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Original Article

Evaluation of Tigris River water quality within Baghdad City using the CCME index for various purposes

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Abstract: This study evaluated the Tigris River's water quality in Baghdad City for four different purposes, including drinking water supply, aquatic life, and agricultural requirements using Canadian WQI. The evaluation is based on data collected over 2021 and 2022. The parameters of water temperature, turbidity, total dissolved solids, pH, DO, nitrate, nitrite, ammonia, phosphate, chloride, fluoride, magnesium, calcium, sulfate, sodium, magnesium hazard (MH), and sodium adsorption ratio (SAR) were measured for index CCME calculation. The results indicated that water temperature and turbidity are the variables that crossed standard guidelines for aquatic life protection, ranked within fair quality. In contrast, water temperature, turbidity, and TDS are the variables that exceeded the allowable levels for overall water quality, mainly ranked within a good class. For drinking water purposes, turbidity and Ca are among the parameters that fall outside the acceptable limits, rated between marginal and fair class.

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Introduction

Water is the most abundant and valuable resource on Earth's surface and is essential to all life forms (Westall and Brack, 2018). Water covers 71% of Earth's surface, with the oceans holding 96.5% of the planet's total water mass (Rhoads, 2020). Rivers cover only 0.58% of the non-glacial land area on Earth (Allen and Pavelsky, 2018). With increasing urban areas, water demand and supply modeling are extremely important. The water quality index (WQI) model is a popular tool for assessing the river's water quality (Aljanabi et al., 2021; Uddin et al., 2021). One of the most common WQI models used by researchers is the Canadian Council of Ministers of the Environment (CCME), which is an objective-based index that generates a number, typically between 0 and 100, by comparing measured water quality values to guidelines (CCME, 2001; 2006; Poonam et al., 2013). This index is based on statistical techniques and does not consider individual opinions. At least four variables must be sampled four times to calculate the Canadian WQI (CCME, 2001; Uddin et al., 2021). A water quality index (WQI) combines the measures of several water quality variables in such a way as to produce a single score that is representative of quality impairments or suitability of use (Hurley et al., 2012; Poonam et al., 2013; Chidiac et al., 2023).

One of Iraq's most significant rivers is the Tigris. It supplies water for various uses, such as drinking and agricultural activities like irrigation, livestock production, crop cultivation, fish culture, and hydropower plants. This is why monitoring the river's water quality is very important. Therefore, this study aimed to use the CCME-WQI model to evaluate Tigris water's suitability for these uses.

Materials and Methods

Study area: Baghdad, Iraq's capital, is in the Mesopotamian Plain. The region's climate fluctuates between arid and semi-arid, with hot, dry summers and cold, rainy winters. Tigris is one of the largest rivers in the Middle East and runs through Baghdad City. Its flow is influenced by climate change and the amount of rainfall. The second factor affecting the flow is the building of dams and barrages upstream from Baghdad (Majeed et al., 2021, 2023a; Majeed

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and Ibraheem, 2024).

Sampling and measurements: Samples were taken every month from January 2021 to December 2022 for two years. Twelve sites were selected for this research namely S1: Al-Karkh; S2: Al-Rusafa; S3: Sharq Dijla; S4: Al-Sadir; S5: Al-Kadhimiya; S6: Al-Karama; S7: Al-Wathba; S8: Al-Baldiat; S9: Al-Qadisya; S10: Al-Dawraa, S11: Al-Wahda and S12: Al-Rasheed along the main stream of the river from northern to southern directions (Fig. 1).

Data for index calculation: The water quality parameters measurements' equipment used in this research are provided by the Mayoralty of Baghdad (Amanat Baghdad). Sixteen physicochemical water parameters were considered in the index calculation, depending on the purpose of water quality analysis, including water temperature, turbidity, total dissolved solids, pH, DO, nitrate, nitrite, ammonia, phosphate, chloride, fluoride, magnesium, calcium, sodium, magnesium hazard (MH), and sodium adsorption ratio (SAR) based on both availability and importance (Tables 1, 2) (Lumb et al., 2006).

The magnesium hazard ratio (MH) equation was calculated based on Paliwal (1972), Jafari et al. (2018), Abdelbaki et al. (2022), and Mohammed et al. (2023) using the formula of $MH = (Mg^{2+} / (Ca^{2+} + MG^{2+})) \times 100$. The value of MH > 50 is considered harmful and unsuitable for irrigation use (Uddin et al., 2024). Sodium absorption ratio (SAR) was calculated based on the equation of $SAR = (Na^{+} / (\sqrt{Ca^{2+} + Mg^{2+} / 2}))$, proposed by Richards (1954), Zaman et al. (2018), and ur Rehman et al. (2024), expressed as milli equivalents per liter (meq/L). Zaman et al. (2018) advised not to use water for irrigation with a SAR value higher than 10 meq/L. The relative amount of sodium to calcium and magnesium ions in irrigation water was indicated by the sodium adsorption ratio (SAR), which also indicated the sodium hazard (Zaman et al., 2018). Cations, such as magnesium, calcium, and sodium, primarily impact the quality of water used for irrigation and other uses. Excess salt in the water is a major concern for crop cultivation because it degrades water quality and reduces crop yields (Kundu and Ara, 2019). Other water quality parameters by the laboratory of the mayoralty of Baghdad.

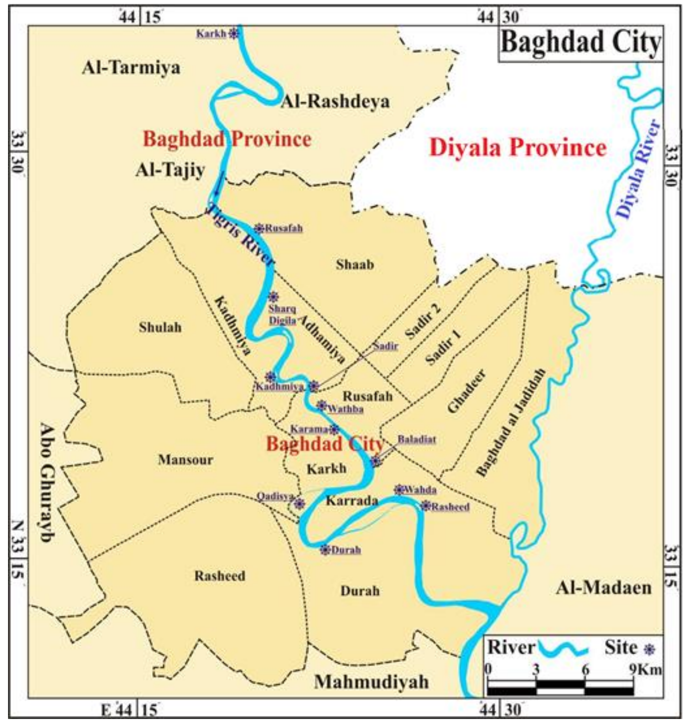

Figure 1. Map of the research area. The scale is 1/300000.

Calculation of the index: According to CCME (2001a, b), the following formula was used in the calculation of the CWQI: CCME WQI -100 $((\sqrt{F_1{}^\wedge 2+F_2{}^\wedge 2+F_2{}^\wedge 2}) / 1.732)$, where F1 is the scope or the proportion of parameters greater than the recommended level (F1 = Number of failed parameters / Total number of parameters x100), F2 is the frequency: The frequency which the aims are not achieved (F2 = [Number of failed tests / Total number of tests] x 100), F3 is the Amplitude: The range to which the failed tests exceed the recommended level.

(a) Range / Excursioni = [Failed test result/Objective] -1

(b) $nse = \sum_{i=1}^{n} excursion$ / Number of tests

(c) F3 = (nse / (0.01 x nse + 0.01))

The square root of three factors is used as the constant, 1.732, to guarantee the index fluctuates between 0 and 100. Canadian WQI is divided into five categories, as described in Table 3 (CCME 2001a, b, 2006; Hu et al., 2022; Panagopoulos et al., 2022). Microsoft Excel is used to implement the CCME-WQI (Noor et al., 2022).

Table 1. The average and standard errors of the Tigris River's physicochemical characteristics in 2021.

2021												
Sites / Param.	Karkh	Rusafa	Sharq Digila	Al-Sadir	Kadhmiya	Karama	Wathba	Baladiat	Qadisya	Dawara	Wahda	Rasheed
Temp.(°C)	23.6±1.58	22.2±1.6	23.2±0.7	22.6±1.7	24.4±0.2	23.7±1.9	22.9±1.9	23.3±1.9	23.4±1.7	22.25±1.7	23.25±1.97	24.2±1.85
TUR(NTU)	29.5±3.3	33.6±3.1	23.2±2.3	24.0±3.0	33.75±2.5	30.3±2.6	29.7±3.1	31.4±4.3	28.6±2.9	26.25±2.9	38.25±3.5	26.6±2.5
pH	7.97±0.025	8.1±0.01	8.0±0.01	7.9±0.04	7.81±0.02	8.0±002	7.7±0.01	8.0±0.04	7.8±0.03	7.9±0.028	7.89±0.002	7.9±0.021
TDS(mg/L)	488±18.0	621±16.7	641±21.7	683±140	678±18	582±15.4	714±19.5	736±19.5	695±19	706±19.5	713±18.8	711±20
Ca^{2+}(mg/L)	63.4±0.81	80.9±2.9	84±2.3	80.25±3.2	104.3±5.6	110±5.7	108±5.7	97.3±3.1	112.8±6.6	114.1±6.8	118.9±5.1	118.5±5.6
Mg^{2+}(mg/L)	33±1.23	29±1.08	33.8±1.2	37±0.60	32.5±0.51	29.8±1.19	31.2±0.93	36.3±1.91	30±0.712	32±0.54	26±053	27.5±1.55
Cl^-(mg/L)	54±3.4	77±2.45	79±2.24	81±2.1	6.25±1.7	87.7±1.4	79.6±1.5	88.5±1.55	81.3±1.6	85.75±1.9	76.75±2.8	79.4±3.2
NO_2^-(mg/L)	0.0035±00003	0.009±0.001	0.016±0.001	0.005±0.0001	0.01±0.0004	0.007±0.0003	0.008±0.0005	0.014±0.003	0.005±0.0005	0.012±0.001	0.020±0006	0.02±0.001
NO_3^-(mg/L)	0.9±0.06	0.6±0.05	1.2±0.06	0.6±0.02	0.8±0.1	0.9±0.080	1.2±0.02	0.69±0.04	0.8±0.03	0.69±0.05	1.6±0.06	1.7±0.04
PO_4^{3-}(mg/L)	0.04±2.09	0.01±5.23	0.01±5.23	0.01±5.23	0.03±0.003	0.04±0.0041	0.02±1.04	0.01±5.23	0.09±0.005	0.06±0.08	0.18±0.003	0.16±0.014
NH_3(mg/L)	0.013±0.0014	0.1±0.09	0.2±0.008	0.1±0.003	0.04±0.002	0.02±0.002	0.21±0.015	0.37±0.02	0.11±0.012	0.3±0.04	0.15±0.054	0.15±0.05
Na^+(mg/L)	37.8±2.4	53.9±1.7	55.3±1.5	56.7±1.5	53.3±1.2	61.4±1.0	55.7±1.1	61.95±1.1	56.8±1.1	60.2±1.3	53.7±1.96	55.6±2.27
F^-(mg/L)	0.11±0.008	0.14±0.005	0.015±0.004	0.156±0.007	0.205±0.01	0.16±0.007	0.16±0.003	0.01±0.003	0.135±0.005	0.143±0.02	0.3±0.096	0.16±0.053
SO_4^{2-}(mg/L)	171.6±9.5	205.6±5.61	201.8±7.8	236.75±8.4	288.3±13	252±6.56	281±16.37	253±10.25	286.6±15.73	296.5±17.4	279.7±8.4	277.1±10.9
MH	34.1±0.70	26.6±1.03	28.7±0.76	31.8±0.69	24.2±1.1	21.8±1.4	22.9±1.30	27.0±0.85	21.6±1.2	22.6±1.2	18.1±0.50	19.1±1.4
SAR(meq/L)	1.5±0.058	2.3±0.08	2.1±0.03	2.0±0.04	2.01±0.03	2.4±0.06	2.1±0.04	2.2±0.05	2.2±0.03	2.2±0.034	2.2±0.05	2.2±0.059

Table 2. The average and standard errors of the Tigris River's physicochemical characteristics in 2022.

2022												
Sites / Param.	Karkh	Rusafa	Sharq Digila	Al-Sadir	Kadhmiya	Karama	Wathba	Baladiat	Qadisya	Dawara	Wahda	Rasheed
Temp.(˚C)	23±1.6	21.8±1.7	22.6±0.61	21.6±1.7	24.25±0.17	23.16±1.8	23.16±2	21.6±1.79	22.5±1.5	21.75±1.7	21.5±1.8	22.5±1.7
TUR (NTU)	44.75±5.1	46.25±74	55±9.6	43.58±8.5	35.8±3.91	44.4±6.66	45.75±5.5	42.16±5.88	43.75±7.8	44.58±8.3	53.3±9	45.75±5.5
pH	8.06±0.023	8.1±0.009	8.02±0.01	7.9±0.037	7.8±5.3	8.1±0.021	7.8±0.025	7.9±0.03	7.8±0057	7.9±0.02	7.89±0.001	7.89±0.002
TDS(mg/L)	437.5±13.06	491±13.1	533±16.3	558.5±17.1	552.6±20.4	469.2±18.3	583.1±23.1	597.3±23.9	559±22.2	571±21.5	574.5±22.1	580±23.7
Ca^{2+}(mg/L)	57.8±1.5	67.6±1.7	72.6±1.5	68.4±1.5	79.3±44	85.7±4.7	81±4.3	82±3.2	85.08±4.7	83.2±4.5	90±5.31	91.58±5.4
Mg^{2+}(mg/L)	28.58±0.66	25.8±1.02	25.6±0.8	30.3±0.99	26.6±1.2	28.8±0.84	27.75±0.96	25.6±0.855	26.75±0.73	30±1.02	28.75±0.96	28.8±0.99
Cl^- (mg/L)	41.58±1.4	57.7±2.28	59.6±2.41	61.5±2.27	60.08±2.8	69.6±2.7	65.9±2.9	71.6±3.02	64.1±2.7	69±2.25	61.1±2.8	62.58±3.2
NO_2^-(mg/L)	0.0047±0.0005	0.013±0.001	0.015±0.0007	0.005±0.0005	0.02±0.003	0.007±0.0005	0.013±0.0037	0.02±0.003	0.005±0.0004	0.02±0.008	0.02±1	0.02±1
NO_3^-(mg/L)	0.81±0.067	0.9±0.056	1.135±0.067	0.49±0.023	1.08±0.07	0.915±0.06	0.4±0.078	0.67±0.023	0.85±0.019	0.86±0.086	1.69±0.06	1.72±0.05
PO_4^{3-}(mg/L)	0.04±2.09	0.01±5.23	0.01±5.23	0.01±5.23	0.04±0.0046	0.028±0.002	0.023±0.009	0.01±5.23	0.13±0.0096	0.096±0.008	0.17±0.009	0.17±0.009
NH_3(mg/L)	0.01±0.001	0.1±0.001	0.17±0.02	0.1±0.002	0.06±0.006	0.02±0.0017	0.15±0.015	0.33±0.02	0.17±0.04	0.37±0.03	0.08±0.0027	0.08±0.002
Na^+ (mg/L)	29.1±1	40.4±1.6	41.7±1.69	43.05±1.59	42±2.01	48.7±1.9	46.1±2	50.1±2.1	44.8±1.9	48.3±1.57	42.8±1.97	43.8±2.23
F^-(mg/L)	0.097±0.004	0.13±0.003	0.1±0.002	0.13±0.008	0.21±0.01	0.14±0.006	0.13±0.01	0.1±0.007	0.12±0.003	0.14±0.01	0.077±0.003	0.08±0.003
SO_4^{2-} (mg/L)	151±3.94	165.4±4.2	172.5±5.4	182.9±7.5	203.8±13.4	206.9±7.3	202.8±14	196.5±9.8	200.2±12.9	230±12.4	222±15.9	234±16
SAR(meq/L)	1.32±0.028	1.91±0.05	1.9±0.05	1.8±0.038	1.89±0.05	0.95±0.02	2±0.08	2.28±0.07	1.98±0.04	2±0.03	1.8±0.08	1.8±0.09
MH	33.1±0.46	27.5±0.4	26.1±0.49	30.6±0.35	25.4±1	25.49±0.9	25.7±0.71	24±0.9	24.2±0.91	26.73±0.632	24.9±1.29	24.4±1.35

Table 3. Water quality classification based on Canadian WQI for different applications.

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

Table 4. Standard values of physiochemical parameter of CCME-WQI for various uses.

Guidelines for overall water quality (Lumb et al., 2006).	
Parameter	Standard values
Turbidity	< 50 NTU
TDS	< 500 mg/L
pH	6.5-8.5
DO	> 5 mg/L
Nitrate	< 15 mg/L
Phosphate	< 0.4 mg/L
Chloride	< 200 mg/L
Guidelines for aquatic life protection (CCME, 2017)	
Water Temperatures	≥15 ˚C
Turbidity	< 5 NTU
TDS	< 500 mg/L
pH	6.5-9
DO	≥ 5.5 mg/L
Ammonia	< 1.37 mg/L
Nitrate	< 13 mg/L
Nitrite	< 0.06 mg/L
Phosphate	< 0.1 mg/L
Chloride	< 250 mg/L
Guidelines for drinking water supply	
Turbidity	< 5 NTU
TDS	< 1000 mg/L
pH	6.5-8.5
Nitrate	< 50 mg/L
Chloride	< 250 mg/L
Calcium	< 50 mg/L
Magnesium	< 50 mg/L
Sodium	< 200 mg/L
Guidelines for agricultural uses (CCME, 2005; Olkowski, 2009; Zaman et al., 2018).	
TDS	1500-3000 mg/L
pH	6.5-8.4
Chloride	< 100 mg/L
Fluoride	1 to 2 mg/L
Nitrite	< 10 mg/L
Sulphate	< 1000 mg/L
SAR	< 18 meq/L
MH	< 50

Results and Discussions

To calculate index values, sixteen water parameters, including water temperature, turbidity, total dissolved solids, DO, pH, nitrate, nitrite, ammonia, orthophosphate, chloride, fluoride, sulphate, magnesium, calcium, sodium, magnesium hazard, and sodium adsorption ratio were used and were compared with index guidelines for multiple purposes (Table 4). The following table summarizes the water quality guidelines necessary for applying the CCME WQI.

Evaluation of water quality: The freshwater quality index is an appropriate indicator that gives an overall water quality assessment (CCME, 2003; Lumb et al., 2006). Seven physicochemical parameters were

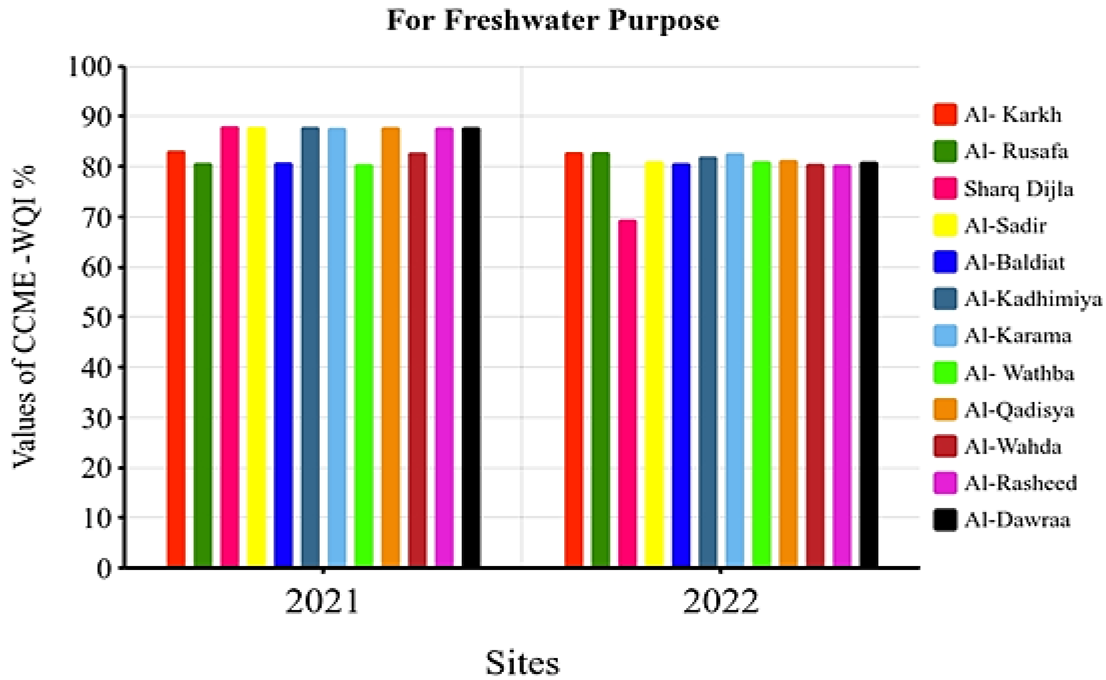

Figure 2. Variations in the water quality index for overall uses between the studied sites in 2021 and 2022.

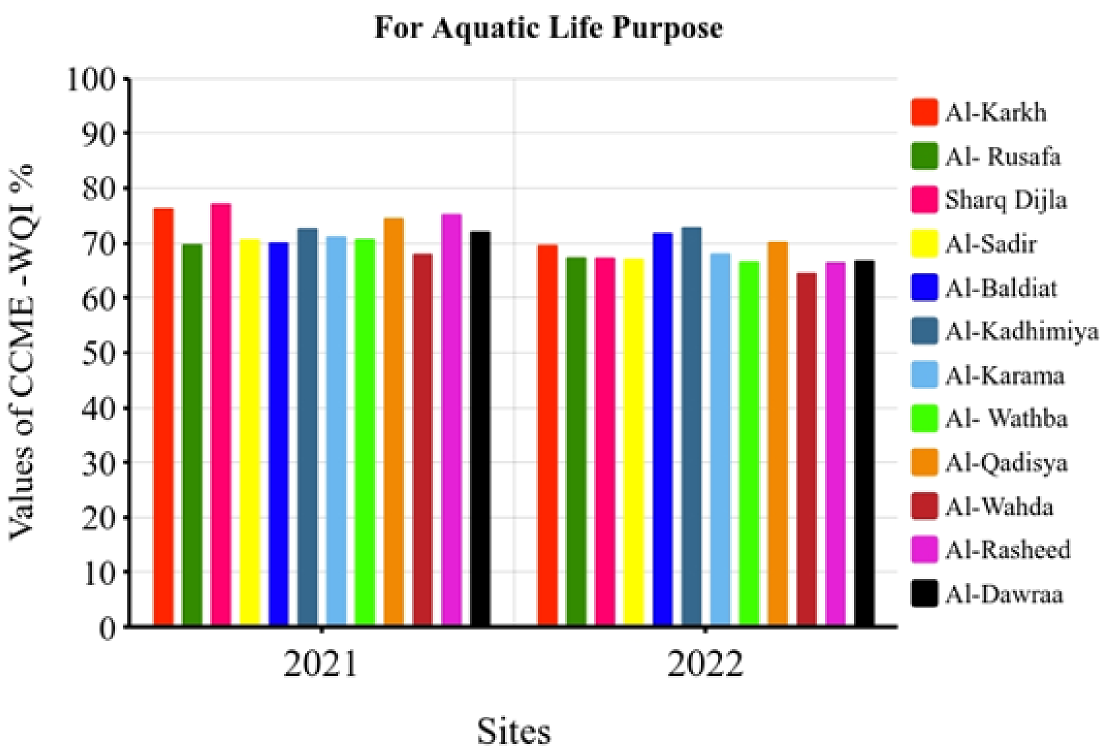

Figure 3. Variations in the water quality index for aquatic life purpose between the studied sites in 2021 and 2022.

applied to overall water quality, including turbidity, TDS, pH, DO, nitrate, phosphate, and chloride (CCME, 2003; Lumb et al., 2006). The calculated values and the rating of the freshwater quality index are presented in Table 5. The percentage values of the index ranged between 80.79 and 88.12 within the good class for all sites in 2021. It ranged between 69.49 in Sharq Dijla and 82.91 in Al-Karkh, ranked between fire to good class, in 2022 (Fig. 2). Table 6 gives a clear vision of the conditions of water quality at the study sites, showing that TDS and turbidity were the largest variables crossed the allowable levels during the study period. However, the other parameters (pH, DO, nitrate, phosphate, and chloride) followed the quality standard for freshwater purposes.

Compared with similar works on the Tigris River, Alazawii et al. (2018) showed that water quality in the Tigris River, southern Baghdad City, varied between poor and marginal for overall uses impacted by the Al-Rasheed power plant. Al-Bahathy et al. (2023) pointed out that the water status of the Tigris River based on CCME WQI varied between marginal, fair, and good quality for river maintenance systems within six years (2008-2023). In addition, Bilgin (2018) found that the water quality of the Coruh River Basin was not close to natural or desired levels and rated between poor, marginal, and fair class for four years, from 2011 to 2014, due to copper mining wastewater discharged. Our findings also contrasted with those of Ewaid (2016), who showed that the values of Al-Gharraf River's water quality varied between 30 and 39, classified within the poor class, due to the runoff of domestic sewage into this river.

Water quality evaluation for aquatic life preservation: To determine the suitability of water quality for aquatic life, ten physicochemical parameters, including water temperature, turbidity, TDS, pH, DO, nitrate, nitrite, ammonia, and phosphate were applied (CCME, 2017). The calculated values and the rating of WQI are presented in Table 5. The percentage values of the index ranged between 68.09 in the Al-Wahda site and 77.19 in the Sharq Dijla site, ranked within the fair class in 2021. It also ranged between 64.58 in Al-Wahda and 72.94 in the Sharq Dijla site, ranked between marginal and fair class for 2022 (Fig. 3). The results revealed that water temperature, turbidity, and TDS impact the Tigris River's water quality, causing the values to fall within the fire and marginal levels (Table 6), i.e., three out of nine parameters exceeded the allowable limits.

These findings agree with previous studies, e.g., Lumb et al. (2006) showed that a high amount of turbidity and suspended sediment led to CCME WQI value decreasing to the marginal level downstream of Mackenzie River. Hassan et al. (2013) recorded that Canadian WQI varied between marginal and poor classes in the Al-Kriat and Diyala Bridge sites (Tigris River), respectively, due to rising water temperature, BOD5, and total nitrogen. Al-Janabi et al. (2015) also found that the values of Canadian WQI for aquatic life ranged between marginal and poor classes within Baghdad City because of higher lead, iron, zinc, and turbidity levels. Alazawii et al. (2018) demonstrated that the discharge of the Al-Rasheed electrical station has an impact on the quality of the river water quality. Due to the discharge of hot water into the river, the DO and pH levels drop, causing the index to shift from fair in the winter to marginal in the summer. Al-Obaidy et al. (2022) indicated that water quality for aquatic life ranked as a poor class, related to the discharge of different pollutants directly into Tigris water, due to increasing Turbidity and TDS values. Noor et al. (2022) found that raising the values of six physiochemical parameters to the standard limits caused the Tigris River water in Baghdad City to decrease to marginal quality for aquatic life because of domestic and industrial effluents. Majeed et al. (2023b) also found that the values of the Canadian index for aquatic life in Tigris and Tharthar river water, which were between marginal and fair class, decreased due to increasing TDS, turbidity, and water temperature. In Al-Shamiyah River, Hassan et al. (2018) found that the value of the Canadian index fluctuated between 70.1 and 84.47 within the fire to good quality.

In contrast, Ewaid (2016) showed that the values of Al-Gharraf River's water quality ranged from 34 to 37, within the poor class and unsuitable for aquatic life due to the runoff of domestic sewage into the river. In Indonesia, Tanjung et al. (2022) found that the water quality of the two rivers (Jabawi and Komba) was fair, whereas the quality of the other rivers (Damsari and Kleblow) was marginal for aquatic life protection due to anthropogenic source pollution.

Assessment of water quality for drinking use: Ten physicochemical parameters, viz. turbidity, TDS, pH, nitrate, chloride, calcium, sodium, and magnesium, were applied to assess drinking suitability. Table 5

Table 5. Water quality values classified for multiple purposes (2021-2022).

Sites	Purpose of use	2021		2022	
		Value %	Category	Value %	Category
Al-Karkh	Overall	83.27	Good	82.97	Good
	Aquatic life	76.39	Fair	69.64	Fair
	Drinking	69.50	Fair	64.48	Marginal
	Agricultural	100	Excellent	100	Excellent
Al-Rusafa	Overall	80.79	Good	82.91	Good
	Aquatic life	69.77	Fair	67.43	Fair
	Drinking	67.29	Fair	63.78	Marginal
	Agricultural	100	Excellent	100	Excellent
Sharq Digila	Overall	88.12	Good	69.49	Fair
	Aquatic life	77.19	Fair	67.35	Fair
	Drinking	71.26	Fair	61.44	Marginal
	Agricultural	100	Excellent	100	Excellent
Al-Sadir	Overall	87.98	Good	81.09	Good
	Aquatic life	70.75	Fair	67.15	Fair
	Drinking	71.03	Fair	64.51	Marginal
	Agricultural	100	Excellent	100	Excellent
Al-Kadhimiya	Overall	88.00	Good	82.08	Good
	Aquatic life	72.68	Fair	72.94	Fair
	Drinking	66.46	Fair	66.60	Fair
	Agricultural	100	Excellent	100	Excellent
Al-Karama	Overall	87.76	Good	82.75	Good
	Aquatic life	71.23	Fair	68.13	Fair
	Drinking	67.44	Fair	63.78	Marginal
	Agricultural	100	Excellent	100	Excellent
Al- Wathba	Overall	80.58	Good	81.09	Good
	Aquatic life	70.78	Fair	66.65	Fair
	Drinking	67.73	Fair	79.57	Fair
	Agricultural	100	Excellent	100	Excellent
Al-Baladiat	Overall	80.84	Good	80.73	Good
	Aquatic life	70.16	Fair	71.89	Fair
	Drinking	67.50	Fair	66.73	Fair
	Agricultural	100	Excellent	100	Excellent
Al-Qadisya	Overall	87.94	Good	81.39	Good
	Aquatic life	74.55	Fair	70.28	Fair
	Drinking	67.97	Fair	63.99	Marginal
	Agricultural	100	Excellent	100	Excellent
Al-Dawraa	Overall	87.90	Good	81.06	Good
	Aquatic life	72.14	Fair	66.84	Fair
	Drinking	68.79	Fair	63.81	Marginal
	Agricultural	100	Excellent	100	Excellent
Al-Wahda	Overall	82.90	Good	80.63	Good
	Aquatic life	68.09	Fair	64.58	Marginal
	Drinking	64.60	Marginal	61.43	Marginal
	Agricultural	100	Excellent	100	Excellent
Al-Rasheed	Overall	87.87	Good	80.40	Good
	Aquatic life	75.25	Fair	66.49	Fair
	Drinking	68.50	Fair	63.26	Marginal
	Agricultural	100	Excellent	100	Excellent

presents the calculated values and the rating of WQI for drinking water supply. The index's percentage values ranged between 64.60 in the Al-Wahda site and 71.26 in the Sharq Dijla site, ranked between marginal and fair quality, respectively, in 2021. They also ranged between 61.43 in the Al-Wahda site and 79.57 in the Al-Wathba site, ranked from marginal to fair quality, respectively, in 2022 (Fig. 4). Furthermore, the results demonstrated that high turbidity and calcium impact the Tigris River's water quality, causing the CCME WQI value to drop to fire and marginal ranks (Table 6). Meanwhile, the other recommended parameters used in index calculation (pH, nitrate, chloride, calcium, sodium, and

Table 6. Summary of failed variables and tests for each site according to CCME guidelines.

Sites	Purpose of use	2021			2022		
		No. of Variables	**No. of Tests**	**Variables with most failed tests**	**No. of Variables**	**No. of Tests**	**Variables with most failed tests**
Al-Karkh	Overall	1	4	TDS	2	6	Turbidity, TDS
	Aquatic life	2	16	Turbidity, TDS	2	14	Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-	0	0	-
Al-Rusafa	Overall	2	14	Turbidity, TDS	2	7	Turbidity, TDS
	Aquatic life	3	25	Temp. Turbidity, TDS	3	18	Temp. Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-	0	0	-
Sharq Digila	Overall	1	12	TDS	2	14	Turbidity, TDS
	Aquatic life	2	23	Turbidity, TDS	2	20	Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-	0	0	-
Al-Sadir	Overall	1	12	TDS	2	13	Turbidity, TDS
	Aquatic life	3	25	Temp. Turbidity, TDS	3	24	Temp. Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-			
Al-Kadhimiya	Overall	1	12	TDS	2	10	Turbidity, TDS
	Aquatic life	2	24	Turbidity, TDS	2	21	Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-	0	0	-
Al-Karama	Overall	1	11	TDS	2	7	Turbidity, TDS
	Aquatic life	3	24	Temp. Turbidity, TDS	3	17	Temp. Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-	0	0	-
Al-Wathba	Overall	1	12	TDS	2	13	Turbidity, TDS
	Aquatic life	3	25	Temp. Turbidity, TDS	3	23	Temp. Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-	0	0	-
Al-Baladiat	Overall	2	13	Turbidity, TDS	2	14	Turbidity, TDS
	Aquatic life	3	25	Temp. Turbidity, TDS	3	25	Temp. Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-	0	0	-
Al-Qadisya	Overall	1	12	TDS	2	12	Turbidity, TDS
	Aquatic life	2	24	Turbidity, TDS	2	21	Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-	0	0	-
Al-Dawraa	Overall	1	12	TDS	2	13	Turbidity, TDS
	Aquatic life	3	25	Temp. Turbidity, TDS	3	24	Temp. Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-	0	0	-
Al-Wahda	Overall	2	14	Turbidity, TDS	2	14	Turbidity, TDS
	Aquatic life	3	25	Temp. Turbidity, TDS	3	23	Temp. Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-	0	0	-
Al-Rasheed	Overall	1	12	TDS	2	15	Turbidity, TDS
	Aquatic life	2	24	Turbidity, TDS	3	24	Temp. Turbidity, TDS
	Drinking	2	24	Turbidity, Calcium	2	24	Turbidity, Calcium
	Agricultural	0	0	-	0	0	-

magnesium) were within standard limits for drinking purposes over two years.

High turbidity values in Tigris River water could be due to the high rate of discharge and rainfall in winter seasons, which subsequently increased soil erosion along riverbanks; these results agree with Majeed et al. (2022a, b) findings. The primary reason for increasing Ca^{2+} in Tigris River water may originate from the chemical weathering of sedimentary rocks (Majeed et al., 2022a, b). Our results coincided with those of Lumb et al. (2006), who reported that the water quality in the Mackenzie

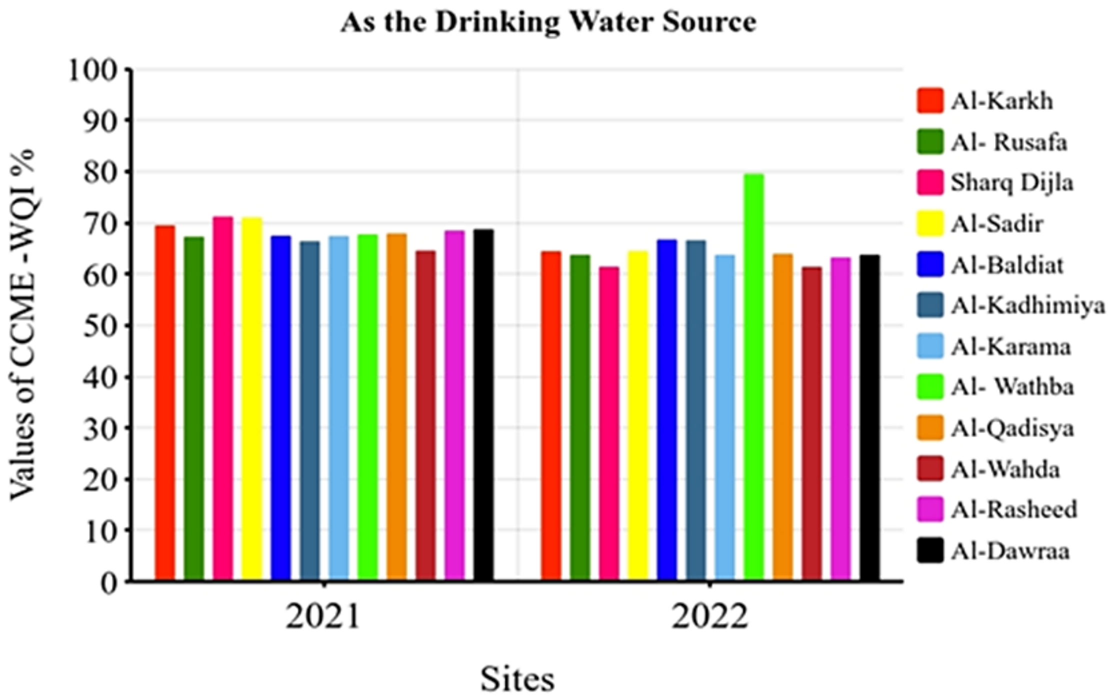

Figure 4. Variations in the water quality for drinking use between the studied sites in 2021 and 2022.

River basin was affected by high amounts of TSS and turbidity due to suspended solids derived from the weathering of bedrock and soil.

In comparison with other studies carried out in the Tigris River, Al-Janabi et al. (2012) and Al-Obaidy et al. (2022) showed that the quality of the water is not good enough for drinking purposes because of the discharging of different pollutants directly into the Tigris River. Alazawii et al. (2018) showed that the discharge from the Al-Rasheed power plant affected the quality of the Tigris River for drinking purposes. It ranks the water quality between marginal in the summer and poor in other seasons due to a decrease in DO and pH. Ramadhan et al. (2018) indicated that the bad quality of the Khosar River impacts the water quality of the Tigris River, which is ranked as a poor class for drinking purposes. Also, Farhan et al. (2020) reported that Tigris River water was good quality and suitable for drinking purposes after treatment. Similarly, Ali et al. (2021) found that the water quality of the Tigris River within Wasit Province ranged between 56 and 62, ranked as a marginal class for drinking purposes due to the increasing concentrations of nitrate phosphate, sulfate, manganese, and lead. Another study by Kizar (2018) indicated that the water quality of Shatt Al-Kufa in the winter season dropped from good to poor for drinking use due to increasing the concentration of Sulphate ions and electrical conductivity. Whereas, in the Euphrates River, Hasham and Ramal (2022) mentioned that the water quality in Fallujah City varied between marginal, fair, and good quality for drinking purposes due to a decrease in dissolved oxygen and an increase in turbidity, BOD5, TDS, and sulfate. In contrast, Ewaid (2016) showed that the values of Al-Gharraf River's water quality ranged from 40 to 44, within the poor class for drinking purposes and unfit for use in water supply without treatment because of runoff of domestic sewage into the river.

In other regions, Ismail (2018) found that the Danube River's water quality varied from marginal to fair for drinking purposes impacted by rising temperature, ammonium, phosphate, and TSS levels. Kujiek and Sahile (2024) discovered that the water quality of the Ethiopian Elgo River was poor; the values fluctuated between 38.38 and 36.6 due to an increase in several recommended parameters due to increased pollution. In Indonesia, Tanjung et al. (2022) demonstrated that the four rivers in the Jayapura Regency - the Damsari, Jabawi, Kleblow,

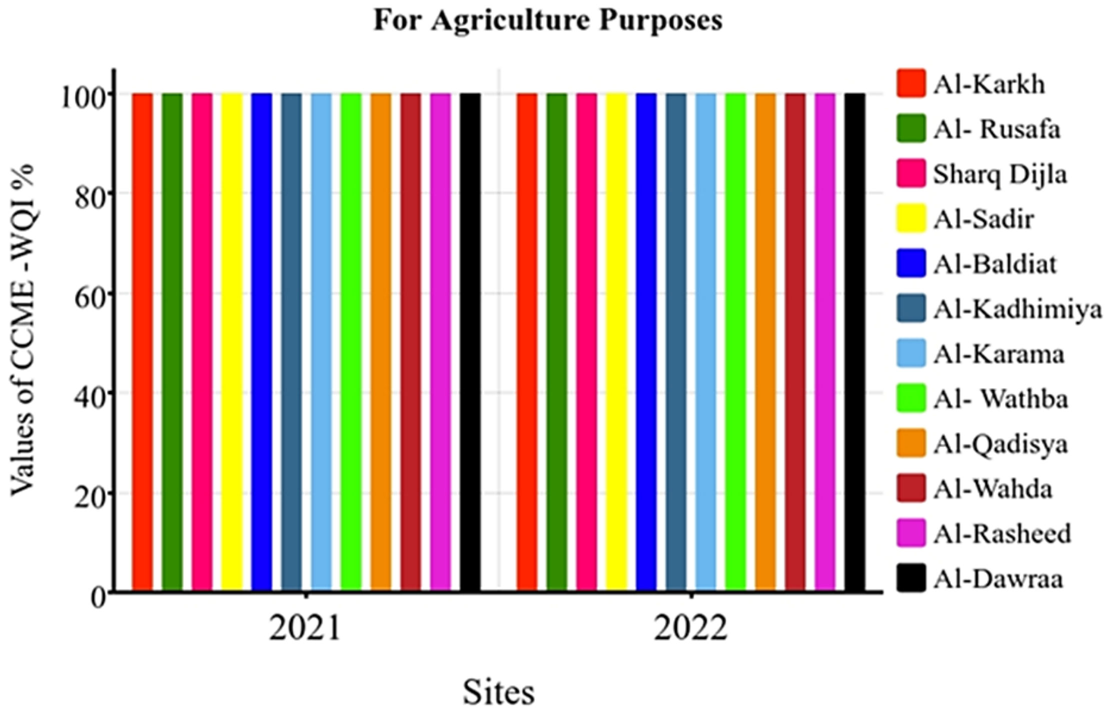

Figure 5. Variations in the water quality index for agricultural purposes between the studied sites in 2021 and 2022.

and Komba - were unfit to use as a drinking water source, categorized between poor and marginal quality associated with anthropogenic pollution.

Evaluation of water quality for agriculture use: To evaluate the suitability of water for agriculture, eight physicochemical parameters of water, including TDS, pH, chloride, fluoride, sulfate, nitrate, magnesium hazard, and sodium adsorption ratio, were used (CCME, 2005; Olkowski, 2009). Table 5 presents the calculated values and the rating of WQI for agricultural purposes (irrigation, crop production, and livestock watering). The index's percentage values always were 100%, falling in excellent class for all sites over two study years (Fig. 5). This is because all recommended variables mentioned above did not exceed the Canadian water quality guidelines for agricultural uses during the study period.

The low sodium adsorption ratio values for agricultural WQI guidelines did not surpass allowable limits at any studied sites during the two years, which were associated with the low sodium, calcium, and magnesium ion values. This result is consistent with Oke et al. (2017)'s findings that the sodium adsorption ratio in Ogun and Opeki rivers was within allowable ranges. This indicates that the sodium, magnesium, and calcium balances are within permissible ranges, making the river water useful for irrigation in all seasons. In contrast, Buhlool et al. (2014) showed that the water quality of the Euphrates River within Al-Nassiryia City ranked between marginal and fair levels for irrigation purposes attributed to the discharge of different pollutants into the river. Also, Ewaid (2016) showed that the values of Al-Gharraf River's water quality ranged from 70 to 73, within fire class for irrigation water requirement, due to the runoff of domestic sewage into the river.

In contrast, Oke et al. (2017) showed that the values of agricultural WQI ranged between 31-43 and 29-31 for Ogun and Ofiki rivers, respectively. ranked poor quality and did not meet the aquaculture and livestock requirements, due to high levels of TDS, turbidity, and nutrients. In Indonesia, Tanjung et al. (2022) showed that the water quality of the several rivers in Jayapura Regency (the Damsari, Jabawi, Kleblow, and Komba) was suitable for irrigation, categorized between marginal and excellent quality. In Serbia, Pivic et al. (2022) showed that the water quality of the three Morava rivers is suitable for irrigation varied between good and excellent.

Based on the results of the present work, the SAR values were mostly in the excellent class, ranging from 0.01 to 10.34 meq/L. Therefore, the Tigris River's water quality is excellent for irrigation uses and suitable for agriculture purposes. SAR values in the Tigris water are below recommended standards for agricultural use (<18 meq/L) due to low concentrations of Na^{+}, Mg^{2+} and Ca^{2+} ions. MH values in the Tigris water are below recommended standards for agricultural use (>50) due to low concentrations of Mg^{2+} and Ca^{2+} ions.

Conclusions

The findings of this study indicated that the number of parameters used in the computation of the CCME-WQI impacts its values. The scope factor (F1) does not rise with a small number of failed parameters. Furthermore, a small number of failed tests does not cause the frequency factor (F2) to increase. This, in turn, increased the index value. The most failed parameters that affected the river's water quality were turbidity, TDS, water temperature, and calcium, depending on index requirements. According to the CCME WQIs, Tigris water is classified as good, marginal, fair, and excellent for overall, drinking, aquatic life, and agricultural purposes, respectively. The results also indicated that river water suits agricultural activities like crop irrigation, livestock production, and fish culture. Meanwhile, the distribution between marginal and fair-quality drinking water supply is mainly affected by turbidity and calcium. Natural and anthropogenic processes like erosion, precipitation, and runoff from agriculture and industry majorly impact the river water's quality. Finally, Water suppliers, consumers, planners, policymakers, and environmental scientists can all benefit from the research's data.

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