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Water quality assessment of the upper Euphrates River basin using NSF and CCME indices in western Iraq

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ABSTRACT

Many developing countries with river systems face persistent challenges related to water pollution, complicating efforts to meet safe drinking water standards. This study evaluates the water quality of the Euphrates River along the Anbar Governorate using two widely recognized models, including NSF Water Quality Index (NSF-WQI) and CCME Water Quality Index (CCME-WQI) developed by the Canadian Council of Ministers of the Environment. Seven monitoring sites were selected along the upper Euphrates basin, from Al-Qaim to Fallujah. Seventeen key parameters were analyzed, including physicochemical and biological indicators. Both indices produced similar classifications at upstream locations (Al-Qaim, Al-Haditha, and Al-Baghdadi), indicating marginal water quality, which reflects limited suitability for direct human use without treatment. CCME-WQI values were consistently lower than NSF-WQI results, indicating a more stringent assessment approach. The results align with documented pollution trends linked to urban and agricultural practices, particularly in highly populated regions. The study concludes that both models are effective for assessing water quality; however, the CCME-WQI provides greater flexibility and wider applicability across diverse environmental conditions due to its capacity to accommodate a broader range of parameters and site-specific considerations. In contrast, the NSF-WQI demonstrates increased sensitivity to particular input parameters. These findings can enhance strategies for managing water resources and controlling pollution along the Euphrates River.

Keywords: *CCME-WQI, Euphrates River basin, NSF-WQI, Water quality*

1 INTRODUCTION

Freshwater sources are the primary suppliers of drinking water worldwide and are vital to human societies, providing essential social and economic value. The sustainability of human life and ecosystem services depends critically on their availability and quality [1, 2]. In Iraq, rivers are increasingly challenged by rising industrial and agricultural pollution, increasing salinity and hardness, declining water levels exacerbated by climate change and minimal rainfall (especially in the north), and the construction of numerous dams in Turkey, Syria, and Iran. Inadequate irrigation planning further intensifies these pressures [3, 4].

As in many countries, pollution levels in Iraqi rivers often exceed safe limits for consumption, and water distribution and availability fall short of demand. Deteriorating water quality poses a serious threat, compounded by the lack of an effective monitoring network, particularly in the Euphrates Basin [5].

Water from the upper Euphrates is the principal source of potable water for urban areas along its course in Anbar Governorate, yet its quality is adversely affected by domestic, industrial, and agricultural contamination [6]. Consequently, drinking-water pollution and the feasibility of its treatment have become two of the most significant challenges of the current century [7].

High water quality is essential for maintaining healthy aquatic ecosystems, as it reflects the natural baseline conditions. Some aquatic systems tolerate changes in water quality with little observable effect on ecosystem structure and function, whereas others are sensitive to physical, chemical, and biological alterations, resulting in ecosystem degradation and biodiversity loss [8, 9]. The Canadian Council of Ministers of the Environment (CCME) developed a Water Quality Index (WQI) to simplify reporting and monitoring of water quality. This index applies adaptable physical and chemical parameters together with predefined thresholds to assess compliance with acceptable standards. The final value, ranging from 0 to 100, is calculated from a mathematical combination of three component measures [10]. Several studies have evaluated water quality in the middle and southern Euphrates using the CCME-WQI [3, 11–15].

The National Sanitation Foundation Water Quality Index (NSF-WQI) is also widely used due to its reliability and simplicity, condensing multiple parameters into a single value that represents overall water quality in a fast, objective, and repeatable manner [16–18]. This study applies water-quality indices within the upper Euphrates River Basin to evaluate suitability for multiple uses and compares the indices to identify the most effective and straightforward tool for characterizing water quality in the study area.

2 MATERIALS AND METHODS

2.1 Study area and collecting samples

Figure 1 shows the distribution of sampling points, where seven locations were selected along the Euphrates River, from Al-Qaim at the Syrian border to Fallujah in western Iraq. The study area covered more than 300 km. Surface-water samples, together with samples for fecal coliform analysis, were collected monthly from January through December 2023. Table 1 lists the geographic coordinates of the sampling sites and the adjacent cities along the upper Euphrates. These urban areas have high population density. River water quality in these zones is influenced by anthropogenic and industrial inputs as well as wastewater runoff from agricultural lands.

2.2 Physical, chemical and biological analysis

Water samples were collected from each site using sterile bottles and transported to the laboratory for analysis. Water temperature was measured directly in situ using a mercury thermometer. A multi-parameter meter (HI-5522, HANNA, Italy) was used to measure pH, electrical conductivity (EC), and total dissolved solids (TDS). Standard methods were applied to evaluate additional water quality indicators, including chloride (Cl), total alkalinity (TA), dissolved oxygen (DO), biochemical oxygen demand (BOD), total hardness (TH), calcium (Ca), magnesium (Mg), total suspended solids (TSS), nitrate (NO_3-), nitrite (NO_2-), sulfate (SO_4-2), phosphate (PO_4-3), and fecal coliform bacteria. All analyses were performed following the protocols indicated in Lipps et al. [19].

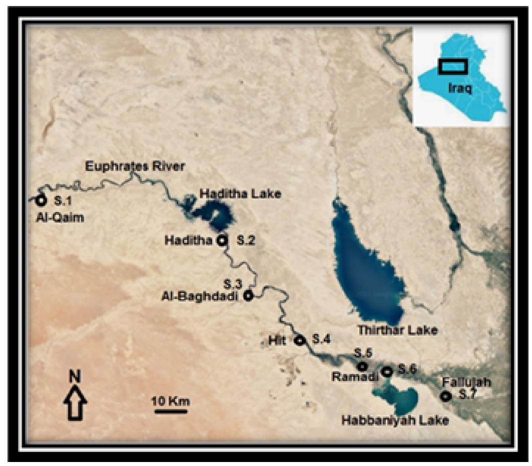


Fig. 1 Sampling Sites in the Euphrates River, Anbar, Iraq

Table 1 Geographic location of study Sites

Site	Location	Longitudes (Eastward)	Latitudes (Northwards)
S1	Al-Qaim	E 34°25’ 07”	N 41°08’ 32”
S2	Haditha	E 34°08’ 16”	N 42°21’ 36”
S3	Al-Baghdadi	E 33°52’ 39”	N 42°30’ 51”
S4	Heet	E 33°45’ 43”	N 42°43’ 18”
S5	North of Ramadi	E 33°26’ 16”	N 43°20’ 19”
S6	South of Ramadi	E 33°26’ 25”	N 43°24’ 16”
S7	Fallujah	E 33 °0’ 27”	N 43°47’ 32”

2.3 Water Quality Indices

1. The CCME WQI is characterized by its high accuracy. The index incorporates 14 physicochemical variables, including water temperature (WT), pH, total alkalinity (TA), electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), total hardness (TH), calcium (Ca), magnesium (Mg), nitrite (NO_2), nitrate (NO_3), phosphate (PO_4), sulfate (SO_4), and chloride (Cl). Fecal coliform (FC) bacteria was also

included as a biological indicator. Index values were determined by evaluating three factors [20].

$F1$ (range) represents the percentage of parameters that exceeded their permissible thresholds at least once during the monitoring period in relation to the total number of parameters evaluated.

$$F1 = \frac{\text{number of overridden variables}}{\text{total number of variables}} \quad (1)$$

$F2$ (frequency) denotes the proportion of individual tests that exceeded the standard limits relative to the total number of tests conducted.

$$F2 = \frac{\text{number of test exceeded}}{\text{number of total tests}} \quad (2)$$

$F3$ (Amplitude) quantifies the total count of tests exceeding the standard limits and is determined through a two-step process. The first step involves counting the number of instances where individual concentrations surpass the standard thresholds.

$$F3 = \frac{\text{Exceeded test value}}{\text{Standared value}} \times 100 \quad (3)$$

If the exceeded test value is higher than the standard value, it is calculated by taking the inverse of the ratio. The second step involves quantifying the magnitude of exceedance for the individual set of tests. This is mathematically achieved by summing the individual deviations and dividing the total by the combined number of exceeded and non-exceeded tests (nse).

$$\text{nse} = \frac{\sum \text{deviation of each test}}{\text{total number of testes}} \quad (4)$$

$$F3 = \frac{\text{nse}}{0.01\ \text{nse} + 0.01} \quad (5)$$

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732} \right) \quad (6)$$

The constant 1.732 serves as a scaling factor to adjust the index value, ensuring it falls within the range of 0 to 100 (Table 2).

Table 2 Canadian Water Quality Index values for water quality rating [20]

CCME-WQI	Category	Description
0–44	Poor	Always polluted or at risk
45–64	Marginal	Often polluted or at risk
65–79	Fair	Usually protected, sometimes at risk
80–94	Good	Protected, with slight threats
95–100	Excellent	Fully protected in absence of threats

2. The NSF-WQI is derived from both field and laboratory data for nine essential parameters: temperature, pH, TDS, dissolved oxygen, biochemical oxygen demand, total phosphate, nitrate, turbidity, and fecal coliform bacteria. Each parameter is interpreted through conversion curves, and the resulting index score is computed based on the formula proposed by Brown et al. [21].

$$\text{NSF - WQI} = \sum_{i=1}^{n} W_i Q_i \quad (7)$$

Where W_i represents the weight assigned to the importance of each water quality parameter, and Q_i denotes the sub-index for each parameter. The sub-index values are obtained by correlating measured parameters with corresponding evaluation curves. NSF-WQI scores reflect the extent of surface water contamination: lower values correspond to higher pollution levels, while higher values indicate cleaner conditions. This index ranges from 0 to 100, as outlined in Table 3.

Table 3 NSF-WQI classification scheme with descriptive ratings and category labels [21]

Category	NSF-WQI Score Range	Water Quality
A	91 – 100	Excellent
B	71 – 90	Good
C	51 – 70	Moderate
D	26 – 50	Poor
E	0 – 25	Very Poor

2.4 Statistical analysis

Data were analyzed in Prism 10 software to assess the effect of location on the investigated variables. Differences in mean values were tested for statistical significance using Tukey's multiple comparisons test [22].

3 RESULTS AND DISCUSSION

3.1 Physical, chemical and biological characteristics

The physical, chemical, and biological characteristics of upper Euphrates River water were evaluated using systematic sampling at seven monitoring sites. Figure 2 summarizes the measured parameters, and Table 4 illustrates the descriptive statistics alongside the corresponding permissible limits.

3.2 Water temperature and pH

FigFigure 2 shows water temperature across the study sites ranging from 21.8 to 24.6°C, reflecting relatively warm conditions. pH values ranged from 7.57 to 8.07, indicating alkaline water. Spatial variation was minor, consistent with strong buffering capacity in the river [23].

3.3 Total alkalinity

High alkalinity indicates strong buffering capacity against pH change, stabilizing aquatic conditions. For human use, moderately high alkalinity is generally not harmful. However, when markedly elevated it can affect taste, interfere with disinfection during treatment, and promote scaling in industrial and domestic systems [24]. Total alkalinity exceeded the permissible limits at all locations, ranging from 115 to 123.7 mg $CaCO_3$/L. The highest value appeared at Site 4 (Heet), likely reflecting the combined influence of bicarbonate-rich spring discharges and nearby anthropogenic inputs such as agricultural runoff and industrial effluents. These findings reinforce the alkaline nature of the Euphrates system and underscore the need for seasonal assessments to resolve source contributions and guide appropriate water-management strategies [25].

3.4 Electrical conductivity and TDS

Electrical conductivity showed no significant difference between sites (P ¿ 0.05), with values ranging from 821 μS/cm at Site 1 to 971 μS/cm at Site 7. All values were within acceptable limits, suggesting adequate dilution and limited anthropogenic disturbance [26]. Total dissolved solids ranged from 380 to 493 mg/L, highest at Site 7 and lowest at Site 1. These relatively low TDS values are consistent with the river's rocky limestone bed [6].

3.5 Total suspended solids (TSS)

Total suspended solids varied among sites and exceeded permissible limits. The highest value occurred at Site 5 (258 mg/L), and the lowest at Site 3 (195 mg/L). These differences reflect variability in suspended load, likely influenced by local runoff, hydrodynamics, soil erosion, upstream disturbances, and resuspension of bottom sediments, particularly in areas affected by human activities or fluctuating flow regimes [27].

3.6 Hardness, calcium, and magnesium

Total hardness varied significantly among sites ($P < 0.05$), with a maximum of 406.6 mg $CaCO_3$/L at Site 7 (Fallujah), and a minimum of 315.1 mg $CaCO_3$/L at Site 5. Calcium levels exceeded permissible limits and varied significantly, peaking at 98.4 mg/L in Site 7 and dropping to 77.3 mg/L at Site 1. Magnesium concentrations were lower than calcium, consistent with most Iraqi waters [28]. Site 7 recorded the highest Mg concentration (46.4 mg/L), while Site 3 had the lowest at 34.3 mg/L.

3.7 Dissolved oxygen and biochemical oxygen demand

All sites showed adequate dissolved oxygen levels ranging from 8.1 to 9.1 mg/L, remaining above permissible thresholds. This is likely due to the river's rapid flow and self-aeration capacity [6]. Site 5 had the highest DO, and Site 2 had the lowest. In contrast, BOD values exceeded permissible limits at thee upstream sites 1, 2, and 3 with a maximum of 8.4 mg/L. Downstream sites recorded lower values showing a minimum of 2.1 mg/L. Elevated BOD levels at upstream sites suggest the presence of significant organic pollution, likely comming from anthropogenic activities, including the discharge of untreated or partially treated domestic wastewater, sewage effluents, and organic-rich runoff from nearby residential or agricultural areas. These inputs increase the level of biodegradable organic matter into the river, activating microbial activity and oxygen consumption, as reflected in the higher BOD values [29].

3.8 Nitrate and phosphate

Nitrate (NO_3) and phosphate (PO_4) levels remained within acceptable limits at all sites, with no significant differences. PO_4 ranged from 0.05 to 0.16 mg/L, with the highest value at Site 2 and the lowest at Site 4. NO_3 concentrations ranged from 1.05 mg/L (Site 4) to 5.42 mg/L (Site 1). Although nitrate and phosphate levels were within permissible limits, their presence suggests possible sources such as fertilizer runoff, leaching from latrines or septic systems, and sewage discharge. Urban runoff and animal waste may also contribute, but the river's high flow likely helps dilute these inputs [24].

3.9 Sulfate and chloride

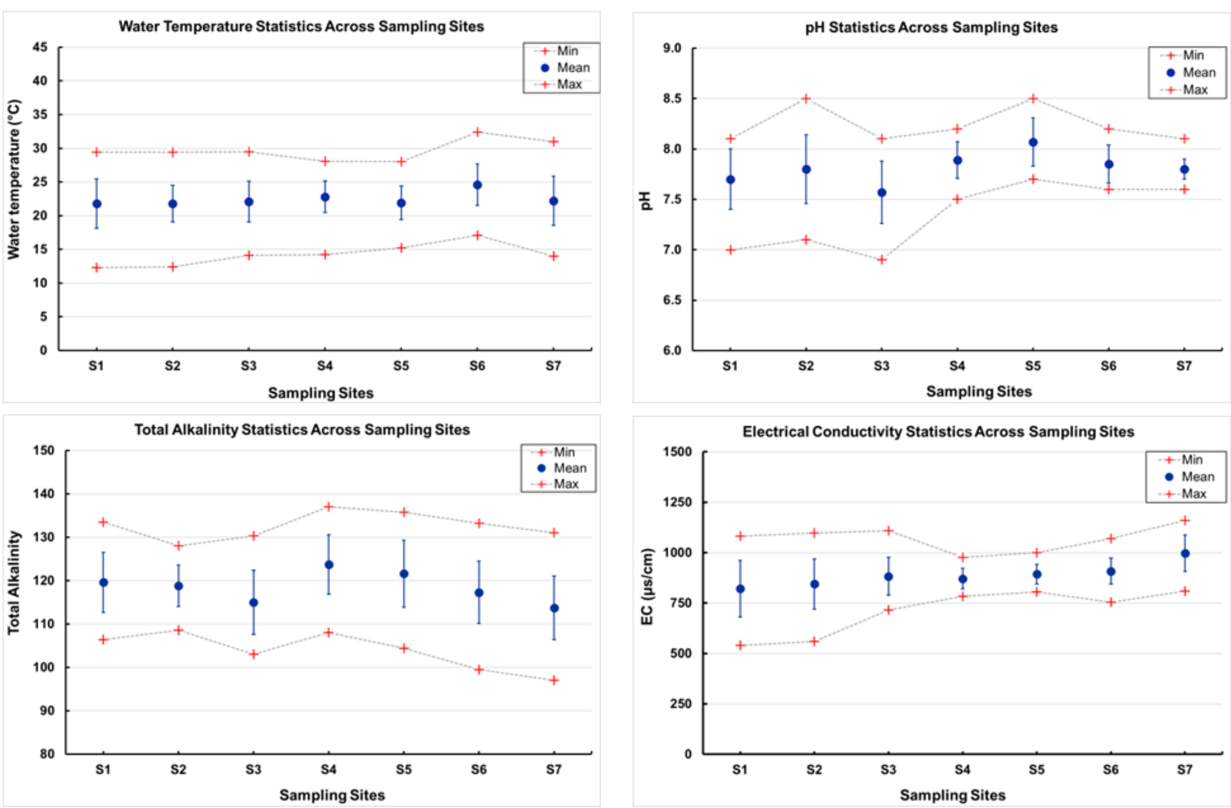
SO_4 levels complied with regulatory standards, with the highest value (221.3 mg/L) found at Site 7. These levels may result from interaction with sulfur-rich springs, particularly in the Heet and Haditha regions [6]. Cl^- concentrations also varied significantly ($P < 0.05$) but remained within safe limits. The highest level (120.9 mg/L) was recorded at Site 7, and the lowest (78.3 mg/L) at Site 1 [30].

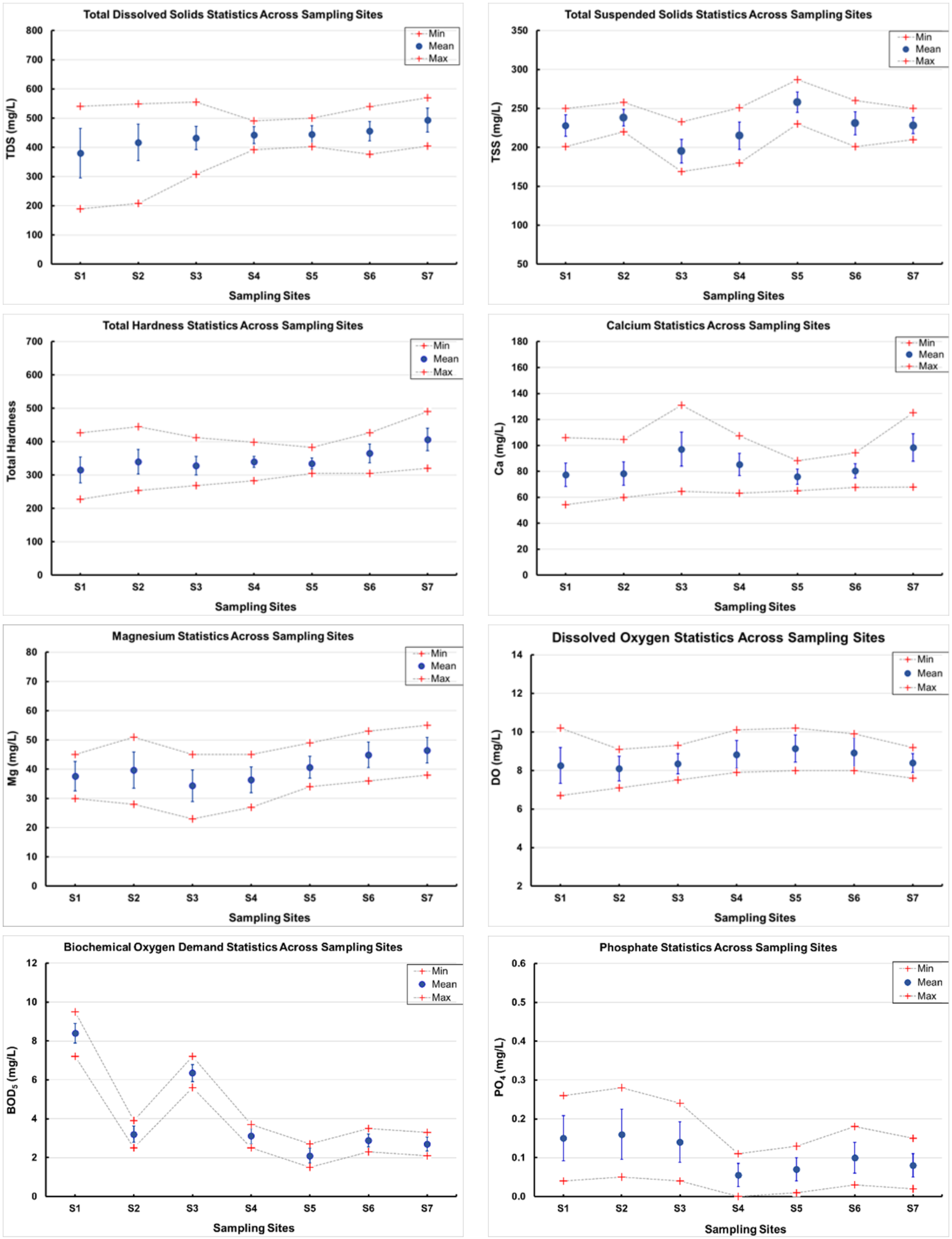
3.10 Turbidity

Turbidity values exceeded WHO limits across all sites. Site 1 exhibited the highest turbidity (13.3 NTU), and Site 4 the lowest (7.2 NTU). Seasonal changes (e.g., winter flows), increased solids, and discharge of untreated wastewater may have contributed to elevated turbidity [25].

3.11 Fecal coliform (FC)

FC concentrations remained within acceptable limits. Site 4 recorded the highest count (91.8 CFU/100 mL), and Site 3 the lowest (52.7 CFU/100 mL). Differences between sites were not statistically significant. However, elevated FC in some areas likely reflects contamination from nearby human settlements or agricultural runoff [20, 31]. These bacteria serve as key indicators of fecal contamination and the possible presence of intestinal pathogens. It is also important to consider the role of seasonality and hydrological conditions, as FC levels often rise during rainfall events due to surface runoff or during low-flow periods when dilution capacity is reduced [32].




Total Dissolved Solids Statistics Across Sampling Sites
TDS (mg/L)
Sampling Sites
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Total Hardness
Calcium Statistics Across Sampling Sites
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Magnesium Statistics Across Sampling Sites
Mg (mg/L)
Dissolved Oxygen Statistics Across Sampling Sites
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Biochemical Oxygen Demand Statistics Across Sampling Sites
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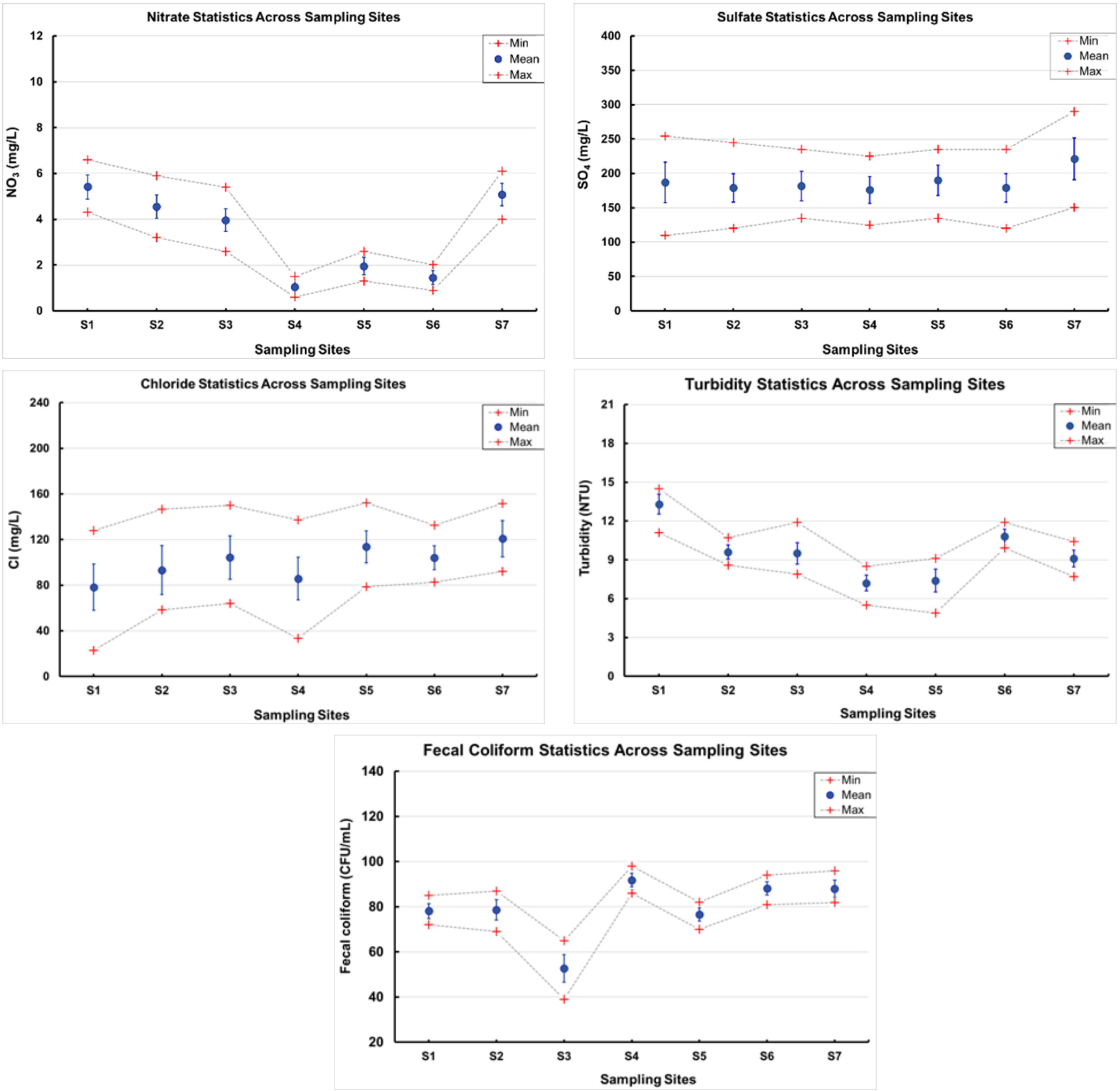

Fig. 2 Descriptive analysis (minimum, maximum, mean, and standard deviation values) for 17 water quality parameters recorded at the seven sampling locations along the Upper Euphrates River

3.12 Assessment of Euphrates using CCME-WQI

Table 5 presents the results of the Canadian Water Quality Index for the current study sites along the Upper Euphrates River Basin. The highest index value of 57.1 was recorded at Site 2 (Haditha). In contrast, the lowest value of 46.8 was noted at Site 4 (Heet), where the river water is classified as marginal, indicating that its quality is primarily threatened or poor (Table 2). This assessment highlights spatial variations throughout the Upper Euphrates River Basin, indicating a relative decrease in water quality toward the lower basin, particularly near the cities of Ramadi and Fallujah. This trend suggests the potential for water pollution in these areas, likely attributed to increased human activity and waste generation, especially given the higher population density compared to the upper regions of the basin [24].

Table 4 International and local standard values for physical and chemical water quality parameters for rivers [20, 26, 33]

Parameter	CCME Guideline	WHO Standard	Iraqi Standard
BOD_5 (mg/L)	≤ 5	2–6	≤ 10
Ca (mg/L)	–	40–50	≤ 50
Cl (mg/L)	≤ 250	≤ 250	≤ 250
DO (mg/L)	5.5–9.0	6	–
EC (µS/cm)	–	≤ 1000	≤ 2000
FC (CFU/100 mL)	≤ 200	0–10	≤ 200
Mg (mg/L)	–	30–50	≤ 50
NO ($_3$mg/L)	≤ 48.2	≤ 50	≤ 50
pH	6.5–8.5	6.5–8.5	6.5–8.5
PO $_4$(mg/L)	≤ 0.1	≤ 0.1	–
SO_4 (mg/L)	–	≤ 400	–
TDS (mg/L)	≤ 500	500–1000	≤ 1000
Temperature (∘ C)	≤ 15	15–25	≤ 25
Total Hardness (mg $CaCO_3$/L)	–	–	≤ 500
TSS (mg/L)	–	1–5	–
Turbidity (NTU)	≤ 5	≤ 5	≤ 5

The primary objective of using this index is to facilitate the assessment of water quality by converting large amounts of data and complex water quality studies into straightforward, easy-to-understand values that can be utilized by both experts and non-experts in the field of water quality [34]. Canadian Water Quality Index (WQI) values decreased at all sites, corresponding to measurements of physical and chemical properties that exceeded permissible levels, such as electrical conductivity (EC), total alkalinity (TA), total hardness (TH), total suspended solids (TSS), calcium (Ca), biochemical oxygen demand (BOD), and turbidity. The extraction process for this index relies on these acceptable limits, which negatively impact the results [35].

Table 5 Canadian Water Quality Index values at sampling sites in the Upper Euphrates River

Site	F1	F2	F3	Water Quality Index	Water Quality Status
S1 (Al-Qaim)	0.38	0.71	0.55	54.9	Marginal
S2 (Haditha)	0.31	0.57	0.48	57.1	Marginal
S3 (Al-Baghdadi)	0.38	0.71	0.53	61.1	Marginal
S4 (Heet)	0.23	0.43	0.40	46.8	Marginal
S5 (North of Ramadi)	0.19	0.36	0.35	48.4	Marginal
S6 (South of Ramadi)	0.31	0.57	0.45	48.2	Marginal
S7 (Fallujah)	0.27	0.50	0.42	46.2	Marginal

3.13 Evaluating euphrates water using NSF-WQI

Water quality at nine sites within the upper Euphrates River Basin was assessed using the NSF-WQI model. Site 6, located south of Ramadi, recorded the highest water quality value of 62.02, while Site 1, in Al-Qaim, had the lowest value of 54.15 (Table 6). Most sites exhibited fair to good water quality, with index values clustering around the medium range. However, the average values for several water properties measured in the river exceeded permissible limits, particularly for total suspended solids (TSS), biochemical oxygen demand (BOD), and turbidity. The decline in water quality can be attributed to pollution from human activities, such as sewage discharge, industrial waste, and agricultural runoff. Consequently, as the concentrations of these properties exceed standard criteria, the overall NSF-WQI value decreases (Table 6).

Table 6 NSF-WQI values at sampling sites in the Upper Euphrates River

Site	NSF-WQI value	Water Quality Rating
S1 (Al-Qaim)	54.15	Fair
S2 (Haditha)	60.07	Good
S3 (Al-Baghdadi)	58.79	Fair
S4 (Heet)	59.8	Good
S5 (North of Ramadi)	59.59	Good
S6 (South of Ramadi)	62.02	Good
S7 (Fallujah)	58.41	Fair

3.14 Comparison between ccme and nsf water quality indices

Figure 3 presents a comparison of the water quality indices calculated according to the CCME-WQI and the NSF-WQI at various sites along the Upper Euphrates River Basin. The values derived from both models were found to be identical at the upstream locations of the river, specifically at Sites 1, 2, and 3, where the water was classified as medium (marginal). Despite this agreement, the CCME index typically reported lower values than the NSF-WQI. The CCME-WQI is based on factors that go beyond acceptable limits, such as total hardness (TH), electrical conductivity (EC), total alkalinity (TA), total suspended solids (TSS), calcium (Ca), biochemical oxygen demand (BOD), and turbidity [36].

These elements caused a decrease in the index values downstream (at Sites 4, 5, 6, and 7), whereas the NSF-WQI calculations are contingent upon the weighted values of these measured factors [37]. These results are consistent with the chemical properties that have been recorded in the downstream section of the Euphrates River Basin, which suggest that humans are responsible for the contamination. The downstream sites are in major urban areas with high population densities, which leads to substantial waste releases, such as industrial and municipal discharges [38, 39].

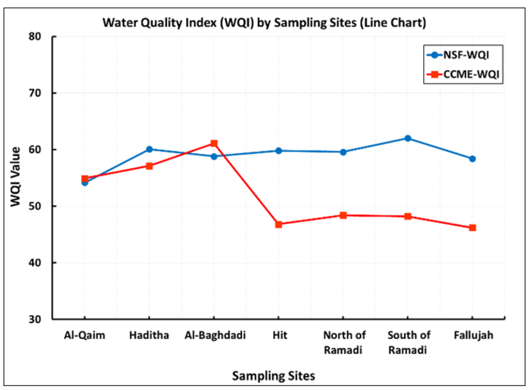

Fig. 3 Comparison between Water Quality Indices values at the sampling sites

4 CONCLUSION

The study indicated that the values of the water quality index calculated according to the NSF-WQI model varied slightly with those calculated according to the CCME-WQI model, despite their consistency. This variability is due to several factors. First, the NSF–WQI model uses nine standard parameters to determine water quality, which are WT, pH, turbidity, DO, BOD, TP, NO_3, TDS, and FC. Unlike the NSF-WQI, the CCME-WQI offers flexibility to include a broader range of well-defined physical, chemical, and biological variables selected according to the monitoring context and regulatory objectives, as it relies on 13 parameters to determine water quality. The difference in the number of characteristics used in the two indices resulted in a relative difference in their results. Second, when applying the NSF-WQI model, a standard curve is used to determine the Q value for each measured factor specified by weights (W) without giving importance to the extent to which those factors exceed the permissible limits, while when applying the CCME-WQI model, it provides sufficient value for the values exceeding the allowable limits. The current study demonstrates that the CCME-QWI model can be used in a broader range of situations, as it can be adjusted to account for the physical, chemical, and biological properties.

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DATA AVAILABILITY

Study data will be available upon request to the corresponding author.

DECLARATIONS

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Consent to publish

All authors consent to the publication of this work.

Ethical approval

Not Applicable.

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