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Evaluation of Water Quality using Bhargava Water Quality Index Method and GIS, Case Study: Euphrates River in Al-Najaf City

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Abstract: ***In this study, water quality index (WQI) was calculated to classify the flowing water in the Euphrates River at Al-Najaf City and try to correlate the results with the satellite image for making colored analytical models to the river that can be used to predict the classification of river water quality for drinking purpose. Bhargava WQI method was adopted to evaluate and judge the suitability of Euphrates River in Al-Najaf City, this was done by testing the water quality of the samples collected from intakes of two stations (Al-Kufa Water Project and Manathira Water Project) in Al-Najaf city. The analysis includes different polluted parameters: Total Hardness (T.H), Sulfate (SO_4^{-2}), Chloride (Cl^{-1}), Total Dissolve Solids (TDS), Calcium (Ca^{+2}), pH value, and Biochemical Oxygen Demand (BOD) as a monthly average base during the year 2015. The results from WQI analysis classified the Euphrates River "acceptable" to "polluted" at Al-Kufa station while it was "acceptable" to "severely polluted" at Manathira station. WQI reached a maximum value of 43.65 in July at Manathira station through the study period, while the average annual overall WQI was 33.34 at Al-Kufa station and 29.67 at Manathira station. The high value of average annual overall WQI obtained is a result of the high concentrations of Sulfate, Total Dissolve Solids, Calcium and Total Hardness which can be attributed to the various human and industrial activities taking place at the river banks. The results are analyzed by using the Geographic Information System (GIS) which requires building a network database linked to GIS for making benefit from its analysis power and geographical distribution of data across the study area.***

Keywords: Euphrates River, WTP, water quality index, GIS, IDW.

1. Introduction

Water is essential for life on Earth, and any variations in the natural quality and distribution of water have ecological effects that can sometimes be devastating. In general, the human need to safe drinking water that essential to health and must be available to all, the main element of effective policy for health protection and a fundamental human right [1]. The quality of surface water is a very sensitive matter and should be satisfactory (abundant, adequate, accessible and safe). It is necessary to make detailed studies to evaluate the quality of Euphrates River water for drinking purpose. Organic and inorganic pollutants are of worldwide concern, increasing human land occupation and industrial pollutions of river water, have made the river water quality evaluation a crucially important matter [2]. Water quality assessment is essential to prevent and control river pollution and to get reliable information on the quality of water for effective management [3]. Monitoring programs of a river play a significant role in water quality control since it is necessary to know the contamination degree so as not to fail in the attempt to regulate its impact. These pollutants can be carried to the surface water from various sources and the estimation of the response of a river to any proposed pollution abatement action is one of the most complex problems facing the environmental engineers.

Water Quality Index (WQI) can be utilized to observe water quality variation in a specific water supply over time or it can be utilized to contrast a water supply's quality with other water supplies in the region or from around the globe [4].
Objectives of the study:

1) To study the effects of the water quality parameters of the Euphrates River in Al-Najaf city.
2) To determine the water quality of the Euphrates River, depending on Bhargava WQI method.
3) To discuss the suitability of the river in the study area for human consumption based on computed water quality index values.
4) To create WQI colored maps based on GIS according to the classification of river water.
5) To test the water quality parameters with the Iraqi standards for drinking purpose.

2. Study Area

Al-Najaf is a governorate in Iraq, about 100 miles south of Baghdad (the capital of Iraq). It is a flat region extending from the Euphrates River in the northeast to the Saudi Arabian border in the southwest. Except for the area near the river, the region is sparsely populated. Area governorate is 28,824 square km and estimated population in 2014 was 1,389,500 people. Al-Najaf has a typical dry desert climate. The summer months are hot and dry, while precipitation is very low and limited to the winter months. The governorate receives an average amount of only 99 mm of rainfall a year [5]. Euphrates River passes through Al-Najaf city, which is the longest river in western Asia. It originates in Turkey, runs through Syria entering Iraq from the western border and discharge in Shatt Al-Arab (the confluence of the Tigris and Euphrates Rivers). In Al-Najaf city, a tremendous increase in freshwater demand is required due to the rapid growth in population and accelerated industrialization. As well as the pollution increase in the river stretch due to effluent discharges by various uncontrolled sources as domestic, industries and agriculture along the downstream stretch and most industrial institutions and factories are located on both sides of the Euphrates. This condition generates ecological problems threatening the ecosystem of Al-Najaf city, due to the drainage of sewages and byproducts of these institutions and factories directly to the body of Euphrates River. Therefore, river water quality monitoring is necessary to evaluate the water quality for different purposes. The nature of the land around the river in Al-Najaf city is a farming area, with some residential buildings and agricultural land [6]. Fig. 1 shows the study area.

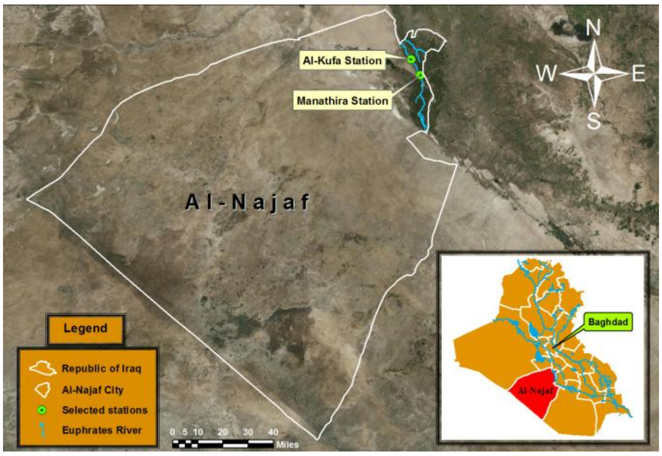


Figure 1: The study area

3. Data Collection

The data used in this research were provided by Ministry of Water Resources in Iraq for the year 2015 which represented the monthly average values for seven water parameters that are used to find a water quality index for Bhargava method. In order to give a comprehensive idea of the overall water quality of the river in a study area, samples are collected from two stations along Euphrates River nearby Al-Kufa Water Project and Manathira Water Project. These stations were selected to carry out the present study along 26.107 km stretch of Euphrates River situated in AI-Najaf city. The coordinates (x, y, z) for the locations of stations are described in table 1. Fig. 2 show stations location for water quality monitoring along Euphrates River in Al-Najaf city.

Table 1: Description of the monitoring stations along Euphrates River within Al-Najaf city

Stations	*Location*	*Coordinates*		
		X	*Y*	*Z (meters above sea level)*
Al-Kufa Station	Near Al-Kufa Water Project	445763.85	3542388.27	13
Manathira Station	Near Manathira Water Project	451738.89	3532064.57	11

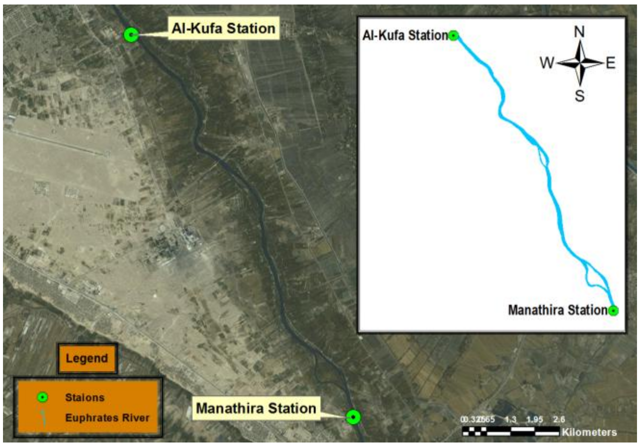


Figure 2: Stations location for water quality monitoring along Euphrates River within Al-Najaf city

4. Water Quality Index (WQI)

Water quality can be extensively defined as the physical, chemical, and biological composition of water as related to its intended utilize for such objectives as drinking, recreation, irrigation, and fisheries [7]. The water quality of rivers and lakes changes with the seasons and geographic regions, even when there is no pollution existent. To explain water quality in general terms, by measured parameters to describe the water quality of a river, stream, or lake. Parameters that are measured include physical, chemical, and biological properties.

Water quality index (WQI) gives a single number that expresses overall water quality at a specific location and time based on several water quality parameters. The target of WQI is to convert complex water quality data into information that is understandable and useable by the public in general. WQI is also a very useful tool for communicating the information on the overall quality of water to the concerned citizens and policy makers and permits the assessment of changes in water quality, to identify water trends and to classify the purpose different water uses [8]. Water quality index idea was first presented in Germany over 169 years prior in 1848 where existence or absence of certain organisms in water was utilized as a pointer of the fitness or otherwise of a water source [9]. In 1965, Horton was developed and expanded WQI concept in United States [10]. He was chosen ten most commonly utilized water quality parameters like dissolved oxygen, pH, coliforms, specific conductance, alkalinity, and chloride etc. and has been approved in European, African and Asian countries [11]. Also, Horton put the rating scales and the weightings for the determinants to give the relative importance of each parameter in the water quality [12]. The formula which he used is:

$$WQI = \left[\frac{\sum_{i=1}^{n} Ci.Wi}{\sum_{i=1}^{n} Wi} \right] .M1.M2 \qquad (1)$$

Where:
WQI: water quality index;
Ci: the rating of the ith determinant;
Wi: the weighting of the ith determinant;
n: number of determinants;
M 1, M 2: additional determinant parameters.

4.1 Bhargava method to determine WQI

Bhargava studied WQI to evaluate the water quality for various activities in Ganga River in India and Saigon River in Vietnam using the sensitivity function method. Bhargava method is simple to deal with relative parameters for several utilizes by using sensitivity functions curves which pick the value between 0 and 1 and the results are accumulated by using the geometric mean [13].

4.2 Bhargava formula

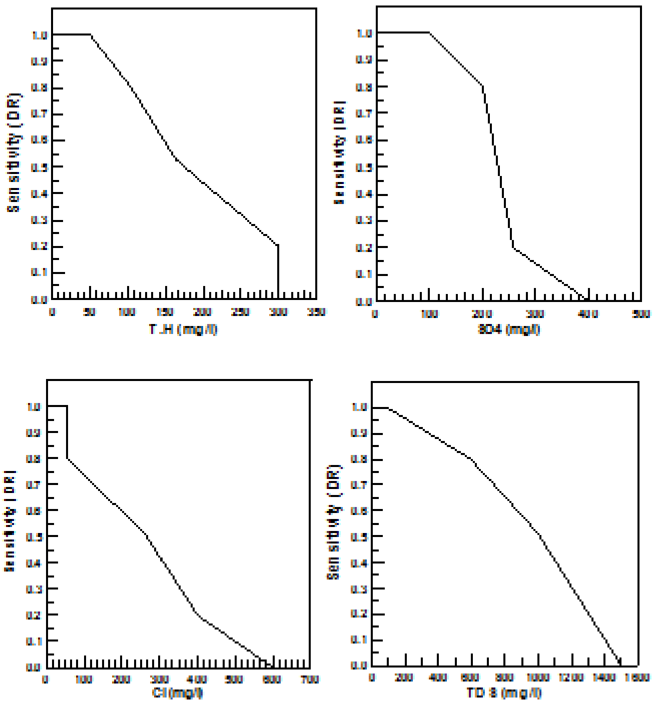
The geometric mean formula was suggested by Bhargava which expressed as:

$$WQI = \left[\pi_{i=1}^{n} \; fi\left(P_i\right)\right]^{1/n} \quad *100 \qquad (2)$$

Where:
fi (Pi): the 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: the number of variables.

4.3 Sensitivity Functions Curves

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 figs. 3 which represents the sensitivity function curves are (T.H, SO_4^{-2}, Cl^{-1}, TDS, Ca^{+2}, pH and BOD) for drinking purpose. These curves are used to evaluate the quality of river water and give the importance with weight to every parameter.



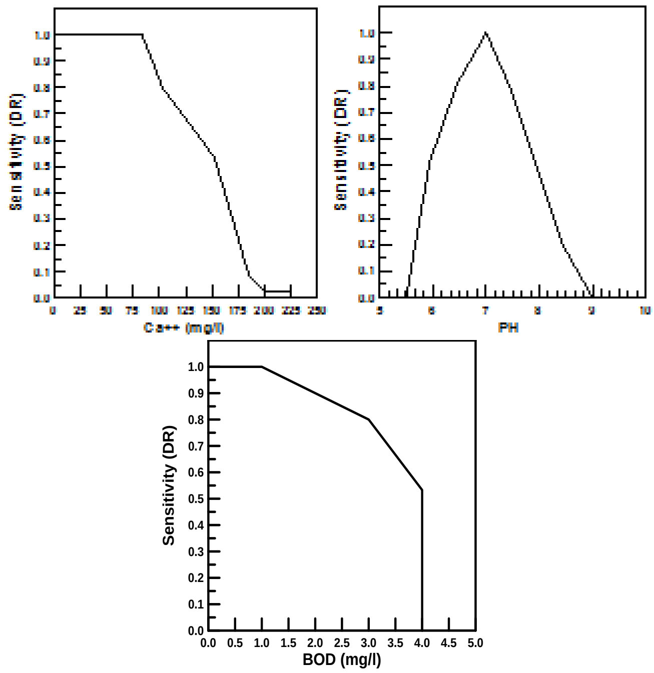


Figure 3: Sensitivity functions curves according to Bhargava for drinking purpose

4.4 Classification of water quality

Depending on the quality of water in the region, the river could be classified into five groups according to Bhargava method for drinking water specifications as shown in table 2 [14].

Table 2: Water quality classification according to Bhargava method

Class	*WQI Value*	*Water Quality*
I	100 - 90	Excellent
II	89 - 65	Good
III	64 - 35	Acceptable
IV	34 - 11	Polluted
V	< 10	Severely Polluted

5. Geographic Information System (GIS)

Geographic Information System (GIS) is a very helpful tool for improving solutions for water resources problems to evaluate water quality, determining water availability and understanding the natural environment on a local or regional scale. From GIS, spatial distribution mapping for various pollutants can be done, and the resulting information is very useful for decision-makers to take remedial measures [15]. Raising public awareness, stricter measures and promulgation of new rules in water quality management have made the utilize of advanced technologies indispensable. GIS is an effective tool for storing, managing and displaying spatial data often encountered in sanitary and water resources management. In order to stress the importance of GIS in water resources management, applications related to this area are addressed and evaluated for efficient future research and development. GIS implementations are presented including water supply, groundwater modeling, surface hydrologic, water and wastewater network, sewer system modeling, stormwater modeling for urban and agricultural areas [16].

GIS has several kinds of tools such as statistical, spatial and geostatistical analyst. Tools of the spatial analyst, for instance, is one of the most important tools that interpolates points data which contain an attribute data and layout. The result in a form of raster format that can take gradient color showing the difference between the values. Geostatistical Analyst contains different tools to deal with point and area data. The geostatistical tools are more advanced than statistical tools which are just the basic statistical process such as mean, median and standard deviation tools [17].
The results of the physical and chemical analysis were then used as input data in ArcGIS 10.4.1. The sampling locations were integrated with the water data for the generation of spatial distribution maps. The present study used the Inverse Distance Weighted (IDW) method for spatial interpolation of water quality parameters. 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 [18].

6. Results

In Al-Najaf city there are many water treatment plants (WTPs) located on the banks of the Euphrates. In this study, two stations were selected near Al-Kufa Water Project and Manathira Water Project. The water quality of the river at the intakes of these plants was taken as the necessary water parameters for the determination of the water quality index in this region.

6.1 Physicochemical parameters of the river water

In this study, it has been found that all examined water samples had values of pH, Ca, SO_4, Cl, TDS and T.H. Figs. 4 to 9 show the variation of each parameter in the selected stations of Euphrates River for the year 2015 and compared with Iraqi drinking water quality standards [19].

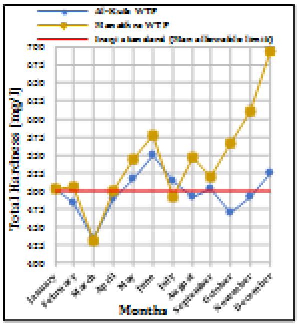


Figure 4: T.H(mg/l) variation in the Euphrates River for the year 2015

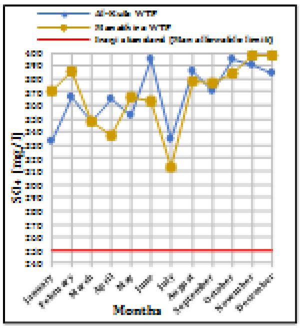


Figure 5: SO_4(mg/l) variation in the Euphrates River for the year 2015

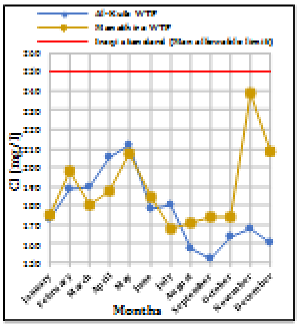


Figure 6: Cl(mg/l) variation in the Euphrates River for the year 2015

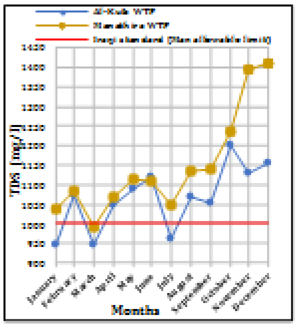


Figure 7: TDS(mg/l) variation in the Euphrates River for the year 2015

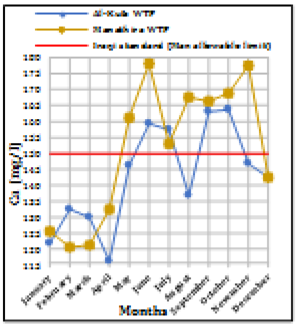


Figure 8: Ca(mg/l) variation in the Euphrates River for the year 2015

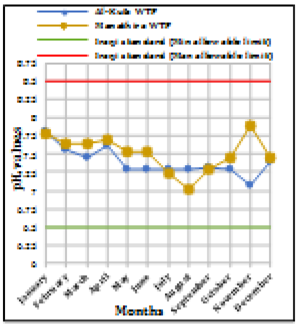


Figure 9: pH variation in the Euphrates River for the year 2015

6.2 Calculation of WQI

Samples of WQI calculations are shown in table 3 and table 4 for the selected stations in 2015. It is noticed from tables that there is deterioration in the water quality of Euphrates River in Al-Najaf city for drinking purpose. The river water at Al-Kufa station was classified from acceptable to polluted for drinking purpose, while in Manathira station was classified from acceptable to severely polluted. Fig. 10 show the variation of WQI between stations during the study period.

Table 3: WQI Calculations for Al-Kufa station in the year 2015

Months	*WQI%*	*Class*	*Categorization*	*Parameters responsible for water quality deterioration**
Jan	41.63	III	Acceptable	SO_4
Feb	35.9	III	Acceptable	SO_4, TDS
Mar **	41.86	III	Acceptable	SO_4
Apr	36.77	III	Acceptable	SO_4, TDS
May	37.98	III	Acceptable	SO_4, TDS, T.H
Jun	22.43	IV	Polluted	Ca, SO_4, TDS, T.H
Jul	41.11	III	Acceptable	Ca, SO_4
Aug	31.4	IV	Polluted	SO_4, TDS, T.H
Sep	32.78	IV	Polluted	Ca, SO_4, TDS
Oct ***	21.49	IV	Polluted	Ca, SO_4, TDS, T.H
Nov	28.25	IV	Polluted	SO_4, TDS, T.H
Dec	28.48	IV	Polluted	SO_4, TDS, T.H
***Max*	*41.86*	**Parameters have sensitivity value less than 0.5 (according to Bhargava sensitivity functions curves for drinking purpose as figure 3)*		
****Min*	*21.49*			
Mean	*33.34*			

Table 4: WQI Calculations for Manathira station in the year 2015

Months	*WQI%*	*Class*	*Categorization*	*Parameters responsible for water quality deterioration**
Jan	34.34	IV	Polluted	SO_4, TDS
Feb	29.79	IV	Polluted	SO_4, TDS
Mar	40.68	III	Acceptable	SO_4
Apr	39.47	III	Acceptable	SO_4, TDS
May	31.74	IV	Polluted	Ca, SO_4, TDS, T.H
Jun	27.79	IV	Polluted	Ca, SO_4, TDS, T.H
Jul **	43.65	III	Acceptable	SO_4, TDS, T.H
Aug	29.61	IV	Polluted	Ca, SO_4, TDS
Sep	29.22	IV	Polluted	Ca, SO_4, TDS
Oct	24.24	IV	Polluted	Ca, SO_4, TDS
Nov ***	10.78	V	Severely Polluted	Ca, SO_4, TDS
Dec	14.69	IV	Polluted	SO_4, TDS, T.H
** *Max*	*43.65*	**Parameters have sensitivity value less than 0.5 (according to Bhargava sensitivity functions curves for drinking purpose as figure 3)*		
*** *Min*	*10.78*			
Mean	*29.67*			

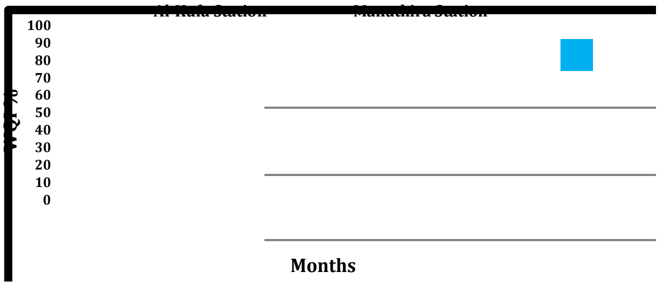
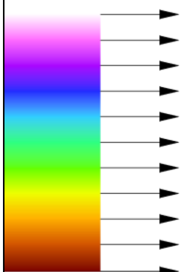


Figure 10: Variation of WQI % between selected stations during the year 2015

6.3 Using the GIS software to build the colored model

The results of the study have been linked with ArcGIS 10.4.1 software to produce layers of represent the nature of the spatial distribution of WQI in the form of a colored map to show pollution zones in the water of Euphrates river at Al-Najaf city because of its importance in this province. Analysis has been to help in identifying the appropriate zones of water quality for drinking purpose. The GIS maps are shown in figs. 11 to 22 that representing WQI of the Euphrates River in Al-Najaf city as monthly maps during 2015 between the intakes of selected stations. Table 5 shows the colors ramp indicator used in the GIS maps according to WQI classification which is already mentioned in table 2.

Table 5: Colors ramp indicator for WQI in the GIS maps

WQI colors ramp	*WQI % values*
	>= 50
	45
	40
	35
	30
	25
	20
	15
	10
	5
	0

The colors ramp indicator started from the value of 50% for WQI to give the largest degree as possible of colors gradation because there are no values exceeding 50%.

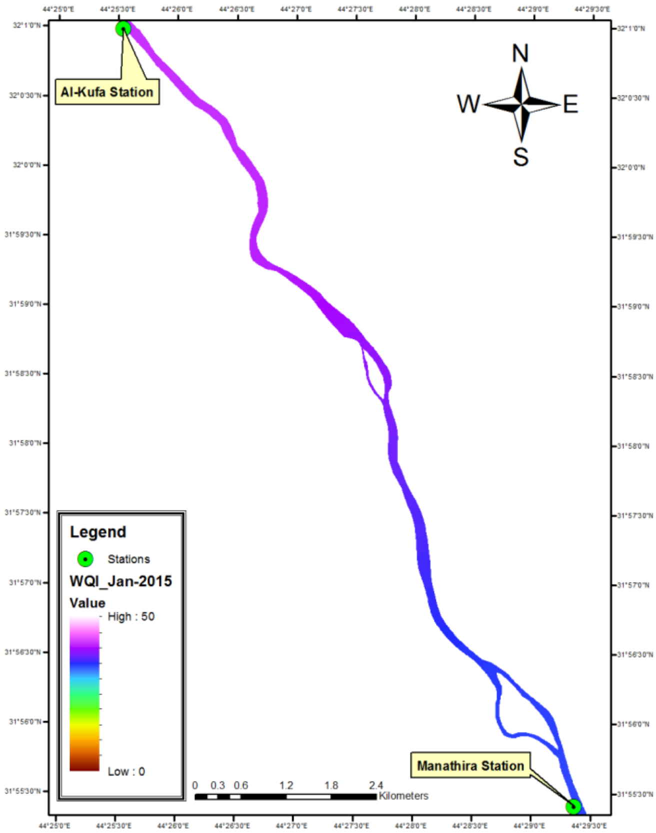


Figure 11: GIS Map for WQI variation in the Euphrates River in January-2015

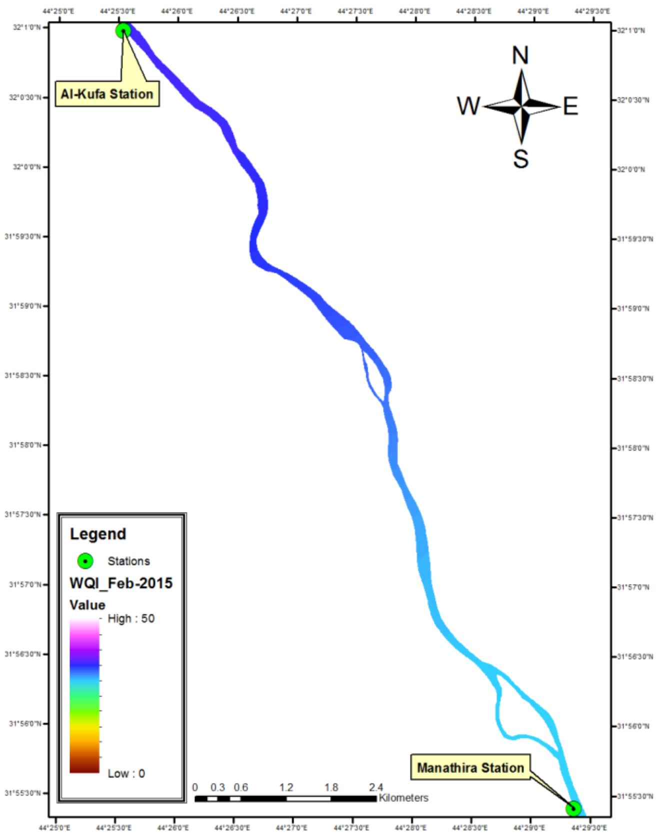


Figure 12: GIS Map for WQI variation in the Euphrates River in February-2015

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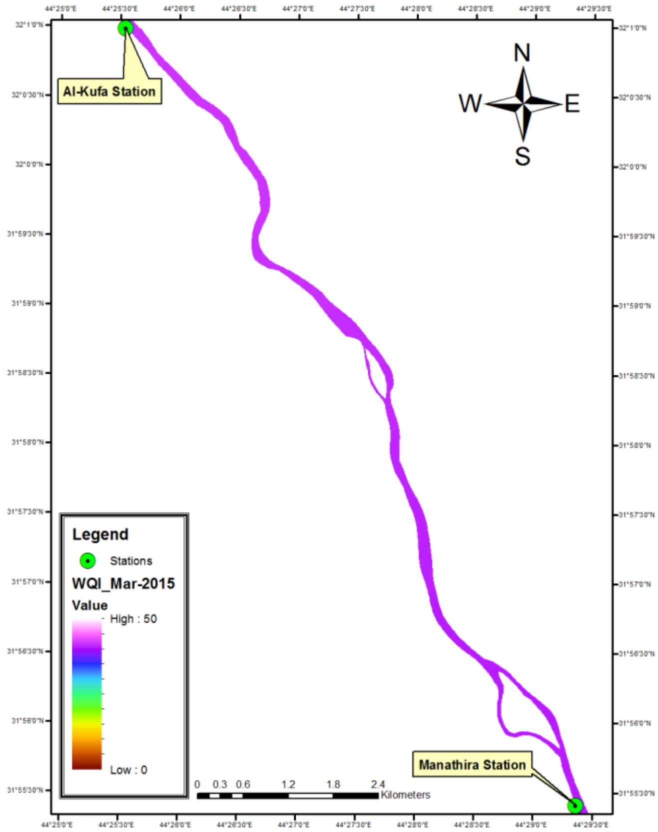

Figure 13: GIS Map for WQI variation in the Euphrates River in March-2015

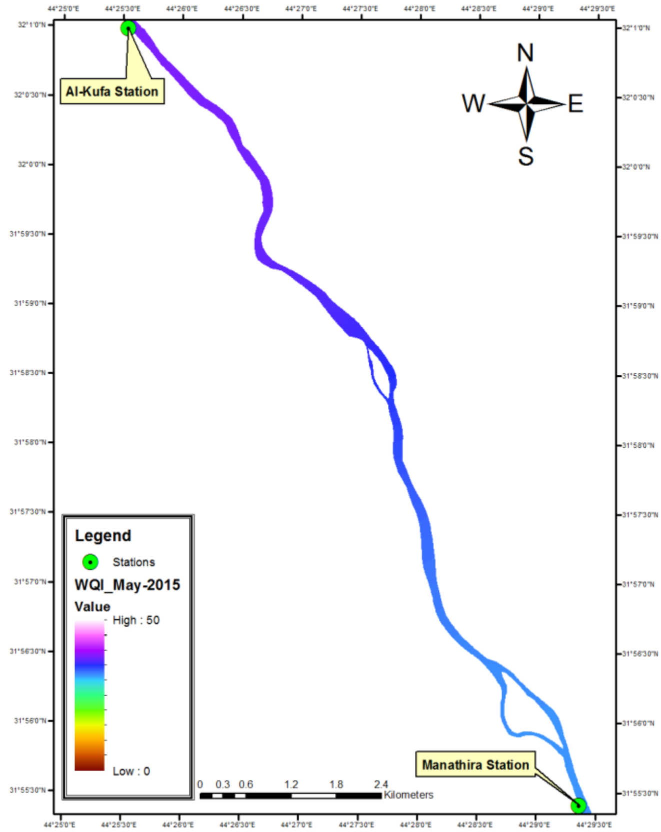

Figure 15: GIS Map for WQI variation in the Euphrates River in May-2015

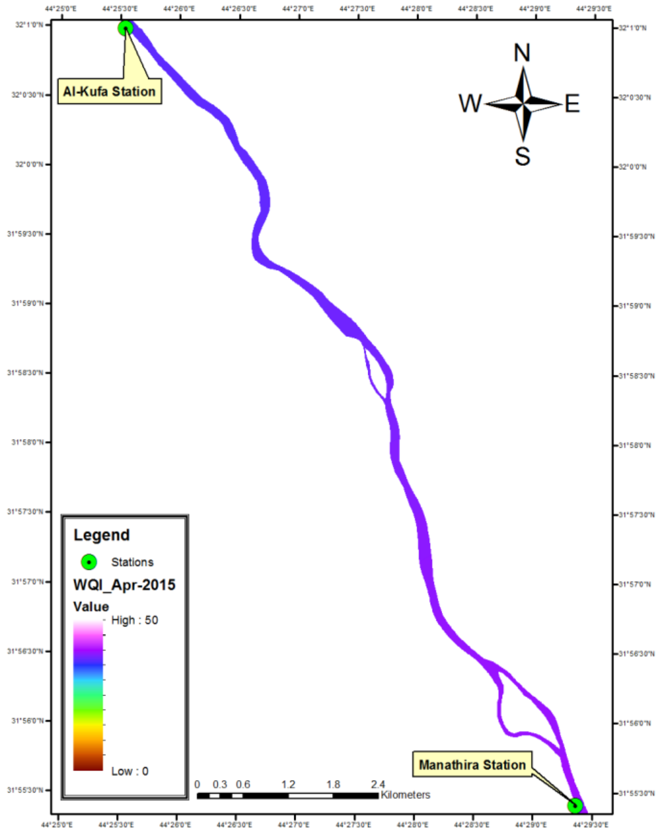

Figure 14: GIS Map for WQI variation in the Euphrates River in April -2015

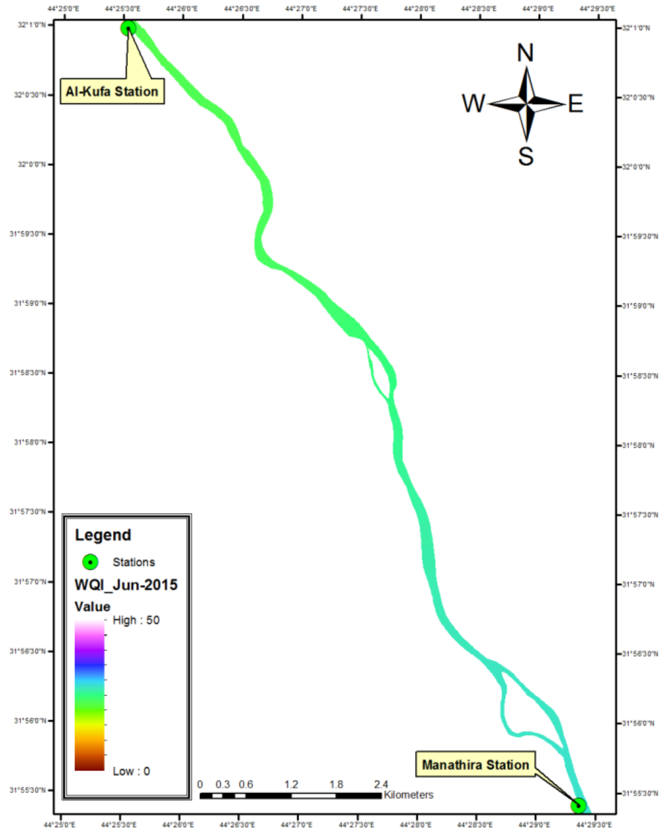

Figure 16: GIS Map for WQI variation in the Euphrates River in June-2015

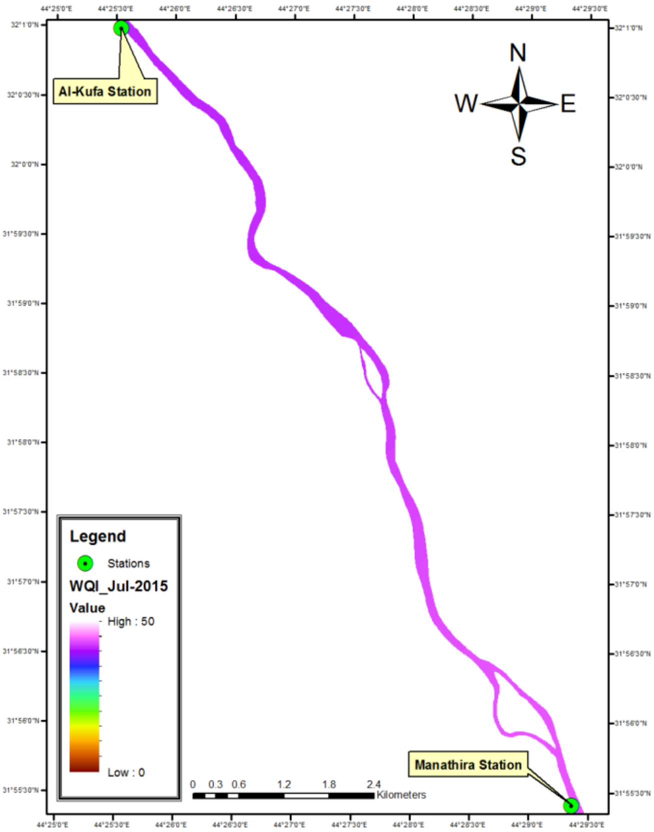

Figure 17: GIS Map for WQI variation in the Euphrates River in July-2015

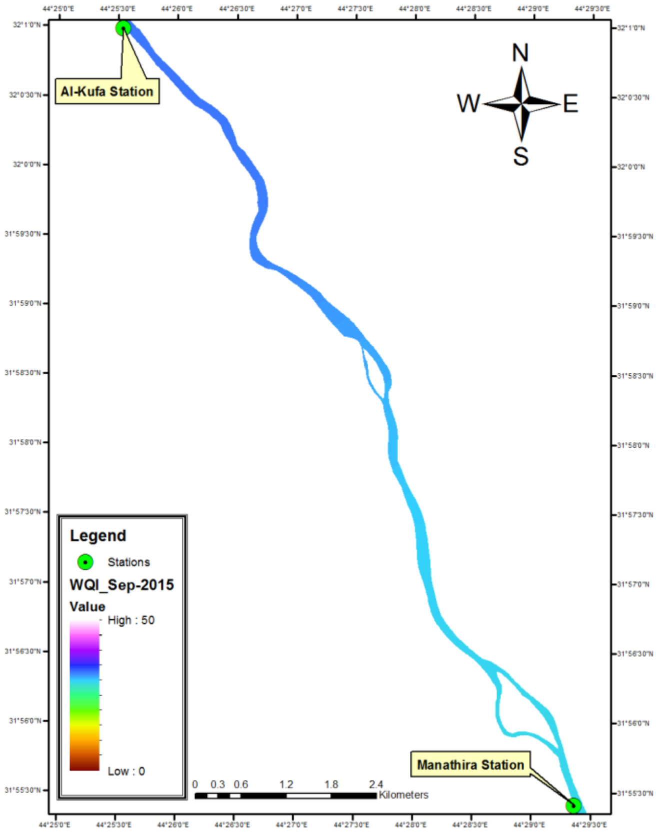

Figure 19: GIS Map for WQI variation in the Euphrates River in September-2015

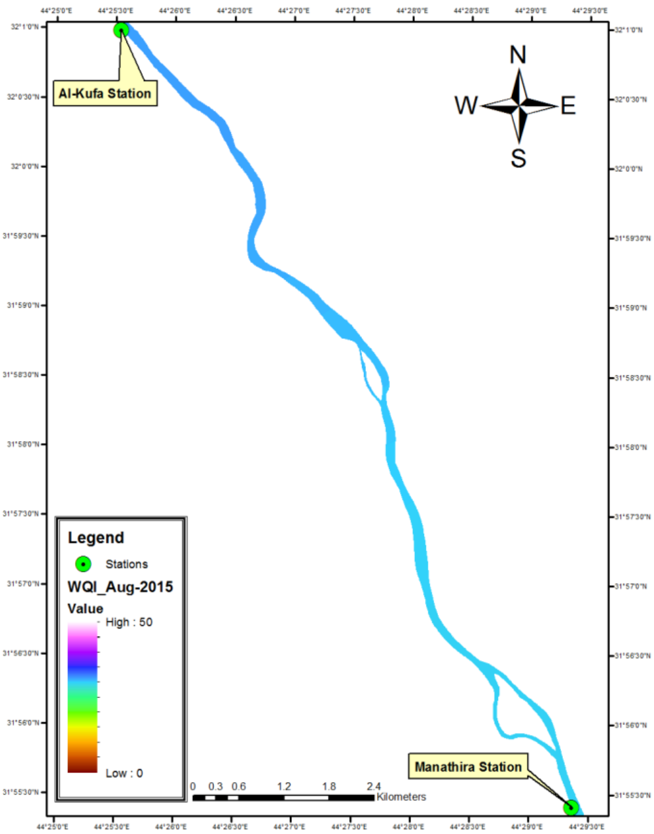

Figure 18: GIS Map for WQI variation in the Euphrates River in August-2015

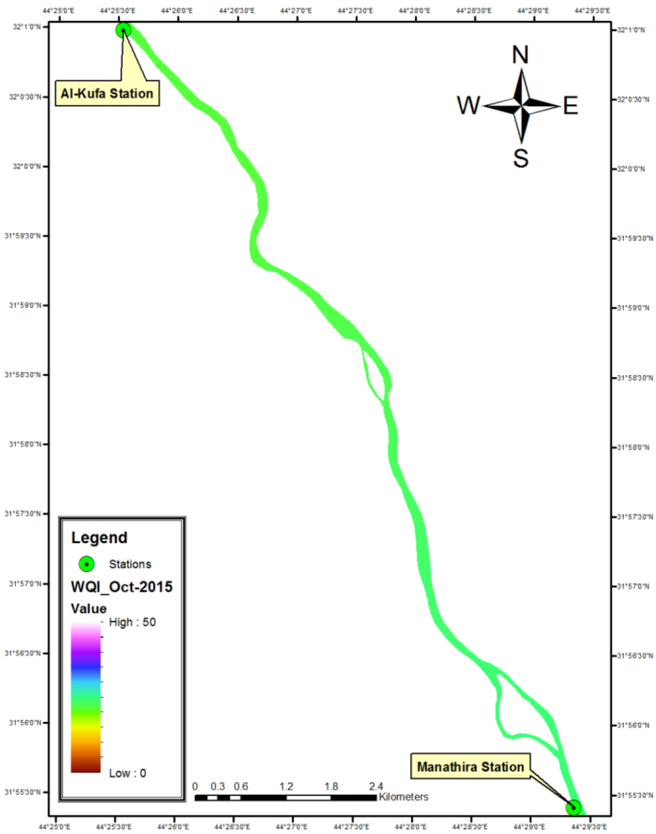

Figure 20: GIS Map for WQI variation in the Euphrates River in October-2015

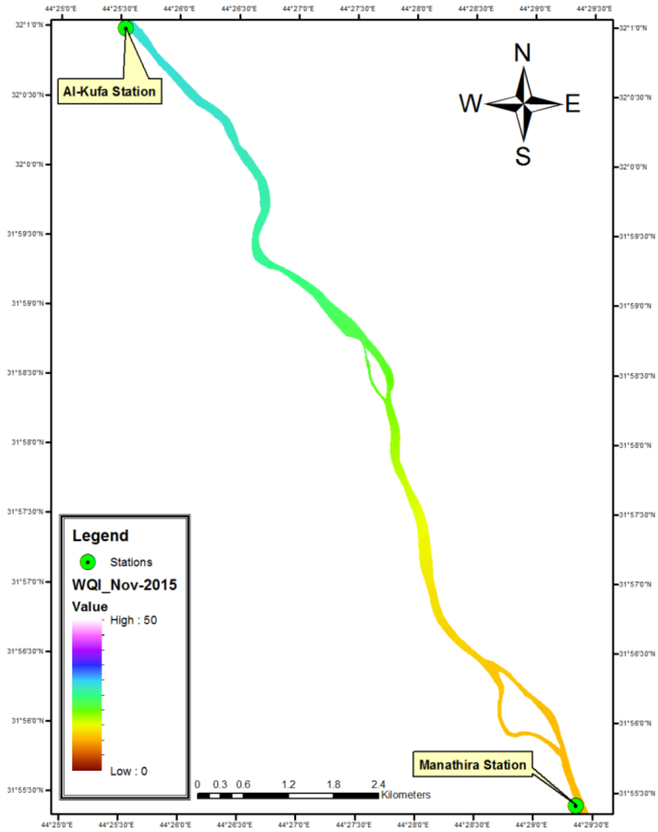

Figure 21: GIS Map for WQI variation in the Euphrates River in November-2015

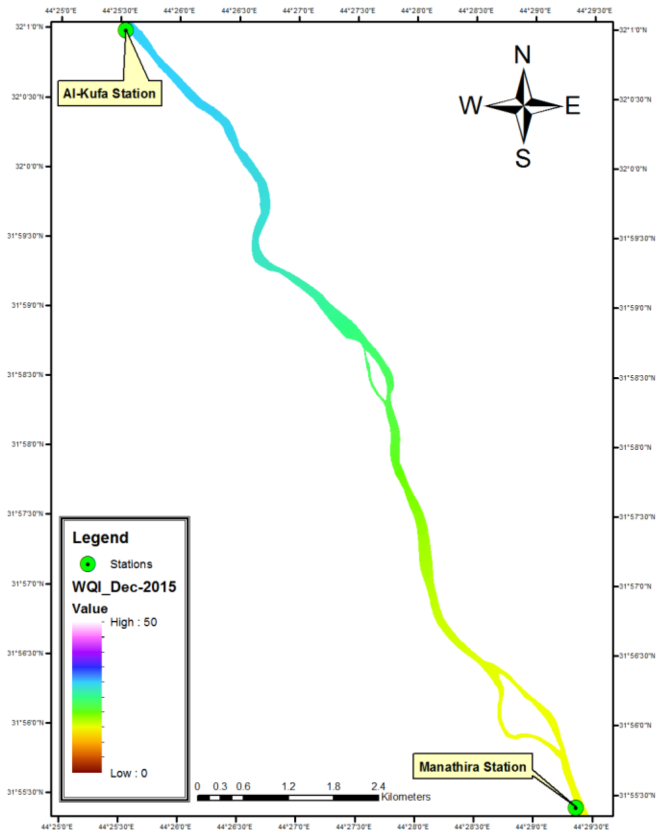

Figure 22: GIS Map for WQI variation in the Euphrates River in December-2015

7. Discussion

From the results, it can be observed that the quality of the river water was acceptable to polluted in the first station (Al-Kufa) and WQI% reached a maximum value of 41.86 in March while it was recorded a minimum value of 21.49 in October. The second station (Manathira), the quality of water was acceptable to severely polluted in a few months but mostly was polluted with maximum WQI% value of 43.65 in July and a minimum value of 10.78 in November according to Bhargava water quality index method for drinking purpose during the study period.

The main water parameters causing these low values of WQI% and responsible for deterioration is the high concentrations of Total Dissolve Solids, Sulfate, Calcium, and Total Hardness in the flowing water that noticed from the sensitivity functions of the relative parameters (have sensitivity value less than 0.5).

In general, the main water parameter causing deterioration in results of water quality for selected stations is the high concentrations of Total Dissolve Solids (TDS). TDS in water supplies can be from natural sources, sewage, urban and agricultural runoff, and industrial wastewater. There is no reliable data showing potential health effects when ingested of TDS in drinking water [20].

In case of Al-Kufa station, TDS values ranged from 946 mg/l in March to 1200 mg/l in October, while regarding Manathira station, it has been found that these values varied from 991 mg/l in March to 1408 mg/l in December where the permissible limits in drinking water are 1000 mg/L according to the Iraqi standards for drinking purpose.

The results of Sulfate (SO_4) varied from 333.33 mg/l in January to 395.3 mg/l in June for Al-Kufa station, while it was recorded 313.7 mg/l to 398.1 mg/l for Manathira station in July and December respectively, this indicates that it has exceeded the permissible limits in Iraqi standards (not exceed 250 mg/l).

Sulfates are a combination of sulfur and oxygen and arrive to river water from gypsum and anhydrite or from the oxidation of sulfuric compounds that result from the industrial discharges, sewerage water, and groundwater [21]. Sulfate minerals can cause a bitter taste in water that can have a laxative effect on humans when found above the permissible limit [22].

Calcium (Ca) is naturally present in river water by dissolving limestone, marble, calcite, dolomite, gypsum, fluorite and apatite. Calcium is a determinant of water hardness because it can be found in water as Ca^{+2} ions [23]. The high concentrations of calcium in drinking water have adverse health effect that can interact with elements such as copper, lead, iron, zinc, magnesium, and phosphorus within the intestine, thereby reducing the absorption of these minerals [24].

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The range of Calcium concentrations were 116 mg/l to 164 mg/l in April and October respectively for Al-Kufa station while it was varied from 120.4 mg/l in February to 178 mg/l in June for Manathira station where the permissible limits in drinking water are 150 mg/L according to the Iraqi standards for drinking purpose.

Total Hardness (T.H) is defined as the total amount of polyvalent cations mainly Ca^{+2} and Mg^{+2} found in water expressed in mg/l as $CaCO_3$. Other ions, such as strontium, barium, aluminum, manganese, iron, copper, zinc, and lead also are responsible for hardness, but to a lesser degree (low concentrations in nature) [25].

Hardness usually divided into two categories: temporary or carbonate hardness and permanent or noncarbonate hardness. Sources of water hardness due to the entry of ions into a river by leaching from minerals within an aquifer such as Calcite and Gypsum that it's containing Ca^{+2} and Dolomite containing Mg^{+2}.

World Health Organization (WHO) reported that hard water may cause cardiovascular disease, although there were not enough researches for this finding to be conclusive [26].

The recorded data indicated that Total Hardness concentrations ranged from 433 mg/l in March to 550 mg/l in June for Al-Kufa station while regarding Manathira station, it has been found that these values varied from 430 mg/l in March to 695.5 mg/l in December where the permissible limits in drinking water are 500 mg/L according to the Iraqi standards for drinking purpose.

Chloride (Cl) and pH were within the allowable limits according to the Iraqi standards for drinking purpose and they were not included in the responsible parameters that caused deterioration of the river water according to Bhargava sensitivity functions curves for drinking purpose.

8. Conclusions

In general, the results showed that the WQI has the capability to reduce the extent of large information of parameters into a single value to express the data in a simplified and concept form. This indicator can use to evaluate the effectiveness of river water and senses the need of protective practices.

The results of Bhargava water quality index analysis have shown that the water quality index in the Euphrates River at Al-Najaf city classified from class (III) to class (IV) for drinking purpose in Al-Kufa station, while in Manathira station classified from class (III) to class (V). This classification considers the river unfit for drinking water purpose, and this means the river water would need further treatments in the water treatment plants near the study area which reflects the effect of pollution due to domestic and industrial effluents.

In this study, application of GIS maps assisted to link the collected data and convert them into simplified and colorful maps together with its related analysis, calculation, graphs, and results. Besides, the GIS technique could represent the reliable picture of water quality which may be used in general without show the bulk of results data and it became easy to re-analyze and update.

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