JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(3), 264–273
https://doi.org/10.12911/22998993/197497
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.12.10
Accepted: 2025.01.17
Published: 2025.02.01

Effect of pollutants on phytoplankton biodiversity in the Tigris and Diyala Rivers in Baghdad Province

Hiba Adil Alfalahi[1], Ahmed S. Aldhamin[2*]

[1] Ministry of Water Resources, Baghdad, Iraq
[2] Department of Biology, College of Science, University of Baghdad, Baghdad, Iraq
* Corresponding author's e-mail: ahmedsaadaldhamin@gmail.com

ABSTRACT

The Tigris River is the second longest river in West Asia. It passes through densely populated areas, especially in the city of Baghdad. As a result of the demand for water that become at its highest levels. In contrast, the discharge of the Tigris River has decreased, in addition to the poor quality of the water of the Diyala River, which is one of the tributaries of the Tigris River on the Baghdad side, due to the increasing amounts of wastewater in it. In addition, the deficiency and poor quality of wastewater treatment plants, which in turn affects the life balance of living organisms, including phytoplankton, which is considered one of the components of the food chain for living organisms in the ecosystem. Wide differences exist among algal species in their requirements for nutrient metals or in their sensitivity to pollutants and thus the predominant effect of pollutants may well be on species composition of phytoplankton communities. Five sites were chosen (Saeda on the Tigris, Al-Multaqa on Diyala, Al-Tuwaitha on Tigris, Al-Jaara on the Tigris, and Jesr Enbopy on Diyala) from which samples were taken to measure heavy metals (Zn, Cu, Fe), chemical oxygen demand COD, pH, and phytoplankton were diagnosed in quantity and quality for three seasons (October, January, and March) Statistical techniques were applied and Shannon-Wiener diversity index (H) to evaluate the changes during the three seasons, and the results that the phytoplankton species showed a dominance of Cyanophyceae in quantity and quality in the study seasons, which is followed by Chlorophyceae and then Baciliariophyceae in quantity. As for quality, Cyanophyceae is followed by Baciliariophyceae and then Chlorophyceae with low specific density and high diversity according to the Shannon-Wiener index only in autumn with a high diversity of 3.39 at site 2 of the Diyala River, followed by spring with a diversity of 3.115 at site 1 of the Tigris River., The highest biomass of phytoplankton occurred in autumn, whereas the lowest biomass was in spring.

Keywords: pollutants, phytoplankton, biodiversity, Tigris River, Diyala River.

INTRODUCTION

The Tigris River is one of the longest rivers in the Middle East, with length of about 1900 km, passing through Iraqi land over nearly 1415 km. The Tigris river shares this role with the Euphrates River, as they are a primary source of water for human consumption. As the increase in population numbers and the expansion of the country's economic activates, has produced an increase in the demand for water to be used in various ways and because of the great pressures on water resources in Iraq during the past twenty years, especially on the issue of the amount of available water. Building dams on the Tigris and Euphrates rivers in neighboring countries, the continuous change in climate around the world, the severe decrease in the amount of rain falling each year in Iraq, poor management of the water used, and other matters contributed to this state of affairs (Al-Harbawee and Mohammed, 2024a). The Tigris River in the heart of the capital, Baghdad, has become more polluted due to human activities (Al-Harbawee and Mohammed, 2024b). The water upstream is polluted with dark organic debris during the summer and autumn (drought seasons), water quality changes (Ali et al., 2019). The reason for the occurrence of pollutants from various sources like municipal and industrial waste, human activities, and runoff from agricultural lands the city is due to the presence of more than 17 stations (pumping + rainwater) located on the Tigris River in Baghdad, which are monitored by the Baghdad Environment Directorate/ Ministry of Environment, and discharge wastewater directly to sources. Water (river – drain – canal) without treatment and treating it in the Tigris River accelerated the deterioration of water quality day after day (Al-Janabi et al., 2024). The Diyala River meets with the Tigris River south of Baghdad and affects the quality of the Tigris River as a result of the connection of the Diyala River catchment, within densely cultivated areas, to many drainage channels, sewage channels, and wastewater, it contributed to influencing the river's water chemistry (Hamza, 2012). The Diyala River receives wastewater discharge from wastewater treatment plants located at its lower zone before its confluence with the Tigris River (Ismail and Muntasir, 2018). The lowest zone of the Diyala River is considered the most polluted area due to the presence of many sewage drains, such as the Nahrawan irrigation drain, the wastewater treatment plant in Rustamiya, the Army Canal, and others (Ismail et al., 2022). Discharge of treated wastewater causes a decrease in biodiversity by selectively benefiting certain species while depriving others by modifying the natural environment (Saravanan et al., 2021). Among the living organisms that are affected by water quality are algae, which are considered the main producer of the aquatic environment, constitute the basis of the food chain as well as have an important role in purifying water and evaluating its quality (Ali et al., 2020). They can be considered a vital indicator because of their short life cycle and rapid response to environmental changes (Febriansyah and Retnaningdyah, 2021). Research has shown that minerals in water can greatly affect the chemical composition and productivity of phytoplankton (Whitfield, 2001). River pollution with heavy metals changes the balance of the aquatic environment, and with the extent of pollution, the diversity of aquatic organisms becomes limited (Ay et al., 2009). Water pollution with heavy metals is very harmful because they do not decompose and accumulate within living organisms (Al-Sudani and Al-Mayaly, 2020). Industry is the main source of heavy metals entering aquatic ecosystems, and their accumulation in water varies depending on the type of wastewater treatment used (Magossi and Bonacella, 1992).

MATERIALS AND METHODS

The study area is located on the Tigris and Diyala rivers within the city of Baghdad. The location were determined using a GPS device on the longitude lines of the five sites (Table 1). The Tigris and Diyala rivers are affected by human and industrial activities due to the presence of many farms, factories, and wastewater treatment plants within the areas of the Tigris and Diyala rivers. The study included collecting seasonal water samples of water and phytoplankton from five sites, three of which are on the Tigris River. The first site (which represents the control site) is Saeeda in the Zafaraniya area, the third is the Tuitha site, and the fourth is the Jaara site. The second is the Al Multaka site, the meeting point of the Tigris and Diyala rivers, and the fifth site is the olde Bridge Tubular site (Jesr Enbopy) on the Diyala River, as shown in (Figure 1).

Sample collection

Samples were collected for three seasons (autumn – October 2023, winter – January 2024, spring – March 2024) from five sites in the study area (Table 1). The samples were taken at approximately 7 A.M and finished at approximately 12:30 P.M. The water temperature was measured directly from the sites using a mercury

Table 1. Global position system (GPS) of the study sites

Sites	Longitude (eastwards)	Latitude (northwards)	Distance	From…...to	Distance in kilometers
S1	44°27'20.3˝E	33°13'58.5˝N	Sit.1 to	Sit.2	5.27
S2	44°30'22.1˝E	33°13'13.5˝N	Sit.2 to	Sit.3	5.16
S3	44°28'57.0˝E	33°10'48.6˝N	Sit.3 to	Sit.4	7.55
S4	44°32'58.4˝E	33°09'08.5˝N	Sit.4 to	Sit.5	14.9
S5	44°31'19.4˝E	33°14'11.1˝N	Sit.5 to	Sit. 2	2.42

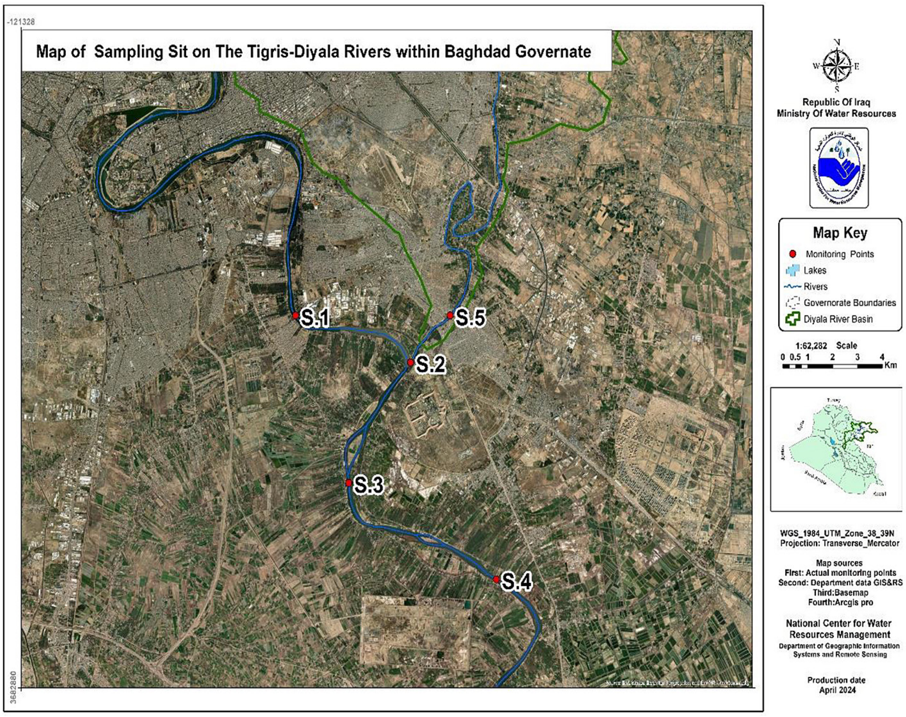

Figure 1. Map the studied area with sampling sites on the Tigris and Diyala Rivers within Baghdad Governorate (Google Earth, 2024): 1 Saeeda (Site 1), 2. Al-Multaka (Site 2), 3. Al-Tuitha (Site 3), 4. Al-Jaara (Site 4), 5. Jesr Enbopy (Site 5)

thermometer (0-80) after leaving it in water, until the temperature stabilized for a few minutes, according to the American Public Health Association (APHA 2005). The pH was measured by using a (pH meter Instrument / PH 7110). Heavy metals (Zn-Cu-Fe) were measured using a device (Atomic Absorption Spectrophotometer – Shimadzu-AA-7000) after acidifying the water samples, 4 ml of HNO_3 was added to reduce the absorption of metals on the walls of the containers (APHA, 1998). Chemical oxygen demand (COD) was measured using closed reflux, colorimetric method (Baird et al., 2017). Phytoplankton samples were collected using a phytoplankton net with diameter of 20 µm of holes, which was thrown in the water and pulled in at an appropriate speed for 10–15 minutes. The phytoplankton was directly collected in a polyethylene containers that contained 1 ml of Lugol's solution per 100 ml of the sample. Lugol's solution was prepared using standard methods, Lind (1979). Then, it settled by using the sedimentation method (Furet and Benson, 1982). The phytoplankton was identified as well as diagnosed quantitatively and qualitatively using standard methods (Al-Hussieny, 2018).

Environmental indicators

Shannon-Wiener diversity index (H), (1948)

The total number of species in the community was identified and calculated based on the following equation:

$$H = - \sum n_i / N \, Ln \, n_i / N \quad (1)$$

where: H – Shannon index, $\sum$ – summation, n_i – number of individuals of each species in the site, N – total number of individuals in the same site.

Values less than 1 bit/person are considered low diversity while values greater than 3 bit/person are considered high diversity (Porto-Neto, 2003).

Statistical analysis

The Statistical Analysis System (SAS, 2018) program was used to detect the effect of difference factors (location and seasons) in study parameters. Least significant difference (LSD) test ($P \leq 0.05$ significant) was used to significant compare between means in this study, NS its means non-significant (SAS, 2018).

RESULTS AND DISCUSSION

The water temperature recorded seasonal differences between the sites during the three seasons, with the highest water temperature reaching 25 °C at S.5 and s.3 for the autumn of 2023 and spring of 2024, while the lowest water temperature reached 14 °C at S.1 and S.4 for the winter of 2024 (Table 2).

The highest PH value was 7.9 in the S.1 and S.4 for the winter season and in the S.4 for the spring season, and its lowest value was 7.3 at S.5 for the autumn and spring seasons and at S.2 for the winter season (Table 3). When measuring Zn, it was observed that it was absent in the winter for all sites and at S.3 and S.5 for autumn season and with its highest value reached to 0.9767 ppm for the spring season (Table 4). Fe values ranged from 0.124 ppm in winter at S.4 to 3.175 ppm in spring at S.5 (Table 5). The Cu values appeared and varied between being absent in winter for all sites and in fall at S.4 to reaching a maximum value in spring at S.2 (Table 6). The COD values ranged from 2.13 ppm in spring at S.1 to a maximum value of 229.3 ppm in winter at S.5 (Table 7).

The phytoplankton species and genera that showed up in the quantitative and qualitative analyses of study locations over all three seasons are detailed in Table 8. As a result of these findings, it can be seen that the autumn of 2023 had the highest biomass at 2.572 (or 57.09% of the total), the winter of 2024 had the second-highest at 1006 (or 22.33% of the total), and the spring of 2024 had the lowest at 927 (or 20.57% of the

Table 2. Water temperature at the five sites during the autumn of 2023, as well as winter and spring of 2024 is measured in °C

Location	Autumn	Winter	Spring
S.1/ Saeeda	22	14	20
S. 2/ Al-Multaka	24	16	20
S. 3/ Al-Tuitha	22	20	25
S. 4/ Al-Jaara	23	14	18
S. 5/ Jesr Enbopy	25	19	22

Note: * (P≤ 0.05), NS: non-significant.

Table 3. Effect of location and season on pH

Location	Season			LSD value
	Autumn	Winter	Spring	
Saeeda	7.7	7.9	7.5	0.411 NS
Al-Multaka	7.6	7.3	7.5	0.379 NS
Al-Tuitha	7.6	7.7	7.5	0.308 NS
Al-Jaara	7.5	7.9	7.9	0.437 NS
Jesr Enbopy	7.3	7.5	7.3	0.298 NS
LSD value	0.415 NS	0.562 *	0.588 *	------

Note: * (P≤ 0.05), NS: non-significant.

Table 4. Effect of location and season on Zn

Locations	Season			LDS value
	Autumn	Winter	Spring	
Saaeda	0.0036	0	0.9688	0.162*
Al-Multaka	0.0028	0	0.9712	0.155*
Tuithah	0	0	0.9563	0.167*
Jaara	0.0149	0	0.9685	0.143*
Jesr Enbopy	0	0	0.9767	0.161*
LSD	0.0028 NS	0.00 NS	0.0487 NS	------

Note: * (P≤ 0.05), NS: non-significant

Table 5. Effect of location and season on Fe

Locations	Season			LSD value
	Autumn	Winter	Spring	
Saaeda	0.415	0.239	0.309	0.118*
Al-Multaka	0.4386	0.145	0.712	0.156*
Tuithah	0.633	0.145	0.214	0.207*
Jaara	0.618	0.124	0.339	0.176*
Jesr Enbopy	1.1173	0.166	3.175	0.487*
LSD	0.372*	0.109*	0.451*	–

Note: * (P≤ 0.05), NS: non-significant.

Table 6. Effect of location and season on Cu

Locations	Season			LSD value
	Autumn	Winter	Spring	
Saaeda	0.011	0	0.042	0.0155*
Al-Multaka	0.005	0	0.11	0.064*
Tuithah	0.005	0	0.007	0.005*
Jaara	0	0	0.007	0.004*
Jesr Enbopy	0.005	0	0.013	0.004*
LSD	0.0067*	0.00NS	0.0184*	–

Note: * (P≤ 0.05), NS: non-significant

Table 7. Effect of location and season on COD

Locations	Season			LSN value
	Autumn	Winter	Spring	
Saaeda	5.33	7.93	2.13	5.61 NS
Al- Multaka	133	79	124	16.42 *
Tuithah	12.13	7.93	18.4	9.85 *
Jaara	11.4	9.87	10.13	4.39 NS
Jesr Enbopy	160	229.3	164	21.47 *
LSD	12.66*	17.94*	12.07*	–

Note: * (P≤ 0.05), NS: non-significant

total). Autumn brings a temperature drop to 17 °C and a decrease in water discharge, both of which are perfect for phytoplankton growth. This lines up with what Al-Shahri found, which was that various kinds of phytoplankton were most abundant in spring and autumn (Al-Shahri et al., 2016). Rapid increases in nutrient concentrations are observed during the winter rainy season, because rainfall introduces large quantities of nutrients into the aquatic ecosystem from surface discharge (Barçante et al., 2020).

This study identified Chlorophyceae, Bacillariophyceae (including both Centrales and Pennales), and Cyanophyceae. The quantitative study indicated that the highest biomass of phytoplankton was attributed to blue-green algae, which reached 2402 cell×10^3/l at a proportion of 53.32%. This was followed by green algae at 1105 cell×10^3/l, comprising 24.53%, while diatoms exhibited the lowest biomass at 998 cell×10^3/l, accounting for 22.15%. Within the diatom category, Centrales represented 215 cell×10^3/l at 4.77%, and Pennales accounted for 783 cell×10^3/l at 17.38%. the Centrales diatoms are typically found in seawater and are sensitive to various pollutants, particularly herbicides, whereas the Pennales diatoms demonstrate greater resilience and prefer freshwater (Abdul Saheb et al., 2022). Consequently, it was noted that the population of the Centrales diatoms is inferior to that of the Pennales diatoms.

In the qualitative study, blue-green algae were predominant at 41.86% (Sp. 18, G. 10),

Table 8. Includes the quantitative study of phytoplankton (cell ×10³/l) for the seasons (autumn 2023 A, winter 2024 W, spring 2024 S) and the specific density with the symbol (+) for qualitative study within the selected study sites in the Tigris and Diyala Rivers section within the city of Baghdad

Sites	S.1			S.2			S.3			S.4			S.5		
Seasons / List of algal taxa	A.	W.	S.	A.	W.	S.	A.	W.	S.	A.	W.	S.	A.	W.	S.
Chlorophyceae															
Ankistrodesmus braunii (Nägeli) Collins	12	7	18	21 +	7	3	0	0	11	16	+	+	34 +	+	+
Crucigenia tetrapdia	8	0	0	32 +	0	0	13	0	0	6 +	0	0	44 +	0	0
Cladophora glomerata (L.) Kützing	11 +	5	5	0	6	6	6 +	2	2	9	+	+	23 +	0	0
Chlorella vulgareis	21	16	16	6	+	+	27	13	13	24 +	6	6	54 +	26	26
Monorohidum sp.	7	0	0	+	0	0	12 +	0	0	20 +	0	0	13	0	0
Oedogonium crissum (Hass.) Wittrock	+	5	+	4	4 +	4 +	0	0	0	4	+	+	32	3	3
Pediastrum boryanum (Turp.) Meneghini	+	2	2	7	0	0	12 +	10 +	6 +	6 +	0	0	21 +	0	0
Scenedesmus arcuatus Lemmermann	6	0	0	8 +	12 +	27 +	24	16	22	0	3	3	7 +	+	+
Tetrastrum stauncota	14 +	0	0	12	0	0	5 +	0	0	13 +	0	0	17	00	0
Cosmarium bioculatum	0	0	0	21	21	21	0	+	+	0	0	+	0	+	+
Chlamydomonas sp.	0	+	25	0	11	+	0	24	13	0	10	6	0	32	15 +
Baciliariophyceae															
A- Centrales															
Aulacoseira varians Agardh	15 +	15	+	+	0	+	+	+	3	9	+	0	0	0	+
Coscinodiscus sp.	0	0	0	21	21	13	13 +	0	+	14	+	6	+	2	8
Cyclotella meneghiniana Kützing	8 +	8 +	+	5	5	8	+	+	0	9	0	+	21	4 +	7 +
B- Pennales															
Achnanthes brevipes var. intermedia (Kütz.) Cleve	17 +	10	16	0	3	+	21	0	+	8	0	+	6	0	+
Cocconeis pediculus Ehrenberg	8 +	+	+	11	7	0	+	13	11	+	+	+	21 +	14	12
Fragilaria brevistriata Grunow	4	4	4	15 +	8	0	33	+	+	0	0	0	+	+	+
F. intermedia Grunow	6	0	0	7	0	0	23 +	0	0	13	0	0	0	0	0
Navicula cincta (Ehr.) Kützing	10 +	3 +	0	+	0	0	15	7	7	+	0	0	0	5	5
N. cryptocephala Kützing	0	8	8	+	5	5	11 +	3	0	21	7	0	0	15	+
N. viridula var. rostellata (Kütz.) Cleve	0	+	+	+	0	0	8	+	+	8	5	5	26	0	0
Nitzschia amphibian Grunow	32 +	0	0	26	2 +	0	+	0	0	0	5	5	22 +	10	17
N. apiculate (Greg.) Grunow	21	11	6	7	9	4	+	6	16	+	+	+	0	+	+
Pinnularia lata (Bréb.) Smith	0	0	0	4	0	0	8	3	3	15 +	12	+	16	0	0
Diatoma elongatum	0	6	6	0	2 +	9 +	0	4	4	0	5	5	0	0	0
Cyanophyceae															
Aphanocapsa grevillea (Cam.) Rabenhorst	18	11	21	21	0	4	13 +	3	0	+	+	5	32	0	+
Aphanothece castagnei (Bréb.) Rabenhorst	+	0	+	22 +	5	0	0	0	+	6	0	8	25	0	+
Lyngbya aestuarii Lammermann	+	14	+	5	+	21	65 +	18	21	15 +	0	+	104 +	34	15
L. martensima Meneghinii	6	0	0	+	0	0	0	0	0	9	0	0	65 +	0	0
L. major	23	0	0	24 +	0	0	12	0	0	0	0	0	21 +	0	0
L. latissima	12	0	0	9	0	0	26	0	0	0	0	0	0	0	0

Table 8. Cont.

Merismopedia elongan Nägeli	+	+	0	23	14	0	+	+	+	32	7	19	45 +	21 +	0
M. glauca Beck	6	11	0	+	7	+	22	6	10	11	0	+	32 +	+	19
M. tenuissima Lemmermann	15 +	+	5	13	5	5	14 +	0	+	21	+	+	23 +	0	32
Microcystis aeruginosa Kützing	0	3	0	21	+	0	0	+	0	+	8	11	20 +	32	0
M. flos-aquae (Wittr.) Kirchner	8	5	0	8 +	11	8	32	10	5	0	0	+	+	12 +	+
M. incerta Lemmermann	30 +	13	32	23	6	6	20	+	+	32 +	0	0	35 +	0	8
Nostoc lobatus Agardh	0	0	0	8 +	0	0	8 +	0	0	6	0	0	7 +	0	0
Oscillatoria anguina Comont	13	0	+	0	+	0	12	8	11	0	0	+	48 +	22	+
O. bornetii	7 +	13	+	43	13	17	19 +	13 +	4 +	16	11 +	0	43 +	0	34
O. chalybea (Mertens) Gomont	8	4	+	23	6	9	21	11 +	0	43	9	17	59	27	34
Chroococcus disperses	0	0	6	0	4	0	0	0	+	0	4	9	0	28 +	0
Haematococcus lacustris	0	4	8	0	7	+	0	8 +	0	0	0	+	0	54	33
Spiruline laxissima	0	+	13	0	8 +	12 +	0	0	+	0	8	15	0	0	4

followed by diatoms at 32.55% (Sp. 14, G. 10), and subsequently green algae at 25.58% (Sp. 11, G. 11). Table 9 illustrates that diatoms qualitatively surpassed green algae. This may be attributed to nutrient runoff (N, P) from fertile agriculture into adjacent waterways, resulting in heightened eutrophication and a decline in various algal species, higher aquatic plants, microorganisms, and numerous invertebrates and vertebrates (Yang et al., 2020). Diatoms are differentiated from other algae by their robust silica wall, known as the frustule, which provides protection (Al-Magdamy et al., 2024).

As shown in Table 10, the Shannon-Wiener diversity index exclusively indicated significant diversity at site 2 on the Diyala River in October 2023, with a value of 3.39. Site 1 on the Tigris River recorded a value of 3.115 in March 2024. A substantial diversity of phytoplankton indicates favourable conditions for the proliferation of these species, such as pH, temperature, and nutrient availability. Conversely,

Table 9. Percentage of quantitative and qualitative study of phytoplankton and number of their species and genera within the study sites

Algae taxa	Quantitative study	Qualitative study %	Species	Genus
Cyanophyceae	53.32 %	41.86 %	18	10
Chlorophyceae	24.53 % ↑	25.58 % ↓	11	11
Baciliariophyceae	22.15 % ↓	32.55 % ↑	14	10
A - Centrales	4.77 %	6.97 %	3	3
B - Pennales	17.38 %	25.58 %	11	7

Table 10. The extent of phytoplankton diversity (species enrichment) of the Tigris-Diyala Rivers within the city of Baghdad during the study period by Shannon-Wiener index (H)

Sites	Seasons		
	October 2023	January 2024	March 2024
Site 1.	2.86	2.497	3.115
Site 2.	3.39	2.769	2.485
Site 3.	2.809	2.55	2.441
Site 4.	2.816	2.562	2.417
Site 5.	2.818	2.433	2.254

a deficiency in diversity is the consequence of specific food source limitations, a reduced number of species, and an excessive population increase of individual species (Atkins, 2007). Phytoplankton diversity is influenced by nutrient enrichment in a variety of ways. In low nutrient environments, it can enhance diversity by accelerating growth rates and reducing competitive pressures among species. Conversely, it can diminish diversity by promoting the proliferation of one or two algal species under high nutrient conditions (Yun et al., 2023).

The statistical study of temperatures revealed seasonal variations between places, characteristic of the Iraqi climate, marked by high summer temperatures and low winter temperatures (Al-Ghurairi, 2014). The pH was within the acceptable limits established by Iraqi drinking water specifications No. (417) of 2009 for aquatic organisms, which range from 6.5 to 9. These findings align with local studies indicating that Iraqi water is slightly alkaline and exhibits a limited range of variation (Al-Azawii et al. 2015).

The concentrations of Zn were found to be below the normal threshold established by System (25) of 1967 for the preservation of Iraqi rivers and public waters from pollution. This decline is attributed to the seasonal reduction of phytoplankton, which sequesters Zn during its initial flowering phase, as corroborated by various studies (Luoma et al., 1998; Jin et al., 2019; Zwolsman et al., 1999). Zn is recognised as a crucial micronutrient due to its role in the mineral enzymes involved in photosynthesis and other biological processes of phytoplankton (Wang et al., 2012). Iron is crucial for enzymes involved in photosynthesis and many metabolic processes, including nutrient absorption and assimilation, underscoring its significance in the global needs of phytoplankton (Morel et al., 1991; Rue and Bruland, 1995).

The elevated concentrations of Fe in freshwater signify pollution by heavy metals resulting from the flow of industrial wastewater into rivers (Ismail and Robescu, 2019). Copper is a vital ingredient for phytoplankton development and serves as a mineral component for plastocyanin and several oxidative stress enzymes. Copper has been identified as a limiting factor for dangerous algal blooms in a hypertrophic lake (Zhang et al., 2019). The COD values, reflecting the overall concentration of organic contaminants in the water (Moussa and Al-Magdamg, 2024), beyond the allowable threshold of 100 ppm, as stipulated by the Iraqi River Maintenance System No. 25 of 1967. The increase in winter pollution in the most contaminated areas, specifically S.2 and S.5, is due to the inadequate effectiveness of the Rustumiyah stations regarding sewage treatment regulations, leading to a decline in water quality (D'Alelio et al., 2022). The prevalence of phytoplankton throughout the autumn and spring seasons is attributed to various variables, including heightened turbidity, pH levels, salinity, vigorous currents, ample sunlight, reduced transparency, and mild temperatures (Adesakin et al., 2019). The actions of herbivores and heterotrophic microorganisms influence phytoplankton growth (Giripunje et al., 2013).

CONCLUSIONS

Trace quantities of Zn, Fe, and Cu were below the natural thresholds of Iraq's public and river water contamination prevention standards. Increasing phytoplankton activity, growth, and eutrophication is nutritious. Organic and industrial waste contain heavy metals, medicines, and other toxins that boost algal biomass. The predominance of blue-green algae is alarming, because some forms survive high antibiotic concentrations, unlike diatoms. Antibiotics break down the silica-based structure of diatom bodies, reducing populations and stopping reproduction. Blue-green algae dominate aquatic environments, degrading water quality. Due to their toxin generation and proliferation in nutrient-rich settings, several species harm aquatic creatures, particularly fish. Numerous studies have demonstrated that Rustamiya's treatment facilities cannot handle the city's growing wastewater output. Innovative tactics to reassess and deploy novel treatment procedures that reduce treatment facility demand are advocated to maintain phytoplankton diversity and abundance, a vital part of the ecosystem's food chain. This reduces the level of pollutants in Tigris and Diyala.

Acknowledgement

The authors are sincerely grateful to an anonymous reviewer for the valuable comments regarding the manuscript.

REFERENCES

1. Abdul Sahib, Z. K. and Al-Magdamy. B. H. A. (2022). The effect of changing the culture medium on the growth curves of some Iraqi diatoms. *Biochem., 22*(1), 473–478.
2. Adesakin, T. A., Adedeji, A. A., Oyewale, A. T., Oni, T. M., Oyebamiji, S. P. & Olowogboyega, V. T. (2019). Ecological studies of phytoplankton distribution and abundance in River Shasha, Southwestern Nigeria. *(IJRISS), III*(VII), 2454–6186.
3. Al-Azawii, L. H., Al-Azzawi, M. N., & Nashaat, M. R. (2015). The effects of Industrial Institutions on ecological factors of Tigris River through Baghdad province. *International Journal of Advanced Research*, *3*(3), 1266–1278.
4. Al-Ghurairi, W. A. S., (2014). *An ecological study of algae in Yusufiyah River, Baghdad, Iraq.* MSc. thesis, College of Science for Girls, University of Baghdad, 91.
5. Alharbawee, N. A., & Mohammed, A. J. (2024). Evaluation of the temporal and spatial variation of the Tigris River in Baghdad. *Ibn AL-Haitham Journal for Pure and Applied Sciences*, *37*(2), 71–85.
6. Alharbawee, N. A., & Mohammed, A. J. (2024a). Water quality assessment of Tigris River using multivariate statistical techniques. *Iraqi Journal of Science*, 1266–1275.
7. Al-Hussieny, Ahmed Aidan. (2018). *Atlas of The Algae in The Iraqi Aquatic Environment.* Scholars press. Book. 195.
8. Ali Abed, S., Hussein Ewaid, S., & Al-Ansari, N. (2019, September). Evaluation of water quality in the Tigris River within Baghdad, Iraq using multivariate statistical techniques. In *Journal of Physics: Conference Series, 1294*, 072025. IOP Publishing. https://doi:10.1088/1742-6596/1294/7/072025
9. Ali, H. A., Owaid, M. N., & Ali, S. F. (2020). Recording thirteen new species of phytoplankton in Euphrates river environment in Iraq. *Walailak Journal of Science and Technology (WJST)*, *17*(3), 200–211.
10. Al-Janabi, Z. Z., Hassan, F. M., & Al-Obaidy, A. H. M. J. (2024). Overall index of pollution (OIP) for Tigris River, Baghdad City, Iraq. *Iraqi Journal of Agricultural Sciences*, *55*(2), 905–916.
11. Al-Magdamy, B. A. A. H., Oda, M. N., AL-Gburi R. I. K. (2024). The effect of Medical city waste on the quality of plankton diatoms in Tigris River at central Baghdad. *Journal of Genetic and Environmental Resources Conservation, 12*(1), 9–16.
12. Al-Shahri, Y., Maulood, B., Toma, J. (2016). A study on a sulfur spring (Ain Al Kibrit) ecosystem along Tigris River Mosul, Iraq. *J. Adv. Lab. Res. Biol*., 7, 6.
13. Al-Sudani, A. G., & Al-Mayaly, I. K. (2020). Use of lanthanum-modified bentonite to remove phosphorus causing the eutrophication in the reservoirs of wastewater treatment plant. *Plant Archives, 20*(2). 3830–3834.
14. APHA (American Public Health Association). (1998). Standard methods for the examination of water and wastewater, 20th Ed. American Public Health Association, Washington, DC.
15. APHA, American Public Health Association (2005). Standard Methods for the Examination of Water and Wastewater, 21, Edition Washington, DC.22621PP.
16. Atkins, W. A. Pollution of the ocean by sewage, nutrients, and chemicals. www.water encyclopedia.com. 2007.
17. Ayandiran, T. A., Fawole, O. O., Adewoye, S. O., & Ogundiran, M. A. (2009). Bioconcentration of metals in the body muscle and gut of Clarias gariepinus exposed to sublethal concentrations of soap and detergent effluent. *Journal of Cell and Animal Biology*, *3*(8), 113–118.
18. Baird, R. B., Eaton, A. D. & Rice, W. R. (2017). Aggregate organic constituent. In: Standard Methods for the examination of water and wastewater 23 rd ed. American Public Health association. Washington. 5–17.
19. Barçante, B., Nascimento, N. O., Silva, T. F., Reis, L. A., Giani, A. (2020). Cyanobacteria dynamics and phytoplankton species richness as a measure of waterbody recovery: Response to phosphorus removal treatment in a tropical eutrophic reservoir. *Ecol. Indic. 117*, 106702. [CrossRef]
20. D'Alelio, D., Russo, L., Del Gaizo, G., & Caputi, L. (2022). Plankton under pressure: How water conditions alter the phytoplankton–zooplankton Link in Coastal Lagoons. *Water*, *14*(6), 974. https://doi.org/10.3390/w14060974
21. Febriansyah, S. C., & Retnaningdyah, C. (2021). Evaluation of the effect of age of cultivation of dumbo catfish (Clarias gariepinus) on changes in pond water quality using plankton as bioindicator in Gondosuli Village, Tulungagung Regency. *Biotropika: Journal of Tropical Biology*, *9*(2), 144–152. https://doi.org/10.21776/ub.biotropika.2021.009.02.07
22. Furet, J. E., & Benson-Evans, K. (1982). An evaluation of the time required to obtain complete sedimentation of fixed algal particles prior to enumeration. *British Phycological Journal, 17*(3), 253–258.
23. Giripunje, M. D., Fulke, A. B., Khairnar, K., Meshram, P. U., & Paunikar, W. N. (2013). A review of phytoplankton ecology in freshwater lakes of India. *Lakes reservoirs and ponds*, *7*(2), 127–141.
24. Hamza N. H. (2012). Evaluation of water quality of Diyala River for irrigation purposes. *Diyala Journal of Engineering Sciences, 5*(2), 82–98.
25. Ismail, A. H., & Muntasir, A. H. (2018). Estimation of river Tigris dispersivities using a steady-state numerical model. *Applied Water Science*, *8*(4), 108.

26. Ismail, A. H., & Robescu, D. (2019). Application of multivariate statistical techniques in water quality assessment of Danube River, Romania. *Environ. Eng. Manag. J*, *18*, 719–726.
27. Ismail, A., Shareef, M., Hussein, H., Salman, H, Kadhim, N., Salim, A., & Matar, A. (2022). Two-dimensional simulation of pollutant dispersion at the confluence of Diyala river with Tigris river using CFD technique. *Journal of Water Resources and Geosciences*, 1(2), 85–100.
28. Jin, Z., Ding, S., Sun, Q., Gao, S., Fu, Z., Gong, M., & Wang, Y. (2019). High resolution spatiotemporal sampling as a tool for comprehensive assessment of zinc mobility and pollution in sediments of a eutrophic lake. *Journal of hazardous materials*, *364*, 182–191.
29. Lind, O. T. (1979). Handbook of common methods in limnology C.V. Mosby, St Iouis. 199.
30. Luoma, S. N., van Geen, A., Lee, B. G., & Cloern, J. E. (1998). Metal uptake by phytoplankton during a bloom in South San Francisco Bay: Implications for metal cycling in estuaries. *Limnology and Oceanography*, *43*(5), 1007–1016.
31. Magossi, L., & Bonacella, P. (1992). Poluição das águas–coleção desafios. 9ª. *São Paulo: Editora Moderna*.
32. Morel, F. M., Rueter, J. G., & Price, N. M. (1991). Iron nutrition of phytoplankton and its possible importance in the ecology of ocean regions with high nutrient and low biomass. *Oceanography*, *4*(2), 56–61.
33. Moussa, Z. F., & Al-Magdamy, B. A. A. H. (2024). Seasonal variations of attached cyanophyta algae on concrete bridges in Tigris River from Baghdad. *Ibn Al-Haitham Journal For Pure and Applied Sciences*, *37*(1). 118–127. https://doi.org/10.30526/37.1.3247
34. Porto-Neto, V. F. (2003). Zooplanktons bioindicator of environmental quality in the tamandane reff system (Pernam bnco-Brazil): An thropogenic influences and Interaction with Mangroves. Ph.D. dissertation, univ. Bremenm Brazil. 41
35. Rue, E. L., & Bruland, K. W. (1995). Complexation of iron (III) by natural organic ligands in the Central North Pacific as determined by a new competitive ligand equilibration/adsorptive cathodic stripping voltammetric method. *Marine chemistry*, *50*(1–4), 117–138.
36. Saravanan, A., Kumar, P. S., Jeevanantham, S., Karishma, S., Tajsabreen, B., Yaashikaa, P. R., & Reshma, B. (2021). Effective water/wastewater treatment methodologies for toxic pollutants removal: Processes and applications towards sustainable development. *Chemosphere*, *280*, 130595. https://doi.org/10.1016/j.chemo sphere.2021.13059
37. SAS. (2018). Statistical Analysis System, User's Guide. Statistical. Version 9.6th ed. SAS. Inst. Inc. Cary. N.C. USA.
38. Shannon, C.E. and wiener, W. (1949). *The Mathematical Theorg of Communication*. Urbana University of Illinois press, Chicago, USA: 117.
39. Wang, B., Axe, L., Michalopoulou, Z. H., & Wei, L. (2012). Effects of Cd, Cu, Ni, and Zn on brown tide alga Aureococcus anophagefferens growth and metal accumulation. *Environmental science & technology*, *46*(1), 517–524.
40. Whitfield, M. (2001). Interactions between phytoplankton and trace metals in the ocean. *Adv. Mar. Biol. 41*, 1–128
41. Yang, C., Yang, P., Geng, J., Yin, H., & Chen, K. (2020). Sediment interal nutrient loading in the most polluted area of a shallow eutrophic lake (Lake Chaohu, China) and its contribution to lake eutrophication. *Environmental Pollution. 262*, 114292. https://doi.org/10.1016/j.envpol.2020.114292
42. Zhang, Yun, Zhang, H., Liu, Q., et al., (2023). Tital nitrogen and community turnover determine phosphorus use efficiency of phytoplankton along nutrient gradients in plateau lakes. *Journal of Environmental Sciences, 124*, 699–711. https://doi.org/10.1016/j.jes.2022.02.005
43. Zhang, X., Li, B., Xu, H., Wells, M., Tefsen, B., & Qin, B. (2019). Effect of micronutrients on algae in different regions of Taihu, a large, spatially diverse, hypereutrophic lake. *Water Research*, *151*, 500–514.
44. Zwolsman, J. J., & van Eck, G. T. (1999). Geochemistry of major elements and trace metals in suspended matter of the Scheldt estuary, southwest Netherlands. *Marine chemistry*, *66*(1–2), 91–111.