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Water Quality of Tigris River in Mosul and Al-Amarah Cities by using CCME Water Quality Index

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ABSTRACT

This study aims to assess the water quality index (WQI) according to the Canadian Council of Ministers of the Environment's Water Quality Index method (CCME WQI). Four locations (measurement stations) are selected along the Tigris River, in Iraq. Two of them are located in the north near Mosul City, (Mosul Dam and Mosul city), and the other two are located in the south near Al-Amarah city, (Ali Garbi and Al-Amarah). The water data collected is for the period 2011 to 2013, including eleven water quality parameters. These are magnesium (Mg^{+2}), calcium (Ca^{+2}), potassium (K^{+}), sodium (Na^{+}), sulfate (SO_4^{-2}), chloride (Cl^{-}), nitrate (NO_3^{-}), bicarbonate (HCO_3^{-}), total dissolved solids (TDS), electric conductivity (EC), and (biochemical oxygen demand BOD_5). Results show that the water quality in Mosul city ranged from (83-94) in the two stations, while it has a range of (52-59) in Al-Amarah city for the two sites as well. According to WHO standards, these ranges indicate that the river waterfalls in a good level in Mosul city, while it belongs to the marginal category for Al-Amarah city. This is expected due to the disposal of many pollution sources along the distance from north to south downstream the river, therefore these pollution sources must be controlled.

Keywords: Tigris River, water quality, CCME WQI.

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نوعية مياه نهر دجلة في مدينتي الموصل والعمارة باستخدام مؤشر جودة المياه الكندي

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الخلاصة

تهدف هذه الدراسة إلى تقييم جودة المياه من خلال استخدام المؤشر الكندي لنوعية المياه. تم اختيار أربعة مواقع على طول نهر دجلة في العراق ،اثنان من هذه المواقع تقع في شمال العراق بالقرب من مدينة الموصل وهي (سد الموصل , مدينة الموصل) والاثنان الاخران في جنوب العراق بالقرب من مدينة العمارة وهما (علي الغربي, مدينة العمارة) للفترة من العام 2011 إلى 2013 متضمنا أحد عشر مؤشرا للمياه (المغنيسيوم Mg^{+2} ، الكالسيوم Ca^{+2} ، البوتاسيوم K^{+1} ، الصوديوم Na^{+1} ، كبريتات SO_4^{-2} ، كلوريد Cl^- ، نترات NO_3^- ، بيكربونات HCO_3^- ، المواد الصلبة الكلية الذائبة TDS ، الايصالية الكهربائية EC ، والمتطلب الحياتي للأوكسجينBOD_5 . اظهرت النتائج بان قيمة مؤشر مياه نهر دجلة في مدينة الموصل تراوحت بين (83–94) للمحطتين ثم انخفضت الى(52–59) في مدينة العمارة لكلا الموقعين ايضا . وهذا يدل على أن النهر يكون بمستوى جيد في مدينة الموصل خلافا لمدينة العمارة التي يقترب فيها المؤشر من الحد الادنى وفقا للمعايير التي نصت عليها منظمة الصحة العالمية وذلك يعود الى تلوث مياه النهر بسبب رمي العديد من المواد الملوثة فيه على امتداد مساره من الشمال إلى الجنوب ، لذلك يجب التحكم في مصادر التلوث هذه من خلال المراقبة.

الكلمات الرئيسية: مؤشر جودة المياه الكندي , نوعية المياه , نهر دجلة

1. INTRODUCTION

Tigris River is one of the two main water sources in Iraq, it is considered crucial for the society because it supplies water for industrial, agricultural, drinking, fishing, cattle, and irrigation. During the past decades, many factors had contributed to the deterioration of this river water quality such as wastewater disposal, economic activities, and the human population rise. This phenomenon is considered the biggest threat to humanity and water resources (**Al-Musawi and Al-Rubaie, 2017; Al-Obaid, et al., 2015; Chabuk, et al., 2020; Ewaid, et al., 2018)** therefore, the pollution monitoring and control for this river is very important for improving the ecosystems, human health, and water resource management. Proper control of these pollution sources should be implemented such that the water quality parameters are kept within the standards of the World Health Organization (WHO), Iraqi Water Quality Standards, etc**. (Abed, et al., 2019; Al-Ani, et al., 2019; Alazawii, et al., 2018).**

River water quality monitoring is necessary to provide field data for proper water management. These data are essential for the wastewater operation and disposal of the river. Using water quality indices is one of the simplest ways to evaluate the state of the municipal water supply. It is applied to both surface water and groundwater. WQI seeks to realize the entire state of the water quality; it employs aggregation techniques that enable the reduction of vast amounts of data into one number or index which simplifies the description **(Al-Obaidy, et al., 2015; Alhashimi and Mustafa, 2012)**.

The CCME WQI model was modified from the British Colombia WQI Model (BCWQI) in 2001 as a tool for simplifying and concentrating on the data related to water quality. It is broadly used due to the easy application and flexible selection of the water quality parameters to be involved in the model **(Uddin, et al., 2021; Li, et al., 2014).**

In literature, many studies were reported on evaluating different models of water quality index in different locations along both Euphrates and Tigris rivers **(Al-Musawi and Al-Rubaie, 2017; Chabuk, et al., 2020; Ewaid, et al., 2018).** However, limited studies focused on evaluating the CCME WQI model. For instance: CCME WQI was calculated for the Tigris River within Baghdad city during 2010, and twelve water quality parameters were selected. The results indicated that the water in stations 1, 2 which were located north of Baghdad is less polluted than that in southern station 3. The CCME WQI ranking was between poor in station 3 to marginal in stations 1 and 2 **(Al-Janabi, et al., 2015)**. CCME WQI was evaluated for the Al-Hussainiya River within Karbala City in 2016; ten water quality parameters were used in different locations (stations) along the river. The CCME WQI ranking was poor in all stations **(Uddin, et al., 2021**). CCME WQI was calculated along the Tigris River in Wassit Governorate for 12 months from October 2015 to September 2016; twelve water quality parameters were utilized. The computed CCME WQI values were in class fair, their range is (65-79), **(Mahmood, 2018)**. The influence of the Al-Rasheed power plant (RPP) was investigated at Al-Zafaraniya City in Baghdad by using CCME WQI; eleven parameters were analyzed in six stations. The results of this study indicated that the disposal of the RPP effluents has a considerable effect on the river water quality. The temperature of the water, electrical conductivity, turbidity, phosphate, and hardness are all considerably increased. The water of the Tigris River was classified as fair to marginal for all seasons except for winter, it was classified as poor (**Alazawii, et al., 2018)**. CCME WQI was used to evaluate the suitability of groundwater for drinking and indoor and outdoor household purposes in the village of Shouira in the Talafar district; thirteen parameters were analyzed for fifty samples of groundwater. The results indicated that groundwater had an unacceptable drinking water quality. It was found that the CCME WQI had a low value, which ranged (17.9 - 32.7) with the poor category; this behavior was mainly due to the low oxygen values **(Al-Mashhadany, 2021)**.

The goal and scope of the present study are to assess the raw water quality of the Tigris River in selected locations, through CCME WQI determinations using physical and chemical water quality parameters to give a clear image of the degree of pollution in the river.

2. MATERIAL AND METHODS

The Tigris River runs through Iraq's border for roughly 1468 kilometers. The River flows through Iraq for approximately 1430 kilometers until joining the Euphrates River near the north of Basra city to form the Shatt Al-Arab River (**Issa, et al., 2014)**. About 470 km^2 make up the Tigris River's catchment, with 0.2 % of the area located in Syria, 12 % in, Turkey, 34 % in Iran, and 54 % in Iraq. Two cities were selected along the Tigris River for this study. Mosul city is located to the north and Al-Amarah city is located in the south of Iraq, as shown in **Fig. 1.** For each city two sampling stations were used. The selection of these two cities is governed by the availability of the data and the pollutant activities along the river. More specifically, these pollution activities are much less upstream of Mosul, compared to downstream of Mosul reaching upstream of Al-Amarah city. Hence the current research results will help decision-makers in adopting different strategies to reduce the effect of these activities between these two stations.

Figure 1. Map of Tigris and Euphrates Rivers **(Encyclopedia Britannica, 2010)**

To evaluate the status of the water's quality for achieving the aim of this study, eleven water quality parameters are used for the analysis. For each of these parameters, monthly measurements are available for the period between 2011 and 2013. These data are provided by the National Center for Water Resources Management (NCWRM). These Parameters are magnesium (Mg^{+2}), calcium (Ca^{+2}), potassium (K^{+1}), sodium (Na^{+1}), sulfate (SO_4^{-2}), chloride (Cl^-), nitrate (NO_3^{-1}), bicarbonate (HCO_3^{-1}), total dissolved solids (TDS), electric conductivity (EC), and (biochemical oxygen demand BOD_5) and the measurements stations were (Al-Mosul Dam, Mosul, Al-Amarah, and Ali Garbi).

The water quality index (WQI) was calculated using the CCME WQI according to the data of the eleven parameters for the Tigris River. To determine the CCME WQI, three available measurements were chosen as presented in Eqs. (1), (2), and (3) **(Al-Janabi, et al., 2012; Hussein, et al.,2015; Ewaid, et al., 2018; Uddin, et al., 2021).**

$$F_1 = \frac{\text{Number of variables that failed}}{\text{Total Number of variables}} * 100 \quad (1)$$

where F_1 is the "scope," and this is the proportion of all parameters that are unsatisfied with the given objectives.

$$F_2 = \frac{\text{Number of failed test}}{\text{Total Number of tests}} * 100 \quad (2)$$

F_2 refers to "frequency", this is the proportion of separate test results that are unmatched by the goals of the test (failed tests). F_3 is calculated such that:

$$F_3 = \frac{\text{nse}}{0.01(\text{nse})+0.01} \tag{3}$$

when a test value deviates from the value of the objective, the excursion (nse) is determined in two ways according to the type of the test value: If a computed test value falls lower than the value of the objective, the excursion for that test value is computed as:

$$\text{excursion} = \left[\frac{\text{failed test value}}{\text{Objective}}\right] - 1 \tag{4}$$

Conversely, if the test value is more than the value of the objective, the calculation of the excursion value is as follows:

$$\text{excursion} = \left[\frac{\text{Objective}}{\text{failed test value}}\right] - 1 \tag{5}$$

Then the nse is expressed mathematically as:

$$\text{nse}= \left[\frac{\sum_{i=1}^{n} \text{excursion}}{\text{total number of test}}\right] \tag{6}$$

Finally, CCME Water Quality Index is evaluated as:

$$\text{CCME} =100-\left[\frac{\sqrt{F1^2+F2^2+F3^2}}{1.732}\right] \tag{7}$$

The final mathematical equation assigns the quality of the water a numerical number between 0 and 100 as given in **Table 1**, noticing that a value near 100 indicates great water quality, while a value nearby zero indicates very low water quality.

Table 1. Classification of the water classes according to the CCME WQI results.

Rank	WQI values for CCME
Excellent	95-100
Good	80-94
Fair	65-79
Marginal	45-64
Poor	0-44

Table 2. Allowable water quality parameters **(WHO, 2006)**

Mg^{+2}	Ca^{+2}	K^+	Na^+	SO_4^{-2}	Cl^{-1}	NO_3^-	HCO_3^-	TDS	BOD_5	EC
mg/l										µmhos/cm
200	200	10	200	250	250	10	126	500	5	1000

Table 3. The annual value of CCME WQI for each Station in Al Mosul and Al-Amarah cities for the period 2011 to 2013

WQI	2011	2012	2013
Mosul Dam	94	83	93
Mosul	93	93	93
Al-Amarah	53	58	52
Ali Garbi	55	54	59

3. RESULTS AND DISCUSSION

CCME WQI parameters were determined on the Tigris River in the cities of Mosul and Al-Amarah based on chemical and physical water parameters. The CCME WQI is calculated monthly over years 2011, 2012, and 2013. The values of concentration for some physical and chemical water quality parameters are presented in this study. The HCO_3^-, TDS, and EC are found the only ones among the eleven water quality parameters mentioned above that exceeds frequently the limits of the (WHO,2006) limits, in all of the stations selected. Hence, the HCO_3^- and TDS are selected here to be shown. The values of bicarbonate HCO_3^- in Mosul city for most months over the study period were found higher than the allowed limits of the (WHO, 2006) as given in **Table 2**. All of its monthly values are greater than 126 mg/l except for June, July, and August for the year 2013. The monthly HCO_3^- in Al-Amarah city is found higher than the allowable limit of WHO. **Fig. 2** demonstrates the difference in bicarbonate concentrations of HCO_3^- during 2013 between the two sites in Mosul and Al- Amarah cities.
The difference in concentrations of HCO_3^- at the selected locations of the Tigris River is due to the variation in the precipitation and the pH value. Also, the concentration of HCO_3^- changes due to the reaction of CO_2 with the gases of atmospheric **(Chabuk, et al., 2020)**.
The TDS values are found to be increasing along the downstream direction. The lowest values are found for Mosul dam station and increased to their higher value at Al-Amarah City station. The TDS values in Al-Amarah city are higher than the limit recommended by WHO more than 500 mg/l for all months as shown in **Fig. 3** Which explains the values of total dissolved solid TDS in 2013 for two sites samples in Mosul and Al-Amarah city.
Also, the same behavior is noted for electric conductivity EC their values exceed the limit of 1000 µmhos/cm. The higher value of TDS and EC was attributed to the effect of anthropogenic activities and pollution from urban wastes. In addition, there are other parameters above the permitted WHO limit for some months (TDS, BOD_5) in Mosul city and (sodium Na^+, chloride Cl^-, sulfate SO_4^{-2}, biochemical oxygen demand BOD_5) for Al-Amarah city.

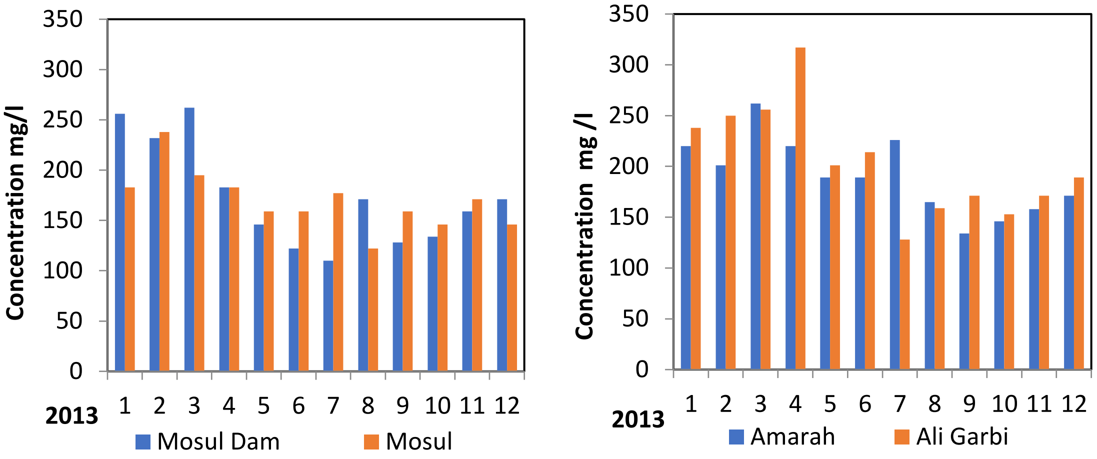

Figure 2. Values of Bicarbonate (HCO_3^-) documented for one year in two sites in Mosul and Al-Amarah cities

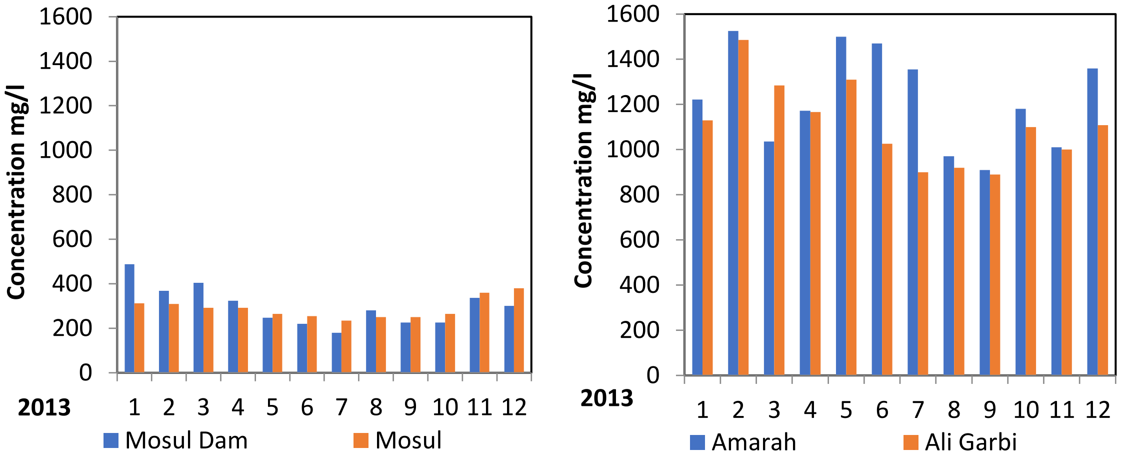

Figure 3. Values of Total Dissolved Solid (TDS) documented for one year in two sites in Mosul and Al-Amarah cities

A t-test with a 95% confidence interval is conducted in SPSS software to evaluate statistical differences between two measurement stations for each site. Also, another evaluation between two measurement stations at different sites is done, for each water quality parameter. The p-value is calculated to test whether or not the mean values for each parameter of the two measurement stations are equal. In the t-test, it is hypothesized that the differences in the measurements of the two stations for each parameter would not be statistically significant at a 95% confidence interval. **Table 4** shows the summary statistics for water quality parameters in two measurement stations for each site. Since the p-value of the t-test for all the parameters is not less than 0.05, the true difference between the means values of the parameters of these stations is zero and the null hypothesis failed to be rejected. However, according to **Table 5**, the evaluation between two measurement stations at different sites has different behavior. The t-test statistics indicated that the measurements of Ali Garbi station are significantly higher than those of Mosul city except for HCO_3^-, NO_3^-, and BOD_5 whereas the differences are not statistically significant.

Table 4. The t-test results for water quality parameters for stations (Mosul Dam and Mosul city) and (Ali Garbi and Al-Amarah) for the year 2013

Quality Parameter	Mosul Dam and Mosul city		Ali Garbi and Al-Amarah	
	t value (DF=22)	p-value	t value (DF=22)	p-value
Ca^{+2}	-0.922	0.366	0.694	0.495
Mg^{+2}	-0.759	0.456	0.423	0.676
Na^+	1.311	0.203	1.672	0.109
K^+	0.184	0.856	1.148	0.263
Cl-	-0.309	0.760	1.769	0.091
SO_4	.0930	0.926	0.965	0.345
HCO_3^-	-0.175	0.863	-0.732	0.472
NO_3^-	0.461	0.649	-1.014	0.322
TDS	-0.389	0.701	1.424	0.168
EC	-0.531	0.600	1.460	0.159
BOD_5	-0.843	0.408	0.543	0.592

Table 5. The t-test results for water quality parameters for stations (Mosul city) and (Ali Garbi) for the year 2013

Quality Parameter	Mosul city and Ali Garbi	
	t Value (DF=22)	p Value
Ca^{+2}	-8.963	0
Mg^{+2}	-6.924	0
Na^+	-10.957	0
K^+	-6.112	0
Cl^-	-14.893	0
SO_4^{-2}	-9.040	0
HCO_3^-	-1.931	0.066
NO_3^-	-2.091	0.048
TDS	-15.206	0
EC	-15.279	0
BOD_5	-0.573	0.572

According to the results shown in **Fig. 4 and Table 3**, the calculated values of the water quality index using the CCME WQI for two stations in Mosul city ranged from (83-94). This means that the river in these two locations and within this part of the Tigris River can be classified as good class (80-94) as displayed in **Table 1.**

The water quality in Al-Amarah city within the two sites varies within the Marginal level (45-64). WQI for Al Mosul was greater than for Al-Amarah which confirmed that the water quality of the Tigris River deteriorates south of Mosul. The causes of the deterioration of the river water were domestic sewage, surface run-off, and the cumulative effect of agriculture and industrial activities **(Alhashimi and Mustafa, 2012).** According to the equations of estimation CCME WQI, its value will be low when the TDS and EC are high; this fact is observed by **(Ewaid, 2017)**.

This behavior can be interpreted as the Tigris River flowing through mountain area before entering Mosul city where there are small cities located outside Iraq country while large cities with high densities of population located south of Mosul which is considered the main cause for the degradation of water quality in the downstream of the river; therefore, the river within this region needs continuous management and treatments to control the sources of pollution that threaten all types of aquatic life, irrigation, drinking and other uses of water **(Suhaili and Nasser, 2008)**.

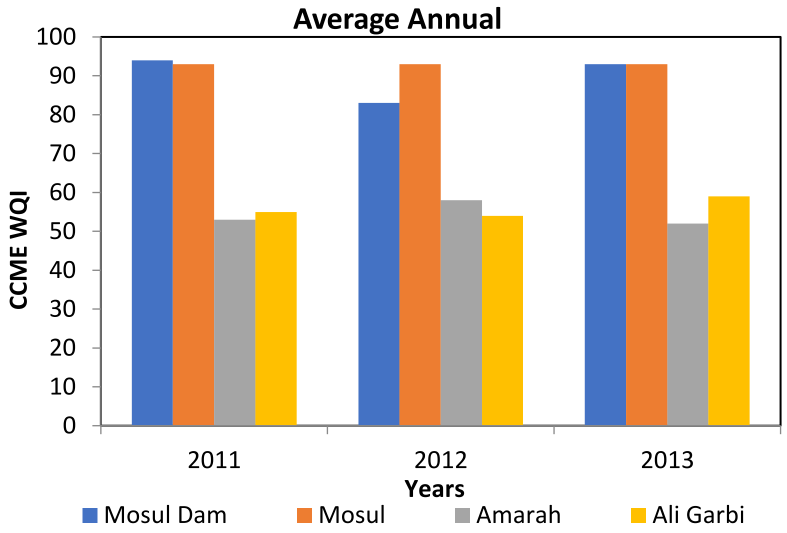

Figure 4. The calculated for CCME WQI at Al-Mosul and Al-Amarah cities.

4. CONCLUSIONS

The CCME WQI model is useful for evaluating the quality of surface water utilizing a water quality index will enable an analysis of domestic policy and international agreements aimed at protecting aquatic resources, as well as the measurement of the variations in water quality across time and space. The following conclusion can be drawn:

1-The monthly values of TDS and HCO_3^- are higher downstream in Al-Amarah city than those the upstream of Tigris River in Mosul city.

2-According to the CCME WQI Tigris river water at Mosul city is classified as Good as its range is (83-94). While the river water in Al-Amarah city downstream is classified as at the Marginal level as its range is (45-64). This confirms that the water quality of the Tigris River deteriorates with the flow direction.

3-The t-test results between the means of each parameter at (Mosul Dam and Mosul city) and (Ali Garbi and Al-Amarah) shows insignificant difference while the t-test show a significant difference between Mosul city and Ali Garbi except for HCO_3^- NO_3^- and BOD_5.

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