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Tigris River Water Quality Quantifying Using the Iraq Water Quality Index (IraqWQI) and Some Statistical Techniques

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Abstract

Evaluation of water quality is important for the management of water resources. The current study is focused on the interpretation of the water quality monitoring data of the Tigris River in Iraq by the application of the principal component analysis (PCA), cluster analysis (CA), and water quality index (WQI). Twelve water quality parameters were taken from 14 stations along the river Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, NO_3^{-}, TH, TDS, BOD_5, and EC to apply the PCA and CA. The results show that the mean of all the parameters was under the standards except Ca^{2+}, EC, Mg^{2+}, TH, and SO_4^{2-}. The amount of EC is the critical factor that affects the river water quality. The PCA obtained one principal component responsible for 97% of the variation caused by different pollution sources. The CA divided the river into three regions of sampling stations with similar water quality, the best in the north, and the worst in the far south. In this paper, the computer-automated tool (IraqWQI) was presented and evaluated, which has been developed by authors to classify and measure the quality of Iraqi surface water. The proposed index is of hundred degrees and includes six variables for drinking water quality Cl^{-}, TH, TDS, COD, DO, and total coliform (TC) according to the Iraqi specifications. The result of the IraqWQI application showed a decrease in the water quality of the river and its suitability for drinking in the south of the country. The best value of the index was (81.48, Good) in Fishkhabour during winter, and the worst value was (46.23, Bad) in

Qurnah during summer. The result of this study proved the success and importance of using statistical techniques and WQI as useful tools for the management, control, and conservation of surface water.

Keywords

Component, Formatting, Style, Styling

1. Introduction

The quality of surface water, including rivers, depends on natural processes (erosion, weathering of soil, rainfalls, etc.), and human activities (agricultural, urban, and industrial activities [1]. Rivers are the most vulnerable water bodies to contamination due to their simple openness to industrial, agricultural, and domestic discharges [2]. Tigris River is the second major river in Iraq; its basin is a heavily populated area due to its fertile soil and the availability of water [3]. River water is used for irrigation, manufacturing, and domestic and acts as a receiver of industrial and municipal wastewater, and the quality of river water has declined as a result during the recent several decades [4].

The assessment of water quality is based on a large number of chemical, physical, and biological data, using descriptive methods of little benefit to decision-makers, and the analysis of water quality data using these basic methods, becomes more complicated as the number of variables increases [5] [6]. Statistical approaches such as multivariate and WQI methods are required to obtain suitable outcomes; these methods provide greater opportunities to help the decision-making process and be effective for environmental quality assessment [7] [8] [9].

The principal component analysis (PCA), cluster analysis (CA), and water quality index (WQI) goals are to better interpret the broad data from several variables identify the factors that cause variations in water quality, and provide a valuable tool for developing appropriate strategies for the effective management of water resources [10]. Water quality indices are important to convert the long, multi-parameter water analysis reports into a single number or word. This, in turn, is easy to understand and useful for comparing the water quality of the various sources and for tracking changes in the water quality of the source as a function of time and other factors of influence [11].

Chabuk, *et al.*, 2020 [12] studied the WQI along the Tigris River using the Weighted Arithmetic Method. They selected 12 parameters that were measured at 14 stations. The results showed that the water quality index was classified as good quality, although the WQI values of stations along the Tigris River showed the degradation of the water quality of the river from upstream at Fishkhabour until Shuhada Bridge, Baghdad. The WQI values indicated the degradation of the Tigris River and were rated as poor water quality starting from Aziziyah to the last station in the south of Iraq at the Quanah, Basrah. Another study using the WQI method of the Tigris River water in Baghdad city through measuring 18 parameters at 10 stations found that it was inadequate for main uses (drinking, irrigation, and industrial) [13]. The WQI model was adopted by Kamil, (2009) [14] to evaluate the water quality of the Tigris River from upstream of the river in Iraq (Feeshkhabour) to Qurnah, Basrah (downstream of the river) by measuring eight parameters (pH, TDS, EC, Ca, total hardness, Cl, SO4, SAR, and BOD) from thirteen stations during 2007-2008. The results showed that the categories (90 - 100) and (65 - 89) were classified for drinking use, while the categories (65 - 89), (35 - 64), and (11 - 34) were classified for irrigation use, the categories of (35 - 64) and (11 - 34) were classified for industrial use [14]. The water quality of the Tigris River within Baghdad (the capital of Iraq) was studied by Alobaidy *et al.* (2010) [15] by selecting 13 parameters (pH, Ca, Mg, Cl, SO_4, TDS, Alkalinity, Turbidity, Total Hardness, NH_3, F, Al, and Fe) from 2002 to 2008, the study showed that the water quality in north Baghdad was poor, while midpart and downstream of the river was poor and very poor. Another variety of Tigris River hydrochemistry studies has been performed [16]-[21]. These studies demonstrated major spatial and temporal changes in the parameters along the river; thus, it is important for continuous monitoring to clarify the key changes and the cause of these changes using appropriate methods and techniques [22].

The current study aims to apply two statistical techniques (PCA and CA) to identify the important water quality parameters that cause pollution to use this information by the water management authority and society. Also, software named the Iraq Water Quality Index (IraqWQI) for assessing surface water quality for drinking demand was developed and applied to the Tigris River from north to south Iraq as a case study. To develop this proposed new WQI, the Iraqi specifications for drinking water [23], and the World Health Organization (WHO) were adopted [24].

2. Data and Methods

2.1. The Study Area

Iraq is part of the Middle East, it occupies an area of 433,970 km^2, has around 39 million inhabitants, and is well known for its two major rivers the Euphrates and Tigris [25], (**Figure 1**). The Tigris River rises in the southeastern part of Turkey on the southern slopes of the Taurus Mountain range and drains an area of 472,606 km^2 shared by Turkey, Syria, Iran, and Iraq. The total length of the river from its sources to its meeting with the Euphrates in Qurnah to form Shatt Al-Arab is 1900 km, of which about 1415 km are inside Iraqi lands, and about 58% of the basin lies in Iraq [26].

The Tigris River in Turkish territory consists of five tributaries; these tributaries pass over rocky lands of various types and are a major source of many types of salts and minerals. In Iraq, the river has five main tributaries; called Fishkhabour, Greater Zab, Lesser Zab, Adhaim, and Diyala, in addition to tens of sub-tributaries [27] [28]. The Tigris River is exposed to erosion like the rest of

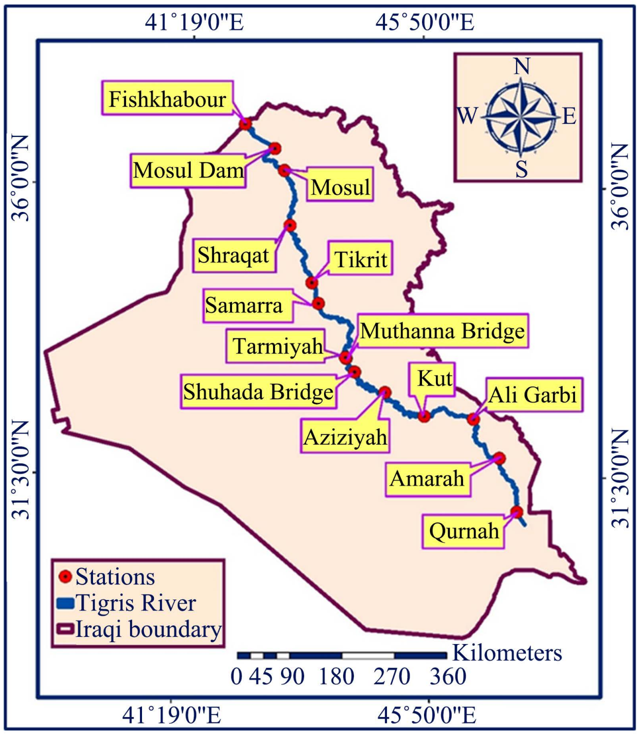

Figure 1. Iraq map showing the sampling stations on the Tigris River [11].

the rivers of the world, especially in the twisting areas of the river, and the depth of the riverbed changes, and the main course of the river is altered by the hydrological and hydraulic variables [29] [30]. The construction of dams on the tributaries of the Tigris River by the Turkish and Iranian governments reduced the amount of water and negatively affected its quality [31] [32].

To track and monitor the water quality of the Tigris River, the National Center of Water Resources Management of the Iraqi Ministry of Water Resources (NCWRM) has launched a monitoring program to monitor the water of the Tigris River for several years. The trained staff of the laboratories in the NCWRM collect and analyze the water samples by the standard methods of Rice *et al.* (2017) within the continuous monitoring program during the study year at the 14 stations along the river [32]. The 14 stations are Fishkhabour, Mosul Dam, Mosul, Shraqat, Tikrit, Samarra, Tarmiyah, Muthanna Bridge, Shuhada Bridge, Aziziyah, Kut, Ali Garbi, Amarah, and Qurnah (**Figure 1**).

2.2. Data Pretreatment and Analysis

In this study, the two 2017 seasons dry (summer and autumn) and wet (winter and spring) monitoring dataset obtained from the National Center of Water Resources Management of the Iraqi Ministry of Water Resources (NCWRM) has been tested by some statistical techniques using twelve water quality parameters *i.e.* calcium (Ca^{2+}), chloride (Cl^-), magnesium (Mg^{2+}), electrical conductivity (EC), sulfate (SO_4^{2-}), total dissolved solids (TDS), nitrate (NO_3^-), biochemical oxygen demand (BOD5), sodium (Na^+), potassium (K^+), total hardness (TH) and bicarbonate (HCO_3). The SPSS 25 statistical software package for Windows was used for descriptive and statistical data analysis. All 12 variables were standardized by log transformation to achieve normality and to recover the effect of variables with very small or very large variance values [33]. The Kolmogorov-Smirnov (K-S) experiment was used to test the goodness of proper data for the distribution. According to the K-S test, all the variables' values had a normal distribution with 95% certainty [34].

2.3. Principal Component Analysis (PCA)

This method of analysis can identify the most important parameters characterizing all datasets and generating variables [35]. Factors with >1 variance are included only because any factor can explain more variance than any single variable [36]. The PCA is used to describe the datasets and data reduction, giving the correlation between water variables without changing the original data [37]. In this analysis, the normalized variables were extracted from the significant principal components and minimized the effect of variables of limited significance by using varimax rotation by extracting the eigenvalues from the matrix of the correlation [37]. Bartlett's and Kaiser-Meyer-Olkin's (KMO) tests were used to check the fitness of data for PCA. The KMO is a degree of sampling competence, which indicates the amount of variance produced by the causal factors [36]. A high value of KMO (close to 1) indicates that PCA may be useful. Bartlett's test of sphericity tests the identity of the correlation matrix and the connection among variants. In this study, KMO = 0.675 and 0.702 for dry and wet seasons respectively, the significance level is ($0 < 0.05$) showing the significant relationships among variables (**Table 1**).

Table 1. Loadings of the 12 variables on one significant PC in the component matrix and the Kaiser-Meyer-Olkin (KMO) and Bartlett's Test, (for both 2017 seasons).

Variables	Principal Component
TH	0.999
Na^+	0.995
Mg^{2+}	0.993
NO_3^-	0.993
TDS	0.989
EC	0.989
Cl^-	0.987
K^+	0.986
BOD_5	0.986
Ca^{2+}	0.977
HCO_3^-	−0.970
SO_4^{2-}	0.956

Continued

The KMO and Bartlett's Test		Dry Season	Wet Season
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.675	0.702
Bartlett's Test of Sphericity	Approx. Chi-Square	646.715	614.214
	df	66	66
	Sig.	0.000	0.000

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. One principal component was extracted.

2.4. Cluster Analysis (CA)

Cluster analysis (CA) is a multivariate statistical analysis methodology that classifies all dissimilar objects into separate classes with an unsupervised pattern based on their characteristics. High internal (within the group) homogeneity and external (among the groups), in the resulting groups of objects, heterogeneity should be observed [38] [39].

Cluster analysis was used here to examine the dataset to define the spatial similarity of the water quality of river stations. The hierarchical CA was achieved on the standardized dataset using the Pearson correlation technique as a similarity measure using linkage distance by showing an illustrated dendrogram [40] [41].

2.5. The Iraqi Water Quality Index (IraqWQI)

The IraqWQI was developed using these four steps [20].

1) Selection of suitable parameters.

2) Weight assignment for the selected parameters.

3) Sub-indexes' functions development using the Iraqi specifications.

4) Formation of the final equation of the index by aggregation of the sub-indices.

The authors' experiences, information from previous studies, and two statistical methods (the PCA and the modified Delphi method in the survey of expert opinions) were used in the first and second steps.

Based on the foregoing, the index is based on six important water variables according to the Iraqi standard, the final list of parameters from which the index was derived was COD, DO, TC, TDS, TH, and Cl^-. Accordingly, the final formula for the Iraqi Water Quality Index was as follows: [20].

Iraq WQI =

$$[(-0.019\ TDS + 84.587) \times 0.2] + [-0.006\ TC + 86.231) \times 0.2] + [10\ DO \times 0.2] + [(-0.119\ TH + 113.68) \times 0.15] + [-5.886\ COD + 99.846) \times 0.1] + [(-0.12\ Cl + 106.58) \times 0.15]$$

2.5.1. The Specification of the IraqWQI V.1 Software

The Iraqi water quality index (IraqWQI V.1) is computer software for evaluating surface water quality for drinking purposes and is programmed using the C Sharp programming language with XAML and Xamarin languages in both versions (Windows and Android). It contains a simple user interface to enter the data and calculate the results (Figure 2 and Figure 3). The program contains a studio that connects the user to the program's social networking sites for help or to view the details of the authors. The design of the program is based on a kind of artificial intelligence to perform the job on behalf of the user.

The IraqWQI is developed to classify the river's water into five categories, viz. Very good (90 - 100), Good (70 - 90), Acceptable 50 - 70, Bad 20 - 50, and Very bad (0 - 20) [20].

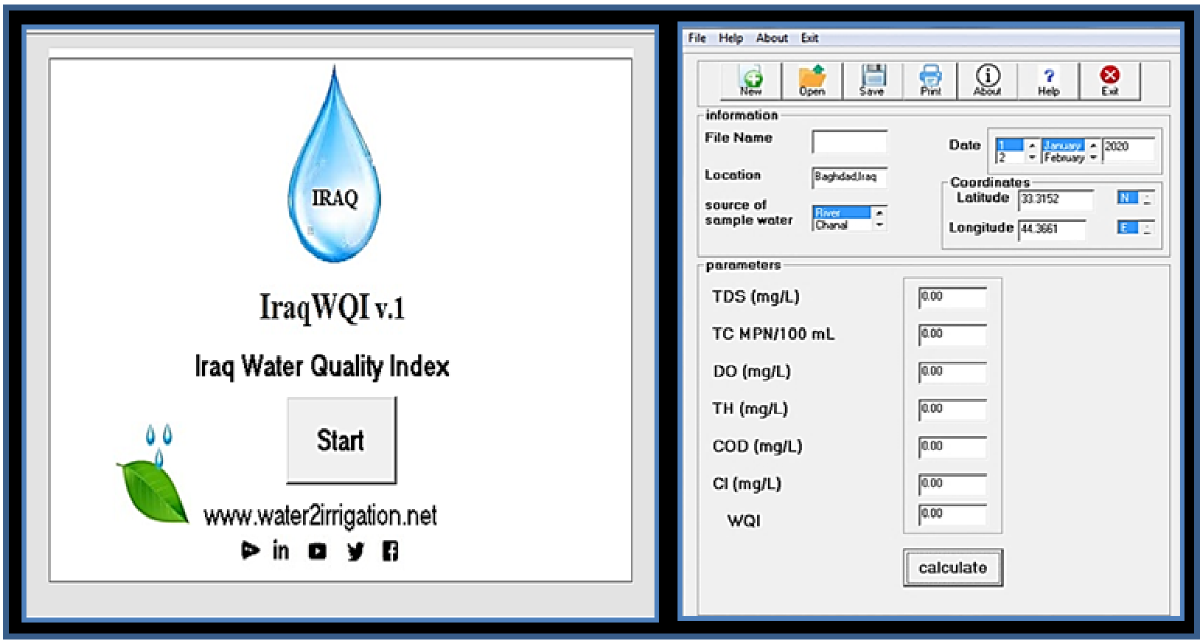

Figure 2. The Windows start and main menu of the graphic user interface of the IraqWQI for entering, calculating, and saving results.

Figure 3. The Android icon and main menu of the user interface of the IraqWQI for entering and calculating the results.

The IraqWQI V.1 user-friendly software was developed based on the Iraqi specifications for drinking water and includes features that help researchers, specialists, organizations, and ministries set up their water assessment and propose management methods. The authors provide free access to the software, the Android free version is available on the Google Play market under the name (IraqWQI) (https://play.google.com/store/apps/developer…) and the Windows version is available here: (http://water2irrigation.net/download.php).

This index will be of help to researchers and state departments concerned with the quality of the Iraqi surface water and its suitability for drinking and is an alternative to foreign models or indices designed for the waters of other countries. The index is characterized by a simple and easy-to-use interface. Figure 2 and Figure 3 show the program interface on Windows computers and Android phones. This application has been developed to save time and avoid errors related to manual calculations.

2.5.2. How to Use the IraqWQI

After installing and running the application, the user interface for calculating the quality index pops up. It consists of a menu to calculate the Iraq water quality index (IraqWQI). The user must have raw data on water quality parameters in mg/l for chemical parameters and the most probable number per 100 ml (MPN/100mL) unit for the total coliform. Once the raw data is entered for the parameters, the "Calculate" button in Windows and "Results" in Android allow us to immediately calculate the numerical value and the class matching the interpretation of this numerical value. The "Remove" button allows the user to clean up the operation previously performed and repeat the data entry. The "Exit" button allows the user to exit the application. Figure 2 and Figure 3 show the different functionalities of the application.

3. Results and Discussion

The General status of the river water: The descriptive statistics with the range, minimum, maximum, mean, standard error (SE), standard deviation (SD), and variance values of the 12 physicochemical parameters during the year 2017 are tabulated in Table 2 and Table 3.

The study of the physicochemical parameters (TH, Ca^{2+}, Cl^-, Mg^{2+}, EC, SO_4^{2-}, K^+, NO_3^-, BOD5, Na^+, HCO_3^-, and TDS) of the river water gives a more understanding of water quality and discriminates the parameters which are responsible for diminishing the water quality. In this study, the mean values of the parameters were compared with the Iraqi standards for drinking purposes (COQS, 2009). The results showed that the parameters were within the standards except for Mg^{2+}, TH, and Ca^{2+}, which were always more than the standards, and sometimes the EC and SO_4^{2-} were (Table 2 and Table 3).

It seems that the amount of EC and TH are the critical factors, which affect the river water quality, especially in the middle and south of the country. The

Table 2. Descriptive statistics of the year 2017 Tigris River data (dry season).

	Range	Min	Max	Mean	Std. Error	Std. Dev.	Variance	Iraqi Standard
Ca^{2+}	43.00	79.00	122.00	102.35	3.42	12.79	163.78	50
Mg^{2+}	56.00	54.00	110.00	80.35	4.51	16.89	285.47	50
Na^{+}	156.00	34.00	190.00	97.57	12.09	45.24	2046.72	200
K^{+}	3.10	5.10	8.20	6.62	0.24	0.92	0.85	-
Cl^{-}	337.00	33.00	370.00	155.00	29.86	111.74	12486.76	250
SO_4^{2-}	170.00	360.00	530.00	457.07	12.83	48.03	2306.99	250
HCO_3^{-}	30.00	164.00	194.00	182.00	2.77	10.37	107.69	-
TH	587.00	726.00	1313.00	986.87	47.87	179.11	32081.76	500
TDS	947.00	438.00	1385.00	833.42	78.19	292.58	85604.11	1000
BOD_5	3.90	3.20	7.10	4.52	0.30	1.149	1.32	5
NO_3^{-}	11.40	5.90	17.30	10.21	0.96	3.59	12.94	50
EC	1457.00	674.00	2131.00	1282.2	120.29	450.11	202603.1	1000

Note: All parameters in mg/l except for EC in (μS/cm) unit.

Table 3. Descriptive statistics of the year 2017 Tigris River data (wet season).

	Range	Min.	Max.	Mean	Std. Error	Std. Dev.	Variance	Iraqi Standard
Ca^{2+}	35.00	75.00	110.00	93.57	2.64	9.91	98.26	50
Mg^{2+}	45.00	50.00	95.00	72.28	3.78	14.14	200.06	50
Na^{+}	140.00	30.00	170.00	87.35	11.12	41.62	1732.70	200
K^{+}	3.10	5.30	8.40	6.85	0.24	0.92	0.86	-
Cl^{-}	328.00	32.00	360.00	148.14	28.82	107.86	11635.82	250
SO_4^{2-}	164.00	353.00	517.00	446.57	12.31	46.06	2121.80	250
HCO_3^{-}	30.00	168.00	198.00	184.71	2.77	10.36	107.45	-
TH	555.00	712.00	1267.00	955.21	44.75	167.43	28036.02	500
TDS	951.00	443.00	1394.00	843.35	77.94	291.64	85057.63	1000
BOD_5	3.80	3.10	6.90	4.40	0.30	1.12	1.27	5
NO_3^{-}	11.40	5.70	17.10	10.01	.96	3.62	13.15	50
EC	1463.00	682.00	2145.00	1297.60	119.92	448.72	201356.26	1000

Note: All parameters in mg/l except for EC in (μS/cm) unit.

Tigris River has a real shortage of water and annual fluctuations in water quantity and quality; this is because of climate change and the many dams constructed by neighboring countries and the river does not follow the pattern of the river's annual discharge. In summer and autumn (dry seasons); water comes from the reservoirs in the north, filled with dark organic materials, causing a shift in the consistency of the water (Al-Sharqi, 2020).

3.1. Principal Component Analysis (PCA)

The PCA is calculated in this study for the 12 variables from the 14 sampling stations on the river during 2017, to identify the most important water quality variables by knowing the eigenvalues that give the highest degree of significance. Eigenvalues of 1.0 or more are considered significant (**Table 1** and **Figure 4**) [42]. The PC which had an eigenvalue of more than one used to assess the important parameters in the river water [43].

In the obtained PCA data (for both seasons); one component was extracted, explaining 97% of the total variance which helps clarify the results and find out the sources of pollution from the water quality data. **Table 1** and **Figure 4** include the eigenvalues and loadings of the PC, explaining the total variance.

The rotation, which increased the factors number, is necessary to clarify the same variance amount in the original dataset, here, only one component was extracted, and the solution cannot be rotated [42].

The extracted PC explained 97% of the variance and loaded heavily on all the 12 variables, it is a result of the point and non-point source pollution of the hydro-geochemical and mineralization processes of the soil components.

Cl^-, TH and Mg^{2+} represent the contribution of point pollution and the chemistry of the river [44]. The BOD5, Na^+, and TDS represent the role of the non-point source of organic pollution from agricultural areas and the point's source of pollution from domestic sewage [45]. The rest variables represent the runoff the municipal sewage and the contribution of the geological components of soil [46].

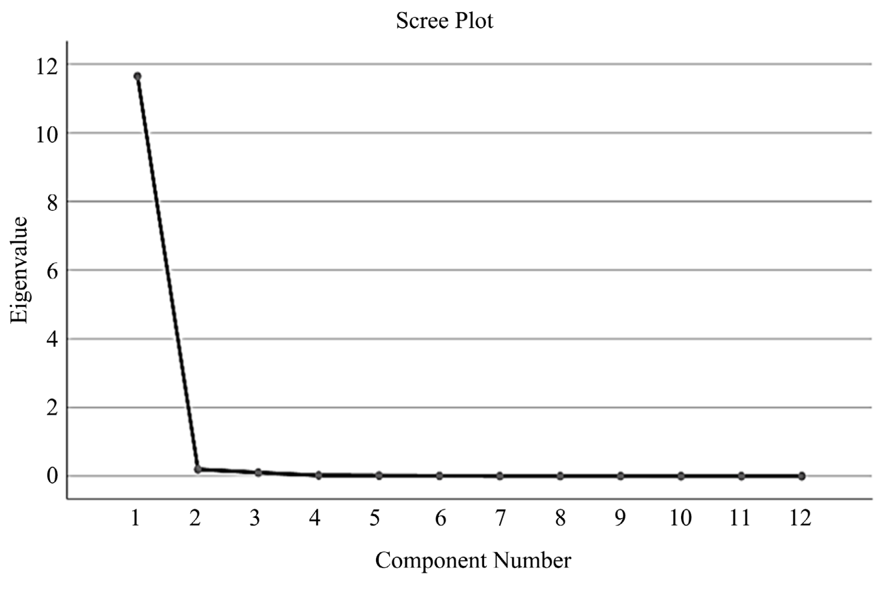

Figure 4. Scree plot of the eigenvalue of the extracted component.

3.2. Hierarchical Cluster Analysis (HCA)

The HCA gathered sampling stations in the river into 3 clusters of similar water quality features (there is no significant difference between the dry season and the wet season). Figure 5 illustrates the dendrogram output by using Ward's linkage method and square Euclidean distances.

Cluster 1 (stations 1, 2, 3, and 4), Cluster 2 (stations 5, 6, 7, 8, 9, 10, and 11), and Cluster 3 (stations 12, 13, and 14) correspond to the relatively low pollution, moderate pollution, and high pollution regions respectively from north of the country to south.

In Cluster 1, which contains relatively less polluted sites (Feeshkhabour, Mosul Dam, Mosul, and Shraqat stations), this could be accredited to the fact that fewer human activities were taking place at stations upstream of the river; they are far from the discharge of effluent. The river's water here is close to its springs in the mountains, and there are no big cities that drain their waste into the river.

Cluster 2 is made up of moderately polluted sites (the seven stations; Tikrit, Samarra, Tarmiyah, Muthanna Bridge, Shuhada Bridge, Aziziyah, and Kut) are located in the middle of the country, the river here is characterized by agricultural fields on both sides, incidence under the influence of the human activity of many towns as the untreated domestic wastewater is added directly to the river.

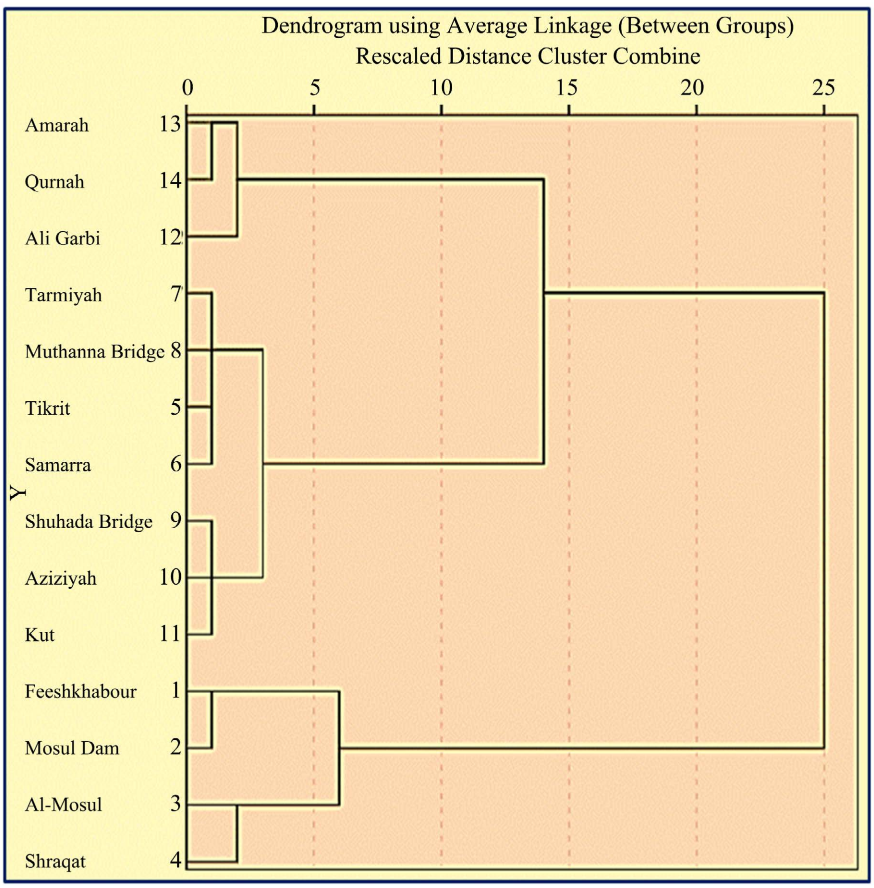

Figure 5. The CA Dendrogram of the study stations on the river (the dry season).

Cluster 3 contains the last three southern stations (Ali Garbi, Amarah, and Qurnah) which are located downstream of the river where the river region is characterized by a significant reduction in water level, high population density, under the influence of agricultural drainage projects as well as high evaporation that increases salinity and pollutants.

3.3. Application of the IraqWQI V.1 Software

In this study, to ensure the validity of the proposed IraqWQI, it was applied to estimate the two-season water quality of 14 sites on Tigris from north to south. The data of these sampling locations are taken from the National Center of Water Resources Management of the Iraqi Ministry of Water Resources [11]; the total coliform values were assumed to be zero due to the unavailability of data, the COD values calculated by this equation: BOD/COD = 0.40 [46] [47], (**Table 4** and **Table 5**).

It is observed from **Table 4** and **Table 5** that the IraqWQI values are gradually descending as we head downstream. In the dry season, three regions can be distinguished on the river, in which the index values of water quality converge. The northern region includes the first four stations, where the values of the index were (74.94, 73.81, 72.32, and 71.20 respectively) in the category "Good".

The second region includes eight stations with a value index ranging between 68.28 and 51.60 in the category "Acceptable". There are two stations in the south of the country with a value index of 48.28 and 43.55 in the category "Bad".

Table 4. The IraqWQI values of the 14 stations along the Tigris River during the dry season.

Stations	Cl^-	TH	TDS	COD	DO	TC	Iraq WQI	
1) Feeshkhabour	33	726	438	4.8	9	0	74.94	Good
2) Mosul Dam	39	777	490	4.95	8	0	73.81	Good
3) Mosul	54	822	560	5.25	8	0	72.32	Good
4) Shraqat	66	852	634	5.4	8	0	71.20	Good
5) Tikrit	78	875	710	5.4	7	0	68.28	Acceptable
6) Samarra	92	912	720	5.85	7	0	67.07	Acceptable
7) Tarmiyah	110	942	755	6.3	7	0	65.81	Acceptable
8) Muthanna Bridge	128	974	790	6.75	6	0	62.52	Acceptable
9) Shuhada Bridge	158	1012	844	6.9	6	0	61.01	Acceptable
10) Aziziyah	190	1056	890	7.5	6	0	59.12	Acceptable
11) Kut	230	1115	952	7.8	5	0	54.93	Acceptable
12) Ali Garbi	284	1185	1152	8.4	5	0	51.60	Acceptable
13) Amarah	338	1255	1348	9	5	0	48.28	Bad
14) Qurnah	370	1313	1385	10.65	4	0	43.55	Bad

Note: All parameters in mg/l except for the total coliform (TC) in (MPN/100mL) unit.

Table 5. The IraqWQI values of the 14 stations along the Tigris River during the wet season. All parameters in mg/l except for the total coliform (TC) in (MPN/100 mL unit.

Stations	Cl^-	TH	TDS	COD	DO	TC	Iraq WQI	
1) Feeshkhabour	32	712	443	4.65	11	0	81.48	Good
2) Mosul Dam	38	762	500	4.8	11	0	80.16	Good
3) Mosul	52	804	575	5.1	10	0	76.71	Good
4) Shraqat	64	831	650	5.25	10	0	75.62	Good
5) Tikrit	74	855	725	5.25	9	0	72.74	Good
6) Samarra	88	888	730	5.7	9	0	71.62	Good
7) Tarmiyah	105	908	764	6.15	8	0	68.57	Acceptable
8) Muthanna Bridge	120	941	800	6.45	8	0	67.31	Acceptable
9) Shuhada Bridge	145	972	850	6.75	7	0	64.02	Acceptable
10) Aziziyah	180	1014	900	7.2	7	0	62.18	Acceptable
11) Kut	220	1072	960	7.65	6	0	57.94	Acceptable
12) Ali Garbi	270	1136	1160	8.25	6	0	54.78	Acceptable
13) Amarah	326	1211	1356	8.65	6	0	51.54	Acceptable
14) Qurnah	360	1267	1394	10.35	5	0	46.23	Bad

Note: All parameters in mg/l except for the total coliform (TC) in (MPN/100mL) unit.

In the wet season, the river's water quality improves a little, so the number of stations in the north becomes six stations and the index value varies between 81.48 and 71.62 in the category "Good". Next, come seven stations with an index value of between 68.28 and 51.60 in the category "Acceptable". Qurnah is the last station in the south with an index value of 46.23 in the category "Bad". Sure enough, the river water in all regions needs a traditional purification treatment (sedimentation, filtration, and disinfection) to make it drinkable.

The WQI reached its maximum in the north sampling points during the wet season when the flow of the river was high. The values of the WQI in these points are the highest because there is no more pollution on the river. The values of the water quality parameters in this area never exceed the maximal except for the values for TH.

The index smaller values were recorded in the south during the dry season when the flow of the river water was low, the values of the dissolved oxygen were low, and the values of Cl^-, TH, TDS, COD, and TC were high. It can be seen that the values of all parameters except for dissolved oxygen increase as we head south, indicating the presence of more organic and mineral materials. The COD values are an important indicator of the efficiency of municipal wastewater treatment plants existing along the river.

Iraq currently faces three forms of water quality problems, the first is the scarcity of water, the second is salinity and the third is the accumulation of contaminants in water linked to municipal, industrial, and agricultural activities (Rahi and Halihan, 2018). Water quality depletion is further exacerbated by drought events and is a significant contributor to agricultural land desertification [48] [49]. As the water flows downstream, the salinity of the Tigris River worsens because of local geological features, city waste disposal to the river, and agricultural irrigation and drainage activities [50].

From the above results, we notice a congruence between the cluster analysis and the IraqWQI in classifying the water quality of the river stations. Cluster analysis divides the river into three groups of stations with similar water quality, the index divides the stations on the river into three categories: "Good", "Acceptable" and "Bad" of the five categories of the index: "Very good", "Good, "Acceptable", "Bad", and "Very bad". In the north of the country, the water is "Good" because it has not yet passed through sources of pollution such as large cities and industrial areas, as well as the riverbed is stony and erosion being little [51].

When the river leaves the mountainous region and enters the plains region in the center and south of the country, the water quality according to the index turns into "Acceptable" and in the far south to "Bad", because the river passes through large cities such as Mosul and Baghdad and passes through a loose plain where erosion occurs frequently [52]. In the far south, according to the index, the water quality becomes "Bad" during the dry and wet season, due to the combination of agricultural, industrial, and human pollution factors. The increase in evaporation due to the high temperature also helps to increase pollutants, salinity, and dissolved solids [53].

4. Conclusion

In this study, statistical techniques were applied to evaluate the complex water quality data along the Tigris River. The strong loading of all the 12 variables in the PCA identified the pollution sources' inputs. This study will be supportive of controlling critical parameters existing in the river route and supportive of the application of techniques as per calculated parameters. Thus, for the improvement of the river system, the managing authorities should consider the results of PCA, CA, and the IraqWQI for a complete valuation of the river ecosystem. The use of a water quality index based on Iraqi legislation is of great help to water resource managers. This computer application represents a key tool for public and private water resource managers, to determine the status of water intended for drinking.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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