

Assessment of the Water Quality of the Tigris River in the City of Mosul

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Article Info	Abstract
<p>Received 01/08/2024</p> <p>Revised 16/06/2025</p> <p>Accepted 16/06/2025</p>	<p>In this study, a total of 120 water samples were collected from five stations along the Tigris River within Mosul City and tested to assess their quality. Water samples were collected over the course of a year. The study included determining thirteen physical, chemical, and biological parameters of the water. The water quality assessment for river water was done using the Weighted Arithmetic Water Quality Index Method (WA WQI), the Canadian Council of Ministry of Environment (CCME WQI), and the method developed by Erdenebayar. The test results showed that the parameters included in the study were within the allowable limits. The overall results of the water quality index revealed that the water quality can be classified as good, which means that the water still meets the different domestic, industrial, aquatic life, and agricultural needs. The maximum water quality index values were 36, 81, and 79, and the minimum values were 18, 76, and 35 for the WA WQI, CCME WQI, and E WQI methods, respectively. A slight difference in water quality was detected during the different seasons, with a slight deterioration in its quality as water flows from north to south. Generally, a good agreement was observed among the three methods.</p>

Keywords: Climate Change, Erdenebayar, Mosul, Pollution, River, Water Quality Index.

1. Introduction

Iraq is considered the fifth most vulnerable country in the world to climate change, as it is greatly affected by rising temperatures [1]. The continuous decrease in rainfall, water scarcity, and frequent dust storms. This problem is exacerbated by the fact that neighboring upstream countries are implementing water policies that reduce water sources. The International Organization for Migration recorded that many people were displaced as a result of water shortages, high salinity, and deteriorating water quality throughout Iraq [2]. As the quantity of good water reduced, concerns about the deterioration of water quality and the possibility of its contamination began to increase. Therefore, it is necessary to monitor water quality to diagnose defects, problems, and potential sources of pollution before treating them. In the Middle East, the shortage of good-quality water resources poses a significant challenge to progress and stability [3], [4]. What further complicates water-related issues is the continuous decline in the quantity and quality of groundwater [5]. Many factors cause deterioration in water quality; some of these factors can be treated, and others are out of control [6]. The main human causes of the decline in water quality include improper irrigation practices, industrial

pollution, and inadequate wastewater treatment. Factors considered uncontrollable include climate change and natural biochemical processes, and they also affect water quality. To address water pollution issues, efforts are being made in Iraq, such as monitoring and evaluating contaminant levels in river watercourses to safeguard water quality [7].

Numerous environmental and human-induced factors, including climatic conditions, atmospheric influences, topography, lithology, and human activities, have also significantly deteriorated groundwater as well as surface water quality [8]. Water quality is typically evaluated based on physical, chemical, and biological characteristics [9]. Various evaluation techniques, such as single-factor assessment, comprehensive pollution index, water quality index, component analysis, and fuzzy comprehensive evaluation, among others, are employed in numerous studies utilizing different methodologies like multivariable statistical techniques, indexing approaches [10], Geographic Information System (GIS), and remote sensing [7].

The Water Quality Index (WQI) is a standard method for assessing water quality worldwide, providing a singular value

that summarizes the general quality of large water bodies [11]. The WQI comprises multiple steps, including parameter selection, data documentation, sub-index calculation, and final WQI calculation. In some methods, such as the weighted arithmetic index method, a low WQI value indicates higher water quality, whereas a higher value indicates poorer quality [12]. Conversely, the situation is reversed in other methods like the Canadian Council of Ministers of Environment method (CCME WQI) and the Erdenebayer WQI method. The Water Quality Index method takes into account many water parameters when assessing water quality. These parameters include important and general properties such as pH, temperature, dissolved solids, and the percentage of dissolved oxygen in the water [13]. It may also include some nutritional factors that are mainly related to irrigation uses, such as concentrations of phosphate, ammonium, phosphorus, nitrate, and nitrite. The WQI method may also include considering the presence of trace elements, inorganic pollutants, and oxygen parameters [14].

In recent years, the process of evaluating water quality through the water quality index and other methods has gained significant importance in pursuing successful policies to protect water resources and their sustainable management. In 2002, Abahussain et al [15] conducted a study to shed light on the state of desertification in the Arab region and its causes. The study revealed that a high percentage of the lands in the Euphrates Plain were salinized due to different reasons, such as the rise of the water table, reduced water flow in the river, and water pollution [15]. The suitability of water for different purposes can be determined by measuring the characteristics of that water and comparing it to international standards for various human, industrial, and agricultural uses [16]-[19].

Abbood et al. conducted a study in 2014 [20], in which the CCME WQI method was used to assess the waters of a major drainage river in Iraq. Fifteen key water quality parameters were considered across ten stations. The study showed high concentrations of total dissolved solids, total hardness, and chlorine. The study indicated poor river quality due to the pollutants.

In this research, the water quality index was assessed on a seasonal basis using three different methods. The comparison of the water quality parameter values indicates the degree of water pollution during its flow within the city. The quality of water taken from five stations in the Tigris River, distributed from the north to the south of the city, was tested and analyzed. This water quality assessment process is considered extremely important to understand, monitor, and ensure the sustainability of water quality to meet various human, industrial, and agricultural needs.

2. Methodology

2.1. Description of the Study Area

The Tigris River, which originates from Lake Hazar in Turkey, extends 1,750 kilometers. It runs parallel to the Euphrates River before meeting it in the lowlands and eventually empties into the Arabian Gulf through the Shatt al-Arab waterway. The Tigris flows through three countries – Turkey, Syria, and Iraq –

passing by significant cities like Diyarbakir, Mosul, Samarra, and Baghdad. It travels 25 km southeast of Elazig, covers 30 km of the headwater of the Euphrates River, and flows for 400 km before reaching the Turkey-Syria border. It passes through Syria for 44 kilometers and finally merges into Iraq, and its basin area is 375,000 km².

2.2. Sample collection

The study used three main approaches: field measurements, GIS mapping, and calculations with equations. Five stations (Fig. 1) were strategically chosen along the banks of the Tigris River at consistent intervals. Water samples were collected twice monthly over 12 months, starting from the onset of winter on November 1, 2021, until October 31, 2022. 2-liter polyethylene bottles were used to sample water from below the water surface at a depth of 20–40 cm [21] to avoid surface layers carrying floating pollutants and dust. After collection, all samples were immediately transferred to the research laboratory for detailed testing. The data was organized on a seasonal basis by taking the average of the data for each season. The stations were selected based on the anthropogenic activities in the respective areas. The chosen stations were designated as P1, P2, P3, P4, and P5. The GPS was used to record the coordinates of the sampling stations (Fig. 1). During the study period, the water flow rate was approximately 250–300 m³/s [22]. The parameters under investigation included total dissolved solids, pH levels, dissolved oxygen, Alkalinity (ALK), calcium, magnesium, total hardness (TH) determined through titrimetric analysis, the content of sodium, potassium, chloride, sulfate, nitrate, and electrical conductivity monitored with an Electrical Conductivity (EC) meter. The analytical methods specified by the American Public Health Association were followed to evaluate these parameters accurately [23]. Three methods were used to calculate the WQI: the Weighted Arithmetic Index Method, the Canadian Council of Ministers of Environment Water Quality Index Method, and the Erdenebayer Water Quality Index Method.



Figure 1: Locations of the sampling stations along the Tigris River through the city of Mosul

2.2.1. Weighted Arithmetic Index Method

This method is particularly suitable for assessing surface water quality for human use [24]. This method was developed by Tiwari and Mishra and is employed in this analysis. The thirteen water quality parameters selected in the study were included in the water quality index calculation process.

A unit weight denoted as W_i was assigned to each parameter according to its importance,

The following formula is used to calculate the WQ for this method:

$$WQI = \frac{\sum Q_i W_i}{\sum W_i} \tag{1}$$

Where:

W_i : assigned unit weight to the i th parameter

$$Q_i = 100[(V_i - V_0)/(S_i - V_0)] \tag{2}$$

V_i = calculated concentration of the i th parameter in the analyzed water\

V_0
= 0 (except for pH, which equals seven, and DO, which equals 14.6 mg/L)

S_i : Standard typical value of the i th parameter

Iraqi standards were used in this study to obtain the typical and allowable values in the three methods (Table 1).

Table 1. Iraqi standard specification for drinking water. 2001 No. (417) [25].

Parameter	Unit	Iraqi Standard	Allowable Level
PH		6.5-8.5	8.5
EC	μs/cm	1000	2000
TUR	NTU	5	5
DO	mg/L	5	5
T.H	mg/L	500	500
Ca	mg/L	50	150
Mg	mg/L	50	100
SO4	mg/L	250	400
PO4	mg/L	0.4	0.4
NO3	mg/L	50	50
TDS	mg/L	1000	1000
ALK	mg/L	200	200
CL	mg/L	250	250

$$W_i = \frac{K}{S_i} \tag{3}$$

$$K = \frac{1}{\sum \frac{1}{S_i}} \tag{4}$$

K: proportionality constant

Table 2 shows the classification of WQI by this method.

Table 2. Classification of water quality according to the WAWQI method [24].

WAWQI	Quality of Water	Grade
0 - 25	Excellent	A
26 - 50	Good	B
51 - 75	Poor	C
76 - 100	Very Poor	D
> 100	Unsuitable	E

2.2.2. Canadian Council of Ministers of Environment Water Quality Index Method

The CCME WQI method was designed to simplify the process of presenting water quality data. Although detailed reports that review all water parameters are valuable to relevant authorities regarding water quality, they are incomprehensible to non-experts. Therefore, the CCME WQI method was designed to provide general and useful indicators of water quality and trends that managers can use, and also laypersons who are not technical [26].

Three factors determine the index value; each factor has a maximum value of 100. According to this method, the water quality index consists of a vector with three dimensions: scope, frequency, and amplitude. The vector length is then normalized to a maximum of 100. For the index to produce high numbers for high water quality (i.e., the value of the index increases as the water quality improves), the index is then calculated by subtracting the value of the vector obtained from the geometric combination of the three factors from 100. The CCME WQI should include at least four parameters and four water samples per year [26]. This method provides a clear and straightforward way to describe water quality by classifying water quality according to the index value into poor, marginal, fair, good, and excellent. The factors that make up the index are:

1- Scope (F1): This factor measures the degree of non-compliance of the water quality standards over a specified period. This factor was initially adopted from the British Columbia Index. F1 is represented mathematically as follows:

$$F1 = 100 \left[\frac{\text{Number of failed variables}}{\text{Total number of variables}} \right] \tag{5}$$

2- Frequency (F2): This factor measures the number of times water quality does not meet relevant standards during a specified period and is expressed as a percentage. F2 is represented mathematically as follows:

$$F2 = 100 \left[\frac{\text{Number of failed Variables}}{\text{Total number of Tests}} \right] \tag{6}$$

3- Amplitude (F3): This factor measures the degree of variation in water quality values and indicates the extent

of deviation from the required water quality. The following three steps calculate the amplitude (F3):

Step 1: Calculation of Excursion

The excursion counts the number of times the value of an individual parameter exceeds the maximum permissible limit (or is below the minimum, when the target is the minimum). The excursion is calculated by Eq. (7) when the value of the parameter should not exceed the maximum permissible limit.

$$excursion = \frac{Failed\ test\ value}{Objective} - 1 \quad (7)$$

When the test value of the parameter should exceed the objective, the excursion is calculated as:

$$excursion = \frac{Objective}{Failed\ test\ value} - 1 \quad (8)$$

Step 2: Calculation of Normalized Sum of Excursion

The combined excursion sum (*nse*) represents the overall deviation of single tests from compliance. It is derived by adding up each test's deviations from its standard value, divided by the overall number of tests (including successful and failed attempts to meet the objectives).

$$nse = \frac{\sum_i^n excursion}{Number\ of\ tests} \quad (9)$$

Step 3: Calculation of Amplitude (F3)

The amplitude is determined using an asymptotic function that multiplies the normalized total deviations from objectives, giving a scale from 0 to 100.

$$F3 = \frac{nse}{0.01nse + 0.01} \quad (10)$$

Then, the WQI is calculated as:

$$CWQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \quad (11)$$

Table 3 presents the water quality description according to the WQI value for this method

Table 3. Description of the water quality for the CCME WQI method [26].

WQI Value	Water Quality Description
95 - 100	Excellent
80 - 94	Good
60 - 79	Fair
45 - 59	Marginal
0 - 44	Poor

2.2.3. Erdenebayar Water Quality Index Method

The following formula is used to evaluate water quality for surface water in this method:

$$WQI = 100 \left[\frac{\sum_{i=1}^n \frac{C_i}{PI_i}}{n} \right] \quad (12)$$

Where:

WQI: Erdenebayar Water Quality Index

PI_i: allowable level of the i-th parameter

n: total number of parameters

C_i: concentration of the i-th parameter. Table 4 shows the water quality classification according to this method.

Table 4. Classification of water quality according to the Erdenebayar Method [27]

WQI Value	Water Quality Classification	Grade
≤ 30	Very Clean	1
31 - 89	Clean	2
90 - 249	Slightly Polluted	3
250 - 399	Moderately Polluted	4
400 - 599	Heavily Polluted	5
≥ 600	Dirty	6

2.3. Statistical Analysis

The data obtained were analyzed through the mean, minimum, maximum, and standard deviation values. These values are then compared with the corresponding standard values for each parameter.

3. Results and Discussion

Tables 5 to 9 display the results obtained for the 13 selected parameters recorded between November 1, 2021, and October 31, 2022. Discrepancies in these parameters were observed based on the sampling location and the season during which samples were collected. The study concludes that the pH fluctuated between 7.1 and 8.5 over the year, indicating a sub-alkaline nature [28], consistent with published data from Iraq [29]. Alkalinity levels increased with river flow, likely due to wastewater discharge. However, this value remains within a safe range for irrigation purposes [30]. Electrical conductivity (EC) is a critical parameter for water quality evaluation, as higher EC values indicate deterioration of water quality. The study found electrical conductivity levels to range from 395 to 543 micro-Siemens/cm, placing it in the moderate salinity risk category (good quality range).

Discharging domestic wastewater without treatment into the river likely contributed to a slight rise in salinity levels. The recorded turbidity values ranged from 1.13 NTU (lowest) to 45.7 NTU (highest), remaining within acceptable standards. Higher turbidity values were observed in river banks, attributed to bank erosions, domestic wastewater discharge, and soil runoff during rainfall [30]-[32]. The Mosul Dam, located approximately 40 km north of Mosul City, has helped reduce turbidity in the river by allowing for natural sedimentation in

the dam lake and maintaining an almost constant discharge of downstream water throughout all seasons [32]. The highest chloride level was detected at P3, measuring 25 mg/L, while the lowest was at P1, with a value of 15 mg/L. Elevated chloride ions in water can elevate osmotic pressure, impeding crop growth and limiting plant water availability [33]. The recommended chloride range for safe drinking water falls between 200 and 500 mg/L [34],[35]. Nitrite concentrations ranged from 3.1 to 4.43 mg/L. The minimum alkalinity concentration was 132 mg/L, with the maximum at 164 mg/L.

A change in total hardness and sulphates was observed in the different stations, as their concentrations increased during the river flow through the city of Mosul due to the discharge of untreated residential sewage into the river, and a change also occurred during the seasons of the year.

Total hardness and sulfate variations along the Tigris River increase their concentrations during the passage of the river in Mosul city due to the discharge of untreated residential sewage water into the river. There was also variation during the seasons of the year; the reduced levels of hardness in winter may be due to the dilution in salt concentration in the flood period [21]. In general, sulfate concentrations in the rainy season were higher than their dry season values along the river [36], with the highest sulfate concentration, 58 mg/L, recorded at stations P1 and P3 in spring. In comparison, the lowest level was found at station P1 at 35.4 mg/L in summer, where the nature of the gypsum rocks in the river basin in Mosul city leads to an increase in sulfate concentrations with the flow of the river [37].

Nevertheless, the sulfate concentration is well below the permissible limit. The absence of direct industrial wastewater discharge from manufacturing plants may be the reason for the relatively low levels of sulfates in the Tigris River.

[31],[32]. The maximum values of magnesium (Mg) and calcium content were 23 mg/L and 61.6 mg/L, respectively. This can be attributed to the various wastes that are discharged into the river through the wastewater discharge points spread on both sides of the river [2], [35]. The concentrations of total hardness, sulfate, magnesium, and calcium were within the permissible limits according to Iraqi standard specifications for drinking water. 2001 No. 417), which were 500 mg/L, 250 mg/L, 100 mg/L, and 100 mg/L, respectively [25].

Water, inorganic phosphorus is generally present in the form of phosphate, which is usually non-toxic to humans and animals unless present in very high concentrations. Across all five stations, the phosphate level remained constant at 0.1 mg/L, making it suitable for all purposes of use [38]-[42]. The dissolved oxygen (DO) percentage varied between 5.0 and 9.4 mg/L, representing oxygen-rich water ideal for supporting aquatic life [43]-[45]. The variation in total hardness is very high during the seasons, especially in spring, with a standard deviation greater than the average value at all stations due to the effect of valley water on the river water below Mosul Dam during the rainy season.

Table 5. Data on water quality parameters at the P1 station

Seasons	Parameter Statistical	EC μS/cm	pH	DO mg/L	TUR NTU	TH mg/L	Ca mg/L	Mg mg/L	SO4 mg/L	PO4 mg/L	NO3 mg/L	TDS mg/L	ALK mg/L	CL mg/L
Winter	Mean	477	7.4	8.8	6.3	155	55.5	3.5	52.6	0.02	3.2	278	149	21
	Min	463	7.2	8.7	2.4	154	54.4	2.4	52.1	0.01	3.1	270	144	18
	Max	488	7.5	8.9	13.3	156	56.0	4.8	53.0	0.02	3.5	285	154	23
	SD	13	0.2	0.1	6.0	1	0.9	1.2	0.5	0.01	0.3	8	5	3
Spring	Mean	486	7.9	7.5	11.9	187	54.3	12.3	55.4	0.05	3.8	285	157	19
	Min	468	7.7	5.9	2.2	156	52.8	5.8	53.2	0.03	3.5	280	148	18
	Max	507	8.1	8.4	28.5	240	57.2	23.0	58.0	0.08	4.4	290	164	20
	SD	20	0.2	1.4	14.4	46	2.5	9.3	2.4	0.03	0.5	5	8	1
Summer	Mean	427	8.0	5.6	3.9	184	51.5	13.2	46.5	0.03	3.4	243	145	18
	Min	407	7.7	5.0	3.0	178	49.6	12.0	35.4	0.02	3.1	230	140	17
	Max	442	8.5	6.0	5.3	190	53.6	14.8	53.0	0.03	3.5	250	148	19
	SD	18	0.4	0.5	1.2	6	2.0	1.4	9.6	0.01	0.3	12	4	1
Autumn	Mean	405	7.3	5.6	9.7	180	49.6	13.4	43.7	0.03	3.8	240	144	18
	Min	398	7.2	5.2	5.0	170	47.2	12.4	36.9	0.03	3.5	230	136	15
	Max	418	7.5	6.1	17.0	190	52.0	14.4	49.1	0.03	4.0	250	154	22
	SD	11	0.2	0.4	6.4	10	2.4	1.0	6.2	0.0	0.3	10	9	4

Table 6. Data on water quality parameters at the P2station

Seasons	Parameter Statistical	EC μS/cm	pH	DO mg/L	TUR NTU	TH mg/L	Ca mg/L	Mg mg/L	SO4 mg/L	PO4 mg/L	NO3 mg/L	TDS mg/L	ALK mg/L	CL mg/L
Winter	Mean	478	7.4	8.81	4.67	159	56.27	4.31	52.93	0.02	3.25	270	150.7	20.7
	Min	462	7.4	8.7	2.5	156	54.4	3.8	48.5	0.01	3.1	260	146	20
	Max	502	7.5	8.9	8.6	164	58.4	4.8	56.0	0.03	3.5	280	156	22
	SD	21	0.1	0.1	3.4	5	2.0	0.5	3.9	0.01	0.3	10	5	1.15
Spring	Mean	476	7.8	8.1	15.8	178	54.1	10.2	55.7	0.05	3.2	285	155	19
	Min	456	7.7	6.1	2.9	152	52.0	4.3	54.1	0.03	3.1	275	154	18
	Max	487	7.9	9.6	40.0	220	56.8	18.7	57.0	0.07	3.5	295	156	20
	SD	17	0.1	1.8	21.0	37	2.4	7.5	1.5	0.02	0.3	10	1	1.00
Summer	Mean	430	7.8	5.7	4.4	184	51.7	13.1	47.6	0.03	3.4	250	148	18.3
	Min	406	7.7	5.5	3.8	174	48.0	12.0	37.6	0.01	3.1	229	146	18
	Max	452	8.0	6.0	5.5	192	54.4	14.4	53.2	0.05	3.5	260	152	19
	SD	23	7.8	5.7	4.4	184	51.7	13.1	47.6	0.03	3.4	250	148	18
Autumn	Mean	408	7.4	5.6	9.6	182	50.6	13.3	43.1	0.04	3.7	239	141	19

Min	397	7.1	5.3	6.0	176	48.0	13.0	41.5	0.03	3.5	238	140	17
Max	428	7.6	6.0	16.3	188	53.6	13.4	44.8	0.04	4.0	240	142	21
SD	18	0.3	0.4	5.8	6	2.8	0.3	1.7	0.01	0.3	1	1	2.1

Table 7. Data on water quality parameters at the P3 station

Parameter	EC	pH	DO	TUR	TH	Ca	Mg	SO4	PO4	NO3	TDS	ALK	CL	
Seasons	Statistical tools	µS/cm	mg/L	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
Winter	Mean	509.0	7.3	8.4	6.6	161	57.6	4.2	53.5	0.02	3.4	287	150	25
	Min	490	7.2	8.0	1.7	156	56.0	3.4	52.4	0.02	3.1	280	146	25
	Max	543	7.4	8.9	13.9	168	60.0	4.8	55.0	0.03	3.5	290	152	25
	SD	30	0.1	0.5	6.4	6	2.1	0.7	1.3	0.01	0.2	6	3	0
Spring	Mean	506	7.5	6.2	18.2	177	52.3	11.0	55.4	0.06	3.5	288	153	22
	Min	467	7.3	5.3	4.2	158	49.6	3.4	52.2	0.04	3.1	280	144	20
	Max	529	7.7	7.3	45.0	200	57.6	18.2	58.0	0.08	4.0	300	160	24
	SD	34	0.2	1.0	23.2	21	4.6	7.5	2.9	0.02	0.4	10	8	2
Summer	Mean	434	7.8	5.4	5.2	186	52.0	13.4	47.63	0.04	3.4	252	151	19
	Min	416	7.6	5.1	4.3	180	48.8	12.9	38.00	0.03	3.1	232	146	18
	Max	453	7.9	5.6	6.5	190	53.60	13.9	56.00	0.05	4.0	270	156	20
	SD	19	0.2	0.3	1.2	5	2.77	0.5	9.07	0.01	0.5	19	5	1
Autumn	Mean	403	7.4	5.8	9.6	177	53.60	10.24	43.73	0.04	3.7	235	143	19
	Min	395	7.2	5.3	6.2	170	52.00	9.12	39.80	0.03	3.5	230	132	17
	Max	416	7.7	6.0	15.5	186	54.40	12.00	48.70	0.04	4.0	240	154	20
	SD	11	0.3	0.4	5.1	8	1.39	1.54	4.54	0.01	0.3	5	11	2

Table 8. Data on water quality parameters at the P4 station

Parameter	EC	pH	DO	TUR	TH	Ca	Mg	SO4	PO4	NO3	TDS	ALK	CL	
Seasons	Statistical tools	µS/cm	mg/L	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
Winter	Mean	491.0	7.5	9.4	7.2	165	58.7	4.3	55.4	0.03	3.4	280	153	24
	Min	476	7.4	8.7	2.1	154	56.8	2.4	54.5	0.01	3.1	275	150	23
	Max	503	7.5	10.6	13.3	170	61.6	6.7	56.2	0.06	3.5	285	156	25
	SD	14	0.1	1.1	5.7	9	2.6	2.2	0.9	0.03	0.2	5	3	1
Spring	Mean	480	7.7	7.5	18.1	169	52.0	9.4	53.7	0.07	3.4	284	156	20
	Min	453	7.6	6.0	3.5	146	48.8	3.8	52.0	0.05	3.1	275	148	18
	Max	515	8.0	8.6	45.7	210	54.4	18.7	55.1	0.10	4.0	300	164	22
	SD	32	0.2	1.4	23.9	35	2.9	8.1	1.6	0.03	0.5	14	8	2
Summer	Mean	437	7.7	5.9	5.5	189	53.9	13.0	46.7	0.04	3.7	259	151	19
	Min	420	7.7	5.7	5.1	184	49.6	10.1	37.4	0.02	3.5	238	146	18
	Max	455	7.7	5.9	6.2	192	59.2	14.4	55.0	0.06	4.0	280	156	20
	SD	18	0.0	0.1	0.6	4	4.9	2.5	8.8	0.02	0.3	21	5	1
Autumn	Mean	406	7.4	5.9	11.5	181	53.6	11.2	48.8	0.04	4.1	234	140	20
	Min	397	7.1	5.3	5.5	180	52.0	10.1	45.7	0.04	4.0	230	134	18
	Max	420	7.7	6.9	23.0	182	55.2	12.4	51.4	0.05	4.4	240	144	21
	SD	12.3	0.3	0.8	10.0	1	1.6	1.2	2.9	0.01	0.3	5	5	2

Table 2. Data on water quality parameters at the p5 station

Parameter	EC	pH	DO	TUR	TH	Ca	Mg	SO4	PO4	NO3	TDS	ALK	CL	
Seasons	Statistical tools	µS/cm	mg/L	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
Winter	Mean	494.3	7.5	8.7	6.6	163	58.4	4.2	55.7	0.02	3.4	280	151	24
	Min	481	7.4	8.4	1.1	156	57.6	2.4	54.6	0.01	3.1	275	148	23
	Max	502	7.5	9.0	15.0	170	59.2	5.3	56.6	0.05	3.5	285	154	25
	SD	12	0.1	0.3	7.4	7	0.8	1.5	1.0	0.02	0.2	5	3	1
Spring	Mean	489	7.7	7.4	13.8	175	53.1	10.2	52.2	0.05	3.7	288	157	20
	Min	454	7.5	5.9	3.2	154	51.2	4.3	47.4	0.02	3.1	275	152	16
	Max	539	8.0	8.4	35.1	198	54.4	15.4	57.3	0.09	4.4	310	160	23
	SD	44	0.3	1.3	18.4	22	1.7	5.6	5.0	0.04	0.7	19	5	4
Summer	Mean	436	7.8	5.8	5.5	188	52.0	13.9	46.3	0.04	3.4	259	153	20
	Min	415	7.8	5.5	4.0	178	49.6	12.9	39.0	0.03	3.1	233	148	19
	Max	455	7.8	6.1	7.6	194	53.6	14.8	54.0	0.05	3.5	280	158	21
	SD	20	0.0	0.3	1.9	9	2.1	1.0	7.5	0.01	0.3	24	5	1
Autumn	Mean	409	7.5	6.0	13.0	183	55.2	10.7	50.6	0.04	4.1	240	140	19
	Min	403	7.2	5.6	6.0	180	52.8	9.1	46.9	0.03	3.5	235	132	18
	Max	419	7.8	6.8	26	184	58.4	12.5	56.0	0.04	4.4	250	144	20
	SD	9	0.3	0.7	11.3	2	2.9	1.7	4.8	0.01	0.5	9	7	1

3.1. Results using the WAWQI Method

The water quality for the Tigris River was calculated using the WAWQI method, with all thirteen water quality parameter values ranging from 18 to 36, indicating a water quality ranging from good to excellent, as depicted in Fig. 2. During winter, the WAI consistently reflected excellent water quality at all stations. In other seasons, the water quality was good overall, except for station P2 in summer, where it was rated as excellent.

The figure illustrates an almost consistent increase in WQI values from station P1 to station P5, indicating a decline in water quality as the water flows from north to south. This deterioration in water quality is attributed to various polluting activities that release contaminated water into the river.

3.2. Results using the CCME WQI method

Fig. 3 illustrates the water quality index at various stations in Mosul City over the study period using the CCME WQI method. The figure exhibits good water quality during winter at all stations, with the remaining stations rated as fair. These results are in good agreement with previous results of the WAWQI method. Overall, the figure indicates that water quality in the Tigris River within Mosul city is generally fair. Additionally, fluctuations in water quality are observed across stations over time, with stations P1 and P2 exhibiting good water quality in autumn, while the other stations show poor

quality. With appropriate treatment, purification, and sterilization processes, the water can be considered suitable for drinking purposes, as indicated by WQI values ranging between 75 and 81. Fig. 3, much like Fig. 2, illustrates the gradual deterioration of water quality as it flows from station P1 in the north to station P5 in the south of the city.

3.3. Results using the E WQI method

To assess the spatial variations in the quality of water across all stations in the study area, the method established by Erdenebayer was employed. Refer to Fig. 4 for a visual representation. The figure illustrates that all stations exhibit clean water quality. The analysis indicates that the water quality in the Tigris River within Mosul City is generally good (refer to Table 3). Despite the vigilant monitoring of the government to reduce pollution to a minimum, pollution levels have increased from station P1 to P5 due to ongoing polluting activities in the area [46]. This result is consistent with the findings obtained using the methods above, namely the arithmetic index method and the CCME WQI method.

The nearly consistent WQI across all seasons in the three methods can be attributed to the Mosul Dam, which maintains a roughly constant discharge year-round. The dam plays an important role in sedimentation and water purification by retaining water in its reservoir and facilitating self-purification processes [32].

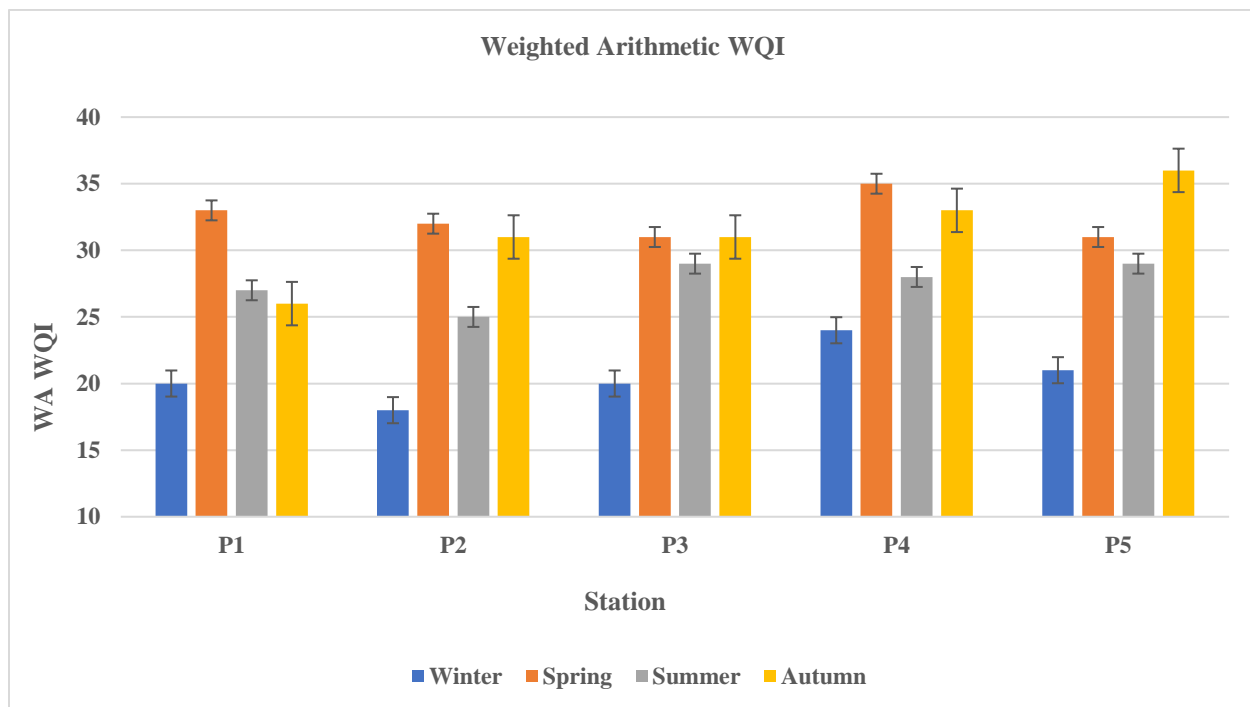


Figure 2. Seasonal Variation of WQI at each station in the Tigris River for one year using the WAWQI Method

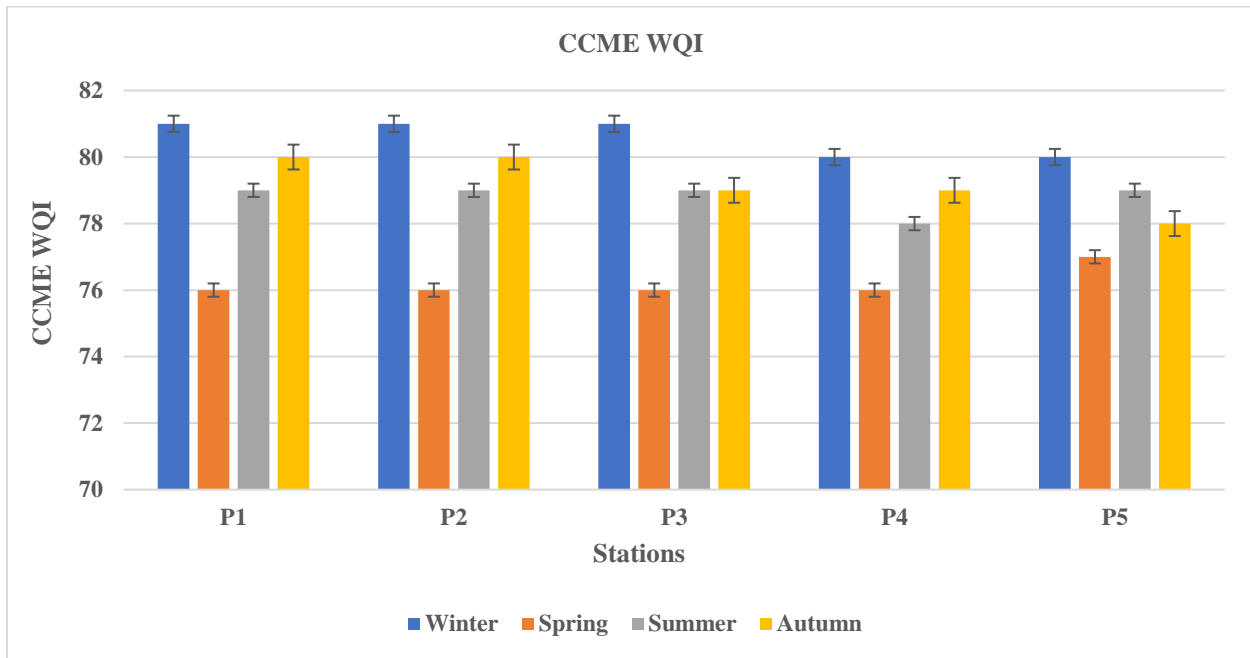


Figure 3. Seasonal Variation of WQI at each station in the Tigris River for one year using the CCME Method

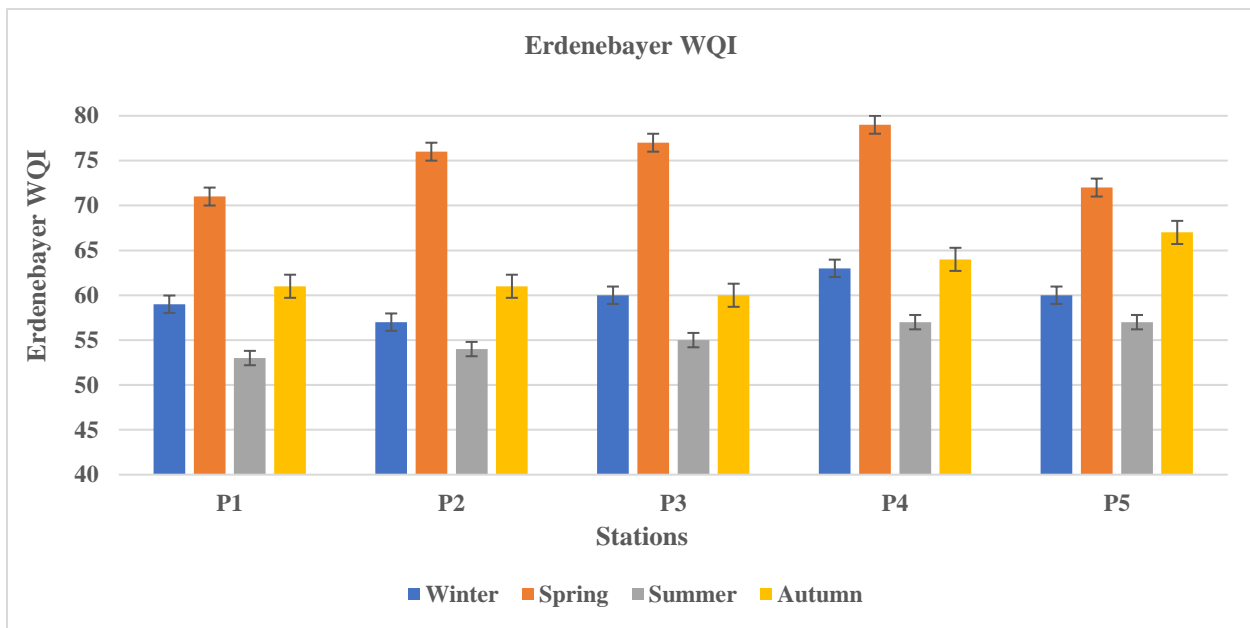


Figure 4. Seasonal Variation of WQI at each station in the Tigris River for one year using the Erdenebayer Method

4. Conclusion

The decreased rainfall rates and water releases coming from Turkey into the Tigris River have begun to decline, raising concerns about the water's quality and the possibility of it being affected by various pollutants. This study involved collecting water samples from five chosen stations along the river over 12 months and analyzing them for 13 different parameters using three different methods. Data were organized seasonally, and stations were selected based on human activities in the areas at consistent intervals. The results indicate that all 13 parameters

consistently fall within safe and permissible ranges, making the water suitable for aquatic ecosystems, human consumption, and irrigation.

The quality of water in the Tigris River within Mosul City is deemed satisfactory, necessitating minimal purification beyond sedimentation and sterilization procedures. Mosul Dam helps purify the water through retention and self-purification mechanisms, with limited sources of pollution through vigilant monitoring to control pollutants entering the river. The results obtained by the three WQI methods were consistent. Many

waste waters that are discharged directly into the river on both sides of the river have increased some of the pollution parameters. Therefore, further monitoring and pollution control measures are necessary to diminish water contamination and maintain its high quality downstream of the city of Mosul.

Conflict of Interest

The author declares that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Both authors planned the research, performed the experimental and analytical work, and wrote the paper.

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