CONSTRUCTION
E-ISSN: 2785-8731
VOLUME 4, ISSUE 1, 2024, 37 – 44
DOI: https://doi.org/10.15282/construction.v4i1.9748

RESEARCH ARTICLE

Water Quality Evaluation of Tigris River by using Canadian and Horton Water Quality Index

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ABSTRACT - Water quality index (WQI) is a simplified and explicable number calcuated from data on tested prameters in water. In this study, two methods for calculating water quality index (WQI) were used to assess the water quality of Tigris River using monthly data from 2011 to 2013. The data were collected at four different gauging stations. Two gauing stations are located on Tigris River at upstream in Mosul city while the other two downstream gauging stations are located on Tigris River at downstream in Al-Amarah city. The Canadian Council of Ministers of the Environment's (CCME WQI) and Horton (Horton's WQI) methods were applied to assess the water quality of Tigris River at the selected stations. The data used in the assessment included several parameters such as calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chloride (Cl), sulfate (SO_4), bicarbonate (HCO_3), nitrate (NO_3), total dissolved solid (TDS), biochemical oxygen demand (BOD_5) and electric conductivity (EC). According to the values of CCME WQI mehod, the quality of Tigris River in Mosul city was at a good level (the values of WQI were varied from 83 to 94) while it and falls under the marginal category in Al-Amarah city (the values were varied from varied from 52 to 59). However, the application of Horton's WQI method showed that the quality of Tigris River in Mosul city was fluctuated from excellent to good (values of WQI varied from 24 to 80 per month) while it was poor in Al-Amarah city (values of WQI varied from 74 to 160 per month). In conclusion, the Horton's WQI method was found more relastic when used to assess the water quality of Tigris River compared with CCME WQI method.

ARTICLE HISTORY

Received	:	13 Sept. 2023
Revised	:	22 Jan. 2024
Accepted	:	22 Feb. 2024
Published	:	13 Mar. 2024

KEYWORDS

Tigris River;
Water quality index;
CCME;
Horton's WQI;

1.0 INTRODUCTION

Water is the major requirement for the survival of life, human health and is essential to most industries. Rivers are considered as the most significant source for fresh water and is also important in maintaining the balance of the ecosystem [1]. Officials worried that fresh water would become a limited resource in the future; therefore, management of water resources quality is becoming more crucial in rivers and other bodies of water. Surface water quality is a very delicate subject that is indispensable for long-term economic growth, social welfare and environmental sustainability. Deteriorating water quality happened between the points of supply and consumption due to a lot of factors such as industrial production, power generation, home and agricultural usage [2-7]. As a case study, Tigris River in Iraq turned out to be a typical example of deteriorating water quality. Tigris River is one of the biggest in the Middle East, serves as the primary source of water for drinking, agriculture, industrial use, and other purposes. It originates in Turkey's eastern mountains and has a length of roughly 1,900 km. The catchment area is over 235,000 km^2, and it encompasses Turkey, Iraq, and Syria. The river flows from north to south across the entirety of Iraq over a distance of around 1,415 km. The Tigris River's salinity varies from 280 ppm at the Iraq-Turkey border in the northwest to 1800 ppm below Basra in the south of Iraq [4, 8-11]. Water quality index (WQI) functions in obtaining a single value for the water quality from a source of physical, chemical and biological parameters by combining the collection of parameters and their concentrations, which in turn offers a thorough justification of the water quality and suitability for various uses, including drinking, irrigation, and industrial [1, 6-16]. Thus, the current study focuses on:

Calculating two types of water quality indices CCME WQI and Horton's WQI and comparing their results to the standard limit then decide whether any concern exists.

2.0 METHODOLOGY

2.1 The Case Study

Two cities Mosul and Al-Amarah in the north and south of Iraq respectively along Tigris River were selected to assess the river's water quality. Mosul city is located between (37° 1' 45.51" to 35° 25' 12.78" N) latitude and (42° 21' 40.14" to 42° 47' 31.17" E) longitudes while Al-Amarah city is between (31° 15 N to 32° 45 N) latitude and (46° 35 E to 47° 45 E) longitude [3]. Each of the cities examined in this study have two sampling stations: Mosul and Mosul Dam for Mosul city

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and for Al-Amarah city: Ali Al-Gharbi and Al-Amarah. These stations were selected to assess the chemical and biological testing. Eleven water quality indicators from 2011 to 2013 were analyzed monthly to determine the water's current quality in order to achieve the study's goal [2-4, 16-21].

2.2 The Water Quality Index (WQI)

WQI has been used as a simple and practical mathematical tool to evaluate water quality. The Canadian Council of Ministers of the Environment's (CCME WQI) is categorized into five classes namely as Excellent, Good, Fair, Marginal and Poor [2, 22, 23], while the classification is: Excellent, Good, Poor, very Poor and Unsuitable for Horton's WQI which can then be entered into various programs [23].

2.2.1 Selection of Parameters

To assess Tigris River's water quality and meet the study's goal, eleven water quality indicators were evaluated monthly from 2011 until 2013 using data from the National Center for Water Resources Management (NCWRM). These Parameters are: calcium Ca, magnesium Mg, sodium Na, potassium K, chloride Cl, sulfate SO_4, bicarbonate HCO_3, nitrate NO_3, total dissolved solid TDS, biochemical oxygen demand BOD_5 and electric conductivity EC [10, 11]. A complete set of data between 2011 to 2013 was available without gaps.

2.2.2 The Canadian Council of Ministers of the Environment (CCME WQI)

After compiling the data and segregating it by time and location, (CCME) model was utilized by comparing it with the standard value of World Health Organization 2006 as indicated in Table 1. CCME WQI provides flexibility to researchers. The model uses a combination of three mathematical parameters to determine the final number representing a certain scenario. Using equations specific to each variable, the WQI can be estimated. The following summarizes the water quality state as expressed by obtaining [2, 11, 21- 23]:

F1: known as the "scope," this statistic represents the proportion of all parameters that fall short of the predetermined goals. It is expressed as

$$F1 = \frac{Numberof\ parameters\ that\ failed}{Total\ Number\ of\ parameters} * 100 \quad (1)$$

F2: known as "frequency," this is the proportion of individual test results that fall short of the set goals (also known as "failed tests").

$$F2 = \frac{Number\ of\ \ failed\ test}{Total\ Number\ of\ tests} * 100 \quad (2)$$

F3: known as the "amplitude," this statistic measures how much test results fall short of the desired results and is calculated by the following steps:

Step 1: find the excursion measure which means how many times the test value deviates from the desired value as follows: if the test value does not exceed the desired value then use Equation 3 otherwise use Equation 4

$$Excursion = \left[\frac{failed\ test\ value}{Objective}\right] - 1 \quad (3)$$

$$Excursion = \left[\frac{Objective}{failed\ test\ value}\right] - 1 \quad (4)$$

The total amount of tests that did not match Excursions, also known as normalized sum of excursions (NSE), are the result of dividing the sum of the deviations (excursion) for these tests by the total number of tests. This calculation is used to determine specifications.

$$NSE = \left[\frac{\sum_{i=1}^{n} excursion}{total\ number\ of\ test}\right] \quad (5)$$

Then, using the Equation shown below, calculate F_3:

$$F3 = \frac{nse}{0.01nse + 0.01} \quad (6)$$

Finally, the following Equation determines an index for water quality as shown in Table 2 after computing the three primary steps.

$$CCME\ Water\ Quality\ Index\ = 100 - \left[\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right] \quad (7)$$

Table 1. Standard values in accordance with the Iraqi Drinking Sandares and WHO [11, 17, 24]

Standard values	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	SO_4 mg/l	HCO_3 mg/l	NO_3 mg/l	TDS mg/l	BOD_5 mg/l	EC µmhos/cm
WHO	200	200	200	10	250	250	126	10	500	5	1000
Iraqi standard	50	50	200	10	250	250	200	50	500	3	2000

Table 2. Categories of water classification based on CCME [22]

Group	Excellent	Good	Fair	Marginal	Poor
Degree	95-100	80-94	65-79	45-64	0-44

2.2.3 The Horton water quality index (Horton's WQI)

Horton created the first WQI model in the 1960s which was based on 10 water quality indicators considered important in most water bodies (Horton, 1965). The following procedures are used to determine WQI:

a) Calculating weight (wi) for each parameter based on its effect on general health and relative significance for drinking purpose as shown in Table 3.

b) Determining the relative weight (Wi) of each parameter utilizing Equation 8:

$$Wi = \frac{Wi}{\sum_{i=1}^{n} Wi} \tag{8}$$

where n is the number of parameters, wi is the weight of each parameter, and Wi is the relative weight.

c) The (qi) of each parameter is determined by dividing the parameter's concentration by its standard value in accordance with the specifications outlined by Drinking Iraqi Sandares utilizing Equation 9 and Table 1.

$$qi = \left(\frac{Vn - Vi}{Vs - Vi}\right) * 100 \tag{9}$$

where qi is the parameter quality rating, Vn is the actual quantity of the nth parameter present, Vi is the parameter's ideal value Vi = 0 except for pH (Vi = 7)), and Vs is the Iraqi Drinking Water Standard for each parameter.

d) The relative weight of the parameter is multiplied by its (qi) to determine the quality subindex for each parameter (SIi). Using Equation 10.

$$SIi = Wiqi \tag{10}$$

e) WQI is calculated by adding up each parameter's overall quality subindex using Equation 11 and Table 4. shows the classification of Horton's WQI.

$$WQI = \sum_{i=1}^{n} SIi. \tag{11}$$

Table 3. The weight of chemical and biological parameters [8, 14, 25]

Parameters	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	SO_4 mg/l	HCO_3 mg/l	NO_3 mg/l	TDS mg/l	BOD_5 mg/l	EC µmhos/cm
Wi	2	2	3	2	3	3	2	5	5	3.88	3

Table 4. Water quality scale by Horton's WQI [22]

Class	Excellent	Good	Poor	Very poor	Unsuitable
WQI	< 50	50–100	100–200	200–300	> 300

3.0 RESULTS AND DISCUSSION

In this study, the WQI was determined via two methods: CCME and Horton's WQI. Table 5 below shows the average annual results of the CCME WQI and Horton's WQI for four stations along Tigris River. According to the Canadian index's classification system the values of WQI in Mosul city were found to be within a good range of 80-94, as shown in Figure 1. On the other hand, the WQI values in Al-Amarah city were found within the marginal category 45 - 64 of the CCME WQI. This low WQI values is due to the high chemical concentrations of the total dissolved solid TDS and the electric conductivity EC as shown in Figure 2 and Figure 3 respectively.

Even though the WQI is affected by the concentration of the eleven water quality parameters (for the two methods), the disscusion here focused on the effect of TDS and EC. The reason for that is the observation of the high values of these two parameteres compared to the other parameters.

The deterioration of the river reflects the cumulative effect of agriculture and industrial activities [1, 10, 11, 18, 26-28]. Therefore, continuous management and treatment are required to keep the sources of pollution under control, which endangers all forms of aquatic life and negatively impact drinking, irrigation and other uses of water.

Table 5. Average annual values of WQI for each station in Mosul and Al-Amarah city for the period from 2011 to 2013 by CCME WQI and Horton's WQI

Locations	CCME WQI			Horton's WQI		
	2011	2012	2013	2011	2012	2013
Mosul Dam	94 G	83 G	93 G	39 E	41 E	38 E
Mosul	93 G	93 G	93 G	38 E	35 E	35 E
Al-Amarah	53 M	58 M	52 M	112 P	108 P	117 P
Ali Garbi	55 M	54 M	59 M	104 P	105 P	106 P

E : Excellent
G : Good
M : Marginal
P : Poor

Comparing the results of the two methods shown in Table 5 indicate that the CCME method is more restrictive in the high-quality range classification compare to Horton's method. This is shown for Mosul dam and Mosul stations as it classified the water as good while it is classified as excellent using Horton's method for the three years 2011 to 2013. On the other hand, Horton's method is more restrictive in the low water quality classification range than the CCME method. This is shown for Al-Amarah and Ali Garbi stations as they are classified as poor using Horton's method and Marginal using CCME method for the three years 2011 to 2013.

Horton's WQI was used as a second technique to determine the quality of water where the average annual results shown in Table 5 and Figure 4 indicated that the Tigris River's WQI has altered at an annual rate between 35 and 41 in Mosul city for both sites, and according to the Horton's WQI, this percentage is within the excellent categorization. This behavior could be explained by the short distance between Mosul and the origin of the Tigris River in Turkey so there is not enough pollution to degrade the state of the river. Meanwhile the average annual values are between 104-117 in Al-Amarah city which is in the poor category as shown in Figure 4.

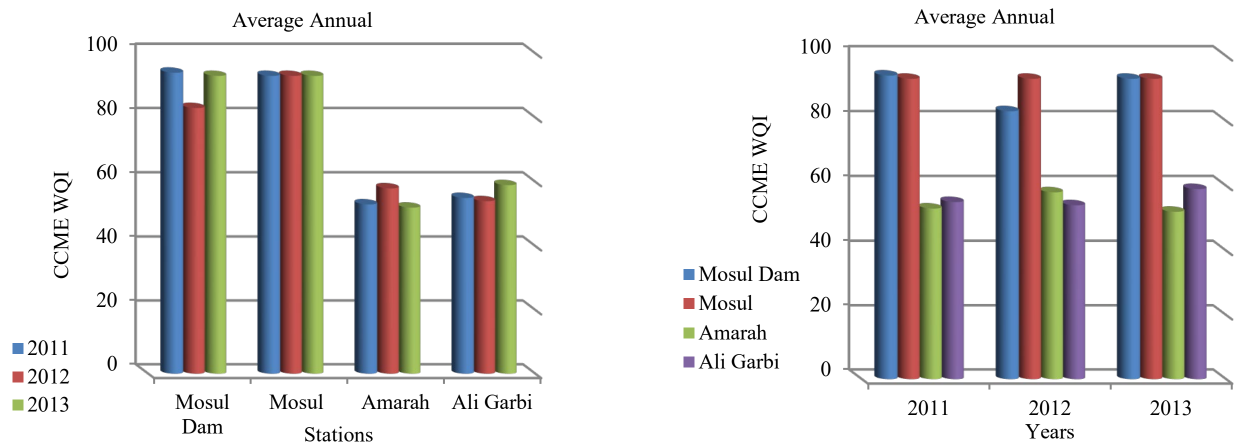

Figure 1. CCME WQI calculated along Tigris River

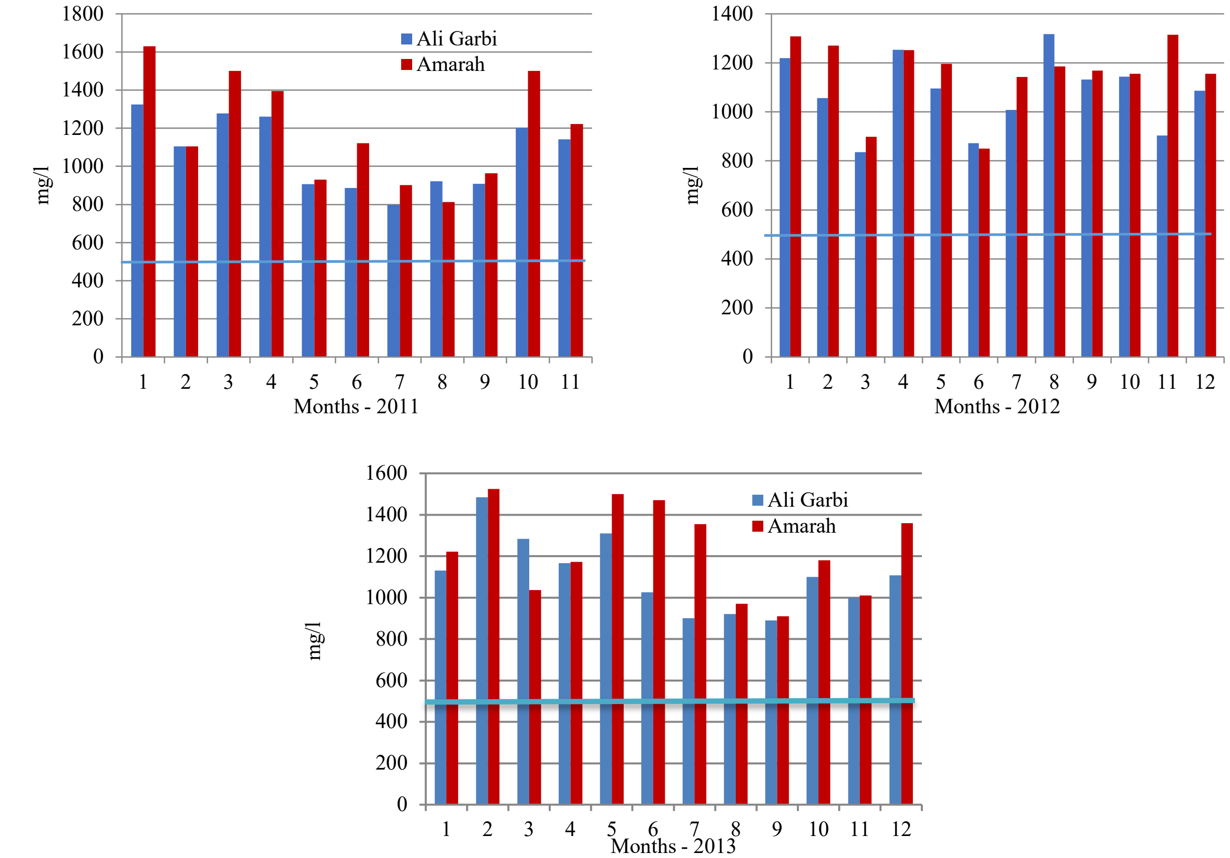

Figure 2. Comparison of monthly total dissolved solid TDS between Al-Amarah and Ali Garbi for years 2011-2013

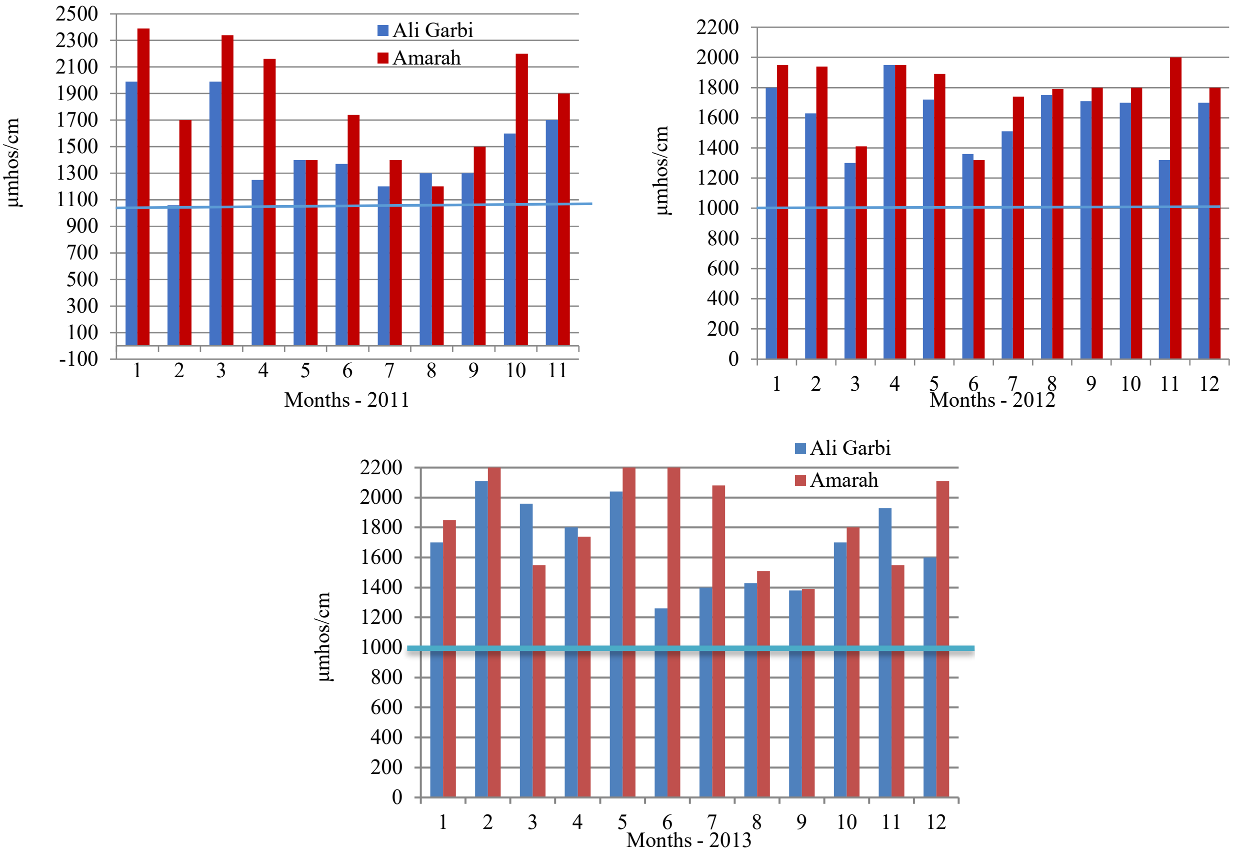

Figure 3. Comparison of monthly electric conductivity EC between Al-Amarah and Ali Garbi for years 2011- 2013

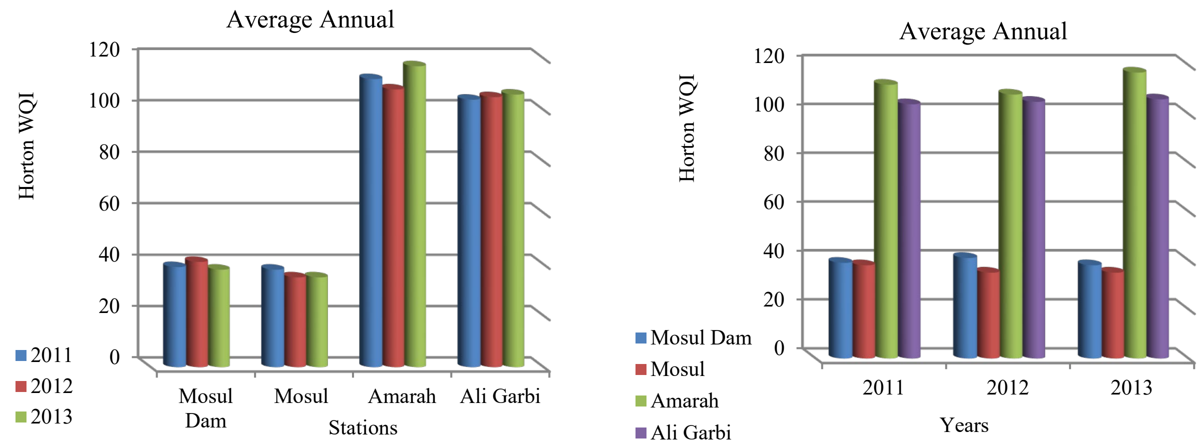

Figure 4. Horton's WQI calculated along Tigris River

4.0 CONCLUSIONS

WQI is a useful tool for assessing the quality of surface water. Using WQI will allow an analysis of the efficacy of domestic policy and international agreements aimed at protecting aquatic resources, as well as the measurement of changes in water quality over time and space.

The following conclusion can be drawn:

- The values of WQI upstream of Tigris River at Mosul for the two stations for the two types of indices were greater than the water quality indices downstream at Al-Amarah which indicates that the water quality of Tigris River declines south of Mosul.
- The main point sources that cause the degradation of water quality in the study are domestic sewage, surface run-off, and the cumulative effect of agriculture and industrial activities (Discussion with MOWR ministry of water resources representatives). The waste from nearby communities flows into the rivers especially at Baghdad (the capital of Iraq) which is located south of Mosul (Discussion with Baghdad Morality representatives).
- The wastewater from industrial, commercial areas and residential must be managed and treated before being released into the river.

The comparison of the results of the two methods showed that the CCME method is more restrictive on the water quality high range classification than the Horton's method. Oppositely results indicated that the case is reversed for the water quality low range classification, Horton's method is more restrictive.

5.0 CONFLICTS OF INTEREST

There is no conflict of interest from publishing this manuscript.

6.0 AUTHOR CONTRIBUTIONS

Z. AL-Temimi: Manuscript preparation, Drawing and Tables, WQI calculations, Data preparation

M. AL-Juhaishi: Research problem identification, Manuscript preparation and editing, Respond to reviewers

6.0 DATA AVAILABILITY STATEMENT

Data was provided by "The National Center for Water Resources Management (NCWRM)/ Baghdad/ IRAQ," upon official request from the authors.

7.0 ACKNOWLEDGEMENT

We would like to express our deep gratitude to "The National Center for Water Resources Management (NCWRM), Baghdad, Iraq," for providing the data. Special thanks goes to Prof. Dr. Basim Sh. Abed, the head of the water Resources Engineering Department at the College of Engineering, University of Baghdad, Iraq, for his continuous support and providing all the facilities to conduct the work. Great appreciation for Prof. Dr. Hayder A. Al Thamiry the head of the Scientific Committee in the same department for his effort in negotiation with (NCWRM) to provide the data. The authors did not receive funds from any organization for the submitted work.

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