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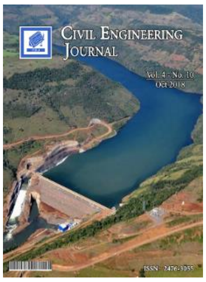

Developing Water Quality Index to Assess the Quality of the Drinking Water

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Abstract

In the present study, an attempt has been to develop a new water quality index (WQI) method that depends on the Iraqi specifications for drinking water (IQS 417, 2009) to assess the validity of the Euphrates River for drinking by classifying the quality of the river water at different stations along its entire reach inside the Iraqi lands. The proposed classifications by this method are: Excellent, Good, Acceptable, Poor, and Very poor. Eight water quality parameters have been selected to represent the quality of the river water these are: Ion Hydrogen Concentration (pH), Calcium (Ca), Magnesium (Mg), Sodium (Na), Chloride (Cl), Sulphate (SO_4), Nitrate (NO_3), and Total Dissolved Solids (TDS). The variation of the water quality parameters along the river have been represented by graphs using Excel.2013 software. The results revealed that the quality of the Euphrates River ranges from "Good" to "Poor", it enters the Iraqi borders with "Good" water quality and gradually its quality begins to decrease after it receives pollution from many sources such as domestic sewage and different industrial effluents until its quality becomes "Poor" according to the proposed classification. Finally the proposed WQI can be used as a tool to assess the quality of the river with both place and time.

Keywords: Drinking Water Quality Index; Surface Water; Iraqi Specifications for Drinking Water; Euphrates River.

1. Introduction

Freshwater sources in the form of rivers are considered a fundamental for the wellbeing of a hale and healthy society. Unfortunately, during the last decades these natural resources were being tainted in the sake of the development and flood hazard mitigation [1]. Water scarcity is increasing worldwide and the pressure on the existing water resources is being increased continuously due to the growing demand by the several sectors such as, domestic, agricultural, industrial, hydropower generation, etc.. Surface water pollution was and will be a major problem worldwide, caused by both natural processes and anthropogenic activities [1]. The surface water quality in a region can be affected by both point and nonpoint sources of pollution [2]. Point source pollution comes from a single known source such as effluents from industries and wastewater treatment plants [3], whereas nonpoint sources may be runoff associated with a particular land use such as urban (e.g., storm water, sewage overflows), agriculture (e.g., fertilizers, pesticides, animal manure) [4]. Entry of these sources into water can represent the discharge of toxic chemicals and pathogenic microorganisms; therefore, water quality monitoring and sanitary risk identification are essential to protect the population from waterborne diseases and to develop appropriate evaluation of surface water quality especially in drinking water sources [5, 6]. Thus, identifying the sources of contamination and developing appropriate management strategies is essential for minimizing potential public health risks. The assessment of water quality in various countries has become a critical research topic in the last few years [5]. Many water quality assessment models have been used to assess the quality of

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many surface waters. Vadde, et al., [7] used a multivariate statistical analysis called the cluster analysis to assess the quality of Taihu Lake in China which serves as a drinking water source for about 30 million residents. Water samples were taken from 25 sampling locations to be tested for fourteen water quality parameters. The cluster analysis showed that the sampling sites could be grouped into three clusters based on water quality, which were categorized as low, moderate, and high pollution areas.

Sarkar and Pendy [8] used the artificial neural network (ANN) to model the water quality of River Yamuna in the state of Uttar Pradesh, India. The dissolved oxygen was used as the primary indicator for the quality of the river. The inputs of the model were the monthly data sets on flow discharge, temperature, pH, biochemical oxygen demand (BOD) and dissolved oxygen (DO) at three locations upstream, central and downstream of Mathura city and the output was the values of (DO) downstream of Mathura City. The model showed high prediction efficiency since a high correlation was noticed between the measured and the predicted values.

In Iraq, there are two main sources for the drinking water, these are the Tigris and the Euphrates Rivers. These two rivers have been suffering a significant stress in terms of quantity and quality due to many reasons such as the dams constructed on both of the rivers in each of Turkey, Syria, and inside Iraq, the global climate change, and the decline in the local annual rainfall rates and the improper planning for the water uses inside Iraq [6].

For all the previous reasons, the overall planning and management for the surface water quality becomes necessary in order to assess the quality of water in the river. In Iraq, the Euphrates River is considered the main source for the drinking water in several governorates through which it passes. Thus an assessment for the suitability of its water for the drinking purpose is a must.

The Assessment of the suitability of the Euphrates River for dinking will be done using the water quality index (WQI) concept. Which is a mathematical tool that describes the quality of the water in a certain level [9]. In other words WQI describes the quality of the water in a single number which is understandable by both the experts and the public, instead of a large data of many water quality parameters that cannot be interpreted easily.

The very first idea for the WQI was introduced by Horton in (1965) and was developed continuously by many researchers and used to assess the quality of many water resources in different countries [2]. WQIs have been used as a management tool in water quality assessment because they provide a classification for the water quality according to a specific scale e.g. from zero to hundred, lower values indicate poor water quality while higher values indicate a better water quality, thus a clear idea on the situation of the water in a specified location can be made [3].

Pham et.al, [10] assessed the surface water quality of the Dong Nai River Basin in Vietnam by using water quality index (WQI) technique. Eight physico-chemical parameters of surface water samples were collected from 42 monitoring sites for assessing spatial and temporal water quality variations during the period of 2012-2016. The results revealed that surface water of the river was moderately polluted and the water quality highly varied between monitoring sites and seasons.

Hamdan et.al, [11] used WQI tool to assess the water quality of Shatt Al-Arab River in south of Iraq, it has been formulated making use of several water quality parameters such as pH, temperature, Dissolved Oxygen (DO), Biological Oxygen Demand（BOD5), Chemical Oxygen Demand (COD), Nitrate (NO3-2), Phosphate (PO4-3), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Turbidity (Tur), and Electrical Conductivity (E.C) which were measured at 37 sites along the river, bad water quality was observed at the sites of the river branches.

In this study, the WQI concept was chosen to assess the quality of the Euphrates River as a drinking water source and to classify the quality of the river's water at certain sites along the river because there is no previously developed WQI to assess the quality of the drinking water for the rivers inside Iraq, there is only an Iraqi specifications for the maximum allowable limits of water quality parameters in the drinking water, which cannot be used to classify the quality of the drinking water at a certain location.

2. The Developed Water Quality Index

Four major steps will be taken in order to develop the water quality index, these are[4]:

- Selection of water quality parameters.
- Assignments of weights.
- Making sub-indices.
- Finding the final index score.

2.1. Selection of Water Quality Parameters

Eight water quality parameters have been chosen due to their importance and their aesthetic effect on water and on the acceptability by the consumers, these are Hydrogen Ion Concentration pH, Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Sodium (Na^{+1}), Chloride (Cl^{-1}), Sulphate (SO_4^{-2}), Nitrate (NO_3^{-1}) and Total Dissolved Solids (TDS). The data of these parameters was provided by the ministry of Environment in Iraq.

pH is an indicator for the acidity and alkalinity of the water. pH is an important parameter to monitor as it can affect the physiological processes of aquatic biota [12]. pH is also important in assessing the suitability of water for drinking [13]. Calcium and Magnesium both comprise the total hardness in water which exist in the rivers water as a result of the river's passage over a lime stone, calcite, dolomite rocks which contain these two parameters in high ratio, thus calcium and magnesium will be dissolved and naturally contained in the rivers water. Ca and Mg does not have a direct health effect on the human but mainly affect the acceptability of the consumer as it affects the taste of water. Sodium gets dissolved in the rivers water from rocks, soils and salts. High concentrations of sodium in the water cause the corrosion of copper form the plumbing and metal fixtures thus results in increasing copper concentrations in the drinking water. Chloride naturally exists in surface water from road salt, fertilizers, and industrial wastes. High concentrations of chloride when mixed with sodium gives a salty taste to the water and thus affect the acceptability of the drinking water by the consumer [14]. Nitrate are an important indicator of water quality and originate from the agricultural runoff (fertilizers) [15].

Total dissolved solids (TDS) represent salts and minerals dissolved in the water and cannot be removed by conventional filtration [4]. Water salinity (expressed as TDS) is an increasing problem in Iraq. Salinity increases as the river water flows southward and evaporation, sewage effluent, dissolution of limestone and evaporate bedrock, and agricultural drainage all increase the salinity.

2.2. Assignment of Weights

Weights are given to parameters in order to refer to the importance of each parameter and its effect on the quality of water. Here a weight value ranged from 1 to 5 will be given to each parameter, 1 is given to the least important parameter and 5 is given to the parameter of the highest importance [16], as in (Table 1).

Table 1. The selected parameters and their weights

Parameter	Weight
pH	1
Ca	3
Mg	3
Na	2
Cl	5
SO_4	5
NO_3	2
TDS	2

2.3. Creating Sub-Indices

Creating sub-indices simply means the transformation of the parameters values which have different units and dimensions into a common scale. In the present study this will be done in three steps [16]:

- Finding the relative weight for each parameter as in (Equation 1):

$$\hat{W}_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

Where:

$\hat{W}_i$: Relative weight for the i^{th} parameter.

w_i: Weight if the i^{th} parameter.

- Finding the scale of quality rating for each parameter

$$Q_i = \frac{C_i}{I_i} \times 100 \tag{2}$$

Where:

Q_i: The scale of quality rating for the i^{th} parameter.

c_i: The actual concentration of the parameter expressed in (mg/l).

I_i: The maximum acceptable limit set by the Iraqi standards for drinking water.

- Finding the sub-index value for each parameter as in (Equation 3):

$$S_i = \hat{W}_i \times Q_i \tag{3}$$

Where:

S_i: sub-index value for the i^{th} parameter.

2.4. Finding the Final Index Score

The final drinking water quality index (DRWQI) score is found by the aggregation of the sub-indices. Here the summation aggregation will be used as in (Equation 4):

$$\mathrm{DRWQI} = \sum \mathrm{S_i} \tag{4}$$

3. Classification of Drinking Water Quality

Any water source can be classified into many grades according to a specific intended use. In the present study, these grades are based on the maximum permissible limits provided by the Iraqi standards for drinking water. The Euphrates River could be classified as in (Table 2):

Table 2. Drinking Water quality classification according to the WQI values [17]

Range of DRWQI	Type of Water
<20	Excellent
20-60	Good
60.1-140	Acceptable
140.1-200	Poor
>200	Very poor

4. Materials and Methods

4.1. Methodology

An average yearly values for eight water quality parameters (pH, Ca, Mg, Na, Cl, SO_4, NO_3 and TDS) were analyzed along the Euphrates River for the years 2012 and 2013 for eleven sampling stations along the river. The available data of the water quality parameters from the ministry of Environment were used and the developed water quality index was used to gather the effect of the eight water quality parameters in one number that can display and classify the quality of the rivers water as a drinking water source at each one of the sampling stations.

4.2. Case Study

The Euphrates River originates in the high lands of eastern Turkey, and flows in three countries which are: Turkey, Syria and Iraq until it discharges in Shatt Al-Arab which is the confluence of both the Euphrates and the Tigris Rivers south of Iraq[18]. The Entire length for the Euphrates River is about 2786 kilometres. 41% of its length flows within the Turkey lands, 24% of its length flows in Syria and 35% of it flows inside the Iraqi lands[19]. Inside Iraq, the Euphrates River passes through eight governorates, these are: Al-Anbar, Karbalaa, Babil, Al-Najaf, Al-Qadisiyah, Al-Muthanna, Thee-Qar and Al-Basrah. The Euphrates River is the only source for drinking water in these eight governorates, thus the assessment of the validity of its water for drinking is very necessary. Fourteen sampling stations distributed among these governorates were chosen to assess the water quality of the Euphrates River. These stations are: St.1 (Al-Qaem), St.2 (Al-Baghdadi), St.3 (Al-Ramadi), and St.4 (Al-Fallujah) which are located in Al-Anbar governorate, St.5 (Al-Hindiyah) which is located in Karbalaa governorate, St.6 (Al-Msayab) and St.7 (Al-Kafal) which are located in Babil governorate, St.8 (Al-Koufa) and St.9 (Almanathira) which are located in Al-Najaf governorate, St.10 (Al-Shanafiyah) in Al-Qadisiyah governorate, St.11 (Al-Samawah) in Al-Muthanna governorate, St.12 (Al-Nasiriyah) in Thee-Qar governorate and St.13 (Al-Karma) in Al-Basrah governorate. The sampling stations are all shown in (Figure 1.). The sapling stations and their corresponding governorates are shown in (Table 1.).

Figure 1. Sampling Stations along the Euphrates River inside Iraq

Table 1. The Sampling Stations and the corresponding governorates

Name of the station	The governorate
Al-Qaem (St.1)	Al-Anbar
Al-Baghdadi (St.2)	Al-Anbar
Al-Ramadi	Al-Anbar
Al-Fallujah	Al-Anbar
Al-Hindiyah	Karbalaa
Al-Msayab	Babil
Al-Kafal	Babil
Al-Koufa	Al-Najaf
Almanathira	Al-Najaf
Al-Shanafiyah	Al-Qadisiyah
Al-Samawah	Al-Muthanna
Al-Nasiriyah	Thee-Qar
Al-Haritha	Al-Basrah

5. Results

5.1. Variation of the Physicochemical Parameters along the Euphrates River

Eight physicochemical parameters will be assessed to represent the quality of the Euphrates River, these are: pH, Ca, Mg, Na, Cl, SO_4, NO_3, and TDS. The variation of these parameters will be assessed at eleven stations along the Euphrates River inside the Iraqi lands and will be compared with the maximum limit set by the Iraqi drinking water specifications (IQS 417, 2009) for each one of the eight parameters as shown in (Figures 2-9.).

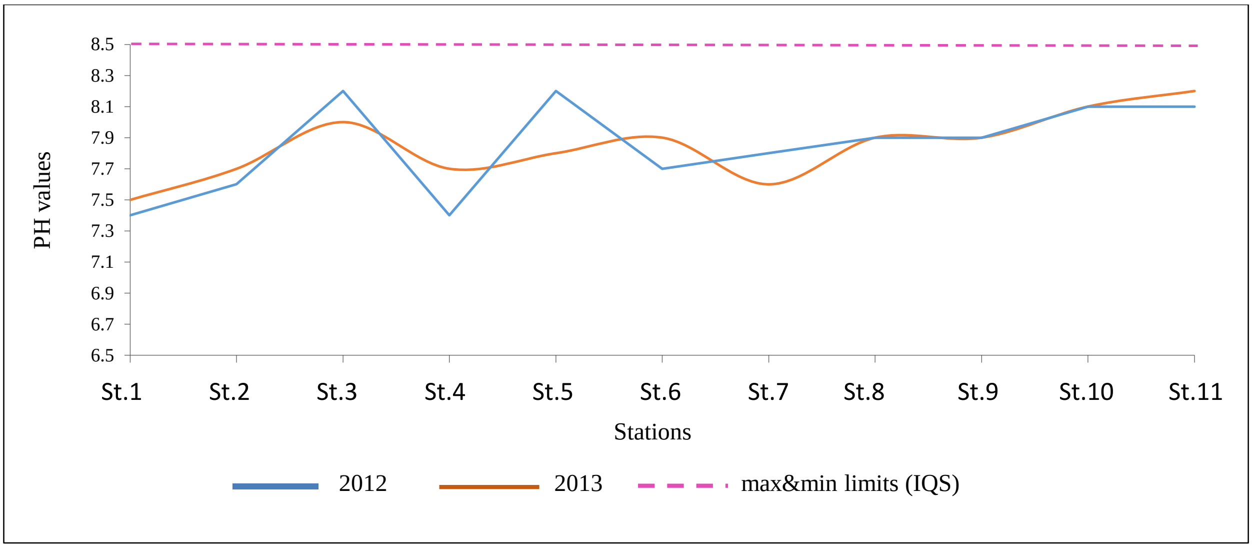

Figure 2. pH variation along the Euphrates River for the years 2012 and 2013

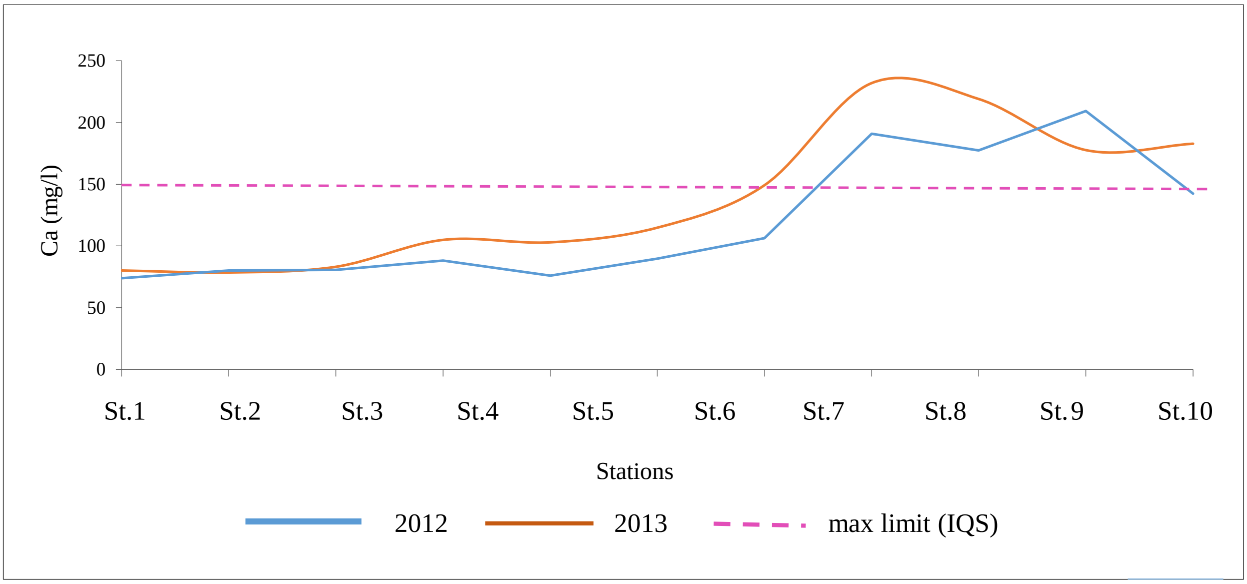

Figure 3. Ca variation along the Euphrates River for the years 2012 & 2013

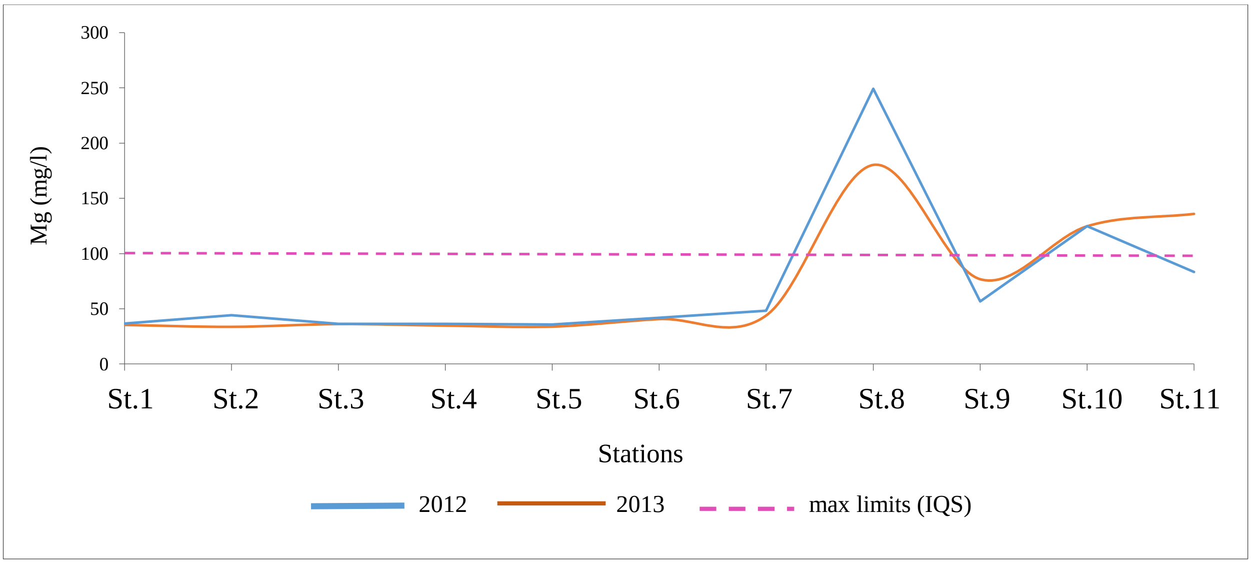

Figure 4. Mg variation along the Euphrates River for the years 2012 & 2013

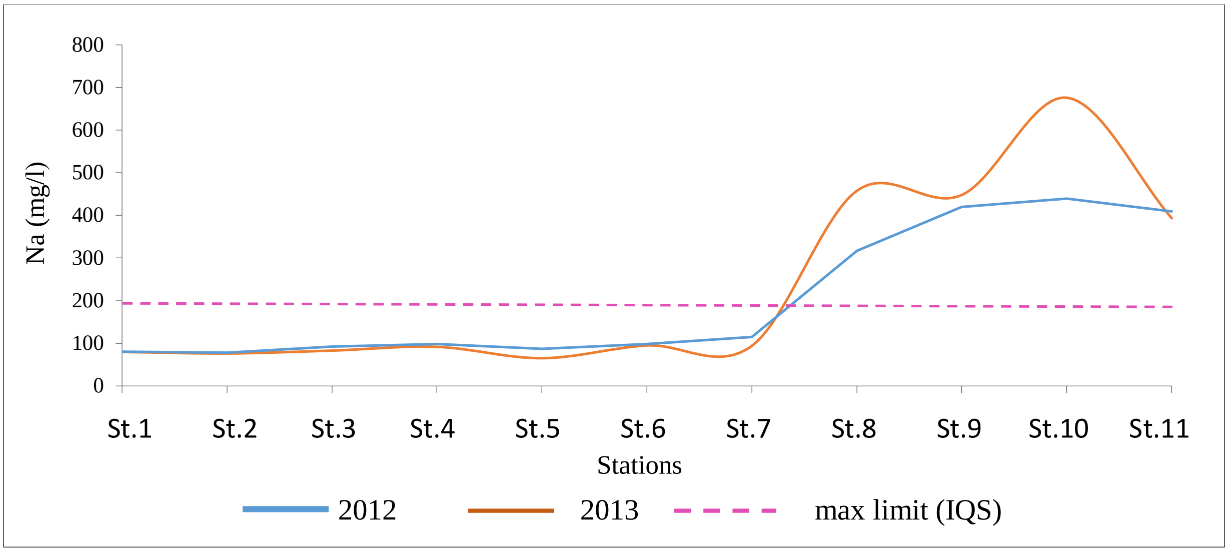

Figure 5. Na variation along the Euphrates River for the years 2012 & 2013

Figure 6. Cl variation along the Euphrates River for the years 2012 & 2013

Figure 7. SO_4 Variation along the Euphrates River for the years 2012 & 2013

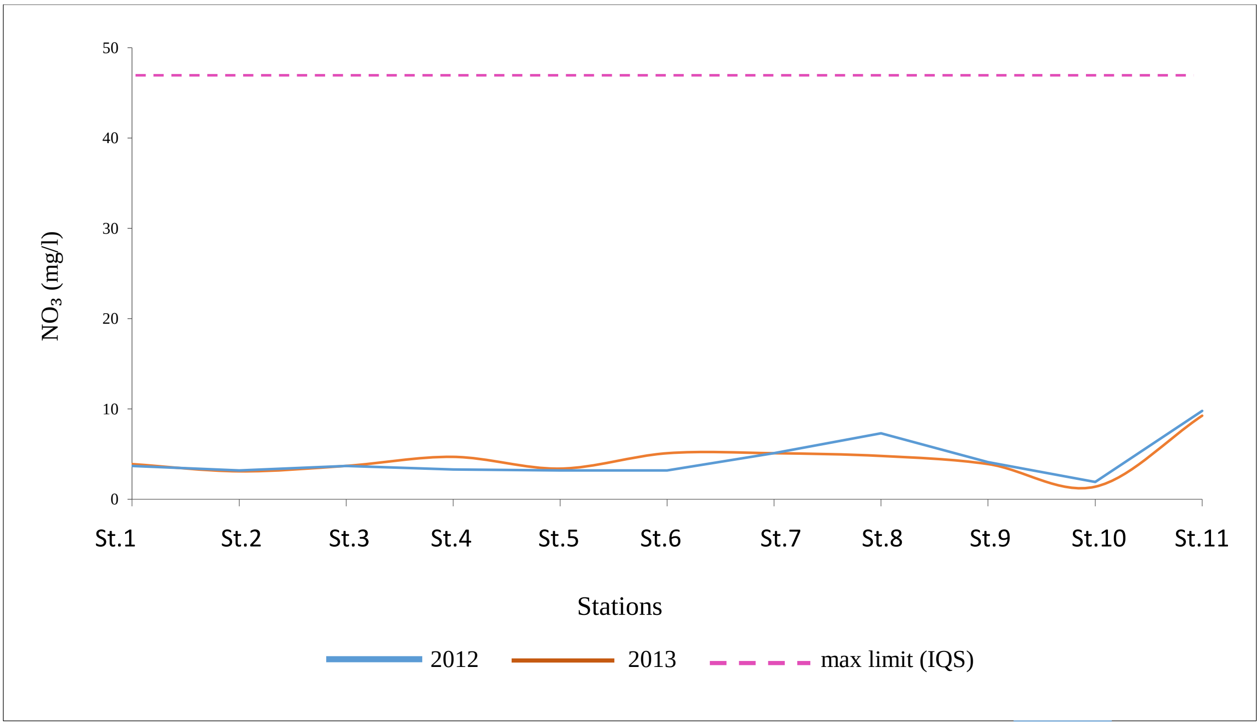

Figure 8. NO_3 Variation along the Euphrates River for the years 2012 & 2013

Figure 9. TDS Variation along the Euphrates River for the years 2012 & 2013

5.1.1. Variation of the Water Quality Index along the Euphrates River

Water quality index will be determined for the selected stations along the Euphrates River for the years 2012 and 2013 according to the developed method to assess the suitability of the Euphrates River as a drinking water source for the regions through which it passes in Iraq as shown in (Figure. 9).

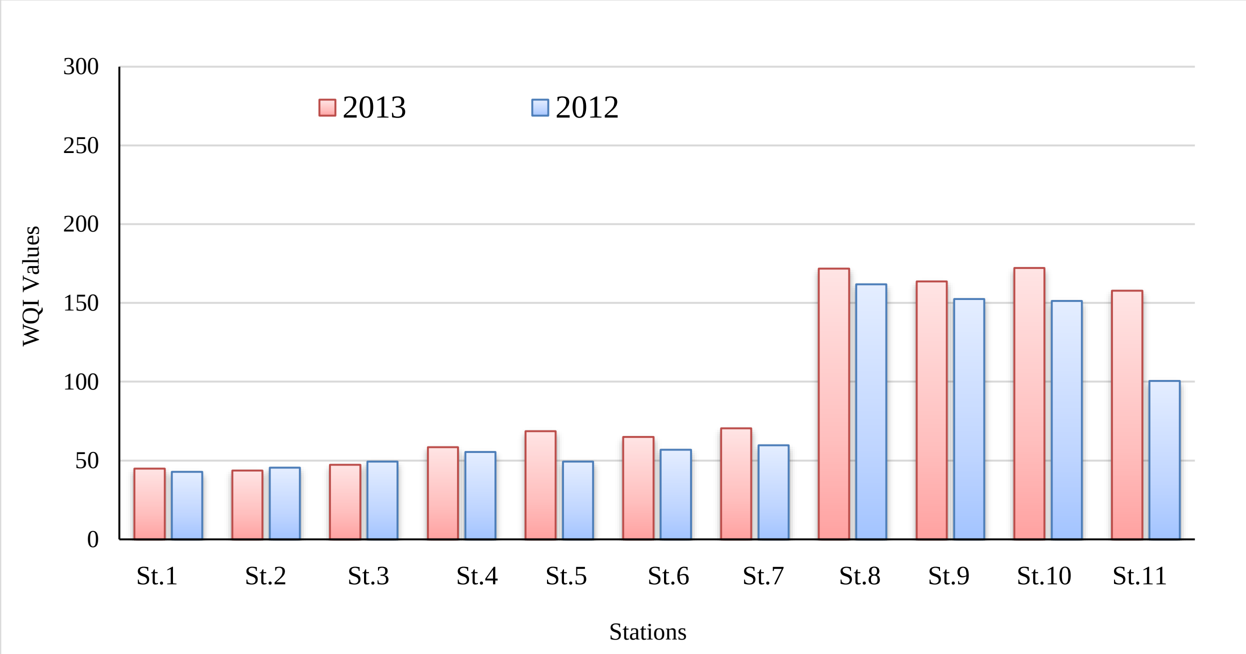

Figure 9. WQI Variation along the Euphrates River for the years 2012 & 2013

6. Discussion

The pH values of the river water during the study period ranged from 7.4 at Al-Qaem station in 2012 to 8.2 at Al-Haritha station in 2013. All values of pH are within the range of pH values set by (IQS 417, 2009) which is from 6.5 to 8.5 as shown in (Figure 2). Calcium exists in the river water because when that river flows over a land rich with limestone, calcite, dolomite, gypsum, these elements will be dissolved in the water and form part from the water hardness which affect the acceptability of the water by consumers [20]. Ca Values in the river ranged from 74 at Al-Qaem station in 2012 to 232 at Al-Shanafiyah station in 2013, the area from Al-Shanafiya to Al-Haritha had values of Ca which exceeded the maximum limit for the Calcium set by (IQS 417, 2009) which is 150 mg/l. Magnesium exists in many minerals such as magnesite and dolomite, it exists in water when the water flows over rocks which contain these mineral, eventually these minerals will be washed of the rocks and maintained in the river water. Magnesium may end up in the river water in other forms such as fertilizer application, chemical industries and cattle feed [21]. Mg values in the river water ranged from 43 mg/l at Al-Baghdadi in 2013 station to 249 mg/l at Al-Shanafiyah station in 2012, the two stations Al-Shanafiyah and Al-Nasiriyah had values of Mg that exceeded the maximum limit for Magnesium which is 100 mg/l set by (IQS 417, 2009). Sodium is found naturally in water since it is one of the abundant elements in the earth, soil and water. It also may come from the treatment processes such as water softeners [22]. Values of Na in the river water ranged from 65 mg/l at Al-Hindiyah station in 2013 to 676 mg/l at Al-Nasiriyah station in 2013. The area from Al-Shanafiyah to Al-Haritha had values of Na that exceeded the maximum limit of Na set by the (IQS 417, 2009) which is 200 mg/l. Chloride is found in nature mainly as sodium chloride and potassium chloride and it ends up in water because of the ease of solubility of these salts in water [23]. Chloride cause problems in the taste and the odour of the water which affect thepalatibility of the water [24]. Values of Cl ranged from 112 mg/l at Al-Qaem station in 2012 to 796 mg/l at Al-Samawah station in 2013, the area from Al-Shanafiya to Al-Haritha had values of Cl that exceeded the maximum limit for Cl which is 350 mg/l set by the (IQS 417, 2009). Sulphates are formed by the combination of sulfur and oxygen, it ends up in the river water mainly from gypsum and anhydrite or as a result of the oxidation of the sulfuric compounds which may exist in the sewerage water and industrial effluents [13]. Sulphate in high concentrations results in a bitter taste in the water which results in a laxative effect on humans [25]. Values for the river water ranged from 162 mg/l at Al-Qaem station in 2012 to 791 mg/l at Al-Shanafiyah station in 2013, SO_4 values for the area from Al-Shanafiyah to Al-Nasiriyah had values of SO_4 that exceeded the maximum limit for SO_4 which is 400 mg/l according to (IQS 417, 2009). Nitrate exists in the river water as a result of the agricultural activities in which it is being applied as a fertilizer to the plants. Other sources of nitrate is the discharge of waste water that contains nitrogenous compounds [12]. NO_3values in the river water ranged from 1.4 mg/l at Al-Nasiriyah station in 2013 to 9.8 mg/l Al-Haritha station in 2012, generally the entire reach of the Euphrates River had values of NO_3 that are much less than the maximum limit for NO_3 which is 50 mg/l according to (IQS 417, 2009). Total dissolved solids may have an inorganic content such as many salts, mainly the carbonates, chlorides, silicates of sodium, magnesium, potassium and calcium. Other contents of the total dissolved solids is the organic matter that get dissolved in the river water [26]. Values of TDS in the river water ranged from 545 mg/l at Al-Baghdadi station in 2013 to 3113 mg/l at Al-Haritha station in 2013, the TDS values for the area from Al-Shanafiyah to Al-Haritha were higher than the maximum limit set by the (IQS 417, 2009) for drinking water which is 1000 mg/l.

Water quality of the Euphrates River ranged from “Good” to “Poor” according to the classification of the water quality in the developed water quality index. The minimum value of WQI was 43 at Al-Qaem station in 2012, while the maximum value of WQI is 172 at Al-Shanafiyah and Al-Nasiriyah stations both in 2013. Generally the water quality witness a large decrease starting from Al-Shanafiyah station to the end of the river due to the pollution introduced to the river by many sources such as domestic and industrial effluents.

7. Conclusion

The developed water quality index was used as a tool to express the validity of the Euphrates River for drinking. It is much easier to check the validity of an area of a river by one number (WQI), than studying many parameters and comparing their values with the maximum limit for each parameter set by the (IQS 417, 2009) for drinking water. Eight water quality parameters was chosen to represent the quality of the Euphrates River in Iraq, their values were analysed for eleven stations along the river and compared with the Iraqi specifications for drinking water to allocate the stations at which each parameter has crossed the maximum limit. Then, these parameters have been given a weight value from 1 to 5 in order to refer to the importance of each parameter. Then an equation was created to calculate the final index value which gathers the effect of all the eight parameters.

The results of the developed WQI showed that the area starting from Al-Shanafiyah station to the end of the river at Al-Haritha station unsuitable as a source for drinking water because the classification of the drinking water at the stretch of the river was “Poor” according to the developed WQI. This classification was due to the increased values of six water quality parameters (Ca, Mg, Na, Cl and TDS) which crossed their maximum limits according to the (IQS 417, 2009). Thus, further treatment need to consider in order to produce a water with a quality suitable for drinking.

Finally, further studies should be made to assess the sources of pollution and their effect on the quality of the river water by checking the quality of the river just before and after the source of the pollution and studying the change in the quality of the river water.

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