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Monitoring Nutrient Levels in the Tigris River: Reality Versus Regulatory Standards

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Abstract

The current study aims to address the environmental challenge of nutrient enrichment in freshwater ecosystems, particularly in the Tigris River, by providing a comprehensive assessment of nutrient concentrations, including sulfates (SO_4^{2-}), nitrites (NO_2^-), nitrates (NO_3^-), ammonium (NH_4^+), and phosphates (PO_4^{3-}), evaluating the temporal and spatial distribution, and identifying the most important human -based activities contributing to the load of nutrient. Samples were collected from six sites distributed along the river within Baghdad city, over three years (2020–2022). The results showed a clear spatial variation, with concentrations of most nutrients gradually rising towards southern sites, indicating the impact of accumulated human activities such as sewage, industrial discharges, and agricultural runoff. Nitrates and phosphates were highest at sites near dense urban and industrial areas, while nitrite concentrations were generally low but appeared to be an indicator of incomplete biological activity. Sulfate concentrations (211–233 mg/L) exceed the environmental limits allowed under the 1967 Iraqi River Maintenance Regulation, and show a need for better water management and regular monitoring. In terms of time, the data showed significant annual changes in nutrient concentrations, with an increase in sulfate and phosphate concentrations recorded in 2022 and 2021, respectively, compared to previous years, which may reflect an increase in untreated discharges or the effects of drought and reduced river flow. In contrast, nitrate concentrations declined sharply in 2021 and rose again in 2022. Nitrite and ammonia concentrations remained relatively stable over the three years. The research recommends the need to strengthen continuous environmental monitoring systems, update national laws to include nutrient pollutants such as nitrite, and enhance the efficiency of water treatment plants, with the aim of reducing eutrophication and protecting the river ecosystem.

Keywords— Ammonium, Nutrient, Spatio-Temporal variation, Sulfate, Tigris, Water quality.

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1 Introduction

Rivers are considered one of the largest natural resources, playing an essential role in sustaining a wide variety of ecosystems and providing fresh water to people (Hildrew and Giller, 2023). They support industry, irrigation, and power production, while also providing habitats for both terrestrial and aquatic organisms (Grizzetti and Poikane, 2024). As the human presence is increasing with the improvement of agriculture and industries, the water quality of the rivers in question should be considered, i.e., the nutrient levels that have a direct impact on the ecosystem of these rivers both in terms of health and sustainability (Bouchareb et al., 2022; Mallin, 2023a). The two significant nutrients that impact the water quality and are needed to support the development of aquatic life include Nitrogen and phosphorus (Shakir, 2016; Paná et al., 2024). Nevertheless, the excessive accumulation of these two substances results in eutrophication and subsequent deterioration of water quality due to the algae bloom producing toxins in water, oxygen deficiency, and biodiversity loss (Horka et al., 2023; Mallin, 2023a). These elements are not only measured in the course of the study, but it is a way of understanding the dynamics of the river system and determining the sources of industrial, agricultural, and urban pollution. This is also facilitating the development of effective measures to curb environmental degradation and to have sustainable utilization of the freshwater. In this way, the nutrient test of the Tigris will be significant in terms of making the development needs balanced and ensuring a healthy environment in the water mass (Addo-Bediako, 2024). The Tigris River, which is unstable in nature, has not only one environmental issue regarding the accumulation of nutrients. These are either directly or indirectly considered a cause of concern because of the diverse human activities that include agricultural and industrial discharge and pollution by untreated wastewater (Tiwari, 2022; Mallin, 2023b). These activities interfere with the ecological stability of the river and hurt the aquatic life, creating environmental problems that include nutrient enrichment and the worsening of the water quality, consequently impacting the health of the population and other water uses (Addo-Bediako, 2024; Madjar et al., 2024; Nie et al., 2018).

Many researchers have identified the great impact of nutritional enrichment on the ecosystems of the river. Ogendi examined how the nutrients affected the water quality of a large river system in Kenya and discovered that the levels of the nutrients were higher downstream, due to the eutrophic conditions, and confirmed the need to continue with the nutritional observation to ensure the river ecosystem remains healthy (Ogendi et al., 2022). Likewise, Addo-Bediko studied a spatiotemporal study of the nutritional quantities in the South African river. The research showed high concentrations of nutrients such as nitrates, ammonia, and others in the wet season, which is due to the agricultural drainage and the discharge of untreated sewage (Addo-Bediako, 2024). In the local research of the river Tigris, Awad et al. evaluated the nutritional levels of the raw water near water treatment plants of Baghdad city, and demonstrated that urban and industrial activities played a significant role in increasing the levels of nutrients, which slowly weakened the quality of water (Shakir, 2016). In spite of the above research, there is a very big gap in the evaluation of the dynamics of nutrients in the Tigris River. It tends to be narrow in its parameters or localized to single locations, so that there is a lack of knowledge about the spatial and temporal changes of nutritional enrichment and their ecological effects. Thus, the given research will be used to assess the levels of significant nutrient concentrations in the Tigris River in Baghdad City, examine their spatiotemporal changes, and solve knowledge gaps related to nutrient pollution origin. It is based on that that this study attempts to offer a scientific rationale for the development of superior policies that will reduce the level of nutrient contamination, facilitate the sustainability of the environment, and ensure that future freshwater uses.

2 Materials and Methods

2.1 Sampling

The Tigris River is one of the most substantial rivers in the Middle East, originating in the Taurus Mountains in Turkey and extending through Iraq to the Shatt al-Arab, where it meets the Euphrates River to flow into the

Arabian Gulf (Al-Obaidy et al., 2015). The river is a main water artery for the countries it passes through, imparting cities with water for drinking, industry, and agriculture (Aljanabi et al., 2022). Six sites were chosen to conduct this study during 2020-2022 on the Tigris River in Baghdad city, as shown in Figure 1. The Sites are characterized by: Site 1, near Baghdad Island Park, northern entrance of the Tigris into Baghdad, a natural area influenced by fisheries/agriculture (no industry). Features a water treatment plant on the Al-Rissafa bank. Site 2 is located at the Al-Ghreaiat area, ~8 km downstream under a floating bridge. Agricultural area with palms/submerged plants. Popular recreation spots lead to significant food scraps and plastic waste pollution. Site 3 is located at Bab Al-Mu'adham, ~7.5 km downstream in central Baghdad. High human activity (restaurants, fisheries, residential buildings). Site 4 is located at Al-Jaderia, ~8 km downstream. Predominantly urban (University of Baghdad campus) with minimal agriculture.

Sites 5 and 6 are located at Al-Zafarain downstream of the Tigris River in Baghdad. Site 5 at the beginning of Al-Zafarain. While Site 6 is near the Diyala River mouth. These two areas are influenced by various industrial discharges (government & private sector plants) like the General Company for Food Products, Al-Dora thermal power plant, southern Baghdad thermal power plant, and Al-Rasheed Gas Power Plant. Receives various discharges and is densely populated due to urban development.

Water samples were collected from these six sites seasonally. Field measurement included water temperature (WT) and hydrogen ion pH. For chemical measurement of nutrients (sulfate- SO_4^{2-}, Nitrite- NO_2^-, Nitrate- NO_3^-, Ammonium-NH_4^-, phosphate-PO_4^{3-}), 1 liter of water sample was collected in clean polyethylene bottles and stored in a cooling box until transported to the laboratory. All parameters were measured according to APHA (2017), using the following instruments: Temperature/pH portable meter H19811 for WT and pH, Sulfate meter/ HI 93751 for SO_4^2, Spectrophotometer UV-1200 for PO_4^{3-}, while Multiparameter photometer/HI 83200 was used to measure the NO_2^-, NO_3^-, NH_4^-. NH_4 was collected in polyethylene bottles and acidified with H_2SO_4.

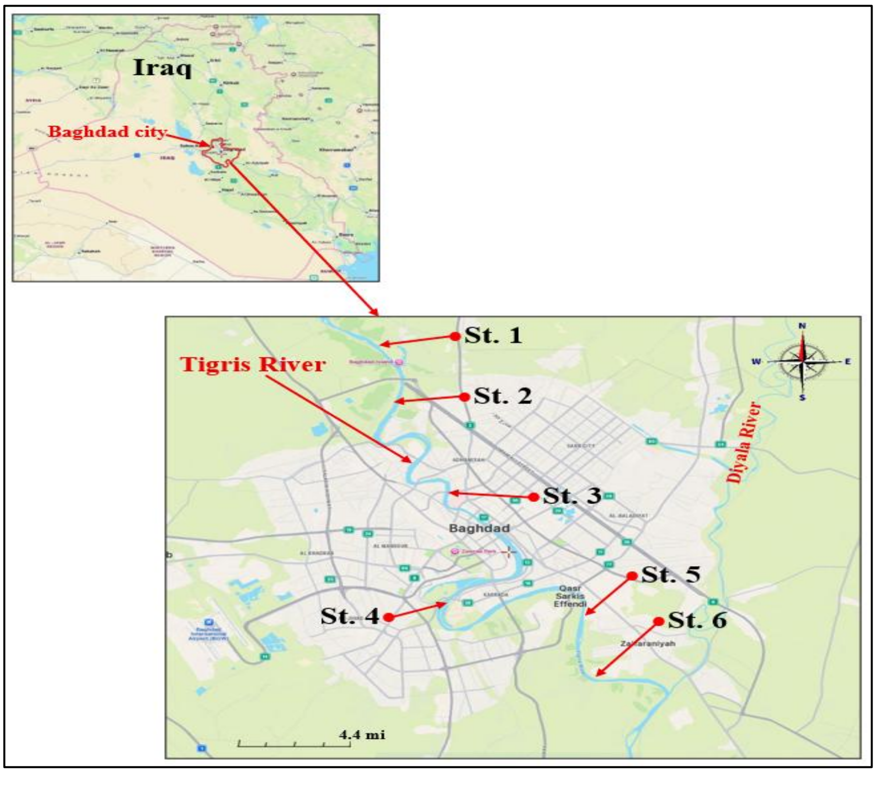

Figure 1: Map showing the study area (Google Earth, 2023)

2.2 Statistical analysis

OriginLab Pro (learning edition 2025) was used to statistically analyze and plot the parameters of the water quality. Using SPSS, the following processes were computed: mean, maximum, minimum, and standard deviation of both temporal and spatial data, in addition to visualizing the dataset with the boxplots to display the distribution, and testing the normality through the Kolmogorov-Smirnov test.

3 Results and Discussion

The spatial and temporal variation of the parameters under this study is illustrated in Tables 1 and 2. The variation in each parameter concentration is visualized using a box plot (Figure 2-8), which is a powerful tool used to represent the distribution of data, consisting of several key components. First, it describes the central area of the data, stretching from the 25th percentile (lower quartile) to the 75th percentile (upper quartile) with a line within it stating the median, dividing the data into two halves. Second, the whiskers hang from the box's top and bottom, wherein the lower whisker denotes the smallest value within the range of extraordinary (normal) values, whereas the upper whisker denotes the largest value within the same range. Third, the outliers show up in small circles outside the whiskers, showing those values that do not fall in the extraordinary (normal) range, which could point towards an unusual measurement (Huang et al., 2021). Also, the interquartile range (IQR) is the difference between the 75th percentile and the 25th percentile, which gives an idea of how much variability lies in the data inside the box. Box plots are used to compare data distributions across groups. The plots also allow for the observation of variability and outliers for each group (Aisyah et al., 2022).

Table 1: The spatial fluctuation in water quality data in the Tigris River during the study period

Parameter	Site	Aver	Min.	Max.	SD.	Site	Aver	Min.	Max.	SD.
WT	St. 1	20.94	11.50	29.40	6.48	St. 4	20.76	11.57	30.50	6.71
pH		8.00	7.60	8.30	0.22		8.05	7.64	8.40	0.22
SO_4^{2-}		220.42	196.00	252.00	17.02		226.50	195.00	261.00	21.85
NO_2^-		0.04	0.00	0.10	0.03		0.03	0.00	0.11	0.03
NO_3^-		1.18	0.08	3.60	0.96		1.92	0.07	5.10	1.63
NH_4^+		0.25	0.02	0.93	0.25		0.27	0.02	0.90	0.25
PO_4^{3-}		0.29	0.00	1.67	0.36		0.39	0.01	1.64	0.41
WT	St. 2	20.28	11.50	29.90	6.35	St. 5	21.97	12.50	31.00	6.71
pH		8.03	7.60	8.30	0.24		8.13	7.65	8.40	0.24
SO_4^{2-}		211.61	186.00	236.00	15.68		218.67	185.00	255.00	17.50
NO_2^-		0.03	0.00	0.09	0.02		0.04	0.00	0.15	0.04
NO_3^-		1.51	0.09	3.45	1.13		2.17	0.50	6.40	1.26
NH_4^+		0.27	0.02	1.09	0.29		0.33	0.02	1.15	0.33
PO_4^{3-}		0.32	0.01	1.80	0.43		0.24	0.02	0.84	0.18
WT	St. 3	20.37	11.70	30.00	6.40	St. 6	22.27	12.50	32.00	6.90
pH		8.10	7.60	8.40	0.26		8.10	7.60	8.41	0.23
SO_4^{2-}		227.08	206.00	280.00	22.91		231.14	177.00	280.00	32.25
NO_2^-		0.05	0.00	0.13	0.03		0.04	0.00	0.13	0.04
NO_3^-		1.71	0.03	4.50	1.44		2.93	0.42	6.80	1.63
NH_4^+		0.23	0.05	0.66	0.19		0.43	0.08	2.00	0.51
PO_4^{3-}		0.39	0.03	1.95	0.49		0.28	0.01	0.93	0.22

Table 2: The temporal fluctuation in water quality data in the Tigris River during the study period

	Year											
	2020				2021				2022			
Parameter	Aver.	Min.	Max.	SD.	Aver.	Min.	Max.	SD.	Aver.	Min.	Max.	SD.
WT	20.58	19.85	21.40	0.65	21.28	20.50	22.35	0.72	22.43	20.38	23.18	1.16
pH	8.04	7.84	8.17	0.11	8.05	7.96	8.11	0.06	8.12	8.03	8.26	0.08
SO_4^{2-}	216.2	201.7	232.7	9.9	217.5	201.2	231.1	10.28	233.9	218.5	248.7	10.44
NO_2^-	0.04	0.02	0.05	0.01	0.03	0.02	0.05	0.01	0.05	0.04	0.06	0.01
NO_3^-	2.75	1.76	4.42	0.89	1.04	0.49	1.82	0.62	1.99	1.15	2.89	0.68
NH_4^+	0.31	0.19	0.54	0.13	0.30	0.23	0.39	0.06	0.33	0.30	0.39	0.04
PO_4^{3-}	0.20	0.07	0.40	0.11	0.55	0.28	0.75	0.19	0.20	0.16	0.26	0.04

3.1 Spatio-Temporal Water Temperature (C°)

This study took a period of three years, and the temperature of water was recorded at six sites. The measurements showed significant variations. The lowest water temperature was at site S1 (11.50 ^{o}C or 32.00 ^{o}C). In between these extremities, values at the other locations were between 11.50 and 31.00 ^{o}C (Table 1). To illustrate, Site S3 showed a large difference in temperature between 11.70 to 30.00 ^{o}C, whereas Site S4 had a range of 11.57 ^{o}C to 30.50 ^{o}C. The findings therefore suggest the geological and environmental factors on water temperature, such as the topography of rivers and solar radiation (Lorenzo-Gonzalez et al., 2023; Johnson et al., 2024). Water temperature is a very useful measurement in evaluating the variation of temperature and its implications for the aquatic ecosystem.

By analyzing the successive values of the series, they may be considered significant. The average water temperature was recorded as 20.58°C in 2020 and continued to rise sequentially through 2021 and 2022, presenting values of 21.28 and 22.43°C, respectively. This increasing trend could reflect the effect of global warming or local environmental change (Al-Salihi et al., 2022).

Looking at the distribution of the data, based on the boxplot, it's easy to notice that the temperature is heterogeneously distributed (indicating potential measurement anomalies or natural variability). For example, some sites measured temperatures as low as 11.5°C, with others seeing temperatures as high as 32°C. The whiskers in the box plot represent ranges of normal values, with the lower whisker indicating the lowest value and the upper whisker indicating the highest value within the data range for each site (Figure 2).

Based on previous studies of the Tigris and Euphrates rivers (Al-Ansari et al., 2019; Abdullah et al., 2019; Abdullah et al., 2024), which recorded a cumulative temperature rise (+1.5°C since 1990), the data from 2020–2022 for the six sites show an unprecedented acceleration (+0.55°C between 2020-2021 and +1.15°C between 2021-2022), exceeding three times the global average, with a concerning peak (32°C) recorded at S6 in 2022 (Table 2), exceeded the limit for protection of aquatic life (30°C) warned about in marsh studies (Al-Janabi et al., 2025).

There is a sharp spatial variation, with sites S5 and S6 experiencing accelerated increases (+1.5°C/3 years) due to industrial pollution located in the southern part of Baghdad, where this area (S5 and S6) is distinguished by the presence of many industrial complexes like General Company for Food Product, Al-Dora thermal power plant, southern Baghdad thermal power plant and Al-Rasheed Gas Power Plant, as confirmed by (Wadeea et al. 2022; Al-Janabi et al., 2024), while S3 recorded the greatest thermal fluctuation (11.7–30°C) due to extreme climatic factors.

Overall, these results help in understanding the changes in water temperatures and identifying potential factors that affect these changes, providing a valuable database for further environmental and aquatic studies.

Ultimately, there are concerns about the environmental impacts that necessitate the implementation of the United Nations Environment Program recommendations for urgent monitoring of hot spots.

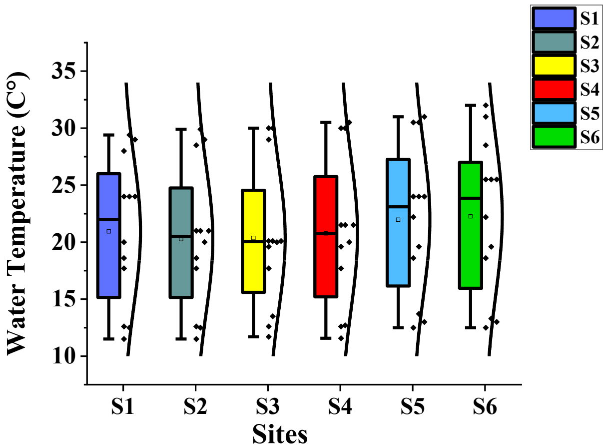

Figure 2: Values of water Temperature across monitoring sites

3.2 Spatio-Temporal Hydrogen Ion Concentration pH

The pHs of six locations varied between 7.60 (alkaline) and 8.41 (even more alkaline), with an alkaline environment mostly dominant (85 percent of values fell above 7.8). Sites 3 and 4 contain the highest variations (7.64-8.40 and 7.67-8.40, respectively), therefore, the external effect could be external pollution of the industrial/agricultural sources or water source mixing, as Figure 3 demonstrates. The same thing applies to sites 2 and 5 (7.60 -8.30 and 7.65 -8.40). The general alkalinity can be explained by the existence of minerals of calcium carbonates or photosynthetic activities, whereas the sudden decreasing values (7.60 at site 4) can be explained by acid pollution or organic decay. It may be caused by several potential factors, such as Site-specific conditions (equipment, location, etc.) and time changes, where any change in the temperature of water within a day can dramatically impact the pH of water in aquatic ecosystems (Nowak et al., 2022; Mosley et al., 2024). By default, elevated temperatures decrease the solubility of gases (like CO_2) and hence also cause a rise in pH (during the day), which returns to productive photosynthesis activity of aquatic plants and algae, which consume this gas (Wang et al., 2021) Conversely, as temperatures drop overnight, the respiration releases CO_2 that is commonly diffused into the water, resulting in lower pH (acidic conditions) (Wang et al., 2021). In addition to that, the increased activity of microbes caused by high temperature may contribute to the postulated variations through the increase in respiration rate and consequent variation in pH (Zeng et al., 2021). All these processes highlight the interplay of temperature and pH to maintain the health of the aquatic ecosystem; in essence, temperature is a contributing factor, with temperatures lowering the solubility of gases like carbon dioxide (CO_2) in water, causing high pH during warm weather, and the opposite as temperatures decrease (Di Paolo et al., 2019). In addition to this, other environmental parameters moderate pH in water bodies in various mechanisms in which agricultural drainage might contain excess nutrients (primarily P and N), which in turn may have an algal bloom that has been repeatedly shown to raise pH during photosynthesis as nutrients are consumed, and with decomposition of the algae more CO_2 will produce that can causes decreased pH stability (Lan et al., 2024). Moreover, dissolved organic matter (DOM) also influences the pH and may dissociate in the water, eventually causing acidification of the water (Palma et al., 2024). Salinity changes also impact pH; an increase in salinity of water can increase the buffering capacity, so that water would be less influenced by pH than when it has low salinity, and pH might fluctuate (Rugebregt et al., 2023). Finally, carbonate chemistry plays a crucial role in controlling pH, where the presence of carbonate ions (CO_3^{2-}) can buffer changes in pH, while depletion by biological activity or precipitation can lead to more acidified conditions (Kwame & Mbage, 2024). All these environmental factors can act in complicated synergetic ways in controlling the pH of aquatics, and hence on the health and biodiversity of aquatic life (Rugebregt et al., 2023; Zakir & Rajshekhar, 2020).

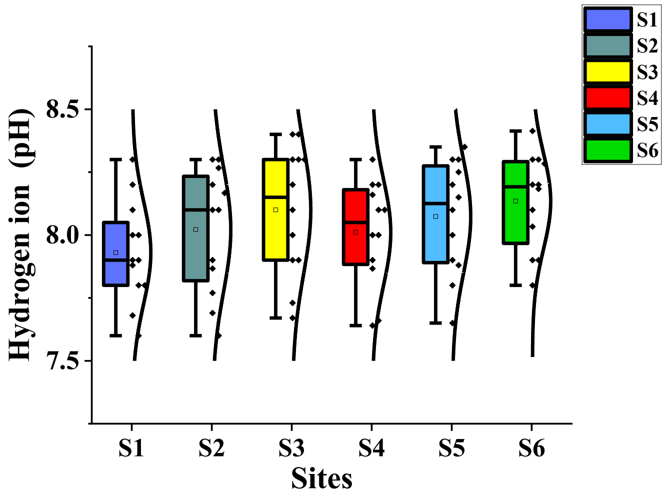

Figure 3: Concentration of pH across monitoring sites

3.3 Spatio-Temporal Distribution of Sulfate Concentrations

Spatial analysis of sulfate (SO_4^{2-}) concentration shows a clear increase from the upstream to the downstream across the six sampling sites in the Tigris River, in which the highest values of the sulfate level are recorded in the southern sites. From Table 1 and Figure 4, the lowest mean concentration was measured for Site S2 (211.61 mg/L) and the highest for Site S6 (231.14 mg/L; with a wide range of 177–280 mg/L and a high standard deviation of 32.25), indicating large local dispersion.

This spatial pattern is directly related to the geographical location of the sampling sites (Figure 1). Sites S1 and S2 are located in the northern upstream part of the Tigris within a less urbanized and industrialized area, where there a little anthropogenic input. The remaining downstream sites, specifically S5 and S6, are located in and around the heavy urban and industrial areas of central and southern Baghdad. The increased levels of sulfate at these lower sites are likely associated with multiple sources of pollution, including (Table 3):

- Effluents from industrial sources: namely, from the Al-Doura Oil Refinery and Doura Thermal Power Sites, both situated in the vicinity of sampling site S4; discharges from small-scale workshops of chemical and detergent production, which operate in the Al-Zaafaraniya industrial zone near Site S5. These plants are a major source of effluents that contain high concentrations of sulfur species as a result of petroleum desulfurization and/or chemical synthesis (Al-Obaidy et al., 2016; Saleh, 2020).
- Urban wastewater flow: particularly in southern Baghdad, where there is a discharge of inadequately treated or untreated sewage from residential areas (Abu-Disheer, parts of Al-Rasheed and Al-Mada'in) close to S6. This wastewater is likely to be high in sulfate from household detergents, personal hygiene products, and the degradation of organic material in an aging or overburdened sewer system (Abed and Alrawi, 2022).
- Agricultural runoff: in the rural and peri-urban riparian areas downstream of site S5 in particular affecting S6, there are large areas of farmland served with surface irrigation. Sulfur-based fertilizers (including those with ammonium sulfate and potassium sulfate) and sulfur-containing soil minerals are leached into the river at irrigation return flows, especially during the spring and summer (Nuruzzaman et al., 2025).

Sulfate concentrations (211–233 mg/l) in the Tigris River exceed the 200 mg/L limit for surface water discharge set by the Iraqi River Maintenance Regulation No. 25 for 1967 (Iraqi laws and legislation, 1967). This indicates non-transport in many places and emphasizes the need for better water management and regular monitoring.

Sulfate concentrations in the Tigris River showed a slight upward trend during 2020–2022, rising from 216.25 mg/L in 2020 to 233.93 mg/L in 2022. This gradual rise reflects the increasing impacts of industrial and sanitary discharges and the poor ability of the river to mitigate during periods of drought.

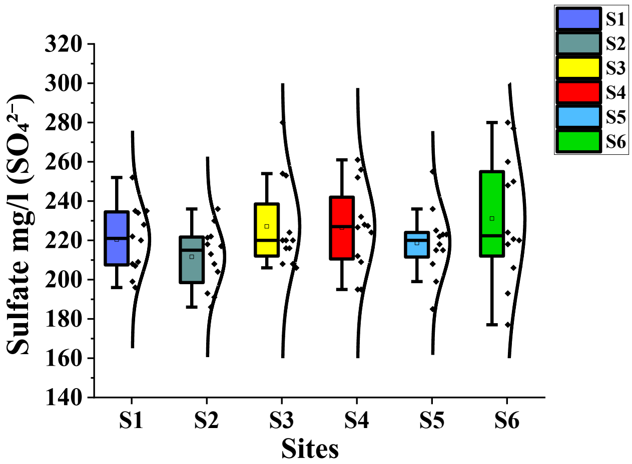

Figure 4: Concentration of Sulfate across monitoring sites

Table 3: Summary of spatial distributions of the sources of SO_4^{2-} at sampling sites*

Site	Sources of increased SO_4^{2-}	Source Type
S1, S2	Kadhraa / Al-Kadhimiya sewage station/, carwash stations	Domestic and service-related
S3	aging sewer network, mixed drainage	Urban
S4	Doura Thermal Power Plant, Al-Doura Refinery	Heavy industrial
S5	Former detergent and food processing plants, Al-Zaafaraniya Industrial Zone	Medium-scale industrial and service-related
S6	Southern Baghdad agriculture, Al-Mada'in light industries, Abu Disheer sewage outfall	Agricultural + Municipal sewage + Industrial

***** This table is an inference from a field study of sampling sites and publicly available information on local pollution sources along the Tigris River in Baghdad.

3.4 Spatio-Temporal Distribution of Nitrite Concentrations

The spatial distribution of NO_2^- concentrations along the six sampling sites in the Tigris River is an observed variation that means the NO_2^- concentrations are always low, with an average of 0.03–0.05 mg/L. The highest value appears at S3 (0.05 mg/L), and the lowest averages were found at S2 and S4 (0.03 mg/L), as shown in Figure 5. This small degree of variation indicates input of organic pollution from continuous or intermittent sources, including those from sewage, stormwater runoff, or the presence of decomposing organic material entering the river. These results agree with ref. (Shakir, 2016).

The appearance of nitrite, even in low concentrations, is relevant as it reflects incomplete nitrification. This results when ammonia is only partially oxidized due to inadequate dissolved oxygen concentration, microbial population imbalance, or high organic loading (Blackburne et al., 2008). Higher values of nitrite can also be a sign of a recent or current wastewater input, in particular where the self-purifying potential of the river is constrained by flow impedances or urban discharges (Bayram et al., 2013).

Despite the low concentrations of nitrite, their presence indicates ongoing biochemical reactions in the river and should be closely followed. Specifically, S3, situated near a highly urbanized area, exhibited slightly higher levels, thus indicating that mixed domestic and institutional wastewater sources may be contributing influence. Similarly, S5 and S6 demonstrated moderate values and are probably related to the accumulation of nitrogenous compounds downstream and the low flow regime (Jani et al., 2020).

In general, nitrite is a very early warning for organic contamination and oxygen stress in freshwater systems. The spatial distribution may indicate that urban expansion and poor wastewater treatment are potential contributors to the low nutrient enrichment (supported by the proximity of some sampling sites to densely populated urban areas), which may draw attention to the integration of nitrite monitoring into routine river health assessment programs in Iraq. While nitrite is not specifically one of the substances mentioned in the Iraqi River Maintenance Regulation No. 25 for 1967 (Iraqi laws and legislation, 1967). Its presence is indirectly covered through limitations on discharges consisting of hazardous byproducts of organic pollution. The rule focuses on avoiding discharges of wastewater, which could cause the creation of harmful substances, a situation in which nitrite may be present.

Nitrite concentrations (NO_2^-) in the Tigris River showed relative stability during the period 2020–2022, with averages ranging from 0.03 to 0.04 mg/L without much change. This persistence indicates a persistent source of low-intensity organic pollution, with environmental conditions remaining without significant improvement in nitrification efficiency.

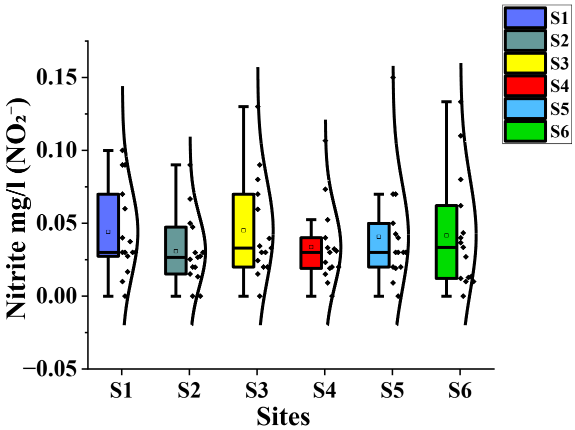

Figure 5: Concentration of Nitrite across monitoring sites

3.5 Spatio-Temporal Distribution of Nitrate Concentrations

According to the findings of the 2020–2022 Tigris River Nutrient Assessment Study, nitrate (NO_3-) concentrations at the six monitoring sites varied between 0.03 and 6.8 mg/L. Site S6, which is situated in the Zafaraniya area, a densely populated area with extensive agricultural and industrial activity, recorded the highest value. The overall averages over the study period ranged from 1.0 to 2.75 mg/L. This shows that NO_3^- levels varied a lot across time and space because of the numerous pollution sources and the amount of human activity around each site. The lower sites, especially S5 and S6 (Figure 6), had the highest levels of contaminants, which were caused by sewage discharge and agricultural irrigation water that was full of nitrogen fertilizers. When we look at these data next to the rules in Law No. 25 of 1967 for the Protection of Rivers and Public Waters from Pollution, the law indicates that the maximum NO_3^- that can be in wastewater that is dumped into water sources is 50 mg/L. So, all the values recorded in the Tigris River throughout the study were below this limit. This means that, according to

current Iraqi law, the water did not have more nitrates than what is allowed. However, this does not disprove the existence of concerning environmental indicators, particularly given the rising concentrations in some locations, which, if preventative action is not taken, may portend a more polluted future.
From an environmental standpoint, even if the current NO_3^- concentrations are within the permitted limits, they are an important indicator of the continuous environmental strain brought on by human activity (Moloantoa et al., 2022), especially uncontrolled agriculture and the release of untreated wastewater (Tariq and Mushtaq, 2023). The natural equilibrium of the river may be upset if nitrate levels continue to grow in some places, since they are essential to eutrophication, which causes algae blooms and low oxygen levels in the water (Wurtsbaugh et al., 2019).
Nitrate concentrations fluctuated significantly over the years, peaking in 2020 (2.75 mg/L), decreasing significantly in 2021 (1.04 mg/L), and rising again in 2022 (1.99 mg/L). This change indicates seasonal or intermittent impacts of agricultural and health pollution sources.

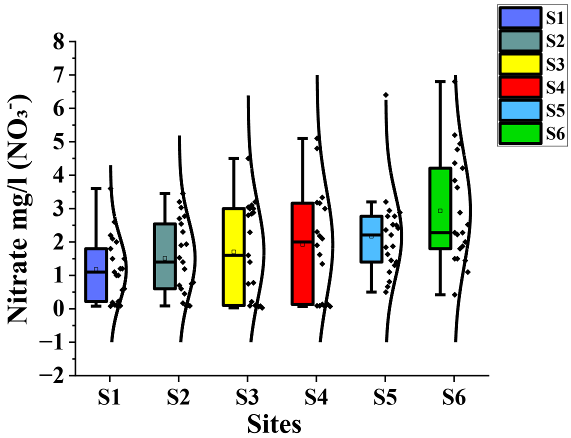

Figure 6: Concentration of Nitrate across monitoring sites

3.6 Spatio-Temporal Distribution of Ammonium Concentrations

Ammonium (NH_4^+) concentrations in river water differed considerably among the six sites. At site S6, a location with a high population and industrial density that raises the possibility of sewage and industrial waste spilling into the river (Singh et al., 2022). The measured values varied from a minimum of 0.02 mg/L to a maximum of 2.00 mg/L. The overall average NH_4^+ concentration across the various sites ranged from 0.23 to 0.43 mg/L, with a clear standard deviation indicating significant variation between readings, reflecting the presence of irregular or intermittent pollution sources. These findings are compared to the restrictions outlined in the Iraqi River Conservation Regulation, which states that wastewater released into water sources must contain no more than 1.0 mg/L of NH_4^+. Similarly, according to the World Health Organization (WHO) and the US Environmental Protection Agency (EPA), the maximum limit for Ammonium should not exceed 1.5 mg/L. This indicates that, aside from a few isolated high values obtained in lower areas, especially at S6 (Figure 7), where the concentration exceeded the allowable limit by two times, the majority of measurements were within the legally allowed levels. This increase indicates the possibility of direct, untreated sewage or industrial waste being discharged, as well as the potential for organic matter to decompose in the water due to the weak river flow in that area (Akhtar et al., 2021).

When it comes to the environment, high NH_4^+ levels are a sign of recent organic pollution in the water since they are a byproduct of the first breakdown of organic matter or the direct release of nitrogen fertilizers or urine (Madhav et al., 2020). The NH_4^+ poses a threat to aquatic life because it is converted to NO_2^- and subsequently to NO_3^- during the nitrification process, which uses up the dissolved oxygen in the water and may cause oxygen depletion (Robles-Porchas et al., 2020). Fish and invertebrates may also be directly poisoned by excessive NH_4^+ concentrations, particularly in high pH conditions where some of the NH_4^+ is transformed into the more hazardous free ammonia (NH_3) (Zhang et al., 2023). Clear exceedances in some places, especially in industrial and agricultural areas, should be treated seriously even when the majority of reported values are below the official regulation limits. This is because they show the presence of ongoing or uncontrolled sources of pollution. The river maintenance system does not include limits for free NH_3, nor does it indicate the relationship between pH and NH_4^+ concentration, which are essential elements that have now become a standard in assessing the environmental risks of water (Ding et al., 2021).

Ammonia concentrations remained semi-stable over the three years, averaging between 0.32 and 0.37 mg/L. This stability indicates a relatively permanent source of organic pollution, often from domestic wastewater discharges.

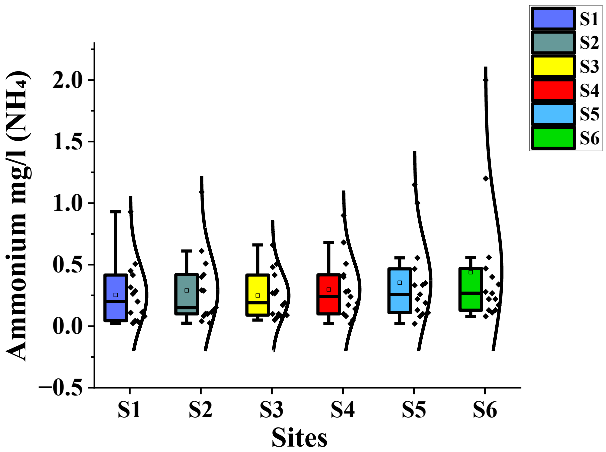

Figure 7: Concentration of Ammonium across monitoring sites

3.7 Spatio-Temporal Distribution of Phosphate Concentrations

Phosphate (PO_4^{3-}) concentrations at the six monitoring locations varied greatly, with recorded values ranging from 0.00 to 1.95 mg/L. The third location (S3) had the highest value, while the average for all sites was between 0.24 and 0.39 mg/L (Figure 8). The spatial distribution reveals that certain sites, especially S3 and S4, had notable concentration swings, which may indicate the existence of sporadic PO_4^{3-} discharge sources like untreated home and commercial wastewater or PO_4^{3-} fertilizer-rich agricultural drainage water (Mengqi et al., 2023). The Law for the Conservation of Rivers and Public Waters from Pollution states that a maximum of 3.0 mg/L of PO_4^{3-} may be present in water that is released into water sources. Therefore, there are no obvious excesses of PO_4 levels in comparison to the authorized criteria, and all values documented in the study fit within the legal bounds. These restrictions, meanwhile, might not accurately represent current environmental patterns that alert people to the cumulative impacts of nutrients, even at legally "safe" levels.

Even at low amounts, PO_4^{3-} in surface water can have a major impact on the ecosystem of rivers from an environmental standpoint (Mallin and Cahoon, 2020). An important nutrient called PO_4^{3-} is in charge of causing eutrophication, which is the overgrowth of aquatic plants and algae. As the plant mass breaks down, this imbalanced growth uses up a lot of dissolved oxygen, which causes the oxygen concentration to drop sharply and suffocate fish and other species (Akinnawo, 2023). According to several recent investigations, these phenomena can occur in stagnant or low-flowing water at PO_4^{3-} concentrations more than 0.1 mg/L (Rahman, 2020). This puts a large number of the Tigris River measurements within the critical environmental range, particularly in areas with limited flow or that receive constant discharge from industrial and residential sectors.

Surprisingly, the study's highest readings were found in central Baghdad, where the water is combined with commercial and residential effluent, suggesting that there may not be a water treatment system in place in some places, PO_4^{3-} levels in the water are also significantly increased by the use of chemical fertilizers in agricultural areas close to river banks, especially during the planting and irrigation seasons (Liu et al., 2021).

Based on the aforementioned, even while the measured PO_4^{3-} levels fall within the Iraqi system's allowable bounds, they are nonetheless regarded as comparatively high from an environmental standpoint and call for precautionary actions.

There was a clear increase in phosphate concentration in 2021 (0.55 mg/L) compared to 2020 (0.36 mg/L) and 2022 (0.26 mg/L), which may be attributed to increased detergent discharge or heavy use of phosphate fertilizers and natural soil erosion during that year.

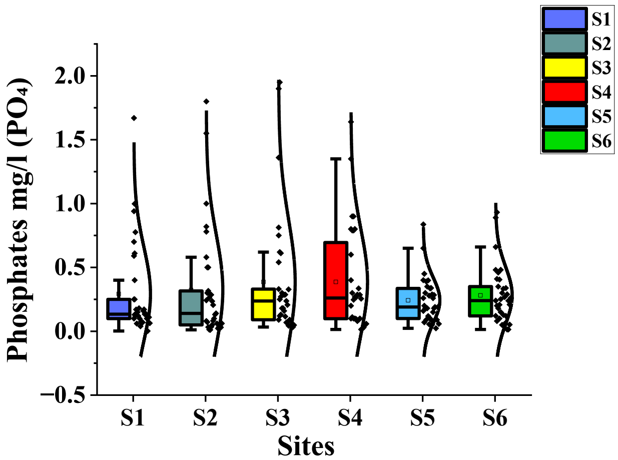

Figure 8: Concentration of Phosphates across monitoring sites

3.7 Pearson's Correlation

The Correlation matrix reveals the important relationship between different water parameters (Kothari et al., 2021). As can be seen in the heatmap (Figure 9) for the parameters under study, there is a gradient of colors, where blue color indicates positive correlation between variables, which means whenever the variable increases, the other variable tends to increase too. Color intensity (darker blue) indicates the strength of this positive correlation. While the red color represents the negative correlation between variables, which means one of the parameters tends to decrease whenever the other parameter increases. Color intensity (darker red) indicates the strength of the negative correlation. The parameters with lighter or white color indicate a weak or very weak correlation, like the correlation between NO_2^- with both NH_4^+ and NO_3^- (r= 0.03 and r=0.08, respectively). On the other hand, NH_4^+ and NO_3^- exhibit a very strong positive correlation (r=+0.90), which may refer to the active nitrogen cycle in the aquatic system (He et al., 2025). This correlation stands as one of the indicators that have to be proved, but it is not direct evidence of N-cycle activity. Where NH_4^+ can be converted to NO_3^- in the presence of adequate oxygen in water (Mohammed et al., 2022). Many studies on the Tigris River have demonstrated that the water of the Tigris River has good aeration conditions (Abed et al., 2022; Al-Sudani, 2021; Hassan et al., 2025; Al-Hamadany et al., 2024; Noor et al., 2022). Also, there is a positive correlation between water temperature and each of NH_4^+ (r=+0.88) and NO_3^- (r=+0.79), which may reflect the increase in biological activity and the nitrification process at high temperatures (Li et al., 2020), in addition to the effect of the agricultural runoff (Hong et al., 2019). In contrast, PO_4^{3-} shows a strong negative correlation with water temperature (r=-0.75), which indicates to decrease in PO_4^{3-} concentration with an increase in water temperature, which may result in the increase of nutrient absorption by aquatic life or PO_4^{3-} precipitation in water (Hassan et al., 2025). Moreover, there is a moderate positive correlation between NO_3^- with each of pH and SO_4^{2-} (r=+0.69 and r=+0.60, respectively), in addition to pH and water temperature (r=+0.56), which indicates mutual effects between these parameters, like (i) the effect of water temperature on the availability of nutrient in general way by accelerating of nutrient cycle in aquatic system (Dory et al., 2024), and (ii) the effect of common sources of pollution (Xin et al., 2024). These correlations highlight the complicated correlation between physical, chemical, and biological factors that affect water quality.

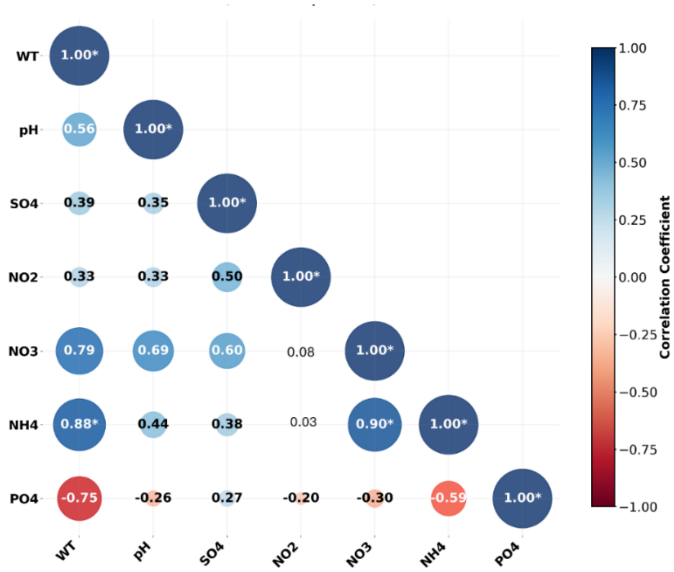

Figure 9: Correlation heatmap for water parameters with significance (*indicates p<0.05)

4 Conclusion

- The Iraqi water temperature is highly affected by the high summer air temperature, in addition to the presence of sources of thermal pollution (e.g., industrial discharge) in the study area. whether it requires so much control and caution. Also, the alkali condition of the Iraqi water is a distinctive feature due to the geological and soil characteristics. It must be monitored and, when necessary, treatment measures applied to ensure its adequacy for all intended uses, including where excessive alkalinity renders water both functionally and environmentally unacceptable.
- Sulfate concentration increased downstream, reaching maximum values at S6, which was attributed to accumulated industrial, municipal, and agricultural sources. This result confirms previous studies.
- All sulfate contents were lower than the Iraqi River Maintenance Regulation standard (400 mg/L), but the increasing trend indicated that surveillance and prevention of pollution are crucial.
- Nitrite levels were uniformly low across locations, indicating no recent nitrogen pollution but the presence of partial nitrification and occasional organic imposition. Except in the urban sites (especially S3), nitrite concentration was a little high because of the combined wastewater inflow and reduced conditions of oxygen. The Iraqi regulation does not mention nitrite as a parameter, which requires updating it to reflect modern pollution indicator concepts.
- According to Iraqi River Conservation Regulation No. 25 of 1967, all recorded values for NO3-, NH4+, and PO43- are within allowable bounds. The highest values were frequently found in the southern sites, such as S5 and S6, which are immediately impacted by the outflow of sewage and agricultural and industrial waste. Nevertheless, the data revealed notable regional and temporal variability.
- Relative to NH4+ and PO43-, the measured quantities are high in comparison to current standards of environmental preservation of aquatic systems that are meant to avoid the effects of eutrophication and the absence of oxygen, although they are not beyond the legal limits. Higher nutrient contents in some areas demonstrate the presence of existing or non-existent sources of pollution to be closely monitored, remediated, and controlled to contain uncontrolled releases.

- Current legal requirements are not only to be adhered to, but also, they are to be checked and revised according to scientific developments and potential environmental risks. Also, environmentally sensitive areas should have enhanced surveillance and treatment programs.
- Future research can expand the temporal coverage and contain a seasonal sample to accurately measure the nutrient variability. Also, including the biological indicators may help to assess the ecological effects. Moreover, from a practical perspective, it is recommended to upgrade treatment plants for wastewater, promote sustainable agricultural applications, and ensure compliance with Iraqi maintenance regulations of the river to reduce the nutritional load in the Tigris River.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript

Contribution

Authorship Contributions: A.N.A. conducted field and laboratory measurements and contributed to writing the first draft. Z.Z.A. conducted the statistical analysis and contributed to writing the first draft. E.S.A. designed the study, developed the theory, and contributed to writing the first draft. A.N. G. and E.A.H. contributed to sample preparation. G.H. A. and WA.K.A reviewed the final draft. Z.B.M and R.A.H.A helped supervise the project.

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Data Availability

The data are available on request from the corresponding author.

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