Pol. J. Environ. Stud. Vol. 32, No. 5 (2023), 4201-4217
DOI: *10.15244/pjoes/163505* ONLINE PUBLICATION DATE: 2023-07-13

Original Research

Applying Different Water Quality Indices and GIS to Assess the Water Quality, Case Study: Euphrates River in Qadisiyah Province

Eman Al Mousawi[1], Udai A. Jahad[2], Ali Chabuk[3], Nadhir Al-Ansari[4]*, Ali Majdi[5], Jan Laue[6]

[1]Department of Civil Engineering, Faculty of Engineering, University of Babylon, Hillah, Babylon 51001, Iraq
[2]Department of Environment Engineering, Faculty of Engineering, University of Babylon, Hillah, Babylon 51001, Iraq
[3]Department of Environment Engineering, College of Engineering, University of Babylon, Babylon 51001, Iraq
[4]Department of Civil Environmental and Natural Resources Engineering, Lulea University of Technology, SE-971 87 Lulea, Sweden
[5]Building and Construction Techniques Engineering, Al-Mustaqbal University College, 51001, Babylon, Iraq
[6]Department of Civil Environmental and Natural Resources Engineering, Lulea University of Technology, SE-971 87 Lulea, Sweden

Received: 1 February 2023
Accepted: 21 April 2023

Abstract

A well-known tool for assessing the quality of surface water is the water quality index (WQI) model. In this study, the WQI was generated to classify the water flowing in the Euphrates River in Qadisiyah Province. To develop analytical models, a connection between the findings and satellite images was developed. It is possible to determine what category a river's water quality for domestic use will fall into. The Weighted Arithmetic Water Quality Index (WWQI), Canadian Water Quality Index (CWQI), and Bascarón Water Quality Index (BWQI) were used to evaluate and examine the suitability of the Euphrates River in the city by analysing the water quality of samples taken from the five locations (Muhanawia (L1), Salahia (L2), Shamiyah (L3), Shamiyah (L4), Gammas (L5)). The hydrogen ions pH, temperature T, dissolved oxygen DO, nitrate NO_3, calcium Ca, magnesium Mg, total hardness TH, potassium K, sodium Na, sulfate SO_4, chlorine Cl, total dissolved solids TDS, and electrical conductivity ECvalues are provided for 2020 and 2021. Results showed the Euphrates River was deemed severely contaminated at location Gammas (L5) but acceptable at location Muhanawia (L1). During the research phase, the water quality for the Euphrates achieved a maximum of 87.43 using the CWQI for Muhanawia (L1) in 2021 and a minimum of 15.6 using the BWQI for Gammas (L5) in 2021. The excessive sulphate, total dissolved solids, calcium, and total hardness concentrations led to the low WQI. The results are analysed using a GIS, and a network database connected to the GIS is required to utilize its analytical capabilities and the geographically scattered data throughout the study region. The

*e-mail: nadhir.alansari@ltu.se

Water Quality Index (WQI) is not suitable for drinking, as it is below the average of the World Health Organization (WHO) suggestions.

Keywords: water quality, index, Euphrates River, Qadisiyah Province, GIS

Introduction

Water is undoubtedly one of the most important elements of life. Without it, nothing on Earth could exist. It is essential for sustaining life, and any disruption to its quality or availability can have far-reaching effects on the environment. In addition, clean water is a fundamental human need. Every person on the planet deserves access to clean and safe drinking water, yet many countries still lack this basic requirement [1]. In 2015, over 663 million people lacked access to improved drinking water sources, with nearly 159 million people relying on contaminated rivers, lakes, and other surface water sources. As urbanization, land occupation, population growth, water conflicts, low environmental awareness, and climate change all continue to challenge water delivery systems, it is expected that by 2025, half of the world's population will reside in areas with limited water resources. To combat this, reusing wastewater to recover nutrients, energy, and water is becoming a more popular method [2]. The Euphrates River is one of Iraq's primary waterways, yet its water resources have been significantly strained in the last two decades. The cause of this can be attributed to a variety of factors, the most prominent being climate change, construction, and human activities in Turkey and Syria. Other contributing elements include Iraq's inherently low annual rainfall and inadequate management, use, and planning [3]. It is projected that by 2025, the Tigris and Euphrates Rivers will be substantially reduced in volume, with the Euphrates predicted to decrease by at least half [4]. The quality of surface water can differ depending on the time and location. Pollutants such as silt, debris, and minerals from surface runoff can lead to streams that are often cloudy or murky. Wastes have a major impact on water quality and can increase the range of contaminants present in the water [5]. Water quality monitoring is an essential tool for environmental protection and management. Not only does it help protect rivers, lakes, and other water bodies from pollution, but it also provides us with valuable data on the condition of the water. This data helps us to develop strategies to protect, restore and manage our water resources, ensuring their sustainability and providing us with safe drinking water [6].

Water quality is a major concern when it comes to water resource planning and management. To address river water contamination, significant effort must be taken in terms of data collection, analysis, and interpretation [7]. The Water Quality Index (WQI) is an invaluable tool for assessing the overall health of a body of water. It is a straightforward technique that considers a variety of physical, chemical, and biological parameters, such as dissolved oxygen, pH, turbidity, and total suspended solids, to create a single numerical value. This provides a convenient way to condense a large amount of data into a single, dimensionless number that can be easily repeated for comparison and assessment [8]. Water quality indices (WQIs) provide an effective way to simplify the presentation of intricate and technical water quality data. These communication models, built on a scientific foundation, can convert data on various water quality variables into a single score of no more than ten digits that accurately summarizes the overall water quality. This is essential for assessing and comparing different water supplies, as it creates a framework for understanding the quality of each [9, 10]. Water quality indices are tools that attempt to help water quality specialists, policymakers, and the public by disseminating water quality data more consistently and continuously rather than replacing in-depth water quality studies [11]. The use of several WQI models has recently drawn a lot of interest because there are many different WQIs accessible, but no one is universally recognized [12].

To assess the river's appropriateness for drinking, an Iraqi WQI was developed in 2020 by a team of Iraqi researchers. An overall water quality index for the surface waters of Iraq is being developed, and this index is regarded as the first step. The Delphi approach was employed. Only 10 of the 27 water quality measures were asked to be rated by the 44 experts in water quality management. Only six parameters (total dissolved solids, chemical oxygen demand, dissolved oxygen, total hardens, total coliform, and chloride) were selected for the index at the panel's advice, and each parameter's weight was assigned in accordance with their recommendations. The average curve showing the variance in water quality level on a scale of 0-100 was used to calculate the subindex for each parameter [13]. Additionally, the geographic information system (GIS) has been used in previous studies such as Maurya et al., Noori et al., and Jasrotia et al. [14-16]. With the advent of GIS technology, assessing water quality has become increasingly precise and accurate. GIS can be used to create maps that show the spatial distribution of water quality such as temperature, pH, turbidity, and other parameters. The data generated allows researchers and decision-makers to better understand the sources and impact of pollutants on a local, regional, and global scale. It can also be used to identify areas that are at risk of water contamination and provide strategies for remediation. GIS also helps to identify the potential sources of water pollution and the areas most impacted by it. This data can be used to identify the best strategies for reducing water pollution and improving water quality. Additionally, GIS can be used to monitor the effectiveness of pollution control strategies and identify where additional efforts are needed. GIS technology has revolutionized the way we assess and monitor water quality. It provides a powerful tool for understanding the sources and impacts of water pollution, and for developing solutions to improve water quality. GIS-based maps and models can also be used to identify areas at risk of water contamination and provide strategies for remediation and monitoring. This technology has greatly enhanced our ability to protect and improve the quality of water resources [16].

The current study aims to establish the WQI of the Euphrates River based on physicochemical water quality standards, help local people manage water resources effectively, and contribute to future water management and quality as follows:

(i) Investigate how the study area (cities and towns on the river banks) affects the water quality parameters of the Euphrates River.

(ii) Calculation of the water quality index of the Euphrates River and comparison with the Bascalon method, the Canadian method, and the weighted algorithm.

(iii) Use the calculated WQIs values to discuss whether the rivers at the study site are suitable for human consumption.

(iv) To illustrate the polluted zones of the river WQI and create a color map using the GIS technology according to the classification of river water.

(v) Comparison of water quality characteristics with Iraqi drinking water standards.

Material and Methods

Study Area Description

A governorate in Iraq called Qadisiyah is located around 163 km south of Baghdad (the capital of Iraq). It is situated in southern Iraq between the latitudes of (31°50’00” and 32°20’00”) N and (44°30’00” and 45°20’00”) E as shown in (Fig. 1). The south-central Iraqi planes are home to the Province of Qadisiyah, which is sometimes known by the spellings Qadisiyah or Kadissiyah. The governorates of Muthanna, Najaf, Babylon, Wassit, and Qadisiyah are bordered by Qadisiyah. The governorate is traversed by the Euphrates River which is the main river. The weather of Qadisiyah is typical of the desert, with scorching, dry summers, and milder winters. Rainfall only occurs throughout the winter and only amounts to 110 mm annually on average. The province’s territory is 8,153 square kilometers, and 1,325,031 people were reportedly living there [17]. The Euphrates River has its source in Turkey and passes through Syria and Iraq before joining the Tigris in the Shatt al-Arab. This confluence empties into the Persian Gulf. The total length of the Euphrates River is 2,890 km and in Iraq is approximately 1,800 km. The length of the study section is 77 km. In the study section, the Euphrates flows through many towns and villages in the study area with seasonal changes in the flow rate and water level as shown in Table 1. Table 1 displays the locations of water quality monitoring stations along the Euphrates River. It shows the areas where measurements are taken and

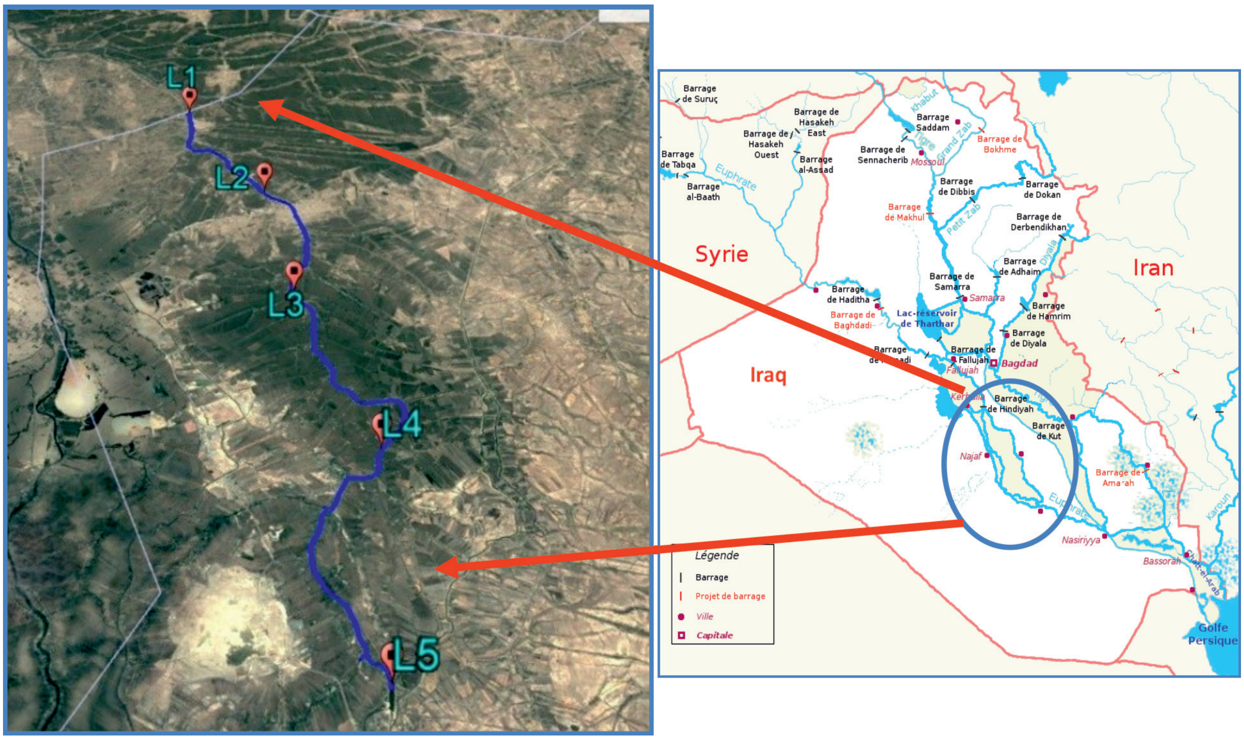

Fig. 1. The study area location (Muhanawia (L1), Salahia (L2), Shamiyah (L3), Shamiyah (L4), and Gammas (L5).

Table 1. The locations of the sampling points.

Location	Place	River width (m)	Discharge m^3/s	Province	UTM Coordinates (38N)	
					E	N
L1	Muhanawia	75.82	65.00	Qadisiyah	44.543519°	32.024128°
L2	Salahia	71.03	53.70		44.553280°	31.999311°
L3	Shamiyah	78.35	51.30		44.581041°	31.972444°
L4	Shamiyah	73.50	48.70		44.599962°	31.947738°
L5	Gammas	70.21	37.50		44.593594°	31.917276°

their corresponding geographic coordinates. The river is the main source of water for the vast agricultural lands on either side of the river. The river is a major source of industrial activity in the city.

Data Collection

Iraq's Ministry of Water Resources has supplied the values of the hydrogen ions pH, temperature T, dissolved oxygen (DO), nitrate (NO_3), calcium (Ca), magnesium (Mg), total hardness (TH), potassium (K), sodium (Na), sulfate (SO_4), chlorine (Cl), total dissolved solids (TDS), and electrical conductivity (EC) readings for both 2020 and 2021. The data is reflected in the monthly average values for the thirteen parameters used to calculate the water quality index. The locations of water quality monitoring stations along the Euphrates are shown in Table 1. The distance from the station to the next one was around 10 to 12 km. These locations were chosen to allow the current study to be conducted along the 77 km of the Euphrates River. These sampling stations were selected because of the limited studies on the section of the river in this zone. Also, the stations are used by Irrigation and Environmental Departments. The chosen stations were before and after the cities and villages that have no sewage water treatment. Monitoring of river water quality is necessary to assess the water quality for drinking water purposes in the study area.

Method

The following steps were used to accomplish the goals of this work:

1. In the Ministry of Water Resources` laboratories, physical and chemical parameters were examined after samples were collected from locations on specific days (It was any day on the last week of each month during the study period).
2. Calculate the WQI by using Excel software.
3. Information from each sampling site was saved in an Excel 2016 format file and later exported to ArcGIS (10.8) and used for the survey. Data were analyzed using an interpolation approach (IDW) using the Spatial Analyst tool of GIS software.
4. Statistical analysis using SPSS Statistics (22.0) to describe the relationships between water quality indicators, test for normalcy, and use descriptive statistics.

Water Quality

The Weighted Arithmetic Water Quality Index (WWQI)

One of the first types of water quality index, the WWQI method, was developed by Brown in 1972 after being introduced by Horton in 1965. The water quality was categorized using this index. The level of purity is the most often used metric to obtain water quality [18]. The water quality index is a set of calculated values, evaluated considering many water quality criteria, to give a clear indication of water quality. Table 2 displays WQI classifications of water and their potential uses according to the weighted arithmetic WQI method. WQI can be calculated using a weighted exponential approach. The fact that this method incorporates multiple water quality parameters into a mathematical equation that rates the health of the water body using a number called the water quality index and describes the suitability of surface and groundwater sources for human consumption has given it advantages over other methods. By using the following steps, the WWQI can be calculated:

1. Gather information on different physicochemical water quality parameters following the appropriate research duration.
2. Calculate (1/Pi) after establishing the n^{th} parameter maximum allowable guidelines permissible values (Pi).
3. Utilize the following equation to determine the value of the proportionality constant (*K*):

$$K = \frac{1}{\Sigma(1/P_i)} \tag{1}$$

Where: P_i: the guidelines permissible values for the n^{th} parameter.

4. Use the Equation (2) below to determine the unit weight (UWi) for the n^{th} parameter:

$$UW_i = \frac{K}{P_i} \tag{2}$$

5. Also, by using Equation (3) to obtain the quality rating scale (Qr_i) for the n^{th} parameter:

$$Qr_i = [\frac{(E_n - I_i)}{(P_i - I_i)}] \times 100 \tag{3}$$

Where: En: the n^{th} parameter's predicted value at the specified sample location.

Ii: pure water's optimum value for the n^{th} parameter. UW_i^{th} the exception of pH = 7.0 and DO = 14.6 mg/L, Ii = 0 is the norm.

6. Obtain ($UW_i \times Qr_i$) of the n^{th} parameter and then the summation of it Σ ($UW_i \times Qr_i$).
7. Calculate the water quality index using Horton's approach. Using Equation (4) to calculate the WWQI:

$$WWQI = \frac{\Sigma UW_i Qr_i}{\Sigma UW_i} \tag{4}$$

The typical ideal value and allowable value for many water quality metrics are shown in Table 3.

Table 3. Referral permissible value of important WQ parameters (Karim et al., 2019).

Parameter	Units	Permissible value (Pi)	Ideal value (Ii)
Temperature	ºC	35º	27º
pH	-	8.45	7.0
DO	mg/L	8.50	9.0
BOD	mg/L	6.0	3.0
COD	mg/L	50.0	20.0
TDS	mg/L	2000	500
PO4	mg/L	0.07	0.06
Ammonium Ion	mg/L	4.0	0.2
Chloride	mg/L	90.0	60.0
Hardness	mg/L	150.0	20.0
Alkalinity	mg/L	300.0	200.0
Turbidity	NTU	70.0	30.0
Conductivity	µS/cm	5000	1500

Canadian Water Quality Index (CWQI)

The Canadian Water Quality Index (CWQI) is a tool developed by the Canadian Council of Ministries of the Environment to assess the quality of water resources across the country. The index is based on a variety of factors, including temperature, oxygen levels, and nutrient levels, to measure the health of a water body. The index can also be used to identify potential pollution sources, such as industrial runoff, agricultural runoff, and sewage inputs [19]. This index allows you to choose the variable and a range of acceptable water specification standards. The final calculation of the water state and the values of the guide, which range from 0 to 100, are based on three interrelated mathematical parameters. The CWQI is helpful for a variety of tasks, including the evaluation, analysis, planning, and management of drinking water quality data as well as the evaluation of the effectiveness of best management practices for decision-making. Table 2 shows the water quality classification for drinking purposes by CWQI. Equation (5) is used to obtain the CWQI as below:

$$CWQI = 100 - [\frac{\sqrt{F_1^2 + F_2^2 + F_3^3}}{1.732}] \tag{5}$$

Where: F1 or (Scope Factor): The number of variables across the interest period that do not meet the requirements for water quality, calculated as:

$$F_1 = (\frac{\text{No. of failed variables}}{\text{Total No. of variables}}) \times 100 \tag{6}$$

F2 (Frequency Factor): This factor, which is calculated as follows, represents the percentage of individual failed test values that do not meet the objectives.

$$F_2 = (\frac{\text{No. of failed tests}}{\text{Total No. of tests}}) \times 100 \tag{7}$$

Table 2. Water quality classification by the used WQI method.

WWQI		CWQI		BWQI		Class	Uses
WQI	Status	WQI	Status	WQI	Status		
0-25	Excellent	100-95	Excellent	100-90	Excellent	I	Drinking, irrigation, and industrial
26-50	Good	95-80	Good	90-70	Good	II	Domestic, irrigation, and industrial
51-75	Poor	80-65	Fair	70-50	Medium	III	Irrigation, and industrial
76-100	Very poor	65-45	Marginal	50-25	Bad	V	Irrigation
>100	Unfit for drinking	45-0	Poor	25-0	V. bad	IV	Proper treatment that required before irrigation

F3 (Amplitude Factor): This factor shows how far the results of failed tests fall short of the desired results. Three steps are taken in the calculation:

Firstly, the Calculation of Excursion (Ex) by:

$$\mathrm{Ex} = \left(\frac{\text{failed test value}_i}{\text{objective}_j}\right) - 1 \quad \text{(Test value < objective)} \tag{8a}$$

$$\mathrm{Ex} = \left(\frac{\text{objective}_j}{\text{failed test value}_i}\right) - 1 \quad \text{(Test value > objective)} \tag{8b}$$

Where Ex is the excursion which is showing the number of times by which an individual concentration is greater than or less than the objective when the test value must not exceed the objective.

Secondly, the normalized sum of excursions should be calculated by Equation (9):

$$\mathrm{NSEx} = \frac{\sum_{i=1}^{n} 1^{\mathrm{Ex}_i}}{\text{No.of tests}} \tag{9}$$

And calculate F3

$$F_3 = \frac{\mathrm{NSEx}}{0.01\ \mathrm{NSEx} + 0.01} \tag{10}$$

Finally, use equation (5) to find CWQI.

Bascarón Water Quality Index (BWQI)

The Bascarón WQI (BWQI), found by the Spanish man Bascarón, The Bascarón Water Quality Index (BWQI) is a widely accepted measure of water quality that was developed by Spanish scientist Bascarón in the early 20th century. The index considers numerous parameters, such as temperature, acidity, dissolved oxygen, conductivity, and turbidity, to calculate an overall score that reflects the overall quality of the water. The BWQI is composed of a formula that is used to calculate the index, which is thought to be the most accurate way to measure water quality [20]. The BWQI is a valuable tool for water management and conservation efforts. It can be used to monitor the health of waterways and identify potential environmental hazards. It is also used to compare water quality between different bodies of water. The BWQI can help identify areas that are experiencing high levels of pollution or degradation, as well as areas that are improving. By understanding the BWQI, it is possible to make informed decisions about the best ways to manage and conserve our water resources [21]. The overall index is thought to be a subjective measure of water quality. The formula is provided below.

$$\mathrm{BWQI} = \sum_{i=1}^{i=n} (A_i R_i)^2 / 100 \tag{11}$$

Where: n is the total number of variables, A_i is the variable's value after normalization, and R_i is the relative weight that was given to each variable, ranging from 1 to 4, depending on how it affected the water quality (4 for the highest impact and 1 for less impact). The main benefit of BWQI is that, after allocating the normalization factors and their weights, a variety of water quality variables can be incorporated into the calculation of the final index. The model suggested 26 water quality parameters, each of which represented a collection of water quality traits. Detergents, hardness, DO, pesticides, oil and grease, sulphates (SO_4), nitrates (NO_3), cyanides, sodium, free CO_2, ammonia nitrogen (ammonia NH_3-N), chloride (Cl), conductivity, magnesium (Mg), phosphorus (P), nitrites (NO), calcium (Ca), and the visual appearance of water were model parameters. The linear transformation function is used to translate observed parameter values into sub-index values that range from 0 to 100 [22]. Local water quality guidelines are used to determine the sub-index values. Table (2) shows the ranges of the WQI and the classifications.

Geographic Information System (GIS)

GIS technology is a powerful tool for tackling water-related issues, such as evaluating water quality, assessing water availability, and understanding the environment. It is particularly useful in areas with limited resources, as it can provide accurate information about water resources and the challenges associated with them, helping communities come up with better solutions. Additionally, GIS technology can be used to track changes in water resources, making it a crucial part of the effort to protect water sources [23]. Recent advances in technology have made it necessary to effectively manage water resources, with GIS playing a key role. GIS is used to store, manage, analyze, and display geographically-related data, which is beneficial for local and regional water resource management [24]. GIS tools provide a variety of ways to analyze spatial data, such as geostatistical, spatial, and statistical analysis. One of the most important tools is the spatial analyst's toolkit, which is used to interpolate point data with attribute and layout information. Output is in a raster format that can show gradient colors to indicate differences in data between various stations. Inverse Distance Weighted (IDW), Spline, Kriging, and Natural Neighbour are all techniques for interpolation that can be used [25]. The outcomes of WQI's study were then used in ArcGIS 10.8 as input data. To create spatial distribution maps, the sampling locations and water data were combined. The Inverse Distance Weighting (IDW) approach was utilized in this work to spatially interpolate water quality indices. The weight assigned depends on how far an input point is from the location of the output cell. The effect of the cell on the output value decreases as the distance increases [26]. Spatial analysis is the use of various analytical techniques to examine the characteristics, positions, and connections of features in spatial data in order to answer a question or gain insight. It involves the calculation of the Inverse Distance Weighted (IDW) interpolation, which creates cell values based on a linear combination of a set of sample points. This interpolation is used to generate a surface of a location-dependent variable [27].

Results and Discussion

Physicochemical Parameters

The results of the water samples taken from the study stations along the Euphrates River in Iraq from 2020 to 2021 indicate a significant change in water quality. In Figs 2 and 3, the pH increased from 6.8 to 8.1, the temperature decreased from 16.2 to 15.2 degrees Celsius. The dissolved oxygen levels dropped from 5.2 to 3.1 mg/L, and the NO_3 levels decreased from 24 to 10 mg/L. The presented concentrations are averages of the five stations in each year. The increase in pH could have a negative impact on the health of aquatic species that are not adapted to such a high pH. The effects of these changes in water quality can have serious implications for aquatic life in the region. The decrease in DO levels could lead to a decrease in the amount of oxygen available to aquatic organisms in the Euphrates River, while the decrease in NO_3 levels could lead to a decrease in the amount of food available to them. Additionally, the concentrations for the other parameters such as Ca, Mg, TH, K, Na, SO_4, Cl, TDS, and EC also fluctuated from year to the next one [28, 29]. Figs 2 and 3 demonstrate that the parameters of pH, Cl, and NO_3 fell within the Iraqi standard across all the sampling locations. In Fig. 2i), the chloride concentrations have been observed in the water from five locations. The values of Cl in L1 were 135 mg/L and 127 mg/L for 2020 and 2021 respectively. The same behavior shows for NO_3 as in Fig. 3d).

While the other parameters (EC, TH, TDS, Mg, Ca, SO_4, and Na) are out of the Iraqi standard limits in some locations. Global warming is the main factor that causes this variation. Also, the river path, which passes through cities that lack wastewater treatment, contributes to the pollution of the river. Consequently, human activities are majorly responsible for the changes in the tested parameters. The findings highlight the need for proper wastewater treatment in the cities to protect the environment and to ensure the quality of water in the river is up to the Iraqi standard. Moreover, it is important to maintain the water quality in the river by implementing measures that reduce human activities that can further pollute the river.

Water Quality Index

To determine whether river water is suitable for general use, thirteen parameters pH, DO, T, NO_3, Ca, Mg, TH, K, Cl, SO_4, Na, TDS, and EC have been tested and used to calculate the water quality index for the river. Three WQI methods were used to generate the descriptive statistics of the physicochemical water quality and their observed standard deviations for each

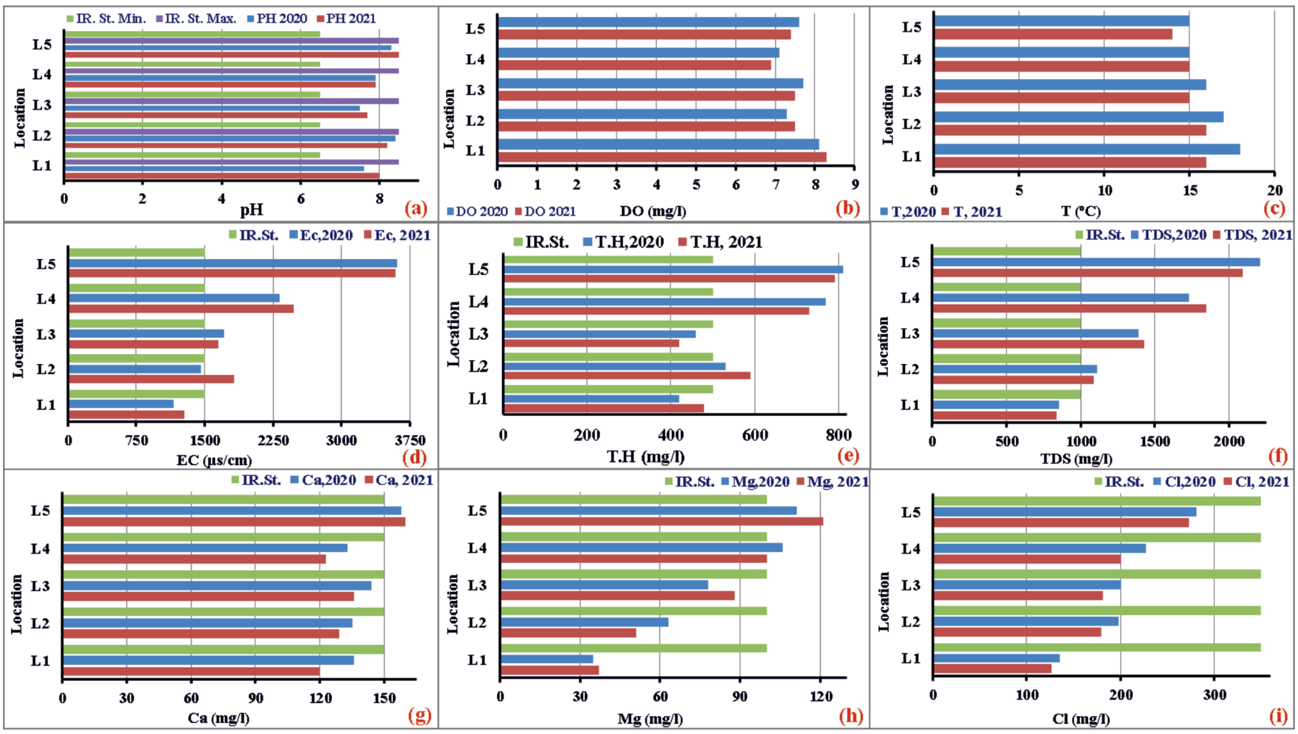

Fig. 2. Variations in the Euphrates River (2020 and 2021), a) The hydrogen ions (pH), b) Dissolved oxygen (DO), c) Temperature (T), d) Electrical conductivity (EC), e) Total hardness (TH), f) Total dissolved solids (TDS), g) Calcium (Ca), h) Magnesium (Mg), and i) Chlorine (Cl). Note, IR.St.Max: Upper limit of Iraqi standard and IR.St. Min: Lower limit of Iraqi standard.

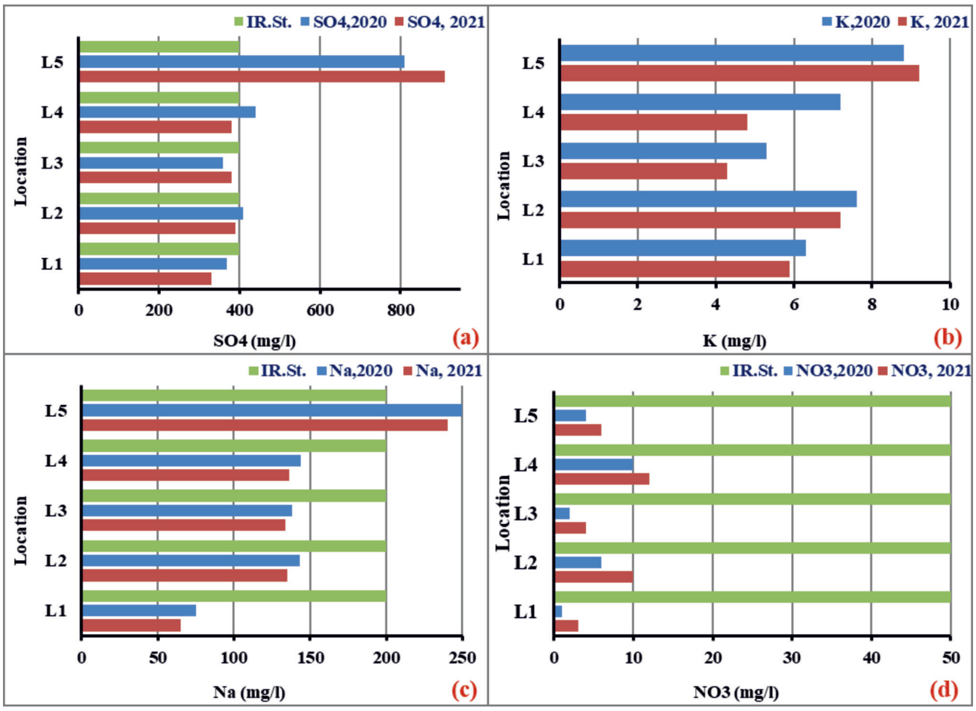

Fig. 3. Variations in the Euphrates River (2020 and 2021), a) Sulfate ($SO_{4)}$, b) Potassium (K), c) Sodium (Na), and d) Nitrate (NO_3). Note, IR.St.Max: Upper limit of Iraqi standard and IR.St. Min: Lower limit of Iraqi standard.

site, as shown in Tables 4, 5, and 6 and Fig. 4. Due to illicit wastewater discharge into the Euphrates River (in Qadisiyah Province) without any treatment or environmental monitoring programs, the river is now endangered by several pollutants. The water quality index showed that the river's status ranged from very poor to good by WWQI, from poor to good by CWQI, and very bad to the medium by BWQI. It had an impact on the biodiversity of the river and determined how river water is used for various reasons. The researchers in Al-Musyiab/Babil province measured the quality of water in the Euphrates river via 13 parameters (pH, DO, EC, etc.). Using these parameters, the Water Quality Index (WQI) was calculated over multiple sampling periods. Unfortunately, the WQI values were suboptimal during both the dry and wet seasons [30]. The water quality tests conducted on the Euphrates River in Qadisiyah Province have revealed a need for an effective monitoring program, a management plan, and periodic testing. This will ensure the river is able

Table 4. Calculations of Weighted arithmetic water quality index (WWQI) for selected locations in the years 2020 and 2021.

Year	2020			2021		
Location	WQI%	Class	Status	WQI%	Class	Status
L1	44.73	II	Good	41.31	II	Good
L2	33.35	II	Good	26.89	II	Good
L3	52.88	III	Poor	50.64	II	Good
L4	36.84	II	Good	41.26	II	Good
L5	85.19	V	Very poor	81.79	V	Very poor
Max. value	85.19			81.79		
Min. value	33.35			26.89		
Mean. value	50.60			48.38		
SD	20.76			20.52		
SEM	9.28			9.18		
N	5.00			5.00		

Table 5. Calculations of the Canadian water quality index (CWQI) for selected locations in the years 2020 and 2021.

Year	2020			2021		
Location	WQI%	Class	Status	WQI%	Class	Status
L1	79.33	III	Fair	87.43	II	Good
L2	71.63	III	Fair	83.32	II	Good
L3	68.82	III	Fair	80.08	II	Good
L4	67.59	III	Fair	79.72	III	Fair
L5	26.14	IV	Poor	47.36	V	Marginal
Max. value	79.33			87.43		
Min. value	26.14			47.36		
Mean. value	62.70			78.58		
SD	20.94			16.08		
SEM	9.37			7.19		
N	5.00			5.00		

Table 6. Calculations of the Bascarón water quality index (BWQI) for selected locations in the years 2020 and 2021.

Year	2020			2021		
Location	WQI%	Class	Status	WQI%	Class	Status
L1	38.93	V	Bad	58.28	III	Medium
L2	47.30	V	Bad	44.18	V	Bad
L3	31.15	V	Bad	34.32	V	Bad
L4	45.35	V	Bad	33.28	V	Bad
L5	22.15	IV	V. bad	15.60	IV	V. bad
Max. value	47.30			58.28		
Min. value	22.15			15.60		
Mean. value	36.97			37.13		
SD	10.42			15.68		
SEM	4.66			7.01		
N	5.00			5.00		

to sustain healthy aquatic life, provide a reliable source of drinking water, and improve the water quality and biodiversity of the river.

The GIS-Colored River Map

Fig. 5a) displays the interpolation of the average magnitude of various water quality metrics of the Euphrates River, mapped using GIS. The data reveals the shift in several parameters from upstream to downstream. Notably, the temperature of the water is a key indicator of the amount of molecule vibrational energy present. This is of particular importance, as variations in water temperature can result in significant biological effects [31]. The temperature of aquatic environments has a major influence on the activity and growth of microorganisms. Generally, as the water temperature increases, biological activity and organism growth rates are also increased. Each aquatic organism has an optimal temperature range in which it can thrive and reproduce effectively. Recently, the water temperature of a particular aquatic environment was recorded to be between 16 and 24ºC, which is quite ideal for aquatic life activity [32, 33]. This temperature range is especially beneficial for organisms that need cold water to survive, as it keeps them from going into hibernation and potentially dying. Furthermore, this optimal temperature range also serves as a great environment for organisms to reproduce, thereby leading to a proliferation of aquatic life forms.

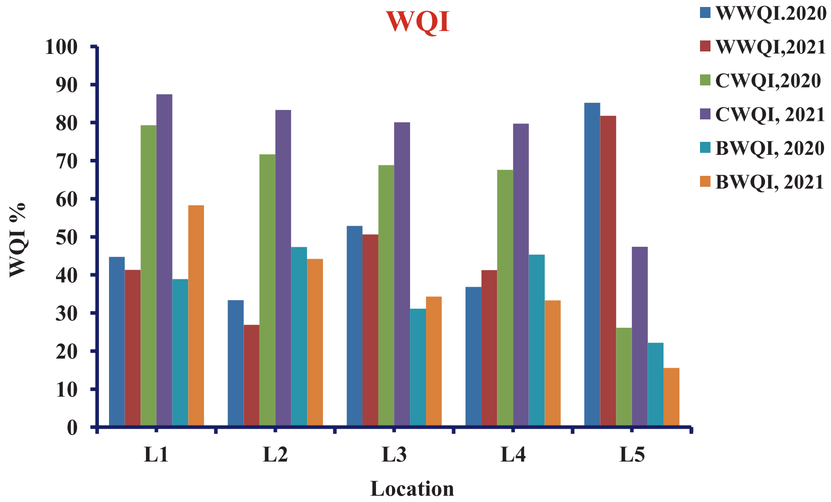

Fig. 4. The calculated WQIs for the five locations along the study area.

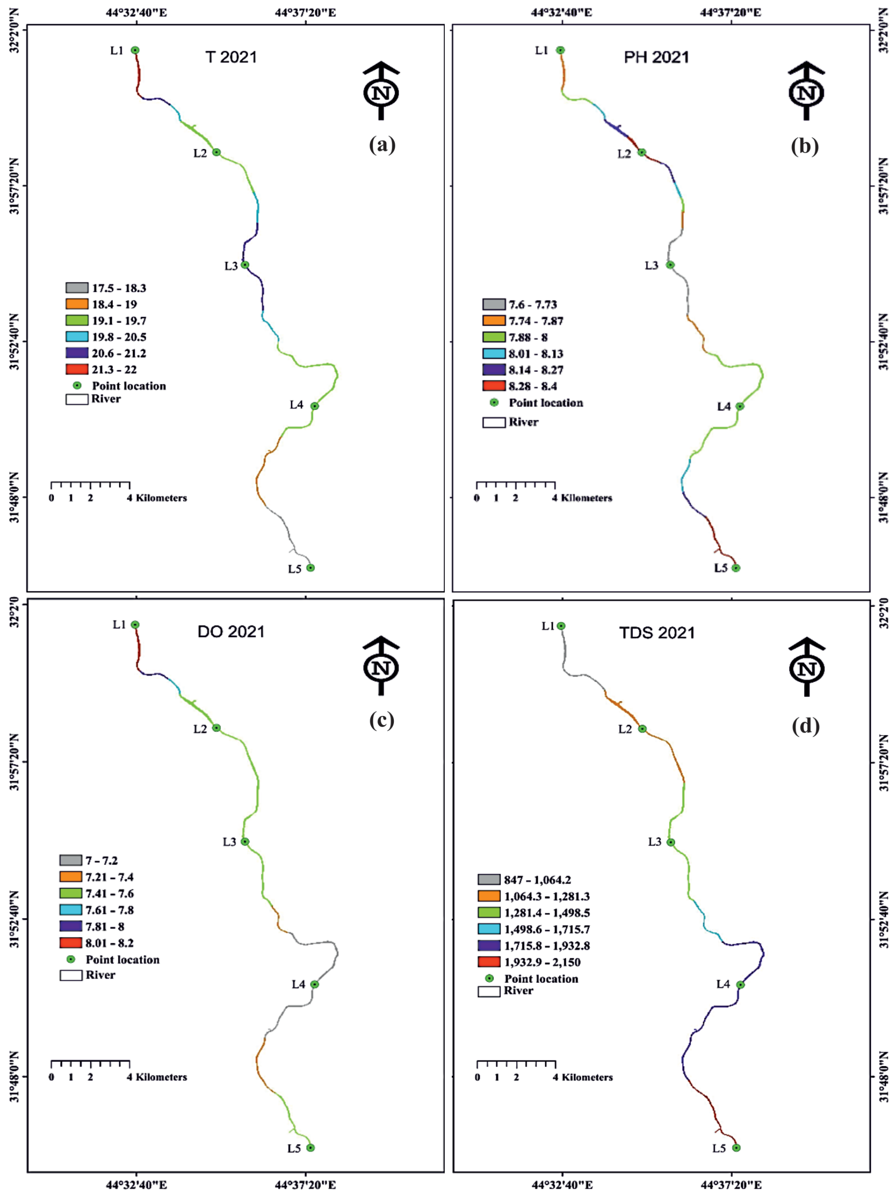

Fig. 5. GIS-colored map of, a) The hydrogen ions (pH 2021), b) Temperature (T 2021), c) Dissolved oxygen (DO 2021), and (d) Total dissolved solids (TDS 2021).

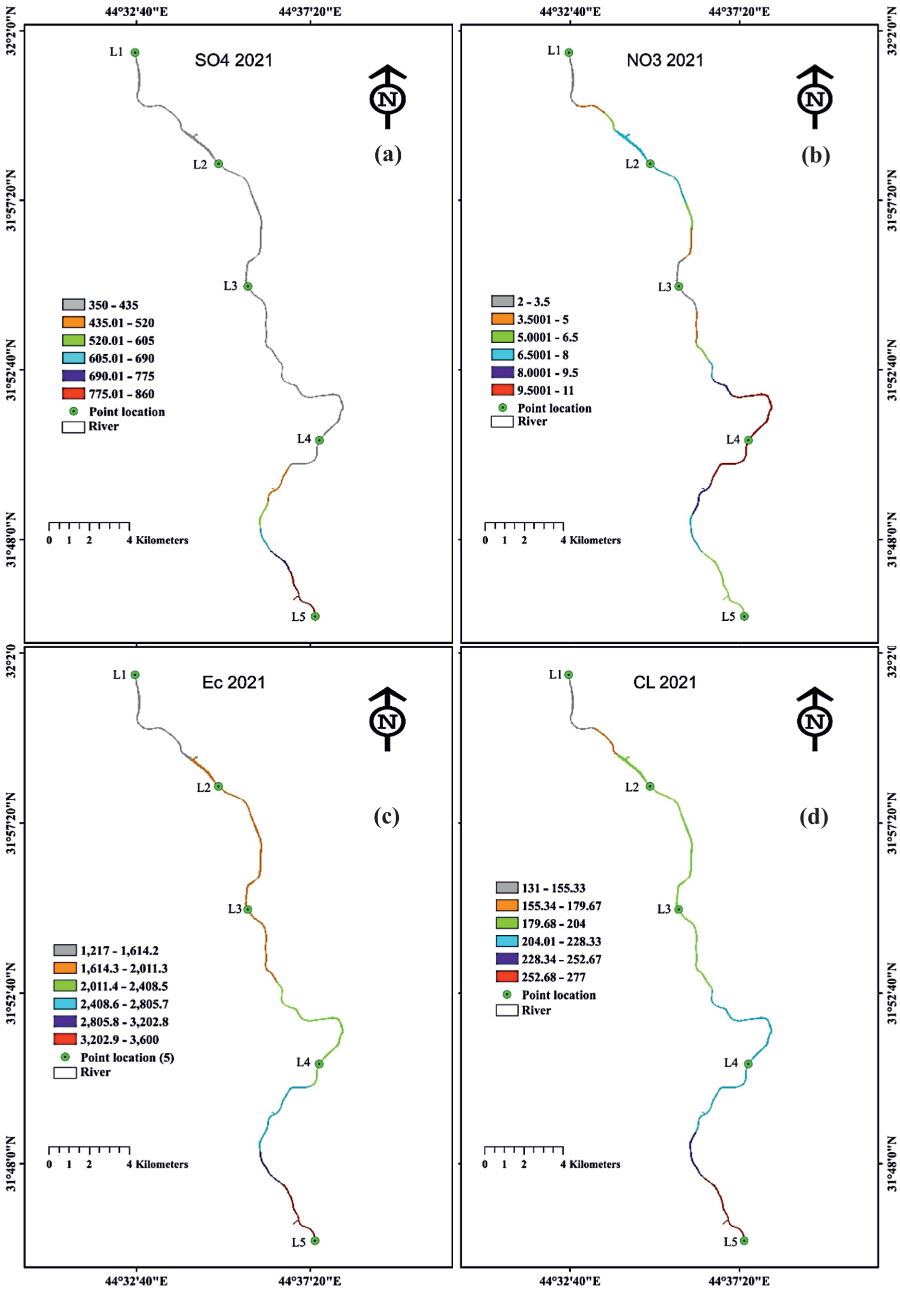

Fig. 6. GIS-colored map of, a) Sulfate (SO4 2021), b) Nitrate (NO3 2021), c) Electrical conductivity (EC 2021), and d) Chlorine (Cl 2021).

In conclusion, it is clear that the temperature of an aquatic environment has a great impact on the activity and growth of the microorganisms within it. Also, the water is frequently alkaline and has a pH between 7.6 and 8.5 (Fig. 5b). The changes in the pH values between the station come as a reaction to crossing the river in some villages and cities. The slightly different pH value that was discovered had no appreciable effects on fish habitat and was nearly identical to the optimum pH of fish blood (7.4). Once more, it stayed below the 8.5 tolerance threshold set by the EQS (Environmental Quality Standards). Although the pH levels were within the ranges permitted by Iraqi requirements for drinking water, location L5 was classified by the BWQI method as having parameters that would cause water quality to deteriorate in 2021.

Moreover, the most important water parameter is DO, which directly affects physiology, survival distribution, behaviour, and growth. Fish suffer from inadequate nutrition, hunger, stunted growth, and eventually reproduction when there is less oxygen in the water. The recommended Standard DO value for river water for fish production is between 6.0 and 6.5 mg/L. The current investigation found that the DO of water varied between 6.90 and 8.30 mg/L (Fig. 5c). The lowest DO was recorded at site L1 and varied between 7.00 and 7.20 mg L^{-1}, with the greatest DO measured at location L1 within the zone of red

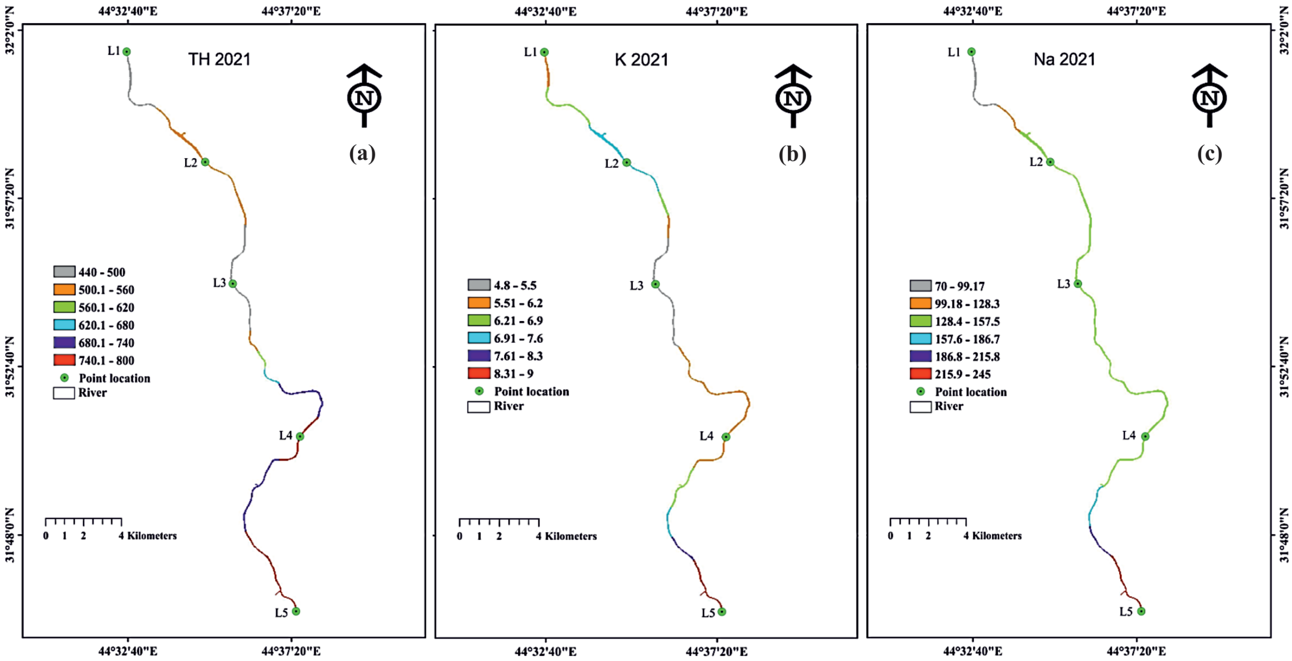

Fig. 7. GIS-colored map of, a) Total hardness (TH 2021), b) Potassium (K 2021), and c) Sodium (Na 2021).

colour (Fig. 5c). The reason for such differences in dissolved oxygen concentration between the sampling stations was the river crossed many towns and most of these towns did not have water treatment stations. The wastewater is discharged (directly or indirectly) to the river. The DO is an important factor in maintaining a healthy aquatic environment. This is because, when oxygen levels are low, fish may suffer from a variety of illnesses and physical ailments. If oxygen levels are too low, fish may experience difficulty in swimming, have difficulty absorbing nutrients, and die from a lack of oxygen. Low oxygen levels can also cause the growth of harmful bacteria and algae, which can further contribute to the degradation of water quality. There are about eight types of bacteria and thirteen types of algae [34].

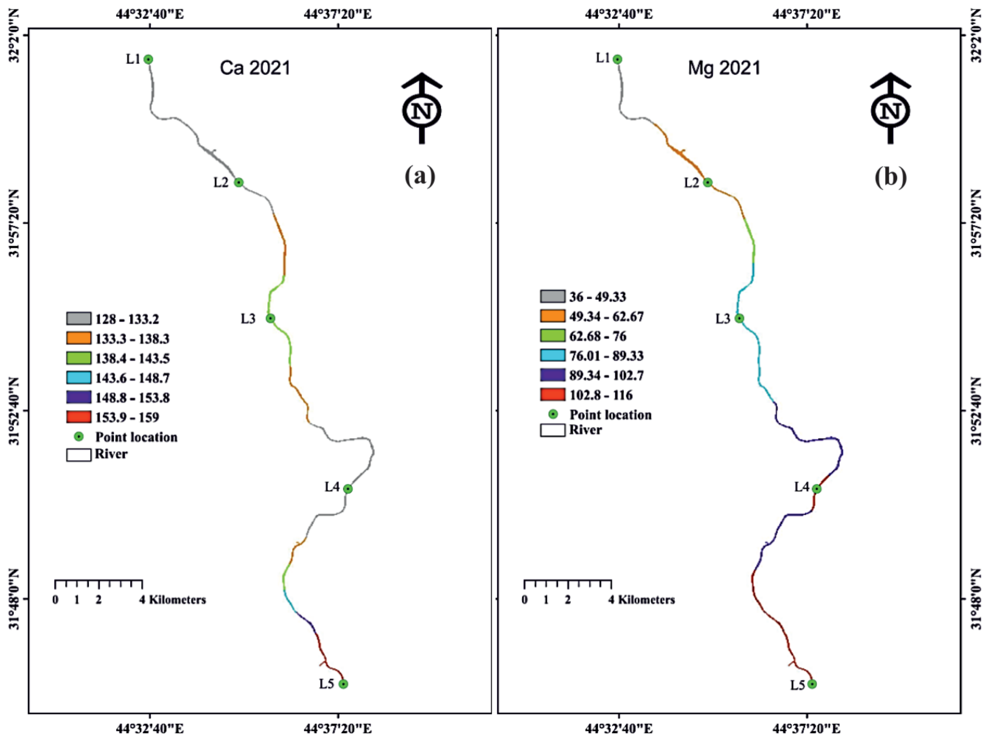

Fig. 8. GIS-colored map of, a) Calcium (Ca 2021), and b) Magnesium (Mg 2021).

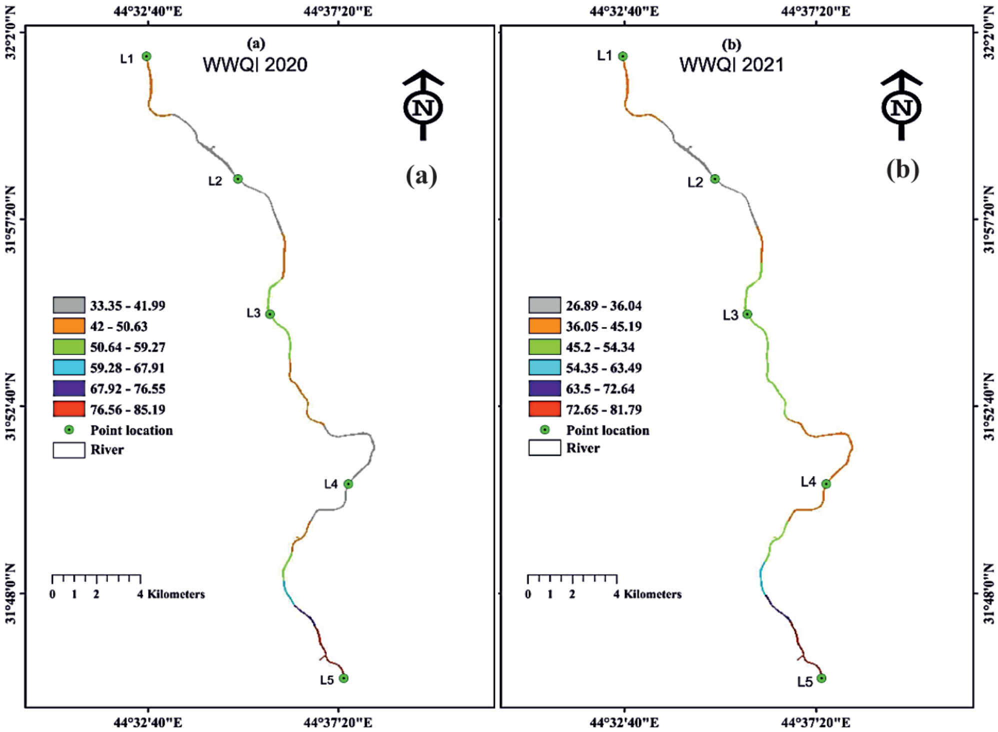

Fig. 9. The GIS map for the weighted arithmetic water quality index (WWQI) a) 2020, and b) 2021.

In addition, low oxygen levels can cause fish to become stressed, resulting in poor reproductive success and a decrease in the population size. It is thus imperative to monitor the DO levels in water bodies to ensure the health of fish populations. DO monitoring can be done by measuring the amount of dissolved oxygen in the water with the help of a DO meter. Additionally, it is important to maintain the ideal temperature of the water to ensure the optimal growth and survival of fish. Furthermore, proper management of pollutants, such as sewage, agricultural runoff, and industrial effluents, should be practiced preventing them from entering the water bodies, which would further reduce DO levels. With the implementation of these measures, fish populations will be able to thrive and sustain their numbers.

TDS value ranged from 847 to 2150 mg/L as seen in this study, which was likewise close to its average value (Fig. 5d). The ideal TDS value is 500 mg/L, while the maximum TDS value is 2000 mg/L. TDS, or total dissolved solids can be found in water supplies from a variety of sources, including sewage, runoff from cities and farms, and industrial effluent. TDS in drinking water may have negative impacts on one's health; however, there is no solid evidence to support this. Also, water samples had SO_4 values ranging from 330.0 to 910.0 (mg/L) (Fig. 6a). Nitrate enters groundwater through cesspools and fertilizer applications to lands. Another important source of nitrate is waste from factories that make chemical fertilizers. Additionally, 50 mg/L of nitrate is the permitted limit for surface water. The studies observed that NO_3 concentration ranged from 1.0 to 12.0 (mg/L) (Fig. 6b). The nitrate levels of the Euphrates River in Qadisiyah Province are likely decreased due to the presence of natural and man-made pollutants. Industrial activity and agricultural runoff from fertilizers and pesticides are the main contributors to pollution. Low water flow due to upstream country policies can also reduce nitrate concentrations.

The number of applications connected to water quality is determined using the measurement of conductivity. As an example, mineralization, quickly noting variations or changes in natural water and wastewater, estimating the sample size required for other chemical analyses, and figuring out how much chemical reagent or treatment chemicals should be added to a water sample are all examples of mineralization. TDS can also be measured using conductivity, which measures the ion content and freshness of the water. Conductivity has typically been determined to be twice as large as TDS. The maximum conductivity allowed is 5000 μScm^{-1}, whereas the optimal conductivity is 1500 μScm^{-1}. The observed conductivity ranged from 1156.0-3611.0 μScm^{-1} (Fig. 6c). Moreover, the Cl concentration that was detected in this investigation ranged from 127 to 281 mg/L. (Fig. 6d). The sample location L5 is coloured red for the highest value (281 mg/L), while L1 is coloured brick Gray for the lowest value (127 mg/L). Because Cl concentrations over about 250 mg/L can generate a perceptible taste in water, the findings demonstrated that the Cl content level in the river is favourable to fish. However, the threshold varies on the related cations. Moreover, the results presented in

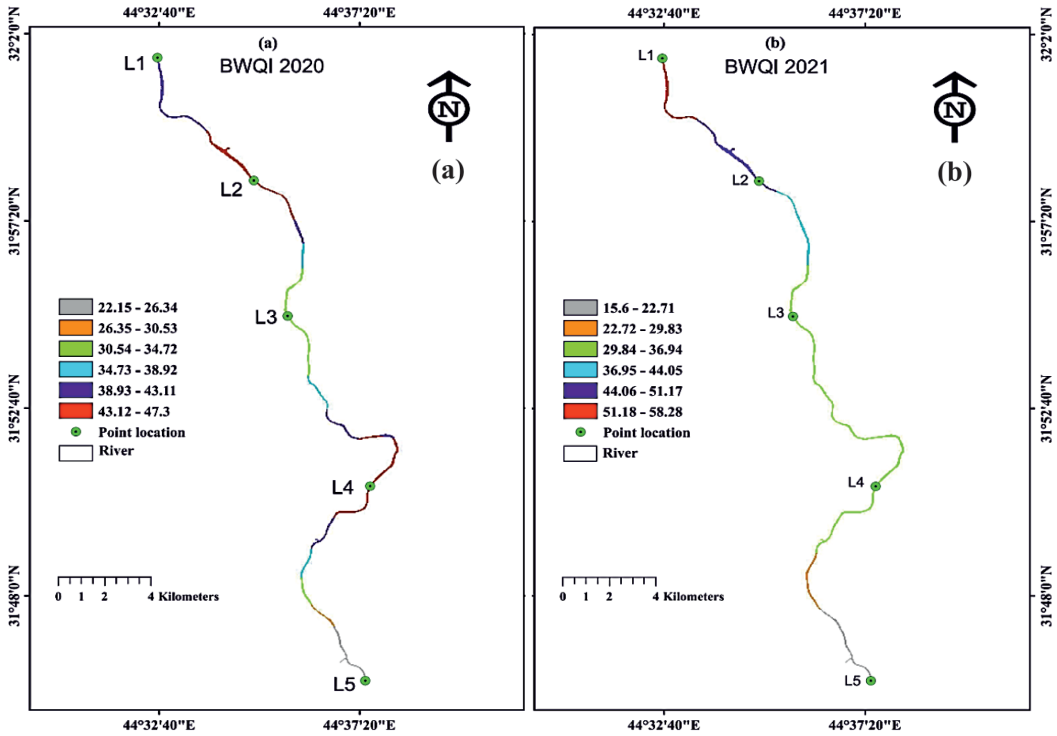

Fig. 10. The GIS map for Canadian water quality index (CWQI) a) 2020, and b) 2021.

for

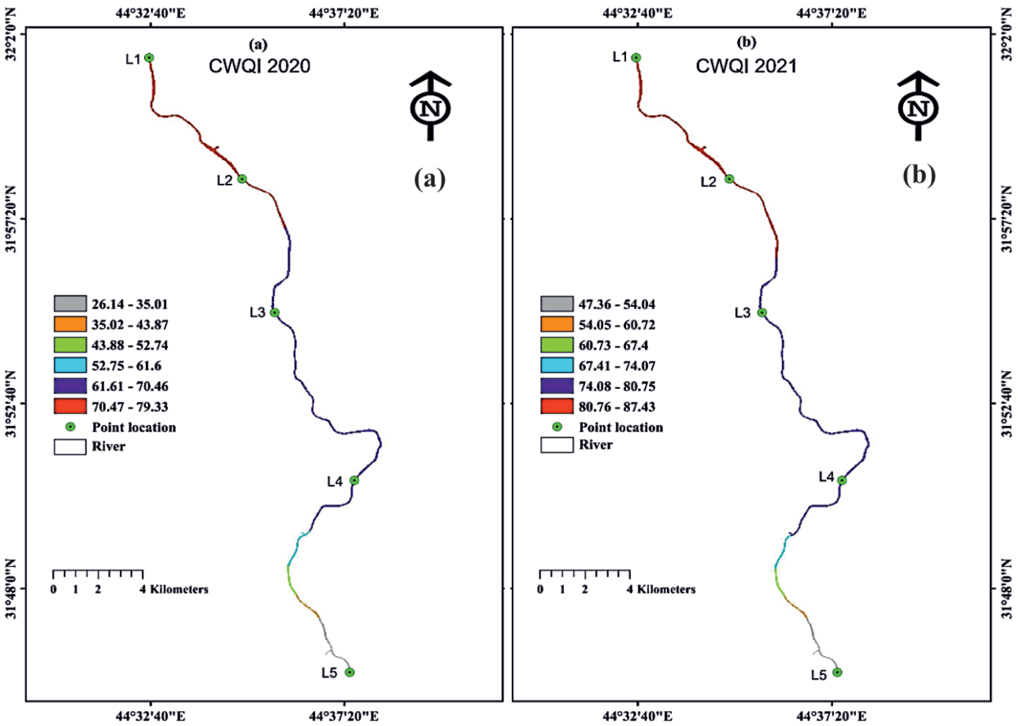

Fig. 11. The GIS map for Bascarón water quality index (BWQI) a) 2020, and b) 2021.

Figs 7 and 8 demonstrate that the concentrations of Mg, TH, Ca, Na, and K were higher than the Iraqi standard in locations L4 and L5. The concentration of Mg in L4 and L5 was 106 mg/l and 121 mg/l, respectively, with TH concentrations of 730 mg/l and 790 mg/l. The concentrations of Ca, Na, and K in L5 were also above the Iraqi standard. The higher concentrations of Mg, TH, Ca, Na, and K are due to various factors, including pollution from agricultural runoff, industrial wastewater, and wastewater, as well as natural sources like weathering of soil. Additionally, climate change and altered hydrological regimes can also contribute to the higher concentrations of these elements. This is concerning as high concentrations of these elements can lead to a decrease in water quality. Alkalinity is a measure of water's ability to buffer against changes in pH and is particularly important for aquatic organisms during the rainy season when concentrations of alkaline elements increase. Alkalinity can be increased by the addition of lime, calcareous materials, fertilizer through the leaching of agricultural land, and alkaline waste from industry. Therefore, it is important to monitor and control the concentrations of alkaline elements in water sources in order to maintain healthy aquatic ecosystems.

The spatial distribution of WQIs has been illustrated in the form of coloured maps to depict pollution zones in the water of the Euphrates River in the study area. The study data have related to ArcGIS 10.8 software to construct these layers. Analysis has been carried out to detect the problem areas and to help determine the zones of water quality that are suitable for consumption. Figs 9-11 display the GIS maps for the WQIs of the Euphrates River for 2020 and 2021 between the intakes of chosen stations.

According to the findings, the quality of the river at the study's selected locations was categorized as class "II" to class "V" according to the WWQI method, class "II" to class "IV" according to the CWQI method, and class "III" to class "IV" according to the BWQI method. The highest WQI values were 87.43% for CWQI recorded at L1 in 2021. High concentrations of pH, Ca, Mg, T.H., Na, SO_4, Cl, TDS, EC, and Alkalinity are the key water factors driving these degradations of WQIs values and accountable for the deterioration of river water. The high concentrations of pH, Calcium, Magnesium, Total Hardness, Sodium, Sulphate, Chloride, Total Dissolved Solids, Electrical Conductivity, and Alkalinity in the flowing water are the main water parameters causing these degradations of WQIs values and are responsible for the degradation of river water, as seen from the deterioration values of WQIs for each method. High quantities of sulphate are typically the primary water characteristic driving deterioration in the outcomes of water quality indices for specific areas (SO_4). Sulphates are oxygen and sulphur compounds that enter river water.

The main source of sulphates in rivers is from industrial wastewater, wastewater from agricultural activities, and runoff from urban areas. When sulphates enter the water, they react with the water to form insoluble salts and other compounds, which can have a negative effect on the water quality. High concentrations of sulphates can lead to a decrease in the dissolved oxygen content of the water, which can be harmful to aquatic life. Additionally, high amounts of sulphates can cause water to become more acidic and can also increase the number of metals present in the water. To improve the water quality of the river in the study area, effective and sustainable pollution control measures must be taken. Wastewater treatment plants should be established to reduce the levels of pollutants entering the river. Additionally, land use management should be implemented to reduce the amount of agricultural and urban runoff entering the river. Furthermore, public awareness campaigns should be conducted to educate the local population on the importance of protecting the water quality of the river. By taking these steps, it is possible to reduce the levels of pollutants and improve the water quality of the river.

Conclusions

The study demonstrated the WQIs' capacity to condense a lot of parameter information into a single number and express the data in a conceptually straightforward manner. The outcomes of WQIs can be used to assess the efficacy of river water and determine the necessity of preventive measures.

Three indexing techniques (WWQI, CWQI, and BWQI) have been applied in this work. The method of measuring the quality of water WQI enables a broad investigation of water quality on many levels that impact a stream's capacity to support life and determines whether the general quality of water bodies offers a possible risk to different water usage. By utilizing the CWQI for L1 in 2021, the water quality for the Euphrates reached a maximum of 87.43 and a minimum of 15.6 employing BWQI for L5 2021. According to WHO recommendations, the average WQI was low and not acceptable for drinking. The WQI value was low for the river in this section because of many factors like human activities, no sewage water treatment plants, and global warming.

In this study, the use of GIS maps helped to link the data that had been gathered and transform it into simplified and colourful maps with all the associated calculations, graphs, and outcomes. Additionally, the GIS technique made it simple to re-analyse and update data and could offer an accurate picture of water quality that could be used generally without revealing the majority of findings data.

This river is vital to the country's economy. This is a protected area where fish can breed. After treatment, the township receives its water supply for drinking. It is also utilized in the farming area for agriculture. A trace level of heavy metals was observed to be present. It can conclude that it will soon present a serious hazard to aquatic life. Determining specific pollutant sources was one of our study's main goals. In all the cities where the study was done, there were few industries and direct river discharge of wastewater. Agriculture-related pesticides and insecticides can contribute to pollution. The appropriate actions should be made right away to preserve this natural resource. Stop in particular the direct discharge of wastewater into rivers, which adds pollution in all the cities. Before being discharged directly, these industries' effluents should be treated. In the end, farming ought to be controlled, and everyone ought to care about it. It is distressing to learn that the local population would lose their main natural economic source if immediate action is not taken.

The results of the water quality tests of the Euphrates River in Qadisiyah Province present a dire situation that needs to be addressed immediately. Without proper wastewater treatment or environmental monitoring, the river has become increasingly polluted, resulting in decreased water quality and biodiversity. The water quality index results suggest that the river is in a state of poor to good health, depending on the WQI method used. This has serious implications for the local population, who rely on the river for drinking water, and local aquatic life, which is now threatened. To ensure the long-term sustainability of the Euphrates River, a comprehensive monitoring program must be implemented. This program should include regular testing of the water quality, as well as periodic monitoring of the sources of pollution. Additionally, an effective management plan should be established to ensure that wastewater is properly treated before being discharged into the river. This will result in improved water quality, a healthier aquatic ecosystem, and better water availability for the local population. Immediate action must be taken to protect and preserve the Euphrates River. With the implementation of an effective monitoring and management program, the river will be able to continue to support healthy aquatic life and provide safe drinking water to the local population.

Acknowledgment

The authors would like to thank all the staff of the Environment Laboratories at the University of Babylon for their assistance and support. The authors would like to grateful Lulea university of technology-Sweden, and Al-Mustaqbal University College-Iraq for supporting the paper with the fund.

Conflict of Interest

The authors declare no conflict of interest.

References

1. World Health Organization, 2021. Silver in drinking water: Background document for development of WHO Guidelines for Drinking-water Quality (No. WHO/HEP/ECH/WSH/2021.7). World Health Organization, **2021**.
2. UNESCO, United Nations Educational. Scientific and Cultural Organization. Wastewater: The Untapped Resource. The report, Paris, France, **2017**. ISBN 978-92-3-100201-4.
3. AL-SAID T., AL-GHUNAIM A., SUBBA R.D.V., AL-YAMANI F., AL-RIFAIE K., AL-BAZ A. Salinity-driven decadal changes in phytoplankton community in the NW Arabian Gulf of Kuwait. Environmental monitoring and assessment, **189**, 1, **2017**.
4. AL-ZAIDY K.J., PARISI G., ABED S.A., SALIM M.A. 2019, September. Classification of the key functional diversity of the marshes of southern Iraq marshes. In Journal of Physics: Conference Series **1294** (7) 072021IOP Publishing, **2019**.
5. AL-ANSARI N., JAWAD S., ADAMO N., SISSAKIAN V. Water quality and its environmental implications within Tigris and Euphrates rivers. Journal of Earth Sciences and Geotechnical Engineering, **9** (4), 57, **2019**.
6. AFED ULLAH K., JIANG J., WANG P. Land use impacts on surface water quality by statistical approaches. Global Journal of Environmental Science and Management, **4** (2), 231, **2018**.
7. YILMAZ E., KOÇ C., GERASIMOV I. A study on the evaluation of the water quality status for the Büyük Menderes River, Turkey. Sustainable Water Resources Management, **6**, 1, **2020**.
8. KACHROUD M., TROLARD F., KEFI M., JEBARI S., BOURRIÉ G. Water quality indices: Challenges and application limits in the literature. Water, **11** (2), 361, **2019**.
9. TRIPATHI M., SINGAL S.K. Use of principal component analysis for parameter selection for development of a novel water quality index: a case study of river Ganga India. Ecological Indicators, **96**, 430, **2019**.
10. POONAM T., TANUSHREE B., SUKALYAN C. Water quality indices-important tools for water quality assessment: a review. International Journal of Advances in Chemistry, **1** (1), 15, **2013**.
11. LUZATI S., JAUPAJ O. Assessment of Water Quality Index of Durresi-Kavaja Basin, Albania. Journal of International Environmental Application and Science, **11** (3), 277, **2016**.
12. ZOTOU I., TSIHRINTZIS V.A., GIKAS G.D. Water quality evaluation of a lacustrine water body in the Mediterranean based on different water quality index (WQI) methodologies. Journal of Environmental Science and Health, Part A, **55** (5), 537, **2020**. https://doi.org/10.1080/10934529.2019.1710956
13. EWAID S.H., ABED S.A., AL-ANSARI N., SALIH R.M. Development and evaluation of a water quality index for the Iraqi rivers. Hydrology, **7** (3), 67, **2020**. https://www.ncciraq.org/images/infobygov/NCCI_Qadissiya_Governorate_Profile.pdf
14. MAURYA P.K., ALI S.A., ALHARBI R.S., YADAV K.K., ALFAISAL F.M., AHMAD A., DITTHAKIT P., PRASAD S., JUNG Y.K., JEON B.H. Impacts of Land Use Change on Water Quality Index in the Upper Ganges River near Haridwar, Uttarakhand: A GIS-Based Analysis. Water, **13** (24), 3572, **2021**.
15. NOORI M.M., ABDULRAZZAQ K.A., MOHAMMED A.H., ABBAS A.I. Assessment of water quality and suitability of Euphrates river in Iraq for drinking purpose by applying water quality indices (WQIs) and geographical information system (GIS) techniques. International Journal of Science and Nature, **8** (4), 741, **2017**.
16. JASROTIA A.S., TALOOR A.K., ANDOTRA U., KUMAR R. Monitoring and assessment of groundwater quality and its suitability for domestic and agricultural use in the Cenozoic rocks of Jammu Himalaya, India: a geospatial technology based approach. Groundwater for Sustainable Development, **8**, 554, **2019**.
17. NCCI (NGO Coordination Committee for Iraq). Qadissiya Governorate Profile, **2015**.
18. TYAGI S., SHARMA B., SINGH P., DOBHAL R. Water quality assessment in terms of water quality index. American Journal of water resources, **1** (3), 34, **2013**.

19. AL-MANSORI N.J. Develop and Apply Water Quality Index to Evaluate Water Quality of Shatt-Al-Hilla River. Journal of University of Babylon, **25** (2), 368, **2017**.
20. AKHTAR N., ISHAK M.I.S., AHMAD M.I., UMAR K., MD YUSUFF M.S., ANEES M.T., QADIR A., ALMANASIR A.Y.K. Modification of the water quality index (WQI) process for simple calculation using the multi-criteria decision-making (MCDM) method: a review. Water, **13** (7), 905, **2021**.
21. UDDIN M.G., NASH S., OLBERT A.I. A review of water quality index models and their use for assessing surface water quality. Ecological Indicators, **122**, 107218, **2021**.
22. SUN W., XIA C., XU M., GUO J., SUN G. Application of modified water quality indices as indicators to assess the spatial and temporal trends of water quality in the Dongjiang River. Ecological Indicators, **66**, 306, **2016**. https://doi.org/10.1016/j.ecolind.2016.01.054
23. KAR S., GHOSH I., CHOWDHURY P., GHOSH A., AITCH P., BHANDARI G., ROYCHOWDHURY A. A model-based prediction and analysis of seasonal and tidal influence on pollutants distribution from city outfalls of river Ganges in West Bengal, India and its mapping using GIS tool. PLOS Water, **1** (2), e0000008, **2022**.
24. ALANBARI M.A., ALQUZWEENI S.S., ALDAHER R.A. Spatial distribution mapping for various pollutants of al-Kufa river using geographical information system (GIS). International Journal of Civil Engineering and Technology (IJCIET), **6** (10), 1, **2015**.
25. MATEJICEK L. Spatial modelling of air pollution in urban areas with GIS: a case study on integrated database development. Advances in Geosciences, **4**, 63, **2005**.
26. CHILDS C. Interpolating surfaces in ArcGIS spatial analyst. ArcUser, July-September, **3235** (569), 32, **2004**.
27. WANG C., YANG D., XU H. Engaging Students in Learning the Relations of Geographical Elements through GIS-Enabled Property Price Visualization. Education Sciences, **12** (10), 727, **2022**.
28. HASAN Z.I., TALEB A.H. Assessment of the Quality of Drinking Water for Plants in the Al-Karkh, Baghdad, Iraq. Ibn AL-Haitham Journal For Pure and Applied Science, **33** (1), 1, **2020**.
29. HASSAN F.M., MAHMOOD A.R. Evaluate the efficiency of drinking water treatment plants in Baghdad City-Iraq. Journal of Applied & Environmental Microbiology, **6** (1), 1, **2018**.
30. HASHIM N.A., AL FATLAWI S. Arithmetic Water Quality Index of the Euphrates River in Al-Musyiab/Babil province-Iraq. Journal of Survey in Fisheries Sciences, **10** (1), 100, **2023**.
31. SAAD-HUSSEIN A., RAMADAN H.K.A., BAREEDY A., ELWAKIL R. Role of climate change in changing hepatic health maps. Current Environmental Health Reports, **9** (2), 299, **2022**.
32. GAURY P.K., MEENA N.K., MAHAJAN A.K. Hydrochemistry and water quality of Rewalsar Lake of Lesser Himalaya, Himachal Pradesh, India. Environmental monitoring and assessment, **190**, 1, **2018**.
33. SAHA A., RAMYA V.L., JESNA P.K., MOL S.S., PANIKKAR P., VIJAYKUMAR M.E., SARKAR U.K., DAS B.K. Evaluation of spatio-temporal changes in surface water quality and their suitability for designated uses, Mettur Reservoir, India. Natural Resources Research, **30**, 1367, **2021**.
34. HUSSEIN A.J., MAHAL J.D. Bacterial and Algal Components of Sediments Close to Sources of Sewage Drainage in The Euphrates River, Anbar Governorate. European Journal of Molecular & Clinical Medicine, **7** (8), 1383, **2020**.