Available online at www.CivileJournal.org

# Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 12, No. 04, April, 2026

# Assessment of Pollution Linked to Surface-Active Materials and Nutrients in Lotic Ecosystem

Rana R. Al-Ani [1*], Zahraa Z. Al-Janabi [2], Fikrat M. Hassan [3], Abdul Hameed M. J. Al-Obaidy [4], Ali N. Al-Aamel [2], Ahmed Al-Taie [2]

[1] *Scientific Affairs Department, University of Technology, Baghdad, Iraq.*

[2] *Environmental Research Center, University of Technology, Baghdad, Iraq.*

[3] *Department of Biology, College of Science for Women, University of Baghdad, Iraq.*

[4] *Department of Civil Engineering, University of Technology, Baghdad, Iraq.*

Received 16 May 2025; Revised 03 March 2026; Accepted 09 March 2026; Published 01 April 2026

**Abstract**

The Tigris River is one of the main rivers and an important resource for the population of Iraq. The present study aimed to quantify the concentration of surface-active substances in the Tigris River and to investigate the dynamics of this ecosystem. Five sampling sites were selected along the river within Baghdad city (Al-Muthanna Bridge, Al-Greaat Bridge, Al-Sarrafia Bridge, Al-Jadriyah Bridge, and Al-Za'franiya Area) for the period from July 2020 to April 2021. The study examined the relationship between the concentrations of surface-active materials (surfactants, including anionic and nonionic types) and their potential interaction with nutrients—nitrate ($NO_3^-$), phosphate ($PO_4$), and sulfate ($SO_4^{2-}$)—as well as the influence of various physicochemical water parameters on surfactant concentrations. The results of the descriptive analysis of water parameters during the dry and wet seasons showed variations and elevated concentrations of some parameters beyond permissible limits, such as TDS, $NO_3^-$, $PO_4$, $SO_4^{2-}$, and DO. According to the OIP analysis, only Site 2 (Al-Greaat Bridge) was classified as polluted (Class-C4) during the wet season (6.58), while the other sites were categorized as slightly polluted (Class-C3) in both dry and wet seasons. Principal component analysis (PCA) indicated that $PO_4$, TDS, and $NO_3^-$ were the most influential parameters and had a strong positive relationship with anionic surfactants. Regarding temporal variation, higher values of TDS, $NO_3^-$, $PO_4$, $SO_4^{2-}$, and DO were observed during the dry season. This reflects the impact of human activities (agriculture, industrial discharge, and sewage effluents) and natural processes (rainfall, evaporation, and biological activity) on the water quality of the Tigris River. Therefore, the Tigris River faces significant water quality challenges due to both anthropogenic and natural factors. Effective management strategies are essential to mitigate these impacts and protect the health of the river ecosystem and the communities that depend on it. The findings of this study align with Sustainable Development Goal (SDG) 6, which focuses on clean water and sanitation.

*Keywords:* Physicochemical Parameters; Anionic Surfactant; Tigris River; Nutrients; OIP Analysis; Detergents; SDG 6.

## 1. Introduction

One of the most important components of existence is water. It is used worldwide for municipal, industrial, and agricultural purposes and is always vulnerable to pollution [1]. There is a global water shortage due to the increasing demand for the world's water supply in many areas of life [2-4].

* Corresponding author: rana.r.khaleel@uotechnology.edu.iq

https://doi.org/10.28991/CEJ-2026-012-04-016

In Iraq, the most common source of water supply is the surface water, especially the Tigris and Euphrates Rivers and their tributaries. There was a huge decline in the water levels of the Tigris River within Baghdad City that had caused a significant reduction in the operation of twelve water supply projects on the banks of the Tigris River within Baghdad City; this is the result of major climate changes and increasing hydraulic construction (dams) activities and more such projects in Turkey. These changes have caused the water level to decline drastically in its flow rates of about 46% [5].

The Tigris River, which divides the capital Baghdad into the right part (Karkh) and left part (Rusafa), with its flow direction from north to south, is one of the most important surface water resources in Iraq [6]; as a result of the slow pace of sedimentation, several islands and river tributaries were formed. The environment of plants and living organisms is threatened by the pollution of river water and the spread of harmful chemicals as a result of human activities, such as companies dumping sewage into the river without any actual treatment as it passes through the city of Baghdad [7].

The majority of detergents used globally consist of 40% nonionic surfactants (NS) and 50-60% anionic surfactants (AS) [8]. Surface-active agents are shortened to surfactants or detergents. These natural substances possess one or more hydrocarbon chains and can be either hydrophilic or hydrophobic [9]. In addition to being commonly used in laundry, surfactants are used in emulsions, insecticide formulations, fibers, wetting agents, cosmetics, and textile processing [10]. Depending on the hydrophilic part's charge, surfactants are classified into anionic, cationic, and nonionic. Various industrial and domestic uses include the application of surfactant molecules of a particular structure. They are, therefore, delivered to the environment in various ways, including soil, water, and sediment components. Many physical and chemical processes, including adsorption, degradation, and free transfer, occur with surfactants [11-13]. They are highly concentrated, as evidenced by their high absorption in sediments [14, 15].

Moreover, solid waste generated by sewage treatment plants is discharged into the river. The ways in which these materials behave and interact with other elements within the surrounding environment vary [16]. Bioaccumulation is one-way surfactants pose a risk to the environment. It can have a negative impact on toxicity and endocrine balance disruption, among other biological components of the ecosystem. In addition, they promote the dissolution of organic pollutants in water, which may cause migration and accumulation in different environmental sectors [15, 17]. Bioaccumulation of surfactants is viewed as an environmental concern that negatively impacts biological components of the ecosystem (e.g., toxicity and disruption of endocrine homeostasis). These materials contribute to dissolving more organic pollutants in the water, which may lead to their migration and accumulation in other environmental parts, such as plants and sediments. Furthermore, synthetic detergents, even in the smallest permissible quantities, are carcinogenic as well as toxic [15].

The chemical components and elements present in the environments necessary for the life and development of plants and animals are known as nutrients. The nutrients of interest in water quality research are the various forms of phosphorus and nitrogen. The forms consist of ammonia, nitrate, nitrite, phosphate (including orthophosphate), and organic nitrogen (found in plant matter or other organic molecules). In natural waterways, $PO_4^{3-}$ is the most prevalent form of phosphorus, while $NO_3^-$ ) is the most common form of nitrogen. Elevated nutrient concentrations in aquatic environments can lead to eutrophication and hypoxia [18, 19].

Al-Ani et al. (2020) [20] studied the qualitative, quantitative, ecotoxicity, and environmental fate of surfactants in aquatic sediment in the Tigris River (Baghdad City, Iraq). They found these compounds in the sediment, which is considered the sink of most pollutant compounds. Rizvi et al. (2021) [21] studied the capability of bio-surfactant produced from *Starmerella bombicola* in emulsifying oil pollutants under harsh environmental conditions, which provides a green remediation strategy. Saxena et al. (2023) [22] illustrated that surfactants can be used for the removal of and eliminate some toxic agents from wastewater, like personal care products, volatile organic compounds, dyes, pesticides, pharmaceutical effluents, petroleum hydrocarbons, and nutrient ions (phosphate and nitrate). For this reason the surfactants provide an efficient process to improve wastewater treatment systems. Caesar et al. (2024) [23] studied the poorly degraded surfactants and their negative effects on the aquatic ecosystem through the analysis of the water quality parameters and concentrations of these compounds in the Porong River, also to determine their correlation.

This research aims to measure the concentration of surface-active substances (anionic and nonionic surfactants, which are the basic detergent compounds) in the Tigris River, which has high toxicity to aquatic organisms, and explore the interplay between surfactants, nutrient concentration, and environmental dynamics in the river.

## 2. Material and Methods

### 2.1. Studied Sites

Five sites in Baghdad city along the Tigris River were chosen for this study (Figure 1). The GPS locations of the studied sites are shown in Table 1: Al-Muthanna Bridge, Al-Greaat Bridge, Al-Sarrafia Bridge, Al-Jadriyah Bridge, and Al Za'franiya Area (see Figure 2).

**Table 1. The GPS of the study site**

| Sites | Position | Longitude | Latitude |
|---|---|---|---|
| S 1 | Al-Muthanna Bridge | 44°20'43.30"E | 33°25'42.19"N |
| S 2 | Al-Great Bridge | 44°20'55.54"E | 33°23'26.41"N |
| S 3 | Al-Sarrafia Bridge | 44°22'22.84"E | 33°21'11.55"N |
| S 4 | Al-Jadriyah Bridge | 44°22'27.69"E | 33°17'1.39"N |
| S 5 | Al-Za'franiya Area | 44°27'18.95"E | 33°14'0.08"N |

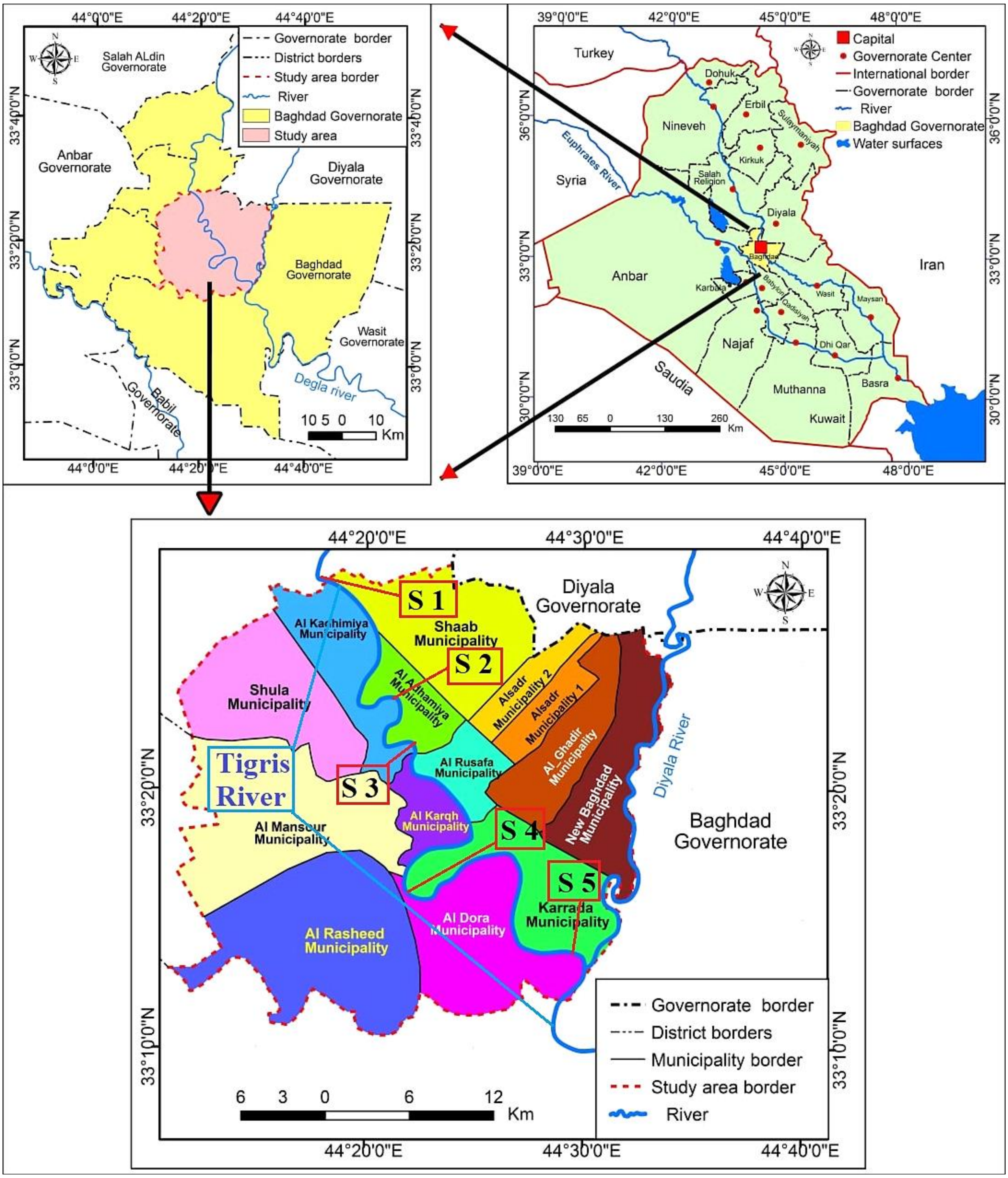



**Figure 1. Studied Sites**


**Figure 2. Images show the sites studies, a) Al-Muthanna Bridge (S 1), b) Al-Great Bridge (S 2), c) Al-Sarrafia Bridge (S 3), d) Al-Jadriyah Bridge (S 4), e) Al-Za'franiya Area (S 5)**

The river divides Baghdad into two regions, Karkh and Rusafa, and is more than 50 kilometers long [24]. These five sites were chosen carefully, where each site has a characteristic effect on the water quality of the Tigris River. The first site is considered the reference site, located in northern Baghdad, before the Tigris enters the city, which means before affecting the population of Baghdad city. Site 2 is influenced by tourism activities, where there are a lot of restaurants on both sides of the river, in addition to the movement of the boats. Site 3 is affected greatly by the effluent of Baghdad Medical City and by small-scale industries.

As the river goes down to sites 4 and 5, the population increases, and in turn, the pollution load increases. In addition, in site 5, there are a lot of governmental and private industrial facilities at the banks of the river, like the Al-Dora Oil Refinery, Alrasheed gas and thermal power plant, and Al-Dora power plant. So, the water of the river is used for various activities like cooling and irrigation and providing raw water to the drinking water treatment plants on both banks [1, 25]. The majority of industrial and municipal pollutants were improperly treated and deposited directly into the river [26].

## 2.2. Sample Collection and Preservation

*Physical and chemical water parameters*: three samples were taken from each site (one from the center and two from the bank of the Tigris River in a polyethylene bottle) from July/2020 to April/2021. The samples were collected from the surface water (20-30 cm) between 7:00 am and 6:00 pm. The bottles of water samples were washed many times (at least 3 times) by river water before filling and then kept chilled in an ice cooler box during transport to the laboratory. At the Environment Research Center, University of Technology/Iraq, laboratory measurements were performed within 24 hours of sampling (Figure 3).

*Surfactant*: Five sites provided collected water samples for surfactant measuring. Using graduated glass bottles, one liter of river water was collected at 5 to 10 cm depth between 7 am and 6 pm from July 2020 to April 2021. Collection samples were cleaned with 10% hydrochloric acid (HCL), rinsed with deionized water, and left to dry. A second rinse with 50-100 mL methanol was performed, followed by another wash with deionized water, and then it was allowed to dry. In order to preserve the samples before testing, formaldehyde (37-40%) was used (30 ml) [27]. Water samples were stored at 4°C in the laboratory before surfactant analysis [28].

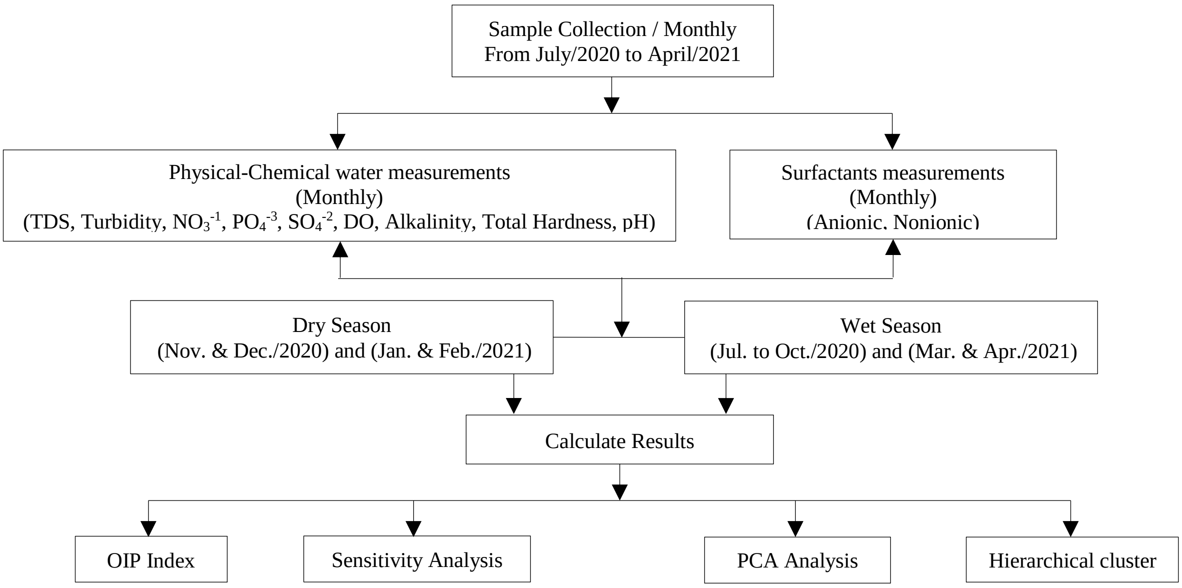



**Figure 3. Methodology Process**

## 2.3. Sample Testing

- The obtained water samples were examined to confirm total dissolved substances (TDS), Turbidity, Nitrate ($NO_3^{-1}$), Phosphate $PO_4^{-3}$, Sulfate $SO_4^{-2}$, Dissolved oxygen (DO), Alkalinity, Total Hardness, and pH. These water parameters were measured using standard methods [29].
- Water samples for surfactants determination:
  - Regarding Anionic surfactants. First, the pH of water samples was adjusted from 5 to 10 using drops of sulfuric acid ($H_2SO_4$) or sodium hydroxide solution (NaOH). After adding 2 drops of T-1K reagent (active ingredients for methylene blue) to 5.0 mL of the water sample in the reaction cell without mixing, the cell is shaken for 30 seconds, then left for 10 minutes to allow the reaction to occur. Finally, a photometer (Photolab S 12 device (WTW) ba75433e09 06/2014) was used for the measurements [30].
  - Nonionic surfactants. The same way as above, the pH of the samples is adjusted to about 3-9. 4.0 mL of the water sample is added to the reaction cell and mixed for 1 minute. Then the cell is given 2 minutes to complete the response time. The photometer Photolab S 12 device is then used for the measurements (WTW) ba75433e09 06/2014 [30].

## 2.4. Climate Exploration Area

Daily and seasonal fluctuations characterize Iraq's climate. The result was a large temperature contrast between summer and winter. The area enjoys hot, dry summers and milder winters due to its arid to semi-arid environment. Baghdad International Airport/Al-Furat District/Ministry of Transport/Iraqi Meteorological organization and Seismology obtained the climate factor results from July 2020 to April 2021. These results showed that precipitation ranged from 0 to 84.2 mm, air temperature ranged from 47.4 to 4.7 °C, total precipitation ranged from 71.3 to 448.7 mm, and relative humidity (RH %) ranged from 21 to 69%.

According to the humidity level, there are two basic seasons in Iraq: the wet season (Jul. and Oct./2020 & Mar. & Apr./2021), which lasts longer than 50% relative humidity, and the dry season (Nov. & Dec./2020 and Jan. & Feb./2021), which lasts less than 50% relative humidity [31] (Table 2).

**Table 2. Monthly Climate data during the study period**

| Month | Jul-2020 | Aug-2020 | Sep-2020 | Oct-2020 | Nov-2020 | Dec-2020 | Jan-2021 | Feb-2021 | Mar-2021 | Apr-2021 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean RH% | 21 | 24 | 27 | 34 | 60 | 69 | 55 | 59 | 41 | 31 |

### 2.5. Overall Index of Pollution (OIP)

OIP was adopted to show the health status of water in the studied area**.** The index was calculated using Equations 1 and 2 [32]:

$$\text{OIP} = \frac{1}{n}\sum_{i=1}^{n} Pi \tag{1}$$

$$Pi = \frac{Vn\,(Obseved\ value\ of\ parameter}{Vs\,(Standard\ alue\ of\ parameter)} \tag{2}$$

Sargaonkar & Deshpande (2003) [32] classified the water quality into 5 classes based on the OIP score (Table 3). The calculation of the index depends on the measured physicochemical parameters, and is compared with the standard value of each parameter, 10 parameters were chosen to run the index (TDS, Turbidity, Nitrate ($NO_3^{-1}$), Phosphorus ($PO_4^{-3}$), Sulfate ($SO_4^{-2}$), DO, Alkalinity, Hardness, pH, and Anionic surfactant).

**Table 3. Water quality classification according to OIP [32]**

| Class | OIP score | Water quality status |
|---|---|---|
| Class-C1 | 0-1 | Excellent |
| Class-C2 | 1-2 | Acceptable |
| Class-C3 | 2-4 | Slightly polluted |
| Class-C4 | 4-8 | Polluted |
| Class-C5 | 8-9 | Heavily polluted |

### 2.6. Data Analysis

Jeffreys's Amazing Statistics Program (JASP) for statistical analysis based on R programming language was used to handle the data, and the following tests were done.

#### 2.6.1. Sensitivity Analysis

The water quality data set from the case study was used for the sensitivity test to evaluate the effective water quality parameters and determine the relationship between water pollution and surface-active materials and nutrients. The sensitivity test used Backward Linear Regression (BLR) to evaluate the importance of the input parameters; different models were developed by eliminating one parameter from each run. BLR performance model was evaluated using the coefficient of determination (R2), Sum Squares Error (SSE), and Root Mean Square Error (RMSE).

#### 2.6.2. Principle Components Analysis (PCA)

Principal Components Analysis and Pearson correlation were calculated. Tukey's test assessed the Tigris River's significant differences in water parameters between wet and dry seasons. A method of statistical feature extraction called principal components analysis (PCA) reduces the number of independent variables from a set of original parameters. A statistical feature extraction method, Principal Component Analysis (PCA), reduces the number of independent variables from a combination of the original parameters [33].

#### 2.6.3. Hierarchical Cluster

Multivariate data analysis includes spatial and temporal clustering analysis for data. Cluster methods groups objects by measuring the distances and identifying each cluster. This is because clusters that are close together according to one metric can be distant from each other according to another metric. High-similarity objects will be grouped in one cluster, while low-similarity objects will be in different clusters [34].

## 3. Results and Discussion

### 3.1. Descriptive Analysis of Physicochemical Water Properties during the Study Period

Table 4 illustrates the descriptive analysis of physicochemical characteristics (mean, standard deviation and range) for both seasons (Dry and Wet) of the Tigris River. For each parameter of river water, the results were compared with local and global determinants of river water [35-38].

**Table 4. Physicochemical characteristics of Tigris River during the study period**

| Parameters | Dry season | | Wet season | | Standard value Law 25, 1967* |
|---|---|---|---|---|---|
| | Mean ±SD | Mini-Maxi | Mean ±SD | Mini-Maxi | |
| Total Dissolved Solids (TDS) (mg/L) | 595.0±100.4 | 425.4-697.9 | 678.3±96.8 | 611.7-820.9 | 500** |
| Turbidity (NTU) | 34.3±12.7 | 15.3-50.1 | 22.4±8.5 | 15.5-34.6 | 50*** |
| Nitrate ($NO_3^-$) (mg/L) | 5.5±4.1 | 0.0-10.8 | 5.3±1.9 | 3.1-7.6 | 1 |
| Phosphorus ($PO_4$) (mg/L) | 0.33±0.30 | 0.06-0.96 | 1.1±0.7 | 0.6-2.2 | 0.40 |
| Sulfate ($SO_4^{-2}$) (mg/L) | 190.6±32.3 | 141.8-223.6 | 228.9±10.8 | 215.2-241.2 | 200 |
| Dissolved Oxygen (DO) (mg/L) | 6.3±0.6 | 5.7-7.4 | 8.1±0.5 | 7.5-8.7 | 5 |
| Alkalinity (mg/L) | 168.8±52.7 | 96.6-253.9 | 163.0±15.5 | 143.1-180.4 | - |
| Total Hardness (TH) (mg/L) | 328.4±38.0 | 273.6-370.0 | 364.1±28.9 | 341.9-404.7 | - |
| pH | 7.9±0.3 | 7.7-8.4 | 8.1±0.2 | 7.8-8.4 | 6.5-8.5 |
| Anionic S. (mg/L) | 0.1±0.1 | 0.04-0.3 | 0.4±0.1 | 0.2-0.5 | 1**** |

Note: *(Law No. 25, 1967) [35]; **(Teixeira de Souza et al. [33]); ***(U.S. Environmental Protection Agency [36]; ****(Sargaonkar & Deshpande) [32].

From the ten parameters analyzed, the TDS exceeded the value limits for the dry season (697.9 mg/L in October 2020) and wet season (611.7 mg/L in December 2020 to 820.9 mg/L in February 2021). For the dry season, the reason is attributed to many factors such as high temperatures and lower water levels leading to increased evaporation rates and, as a result, an increase in the concentration of dissolved solids. It also coincides with dry seasons and agricultural growth, which means using fertilizers, pesticides, and herbicides that flow into rivers, increasing dissolved solids levels significantly [39]. For the wet season, due to heavy rainfall and water runoff from urban areas, agricultural lands, industrial areas, and solid and liquid waste disposal sites, many pollutants are picked up, leading to an increase in dissolved solids levels [40]. $NO_3^{-1}$ exceeded the limited value (10.8 mg/L in September 2020) and (3.1 mg/L in January 2021 to 7.6 mg/L in November 2020) for dry and wet seasons, respectively. The combination of lack of rainfall and irrigation with fertilizers during the dry season, which is rich in nitrogen, may lead to the accumulation of nitrates in the soil that can then seep into nearby rivers and streams [41]. Nitrate concentrations in rivers rise during the wet season due to excess fertilizer runoff from agricultural lands. Heavy rains in areas with untreated or partially treated sewage systems that contain a high percentage of nitrates can also cause an increase in their percentage in water bodies [42]. Also, $PO_4^{-3}$ shows a high limited value (0.96 mg/L in October 2020) for the dry season and (0.6 mg/L in February 2021 to 2.2 mg/L in November 2020) for the wet season. For the same reasons above [41, 42], the presence of phosphorus-rich fertilizers and pesticides in agricultural lands and sewage water leads to increased concentrations of $PO_4^{-3}$ in dry and wet seasons. $SO_4^{-2}$ was measured at a high limited value (Dry season (October 2020) 223.6 mg/L) and (Wet season (January 2021) 215.2 to 241.2 mg/L (February 2021)).

Irrigation is a common agricultural activity during the dry season, and high concentrations of sulfates in the soil are often attributed to their presence in fertilizers, which can leach into rivers through runoff and washing processes [43]. Sulfate leaching from the soil may also occur during the wet season, particularly in areas with acidic soils or where gypsum (calcium sulfate) is present, leading to increased sulfate concentrations in river water [44].

At the same time, dissolved oxygen (DO) recorded higher values than recommended during both the dry season (7.4 mg/L in March 2021) and the wet season (ranging from 7.5 mg/L in November 2020 to 8.7 mg/L in December 2020). Several factors contribute to increased DO levels during the dry season. For instance, reduced water flow and lower temperatures can decrease microbial activity, resulting in lower oxygen consumption by organisms and, consequently, higher DO levels. Additionally, the proliferation of algae enhances oxygen production through photosynthesis, particularly during daylight hours. Although warmer temperatures generally reduce the solubility of oxygen in water, other processes may still lead to elevated DO levels [45].

During the wet season, the growth of submerged aquatic plants and algal blooms increases oxygen levels during the day due to photosynthesis. Increased rainfall enhances water mixing and turbulence, promoting greater oxygen exchange between water and air, which contributes to higher DO concentrations. Furthermore, frequent rainfall reduces the concentration of pollutants and organic matter that consume oxygen during decomposition. As a result, the demand for oxygen by microorganisms decreases, leading to an overall increase in DO levels in the water [46, 47].

## 3.2. OIP

Aquatic life's vital maintenance and survival are important information for surface water quality. In general, Humans depend on river water for daily needs; for this purpose, the OIP was used to assess the water quality of the Tigris River. Ten physicochemical water parameters were analyzed in the current study. Table 4 shows the seasonal water variation at different locations (S1-S5) of the Tigris River. Table 5 illustrates the overall water quality of Tigris River for both seasons (Dry & Wet) as a statistical summary.

**Table 5. OIP Calculation for all sites and seasons in Tigris River during the study period**

| Parameters | Site 1 | | Site 2 | | Site 3 | | Site 4 | | Site 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dry season | Wet season | Dry season | Wet season | Dry season | Wet season | Dry season | Wet season | Dry season | Wet season |
| TDS (mg/L) | 3.12 | 3.36 | 3.13 | 7.11 | 3.20 | 3.39 | 3.27 | 3.38 | 3.23 | 3.37 |
| Turbidity (NTU) | 1.67 | 2.41 | 2.77 | 4.07 | 2.64 | 2.49 | 2.66 | 2.40 | 2.68 | 2.42 |
| $NO_3^{-1}$ (mg/L) | 1.44 | 2.41 | 2.38 | 3.19 | 2.28 | 2.42 | 2.36 | 2.27 | 2.45 | 2.39 |
| $PO_4^{-3}$ (mg/L) | 1.78 | 6.23 | 2.70 | 11.88 | 2.88 | 4.47 | 2.76 | 4.27 | 2.95 | 4.17 |
| $SO_4^{-2}$ (mg/L) | 1.92 | 3.18 | 2.92 | 6.05 | 2.97 | 3.23 | 2.98 | 3.13 | 2.97 | 3.17 |
| DO (mg/L) | 1.78 | 2.61 | 2.79 | 2.16 | 2.76 | 2.60 | 2.78 | 2.61 | 2.83 | 2.63 |
| Alk (mg/L) | 5.03 | 5.56 | 6.02 | 16.38 | 5.61 | 5.15 | 5.63 | 5.20 | 5.47 | 5.19 |
| TH (mg/L) | 1.67 | 2.72 | 2.68 | 5.01 | 2.69 | 2.73 | 2.67 | 2.71 | 2.69 | 2.72 |
| pH | 2.05 | 3.08 | 3.05 | 6.32 | 3.06 | 3.08 | 3.06 | 3.10 | 3.06 | 3.09 |
| Anionic S. (mg/L) | 1.18 | 2.18 | 2.03 | 3.64 | 2.08 | 2.42 | 2.10 | 2.31 | 2.12 | 2.23 |
| $\sum Pi$ | 21.67 | 33.73 | 30.45 | 65.81 | 30.15 | 31.98 | 30.28 | 31.38 | 30.44 | 31.39 |
| OIP | 2.17 | 3.37 | 3.05 | 6.58 | 3.01 | 3.20 | 3.03 | 3.14 | 3.04 | 3.14 |

The OIP was calculated for each site during the dry and wet seasons by taking the mean of all pollution indices (Pi) for individual water quality parameters (Table 5). For all sites except Site 2, the OIP results indicated slight pollution. Specifically, OIP values ranged from 2.17 to 3.37 for Site 1 during the dry and wet seasons, respectively; from 3.01 to 3.20 for Site 3; and from 3.03 to 3.14 and 3.04 to 3.14 for Sites 4 and 5, respectively. Site 2 was evaluated as ranging from slightly polluted to polluted, with OIP values between 3.05 and 6.58 for the dry and wet seasons, respectively.

This finding highlights an urgent need to strengthen environmental mitigation measures for the river, particularly at monitoring station number 2. Such measures should include stricter regulatory controls on stormwater discharges and industrial waste, enhanced seasonal monitoring programs, and stronger enforcement mechanisms, such as increased inspection rates and a penalty system proportional to pollution levels, to effectively address the issue.

In general, the Tigris River suffers from significant water shortages and annual variations in both water quantity and quality, as documented in several Iraqi studies [48–50]. Climate change and dam construction in neighboring countries have contributed to fluctuations in discharge levels. The dynamic flow of dam-regulated waters significantly alters pollutant regimes by suppressing high-flow events and reducing the river's natural dilution capacity, thereby increasing background pollutant concentrations. In addition, sediment trapping upstream creates what is known as "hungry water," which scours downstream channels and remobilizes legacy pollutants. This process also disrupts the natural seasonal transport of contaminants, eliminating cleansing flood events and promoting long-term pollutant accumulation. As a result, the river system becomes more stable but chronically impaired, providing an important context for interpreting pollutant concentrations at the Baghdad study sites [51].

The upstream water becomes polluted with dark organic debris during the summer and autumn (drought seasons), leading to changes in water quality (WQ) [52]. This is attributed to pollutants originating from municipal waste, industrial discharges, human activities, and agricultural runoff within the city, which progressively deteriorate the water quality of the Tigris River [53].

### 3.3. Sensitivity Analysis

Sensitivity analysis is used to determine the relative importance or effectiveness of variables on the output. Input variables that do not significantly affect the performance of a BLR model can be excluded, resulting in a more compact and efficient network. Therefore, applying methods such as sensitivity analysis is essential to enhance the effectiveness of BLR [54].

A sensitivity analysis was conducted using backward linear regression to determine the relationship between surfactants (Anionic S.) in the Tigris River and nutrient parameters. Anionic S. depends on several independent variables, which can be expressed as follows: Anionic S. = f($NO_3^-$, $PO_4^{3-}$, $SO_4^{2-}$, TH, TDS, $NO_2^-$). Sensitivity analysis can be defined as the study of an output variable's response to variations in input variables [55]. Linear regression is one of the oldest statistical modeling approaches, yet it remains a valuable tool, especially when developing predictive models with limited sample sizes [56].

Backward linear regression, also known as the elimination method, involves including the most correlated independent variables in the model, removing one parameter at each step, and evaluating the impact of its removal. To determine the most appropriate model for this study, three linear regression models were developed using the R program based on Python (Table 6). The model outputs were compared with the original dataset containing all seven parameters, and the data were standardized beforehand to ensure fair parameter representation.

The third model includes the most significant factors affecting water quality and, despite having lower $R^2$ and higher RMSE values ($R^2 = 0.683$, RMSE = 0.155), it identifies $PO_4^{3-}$, $NO_3^-$, and TDS as the most influential parameters, showing a strong relationship with the presence of detergents (Table 7). This is because the model incorporates phosphate and nitrate, which are key components of detergents [57]. Additionally, the inclusion of TDS is relevant, as it represents the total concentration of dissolved ions, including phosphate and nitrate [58]. Table 7 also provides detailed equations for the developed models.

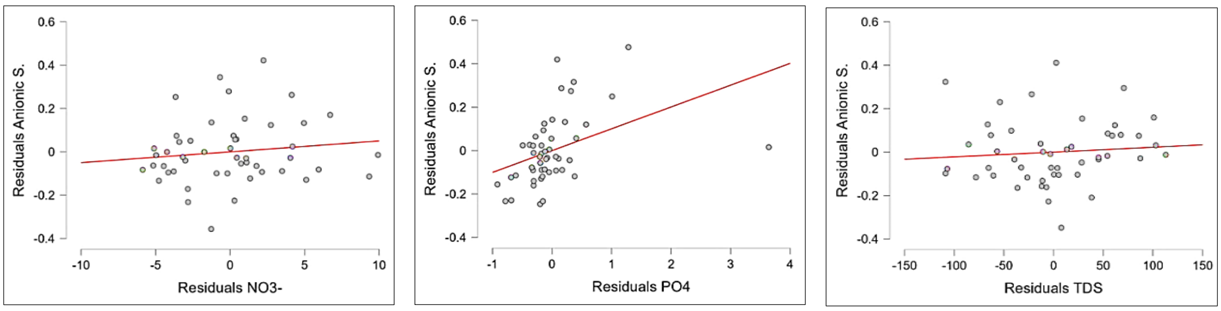
**Table 6. Model Summary of sensitivity analysis for the Performance evaluation of the effective parameters**

| Model | R | $R^2$ | Adjusted $R^2$ | SSE | RMSE |
|---|---|---|---|---|---|
| 1 | 0.828 | 0.685 | 0.641 | 3.270 | 0.152 |
| 2 | 0.827 | 0.684 | 0.648 | 3.270 | 0.153 |
| 3 | 0.827 | 0.683 | 0.655 | 3.270 | 0.155 |

**Table 7. Equations of sensitivity analysis for the Performance evaluation of the effective parameters**

| Models | Equations |
|---|---|
| Model 1 | Anionic S = 0.110 * $NO_3^-$ + 0.407 * $PO_4$ + 0.089 * $SO_4^{-2}$+ 0.056 * TH + 0.130 * TDS + -0.188 * $NO_2^-$ |
| Model 2 | Anionic S = 0.112 * $NO_3^-$ + 0.417* $PO_4$ + 0.057* $SO_4^{-2}$+ 0.079 * TDS + -0.208 * $NO_2^-$ |
| Model 3 | Anionic S =0.121* $NO_3^-$ + 0.428 * $PO_4$ + 0.129 * TDS |

Figure 4 shows the distribution of residual errors for the third model. The relationships between Anionic S. vs. $NO_3^-$, Anionic S. vs. $PO_4^{3-}$, and Anionic S. vs. TDS exhibit lower residual errors, as the residual values are distributed close to the zero line. This indicates the significance of $NO_3^-$, $PO_4^{3-}$, and TDS parameters in relation to the presence of anionic surfactants. The importance of these parameters may be attributed to non-point sources such as industrial and agricultural activities along the river, as well as urban land development, all of which can affect the water quality of the Tigris River [58].




Anionic S. vs. $NO_3^{-1}$ Anionic S. vs. $PO_4^{-3}$ Anionic S. vs. TDS

**Figure 4. Residual error of the third model developed for effective parameters estimation based on sensitivity analysis**

The present findings are consistent with those reported by Caesar et al. (2024) [23], who investigated the relationship between high concentrations of surfactants and water quality parameters in the Porong River. Their study found a positive correlation between surfactant concentration and nitrate levels in river water. Surfactant-containing wastewater, which often includes organic matter such as nitrate, can lead to eutrophication. Eutrophication occurs when nutrient concentrations in water increase, often due to inputs from organic matter in surfactant wastewater [59]. This increase in nutrients stimulates excessive algal growth (algal blooms), which in turn affects various water quality parameters, including biological, physical, and chemical characteristics.

Furthermore, a positive correlation between surfactant concentration and TDS was also observed. This is because surfactants can enhance the solubility of dissolved substances, including TDS, by creating conditions that facilitate their dissolution in water [60]. However, excessive surfactant concentrations can reduce dissolved oxygen levels in river water, thereby disrupting the respiration of aquatic organisms [61].

## 3.4. Principal Component Analysis (PCA)

Principal component analysis (PCA) was conducted to determine the most important factors affecting the water quality of the Tigris River across all parameters and sites by identifying eigenvalues that indicate the highest degree of factor importance.

Table 8 presents the significant eigenvalues greater than 1.0, classified into three categories of principal components (PCs): strong (> 0.75), moderate (0.50–0.75), and weak (0.30–0.50) [33]. One principal component was extracted from the PCA to identify pollution sources based on water quality parameters. Table 8 and Figure 5 illustrate the component loadings of the most significant parameters. The green color indicates positive (+ve) loading, and thicker lines represent stronger loadings, with values closer to 1 indicating higher significance.

PC1 shows strong loadings for $PO_4^{3-}$ > TDS > $NO_3^-$. These parameters ($PO_4^{3-}$, TDS, and $NO_3^-$) are identified as the most influential factors with the strongest impact on anionic surfactants. The water quality of the Tigris River reflects the influence of agricultural and industrial discharges, which have contributed to significant issues related to salinity and drainage in these areas [62].

**Table 8. Component loadings of water quality parameters of the study area**

| Component Loadings | | |
|---|---|---|
| **Parameters** | **PC1** | **Uniqueness** |
| $PO_4^{-3}$ (mg/L) | 0.779 | 0.393 |
| TDS (mg/L) | 0.641 | 0.590 |
| $NO_3^{-1}$ (mg/L) | 0.598 | 0.642 |
| Eigen value | Eigen value | - |

Note: The applied rotation method is varimax.

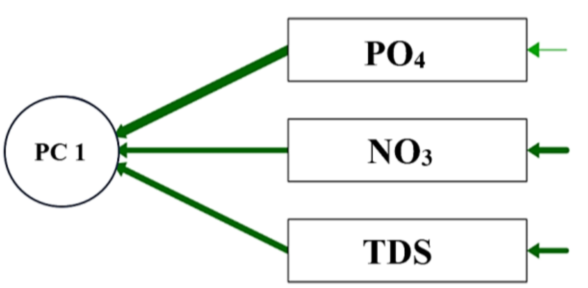



**Figure 5. Component loading diagram of water quality parameters of the study area**

## 3.5. Person's Correlation

This study provides comprehensive insight into the dataset and allows estimation of the relationships among variables. Parameters with higher significance can be identified at the 0.001 significance level. The correlation coefficient (r) ranges between +1 and −1; when r is close to +1, the correlation is considered strongly positive, while values close to −1 indicate a strong negative correlation. When r approaches 0, the variables are considered uncorrelated [2].

According to Pearson's coefficient [54], only variables with correlation values around $r \geq 0.5$ are considered significant. In the dataset, Anionic S., $PO_4^{3-}$, TDS, and $NO_3^-$ were examined. Table 9 shows a strong positive correlation ($P < 0.001$) between Anionic S. and $PO_4^{3-}$ ($r = 0.515$), and a moderate positive correlation between Anionic S. and TDS ($r = 0.319$). At the same time, no significant correlation was observed between Anionic S. and $NO_3^-$ ($r = 0.256$).

**Table 9. Person's correlation coefficient between the water parameters of Tigris River and anionic surfactant during the study period**

| Pearson's Correlations | | | | |
|---|---|---|---|---|
| **Variable** | **Anionic S.** | **$NO_3^-$** | **PO4** | **TDS** |
| Anionic S. | - | | | |
| NO3- | 0.256 | - | | |
| PO4 | 0.515*** | 0.223 | - | |
| TDS | 0.319* | 0.079 | 0.248 | - |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

-The correlation marked is significant at $p < 0.001$

Figure 6 illustrates the correlations between water parameters ($PO_4^{3-}$, TDS, and $NO_3^-$) and Anionic S. The dark purple box indicates a strong positive correlation between Anionic S. and $PO_4^{3-}$, while the light purple box represents a moderate relationship between Anionic S. and TDS. Only these parameters exhibited statistically significant correlations, as shown in Table 9 and Figure 6. The relationship between Anionic S. and $PO_4^{3-}$ is associated with the use of anionic surfactants in detergents, household products, dyes, chemicals, and industrial materials. When these substances are discharged into water bodies, they can release phosphate from sediments and soils, increasing phosphate concentrations in the water column. Elevated phosphate levels, once absorbed by aquatic plants and algae, can lead to significant depletion of dissolved oxygen (DO) during decomposition processes [63, 64].

Wastewater from domestic and industrial sources often contains high concentrations of both anionic surfactants and phosphate, which are discharged into rivers and contribute to increased concentrations in water. These substances can negatively affect aquatic organisms by increasing toxicity, disrupting ecosystems, and stimulating algal growth due to higher nutrient availability [65]. When anionic surfactants are present in soils or sediments, they can enhance the solubility of salts and minerals, leading to increased concentrations in water. Additionally, industrial discharges containing surfactants contribute to higher levels of dissolved solids. The combined effect of solids and anionic surfactants from sources such as mining activities, natural weathering, and urban runoff leads to elevated TDS levels in river water [66]. Anionic surfactants can also form micelles—clusters of active molecules capable of trapping suspended solids—which facilitate the transport of these solids into rivers and increase their concentration [63]. In contrast, $NO_3^-$ shows a weak correlation with Anionic S.

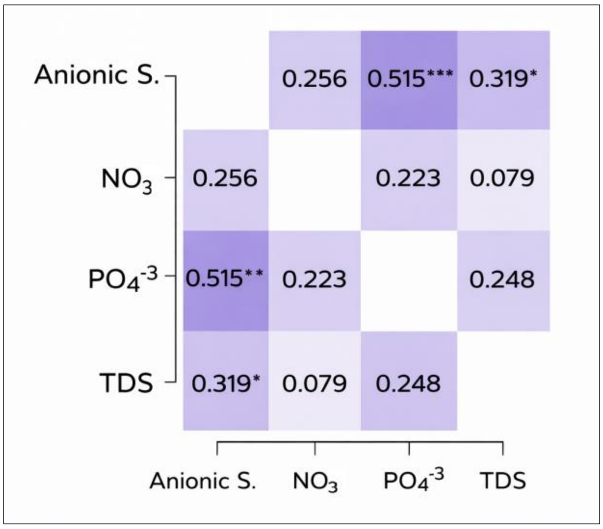



**Figure 6. Person's partial correlations heatmap between anionic surfactant and water parameters**

## 3.6. Cluster Analysis

### 3.6.1. Spatial Variation

Two clusters were identified during the study period using tree dendrogram analysis (Figure 7). The first cluster consisted of two sub-clusters: (1) a paired sub-cluster of Site 3 and Site 5, where the highest value of $PO_4^{3-}$ (0.86 mg/L) was recorded at Site 5 and DO (7.28 mg/L) at Site 3, while the lowest values were observed at Site 5 for DO (6.75 mg/L) and at Sites 3 and 5 for alkalinity (154.19 and 151.03 mg/L, respectively). The remaining parameters showed closely similar values between these two sites. (2) A single sub-cluster represented by Site 4, which exhibited the highest values of TDS (657.12 mg/L), pH (9.66), and $SO_4^{2-}$ (299.6 mg/L), while the lowest values were recorded for turbidity (27.96 NTU), $NO_3^-$ (4.87 mg/L), and total hardness (TH) (344.34 mg/L).

The second cluster included a paired sub-cluster of Site 2 and Site 1. The results indicated the highest values of $PO_4^{3-}$ (0.87 mg/L) at Site 1, alkalinity (172.89 and 179.87 mg/L) at Sites 1 and 2, respectively, TH (353.72 mg/L) at Site 2, and anionic surfactants (0.23 mg/L) at Site 1.

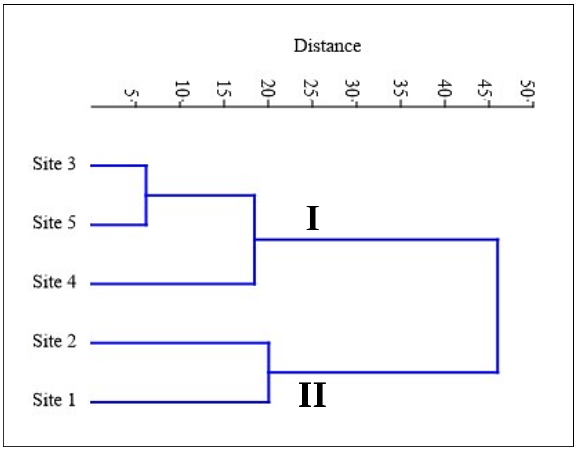



**Figure 7. Dendrogram of spatial clustering of sampling sites during the study period**

### 3.6.2. Temporal Variation

From Figure 8, two clusters were also identified during the study period. The first cluster included: (1) a single sub-cluster representing February 2021 (wet season), which recorded the highest values of TDS (820.87 mg/L), $SO_4^{2-}$ (241.2 mg/L), and TH (404.67 mg/L); (2) a paired sub-cluster of September 2020 (dry season) and December 2020 (wet season), where the highest turbidity (43.62 NTU) was observed in September 2020, while December 2020 showed the highest values of DO (8.68 mg/L) and anionic surfactants (0.454 mg/L); (3) a single sub-cluster representing January 2021 (wet season); (4) a paired sub-cluster of April 2021 (dry season) and November 2020 (wet season), where April recorded the highest pH value (8.39) and the lowest values of $NO_3^-$ (0 mg/L) and alkalinity (96.6 mg/L), while November 2020 showed the highest $PO_4^{3-}$ value (2.19 mg/L); (5) a single sub-cluster representing March 2021 (dry season); and (6) October 2020 (dry season), which recorded the highest values of $NO_3^-$ (9.17 mg/L) and alkalinity (253.87 mg/L).

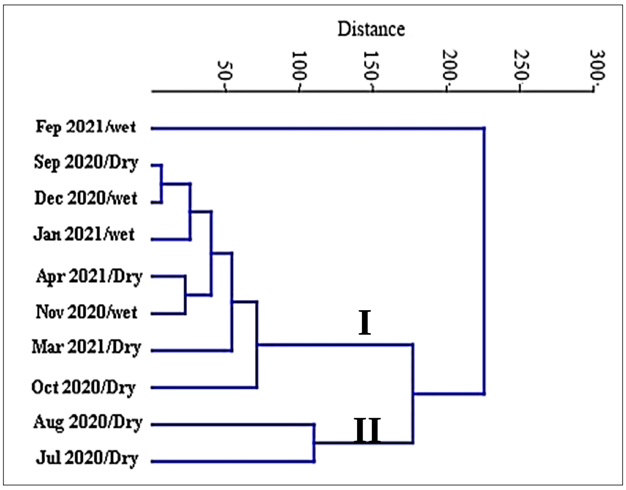



**Figure 8. Dendrogram of temporal clustering of sampling during the study period**

The second cluster included one pair of sub-clusters, August 2020/Dry season and July 2020/Dry season, which referred to the lowest values in TDS (425.4 mg/L), Turbidity (15.32 NTU), $PO_4^{-3}$ (0.064 mg/L), $SO_4^{-2}$ (141.8 mg/L), DO (5.7 mg/L), TH (273.6 mg/L), pH (7.68), and Anionic S. (0.04 mg/L).

## 4. Conclusions

The results of the present study demonstrate the impact of human activities (agriculture, industrial discharge, and sewage effluents) and natural processes (rainfall, evaporation, and biological activity) on the water quality of the Tigris River. Therefore, the river faces significant water quality challenges due to both anthropogenic and natural factors. Effective management strategies are essential to mitigate these impacts and to protect the health of the river ecosystem and the communities that depend on it.

The descriptive analysis of physicochemical parameters showed that TDS, $NO_3^-$, $PO_4^{3-}$, $SO_4^{2-}$, and DO recorded higher concentrations during both wet and dry seasons. In summary, agricultural practices, industrial activities, sewage discharge near the river, evaporation processes, rainfall, and biological activity all influenced the physical and chemical properties of the Tigris River during the study period.

Regarding the OIP results calculated for all sites in both seasons, varying degrees of pollution were observed. For all sites except Site 2, the OIP values indicated slight pollution, ranging from 2.17 to 3.37 during the dry and wet seasons. In contrast, Site 2 ranged from slightly polluted to polluted, with OIP values between 3.05 and 6.58 for the dry and wet seasons, respectively. These findings indicate that the Tigris River experiences varying pollution levels associated with water scarcity, annual fluctuations in water quantity, climate change, and dam development in neighboring countries.

The sensitivity analysis results showed that the most influential parameters with a strong relationship to anionic surfactants were $PO_4^{3-}$, $NO_3^-$, and TDS. Principal component analysis also indicated that PC1 was heavily loaded on $PO_4^{3-}$ > TDS > $NO_3^-$, confirming these parameters as the most significant factors affecting anionic surfactants. In terms of spatial variation, Site 2 (Al-Greaat Bridge) was more polluted than the other sites during the wet season. Regarding temporal variation, the dry season exhibited higher values of TDS, $NO_3^-$, $PO_4^{3-}$, $SO_4^{2-}$, and DO during the study period.

Finally, it should be noted that one major limitation of the study is the monthly sampling frequency. Although this approach is effective for identifying seasonal trends and baseline pollution levels, it may not capture short-term or episodic pollution events. Future studies should incorporate high-frequency sampling sensors or event-based sampling programs, particularly during rainfall events, to better assess the impact of acute weather conditions on water quality.

## 5. Declarations

### 5.1. Author Contributions

Conceptualization, R.R.A. and Z.Z.A.J.; methodology, A.A.; software, A.N.A.A.; validation, F.M.H.; formal analysis, A.A.; investigation, R.R.A.; resources, A.H.M.J.A.O.; data curation, A.H.M.J.A.O.; writing—original draft preparation, R.R.A.; writing—review and editing, R.R.A. and Z.Z.A.J.; visualization, A.A.; supervision, F.M.H.; project administration, R.R.A. All authors have read and agreed to the published version of the manuscript.

### 5.2. Data Availability Statement

The data presented in this study are available in the article.

### 5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

### 5.4. Acknowledgments

The authors would like to thank the Soil & Water Lab., Environmental Research Center, University of Technology–Iraq, for their invaluable support and scientific assistance in conducting the laboratory testing.

### 5.5. Conflicts of Interest

The authors declare no conflict of interest.

## 6. References

[1] Al-Ansari, N., Ewaid, S. H., Chabuk, A., Abed, S. A., Salim, M. A., Laue, J., & Salih, R. M. (2024). Tigris River Water Quality Quantifying Using the Iraq Water Quality Index (IraqWQI) and Some Statistical Techniques. Engineering, 16(06), 149–166. doi:10.4236/eng.2024.166012.

[2] Al-Ani, R. R., Al Obaidy, A. M. J., & Hassan, F. M. (2019). Multivariate analysis for evaluation the water quality of Tigris River within Baghdad city in Iraq. Iraqi Journal of Agricultural Sciences, 50(1), 331–342. doi:10.36103/ijas.v50i1.299.

[3] Salman, J. M., & SauadAl-Shammary, A. A. (2020). Monitoring lotic ecosystem by the application of water quality index (CCMEWQI). Baghdad Science Journal, 17(1), 23–27. doi:10.21123/bsj.2020.17.1.0023.

[4] Ismail, M. M., El-Naggar, A. M., El-Gammal, M. I., & Hagras, A. E. (2021). Drinking water quality evaluation of hand pumping wells using water quality index and standard algal toxicity testing in Mansoura and Talkha cities, Egypt. Baghdad Science Journal, 18(4), 1181–1193. doi:10.21123/BSJ.2021.18.4.1181.

[5] Asaad, B. I., & Abed, B. S. (2020). Flow Characteristics of Tigris River Within Baghdad City During Drought. Journal of Engineering, 26(3), 77–92. doi:10.31026/j.eng.2020.03.07.

[6] Hassan, A. B., Hasan, M. B., Shaban, M. A. A., & Shadhar, M. H. (2025). Assessment of Water Quality in the Tigris River Through Baghdad Using the National Sanitation Foundation and Oregon Water Quality Indices. Civil and Environmental Engineering, 21(2), 757–764. doi:10.2478/cee-2025-0055.

[7] Gadzała-Kopciuch, R., Berecka, B., Bartoszewicz, J., & Buszewski, B. (2004). Some considerations about bioindicators in environmental monitoring. Polish Journal of Environmental Studies, 13(5), 453–462.

[8] Manning, A. J. (2020). River Deltas Research - Recent Advances: HR Wallingford. IntechOpen, London, United Kingdom. doi:10.5772/intechopen.78857.

[9] Olkowska, E., Ruman, M., & Polkowska, Z. (2014). Occurrence of surface-active agents in the environment. Journal of Analytical Methods in Chemistry, 2014. doi:10.1155/2014/769708.

[10] Kreisselmeier, A., & Dürbeck, H. W. (1997). Determination of alkylphenols, alkylphenolethoxylates and linear alkylbenezesulfonates in sediments by accelerated solvent extraction and supercritical fluid extraction. Journal of Chromatography A, 775(1–2), 187–196. doi:10.1016/S0021-9673(97)00279-3.

[11] Madsen, T., Boyd, H. B., Nylén, D., Pedersen, A. R., Petersen, G. I., & Simonsen, F. (2001). Environmental and health assessment of substances in household detergents and cosmetic detergent products. Ministry of Environment, Danish Environmental Protection Agency, Copenhagen, Denmark.

[12] Hassan, & Hameed. (2017). Detection of Detergents (Surfactants) in Tigris River- Baghdad/Iraq. International Journal of Environment & Water, 6(1), 16.

[13] Al-Ani, R. R., Hassan, F. M., & Al-Obaidy, A. H. M. J. (2019). Quantity and quality of surfactants in sediment of Tigris River, Baghdad, Iraq. Desalination and Water Treatment, 170, 168–175. doi:10.5004/dwt.2019.24679.

[14] Pielou, E. C. (1998). Fresh water. University of Chicago Press, Chicago, United States.

[15] Ying, G. G. (2006). Fate, behavior and effects of surfactants and their degradation products in the environment. Environment International, 32(3), 417–431. doi:10.1016/j.envint.2005.07.004.

[16] Lechuga, M., Fernández-Serrano, M., Jurado, E., Núñez-Olea, J., & Ríos, F. (2016). Acute toxicity of anionic and non-ionic surfactants to aquatic organisms. Ecotoxicology and Environmental Safety, 125, 1–8. doi:10.1016/j.ecoenv.2015.11.027.

[17] Ahmed, Z., Kandeel, E. M., Abdelmaksoud, H. F., Aboushousha, T., & Badr, E. E. (2023). In vivo evaluation the efficiency of nitazoxanide with cationic Gemini surfactant on Cryptosporidiosis. Baghdad Science Journal, 20(6), 2086–2105. doi:10.21123/bsj.2023.7960.

[18] U.S. Geological Survey. (2006). Nutrients in streams and rivers across the nation, 1992–2001. U.S. Geological Survey, Reston, United States. Available online: https://pubs.usgs.gov/sir/2006/5107/sir5107abs.html (accessed on March 2026).

[19] Hassan, F. M., Salman, J. M., & Al-Nasrawi, S. (2017). Community structure of benthic algae in a lotic ecosystem, Karbala Province-Iraq. Baghdad Science Journal, 14(4), 692–706. doi:10.21123/bsj.2017.14.4.0692.

[20] R. Al-Ani, R., M. Hassan, F., & Hameed M. Jawad Al-Obaidy, A. (2022). Environmental Evaluation of Surfactant: Case Study in Sediment of Tigris River, Iraq. River Deltas Research - Recent Advances: HR Wallingford, Oxfordshire, United Kingdom. doi:10.5772/intechopen.94324.

[21] Rizvi, H., Verma, J. S., & Ashish. (2021). Biosurfactants for oil pollution remediation. Springer Nature Singapore Pte Ltd., Singapore. doi:10.1007/978-981-15-6607-3_9.

[22] Saxena, N., Islam, M. M., Baliyan, S., & Sharma, D. (2023). A comprehensive review on removal of environmental pollutants using a surfactant based remediation process. RSC Sustainability, 1(9), 2148–2161. doi:10.1039/d2su00069e.

[23] Caesar, N. R., Yanuhar, U., Faqih, A. R., Anitasari, S., Ciptadi, G., Musa, M., Bisri, M., & Wardani, N. P. (2024). Correlation between Water Quality and Surfactant Pollution in the Porong River. BIO Web of Conferences, 117, 1010. doi:10.1051/bioconf/202411701010.

[24] Al-Ani, R. R., Hameed, A., Jawad, M., Obaidy, A., & Badri, R. M. (2014). Assessment of Water Quality in the Selected Sites on the Tigris River, Baghdad-Iraq. International Journal of Advanced Research, 2(5), 1125–1131.

[25] Ewaid, S. H., Abed, S. A., & Kadhum, S. A. (2018). Predicting the Tigris River water quality within Baghdad, Iraq by using water quality index and regression analysis. Environmental Technology & Innovation, 11, 390–398. doi:10.1016/j.eti.2018.06.013.

[26] Al-Musawi, T. J., Mohammed, I. A., & Atiea, H. M. (2017). Optimum efficiency of treatment plants discharging wastewater into river, case study: Tigris River within the Baghdad city in Iraq. MethodsX, 4, 445–456. doi:10.1016/j.mex.2017.10.009.

[27] Eichhorn, P., Rodrigues, S. V., Baumann, W., & Knepper, T. P. (2002). Incomplete degradation of linear alkylbenzene sulfonate surfactants in Brazilian surface waters and pursuit of their polar metabolites in drinking waters. Science of the Total Environment, 284(1–3), 123–134. doi:10.1016/S0048-9697(01)00873-7.

[28] Gordon, A. K., Muller, W. J., Gysman, N., Marshall, S. J., Sparham, C. J., O'Connor, S. M., & Whelan, M. J. (2009). Effect of laundry activities on in-stream concentrations of linear alkylbenzene sulfonate in a small rural South African river. Science of the Total Environment, 407(15), 4465–4471. doi:10.1016/j.scitotenv.2009.04.023.

[29] APHA & WEF. (2017). Standard methods for the examination of water and wastewater. American Public Health Association, American Water Works Association, & Water Environment Federation, Washington, United States.

[30] Hach Company. (2014). Operation manual BA75433E09 06/2014: photoLab® S12 analysis specifications for available test kits. Hach Company, Loveland, United States. Available online: https://www.hach.com/ (accessed on March 2026).

[31] Al-Rawi, A. S., & Al-Samarrai, Q. A. M. (1990). Applied climate (in Arabic). Ministry of Higher Education and Scientific Research / University of Baghdad, Baghdad, Iraq.

[32] Sargaonkar, A., & Deshpande, V. (2003). Development of an overall index of pollution for surface water based on a general classification scheme in Indian context. Environmental Monitoring and Assessment, 89(1), 43–67. doi:10.1023/A:1025886025137.

[33] Teixeira de Souza, A., Carneiro, L. A. T. X., da Silva Junior, O. P., de Carvalho, S. L., & Américo-Pinheiro, J. H. P. (2021). Assessment of water quality using principal component analysis: a case study of the Marrecas stream basin in Brazil. Environmental Technology (United Kingdom), 42(27), 4286–4295. doi:10.1080/09593330.2020.1754922.

[34] Warsito, B., Sumiyati, S., Yasin, H., & Faridah, H. (2021). Evaluation of river water quality by using hierarchical clustering analysis. IOP Conference Series: Earth and Environmental Science, 896(1), 012072. doi:10.1088/1755-1315/896/1/012072.

[35] Iraqi Official Gazette. (1967). Rivers maintaining system and general water protection from pollution (Law No. 25 of 1967). Ministry of Health, Government of Iraq, Baghdad, Iraq.

[36] U.S. Environmental Protection Agency. (1980). Turbidity: Water quality standards criteria summaries (A compilation of state/federal criteria). U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, United States.

[37] Bramblett, R. L., & Frossard, A. A. (2024). Evaluating the Extraction and Quantification of Marine Surfactants from Seawater through Solid Phase Extraction and Subsequent Colorimetric Analyses. ACS Es&t Water, 4(11), 4836–4846. doi:10.1021/acsestwater.4c00497.

[38] Moran, S. (2018). An Applied Guide to Water and Effluent Treatment Plant Design. Elsevier Inc., Amsterdam, Netherlands. doi:10.1016/C2016-0-01092-6.

[39] Tomar, K., & Shalu, S. (2025). Impact of agricultural practices on groundwater quality and quantity in Rajpura Block in Meerut District. International Journal of Engineering Science & Humanities, 15(2), 265–278.

[40] Chandler, D. G. (2006). Reversibility of forest conversion impacts on water budgets in tropical karst terrain. Forest Ecology and Management, 224(1–2), 95–103. doi:10.1016/j.foreco.2005.12.010.

[41] Haycock, N. E., & Pinay, G. (1993). Groundwater Nitrate Dynamics in Grass and Poplar Vegetated Riparian Buffer Strips during the Winter. Journal of Environmental Quality, 22(2), 273–278. doi:10.2134/jeq1993.00472425002200020007x.

[42] Giri, S., & Qiu, Z. (2016). Understanding the relationship of land uses and water quality in Twenty First Century: A review. Journal of Environmental Management, 173, 41–48. doi:10.1016/j.jenvman.2016.02.029.

[43] Palmer, M. A., Filoso, S., & Fanelli, R. M. (2014). From ecosystems to ecosystem services: Stream restoration as ecological engineering. Ecological Engineering, 65, 62–70. doi:10.1016/j.ecoleng.2013.07.059.

[44] Jiang, T., Wang, M., Zhang, W., Zhu, C., & Wang, F. (2024). A Comprehensive Analysis of Agricultural Non-Point Source Pollution in China: Current Status, Risk Assessment and Management Strategies. Sustainability (Switzerland), 16(6), 2515. doi:10.3390/su16062515.

[45] Ali, B. A., & Mishra, A. (2022). Effects of dissolved oxygen concentration on freshwater fish: A review. International Journal of Fisheries and Aquatic Studies, 10(4), 113–127. doi:10.22271/fish.2022.v10.i4b.2693.

[46] Kushwah, V. K., Singh, K. R., Gupta, N., Berwal, P., Alfaisal, F. M., Khan, M. A., Alam, S., & Qamar, O. (2023). Assessment of the Surface Water Quality of the Gomti River, India, Using Multivariate Statistical Methods. Water (Switzerland), 15(20), 3575. doi:10.3390/w15203575.

[47] Aljanabi, Z. Z., Jawad Al-Obaidy, A. H. M., & Hassan, F. M. (2023). A Novel Water Quality Index for Iraqi Surface Water. Baghdad Science Journal, 20(6 Suppl.), 2395–2413. doi:10.21123/bsj.2023.9348.

[48] Mohammed, M. K., Naji, M. S., Ameen, N. H., & Karkosh, H. N. (2021). Assessment of Water Quality for Tigris and Euphrates Water within Iraqi Borders. Journal of Physics: Conference Series, 1999(1), 012152. doi:10.1088/1742-6596/1999/1/012152.

[49] Jabar, S. S., & Hassan, F. M. (2022). Monitoring the Water Quality of Tigris River by Applied Overall Index of Pollution. IOP Conference Series: Earth and Environmental Science, 1088(1), 1–12. doi:10.1088/1755-1315/1088/1/012015.

[50] Aljanabi, Z. Z., Hassan, F. M., & Al-Obaidy, A. H. M. J. (2023). A multivariate approach and water quality index for evaluating the changes in water quality of Tigris River. AIP Conference Proceedings, 2820(050004), 1–12. doi:10.1063/5.0150758.

[51] Krishnan Kutty, S., Damodaran, P., Mathai, J., Mathew, M., Rani, A., Kumar Sharma, R., & Kesavan, M. (2025). Role of Hungry Water on Sediment Dynamics: Assessment of Valley Degradation, Bed Material Changes and Flood Inundation in Pamba River During Kerala Flood, 2018. Hydrology, 12(4), 79. doi:10.3390/hydrology12040079.

[52] Ali Abed, S., Hussein Ewaid, S., & Al-Ansari, N. (2019). Evaluation of Water quality in the Tigris River within Baghdad, Iraq using Multivariate Statistical Techniques. Journal of Physics: Conference Series, 1294(7), 072025. doi:10.1088/1742-6596/1294/7/072025.

[53] Aljanabi, Z. Z., Hassan, F. M., & Jawad Al-Obaidy, A. H. M. (2022). Heavy metals pollution profiles in Tigris River within Baghdad city. IOP Conference Series: Earth and Environmental Science, 1088(1), 012008. doi:10.1088/1755-1315/1088/1/012008.

[54] Dogan, E., Sengorur, B., & Koklu, R. (2009). Modeling biological oxygen demand of the Melen River in Turkey using an artificial neural network technique. Journal of Environmental Management, 90(2), 1229–1235. doi:10.1016/j.jenvman.2008.06.004.

[55] Namugize, J. N., & Jewitt, G. P. W. (2018). Sensitivity analysis for water quality monitoring frequency in the application of a water quality index for the uMngeni River and its tributaries, KwaZulu-Natal, South Africa. Water SA, 44(4), 516–527. doi:10.4314/wsa.v44i4.01.

[56] P Fernandes, A. C., R Fonseca, A., Pacheco, F. A. L., & Sanches Fernandes, L. F. (2023). Water quality predictions through linear regression - A brute force algorithm approach. MethodsX, 10(January), 102153. doi:10.1016/j.mex.2023.102153.

[57] Irawan, C., Ratmasari, A., Rizaldi, F., Nata, I. F., & Putra, M. D. (2020). Removal phospate-containing detergent wastewater by Mg-Al($NO_3$) layered double hydroxide. IOP Conference Series: Earth and Environmental Science, 524(1), 012007. doi:10.1088/1755-1315/524/1/012007.

[58] Verla, E. N., Verla, A. W., & Enyoh, C. E. (2020). Finding a relationship between physicochemical characteristics and ionic composition of River Nworie, Imo State, Nigeria. PeerJ Analytical Chemistry, 2, e5. doi:10.7717/peerj-achem.5.

[59] Zalfiatri, Y., Restuhadi, F., Pramana, A., Rossi, E., Rahmayuni, & Johanes, D. (2023). Development of microalgae and agrobost mutualism symbiotic technology in the aerobic treatment of sago refinery wastewater. IOP Conference Series: Earth and Environmental Science, 1160(1), 012074. doi:10.1088/1755-1315/1160/1/012074.

[60] Wu, Z., Zhang, T., Wang, B., Ji, P., Sheng, N., Zhang, M., Liang, Q., Chen, S., & Wang, H. (2021). Scalable bacterial cellulose biofilms with improved ion transport for high osmotic power generation. Nano Energy, 88, 106275. doi:10.1016/j.nanoen.2021.106275.

[61] Mousavi, S. A., & Khodadoost, F. (2019). Effects of detergents on natural ecosystems and wastewater treatment processes: a review. Environmental Science and Pollution Research, 26(26), 26439–26448. doi:10.1007/s11356-019-05802-x.

[62] Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A., & Umar, K. (2021). Various natural and anthropogenic factors responsible for water quality degradation: A review. Water (Switzerland), 13(19), 1–35. doi:10.3390/w13192660.

[63] Enders, A., Hanley, K., Whitman, T., Joseph, S., & Lehmann, J. (2012). Characterization of biochars to evaluate recalcitrance and agronomic performance. Bioresource Technology, 114, 644–653. doi:10.1016/j.biortech.2012.03.022.

[64] Rebello, S., Asok, A. K., Mundayoor, S., & Jisha, M. S. (2013). Surfactants: chemistry, toxicity and remediation. Pollutant Diseases, Remediation and Recycling, 277-320. doi:10.1007/978-3-319-02387-8_5.

[65] Kulkarni, D., & Jaspal, D. (2025). Techniques for surfactant detection from wastewater: a review. International Journal of Environmental Analytical Chemistry, 105(5), 1115–1131. doi:10.1080/03067319.2023.2285372.

[66] Liu, Z., Hedayati, P., Sudhölter, E. J. R., Haaring, R., Shaik, A. R., & Kumar, N. (2020). Adsorption behavior of anionic surfactants to silica surfaces in the presence of calcium ion and polystyrene sulfonate. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 602. doi:10.1016/j.colsurfa.2020.125074.