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Assessment of Euphrates River Water Quality and Modeling Spatial Distribution of Pollution Zones

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Abstract: To understand the nature of Euphrates River for drinking purpose or any intended use, it is important to study the quality of the water by correlating Water Quality Indices (WQIs) results and Geographical Information System (GIS) techniques which can give an adequate evaluation as well as indicating the pollution, saving time, water resources management and decision-making. Therefore, three WQIs were applied in this study to assess, compare and judge the suitability of Euphrates River for drinking purpose at multi locations within Iraqi territory. These indices include: Bhargava Water Quality Index (BWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) and Weighted Arithmetic Water Quality Index (WAWQI). However, these indices consist of several water parameters such as pH, Nitrate, Calcium, Magnesium, Total Hardness, Sodium, Sulfate, Chloride, Total Dissolved Solids, Electrical Conductivity and Alkalinity that can be used for comparison with the Iraqi drinking water specifications standard. These parameters were recorded at twenty-two monitoring stations to determine the extent of impact of the pollutants carried by the river along the distance, samples were collected based on data from the Iraqi Ministries of Environment and Water Resources during the period from January 2014 to December 2019. The results showed that the overall mean of values of BWQI, CCMEWQI, and WAWQI were 31.66, 62.37 and 59.42 respectively along Euphrates River. The water quality is classified as "Polluted" according to BWQI, "Marginal" according to CCMEWQI and "Poor" according to WAWQI. The results of WQIs were linked with ArcGIS software to represent spatial distribution on satellite maps. Thus, showing the pollution zones in the form of a colored ramp indicator, which describe the state of water quality in Euphrates River. The spatial analyst tool was employed for interpreting the data by applying Inverse Distance Weighted (IDW) interpolation methods. It is noticed that most values of physical and chemical parameters have been exceeded the Iraqi drinking water specifications standard except pH and Nitrate. The WQIs results have been shown that the quality of Euphrates River heading towards the bad situation due to the impact of human activities, natural sources, sewage disposal and industrial wastes. Thus, the raw water of the river would need further treatments to become potable at the water treatment plants nearby the monitoring stations, which have been shown a deterioration in water quality.

Keywords: Euphrates River, WTP, WQIs, GIS, IDW.

1. INTRODUCTION

In the last years, water resources management, problems, and water quality control have received a lot of attention and also it is an important and sensitive issue for environmental protection and safety living. Water quality assessment is essential to prevent and control river pollution and to get reliable information on the quality of water for effective management. In Iraq, especially in the last two decades, water resources have suffered remarkable stress in terms of water quantity and quality due to different reasons such as the dams constructed on Euphrates River in Turkey and Syria, the climatic changes, population growth, decline in local annual rainfall rates, water conflicts, exceeding the planned water quotas by farmers and improper planning of water uses inside Iraq. Furthermore, the flow of the Euphrates is expected to decrease much more by 2025. So, the volume of the Euphrates is expected to drop by at least half [1]. Recently, with advance and increasing role of technology, new techniques and methods were developed for evaluation of water quality using accurate techniques such as Water Quality Index (WQI) to estimate the status of water and maps by Geographical Information System (GIS) to represent the spatial distribution of results which have become an important experimental and practical approach.

2. SITES DESCRIPTION AND DATA COLLECTION

There are several reasons for choosing a study area including the need for a tremendous increase in freshwater demand required due to the rapid growth in population and accelerated industrialization. As well as the pollution is increased in the river stretch due to effluent discharges from various uncontrolled sources as domestic, industries and agriculture along the downstream stretch. It is worth mentioning that the most selected stations are located near the intakes of water treatment plants which represent the clear idea of raw water quality entering to these plants. Euphrates River is the longest river in western Asia. It emerges in Turkey from the confluence of Kara-Su and Murat-Su in the highlands of Eastern Turkey between Lake Van and the Black Sea. It flows through Syria and Iraq to join the Tigris River in the Shatt Al-Arab, which discharges into the Arab Gulf. The length of Euphrates River from its beginning in Turkey to its end in Iraq is about 2,800 kilometers, of which 41% is in Turkey, 23% is in Syria, and 36% is in Iraq. About 10.2 million of the population in Iraq depend on Euphrates River for various purposes [2]. The water quality parameters data used in this study were provided from Iraqi Ministries of Environment and Water Resources during the period from January 2014 to December 2019 which represent average monthly values of eleven water parameters. These data were collected from twenty-two monitoring stations distributed along Euphrates River in eight provinces, between latitudes (34° 23' 35.0808" North - 30° 34' 28.9380" North) and longitudes (41° 13' 14.3217" East - 47° 44' 51.5644" East) within Iraqi territory. The average annual flow of the river is variable, reaching its peak in April and May as the winter mountain precipitation melts. The typical decreasing water season occurs from July to December, reaching its lowest in August and September when water is most needed to irrigate the region's winter crops and the occurrence of summer evaporation [3]. In general, the climate in study regions is a typical dry desert in the last years. Some areas are characterized by arid to a semi-arid climate, especially in Al-Anbar and Al-Muthanna provinces. The summer months are hot and dry while moderate cold and wet in winter. The spring and autumn seasons are relatively short and characterized by a moderate temperature. Rainfall is very limited and concentrated in winter months [4].Monitoring stations are described below in Table (1) and Plate (1) shows the study area.

Table (1): Monitoring stations along Euphrates River.

Station No.	**Station Name**	**Province**	**Distance between stations (km)**	**Accumulated Distance (km)**	**WGS 84 Coordinates**		**Elevation (m.a.s.l)**
					North	**East**	
S1	Al-Qaim	Al-Anbar	-	-	34° 23' 35.0808"	41° 13' 14.3217"	161.7
S2	Haditha		116.73	116.73	34° 07' 48.3204"	42° 23' 26.6217"	103.9
S3	Al-Baghdadi		40.05	156.78	33° 53' 28.7340"	42° 31' 45.6575"	84.2
S4	Heet		69.66	226.44	33° 38' 30.3576"	42° 49' 50.3790"	80.8
S5	Al-Ramadi		51.93	278.37	33° 26' 20.9112"	43° 16' 23.4790"	64.7
S6	Al-Khalidiya		33.21	311.57	33° 23' 48.0480"	43° 30' 24.9081"	55.3
S7	Al-Fallujah		25.73	337.30	33° 20' 50.4132"	43° 45' 28.9497"	46.5
S8	Al-Musayyib	Babil	99.32	436.61	32° 47' 40.5060"	44° 17' 17.5537"	38.3
S9	Al-Hindiya Barrage		13.25	449.87	32° 42' 43.8732"	44° 16' 35.3955"	37.4
S10	Al-Hindiya	Karbala'	23.86	473.72	32° 32' 44.1960"	44° 13' 23.6504"	33.4
S11	Al-Kifl	Babil	48.15	521.88	32° 13' 32.7936"	44° 21' 47.2946"	29.3
S12	Al-Kufa	Al-Najaf	31.44	553.32	32° 00' 58.7340"	44° 25' 32.5332"	27.8
S13	Al-Shamiya	Al-Diwaniyah	42.16	595.47	31° 57' 56.8728"	44° 35' 33.2765"	26.9
S14	Al-Manathera	Al-Najaf	14.55	610.02	31° 55' 24.4236"	44° 29' 22.1484"	23.2
S15	Al-Shannafiya	Al-Diwaniyah	58.85	668.87	31° 34' 47.3772"	44° 38' 50.4740"	21.1
S16	Al-Samawah	Al-Muthanna	87.54	756.41	31° 18' 57.4524"	45° 17' 24.8555"	18.5
S17	Al-Khider		46.14	802.55	31° 11' 53.6532"	45° 32' 42.3686"	12.6
S18	Al-Nasiriyah	Thi Qar	96.45	899.10	31° 02' 16.1520"	46° 12' 29.5592"	10.7
S19	Al-Mutnazah		14.36	913.36	31° 00' 21.2472"	46° 18' 09.7478"	9.9
S20	Souq Al-Shioukh		26.39	939.76	30° 53' 36.5748"	46° 28' 31.3360"	8.1
S21	Al-Qurnah	Al-Basrah	104.43	1044.19	31° 00' 09.4356"	47° 25' 04.6452"	6.4
S22	Karmat-Ali		78.68	1122.86	30° 34' 28.9380"	47° 44' 51.5644"	4.3

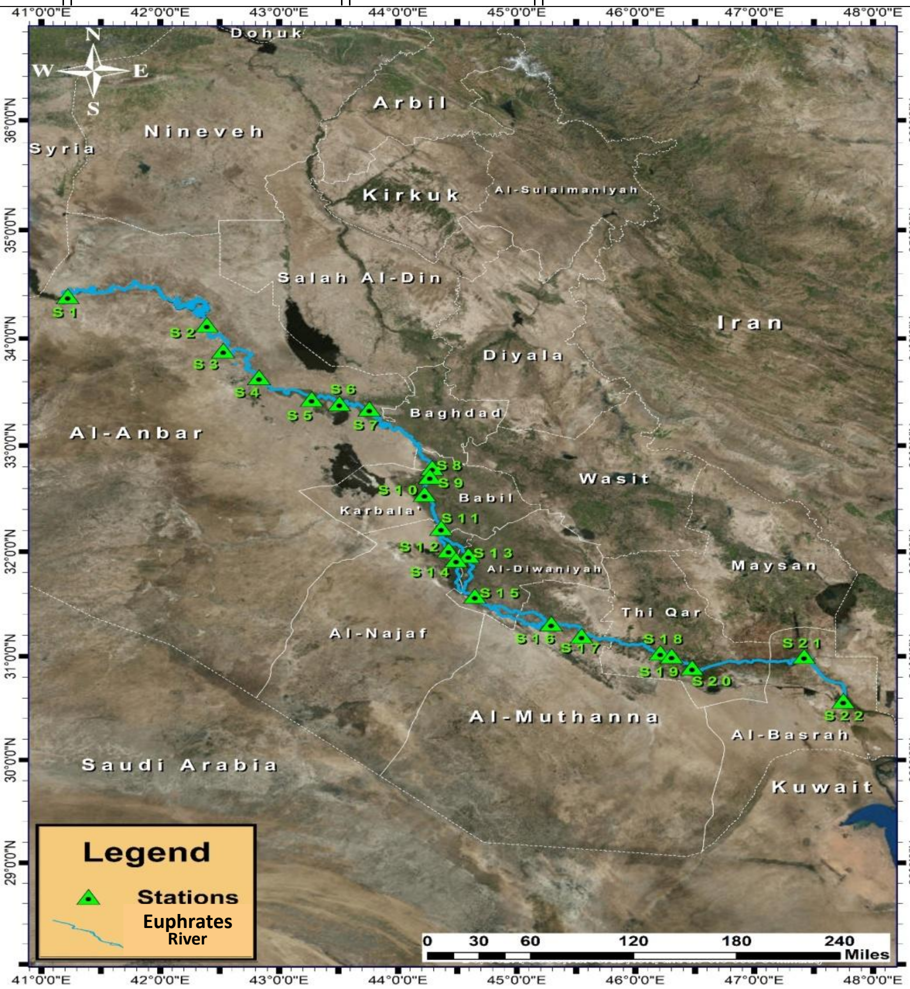


Plate (1): Satellite image map of the study area along Euphrates River.

3. WATER QUALITY INDEX (WQI)

Water Quality Index (WQI) is used for monitoring programs to assess ecosystem health which has the potential to inform the general public and decisionmakers about the state of the ecosystem. Also, it can be used to aggregate data on water quality parameters at different times and different places and to translate this information into a single value defining the period of time and spatial unit involved [5]. In general, WQIs have the capability to reduce the extent of large information of water parameters into a single value to express the data in a simplified and concept form. The results of WQIs can be used to evaluate the state of river water and alert the need for preventive practices. In recent years, WQI is considered as strong tools for the development and converging raw environmental information to assess the degree of pollution that might adversely affect aquatic systems.

3.1 Bhargava Water Quality Index (BWQI):

Bhargava has studied water quality index to evaluate the water quality status for various activities in Ganga, Yamuna and Saigon Rivers in India using the sensitivity function method. This index is based on the Walski-Parker index with slight modifications. Bhargava index is simple to deal with relative parameters for several utilizes using sensitivity functions curves which pick the value between 0 and 1 and the results are accumulated using the geometric mean. BWQI was selected since it was more detailed in its dealing with many sensitive functions where he gave a detailed description to analyze the water quality index for different purposes such as drinking, irrigation, and industrial uses. The geometric mean formula was developed and suggested by Viet and Bhargava as an absolute sub-index which is expressed as: [6]

$$\mathbf{BWQI} = \left[\pi_{i=1}^{n} \mathbf{fi}(\mathbf{P}i)\right]^{1/n} \quad *100 \;\; ..... (1)$$

Where, fi (Pi): Sensitivity function for each variable including the effect of variable weight concentration which is related to a certain activity and varies from 0 to 1; n: Number of variables. The nature of the sensitivity functions is determined by the impact of a change in the value of the parameter on water quality as in Figure (1) which represents the sensitivity function curves of T.H, $SO4^{-2}$, Cl^{-1}, TDS, Ca^{+2}, pH, and BOD for drinking purpose. These curves are used to evaluate the quality of the river water and give the importance of weight to every parameter.

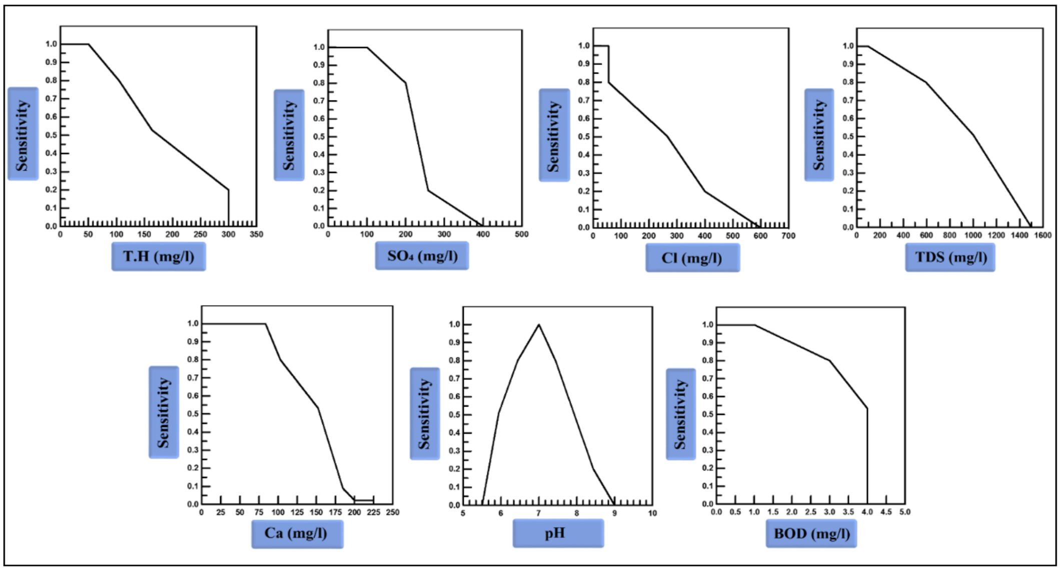


Figure (1): Sensitivity functions curves according to BWQI for drinking purpose.

3.2 Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI):

The Canadian Council of Ministers of the Environment has evolved the water quality index to simplify the reporting of complex water quality data. This index is a science-based communication tool that tests multi-variable water quality data against specified water quality benchmarks determined by the user. The CCMEWQI is a well-accepted and universally applicable model for evaluating water quality index. It is a most important formula and commonly used by researchers. So, it acts as an advantage of the index which can be applied by the water agencies in different countries with little modification. The CCMEWQI is based on relative sub-indices and adopts the conceptual model of British Columbia Water Quality Index (BCWQI). This model formula consists of three factors (scope, frequency, amplitude) as shown in Equation (2): [7]

$$\mathbf{CCMEWQI} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \quad \text{..... (2)}$$

Where the revised CCMEWQI consists of three factors:

- Scope Factor (F1):

The number of variables that are not compliant with the water quality standards over the period of interest, it is calculated as:

$$F_1(Scope) = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) * 100 \quad \text{..... (3)}$$

- Frequency Factor (F2):

This factor represents the percentage of individual failed tests values that are not met the objectives, it is calculated as:

$$F_2(Frequency) = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right) * 100 \quad \text{..... (4)}$$

- Amplitude Factor (F3):

This factor represents the amount by which the failed test values are not met their objectives, it is calculated as:

$$F_3(Amplitude) = \frac{nse}{0.01 nse + 0.01} \quad \text{..... (5)}$$

Where the amplitude factor is calculated in two steps:

Step (1) - Calculation of excursion:

The excursion is the number of times by which an individual concentration is greater than (or less than, when the objective is a lowest) the objective when the test value should not exceed the objective. The excursion is expressed as follows:

$$excursion_i = \frac{\text{Faild test value}_i}{\text{Objective}_j} - 1 \quad \text{or} \quad excursion_i = \frac{\text{Objective}_j}{\text{Faild test value}_i} - 1 \text{ ..... (6)}$$

Step (2) - Calculation of normalized sum of excursions:

The normalized sum of excursions (nse) is the collective amount by which individual tests are out of compliance. This is calculated by summing the excursions of individual tests from their objectives and divided by the total number of tests (those which do and do not meet their objectives). The (nse) is expressed as follows:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{\text{No. of tests}} \text{ ..... (7)}$$

3.3Brown's or Weighted Arithmetic Water Quality Index (WAWQI):

The WAWQI is one of the oldest methods of water quality indices that was proposed by Horton in 1965 and was developed by Brown in 1970 with much greater rigor in selecting parameters, developing a common scale and assigning weights. It has classified the water quality according to the degree of purity by using the most commonly measured water quality variables. This index has offered advantages over other methods such as in this method multiple water quality parameters are incorporated into a mathematical equation that rates the health of water body through a number called water quality index as well as it describes the suitability of surface and groundwater sources for human consumption. The weighted arithmetic mean formula is originally proposed by Brown in the following form: [8]

$$\text{WAWQI} = \frac{\sum_{i=1}^{n}(Wi*Qi)}{\sum_{i=1}^{n} Wi} \text{.....(8)}$$

Where, $\sum_{i=1}^{n} Wi = 1$

The methodology used to calculate the weighted arithmetic mean formula for WAWQI as in steps:

Step (1) - Collecting data of various physicochemical water quality parameters according to the period of study required.

Step (2) - Setting the standard or guideline permissible values (S_i) of the n^{th} parameters and calculate ($1/S_i$).

Step (3) - Calculating the proportionality constant (K) value using the following formula:

$$K = \frac{1}{\Sigma(1/Si)} \text{ ..... (9)}$$

Step (4): Calculating the unit weight (W_i) for the n^{th} parameters using the following formula:

$$Wi = \frac{K}{Si} \text{ ..... (10)}$$

Step (5): Calculating the quality rating scale (Q_i) for nth parameters using this expression:

$$Qi = \left[\frac{(Vn - Vi)}{(Si - Vi)}\right] *100\text{.....(11)}$$

Where, V_n: the estimated value of the nth parameter at a given sample location; V_i: the ideal value of the n^{th} parameter in pure water. In most cases V_i=0 (except pH =7.0 and DO = 14.6 mg/L).

Step (6): Calculate (W_i*Q_i) of the n^{th} parameter and finally calculate $\Sigma(W_i*Q_i)$.

4. GEOGRAPHIC INFORMATION SYSTEM (GIS) TOOLS USED FOR WATER POLLUTION MAPPING

Recently, with advance and increasing role of technology, new techniques and methods are developed for assessing water quality such as GIS which is a very helpful tool for storing, managing, improving solutions for water resources management and pollution problems and displaying spatial data often encountered in sanitary and water resources management to evaluate water quality, determining water availability and understanding the natural environment on a local and/or regional scale [9]. In this study, application of GIS maps helped to link the collected data and convert them into simplified and colorful maps together with it becoming easy for re-analyze and update. Besides, GIS technology can represent the reliable picture of water quality which may be used in general without showing the bulk of the results data. The results of WQIs values (annual mean values per sampling points) were used as input data in ArcGIS program. The sampling locations were integrated with the water data for the generation of spatial distribution maps. The present study has used the Inverse Distance Weighted (IDW) method for spatial interpolation of WQIs. The IDW was determined cell values using a linear-weighted combination set of sample points. The weight assigned is a function of the distance of an input point from the output cell location. The greater the distance, the less influence the cell has on the output value [10]. The suite of tools contained in GIS Analyst facilitates the creation, manipulation, and display of hydro features and objects within the ArcGIS environment. The work plan of GIS steps can be explained in Figure (2).

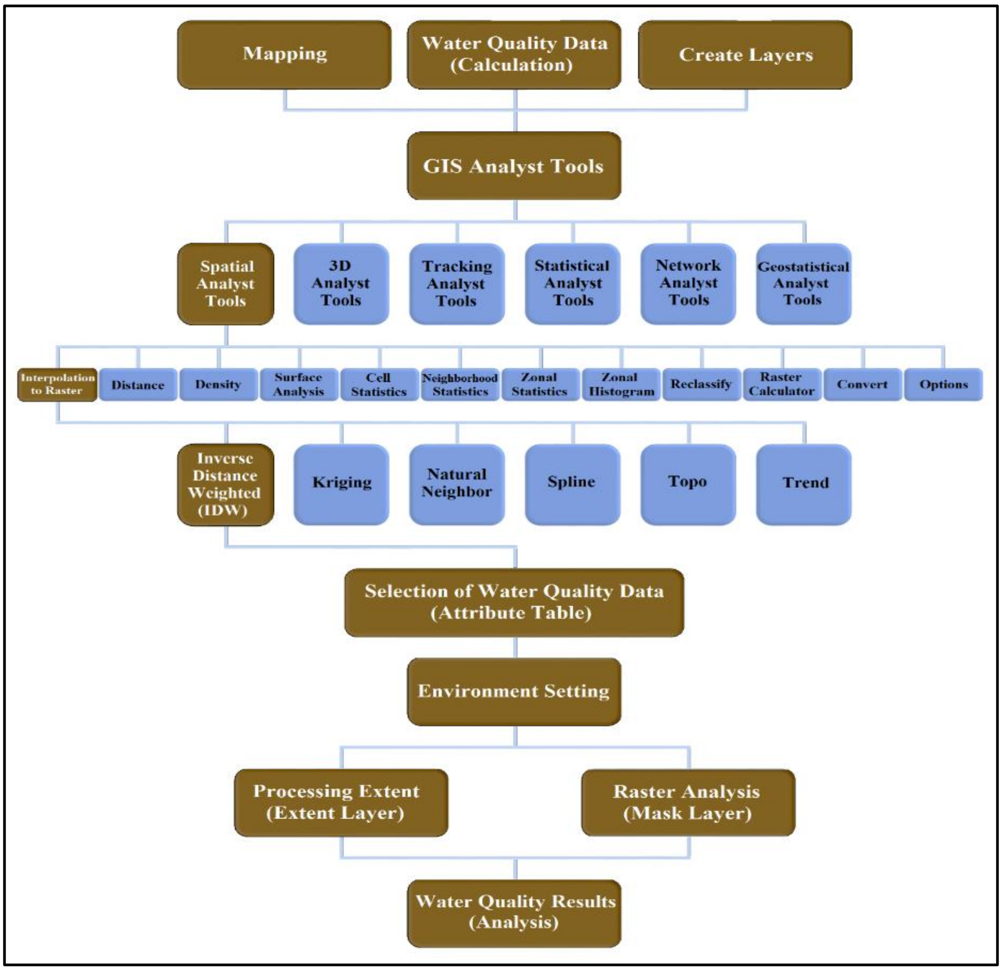


Figure (2): Schematic diagram of the implementation steps of GIS mapping and analysis in this study.

5. RESULTS

5.1 Physicochemical parameters of the river water:

This study involves the determination of physical and chemical parameters of surface water at different stations along the Euphrates River. In order to conclude a better view about the causes of deterioration in water quality, the results are compared with the permissible values of various impurities in drinking water recommended by the Iraqi specifications standard [11]. In present study, the mean concentration value of physicochemical parameters is given as below and shown in Figure (3):

5.1.1. Hydrogen Ion Concentration (pH):

The results of pH varied from 7.208 as a minimum value at Al-Hindiya station (S10) in 2018 to 8.454 as a maximum value at Al-Mutnazah station (S19) in 2015. This indicates that all pH values have not exceeded the permissible limits in Iraqi drinking water specifications standard and not classified with parameters responsible for water quality deterioration. The overall mean of all stations during the study period was 7.809 which was within the allowable limits for surface water and indicated that the water samples were almost neutral to sub-alkaline in nature and pH values of the river was increased along the downstream.

5.1.2. Nitrate (NO_3):

The overall mean of NO3 was 4.09 mg/L which indicates that the nitrate concentration has not caused eutrophication in surface waters and still complies with the IQS recommendations 50 mg/L. The maximum value of nitrate was 10.24 at Karmat-Ali station (S22) in 2015 and the minimum value was 0.975 at Al-Hindiya Barrage station (S9) in 2014.

5.1.3. Calcium (Ca):

The results of Ca varied from 73.83 mg/L as a minimum value at Al-Qaim station (S1) in 2015 to 290.3 mg/L as a maximum value at Al-Shannafiya station (S15) in 2018 and the overall mean of all stations was 142.177 mg/L. Most of Ca values have exceeded the permissible limits in the Iraqi standards for drinking water (not exceed 150 mg/L) and classified with parameters responsible for water quality deterioration especially in the area between Al-Manathera station (S14) and Al-Qurnah station (S21) during the overall study period. The high concentrations of calcium may indicate the geological structure in the river when certain soils may have increased in the calcium content that capable to be dissolved in running water.

5.1.4. Magnesium (Mg):

The data indicated that Mg concentrations have ranged from 22.77 mg/L as a minimum value at Al-Kufa station (S12) in 2019 to 234.9 mg/L as a maximum value at Al-Shannafiya station (S15) in 2015. The overall mean of Mg for all examined stations was 74.19 mg/L which was within the allowable limits, but the annual values of Mg were often higher than the permissible level recommended by the IQS for drinking water (100 mg/L) particularly in stations S15, S18, S19 and S20 during the study period and this rise may be due to the nature of adjacent lands to the banks of Euphrates River.

5.1.5. Total Hardness (T.H):

The results obtained showed that overall mean values of T.H was 653.3 mg/L and this indicates that most of the T.H values was higher than the maximum permissible level recommended by IQS for drinking water (not exceed 500 mg/L). However, the results of T.H varied from 325.7 mg/L as a minimum value at Haditha station (S2) in 2016 to 1476 mg/L as maximum value at Al-Nasiriyah station (S18) in 2018. The increase in T.H rates started after Al-Manathera station (S14) during the study period which can be attributed to the increase in calcium and magnesium levels which caused the presence of T.H in Euphrates River.

5.1.6. Sodium (Na):

The results of Na ranged from 67.99 mg/L as a minimum value at Al-Kufa station (S12) in 2019 to 1103 mg/L as a maximum value at Al-Nasiriyah station (S18) in 2018 and the overall mean of all stations was 291.8 mg/L. This indicates that most of Na values have exceeded the permissible limits of the Iraqi standards for drinking water (not exceed 200 mg/L) and classified with parameters responsible for water quality deterioration. Sodium had a significant rise at the downstream of Euphrates River after Al-Manathera station (S14) during the study period. This increase was an indication of the presence of sodium salts in the river water particularly in Al-Diwaniyah, Al-Muthanna, Thi Qar, and Al-Basrah provinces which depend on the Euphrates River as the main source of drinking water.

5.1.7. Sulfate (SO_4):

The overall mean of SO4 was 439.7 mg/L which was higher than the maximum permissible limit in drinking water (400 mg/L) and the maximum value of sulfate was 1103 mg/L at Al-Shannafiya station (S15) in 2014 and the minimum value was 161.7 mg/L at Al-Qaim station (S1) in 2015. The increase of sulfate content has started after Al-Fallujah station (S7) during the study period but exceeded the upper limits of IQS after Al-Manathera station (S14) except Al-Qurnah station (S21) where the river was improved slightly before returning to rise. This may be due to the man-made activities and natural sources which can also add significant amounts of sulfate to the river.

5.1.8. Chloride (Cl):

The results of Cl concentrations have varied from 102.8 mg/L as a minimum value at Al-Hindiya station (S10) in 2019 to 1403 mg/L as a maximum value at Karmat-Ali station (S22) in 2018 and the overall average of all stations was 390 mg/L. This means that most of Cl values have exceeded the permissible limits according to IQS (not exceed 350 mg/L) and classified with parameters responsible for water quality deterioration. Chloride had a significant rise at the downstream of Euphrates River after Al-Manathera station (S14) with a slight improvement in Al-Qurnah station (S21) during the study period. Chloride values have been approached to sodium values. Thus, forming an indicator of the presence of sodium chloride salts particularly in the river area near the monitored stations that suffer from high levels of sodium and chlorine together.

5.1.9. Total Dissolved Solids (TDS):

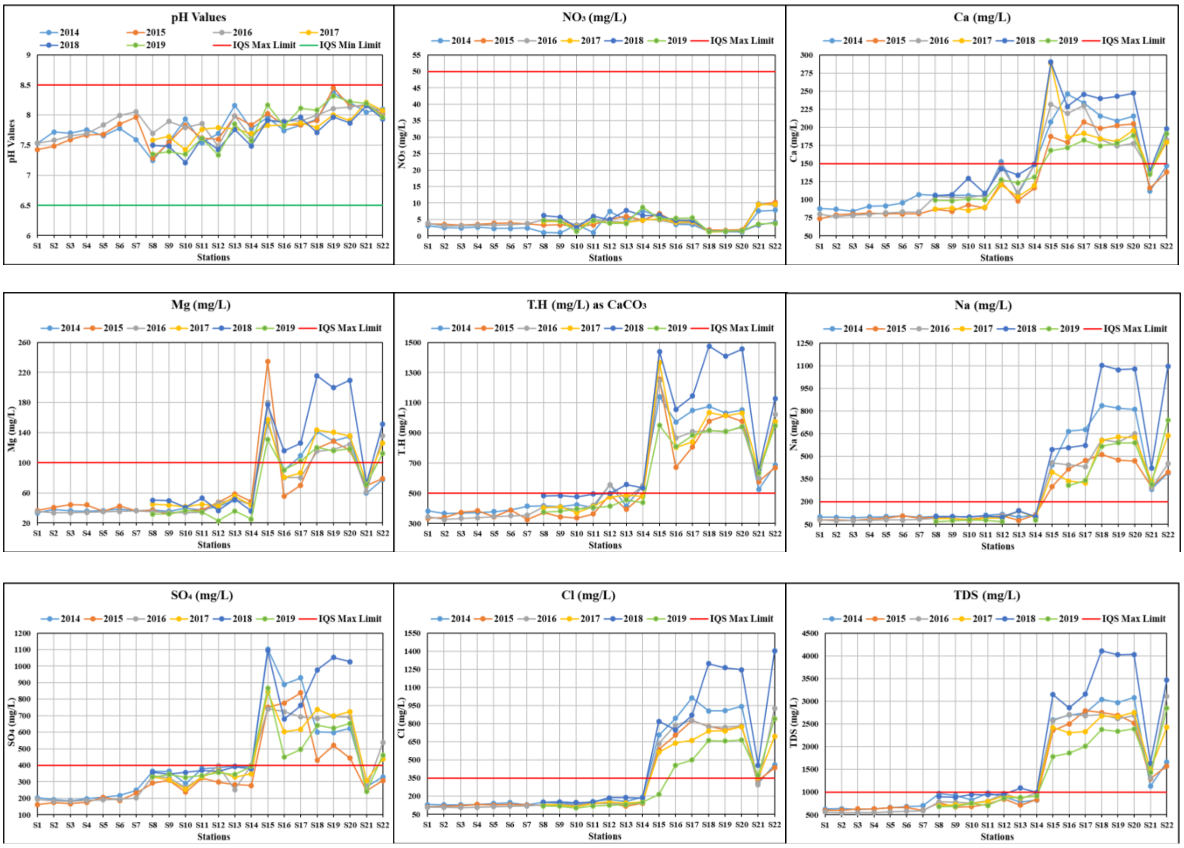
The data indicated that TDS concentrations have ranged from 544.4 mg/L as a minimum value at Al-Baghdadi station (S3) in 2016 to 4107 mg/L as a maximum value at Al-Nasiriyah station (S18) in 2018. The overall mean of TDS was 1526 mg/L which indicates that the annual values of TDS were often higher than the permissible level recommended by the IQS for drinking water (1000 mg/L). TDS began to rise gradually after Al-Fallujah station (S7) where has approached the limits allowed in Iraqi specifications for drinking water and exceeded the limits after Al-Manathera station (S14) during the study period. High concentration of TDS in the downstream of Euphrates River was a pointer to the fact that there were intense anthropogenic activities along the course of the river and run-off with high suspended matter content.

5.1.10. Electrical Conductivity (EC):

The obtained results showed that overall mean values of EC have reached 2480 µS/cm. This indicates that most of the EC values were higher than the maximum permissible level recommended by the IQS for drinking water (not exceed 1500 µS/cm). However, the results of EC have varied from 884.2 µS/cm as a minimum value at Haditha station (S2) in 2016 to 7173 µS/cm as maximum value at Al-Nasiriyah station (S18) in 2018. EC began to rise gradually after Al-Fallujah station (S7) where has approached the limits allowed in Iraqi specifications for drinking water. Then, it has recorded a significant rise at the downstream of Euphrates River after Al-Manathera station (S14) during the study period. This increase was an indication of the relationship between EC and TDS in the river water. High conductivity in Euphrates River may arise through natural weathering of certain sedimentary rocks or may had an anthropogenic source. High electrical conductivity was associated with high TDS, thus forming an indicator of the presence of dissolved salinity, significantly in the river area near the monitored stations that have suffered from high levels of both TDS and EC contents.

5.1.11. Total Alkalinity (Alk.):

The overall mean of alkalinity was 152.4 mg/L which was slightly higher than the maximum permissible limit (150 mg/L). The maximum value of alkalinity was 268.4 at Souq Al-Shioukh station (S20) in 2018 and the minimum value was 106.7 at Al-Shannafiya station (S12) in 2018. In general, total alkalinity began to rise gradually after Al-Manathera station (S14) where has exceeded the limits allowed in Iraqi specifications for drinking water (not exceed 150 mg/L) and has reached the peak values in S18, S19 and S20 stations during the study period.



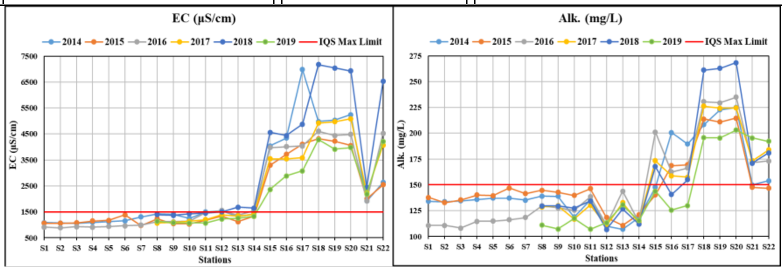


Figure (3): Variation of Physicochemical parameters values in the monitoring stations along Euphrates River during the study period.

5.2Calculation of Water Quality Indices (WQIs):

In this study, the water quality indices (WQIs) along Euphrates River have been calculated by using three WQIs methods to assess, compare and judge the suitability of Euphrates River for drinking purpose at multi locations within Iraqi territory. The aim of using WQIs is to convert complex water parameters data into useful data that is understandable and usable by people in general and it is also a very helpful tool for communicating the information on the overall quality of water to the decision-makers and involved citizens to assess variations in water quality.

5.2.1. Bhargava Water Quality Index (BWQI):

According to BWQI, the overall mean computed was 31.67 where recorded 0.00 as a minimum value at all stations between Al-Manathera station (S14) and Al-Qurnah station (S21) during the study period, while the maximum value was 78.05 at Al-Qaim station (S1) in 2015. Thus, the river was classified good water quality to severely polluted along Euphrates River for drinking purpose. It can be observed that the quality of the river during the study period was good in the first six stations at Al-Anbar province. Then, it began to deteriorate gradually after Al-Fallujah station (S7), and this may reflect the impact of pollutants from municipal wastewater and other human activities wastes. In general, the raw water of the river was classified as a severely polluted in the river area located after Al-Manathera station (S14) except for Al-Qurnah station (S21). Figure (4) shows the variation of BWQI values along selected stations on the Euphrates River during the study period. From correlation coefficient values between BWQI and water quality parameters, it was evident that T.H was the most factors affecting for computed BWQI values of Euphrates River in the study period as shown in Table (2).

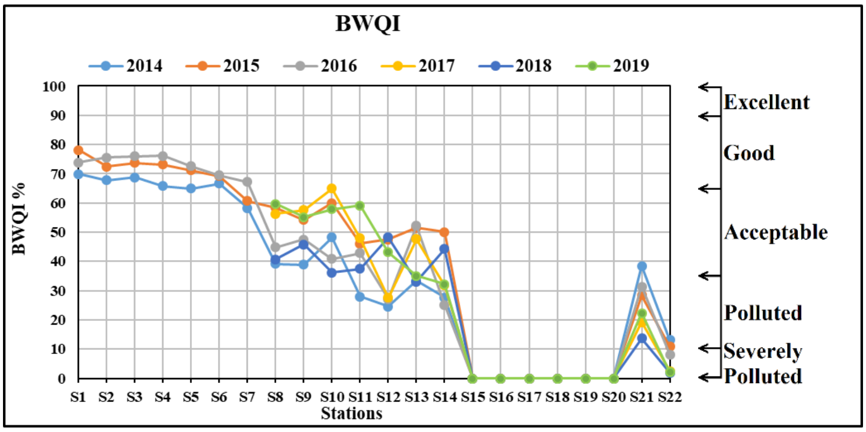


Figure (4): Variation of BWQI in the monitoring stations along Euphrates River during the study period.

Table (2): Correlation coefficient between BWQI and water quality parameters.

Correlation *	BWQI	T.H	SO_4	Cl	TDS	Ca	pH
BWQI	1						
T.H	-0.878	1					
SO_4	-0.836	0.900	1				
Cl	-0.835	0.919	0.847	1			
TDS	-0.887	0.959	0.884	0.984	1		
Ca	-0.905	0.951	0.902	0.884	0.928	1	
pH	-0.572	0.519	0.351	0.519	0.526	0.458	1

* Correlation is significant at the 0.01 level (2-tailed).

5.2.2. Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI):

The overall mean computed was 62.37 where recorded 19.87 as a minimum value at Al-Mutnazah station (S19) in 2018 and the maximum value was 95.37 at Al-Baghdadi station (S3) in 2016. Thus, the river water was classified excellent to poor for drinking purpose. It can be observed that the quality of the river during the study period was excellent, good and fair at the first fourteen stations along the Euphrates River. Then, the quality began to deteriorate after Al-Manathera station (S14) when the Euphrates River passing in the south of Iraq and this may reflect the impact of human activity, sewage disposal and industrial wastes in the river which was severe on most of the parameters. In general, the raw water of Euphrates River was classified as a poor quality in the river area located after Al-Manathera station (S14), except for Al-Qurnah station (S21) where water quality was slightly improved to be classified as marginal. Figure (5) shows the variation of CCMEWQI values along selected stations on the Euphrates River during the study period. From correlation coefficient values between CCMEWQI and water quality parameters, it was evident that TDS was the most factors affecting for computed CCMEWQI values of Euphrates River in the study period as shown in Table (3).

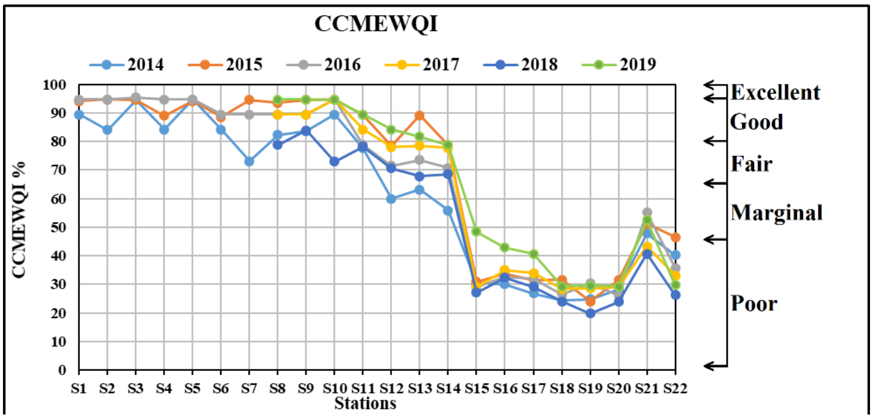


Figure (5): Variation of CCMEWQI in the monitoring stations along Euphrates River during the study period.

Table (3): Correlation coefficient between CCMEWQI and water quality parameters.

Correlation *	CCME	T.H	SO_4	Cl	TDS	Ca	pH	Mg	Na	NO_3	EC	Alk.
CCME	1											
T.H	-0.921	1										
SO_4	-0.826	0.900	1									
Cl	-0.905	0.919	0.847	1								
TDS	-0.934	0.959	0.884	0.984	1							
Ca	-0.919	0.951	0.902	0.884	0.928	1						
pH	-0.642	0.519	0.351	0.519	0.526	0.458	1					
Mg	-0.852	0.964	0.832	0.868	0.905	0.842	0.536	1				
Na	-0.877	0.897	0.811	0.969	0.951	0.830	0.547	0.871	1			
NO_3	0.003	-0.071	-0.133	-0.179	-0.157	-0.037	0.095	-0.100	-0.218	1		
EC	-0.909	0.934	0.870	0.986	0.980	0.894	0.502	0.886	0.966	-0.207	1	
Alk.	-0.786	0.786	0.669	0.848	0.846	0.698	0.539	0.787	0.889	-0.367	0.864	1

* Correlation is significant at the 0.01 level (2-tailed).

5.2.3. Weighted Arithmetic Water Quality Index (WAWQI):

The overall mean of WAWQI was 59.42 where recorded 24.13 as a minimum value at Al-Hindiya station (S10) in 2018 and the maximum value was 103.63 at Al-Mutnazah station (S19) in 2014. Thus, the river water was classified excellent to unsuitable for drinking purpose. From these results, it can be seen that the quality of the river during the study period was fluctuated and classified as excellent, good and poor at the first fourteen stations along the Euphrates River. Then, the quality began to deteriorate after Al-Manathera station (S14) and this may reflect the impact of pollutants from municipal wastewater and other human activities wastes. On the other hand, the raw water of river was classified as a very poor quality in the river area located after Al-Manathera station (S14), except for some time periods at Al-Mutnazah station (S19) where the water quality of the river was classified as unsuitable for drinking use. Figure (6) shows the variation of WAWQI values along the selected stations on Euphrates River during the study period. From correlation coefficient values between WAWQI and water quality parameters, it was evident that TDS and Na were the most affecting factors for the computed WAWQI values of Euphrates River in the study period as shown in Table (4).

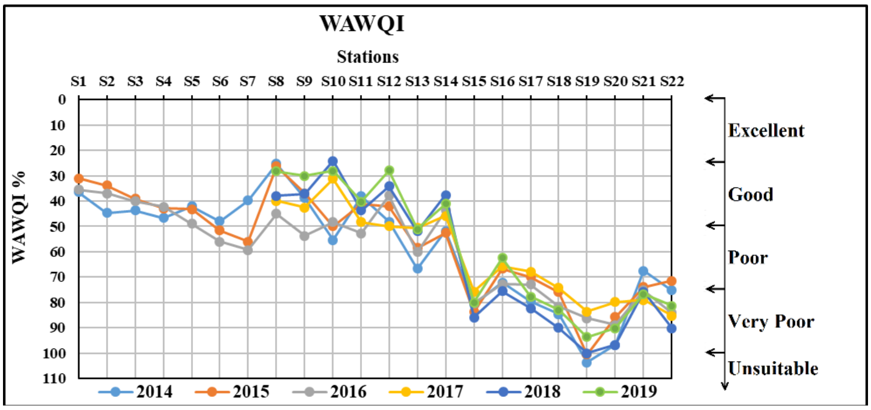


Figure (6): Variation of WAWQI in the monitoring stations along Euphrates River during the study period.

Table (4): Correlation coefficient between WAWQI and water quality parameters.

Correlation *	WAWQI	T.H	SO_4	Cl	TDS	Ca	pH	Mg	Na	NO_3	EC	Alk.
WAWQI	1											
T.H	0.858	1										
SO_4	0.709	0.900	1									
Cl	0.857	0.919	0.847	1								
TDS	0.868	0.959	0.884	0.984	1							
Ca	0.792	0.951	0.902	0.884	0.928	1						
pH	0.670	0.519	0.351	0.519	0.526	0.458	1					
Mg	0.849	0.964	0.832	0.868	0.905	0.842	0.536	1				
Na	0.868	0.897	0.811	0.969	0.951	0.830	0.547	0.871	1			
NO_3	-0.026	-0.071	-0.133	-0.179	-0.157	-0.037	0.095	-0.100	-0.218	1		
EC	0.852	0.934	0.870	0.986	0.980	0.894	0.502	0.886	0.966	-0.207	1	
Alk.	0.806	0.786	0.669	0.848	0.846	0.698	0.539	0.787	0.889	-0.367	0.864	1

* Correlation is significant at the 0.01 level (2-tailed).

5.3Statistical Analysis of Water Quality Indices (WQIs):

In general, the results of WQIs can be summarized in Table (5) which gives a simplified idea of the water quality along Euphrates River during the study period. In this study, statistical analysis of WQIs was used to calculate mean, median, mode, standard deviation, kurtosis, skewness, and coefficient of variation as summarized in Table (6). From correlation coefficient values between WQIs types, it was evident that WAWQI was the most method affecting on the other methods. The main results of Pearson Correlation Analysis showed that the correlation coefficient equals +0.949 between BWQI and CCMEWQI, -0.825 between BWQI and WAWQI and -0.899 between CCMEWQI and WAWQI at significance level (0.01) as shown in Table (7). Figure (7) shows the analysis statistical plots of water quality indices results during the study period.

Table (5): Summary of WQIs Results.

Result		Value	Classification	Grade	Station	Year
BWQI	Max	78.05	Good	B	S1	2015
	Min	0	Severely Polluted	E	S15~S20	2014~2019
	Overall	31.66	Polluted	D		
CCMEWQI	Max	95.37	Excellent	A	S3	2016
	Min	19.87	Poor	E	S19	2018
	Overall	62.37	Marginal	D		
WAWQI	Min	24.13	Excellent	A	S10	2018
	Max	103.6	Unsuitable	E	S19	2014
	Overall	59.42	Poor	C		

Table (6): Description of statistical analyses of WQIs values at the selected stations during the study period.

Statistics		BWQI	CCMEWQI	WAWQI
N	**Valid**	111	111	111
	Missing	0	0	0
Mean		31.6571	62.3667	59.4242
Std. Error of Mean		2.61599	2.59012	1.99638
Median		33.05	71.52	53.68
Mode		0	94.73	24.13
Std. Deviation		27.56115	27.28865	21.03316
Variance		759.617	744.67	442.394
Skewness		0.111	-0.185	0.226
Std. Error of Skewness		0.229	0.229	0.229
Kurtosis		-1.491	-1.694	-1.188
Std. Error of Kurtosis		0.455	0.455	0.455
Range		78.05	75.5	79.5
Minimum		0	19.87	24.13
Maximum		78.05	95.37	103.63
Sum		3513.94	6922.7	6596.09

Table (7): Pearson Correlation Analysis between WQIs methods at the selected stations during the study period.

Methods	WAWQI	CCMEWQI	BWQI
WAWQI	1		
CCMEWQI	-0.899	1	
BWQI	-0.825	0.949	1

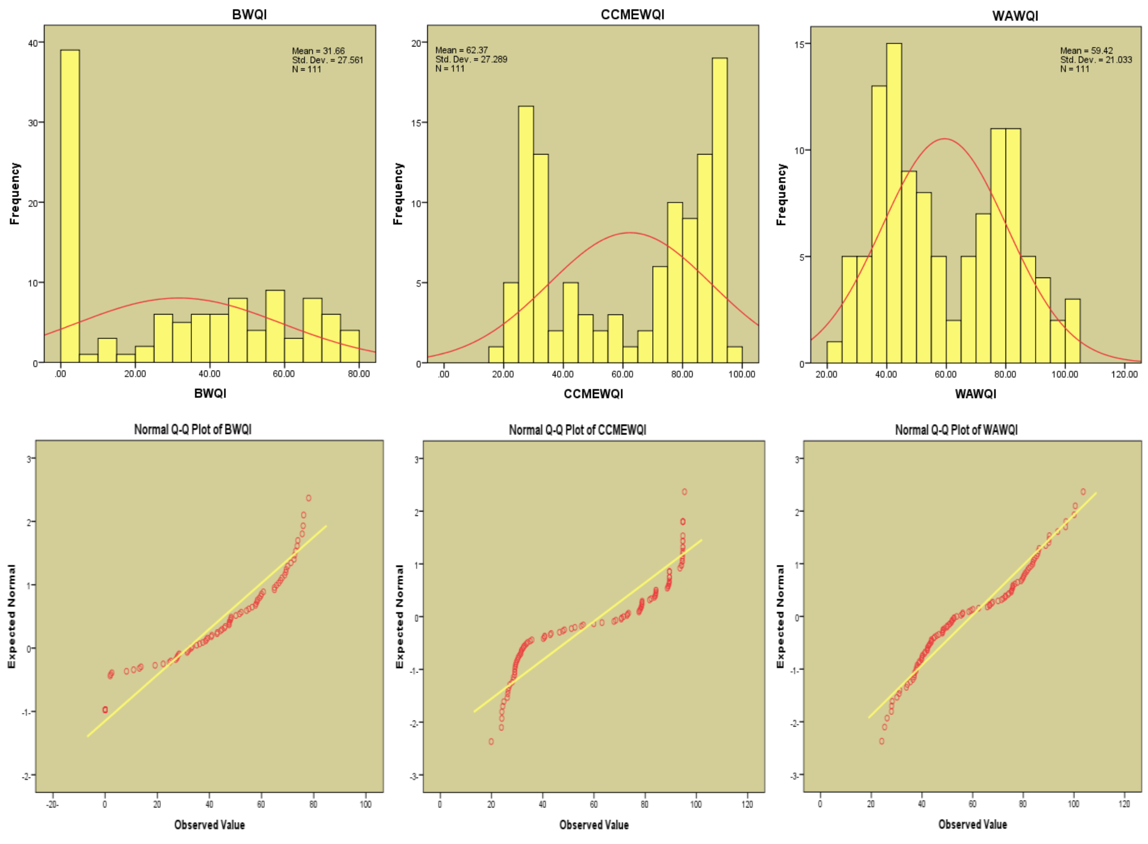


Figure (7): Analysis statistical plots for WAWQI values during overall study period.

5.4GIS model to colored pollution zones of Euphrates River:

ArcGIS 10.4.1 software program was used to produce the layers that shown the distribution and locations of some source's pollution. With the facilities of GIS, it was possible to present digital maps that shown the distribution of pollution areas and their effective zone on the Euphrates River. The results of WQIs values (annual mean values per sampling points) were used as input data in ArcGIS program. The sampling locations were integrated with the water data for the generation of spatial distribution maps. The present study has used the Inverse Distance Weighted (IDW) method for spatial interpolation of WQIs. The IDW was determined cell values using a linear-weighted combination set of sample points. In this study, GIS was showed the comparison between the satellite images and was displayed the change between low and high values of WQIs results. It can be determined the most zones of pollution in Euphrates River depending on the drawing maps with the information from the satellite survey of the study area. The GIS maps are shown in Plates (2, 3 and 4) which was represented the classification of WQIs during the study period and the images were proved that there were changes occurring in quality of the river. From GIS maps, it seemed very clearly that the worst values of water quality were recorded in the downstream of Euphrates River. Thus, identifying the main water parameters that can cause deterioration of water quality and to give a comprehensive idea of the state of Euphrates River. Tables (8), (9) and (10) show colors ramp indicators which used in GIS maps according to WQIs classifications.

Table (8):Colors ramp indicator for BWQI used in GIS maps.

BWQI Ramp Indicator	Value	Class	Water Quality
	100	A	Excellent
	90		
	80	B	Good
	70		
	60	C	Acceptable
	50		
	40		
	30	D	Polluted
	20		
	10	E	Severely Polluted
	0		

Table (9):Colors ramp indicator for CCMEWQI used in GIS maps.

CCMEWQI Ramp Indicator	Value	Class	Water Quality
	100	A	Excellent
	90	B	Good
	80		
	70	C	Fair
	60	D	Marginal
	50		
	40	E	Poor
	30		
	20		
	10		
	0		

Table (10):Colors ramp indicator for WAWQI used in GIS maps.

WAWQI Ramp Indicator	Value	Class	Water Quality
	0	A	Excellent
	10		
	20		
	30	B	Good
	40		
	50		
	60	C	Poor
	70		
	80	D	Very Poor
	90		
	100		
	≥ 100	E	Unsuitable

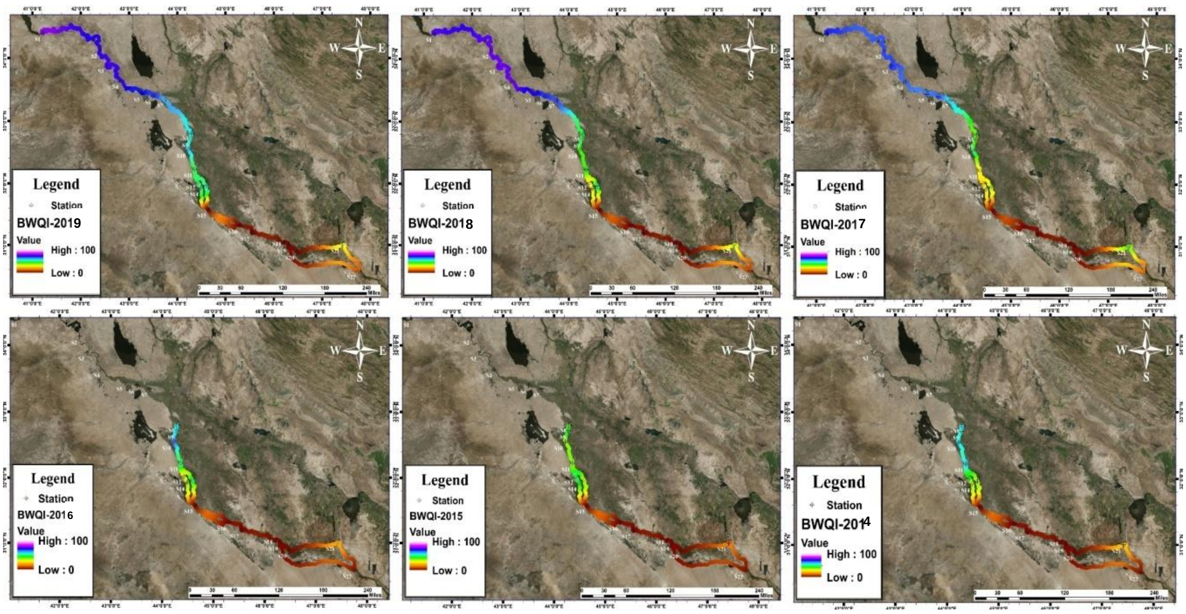


Plate (2): Map of the variation in BWQI values along Euphrates River during the study period.

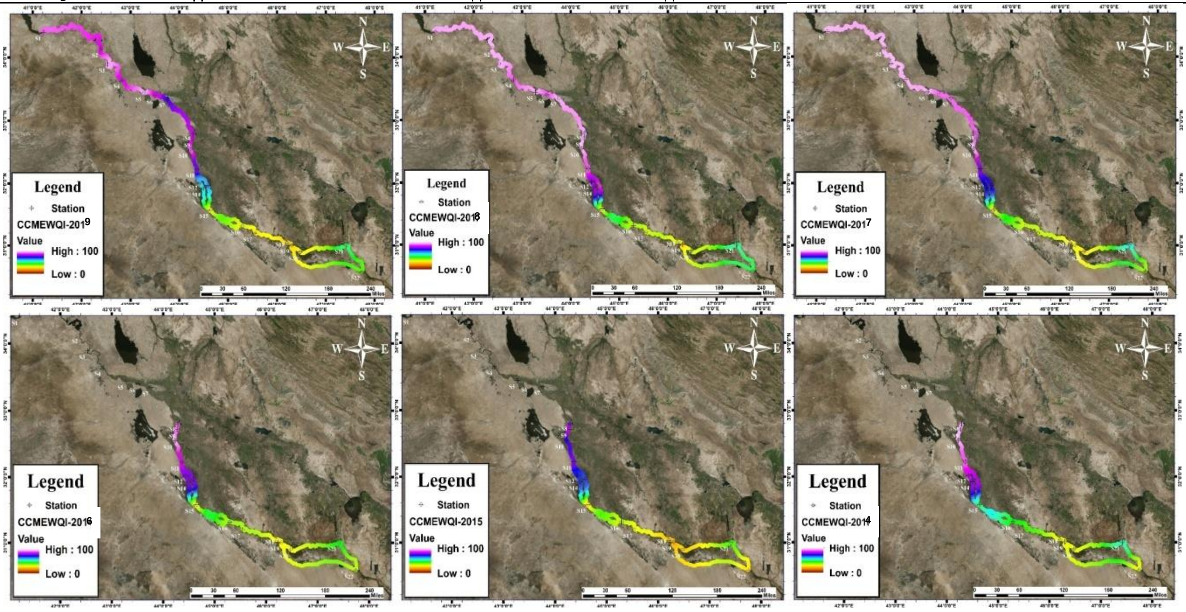


Plate (3): Map of the variation in CCMEWQI values along Euphrates River during the study period.

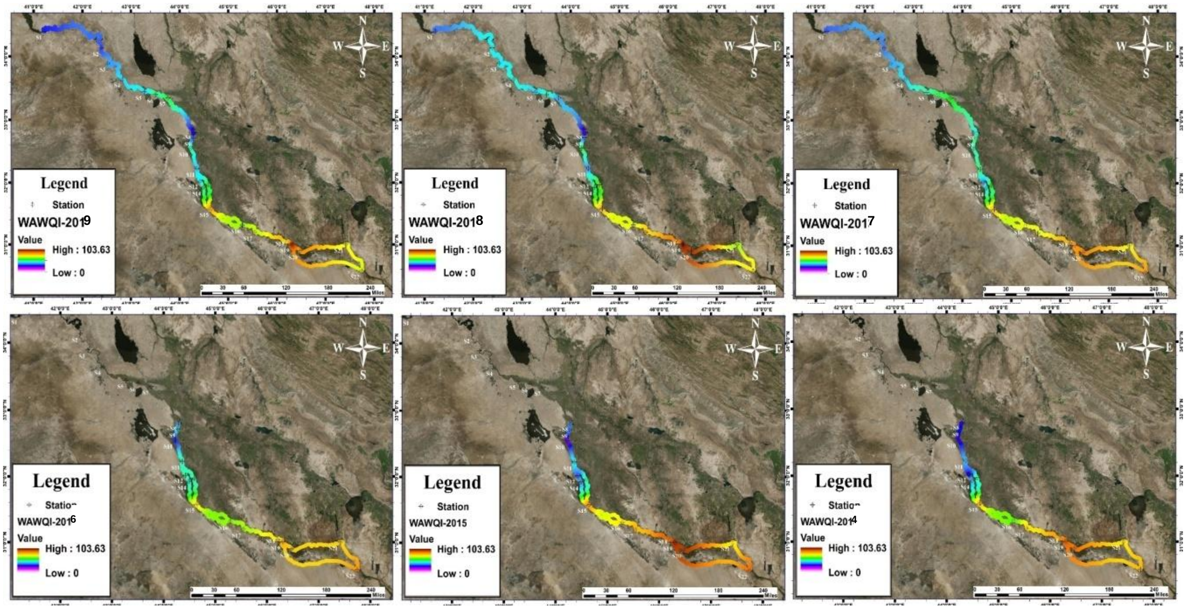


Plate (4): Map of the variation in WAWQI values along Euphrates River during the study period.

6. CONCLUSIONS

Water quality monitoring programs are not a straightforward process and are based mainly on the continuous monitoring operations. Therefore, it is very important to carefully define the objectives of monitoring the water quality of Euphrates River. The objectives statement should include the aim of surveying at these locations, what are the main parameters that cause deterioration in results of water quality indices, what should be monitored and assessing changes in the nature of river quality and the extent of its suffering from many sources of pollution and the risk of these sources on the suitability of the river water for drinking, the following conclusions were observed:

1- In general, the main water parameters causing deterioration of the quality of Euphrates River at selected stations were high in concentrations of Ca, Mg, T.H, Na, SO_4, Cl, TDS, EC, and Alk., where they exceeded permissible limits in IQS for drinking purpose especially after Al-Manathera station (S14) during the study period. On the other hand, pH and NO_3 concentrations were given the best values in all stations.

2- According to BWQI, the overall classification was "Polluted" for drinking purpose and categorized as grade "D" along Euphrates River but according to CCMEWQI, the water quality was "Marginal" and categorized as "D" grade while in case of WAWQI, the water quality was "Poor" and categorized as "C" grade.

3- The WQIs results showed the quality of Euphrates River was going to the bad situation whenever moving towards downstream particularly in stations (S15, S16, S17, S18, S19, S20 and S22) due to the impact of human activities, natural sources, sewage disposal and industrial wastes. There was a slight improvement in water quality at Al-Qurnah station (S21) due to dilution which caused by meeting the Tigris and Euphrates Rivers as a result of the rise of water level at Tigris River.

4- The water of Euphrates River becomes unsuitable for drinking purpose depending on WQIs results in most stations which means that the raw water of the river would need further treatments at the water treatment plants near the study monitoring stations.

5- In this study, the colored satellite maps could represent the reliable picture of water quality which may be used in general without showing the bulk of results data and it's become easy for re-analyzing and updating. In addition, it is considered an environmental application particularly it showed the pollution changes that occurred in the quality of the Euphrates River. Thus, it is easy to suggest the best management and to prepare the requirement which is necessary to control the pollution.

7. RECOMMENDATIONS

1- Adoption of water quality indices to express the extent of the validity of the water for all purposes because it is effective in the delivery of information to decision-makers from non-professionals in the field of environment.

2- Building sensitivity functions curves and creating a special index for water quality that matches with the Iraqi standards according to the quality of Iraqi surface water.

3- The efficiency of treatment plants should be improved to comply with Iraqi environmental standards because these plants are the main source of surface water pollution. On the other hand, the provinces should not allow the construction of industrial projects and factories in the proximity of the river zone and protect the water quality from further deterioration.

4- Monitoring Euphrates River by using GIS techniques to put way a map to control the pollution and to show the change which may happen in the river for supporting decision-makers in the monitoring and to early treatments of the water pollution in the river.

5- Finally, further studies are needed in monitoring and controlling the sources of pollution to protect and enhance the water quality in Iraq especially in the next few years where the country is likely to suffer from a potential water stresses in quantity and quality of the surface water.

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