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Application of the Canadian Index (CCME WQI) to Assess Water Quality for Aquatic Life: A Case Study of Water Quality for the Khoser and Tigris Rivers in the North of Nineveh Governorate

Azhar Younis Reda Al-Assaf, Abdalaziz Y. T. Alsaffawi, Mira A. AI- Katib*
Dept. of Biology, College of Education for Pure Science, University of Mosul, Iraq

***Corresponding Author:** azhar81@uomosul.edu.iq

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ABSTRACT

The present study aimed to assess the water quality of the Khosr and Tigris rivers for aquatic life by applying two mathematical models: the model proposed by Rodriguez de Bassoon and the Canadian model (CCMEWQI). Physical, chemical, and biological properties were estimated to calculate the values for these models. The results indicate that the Khosr River has poor water quality for aquatic life, with Canadian model values ranging between 30.9 and 41.5. In contrast, the Tigris River water at the comparison site was classified under the Marginal water category, with quality further deteriorating after the Khosr River merges with it, showing values between 52.7 and 40.2. Similarly, using Rodriguez de Bassoon's model, the Khosr River was classified as having Bad water quality with values ranging between 26.35 and 35.96, while the Tigris River exhibited Medium water quality with values between 54.81 and 64.33. The deterioration in water quality was mainly attributed to a significant reduction in oxygen levels, reaching as low as 1.2mg/ L, coupled with an increase in organic load to 56mg/ L. This reflects a considerable degradation of the Khosr River, which negatively impacts the water quality of the Tigris River within the Mosul City area.

INTRODUCTION

Surface water resources are crucial for both humans and living organisms, serving as essential sources of fresh water for drinking, agricultural, civil, and industrial purposes. Beyond their practical uses, they also provide significant economic benefits to local populations by supporting fisheries and aquatic ecosystems, which are vital for sustaining livelihoods and biodiversity **(Al-Janabi *et al.*, 2012)**. Unfortunately, Iraqi rivers and tributaries are exposed to many violations that cause the deterioration of the aquatic environment, such as the discharge of wastewater, the disposal of animal and livestock waste, and workshop waste. More dangerously, citizens commit serious violations of the aquatic environment by discharging septic tank water into public sewers, which reaches the Tigris and Khoser rivers. These violations continue and increase day after day for more than three decades due to weak monitoring and following-up. The continuation of these violations will result in the destruction and depletion of vital water resources and fish populations, as evidenced by the case of the Khoser River in Nineveh Governorate. In the 1970s, the river was rich in fish and aquatic life, with clear, transparent waters where fish could easily be seen swimming. However, ongoing environmental degradation threatens to permanently diminish this once-thriving ecosystem. Today, however, the waters are dark, highly turbid, and severely polluted due to the random disposal of most of the water and heavy waste, which has led to the destruction of this environment, leading to the emission of foul odors from the river, indicating the occurrence of anaerobic decomposition processes and lack of oxygen. Most residents of Mosul have observed the dense foam of detergents that the Khoser stream carries into the Tigris River, spreading up to 250 meters from the confluence point. This is indicative of the vast amount of waste dumped daily into the Tigris River, which receives over 28,370 m^3 per hour from various tributaries, including Wadi Akab, Qara Sarai, Al-Kharazi, the Khoser River, and Wadi Al-Danfeli. These pollutants severely impact water quality, further deteriorating the river's ecological health **(Al-Saffawi & Al-Sanjary, 2018; Al-Mshhadany, 2023; Taha, 2023)**. These releases lead to increased levels of nutrients (N and P compounds) that have negative effects on aquatic ecosystems through the phenomenon of eutrophication due to the increase in the number of algae, including blue-green algae and dinoflagellates that secrete types of toxins and chemical compounds that accumulate in the bodies of fish and other aquatic organisms, affecting their lives in addition to their transmission to humans, the final consumer of the food chain **(Al-Saffawi, 2018; Al-Mashhadany, 2022)**. Additionally, these releases also affect the fluctuation of pH values, as low values work to release toxic metals from bottom sediments, which may cause harm to fish and aquatic organisms. High pH values can significantly harm aquatic life by reducing the availability of dissolved oxygen, which is essential for the survival of aquatic organisms **(Dewangan *et al.*, 2023)**. Moreover, elevated pH levels negatively impact the productivity of aquatic ecosystems, as demonstrated in various studies **(Wang *et al.*, 2019)**. To evaluate surface water quality, mathematical models serve as modern and effective tools for monitoring pollution levels in aquatic environments and assessing their suitability for various uses **(Al-Hamdany *et al.*, 2020; Al-Shanoona *et al.*, 2020; Zotou *et al.*, 2020; Mashhadany, 2021b)**. These models simplify complex data by assigning weights to each parameter, allowing for a single, easily understood value that reflects interactions between the studied factors. Some models, like the Canadian model, further enhance accuracy by assigning weights to each test **(Kujiek & Sahil, 2024)**. Accordingly, the present study aimed to assess the water quality of the Khoser and Tigris rivers for aquatic life using mathematical models.

MATERIALS AND METHODS

I. Study area

The Khoser River originates in the Nineveh plain, fed by the slopes of Bashiqa district and Mount Maqlub, along with small springs during its flow, particularly in the Nuran area. It passes through numerous residential areas, including Telskuf and Bahzani districts, and farmlands that discharge waste into the river. As it enters the city of Mosul from the left side, it flows through residential neighborhoods that discharge untreated wastewater via multiple outlets along both banks of the river. During different study periods, the Khoser River's discharge rate before meeting the Tigris River was measured, averaging 565.77 m^3/hour. This discharge contributes to the degradation of river water quality, particularly during the dry season when decreased oxygen levels cause bad odors, ultimately impacting the water quality of the Tigris River. Seven sites were selected for this study: five along the Khoser River and two on the Tigris River, as shown in Fig. (1) and Table (1).

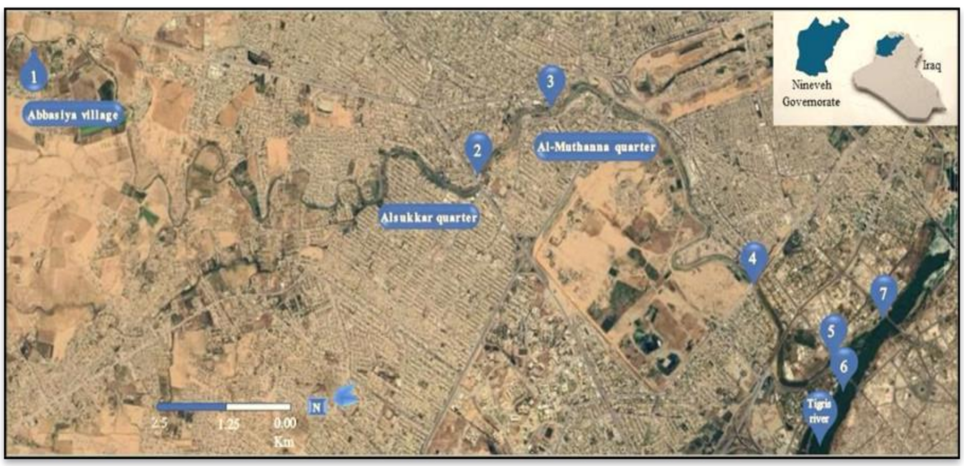

Fig. 1. Satellite image showing sample collection sites

Table1. The latitudes and longitudes of sampling sites for the studied area

Site		Longitudes E	Latitudes N	Notes
Khoser River	1	43°08'14.5"	36°20'46.4"	near Al-Abbasiya village
	2	43°10'11.7"	36°23'05.9"	near Al-Sukkar and Al-Barid quarters
	3	43°10'24.9"	36°22'51.0"	near Al-Zahour quarters
	4	43°09'00.3"	36°21'15.7"	near Suez Bridge
	5	43°08'24.7"	36°20'53.6"	before it meets the Tigris River
Tigris River	6	43°08'17.8"	36°20'46.0"	before it meets the Al-Khoser River
	7	43°08'37.1"	36°20'25.4"	Tigris River 200 meters after the meeting point

II. Methodology

Water samples for chemical, physical and biological measurements were collected at a rate of one sample per month from each site using polyethylene bottles starting from December 2023 to May 2024 based on the internationally approved methods for collecting and preserving water samples. Water samples for bacteriological tests were collected using sterilized glass vials with an autoclave at a pressure of 1.5 pounds for 15 minutes. The sample was stored away from light and in the refrigerator until it reached the laboratory. Standard methods were followed for its analysis in the Environment and Pollution Laboratory, University of Mosul, based on international standard methods **(APHA, 1998, 2017)**. Water temperature and electrical conductivity (EC25) were measured in the field using a field conductivity meter. The pH was determined using a pH meter calibrated with acidity buffer solutions. Dissolved oxygen was measured following the Azide modification method, while Biochemical Oxygen Demand (BOD5) was assessed after a five-day incubation. Chloride ion concentration was determined using the Mhor method, sulfate ions through the Turbidimetric method, phosphate ion concentration via the Stannous Chloride method, and nitrate ion concentration by the Ultra Violet Screening method. Additionally, total bacterial count and fecal coliform bacteria levels were measured.

III. Estimation of water quality indices (WQI)

Water quality indices (WQIs) serve as effective tools for monitoring water quality and facilitating scientific research, providing critical insights for decision-making in water resource management. They offer a comprehensive perspective on temporal and spatial variations in water quality, essential for assessing the status of water resources across regions. To ensure that the evaluation results using mathematical models are accurate and decisive, it is crucial to identify parameters that exhibit significant temporal and spatial differences and have a direct impact on water quality **(Gao *et al.*, 2022; González *et al.*, 2024)**.

In the current study, two mathematical models were utilized to assess water quality:

1. **Water quality index model (WQI)** proposed by Rodriguez de Bassoon **(Kannel *et al.*, 2007)**. The WQI is calculated using the following equation **(Rubio-Arias *et al.*, 2016; Qaseem *et al.*, 2022)**:

$$WQI = K \times \sum (nNi \times Pi)$$

Where:

- n is the number of parameters,
- Ni represents the normalization values for each parameter (%),
- Pi is the weight assigned to each parameter based on its importance, ranging from 1 to 5,
- K is a constant (0.25, 0.5, 0.75, or 1.0) depending on the degree of visible pollution (e.g., smell, color, transparency).

The water quality is classified according to WQI values into five categories:

- 0 to 25: Very bad water,
- 26 to 50: Bad water quality,
- 51 to 70: Medium water quality,
- 71 to 90: Good water quality,
- 91 to 100: Excellent quality **(Kannel *et al.*, 2007; Rubio-Arias 2013; Al-Mashhdany, 2021a)**.

2. **Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI)**, as described by **Al-Gayyim and Al-Asady (2023)** and **Manna and Biswas (2023)**. This index is determined by calculating three factors:
    - *Scope (F1)*: Percentage of variables failing to meet water quality objectives,
    - *Frequency (F2)*: Percentage of failed tests,
    - *Amplitude (F3)*: Degree of exceedance.

The CCMEWQI is calculated using the equation:

$$CCMEWQI = 100 - \sqrt{\frac{F1^2 + F2^2 + F3^2}{3}}$$

This index categorizes water quality into five classes:

- 95 to 100: Excellent,
- 80 to 94: Good,
- 65 to 79: Fair,
- 45 to 64: Marginal,
- 0 to 44: Poor **(Al-Mashhdany, 2021c; Kujiek & Sahile, 2024)**.

These models provide a comprehensive assessment of water quality, making complex datasets more accessible and aiding in the efficient management of water resources.

RESULTS AND DISCUSSION

The results of the water quality assessment of the Khoser River and Tigris River at the center of Mosul City, using the CCME WQI as shown in Table (2), indicate that the water quality of the Khoser River is poor for aquatic life, with values fluctuating between 30.9 and 41.5. The model results highlight that the Khoser River exhibits more significant deterioration in water quality compared to other studied sites. Additionally, the values of factors F2 and F3 increased, reaching 57.1 and 97.1, respectively. This rise in factor values contributes to a reduction in the Canadian index **(Al-Mashhdany *et al.*, 2018)**. Furthermore, the Khoser River adversely affects the water quality of the Tigris River, where the quality at the comparison site was marginal, deteriorating to poor quality at a site 200 meters downstream from the confluence of the Khoser River with the Tigris River.

Table 2. Results of water quality assessment of the Khoser and Tigris rivers using CCMEWQI

Site		F1	F2	F3	CCMEWQI	
					Values	Status
Khosar R.	1	20	28.5	95.0	41.5	poor
	2	40	57.1	96.9	31.0	Poor
	3	30	42.8	96.9	36.4	Poor
	4	40	42.8	97.1	34.5	Poor
	5	40	57.1	97.1	30.9	Poor
Tigris R.	6	10	14.2	79.67	52.7	Marginal
	7	20	28.5	97.5	40.2	Poor

The water condition, as assessed by the Canadian model, aligns with the findings from the second model proposed by Rodriguez de Bassoon, as shown in Table (3). The water quality of the Khoser River was categorized as very bad for aquatic life, with the quality deteriorating at Site 5, just before it meets the Tigris River, to an index value of 11.48. Additionally, there is a noticeable impact of Khoser River water on the quality of the Tigris River at Site 7, where it deteriorated to the poor quality category, reflected in an index value of 47.7. This decline in water quality is primarily attributed to key influencing properties, particularly the concentration of dissolved oxygen, which is crucial for aquatic life. As noted in Table (4), dissolved oxygen levels decreased along the river, fluctuating between 1.2 and 4.8mg/ L, consistently falling below the acceptable limits for aquatic organisms, as defined by the EPA **(Al-Mashhdany *et al.*, 2018)**. This reduction in dissolved oxygen is largely due to increased organic load, resulting from numerous wastewater outlets along both sides of the river, with an average organic load of 46.0 ± 15.8mg/ L

Table 3. Ni*Pi, and WQI values of the Khoser and Tigris Rivers water quality

Site / Param.	Khoser river						Tigris river	
	Pi	1	2	3	4	5	6	7
T. ˚C	2	160	200	200	200	200	160	160
EC_{25}	5	360	400	400	400	400	500	500
Ph	2	180	120	120	120	100	180	180
DO	5	360	150	100	150	100	500	350
BOD_5	3	0.0	0.0	0.0	0.0	0.0	150	60
Cl	1	90	50	80	80	80	100	100
SO_4	2	120	120	120	100	120	160	140
PO_4	2	180	180	140	100	140	200	160
NO_3	3	180	180	210	180	180	210	180
T. H	1	60.0	50.0	50.0	50.0	50.0	70.0	70
F.C	4	8.00	8.00	8.00	8.00	8.00	12.0	8.00
Σ	26	1878	1458	1428	1388	1378	2242	1908
WQI	Values	15.65	12.15	11.90	11.57	11.48	56.05	47.7
	Status	V. B	V. B	V. B	V. B	V. B	M. Q.	Bad

V. B: Very Bad quality.,. M.Q.: Medium water quality

Unfortunately, the decrease in dissolved oxygen has detrimental effects on aquatic ecosystems due to the activity of anaerobic microorganisms. These microorganisms alter the reaction pathways of organic compounds, leading to the production of harmful substances such as ammonia, hydrogen sulfide, and phosphine through oxidation and reduction reactions. This phenomenon explains the foul odors emanating from the Khoser River, particularly in areas close to wastewater outlets. The accumulation of these toxic compounds not only affects water quality but also poses significant risks to aquatic life and overall ecosystem health, as in the equations indicated by **Al-Hamadany *et al.* (2021)**, **Qaseem *et al.* (2022)** and **Ali (2023)**:

$$2[CH_2O] + H_2O + SO_4 \xrightarrow{\text{Anerobic Bact.}} H_2S + CO_2 + 3H_2O$$

$$4C_3H_7O_2NS + 8H_2O \xrightarrow{\text{Anerobic Bact.}} 4CH_3COOH + 4NH_3 + 4H_2O + 4CO_2 + 8H$$

$$4CH_3COOH + 8H^+ \xrightarrow{\text{Anerobic Bact.}} 5CH_4 + 3CO_2 + 2H_2O$$

$$\text{Organic Compounds} \xrightarrow{\text{Anerobic Bact.}} PH_3\uparrow + CO_2 + 2H_2O$$

$$HPO_4^{-2} + 4H_2 \xrightarrow{\text{Anerobic Bact.}} PH_3\uparrow + 2H_2O + 2OH^{-1}$$

$$HPO_4^{-2} + CH_4 \xrightarrow{\text{Anerobic Bact.}} PH_3\uparrow + CO_2 + 2OH^{-1}$$

$$4HPO_3^{-1} + SO_4^{-2} + H^+ \xrightarrow{Anerobic\ Bact.} 4HPO_4^{-2} + HS^{-1}$$

Despite the formation of hydrogen sulfide with an acidic effect, the extent of fluctuation in pH values was small, with values ranging in the Khoser and Tigris rivers between 6.54 to 7.22 and 6.97 to 7.33, respectively. This is due to the high buffering capacity of Iraqi waters due to the presence of carbonate compounds in the bottom sediments. Without this property, the decrease would have been toward acidity, which would have negatively affected aquatic life as a result of the decomposition of toxic heavy metals (HMs) from the bottom sediments. The acidic medium also reduces dissolved oxygen levels, as well as the effect of reducing growth and survival rates due to the disruption of the physiological processes of aquatic organisms **(Yang *et al*., 2019; Dewangan *et al*., 2023)**.

It is noted from Table (3) that the total bacterial count (TPC) and fecal coliform bacteria (F.C.) in the waters of the Khoser River increased to 246 ± 22.5 × 10^5 cells/ml and 668 ± 495 × 10^cells/100ml, respectively, exceeding the acceptable levels for aquatic life. This rise significantly contributes to the deterioration of water quality, which extends to the Tigris River, where counts at Site 7 increased to 17 × 10^5 cells/ml and 141 × 10^4 cells/100ml. Such elevated levels increase the risk of fish being infected with pathogens, subsequently affecting their growth and overall quality **(Taha, 2023)**.

The relative decrease in bacterial numbers during certain periods may be attributed to lower water temperatures, which can drop to 8 and 10°C in the two rivers, respectively.

Regarding plant nutrients, high concentrations of phosphorus and nitrogen compounds can lead to nutrient enrichment, which negatively impacts biodiversity. Notably, 33% of the phosphate concentrations in Khoser River water exceeded permissible levels, while nitrate ion concentrations remained within acceptable limits. Similarly, chloride and sulfate ion concentrations in both rivers did not exceed 82 and 235mg and 27 and 77mg, respectively.

Finally, total hardness levels were relatively high in both the Khoser and Tigris rivers, reaching 443 and 238mg/ L, respectively. This increase is attributed to the decomposition of compounds such as calcite minerals (CaCO3) and dolomite (CaMg(CO3)2), which can help mitigate the toxicity of heavy metals (HMs) and other toxins on aquatic organisms.

Table 4. The range, averages and standard deviation of the characteristics of the waters of the Khoser and Tigris rivers

Sites / Paramet.		T◦C	EC_{25}	pH	DO	BOD_5	Cl^-	T.H	SO_4	PO_4	NO_3	T.P.C	F. C.
1	*Min*	8	509	6.63	5	7.2	10	252	69	0.04	2.4	27	20
	Max	24	1327	7.41	9.6	32	84	476	261	0.19	17	340	93
	Mean	14	869	7.05	7.1	22	49	353	134	0.08	8.78	152	35
	SD±	7.3	28.8	0.36	1.7	9.3	27.0	78.97	75.0	0.05	5.04	139.2	37.8
2	*Min*	10	805	6.59	2.4	24	34	344	86	0.05	5.87	4.41	40
	Max	24	1179	7.25	4.4	68	82	536	204	7.31	7.56	180	1100
	Mean	16	1038	6.87	3.3	46	68	447	138	1.30	6.83	50	325
	SD±	5.9	166.8	0.28	0.8	15.8	17.2	78.32	48.8	2.94	0.59	139.7	414
3	*Min*	10	998	6.54	1.2	28	61	364	74	0.05	4.45	12.4	9.00
	Max	23	1208	7.16	4.8	56	80	496	243	0.30	7.38	74	1100
	Mean	16	1076	6.85	2.8	40	70	443	138	0.14	5.65	49	705
	SD±	5.5	75.4	0.26	1.3	11.3	7.0	59.37	74.2	0.09	1.00	66.4	463
4	*Min*	10	990	6.63	1.3	20	50	356	99	0.05	6.05	60	39
	Max	23	1113	7.23	4.8	60	76	488	235	6.31	9.55	499	1100
	Mean	16	1065	6.88	3.1	43	65	443	154	1.14	7.18	276	497
	SD±	5.2	42.31	0.24	1.2	14.9	9.2	47.29	56.0	2.53	1.44	22.5	492
5	*Min*	10	1027	6.67	1.2	24	48	360	103	0.05	5.14	17	7
	Max	24	1115	7.22	4.4	54	69	468	206	2.96	9.73	230	1100
	Mean	16	1071	6.90	2.7	38	62	435	143	0.58	7.32	76	668
	SD±	5.8	36.07	0.20	1.3	10.3	7.9	39.49	54.1	1.17	1.82	81.4	495
6	*Min*	10	437	7.01	5.6	3.2	13	208	40	0.02	4.26	0.01	0.04
	Max	17	521	7.33	10	8	21	230	86	0.13	6.25	5.8	15
	Mean	14	478	7.11	7.8	6	17	220	57	0.06	4.93	1.0	11
	SD±	3.3	31.9	0.13	1.8	1.9	3.0	9.21	18.3	0.04	0.80	2.6	13.9
7	*Min*	11	484	6.97	4.4	4.8	17	224	49	0.03	4.57	0.08	11
	Max	19	771	7.6	9.2	18	27	248	97	0.15	6.66	17	460
	Mean	14	557	7.18	6.4	10	24	238	77	0.08	6.00	6.0	141
	SD±	3.8	108	0.24	1.7	4.43	7.3	9.50	18.1	0.04	4.57	6.5	165
Stand. L .		25	1500	6-9	5.0	8.0	250	----	500	0.15	13	0.50	0.04

F.C: Faecal coliform $\times 10^4$ cell. 100 ml^{-1} ., TPC: $\times 10^5$ cell. ml^{-1} ., Ec: uS. cm^{-1}

CONCLUSION

1. The quality of Khoser River water has deteriorated significantly due to the large volumes of wastewater discharged into it. This river is characterized by low dissolved oxygen (DO) concentrations in most of the studied water samples, along with elevated levels of organic load and microbial pollution.
2. Based on the calculated indices, the Khoser River water is classified as poor or very bad quality. Furthermore, there is a notable impact of the Khoser River on the water quality of the Tigris River, which shifts from medium quality to poor quality after the confluence of the two rivers. This trend is a concerning indicator that requires immediate attention from the relevant authorities.

Therefore, we recommend that wastewater disposal only occur after proper treatment and emphasize the need to restore the Khoser River ecosystem to its previous state. Continuous monitoring studies should be conducted to assess the river's condition, and environmental laws should be enforced to prevent encroachments on water bodies by citizens.

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