851		
Ni^+	=0.049*56.287	2.749		
Cl^-	=0.049*94.664	4.637		
Pb^+	=0.050*325.144	16.303		
SO_4^{-2}	=0.052*103.527	5.382		
Zn^+	=0.053*3.946	0.208		
Al^{3+}	=0.055*18.367	1.017		
Fe^{2+}	=0.057*63.943	3.636		
F^-	=0.062*73.257	4.564		
TDS	=0.0451*124.738	5.622		
Turb.	=0.055*59.811	15.980		

IQWQI and ERI test

Sutadian [31] reported that CCME could work using four parameters for four sampled times. From this fact, Multiple scenarios were applied to the model inputs to see the effect of the increasing number of parameters. The model started to be built from 4 by 4 until it reached 17 parameters for 10 sampling times. With the increasing number of parameters, the index's value will change, which appears whenever the number of parameters and the sampling time increase, as proven in the cases below Table 9.

Scenario 1: 4 parameters (DO, BOD_5, pH, CN^-**)** by 4 sampled times, the result of the IQWQI was 30.3, and the ERI was 3.57, indicating a **good water quality** with a **low degree of risk** in the same time the IQWQI was compared with CCME to confirm that the new model was compatible with others models. The CCME result was 81.84 (good water quality) and was calculated for the same parameters used for IQWQI. The result of both indices came in the same category.

Scenario 2: 5 by 5 (DO, BOD_5, pH, CN^-, PO_4^{3-}), the resulting rank of both the indices IQWQI and ERI are still the same (a **good water quality** with **a low degree of** risk) with the change in the values 32.98 and 6.2, respectively. The CCMEWQI rank was in the good category.

Scenario 3: 6 by 6 (DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+) with the increase of parameters and the sample times, the value of water quality started to change, where IQWQI was 35.95 as shown in Table 9, the water quality is still within the good category, but the effect of eclipsing starts to rise which couldn't be indicated with IQWQI only, here the value of using the ERI appears as its value was 12.65 because the effect of the Cr^+ where its concentration was way beyond the limits where its concentration reach to 0.33 mg/l while the limits were 0.05 mg/l[18], where this index focus on the effect of only the parameters exceeded the permissible limits, and it could be said that the water quality is **good,** but there is a **medium degree of risk**. The CCMEWQI rank has a fair category. It could be said it's compatible with IQWQI

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https://dx.doi.org/10.21123/bsj.2023.9348
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because the rank of CCMEWQI, in this case, didn't go far from the good Categories of IQWQI. It does not skip to other categories like marginal or poor.

Scenario 4: 7 by 7 (DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+, NO_3^-); in this case, water quality index value was 37.8, and the value of ERI was 14.85, both values (IQWI and ERI) increased, and still with the rank of **good water quality** with a **medium degree of risk**, the increase came from the of PO_4^{3-} where its mean concentration was 0.594 mg/l which is above the limit 0.4 mg/l[19]. CCME is still within the Fair categories.

Scenario 5: 8 by 8 (DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+, NO_3^-, Ni^+), the result of IQWQI was 40.55, and ERI was 19.89. In this case, the ERI values increased, and the categories shifted to the next level (considerable degree of risk) because of the effect of Ni^+ concentration[19]. Here, the importance of ERI can be seen because only it can detect the effect of dangerous parameters. IQWQI and CCMEWQI categories are still good and fair, they couldn't track this problem because they deal with total parameters, and in the end, the effect of the particular dangerous parameters will be lost. So, in this case, the final result of WQ was **good water** with considerable **risk**.

Scenario 6: 9 by 9 **(**DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+, NO_3^-, Ni^+, Cl^-), as the parameters and the sampled increased over time, the results of the three indices changed. The value of IQWI and ERI were 45.18 and 24.26, respectively. This was increasingly caused by the entrance of Cl to the calculations, but still with categories of **good water** with a **considerable degree of risk,** in addition to CCME in fair rank.

Scenario 7: 10 by 10 **(**DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+, NO_3^-, Ni^+, Cl^-, Pb^+). In this study, the concentrations of Pb were mostly out of the limit in all sites. This situation was demonstrated by many researchers that worked on the Tigris River. The mean concentration of Pb^+ was 0.163 mg/l, and the limit was 0.05 mg/l (Law25, 1967), which is threefold the limit. The concentration of this parameter shifted the three indices' rank to a worse situation. IWQ, ERI and CCME results were 61.48, 60.43 and 55.4, respectively. With the presence of Pb, the water quality became poor, and the ERI value doubled, jumping from 24.26 to 55.4 and shifting the index to the worst Scenario. Finally, this case resulted in p**oor water quality** and high **risk.** The CCME category was marginal but still compatible with IQWI, where both scaled down by one step, as mentioned in Scenario 2.

Scenario 8: 11by 10 **(**DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+, NO_3^-, Ni^+, Cl^-, Pb^+, SO_4^{2-}). SO_4^{2-}, With the combination of other parameters, the IQWQI and ERI values increased and became 66.87 and 63.32, respectively, and water quality was **Poor water quality** with a **high degree of risk.**

Scenario 9: 12 by 10 **(**DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+, NO_3^-, Ni^+, Cl^-, Pb^+, SO_4^{2-}, Zn^+). As in the previous case, the water quality is still the same (**Poor water quality** with a **high degree of risk).** Where the value of IQWQI was 67.07 and ERI was 63.32. CCME rank still agreed with IQWQI.

Scenario 10: 13 by 10 **(**DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+, NO_3^-, Ni^+, Cl^-, Pb^+, SO_4^{2-}, Zn^+, Al^{3+}). The water quality was **Poor water quality** with a **high degree of risk.** Where the value of IQWQI was 68.09 and ERI was 63.32. The value of ERI in cases 9 and 10 was the same because no additional exceeded parameters were entered into the index, in contrast to the IQWI and CCME, where their values changed because they considered the total number of parameters. CCME rank still agreed with IQWQI.

Scenario 11: 14 by 10 **(**DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+, NO_3^-, Ni^+, Cl^-, Pb^+, SO_4^{2-}, Zn^+, Al^{3+}, Fe^{2+}). With the entrance of Iron, the IQWQI increased to 71.33. Fe only exceeded the limit once, causing an increase in the ERI value of 66.51. However, the water quality was **Poor water quality** with a **high degree of risk.**

Scenario 12: 15 by 10 **(**DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+, NO_3^-, Ni^+, Cl^-, Pb^+, SO_4^{2-}, Zn^+, Al^{3+}, Fe^{2+}, F^-) The water quality was **Poor water quality** with a **high degree of risk**. The value of IQWQI was 73.4 and ERI was 66.58.

Scenario 13: 16 by 10 **(**DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+, NO_3^-, Ni^+, Cl^-, Pb^+, SO_4^{2-}, Zn^+, Al^{3+}, Fe^{2+}, F^-, TDS): with increasing the number of parameters, the values of IQWQI increased, and its rank lay in **very Poor water quality**. The mean concentration of TDS was above the limit at 657.81 and influenced the values of both indices, where the value of IQWQI was 81.91 and ERI was 77.24. Therefore, in this case, the water quality was very poor, with **high risk.**

Scenario 14: 16 by 10 **(**DO, BOD_5, pH, CN^-, PO_4^{3-}, Cr^+, NO_3^-, Ni^+, Cl^-, Pb^+, SO_4^{2-}, Zn^+, Al^{3+}, Fe^{2+}, F^-, TDS, Turbi.): even with the entrance of turbidity, the water quality status remain the same "**very Poor water quality** with **a high degree of risk,"** but the values of the indices changed a little, the value of

IQWQI was 85.23, and the value of ERI 78.21 where the turbidity exceeds the limit once.

Table 9. Scenarios of IQWQI development for the present study

Scenarios	N. of Parameters	IQWQI	WQI CCME	Environmental Risk Index (ERI)	Only parameter exceeded
Scenario 1	4	30.30 Good water quality	81.848 Good water quality	3.570 low degree of risk	CN^-
Scenario 2	5	32.981 Good water quality	84.483 Good water quality	6.217 low degree of risk	CN^-
Scenario 3	6	35.950 Good water quality	76.822 Fair	12.657 medium degree of risk	$CN^- + Cr^+$
Scenario 4	7	37.802 Good water quality	72.790 Fair	14.856 medium degree of risk	$CN^- + Cr^+ + PO_4^{3-}$
Scenario 5	8	40.551 Good water quality	69.081 Fair	19.893 considerable degree of risk	$CN^- + Cr^+ + PO_4^{3-} + Ni^+$
Scenario 6	9	45.187 Good water quality	65.876 Fair	24.267 considerable degree of risk	$CN^- + Cr^+ + PO_4^{3-} + Ni^+ + Cl^-$
Scenarios 7	10	61.490 Poor water quality	60.430 Marginal	55.432 high degree of risk	$CN^- + Cr^+ + PO_4^{3-} + Ni^+ + Cl^- + Pb^+$
Scenario 8	11	66.872 Poor water quality	58.013 Marginal	63.322 high degree of risk	$CN^- + Cr^+ + PO_4^{3-} + Ni^+ + Cl^- + Pb^+ + SO_4^{2-}$
Scenario 9	12	67.079 Poor water quality	61.423 Marginal	63.322 high degree of risk	$CN^- + Cr^+ + PO_4^{3-} + Ni^+ + Cl^- + Pb^+ + SO_4^2$
Scenario 10	13	68.096 Poor water quality	64.316 Marginal	63.322 high degree of risk	$CN^- + Cr^+ + PO_4^{3-} + Ni^+ + Cl^- + Pb^+ + SO_4^2$
Scenario 11	14	71.733 Poor water quality	62.840 Marginal	66.581 high degree of risk	$CN^- + Cr^+ + PO_4^{3-} + Ni^+ + Cl^- + Pb^+ + SO_4^2 + Fe^{2-}$
Scenario 12	15	73.30 Poor water quality	64.264 Marginal	66.581 high degree of risk	$CN^- + Cr^+ + PO_4^{3-} + Ni^+ + Cl^- + Pb^+ + SO_4^2 + Fe^2$
Scenario 13	16	81.919 very Poor water quality	63.035 Marginal	77.240 high degree of risk	$CN^- + Cr^+ + PO_4^{3-} + Ni^+ + Cl^- + Pb^+ + SO_4^2 + Fe^2$ +TDS
Scenario 14	17	85.232 very Poor water quality	62.039 Marginal	78.241 **high degree of risk**	$CN^- + Cr^+ + PO_4^{3-} + Ni^+ + Cl^- + Pb^+ + SO_4^2 + Fe^2$ +TDS +Turbi

Sensitivity Analysis for IQWQI

This study used the sensitivity analysis based on Artificial Neural Network Regression (ANNR) and Backward Linear Regression (BLR) to determine which water quality parameter most influences the score of IQWQI. Sensitivity analysis studies an output parameter's response concerning input parameter variations[32]. A model performance R^2, RMSE and SSE were used for model performance evaluation for both ANNR and BLR and to make a comparison with them to see which will give the more accurate results, where these three criteria significantly affect the fitness and residual measurement of the ANNR and BLR models in WQI prediction. The comparison was made by removing one parameter each time from the calculation of IQWQI and comparing the results with the result of IQWQI, which includes all parameters (IQWQI-Ref.). High R^2 values and low RMSE and SSE values indicate non-influencing parameters in calculating water quality. In contrast, low R^2 and higher RMSE and SSE values indicate influencing factors in calculating water quality.

The dataset used as input data (108 values for each parameter) was subjected to Standardized to ensure a fair representation of parameters in the value of IQWQI. 17 parameters (from WQI calculation) were selected as input and IQWQI as the output for ANNR-IQWQI and BLR-IQWQI models.

The first model includes all parameters and represents the input parameters called IQWQI-Ref, which serve as a reference model for ANNR and BLR. To assess the significance of the input parameters of IQWQI-Ref, the sensitivity analysis for each model was done by excluding one parameter from the 17 parameters. The ANNR performance model was evaluated using R^2, RMSE and SSE, as shown in Table 10 and Table 11. The results show that the water quality index predicted with the ANNR model brings better and more reliable output (R^2=0.957, RMSE =0.265) compared with the BLR-IQWQI (R^2=0.901, RMSE = 0.504).

Table 10. Result of sensitivity analysis for IQWQI prediction (BLR-IQWQI) for freshwater use

Model	R^2	RMSE	SSE
BLR-IQWQI-Ref	0.901	0.504	23.618
BLR-IQWQI-Turb.	0.901	0.503	23.798
BLR-IQWQI-BOD_5	0.901	0.502	23.641
BLR-IQWQI-Cl^-	0.901	0.502	23.682
BLR-IQWQI-SO_4^{2-}	0.901	0.502	23.685
BLR-IQWQI-TDS	0.901	0.501	23.622
BLR-IQWQI-F^-	0.900	0.505	23.990
BLR-IQWQI-Zn^+	0.898	0.511	24.526
BLR-IQWQI-Fe^{2+}	0.897	0.533	24.782
BLR-IQWQI-Cr+	0.895	0.518	25.201
BLR-IQWQI-PO_4^{3-}	0.895	0.518	25.249
BLR-IQWQI-Al^{3+}	0.890	0.530	26.441
BLR-IQWQI-NO_3^-	0.886	0.540	27.415
BLR-IQWQI-Ni^+	0.886	0.539	27.297
BLR-IQWQI-DO	0.881	0.550	28.444
BLR-IQWQI-CN^-	0.876	0.562	29.722
BLR-IQWQI-pH	0.837	0.645	39.049
BLR-IQWQI-Pb^+	0.789	0.733	50.496

ANNR consists of three layers, input layer, hidden layer and output layer. There are layers and nodes at each layer. Each node at the input and inner layers receives input values (parameters values) which are then processed and passed to the next layer. This process is conducted by weights representing the connection strength between two nodes. The model is shown in Fig. 2, where the input layer consists of 17 parameters and the hidden layer consists of 10 nodes. Output is the value of IQWQI predicted. Table 10, illustrates the sensitivity analysis result for IQWQI prediction by ANNR. The model was run 18 times, in each time, one parameter was excluded, ANNR-IQWQI-DO means the test calculated the IQWQI without the DO, and ANNR-IQWQI-BOD means the IQWQI was calculated without BOD, etc. By comparing the lowest R^2 and highest RMSE from Table 10, the most significant and influential parameters on IQWQI are Pb^+, Ni^+, Cr^+, CN^-, pH, PO_4^{3-}, Zn^+, DO, NO_3^-, Al^{3+}, and Fe^{2+}. The residual error of the 18 models developed for IQWQI prediction is represented in. Fig. 3.

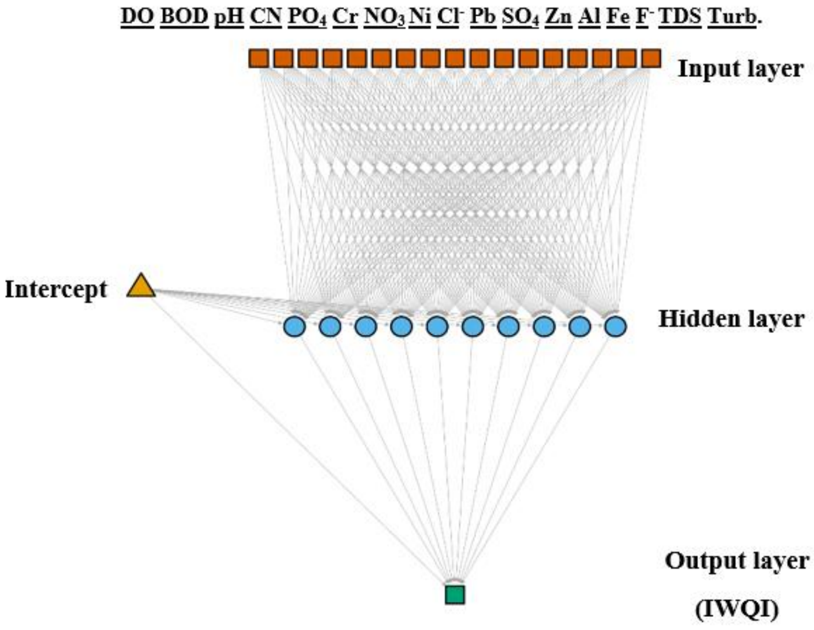
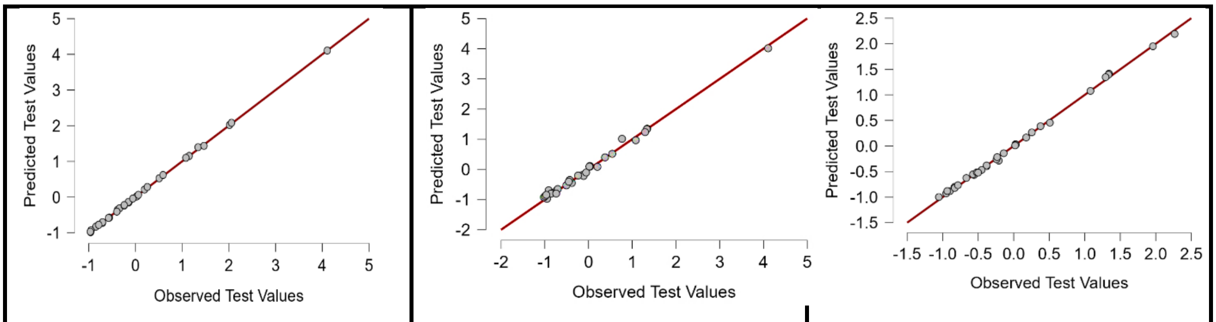


Figure 2. ANNR architecture for ANNR-IQWQI-Ref. model for freshwater use

Table 11. Result of sensitivity analysis for IQWQI prediction (ANNR-IQWQI) for freshwater use

Model	R^2	RMSE	SSE
ANNR-IQWQI-Ref	0.957	0.265	99.21459
ANNR-IQWQI-Cl^-	0.954	0.297	98.971729
ANNR-IQWQI-SO_4^{3-}	0.951	0.211	99.249828
ANNR-IQWQI-F^-	0.95	0.279	98.085531
ANNR-IQWQI-TDS	0.949	0.285	96.59481
ANNR-IQWQI-Turb.	0.942	0.245	99.50127
ANNR-IQWQI-BOD_5	0.940	0.231	96.15614
ANNR-IQWQI-DO	**0.919**	**0.342**	**155.2715**
ANNR-IQWQI-Cr^+	**0.916**	**0.342**	**158.46723**
ANNR-IQWQI-Zn^+	**0.912**	**0.363**	**132.433632**
ANNR-IQWQI-NO_3^-	**0.904**	**0.335**	**124.87653**
ANNR-IQWQI-Al^{3+}	**0.885**	**0.466**	**196.34126**
ANNR-IQWQI-CN^-	**0.882**	**0.457**	**179.87326**
ANNR-IQWQI-Fe^{2+}	**0.870**	**0.431**	**176.25412**
ANNR-IQWQI-pH	**0.866**	**0.491**	**198.76341**
ANNR-IQWQI-PO_4^{3-}	**0.864**	**0.462**	**185.05594**
ANNR-IQWQI-Pb^+	**0.52**	**0.537**	**231.72659**
ANNR-IQWQI-Ni^+	**0.504**	**0.425**	**160.75261**



ANNR-IQWQI-Ref | ANNR-IQWQI-DO | ANNR-IQWQI- BOD

2023, 20(6 Suppl.): 2395-2413
https://dx.doi.org/10.21123/bsj.2023.9348
P-ISSN: 2078-8665 - E-ISSN: 2411-7986
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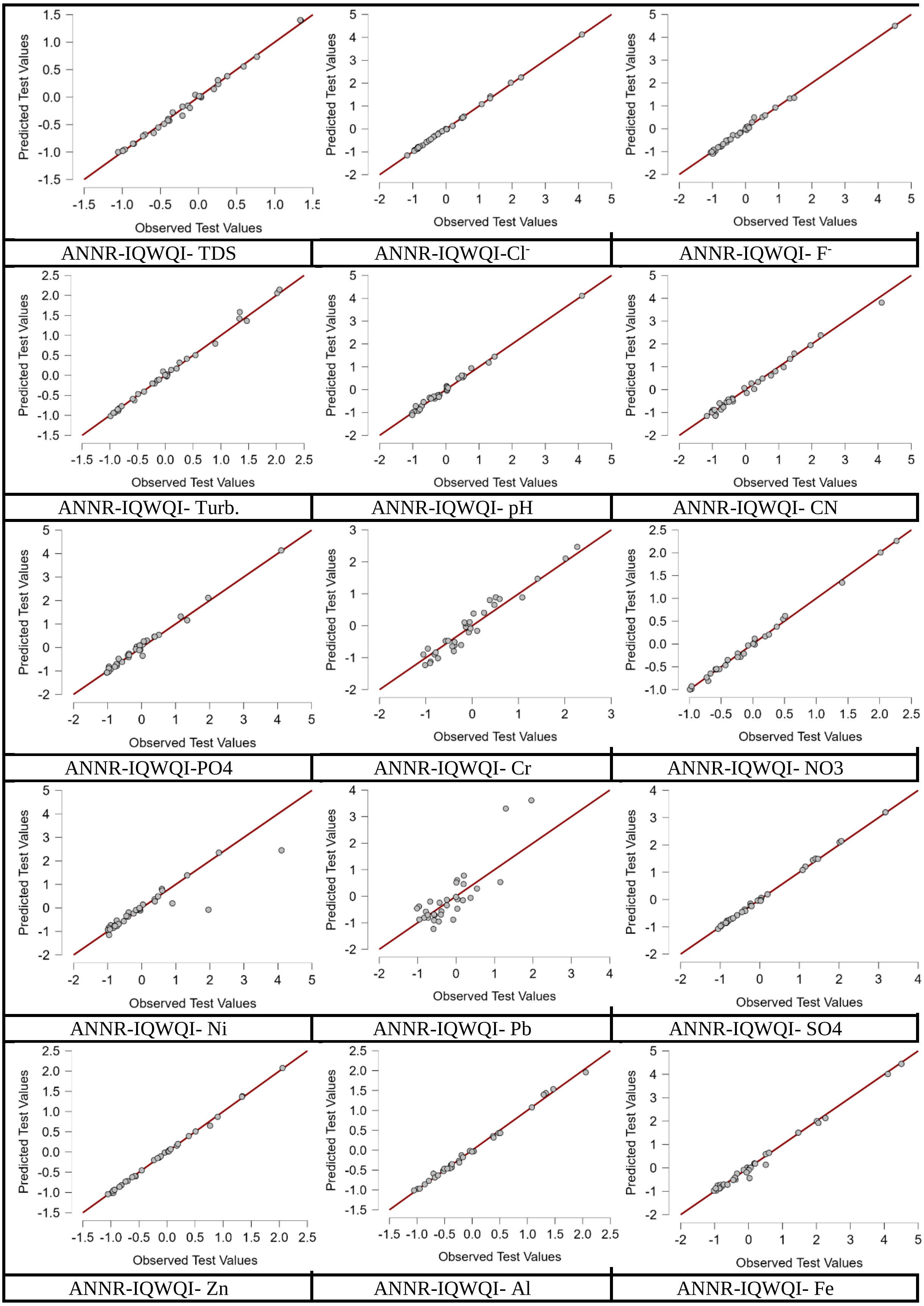

Figure 3. Residual error of the 18 models developed for IQWQI estimation for freshwater use based on sensitivity analysis.

2023, 20(6 Suppl.): 2395-2413
https://dx.doi.org/10.21123/bsj.2023.9348
P-ISSN: 2078-8665 - E-ISSN: 2411-7986
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Result of IQWQI and ERI for this study

The results of IQWQI and ERI for the freshwater at different sites and seasons are represented in Figs. 4 and 5; 17 parameters were used in calculating the two indices. Table 2. During the dry season, all sites fall under the very poor water quality category with a high degree of risk (94.99 and 75.89 to 98.49 and 92.58, respectively). While in the wet season, the values of both indices were lower than in the dry season but still in the same categories except for site 2, where the IQWQI ranking was poor water quality but also with a high degree of risk (71.56-88.90 and 57.14-82.88, respectively). The parameters exceeding the Iraq rivers maintenance system in the dry and wet seasons are represented in Table 12. Pb^+, SO_4^{2-} and TDS concentrations were beyond the limits continuously, and Pb^+ concentration in this study was far beyond the limits. For this reason, the water quality falls into the very poor category.

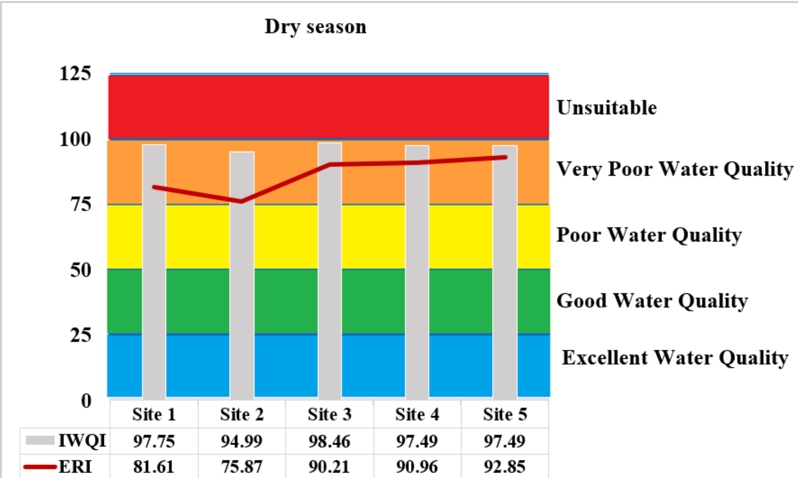

Figure 4. The result of IQWQI and ERI for the freshwater of Tigris River during the dry season

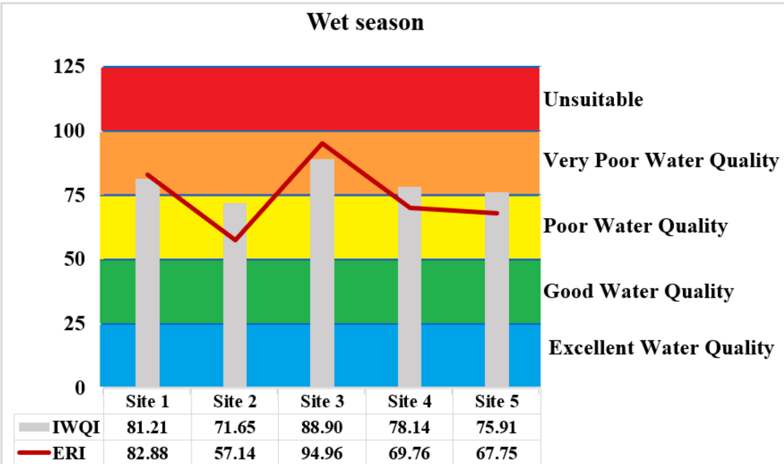

Figure 5. The result of IQWQI and ERI for the freshwater of Tigris River during the wet season

Table 12. Parameters that exceed the Iraq rivers maintenance system during the study period

Sites	Dry season Parameters		Wet season Parameters	
	Numbers	Name	Numbers	Name
Site 1	9	CN^-, PO_4^{3-}, Cl^-, Cr^+, Pb^+, SO_4^{2-}, Fe^{2+}, TDS, Turb.	7	CN^-, PO_4^{3-}, Ni, Cl^-, Pb^+, SO_4^{2-}, TDS
Site 2	9	CN^-, PO_4^{3-}, Cl^-, Cr^+, Pb, SO_4^{2-}, Fe^{2+}, TDS, Turb.	6	CN^-, PO_4^{3-}, Cl^-, Pb^+, SO_4^{2-}, TDS
Site 3	10	CN^-, PO_4^{3-}, Ni, Cl^-, Cr^+, Pb^+, SO_4^{2-}, Fe^{2+}, TDS, Turb.	7	CN^-, PO_4^{3-}, Ni, Cl^-, Pb^+, SO_4^-, TDS

Site 4	10	CN^-, PO_4^{3-}, Ni, Cl^-, Cr, Pb^+, SO_4^{2-}, Fe^{2+}, TDS, Turb.	6	CN^-, PO_4^{3-}, Cl^-, Pb^+, SO_4^{2-}, TDS
Site 5	11	CN^-, PO_4^{3-}, Ni^+, Cl^-, Cr, NO_3^-, Pb^+, SO_4^{2-}, Fe^{2+}, TDS, Turb.	6	CN^-, PO_4^{3-}, Cl^-, Pb^+, SO_4^{2-}, TDS

In general, according to IQWQI and ERI, the water quality of Tigris River in Baghdad city for different uses was ranked between good to unsuitable and never had an excellent ranking in any of the four water purposes. This situation is related to the increasing pollution in Tigris River due to discharging of effluent from various and uncontrolled sources such as industries, domestic waste, and agricultural activities, as confirmed by different researchers like the study of Fadhel[33], which found increasing salinity content in Tigris River water in the Mosul city comparable with the past forty years, in addition to study of Al-Obaidy *et al.*[34] on Tigris river in Baghdad city where recorded high values for electrical conductivity reached to 1205.7 ($\mu s.cm^{-1}$), and in the study of Nashaat *et al.*, [35] on Tigris river south of Baghdad they notice an increase in the nutrient concentrations with decreasing dissolved oxygen. Abdul-Jabar and Thabi [36] applied Heavy Metal Quality Index on two sites on Tigris River in Bagdad City where they found that cadmium, lead, and chromium slightly affected to extremely affected the river's health. Also, Al-Obaidy *et. al.*[37] indicate serious contamination of Tigris River by heavy metals in both sediment and water. So, continuous river water quality monitoring is required to assess water quality for various uses.

Conclusion

Several water quality indices were used to assess the water situation in Iraq, and they showed a discrepancy in the WQI results due to the different variables used and the weights adopted in each index. The results of the new IQWQI showed high efficiency with the possibility of relying on a specific number of parameters that were chosen by water quality experts. Also, the index merges the quality and pollution indices, where IQWQI is linked with ERI to eliminate the eclipse effect in WQI. Finally, the proposed model allowed the Iraqi Water Quality Index (IQWQI) user to eliminate any parameter from the index only in case the final weight does not fall below 0.7. Sensitivity analysis using artificial neural network regression (ANNR), can produce a more reliable and accurate output of prediction of the IQWQI than backward linear regression (BLR).

Acknowledgment

The authors acknowledge the Environment Research Center, University of Technology for providing equipment and technical assistance.

Authors' Declaration

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been included with the necessary permission for re-publication, which is attached to the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University Baghdad.

Authors' Contribution Statement

Z. Z. Al.: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

A.M. J. Al.: Conceived and designed the experiments; Analyzed
and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

F. M. H.: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Supplemental Files

- Supplement 1: Questionnaire

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2023, 20(6 Suppl.): 2395-2413
https://dx.doi.org/10.21123/bsj.2023.9348
P-ISSN: 2078-8665 - E-ISSN: 2411-7986
Baghdad Science Journal

موديل نوعية المياه الجديد للمياه السطحية العراقية

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الخلاصة

هدفت هذه الدراسة الى بناء موديل لنوعية المياه يكون مناسب للنظم المائية العراقي ويعكس الواقع البيئي للمياه العراقية. دليل نوعية المياه العراقية المطور يتضمن عوامل فيزيائية وكيميائية. من اجل بناء دليل نوعية المياه العراقي IQWQI تم استخدام طريقة دلفي للتواصل مع الخبراء المحلين والعالميين المختصين بنوعية المياه لغرض الحصول على اراءهم بخصوص اهم العوامل المهمة التي يمكن استخدامها لبناء الدليل وحسب طبيعية النظام البيئي العراقي وتحديد وزن لكل عامل. 70% من البيانات التي تم الحصول عليها من هذه الدراسة قد استخدمت لبناء الدليل و 30% استخدمت لاختبار الدليل. تم تطبيق عدة سيناريوهات لمدخلات الموديل لغرض دراسة تأثير زيادة العوامل. تم بناء الموديل من 4 عوامل لأربع مرات جمع عينات حتى وصل الى 17 عامل لعشرة مرات جمع عينات. ومن الواضح انه عند زيادة عدد العوامل فان قيمة الدليل سوف تتغير. لغرض تقليل التأثير المخفي للعوامل التي تتجاوز المحددات المسموحة والذي يظهر عند استخدام WQI ولحل هذا التداخل بين النوعية والتلوث فقد اوجدت هذه الدراسة دليل اخر يكون مرتبط بـ IQWQI والذي يضم كلا من درجة النوعية والتلوث. سمي الدليل الثاني دليل المخاطر البيئية ERI ويضم فقط العوامل التي تجاوزت الحدود البيئية المسموح بها. أجري تحليل الحساسية لغرض التنبؤ بقيم IQWQI وتحديد اهم العوامل المؤثرة في قيم IQWQI، تم اختيار موديلين لأجراء تحليل الحساسية وهما انحدار الشبكة العصبية الاصطناعية والمعتمد على التعلم الالي (ANNR) والانحدار الخطي العكسي(BLR) ، طُبق دليل الحساسية باستخدام 17 عامل للمياه العذبة (من حسابات IQWQI). كانت نتائج دليل نوعية المياه العراقي ودليل المخاطر البيئية لاستخدامات المياه العذبة خلال الموسم الجاف رديئة جداً مع درجة عالية من المخاطر. بينما في الموسم الرطب تراوحت نتائج الدليلين من نوعية مياه رديئة الى نوعية مياه رديئة جداً مع درجة عالية من المخاطر.

الكلمات المفتاحية: انحدار الشبكة العصبية الاصطناعية، الانحدار الخطي العكسي، دليل نوعية المياه العراقي، العراق، نهر دجلة، المياه السطحية، نوعية المياه.