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# Evaluation of the Physical Properties and Some Heavy Metals of Tigris River Water in Salah Al-Din Governorate/ Iraq

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## ABSTRACT

Surface water bodies are essential sources of water for human consumption, domestic use, agriculture, industrial activities, and the sustainability of aquatic life and ecosystems. This study aimed to evaluate the physical characteristics and concentrations of heavy metals in the Tigris River water, focusing on the section flowing through Duluiya, from September 2024 to March 2025. Parameters measured included water turbidity, temperature, electrical conductivity, total dissolved solids (TDS), and total suspended solids (TSS). The results of the physical analysis revealed that monthly average water temperatures ranged between 11.9 and 24.8°C, while air temperatures ranged between 13.3 and 31.5°C. Water turbidity values ranged from 3.3 to 34.2 NTU, and electrical conductivity ranged between 338 and 516µS/ cm. TDS levels varied from 237 to 302mg/ L, and TSS ranged between 20 and 400mg/ L. All these concentrations were found to be within the permissible limits set by Iraqi drinking water standards. Statistical analysis showed significant temporal differences in all measured physical parameters, while most spatial differences were not statistically significant, with the exception of water turbidity, air temperature, and TDS. This suggests that seasonal variation plays a greater role than geographic location in influencing the physical properties of the river. Regarding heavy metals, monthly concentrations of lead ranged from 0.011 to 0.67mg/ L, while cadmium was mostly undetected, with a range of 0.00 to 0.90mg/ L. Cobalt concentrations remained below Iraqi drinking water limits, although slight elevations were observed in some December samples. Significant temporal differences were found for both lead and cobalt concentrations, whereas cadmium showed no significant spatial or temporal variation.

## INTRODUCTION

The growing demand for water in many areas—including agriculture, industry, households, and hydropower generation—is putting a strain on the world's water supplies **(Jawad *et al.*, 2010)**. Given the gravity of this global issue, research into water quality is of the utmost importance, particularly from a physical standpoint, since this is one of the most fundamental criteria for determining whether water is suitable for specific purposes **(Papa *et al.*, 2023)**.

In Iraq, there is a clear pattern of regional and temporal variation in water availability. The construction of dams in upstream countries along the Tigris and Euphrates rivers, combined with global climate change, reduced precipitation, and other contributing factors, presents significant challenges to both the quantity and quality of Iraq's water **(Jawad *et al.*, 2010)**. To assess the impact of these stressors on water resources, it is essential to examine the degradation of water's physical characteristics **(Miller *et al.*, 2018)**. Alterations in these characteristics can have an immediate effect on aquatic ecosystems, making their monitoring a crucial part of any long-term environmental observation program. While some ecosystems can withstand significant changes with minimal visible impact **(Iyiola *et al.*, 2022)**, others are highly vulnerable.

Some species are extremely sensitive to even minor changes in water quality and biodiversity due to their reliance on stable chemical and physical water conditions **(Ogidi & Akpan, 2022)**. Heavy metal pollution, due to its toxicity, persistence in aquatic systems, and its potential to affect water quality both physically and chemically, has emerged as a major concern **(Soad *et al.*, 2025)**. The toxicity of heavy metals poses serious health risks, potentially affecting the brain, kidneys, lungs, liver, and blood, and impairing their essential functions **(Jomova *et al.*, 2025)**. Poisoning from these metals can be either acute or chronic, depending on the level and duration of exposure. Symptoms may resemble those of neurodegenerative diseases such as Parkinson's, multiple sclerosis, muscular dystrophy, and Alzheimer's, and exposure is also linked to a higher risk of cancer **(Budi *et al.*, 2024)**.

Hazardous metals of concern, even in small concentrations, include lead, cadmium, copper, and iron. Their increasing presence is alarming, particularly as many institutions release untreated wastewater directly into freshwater bodies **(Munir *et al.*, 2021)**. As a result, the physical properties of the water have changed. A notable example is the Tigris River, which, as it flows through Salah ad-Din, accumulates a significant amount of contaminants from untreated domestic and industrial wastewater. The degradation of its physical properties is a direct consequence of this pollution.

The objective of this research was to assess the extent to which human activities have degraded the water quality of the Tigris River by analyzing its physical properties and the concentration of selected heavy metals at specific sites in Salah al-Din, a city in the Balad province.

## MATERIALS AND METHODS

### Description of the study area

A physical analysis of the Tigris River water in the Duluya district, located in Salah al-Din Governorate, was conducted at the College of Education for Girls, Department of Life Sciences, Tikrit University. The district lies south of Tikrit City and north of

Baghdad, the capital of Iraq. The study site was selected based on the coordinates (N 34.2981, E 44.1469), as illustrated in Fig. (1). This location represents a critical segment of the Tigris River in central Iraq, making it especially important for investigating environmental and qualitative changes in river water resulting from nearby human and natural activities.

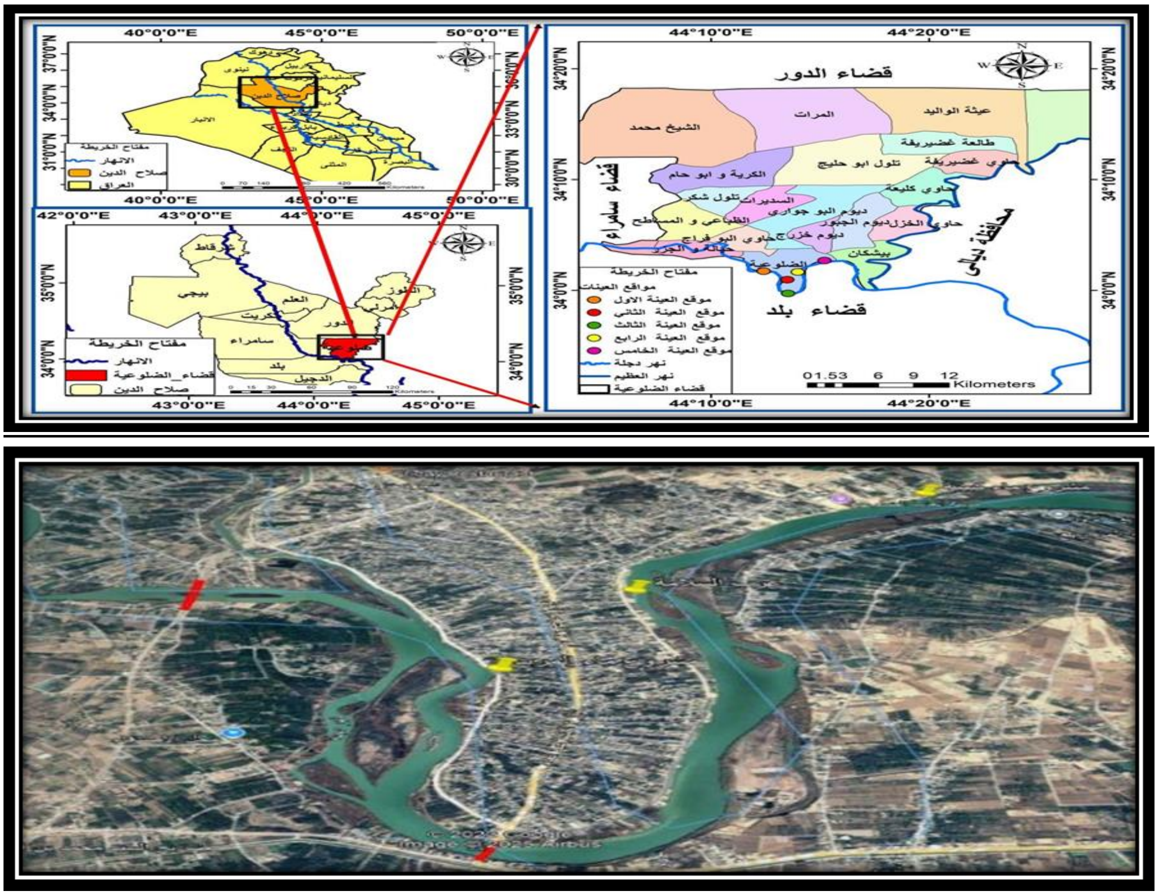


**Fig. 1.** Collecting samples from the Tigris River flowing through the city of Duluiya

The study was conducted on the waters of the Tigris River flowing through the city of Duluiyah in Salah al-Din Governorate. Five distinct locations along the river were selected for sample collection. The sampling process spanned seven months, from September 2024 to March 2025, with an average of one sample collected per month from each location.

The selected sites included the following:

- **Site One**: Al-Dulu'iya Concrete Bridge
- **Site Two**: Al-Murbid Water Project
- **Site Three**: Al-Dulu'iya Wooden Bridge
- **Site Four**: Al-Dawudiya Water Project
- **Site Five**: Al-Kubayba Water Project

Water samples were collected in 1-liter polyethylene bottles, with precautions taken to minimize exposure to light to preserve the physical integrity of the samples.

After collection, samples were stored at a temperature of 4°C, and the storage duration did not exceed 24 hours, in accordance with standard guidelines **(APHA, 2005)**.

Physical analyses of the samples were conducted at the Central Laboratory of Tikrit University and cross-verified at the Quality Control Laboratory of the Salah al-Din Water Department to ensure accuracy and reliability.

**Laboratory tests**

**Physical examinations**

- **Water Temperature**: Measured using a UT3200 Mini Type K/J Dual Thermometer.
- **Turbidity Concentration**: Determined using the method described by **APHA (2017)** and **Ibrahim *et al.* (2025)**.
- **Electrical Conductivity**: Assessed according to the procedure outlined by **APHA (2017)**.
- **Concentration of Dissolved Solids**: Measured following the method of **APHA (2017)**.
- **Concentration of Suspended Solids**: Determined using the procedure described by **APHA (2017)**.

**Determination of heavy metals (Lead, cadmium, and cobalt)**

Heavy metal concentrations in the water samples were analyzed using an atomic absorption spectrophotometer (Shimadzu AA-7000).

## RESULTS AND DISCUSSION

**Physicochemical characteristics**

**Water temperature (°C)**

The outcomes presented in Table (1) indicate notable variations in the temperature of the Tigris River water flowing through the city of Duluiya during the study period. The highest recorded temperature was 24.8 °C at Site 4 in September, while the lowest was 11.9°C at Site 1 in February. Spatially, the average water temperatures ranged from 17.58 to 17.73°C, whereas temporal averages varied from 11.96 to 24.66°C.

Statistical analysis using Duncan's multiple range test revealed no statistically significant differences among the sampling locations. However, significant temporal differences were observed throughout the study period at a probability level of $P< 0.05$.

**Table 1.** Monthly and locational changes in water temperature (°C) in the Tigris River passing through the city of Dhuluiya during the study period

| | 2024 | | | | 2025 | | | |
|---|---|---|---|---|---|---|---|---|
| Months / Samples | September | October | November | December | January | February | March | Average location |
| **St 1** | 24.5 | 22.9 | 18.5 | 13.9 | 12.4 | 11.9 | 19 | 17.58 a |
| **St 2** | 24.7 | 22.8 | 18.5 | 13.9 | 12.5 | 11.9 | 19 | 17.61 a |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **St 3** | 24.5 | 22.9 | 18.5 | 13.8 | 12.7 | 12 | 19.2 | 17.66 a |
| **St 4** | 24.8 | 22.8 | 18.5 | 13.8 | 12.7 | 12 | 19.5 | a217.7 |
| **St 5** | 24.7 | 22.9 | 18.5 | 13.7 | 12.8 | 12 | 19.4 | 17.73 a |
| Average months | 24.66 a | 22.86 b | 018.5 c | 13.82 d | 12.62 de | 11.96 e | 19.22 C | |

**Dissimilar letters denote substantial differences (*P*<0.05), whereas similar letters signify the absence of significance variations at the probability level (*P*<0.05) as determined by the Duncan test.**

The findings of the present investigation were below the standard threshold of 25°C, as established by the Iraqi standard for drinking water (Regulation No. 417, 2009), as shown in **Appendix 1**. These results are consistent with those reported by **Hassan and Wahab (2019)** and **Al-Hasani *et al.* (2022)** regarding the water quality of the Tigris River in the Al-Dour area of Salah al-Din Governorate, where temperatures ranged between 11 and 27.5°C. Similar findings were also noted by **Ali *et al.* (2019)**, who assessed water quality in the Tigris River in Baghdad and confirmed that the recorded temperatures were within acceptable levels according to Iraqi drinking water standards. Additionally, the present study aligns with the results of **Al-Sarraj (2020)**, who examined the seasonal impact on water quality in the Tigris River in Baghdad, where temperatures ranged from 14.2 to 25.4 °C—also within the standard limits.

Temperature plays a critical role in influencing water quality and its physical, chemical, and biological characteristics. Fluctuations in temperature affect the rates of chemical reactions—higher temperatures accelerate these reactions, potentially increasing the concentration of harmful substances. Moreover, elevated temperatures enhance the activity, growth, and reproduction of microorganisms, which can negatively influence the water's taste, odor, and color **(Umar *et al.*, 2019; Ibrahim & Al-Dabbas, 2022)**. Temperature also directly affects gas solubility in water; as water temperature increases, dissolved oxygen levels decrease **(Al-Barzunji, 2020)**.

**Turbidity**

The findings indicated moderate variation in water turbidity among samples collected from the Tigris River in Duluiya throughout the study period. As shown in Table (2), the highest turbidity concentration recorded was 34.2 NTU at Site 4 in September, while the lowest was 3.3 NTU at Site 3 in February. Spatially, average turbidity concentrations ranged between 15.78 and 18.63 NTU, whereas temporal averages ranged from 4.96 to 27.58 NTU.

Statistical analysis using Duncan's multiple range test revealed significant spatial differences among the sampling sites, as well as notable temporal variations during the study period, at a significance level of $P < 0.05$. Except for some sampling sites in February, turbidity levels exceeded the Iraqi drinking water standard of 5 NTU, as specified in Regulation No. 417 of 2009 (Appendix 1).

**Table 2.** Monthly and spatial changes in water turbidity (NTU) in the Tigris River passing through the city of Balad during the study period

| | 2024 | | | | 2025 | | | |
|---|---|---|---|---|---|---|---|---|
| Months / Samples | September | October | November | December | January | February | March | Average location |
| **St 1** | 22.6 | 17.9 | 23.8 | 16.9 | 10.5 | 9.3 | 11.5 | 16.07 bc |
| **St 2** | 23.3 | 21 | 42 | 16.3 | 14.5 | 3.8 | 8.7 | 18.51 a |
| **St 3** | 26.5 | 20 | 21.7 | 17.7 | 8.7 | 3.3 | 12.6 | 15.78 c |
| **St 4** | 34.2 | 26.7 | 23.7 | 22.7 | 10.2 | 4.8 | 8.17 | 18.63 a |
| **St 5** | 31.3 | 18.3 | 23.6 | 19.1 | 15.4 | 3.6 | 10 | 17.33 ab |
| Average months | 27.58 a | 20.78 b | 26.96 A | 18.54 C | 11.86 d | 4.96 e | 10.19 d | |

**- Different letters indicate the presence of significant differences (*P*<0.05), while similar letters indicate the absence of significant differences at the probability level (*P*<0.05) according to the Duncan test.**

The results of the current study are consistent with those reported by **Abd Wahab (2022)** and **Abd Wahab *et al.* (2022)**, who investigated the waters of the Tigris River in the Al-Daur district of Salah al-Din Governorate and found turbidity values ranging from 1.8 to 88.5 NTU. Similar findings were also documented by **Ali *et al.* (2019)** in a study of water quality in the Tigris River in Baghdad, where turbidity levels were reported to exceed Iraqi standards for drinking water. Likewise, this study aligns with the observations of **Al-Sarraj (2020)**, which examined seasonal variations in the turbidity of the Tigris River in Baghdad and recorded values ranging from 2.8 to 23.1 NTU—also exceeding national drinking water requirements **(Al-Sarraj *et al.*, 2022)**.

Turbidity, an optical property that scatters and absorbs light, causes water to appear cloudy or hazy. This property is a key indicator when evaluating the quality and usability of various natural water sources **(Rajesh *et al.*, 2018; Hamilton *et al.*, 2019)**. Elevated turbidity is commonly attributed to increased concentrations of suspended and colloidal particles, including organic and inorganic matter, clay, bacteria, and other contaminants **(Al-Kanani *et al.*, 2023)**. The current findings support this understanding, as evidenced in Tables (4– 6), which show a significant increase in suspended solids concentrations during the study period.

**Electrical conductivity (EC)**

The results indicated a slight increase in electrical conductivity across the study sites over the course of the study, as shown in Table (3). The maximum EC value recorded was 516µS/ cm at Site 5 in March, while the minimum was 348µS/ cm at Site 1 in September. Spatially, the average EC values ranged from 394.29 to 410.29µS/ cm, while temporal averages varied between 345.6 and 489.6µS/ cm.

Statistical analysis using Duncan's multiple range test revealed no significant spatial differences among sampling locations. However, significant temporal variations were observed throughout the study period, with a significance level of *P*< 0.05. All measured values remained below the maximum permissible limit of 2000µS/ cm set by Iraqi drinking water standards (Regulation No. 417, 2009), as indicated in Appendix 1.

**Table 3.** Monthly and spatial changes in electrical conductivity (µS/cm) in the Tigris River flowing through the city of Duluiyah during the study period

| | **2024** | | | | **2025** | | | |
|---|---|---|---|---|---|---|---|---|
| Months / Samples | September | October | November | December | January | February | March | Average location |
| **St 1** | 345 | 338 | 347 | 345 | 454 | 455 | 476 | 394.29 a |
| **St 2** | 350 | 349 | 352 | 344 | 475 | 444 | 496 | 401.43 a |
| **St 3** | 350 | 342 | 351 | 350 | 476 | 454 | 493 | 402.29 a |
| **St 4** | 349 | 348 | 359 | 348 | 476 | 450 | 467 | 399.57 a |
| **St 5** | 363 | 351 | 358 | 354 | 474 | 456 | 516 | 410.29 a |
| Average months | 351.4 c | 345.6 c | 353.4 C | 348.2 c | 471.0 a | 451.8 b | 489.6 A | |

**- Dissimilar letters denote substantial variations (*P*<0.05), whereas similar letters signify the absent of significance variations at the probability level (*P*<0.05) as determined by the Duncan test.**

The findings of the present investigation are consistent with those reported by **Mahmoud *et al.* (2023)**, who found that the electrical conductivity of the Tigris River in Salah al-Din Governorate ranged between 356– 520µS/ cm. These results also align with the findings of **Al-Sarraj (2020)**, who examined seasonal variations in the Tigris River in Baghdad and reported conductivity values between 266– 355µS/ cm **(Al-Sarraj *et al.*, 2022)**. However, the current study's results differ from those of **Ahmed *et al.* (2019)**, which indicated that the electrical conductivity of the Tigris River in Baghdad exceeded the permissible limits set by Iraqi drinking water standards.

Electrical conductivity refers to water's ability to conduct electric current due to the dissociation of dissolved substances into cations and anions **(VanLoon & Duffy, 2017)**. The observed rise in conductivity levels in this study can be attributed to the increased concentration of ions resulting from the decomposition of dissolved organic and inorganic materials **(Al-Hasani *et al.*, 2022)**. This correlation between dissolved solids and electrical conductivity is well-documented—higher concentrations of dissolved substances typically result in higher conductivity **(Dahham & Zulkepli, 2020)**. The findings of the current investigation support this relationship, as illustrated in Table (4).

**Total dissolved solids (TDS)**

The study results indicated a slight increase in total dissolved solids (TDS) concentrations, as shown in Table (4). The highest value was 302 mg/L at Site 5 in March, while the lowest was 237mg/ L at Site 1 in December. Geographically, the average TDS values ranged between 251.9 and 276.6mg/ L. Temporally, values ranged from 248.8 to 296.8mg/ L. The reading of 276.6mg/ L was the most notable peak within the range.

Statistical analysis revealed significant spatial and temporal differences in TDS concentrations throughout the study period, at a confidence level of $P< 0.05$. Despite these fluctuations, all recorded values remained below the Iraqi drinking water standard of 1000mg/ L, as stipulated in Regulation No. 417 of 2009 (Appendix 1).

**Table 4.** Monthly and spatial variations of total dissolved solids (milligrams/liter) in the Tigris River passing through the city of Duluiyah during the study period

| | **2024** | | | | **2025** | | | |
|---|---|---|---|---|---|---|---|---|
| Months / Samples | September | October | November | December | January | February | March | Average location |
| **St 1** | 248 | 244 | 225 | 237 | 266 | 256 | 287 | 251.9 b |
| **St 2** | 244 | 245 | 256 | 350 | 278 | 263 | 300 | 276.6 a |
| **St 3** | 247 | 244 | 250 | 244 | 276 | 249 | 299 | 258.4 b |
| **St 4** | 246 | 253 | 253 | 248 | 270 | 259 | 296 | 260.7 b |
| **St 5** | 256 | 258 | 262 | 251 | 280 | 266 | 302 | 267.9 ab |
| Average months | 248.2 D | 248.8 d | 249.2 D | 266.0 bc | 274.0 b | 258.6 cd | 296.8 a | |

**- Dissimilar letters denote substantial differences (*P*<0.05), whereas similar letters signify the absence of significance variations at the probability level (*P*<0.05) as determined by the Duncan test.**

The study's findings are consistent with those of **Abd Wahab *et al.* (2022)**, who examined the Tigris River in the Al-Dour District of Salah al-Din Governorate and reported total dissolved salts ranging from 211.5 to 297.5mg/ L. Similarly, the results align with those of **Ali *et al.* (2019)**, whose investigation into water quality in the Tigris River in Baghdad demonstrated that total dissolved solids (TDS) levels remained within the permissible limits defined by Iraqi drinking water standards.

Dissolved solids are a critical indicator of river water quality, reflecting the presence of colloidal particles, ions, and dissolved salts in the solution. The concentration of these components is closely related to electrical conductivity (EC), as conductivity increases with rising levels of dissolved ions **(Bhat & Gogate, 2021)**. This relationship was confirmed in the present study, as shown in Table (4), where elevated TDS values corresponded with higher electrical conductivity readings. High TDS concentrations in river water are typically attributed to increased levels of dissolved salts and ions **(Rajamanickam & Nagan, 2016)**.

**Total suspended solids (TSS)**

The results for total suspended solids (TSS), as presented in Table (5), indicated a maximum concentration of 400mg/ L at Site 5 in December, and a minimum of 20mg/ L at Site 4 in March. Spatial averages of TSS concentrations ranged between 69.29 and 125.0mg/ L, while temporal averages varied from 25.5 to 176.0mg/ L.

According to statistical analysis using Duncan's test for means, there were no statistically significant spatial differences among most sample sites, with the exception of

Site 5. However, significant temporal variations were observed throughout the study period at a significance level of $P < 0.05$.

The results exceeded the standard permissible value of 100mg/ L in several sampling locations, in reference to Iraqi drinking water standards (Regulation No. 417 of 2009), as illustrated in Appendix 1.

**Table 5.** Monthly and spatial variations of total suspended solids (milligrams/liter) in the Tigris River flowing through the city of Duluiyah during the study period

| Months / Samples | September | October | November | December | January | February | March | Average location |
|---|---|---|---|---|---|---|---|---|
| | 2024 | | | | 2025 | | | |
| **St 1** | 30 | 35 | 20 | 120 | 140 | 220 | 21 | 83.57 b |
| **St 2** | 33 | 40 | 40 | 60 | 260 | 80 | 40 | 79.00 b |
| **St 3** | 40 | 120 | 20 | 100 | 220 | 80 | 25 | 86.43 b |
| **St 4** | 45 | 80 | 30 | 100 | 100 | 60 | 20 | 69.29 b |
| **St 5** | 40 | 160 | 35 | 400 | 160 | 60 | 21 | 125.00 a |
| Average months | 37.60 e | 87.00 d | 29.00 Ef | 168.00 b | 176.00 a | 100.00 c | 25.00 f | |

**- Dissimilar letters denote substantial differences (*P*<0.05), whereas similar letters signify the absent of significance variations at the probability level (*P*<0.05) as determined by the Duncan test.**

The findings of the present investigation revealed elevated values compared to those reported by **Abd Wahab *et al.* (2022)** in a study of the Tigris River in the Al-Dour District, Salah al-Din Governorate, where salinity levels ranged between 21.0 and 37.0mg/ L. However, the results align with those of **Ali *et al.* (2019)**, who assessed water quality in the Tigris River in Baghdad and found that total suspended solids (TSS) remained within the permissible limits set by Iraqi drinking water standards.

Suspended solids refer to undissolved particles present in the water column and are a key indicator for evaluating water quality and pollution levels, as they constitute one of the most widespread contaminants in riverine environments. These particulates may include both organic and inorganic matter **(Komínková *et al.*, 2016)**.

Human activities—such as dishwashing and food preparation—can introduce substantial amounts of suspended particulates into water systems, further contributing to elevated concentrations. As the proportion of suspended matter increases, water quality declines, potentially rendering it unsuitable for human consumption **(SAAOD *et al.*, 2009)**. To evaluate potential chemical contamination, these findings can be compared with chemical oxygen demand (COD) values, as presented in Table (5).

**Concentrations of selected heavy elements**

**Lead (Pb)**

As shown in Table (6), lead concentrations in water samples from the Tigris River in Duluiya increased over the study period. The highest concentration recorded was

0.67 mg/L at Site 2 in November, while the lowest was 0.011 mg/L at Site 1 (Concrete Bridge) in February. Spatially, lead concentrations ranged between 0.2219 and 0.2919 mg/L, while temporal values varied from 0.075 to 0.474 mg/L.

Statistical analysis revealed no significant spatial differences among the study sites. However, significant temporal variations were observed throughout the study period, with a significance level of $P \leq 0.05$.

Overall, the lead concentrations exceeded the standard value of 0.01mg/L, though they remained within the tolerance range defined by Iraqi drinking water standards (Regulation No. 417 of 2009), as shown in Appendix 1.

**Table 6.** The biweekly and spatial variations of lead (mg/L) in the Tigris River flowing through the city of Dhuluiya during the study period

| | **2024** | | | | **2025** | | | |
|---|---|---|---|---|---|---|---|---|
| **Months / Samples** | **September** | **October** | **November** | **December** | **January** | **February** | **March** | **Average location** |
| **St 1** | 0.155 | 0.33 | 0.11 | 0.19 | 0.27 | 0.011 | 0.52 | 0.2266 a |
| **St 2** | 0.179 | 0.26 | 0.67 | 0.076 | 0.28 | 0.063 | 0.47 | 0.2854 a |
| **St 3** | 0.159 | 0.19 | 0.51 | 0.16 | 0.22 | 0.084 | 0.23 | 0.2219 a |
| **St 4** | 0.138 | 0.1 | 0.48 | 0.1 | 0.19 | 0.091 | 0.63 | 0.2470 a |
| **St 5** | 0.187 | 0.23 | 0.56 | 0.22 | 0.2 | 0.126 | 0.52 | 0.2919 a |
| Average months | 0.164 c | 0.222 B | 0.466 A | 0.149 C | 0.232 b | 0.075 d | 0.474 A | |

**- Different letters indicate the presence of significant differences (*P*<0.05), while similar letters indicate the absence of significant differences at the probability level (*P*<0.05) according to the Duncan test.**

The findings of the current study are consistent with those reported by **Ahmed (2024)**, who evaluated the environmental health of the Tigris River in Baghdad and found that lead (Pb) concentrations exceeded the maximum allowable limit for drinking water. Similarly, the current study aligns with results from a separate investigation on heavy metal contamination and environmental factors in the Tigris River in Maysan Province.

Lead is a cumulative toxic metal that accumulates in the human body, particularly in the kidneys and joints, leading to severe damage to various organs **(Wu *et al.*, 2008)**. Naturally, lead originates from lead-bearing minerals such as cerussite, galena, and anglesite. Elevated lead concentrations have been observed in the Tigris River as it flows through Mosul, primarily due to the discharge of domestic, industrial, and agricultural wastewater, along with untreated sewage.

Another significant source of lead pollution is the historical use of tetraethyl lead in vehicle fuel. This compound can combine with atmospheric moisture to deposit in river systems, contributing to a visible smog phenomenon, particularly at sunset. Additionally, increased lead levels may be detected after periods of snow or ice melt, suggesting possible leaching from deposits on the inner walls of water transport pipelines **(Benjamin & Lawler, 2013)**.

**Cadmium (Cd)**

The results showed that cadmium was not detected in any of the water samples throughout the study period. All recorded values were below the detection limit and lower than the standard permissible value of 0.005mg/ L, as outlined in Iraqi drinking water standards (Regulation No. 417 of 2009), shown in Appendix 1.

These findings are consistent with those reported by **Ahmed and Al-Shandah (2024)**, who studied water quality in the Qayyarah district and found cadmium concentrations in compliance with both Iraqi and international drinking water standards. However, the results contrast with those of **Ahmed (2024)** and **Ahmed *et al.* (2024)**, whose evaluation of trace elements in the Tigris River in Baghdad revealed cadmium levels exceeding the maximum permissible limits for safe drinking water.

**Cobalt (Co)**

The results, as presented in Table (8), indicate a slight increase in cobalt concentrations over the study period. The highest recorded concentration was 0.90mg/ L at Site 4 in January, while the lowest concentration was 0.00mg/ L at the same site in December. Spatially, cobalt concentrations ranged between 0.10 and 0.70mg/ L, whereas temporally, values ranged from 0.33 to 0.63mg/ L.

Statistical analysis revealed significant spatial variation among the different sampling sites, as well as significant temporal differences throughout the study period, with a confidence level of $P \leq 0.05$. Overall, the measured cobalt concentrations exceeded the standard permissible value of 0.01mg/ L, as stipulated by the Iraqi drinking water standards (Regulation No. 417 of 2009), as shown in Appendix 1.

**Table 8.** Monthly and spatial changes of cobalt element (mg/L) in the Tigris River passing through the city of Balad during the study period

| | 2024 | | | | 2025 | | | |
|---|---|---|---|---|---|---|---|---|
| **Months / Samples** | **September** | **October** | **November** | **December** | **January** | **February** | **March** | **Average location** |
| **St 1** | 0.10 | 0.31 | 0.29 | 0.07 | 0.50 | 0.094 | 0.30 | 1.152c |
| **St 2** | 0.12 | 0.27 | 0.31 | 0.01 | 0.45 | 0.055 | 0.28 | 1.125 c |
| **St 3** | 0.16 | 0.25 | 0.31 | 0.01 | 0.60 | 0.025 | 0.37 | 1.155 b |
| **St 4** | 0.18 | 0.23 | 0.32 | 0.00 | 0.90 | 0.11 | 0.41 | 2.133 a |
| **St 5** | 0.15 | 0.22 | 0.51 | 0.00 | 0.42 | 0.021 | 0.35 | 1.185 b |
| **Average months** | 0.142 c | 0.256 bc | 0.348 B | 0.030 d | 0.734 a | 0.062 D | 0.342 b | |

**- Different letters indicate the presence of significant differences (*P*<0.05), while similar letters indicate the absence of significant differences at the probability level (*P*<0.05) according to the Duncan test.**

Cobalt is one of the trace heavy elements that naturally occurs in the environment; however, its concentrations in aquatic systems—particularly rivers—can vary significantly depending on anthropogenic influences and environmental conditions. In freshwater systems, cobalt is typically present either as dissolved ions or adsorbed onto suspended particles and bottom sediments. While it plays a complex environmental role, cobalt becomes hazardous when it accumulates at elevated concentrations. High levels of cobalt are considered a serious environmental contaminant, capable of affecting aquatic organisms through bioaccumulation and subsequently entering the food chain. Chronic exposure in humans may lead to adverse health effects, including cardiovascular and respiratory complications **(Ruiz *et al.*, 2025)**.

Elevated cobalt concentrations are linked to several contributing factors, most notably mining and industrial activities. The extraction and smelting of cobalt-bearing ores are among the principal sources of cobalt leaching into aquatic environments **(Xu *et al.*, 2022)**. Additionally, the discharge of untreated industrial effluents significantly contributes to river pollution by introducing cobalt into surface waters via liquid waste disposal.

Agricultural runoff also plays a role, particularly when chemical fertilizers are used or when irrigation relies on contaminated water sources, further introducing cobalt into river systems **(Raj *et al.*, 2024)**. Natural environmental conditions, such as pH and redox potential, also influence cobalt's mobility and solubility, thereby affecting its release from sediments into the water column.

Conversely, cobalt concentrations in river water may decrease due to environmental processes such as sedimentation and adsorption. These processes allow cobalt to bind with organic matter and fine mineral particles, causing it to settle on the riverbed and reducing its concentration in the overlying water **(Zhang *et al.*, 2023)**.

**Appendix 1.** Iraqi standard specifications No. (417) for the year 2009, and the World Health Organization (WHO) specifications for the year 2008 for evaluating the quality of drinking water.

| **Parameter** | Permissible limit | |
|---|---|---|
| | **Iraqi Standard (2009)** | **WHO Standard (2008)** |
| **Temperature** | 25 C | ------ |
| **Turbidity** | 5NTU | 0-5 NTU |
| **Electrical conductivity (EC)** | 2000 µs/cm | 1500 µs/cm |
| **Total dissolved solids (TDS)** | 1000 mg/L | 1000 mg/L |
| **Total Suspended Solids (TSS)** | 100 mg/L | ------- |
| **Cobalt** | --- | ---- |
| **Lead** | 0.01 mg/L | 0.01 mg/L |
| **Cadmium** | 0.005 mg/L | 0.005 mg/L |

## CONCLUSIONS

The findings indicated that certain physical parameters—such as temperature, electrical conductivity, and total dissolved solids—remained relatively low and within the acceptable limits set by Iraqi drinking water standards. In contrast, other physical characteristics, including turbidity and suspended solids, exhibited elevated concentrations that exceeded the permissible thresholds. Notably, water samples collected during the fifth month of the study demonstrated a marked increase in both turbidity and suspended solids across most testing sites.

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