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Assessing Spatial Changes in Water Quality of the Euphrates River Caused by Al Hindiya Barrage, in the Middle of Iraq, Using CCME WQI

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ABSTRACT
In this study, the Canadian water quality index (CCME-WQI) was employed to evaluate the river's water quality resulting from the influence of the Hindiya Barrage, located along the Euphrates River in central Iraq. This assessment used eight core water quality parameters. Data were collected monthly from January to December 2024 addressing 4 sampling sites near the barrage. Water temperature ranged from 22.66 ± 6.50 °C to 23.1 ± 6.74 °C, while turbidity fluctuated between 12.79 ± 10.13 and 26.99 ± 12.26. TDS values varied from 0.48 ± 0.11 to 0.48 ± 0.12 g/L, and pH ranged from 7.51 ± 0.37 to 7.61 ± 0.35. DO levels were between 8.35 ± 1.67 and 9.33 ± 1.39 mg/L, while BOD_5 concentrations spanned from 3.94 ± 2.52 to 4.45 ± 2.24 mg/L. Nitrate levels ranged from 0.98 ± 0.79 to 1.14 ± 0.96 mg/L, and phosphate levels from 0.01 ± 0.008 to 0.01 ± 0.01 mg/L. Turbidity emerged as a key factor contributing to reduced water quality. Site 3 (downstream of the barrage) recorded the highest turbidity levels relative to other sampling locations. Another significant parameter impacting the index was TDS, particularly where its levels exceeded the standard at Site 3. The highest average BOD_5 was observed at Site 4 (Sadat Al-Hindiya), an area impacted by sewage discharge. The calculated WQI values varied across sites, ranging from marginal at Site 3 (62.3%) to good at Site 2 (above the barrage). Site 1 (upstream of the dam) had a value of 73.7%, classified as fair, while the Hindiya barrage site recorded 80%, falling into the good category. Site 3 consistently displayed the lowest WQI score due to the presence of multiple failing parameters. Our analysis demonstrates the influence of the Hindiya barrage in decreasing water quality downstream, particularly at Site 3, which showed the most degraded conditions among all sites.

INTRODUCTION

The Tigris and Euphrates rivers are the two major rivers found in Iraq. The Euphrates River can be said to be the longest river in Iraq and covers 2786 kilometers. The river originates in the Taurus Mountains in Turkey, and it passes through Syria to Iraq in Western Asia. Euphrates Basin is of utmost importance to the region as it sustains about 47 percent of the Iraqi population (**Adamo *et al.*, 2018**). It is well known that the river experiences seasonal variations with the river flowing at lower levels during summer and at higher stages during March and April. There are a number of dams built along the river path among them is the Hindiya barrage where the river is divided into two main distributaries, the Hindiya River and the Hilla River, in the northern part of Babylon Governorate in central Iraq (**Al-Saati *et al.*, 2021**).

Climate pattern alterations in Iraq have impacted weather patterns such as rainfall and the general hydrological cycle. Moreover, the increasing water demand due to population growth and expanding farming areas is placing further strain on water resources (**Al-Azawi *et al.*, 2024**). The health of the river systems in Iraq is increasingly impacted by various pollutants. Freshwaters are essential habitats of biodiversity, playing a vital role in sustaining ecosystems globally **(Trottier *et al*., 2020)**. The availability of water resources has diminished, with existing resources often characterized by low quality, accessibility challenges, and frequent contamination from effluents **(Madhi & Azeez, 2024)**. The dams have a substantial impact on freshwater ecosystems by disrupting the habitats essential for aquatic life.

The damming of rivers has significantly changed their water systems more than other anthropogenic activities (**Kummu & Varis, 2007**). They lead to alteration of the dynamics of sedimentation, water flow distribution, landscape composition, and wetland arrangements (**Donohue & Molinos, 2009**). Moreover, changes can be extended into water temperature, sediment deposition, and a set of physicochemical characteristics (**Deng *et al.*, 2024**).

Several water quality indices (WQIs) have been used to measure the water quality in various time scales and space. WQI is a collective indicator that measures the general quality of water and determines the presence of undesirable or dangerous water quality (**Galib *et al.*, 2018**). This approach is also known to be very simple and effective in communicating the necessary water quality data to stakeholders as well as policymakers (**Banda & Kumarasamy, 2024**).

The study of limnology of the water systems has become a field of high academic interest, and several studies have been done regarding the water quality issues in areas (**Saleh *et al.*, 2021; Yaseen *et al.*, 2021; Al-Khuzaie *et al.*, 2024; Al-Shorbagy *et al.*, 2024; Altahan & Dobslaw, 2024; Alwan & Saeed, 2024; Al-Bahathy *et al.*, 2025**; **Lembang *et al*., 2025; Nina Gertrude *et al*., 2025; Nirmala *et al*., 2025)**.

The purpose of the present study was to examine the impacts of Hindiya Barrage on the Euphrates River through the Canadian Council of the Ministers of the Environment (CCME) Water Quality Index (WQI) to determine its suitability in protecting life at Sadat alhindiyia area.

MATERIALS AND METHODS

1. Study area description

Hindiya Barrage is located on the Euphrates River, south of the city of Musayyib in northern Babil Governorate in Iraq. The barrage is about 250 meters in length and was originally built to control the flow of sediments of one of the two major branches of the Euphrates River in this region, namely Hilla River. For the purpose of this study, four sampling sites were selected along the Euphrates River in proximity to the Hindiya Barrage (Fig. 1).

- Site 1: Positioned south of Musayyib City, with geographic coordinates 32.744823 N, 44,270677 E.
- Site 2: This location corresponds to the Hindiya Barrage itself, located at 44.2681200 N, 32.7286500 E.
- Site 3: Located approximately 500 meters downstream from the Hindiya Barrage, at. 32.724298 N, 44.268179 E.
- Site 4: This site lies around 5 kilometers downstream of the barrage, with coordinates 32.7071100 E. 32°41'10.7"N 44°15'18.5"E.

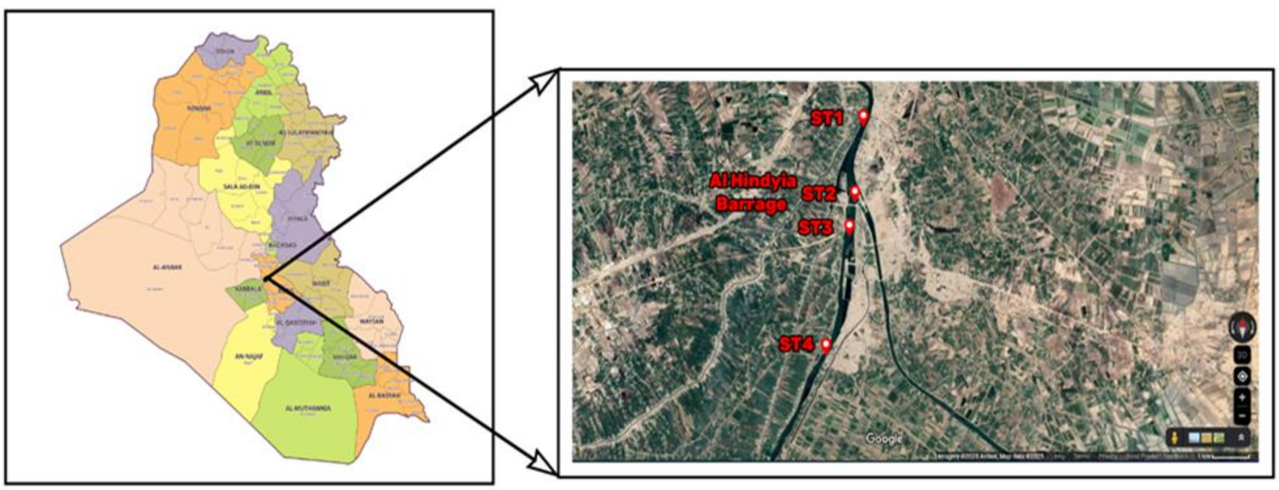

Fig. 1. Study area sites

2. Samples collection

Eight distinct parameters were selected to evaluate the water quality index. Throughout 2024, water samples were gathered monthly using one-liter polyethylene bottles. The parameters examined included temperature, recorded with a mercury-based thermometer. Dissolved oxygen (DO) and biological oxygen demand (BOD) were determined using the modified Winkler approach described in **APHA(1998)**. The pH and concentration of total dissolved solids (TDS) in the water were assessed using a HANA (HI9811) device. Jenwa Model-6035 Turbidity meter was used to measure the level of turbidity. The concentrations of nitrate (NO^{3-}) and phosphate ($PO4^{-2}$) content were determined using the **APHA(1998)** 23 standard .

3.Water quality index (WQI) created by the Canadian environmental agencies, as part of the CCME framework for the protection of the water bodies

The Canadian water quality index (CWQI) was computed by selecting a group of eight indicators, considering both their availability and relevance. These indicators include water temperature, turbidity, total dissolved solids, pH level, dissolved oxygen, biological oxygen demand, nitrate, and phosphate The CWQI framework incorporates three statistical components to assess variation from designated water quality benchmarks—namely scope, frequency, and amplitude. According to **CCME (2001)**, this system has been adopted to categorize water quality status. The CCME index was derived by analyzing eight specific indicators across four different sites during 2024. The collected parameter data were evaluated against corresponding standard reference values (as shown in Table (1)). The CCMEWQI framework relies on three core statistical components: F1, F2, and F3, which represent distinct dimensions of variance.

F1 is calculated as the percentage of parameters that fail to meet the specified water quality standard, determined using the formula:

F1 = (Number of non-compliant variables / Total assessed variables) × 100 (Eq. 1)

Where F1 identifies the proportion of parameters exceeding acceptable thresholds; F2 indicates the proportion of failed tests relative to the total number conducted:

F2 = (Number of non-compliant tests / Total tests conducted) × 100 (Eq. 2)

F3 (Amplitude) reflects the extent to which test results deviate from the standard objective. Excursion values are determined as follows:

(i) When the test result is higher than the permissible limit:

Excursion = (Failed Test Value / Objective) – 1 (Eq. 3)

(ii) When the test result is lower than the acceptable minimum:

Excursion = (Objective / Failed Test Value) – 1 (Eq. 4)

These equations provide a quantitative evaluation of deviation severity for each failed parameter.

Standard values are depicted in Table (1), as outlined in the study of **Lumb *et al.* (2006)**. The CCME WQIs framework centered on criteria was utilized to classify water specifically for sustaining aquatic ecosystems.

The CCME has introduced a classification system for water quality, rating it as Excellent (95–100), Good (80–94), Fair (65–79), Marginal (45–64), and Poor (0–45) (**Karen *et al.*, 2001**).

Table 1. Standard categories of indicators in line with CCME for aquatic life

Variable	Standards (CCME) for life protection
Water Temp.	≥15 C
Turbidity	< 5 NTU
TDS	< 0.5 g/L
pH	6.5-9mg/L
BOD_5	< 5 mg/L
DO	5.5 mg/L
NO^{3-}	< 13 mg/L
$PO4^{-2}$	< 0.1 mg/L

RESULTS

The CWQI was determined by selecting a group of eight indicators, as mentioned above, chosen due to their accessibility and the relevance of the data. A range of water quality factors was examined, and it was observed that temperature fluctuated between 22.66±6.50 & 23.1±6.74°C. Turbidity values were between 12.79±10.13 and 26.99±12.26. TDS concentrations spanned from 0.48±0.11 to 0.48±0.12 g/L. pH values fell within the range of 7.51±0.37 to 7.61±0.35. DO levels ranged from 8.35±1.67 to 9.33±1.39 mg/L, while the BOD_5 varied from 3.94±2.52 to 4.45±2.24mg/ L. NO^{3-} concentrations were between 0.98±0.79 and 1.14±0.96mg/ L, and $PO4^{-2}$ ranged from 0.01±0.008 to 0.01±0.01mg/ L, as provided in Table (2).

Table 2. Indicators of water characteristics in the investigated region

Variable of water	S1 Max-Min Mean± SD	S2 Max-Min Mean± SD	S3 Max-Min Mean± SD	S4 Max-Min Mean± SD	Standards (CCME) for life protection
Temperature Clarity (C°)	11.1-33.1 23.04 ±6.98	15-31.6 22.76±6.04	12.4-31.3 22.66±6.50	12.5-32 23.1±6.74	≥15 C
Turbidity(NTU)	3.1-32 12.79±10.13	3-34 13.66±10.20	10.1-50.1 26.99±12.26	2-35 16.48±9.18	< 5 NTU
TDS (mg/L)	0.31-0.71 0.48±0.12	0.34-0.67 0.48±0.11	0.34-0.67 0.48±0.11	0.34-0.68 0.48±0.11	0.5 g/L<

pH	7.1-8.18 7.57±0.35	7-8.08 7.51±0.37	7-8 7.61±0.35	7-8.07 7.55±0.36	6.5-9mg/L
BOD_5 (mg/L)	1.5-7.1 4.35±2.12	2.1-9 4.10±2.15	1.3-7.9 3.94± 2.52	2-8.8 4.45±2.24	5 mg/L <
DO (mg/L)	7.5-12.1 9.33±1.39	6-12.5 8.80±2.24	5-11.3 8.35±1.67	6-11.4 8.93±1.51	5.5 mg/L
NO_3- (mg/L)	0.21-3 0.99±0.86	0.12-3 1.02±0.89	0.382-3.61 1.14±0.96	0.28-0.62 0.98±0.79	13 mg/L <
PO_4^{-2} (mg/L)	0.001-0.028 0.01±0.008	0.002-0.018 0.01±0.005	0.0032-0.057 0.01±0.01	0.003-0.05 0.01±0.01	< 0.1 mg/L

Table (3) indicates that elevated turbidity and TDS concentration played a significant role in lowering water quality, surpassing the CCME threshold during the monitoring timeframe. Site 3 (downstream of the dam) recorded the most elevated turbidity and TDS concentration measurements relative to the other locations. Conversely, DO concentrations remained within the acceptable thresholds throughout the period of study, except at Site 3 (downstream of the barrage). The highest mean value of BOD_5 was observed at Site 4. Nevertheless, findings confirm that water temperature, pH, phosphate, and nitrate levels remained within CCME recommended limits.

Table (3) and Fig. (2) reveal that water quality index (WQI) readings along the Euphrates River varied across sites, ranging from marginal at Site 3 (below the dam) to good at Site 2 (the barrage location). The water quality index recorded at Site 1 (upstream of the dam) reached 73.7%, which was categorized as fair. In comparison, the WQI at the Hindiyah barrage site reached 80%, falling under the good category. However, the downstream sites showed a reduction in WQI scores, particularly at Site 3, which presented the lowest reading of 62.3%, rated as marginal. In contrast, Site 4 recorded a WQI of 71.5%, placing it under the fair classification.

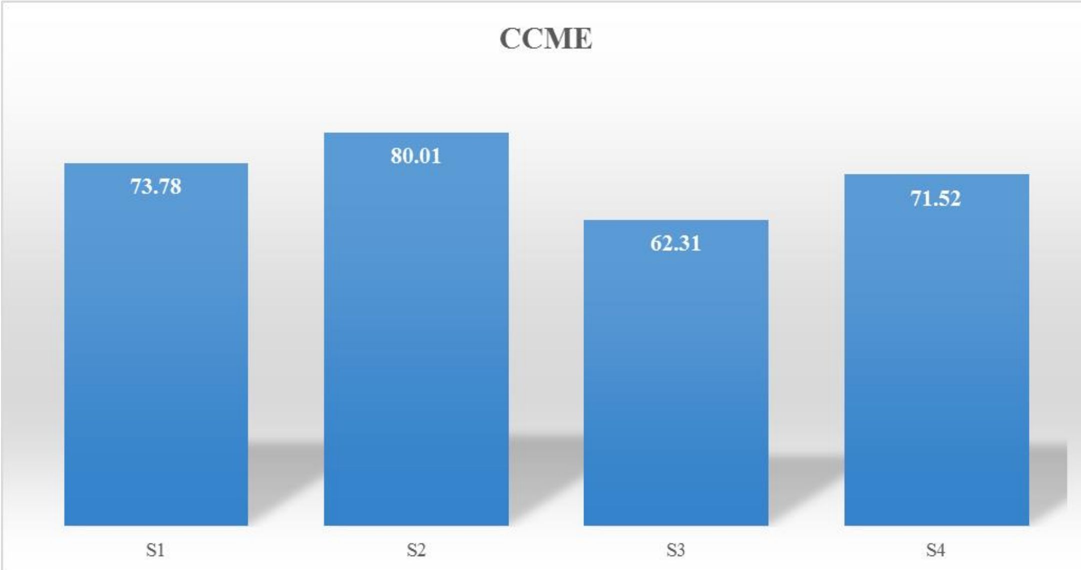

Fig. 2. CCMEWQI values of the study area

Table 3. Summary of variance in CMMEWQI and failed variables and tests for water quality of Euphrates River

Site	The Measures of Variance for CMMEWQI			Failed Tests	Failed Parameters	
	F1	F2	F3		No.	Names
Site 1	17.7	37.5	18.5	17	3	Turb. ,TDS, &BOD_5
Site 2	14.5	25	18.8	14	2	Turb. &TDS,
Site 3	20.8	50	36.4	20	4	Turb. TDS, BOD_5 &,DO
Site 4	20.8	37.5	24.3	20	3	Turb. , TDS, & BOD_5

In general, Fig. (3) shows that higher similarity for water quality variables were between sites 1 & 2, followed by Site 1 and Site 4. Whereas, Site 3 reported less similarity compared to the other sites.

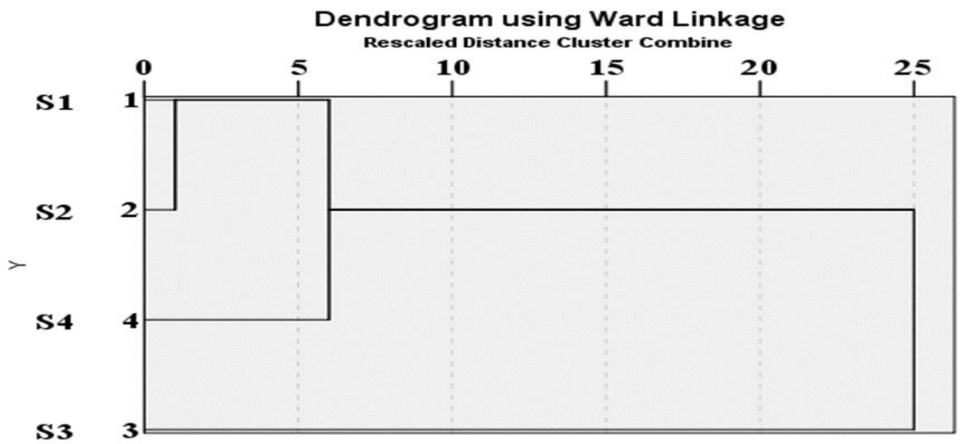

Fig. 3. Dendrogram of Jaccard index percentages of the study sites

DISCUSSION

Site 3 (downstream of the dam) recorded the most elevated turbidity measurements relative to the other locations, attributed to the rapid flow velocity of water discharged from the barrage outlets, thereby raising turbidity levels **(Singh *et al.*, 2024)**. An additional factor that contributed to the reduction of the water quality index was the TDS concentration, which surpassed the CCME limits at Site 3. Conversely, DO concentrations remained within the acceptable thresholds throughout the period of study, except for site 3 (downstream of the barrage), due to the reservoir's bottom zone being under anaerobic conditions in contrast to the surface waters, and due to the release of oxygen-depleted hypolimnetic water caused by the opening of barrage gates toward Site 3, leading to reduced oxygen availability relative to the other study sites (**Hua *et al.*, 2024**). The highest mean value of BOD_5 was observed at Site 4, located in Sadat al-Hindiya Town, which is subject to wastewater discharge (**Das, 2025**).

Table (3) and Fig. (2) reveal that the downstream sites showed a reduction in WQI scores, particularly at Site 3, which presented the lowest reading of 62.3%, rated as marginal. In contrast, Site 4 recorded a WQI of 71.5%, placing it under the fair classification. Site 3 (below the barrage) had lower water quality value due to the more failed tests & parameters recorded for this site.

The study results agree with those of **Winton *et al.*, (2019)** who surveyed the tropical reservoir and found negative effect of reservoirs on the downstream of rivers.

Fig. (3) shows that less similarity for water quality variables were those recorded at Site 3 which reported less similarity compared with other sites due to Site 3 having the lowest water quality which resulted in more failed tests for this site.

Our findings coincide with those of prior studies illustrating that the Hindiya Barrage affected the CCMEWQI values and this impact was cristal clear at site 3 (below the dam) with a degraded water quality.

CONCLUSION

This investigation is the initial attempt to employ the WQI framework to interpret the influence of the Hindiyah Barrage on the Euphrates River's water condition. This approach enabled the assessment of water quality in the Hindiyah Barrage region through the CCME-WQI model. Water quality was evaluated based on measurements of eight key physicochemical indicators, including temperature, turbidity, pH, TDS, BOD_5, DO, nitrate (NO^{-3}), and phosphate (PO_4^{2-}). The analysis showed that turbidity had a significant impact on deteriorating water quality, surpassing the limits set by CCME during the monitoring period. Site 3 (located downstream of the barrage) recorded the highest turbidity values in comparison with the other sampling locations, due to the rapid discharge from the barrage gates, resulting in elevated turbidity **(Singh *et al.*, 2024)**. An additional factor reducing the water quality index was the elevated TDS concentration, which exceeded CCME limits specifically at Site 3. On the other hand, the DO levels remained within acceptable ranges during the entire period, except for Site 3, where the bottom of the reservoir exhibited anaerobic conditions compared to the surface layer, and due to the discharge of low-oxygen hypolimnetic water from the barrage gates, leading to lower dissolved oxygen levels at Site 3 compared to the other sites **(Hua *et al.*, 2024)**. The average BOD_5 value peaked at Site 4, situated in Sadat Alhindiyah Town, an area impacted by wastewater input. However, temperature, pH, NO^{3-}, and PO_4^{-2} levels remained within acceptable CCME limits.

The WQI scores of the Euphrates River across the different study sites varied, ranging from marginal classification at Site 3 (below the barrage) to good classification at Site 2. The downstream locations, particularly Site 3, showed a decline in WQI values relative to the dam site, attributed to the increased number of test exceedances and measured parameters. This outcome supports that the barrage's influence on the Euphrates River negatively affects water quality in downstream areas, particularly at Site 3, which showed the most deterioration according to the CCME-WQI results.

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