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Article

The Study of Changes in the Physicochemical Properties of the Tigris River from an Environmental Perspective in the Cities of Baiji and Tikrit over a Three Months Period

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Abstract: The current study was conducted to assess the water quality of the Tigris River by measuring certain of its physicochemical parameters. In Salah al-Din Governorate, covering the areas of Tikrit, Al-Hajjaj, and Baiji. Samples were collected over three months, from February 2025 to April 2025, at varying times, at a rate of 180 mL per area per month. The study included measurements of air and water temperatures, turbidity, electrical conductivity, pH, salinity, dissolved solids, dissolved oxygen, total hardness, calcium and magnesium hardness in the river water. The study results showed that the values of air and water temperatures have ranged between (18.3-33.7) °C, (11-18.9) °C in the Tigris River, respectively. Turbidity showed a difference in percentages according to the region, as it recorded its highest degrees in the Baiji region, ranging between NUT (7.976.38). In contrast, Tikrit showed the lowest percentage, which ranged between NUT (1.220.38). Electrical conductivity in study sites recorded values ranged between (2711-9655) µs⁄ cm. pH values ranged between (6.6-8.7), and variations were observed in all study areas over the three months. Salinity showed convergence in the results over the three months, and its value ranged between (0.70.4) us/cm. Total dissolved solids showed values that changed throughout the months of study, with the highest value (5800 mg/L) observed at S3. Dissolved oxygen values ranged between 5 and 6 mg/L in the Tigris River. Total hardness, calcium, and magnesium were (700-2000), (580-1090) and (14.16-315.74) mg $CaCO_3$/L, respectively. Statistically significant differences have emerged in all physical and chemical characteristics between months at a probability level ($P \leq 0.05$), while there were no differences between stations, except for calcium hardness.

Keywords: Physicochemical Properties, Tigris River, Baiji, Hajjaj, Tikrit

Introduction

Surface water is an essential natural resource for human existence and developmental activities. Therefore, it is essential to maintain and safeguard high-quality surface water to facilitate sustainable development and protect human health [1]. Assessing water quality involves analysing the state of natural water and its suitability for drinking, agricultural, household, industrial, and irrigation purposes [2]. In recent decades, there has been a persistent decline in surface water quality, primarily due to its susceptibility to pollution from both natural and anthropogenic sources, including industrial effluents, residential waste disposal, and irrigation runoff [3].The quality of river water is critically important, as these resources are extensively used for various purposes, including potable water supply, agricultural irrigation, hydroelectric power generation, transportation and infrastructure, tourism, and recreation [4]. The quality of river water is a dynamic system shaped by natural influences, including climate and rock weathering, as well as manmade pressures such as pollution from agriculture, industry, and urban expansion. Seasonal variations in river flow rates are a crucial mechanism connecting ecosystems, as they influence pollutant dilution and the movement of nutrients and sediments, resulting in quantifiable alterations in water quality metrics such as temperature, nutrient concentrations, and biological indicators. These interactions generate intricate geographical and temporal fluctuations in river ecosystems, necessitating meticulous monitoring and management to safeguard water supplies [5].

The Tigris River is one of Iraq's main water sources, used for drinking, domestic, industrial, and irrigation purposes [6]. Overuse, increased demand, and pollution are placing unsustainable pressure on water availability and quality [7,8]. Many rivers have experienced deteriorating water quality and pollution [9]. Water pollution makes it difficult to maintain river water quality within acceptable limits for drinking, industrial, and agricultural uses [10]. Therefore, determining water quality requires specific criteria related to its physical, chemical, and biological properties [11]. The Tigris River is a vital water source for Tikrit Governorate. This river has become increasingly polluted due to industrialization, agricultural runoff, and population growth, necessitating periodic assessments of water quality [8]. Temperature is a fundamental physical property of water, as its increase affects its quality, leading to increased chemical reactions and decreased solubility of oxygen and other gases [12]. This leads to changes in water properties, including density and viscosity, and impacts aquatic life [13,14]. Turbidity determines the number of suspended particles that affect the path of light rays in the water. Turbidity affects water quality by reducing light penetration in the water column, leading to serious consequences [15]. Electrical conductivity is a measure of water's ability to carry an electric current and depends on the concentration of dissolved ions in the water, temperature, and the geological nature of the riverbed [16]. Dissolved solids represent the measure of inorganic salts and other organic materials in water. They are either found naturally in water or are deposited in it as a result of industrial and domestic waste discharged from the atmosphere, or as a result of evaporation due to high temperatures or rainfall. They also depend on the local geology [17]. PH represents the most important chemical property of water and is a measure of the acidity or alkalinity of a solution. It affects drinking water and wastewater [18]. Most organisms live within a narrow, critical pH range. Dissolved oxygen (DO) is crucial for aquatic life, and its concentration is a key indicator of water quality. However, its solubility in water is low. It depends on the solubility of the gas, the partial pressure of the gas in the air, the temperature, and the water's purity [19]. Hardness represents the ability of water to precipitate soap. Soap precipitates in hard water due to the presence of divalent calcium and magnesium ions, as well as other multivalent metal ions, including iron, aluminum, cadmium, and zinc [20]. It also contains hydrochloride ions, which are salts of hardness in water in the form of carbonates, bicarbonates, chlorides, and sulfates [21]. Calcium and magnesium ions are the main cause of hardness in most waters, despite the presence of other metallic elements [22].

The concentration of calcium in natural waters depends on the quality of the soil or the areas through which the river passes, especially since the Tigris River carries large quantities of calcium due to its passage through areas with chalky soils rich in calcium carbonate, in addition to the decomposition of living organisms, which adds quantities of calcium [23]. This study aims to evaluate temporal changes in the physicochemical properties of the river in Tikrit and Baiji districts to determine its suitability for potable use. Water samples were analysed over three months for essential parameters. Results indicated seasonal fluctuations, characterised by elevated constituents during arid times and diluting effects during precipitation events. Ongoing surveillance is crucial for alleviating any public health hazards, especially for communities that rely on river water.

Materials and Methods

Study location

The Salah al-Din Governorate is situated in central Iraq, north of Baghdad, at coordinates 33°58′28.90″N and 43°53′24.60″E. The region spans 24,363 km² and has a population of 1,559,000 individuals (Fig. 1). The terrain is predominantly semi-flat, characterised by certain elevated features, including river terrace deposits and various depressions. Geologically, the majority of the region is composed of sediments, including mud, sand, and gravel. The research area encompasses the course of the Tigris River in Salah al-Din Governorate. The Tigris River traverses a somewhat small valley within the undulating terrain from the commencement of the study area to the Strait of Fath, which delineates the elevations of Hamrin and Makhoul. The river traverses the terraces until it reaches the sedimentary plain at the Balad area, where its gradient progressively diminishes towards Baghdad, indicating the suspended and bed load within the river [24].

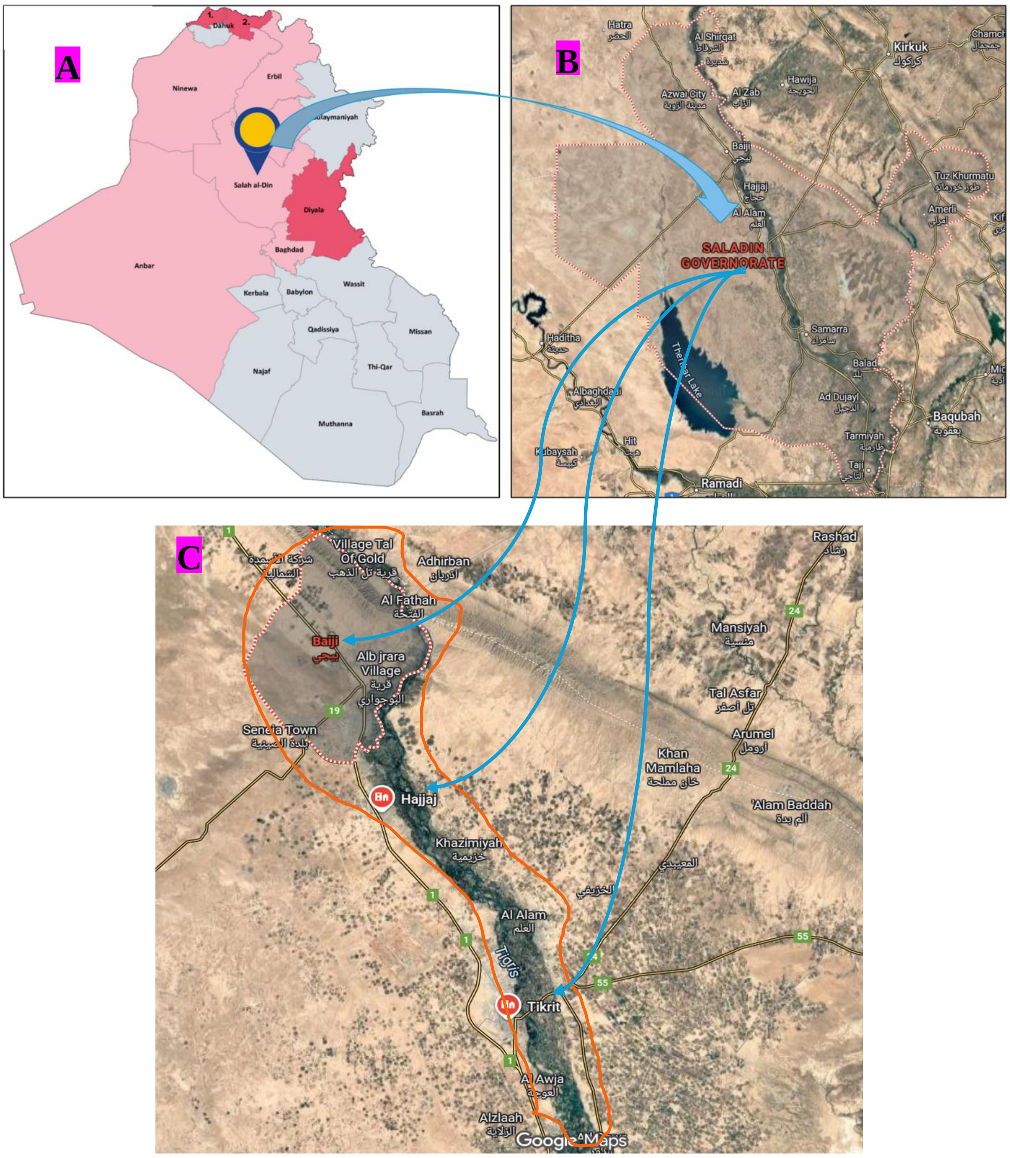

Figure 1. A. Location of the study area within Iraq**, B**, showing Salah al-Din Governorate and **C**, the selected sampling sites along the Tigris River at Baiji, Al-Hajjaj, and Tikrit.

Samples collection

Water samples were collected from the middle of the Tigris River on a semi-monthly basis from the three study areas, between morning and afternoon, for a period of three months, from February 2025 to the end of April 2025. Samples were taken using a 60ml plastic container, at a rate of 180ml per month for each area, after washing it twice with sample water. They were then stored in the refrigerator until they were delivered to the laboratory, and work began.

Physicochemical Properties

Measurement Air and Water Temperature

Air and water temperatures were measured directly at the sampling sites using a conventional thermometer, graduated from 0 °C to 100 °C [25].

Measurement of Turbidity

Water turbidity was measured using an Italian-made Martini Instruments 415 turbidity meter, and the results were expressed in units of Nephelometric Turbidity Units (NTU) [25].

Measurement of Electrical Conductivity (EC).

The electrical conductivity of the water was measured in the field using a Romanian-made Smart Combined Meter 801, and the results were expressed in microsiemens/cm.

Measurement of PH

Use a Romanian-made Smart Combined Meter 801 pH meter after calibrating it with standard solutions.

Measurement of Salinity

Salinity was measured based on the electrical conductivity values of the samples, and the results were expressed in g/L as in the following equation:

Salinity (km/L) = (ECV μS/cm-(14.78) (1589.08)

Measurement of Total Dissolved Solids (TDS)

Total dissolved solids were measured using a Romanian-made Smart combined meter 801, and the results were expressed in parts per million (ppm).

Measurement of Dissolved Oxygen (OD)

To calculate the dissolved oxygen value in each water sample studied, an oxygen thermometer is used. The device must be calibrated for each dissolved oxygen reading. This calibration is performed using the amount of oxygen present in the atmosphere, which constitutes 20.9% of the total atmospheric gases. The amount of dissolved oxygen in the water is then measured after the readings are converted to mg/L [25].

Measurement of total hardness (TH)

Total hardness was quantified following the standard procedures outlined by APHA (2017) by obtaining 50 mL of water sample and including 1 mL of ammonia buffer solution to achieve a pH of 10. Subsequently, 0.5 g of the Eri chromic Black T indicator was incorporated, resulting in a colour transformation to wine red. The solution was filtered using a 0.02N sodium EDTA solution until a blue hue was observed, and the mean of three measurements was recorded. The overall hardness was determined in accordance with the following principle.

$$\text{T.H mg/L as } CaCO_3 = \frac{\text{V x N x wt- as x 1000}}{\text{ml of Sample}}$$

Measurement of Calcium Hardness

The calcium hardness of the samples was assessed in accordance with the APHA (2017) water testing methodology, employing the subsequent procedures: Fifty millilitres of water sample were collected, to which two millilitres of 2.5 N sodium hydroxide solution and few drops of calcium indicator (Murixide) were added. The mixture was subsequently filtered using a normal 0.05 M Na_2 EDTA solution until the colour transitioned from pinkish-red to aquamarine. Calcium hardness was determined using the method that quantifies the calcium hardness of the water sample in milligrammes of calcium carbonate per litre.

$$calicium\ Hardness\ \ mg/L = \frac{\mathrm{V_{EDTA}} \times \mathrm{N_{EDTA}} \times 1000 \times \ \text{Mole} - \text{wt as CaCO3}}{2 \times V_{sample}}$$

Measurement of Magnesium Hardness

According to the APHA standard technique (2017) for water testing, the magnesium hardness of the samples was quantified in milligrammes of magnesium carbonate per litre using the following equation:

$$\text{Magnesium Hardness } mg/L = Total\ Hardnes\ - Calicium\ Hardness$$

Statistical Analysis

The importance of variances, including geographical and temporal disparities in physical and chemical parameters, was assessed utilising the analysis of variance technique and the Statistical Package for the Social Sciences (SPSS) software. The Correlation Coefficient values were computed at a probability threshold of P≤0.05.

Results and Discussion

Air and Water Temperature:

Temperature is one of the most important factors affecting the environment and water quality. The number of gases dissolved increases with the increase in heat value, which is directly proportional to the increase in temperature [12]. Rising groundwater temperatures have many effects, including increased activity of aquatic microorganisms, which in turn leads to the consumption of dissolved oxygen, depending on the concentration of organic matter present in the water [26].

The importance of the effect of air temperature on water is related to the fact that water temperature has a close relationship with the respiration process. When the water temperature increases by one degree Celsius, the respiration rate increases by 15%. This is clearly evident in aquatic organisms that have a high sensitivity to such changes [27]. Additionally, the thermal range of organisms living in water is narrower than that of terrestrial organisms because the change in water temperature is less pronounced than on land [28]. Air temperatures ranged between 18.3°C, the lowest recorded temperature in Baiji during February, and 19.1°C and 20.3°C during March and April, respectively. Tikrit recorded its highest temperature of 33.7°C in April, as well as 23°C and 25°C in February and March, respectively. In Al-Hajjaj City, air temperatures were 19.9°C in February, 20°C in March, and 22.8°C in April. Regarding water temperatures, the study recorded the highest temperature in Tikrit in April at 27.9°C, and the lowest temperatures were 25.23°C in March and February. The lowest temperatures were recorded in Baiji in February at 11°C, 12°C, and 14°C during March and April, respectively. Al-Hajjaj recorded the water temperature in February at 20°C and in March and April at 24°C and 26°C respectively, as shown in figure (2). The results indicated that the highest air and water temperatures were recorded in April, while the lowest values were recorded in February. We attribute this positive result to the climate of the study area, the timing of sample collection, and the sampling process.

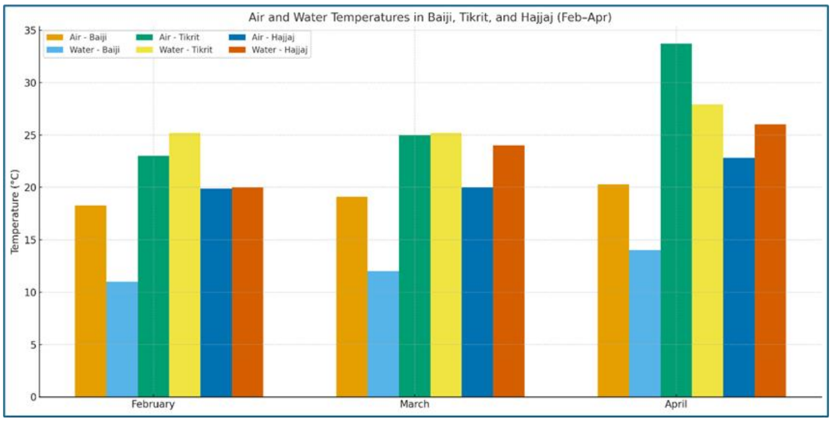

Figure 2. Air and water temperature during the study months

Turbidity

Turbidity is the optical property of water resulting from the scattering, diffusion, and absorption of light by suspended matter rather than its transmission in a straight line through the sample. Both the concentration and size of suspended matter affect the degree of turbidity [29]. The suspended matter causing turbidity is either organic, including phytoplankton and zooplankton, or inorganic, such as clay and silt. Turbidity is responsible for changes in water [30]. A direct relationship has been observed between turbidity and microbiological activity [31]. The substances causing turbidity are diverse and varied, including colloidal materials, clay, organic debris, and various plant and animal matter. These substances are either produced within the river or introduced from outside [32].

The current study revealed variations in turbidity values between months. The highest value was recorded in Hajjaj during February at 89 NTU, and it reached 85 and 80 NTU during March and April. This pattern can be explained by the drift of waste and fine soil particles adjacent to the river, mainly due to the presence of an earthen barrier between the public road and the river's water, which characterizes the Tigris River in Al-Hajjaj. The lowest value was recorded in Tikrit in April, at 33 NTU, 30 and 28 NTU during March and February. In the city of Baiji, the highest turbidity was recorded in February at 65 NTU, with levels of 60 and 55 NTU noted during March and April, respectively. Statistically significant differences were found in all measured physical and chemical properties between months at a probability level ($P \leq 0.05$), as shown in figure (3). This variance is due to differences in weather conditions and their impact on the physical and chemical properties of the water.

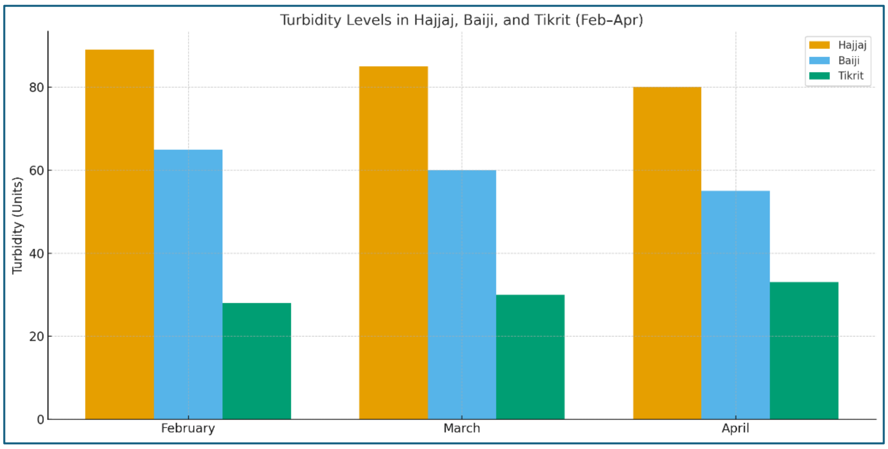

Figure 3. Turbidity during the study months

Electrical conductivity

Electrical conductivity it is a numerical value that indicates the ability of water to carry an electric current, depending on the concentration and valence of the dissolved ions present in the water and their transmission limits. Additionally, the temperature of the water during measurement has a direct impact on the movement and direction of the various ions. The conductivity of water increases by 2% for every one-degree Celsius increase in temperature [33]. Water containing inorganic compounds has high conductivity, while water containing non-degradable organic compounds has low conductivity [34].

Tikrit recorded the highest electrical conductivity value during the study months, reaching its peak in February (8690 µS/cm), followed by March (7870 µS/cm) and April (6980 µS/cm), respectively. Meanwhile, the cities of Al-Hajjaj and Baiji recorded the lowest values during the study months, reaching 2,580 µS/cm in Al-Hajjaj in February, 2,470 µS/cm in March, and 2,240 µS/cm in April. The lowest peak was recorded in Baiji during February (2,360 µS/cm), March (2,310 µS/cm), and April (2,110 µS/cm) , as shown in figure (4). This variation is due to rainfall during these months and the salts it carries during erosion, which leads to the accumulation of these ions in the water [35]. The organic materials in springs cause an increase in electrical conductivity values during heavy rainfall. Generally, electrical conductivity values increase towards the south, which is attributed to the nature of the soil components through which the river passes, as well as human and agricultural activities [36].

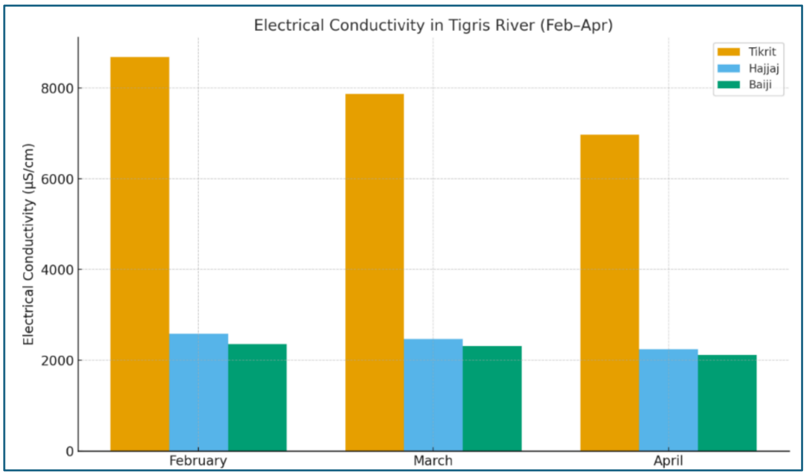

Figure 4. Electrical conductivity during the study months

PH

pH is probably by far the most important physicochemical parameter controlling the behavior of other water quality parameters as well as metals concentration in the aquatic environments [37]. Chemical processes in aquatic systems such as acid-base reactions, solubility reactions, oxidation-reduction reactions and complexations are all influenced by hydrogen ions concentration (pH). Water bodies around the vicinity of mining activities are susceptible to receiving metals from dumpsite leachate and other waste discharge from the mining activities [38]. Metal pollution has become a major concern due to their ability to bioaccumulate along the food chain [39]. The availability of these metals can however be influenced by pH, making pH an important factor in determining the chemical and biological properties of water [37].

The results showed alkaline values for the Tigris River water in Baiji, Al-Hajjaj and Tikrit, where the value reached (7.15,7.35, 7.33) respectively in February, while acidic values were recorded for April and March, ranging between (4.66,4.89,5.66), as shown in figure (5). This is deemed outside the standard parameters for water quality. The alterations can be attributed to climate influences, including heightened surface runoff in spring that transports organic matter and ions, resulting in decreased pH, alongside anthropogenic activities such as agricultural and industrial effluents. Recent studies have demonstrated that seasonal variations are crucial determinants of surface water characteristics, with pH intricately linked to temperature, river discharge, and anthropogenic factors [40, 41]. Reduced pH at certain seasons, particularly spring, enhances the solubility of heavy metals and adversely affects aquatic biodiversity [42]. The observed variability in the Tigris River waters aligns with existing scientific literature regarding the sensitivity of pH to seasonal fluctuations and anthropogenic influences, underscoring the necessity for ongoing monitoring of this critical parameter as a means of evaluating water quality and environmental sustainability.

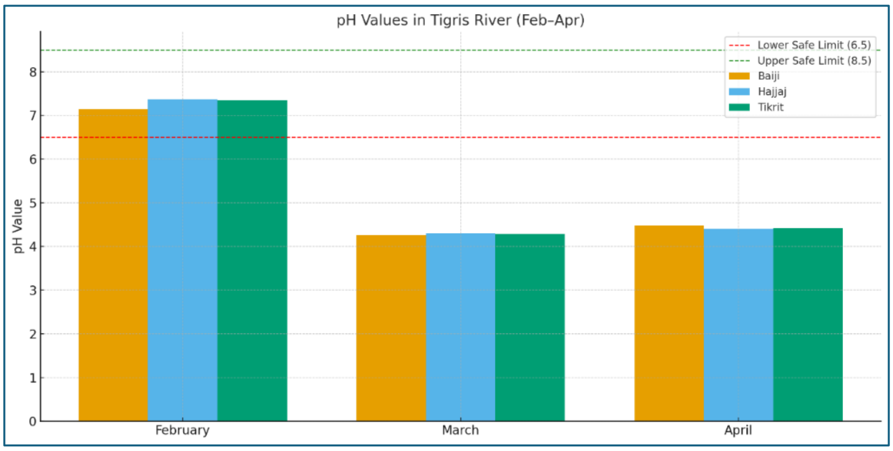

Figure 5. pH during the study months

Salinity

Global freshwater resources are under risk due to the deterioration of freshwater systems caused by salt contamination. Increased specific conductance (conductivity), a stand-in for salt concentrations, is frequently used to detect salinization. The variety of salts that enter freshwaters and the possible effects this may have on microbial populations and functions, however, are not taken into consideration by conductivity [43]. Weather extremes brought on by climate change can lead to long-term salinisation from sea level rise or salt pulse shocks to freshwater habitats during storm events [44]. Furthermore, freshwater in inland waterways becomes salinised as a result of variations in precipitation and evaporation [45]. One of the primary causes of river salinisation is mining-related industrial pollution, which is frequently disregarded [46]. When hypersaline effluents are released into freshwater ecosystems, the salinity levels can rise to brackish levels within a few hours or days [47], resulting in a significant impact on the ecosystem's structure and functionality [48]. Since microorganisms encounter unique obstacles while adjusting to a new salt level, the rise in salinity creates harsh circumstances for freshwater bacterial populations [49]. One of the primary elements influencing the spread of aquatic bacterial communities has been identified as the environment's salt content [50].

The highest salinity level was recorded in Tikrit, reaching 8.8 in February, while it dropped to 8.0 in March and to 7.8 in April. The lowest level was recorded in Hajjaj, reaching 4.0 in April, while during March and February it reached 5.5 and 6, respectively. Finally, in the Baiji, the results were similar to those in Hajjaj, reaching 4.4 in April and 5.2 and 6, respectively, in February and March, as shown in figure (6). This variation is due to the influence of natural factors, such as increased, river flow in the spring, which dilutes salt concentrations, as well as human factors, including agricultural activities and industrial discharges, which may raise salinity levels, especially in the city of Tikrit. From an environmental perspective, these values fall within the range of low-salinity water, making them capable of affecting aquatic biodiversity by creating osmotic stress for freshwater organisms and reducing the activity of coliform bacteria, whose survival rates decline with increasing salinity [51,52]. These results demonstrate that salinity is a vital indicator affected by climatic, human, and hydrological activities, necessitating periodic monitoring to ensure the sustainability of the river system.

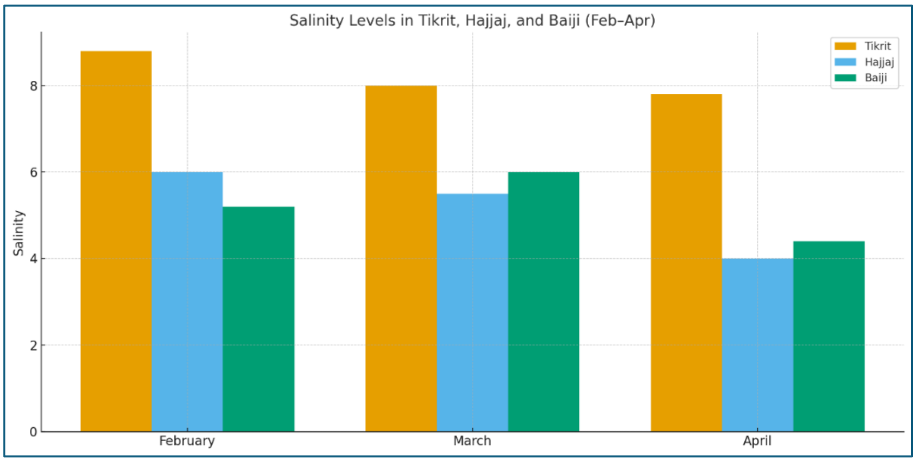

Figure 6. Salinity during the study months

Total dissolved solids (TDS)

The concentration of total dissolved solids (TDS) in a water body is directly correlated with its conductivity level [53]. Elevated TDS levels affect the flavour, hardness, and corrosive characteristics of water, rendering it unfit for consumption [54]. Research conducted by [55] indicates that the geographical and temporal monitoring of electrical conductivity and TDS serves as an effective indicator of water quality. Sources of TDS encompass point source water pollution from industrial and household effluents, agricultural runoff, and the leaching of soil contaminants [56]. Total Dissolved Solids (TDS) influence the capacity of water to solubilize certain inorganic minerals and some organic minerals or salts. Total Dissolved Solids (TDS), salinity, and Total Suspended Solids (TSS) can influence surface water quality. The concentration of Total Dissolved Solids (TDS) can influence the water equilibrium in the cells of aquatic animals, and elevated levels can alter the palatability of water [57]. Consequently, determining this property is crucial to understanding its impact. The highest values were recorded in Baiji, reaching 6,000 mg/L in February, while they reached 5,800 and 5,400 mg/L in March and April, respectively. In Hajjaj, TDS reached 5900 mg/L in February, followed by 5360 mg/L in March and 5100 mg/L in April. The lowest values were recorded in Tikrit, where they reached 3990 mg/L in March, while they reached 4990 mg/L in February and April, respectively, as shown in figure 7. High levels of dissolved solids in the river may result from human activities, such as wastewater from industrial areas, or from the discharge of salt and organic matter [58]. The taste and flavour of water are affected when dissolved solids levels are too high [57].

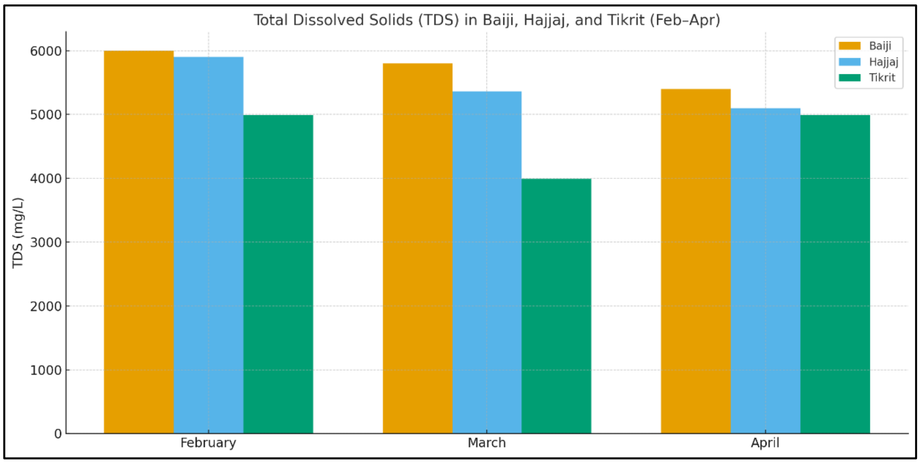

Figure 7. Total dissolved solids during the study months

Dissolved Oxygen (DO)

Dissolved oxygen (DO) is a vital measure for assessing water quality and the extent of pollution in aquatic ecosystems. A low DO concentration indicates water pollution, as the amount of dissolved oxygen is directly related to air pressure and inversely proportional to salinity and temperature. Its presence in water is crucial for respiration and the biodegradation of organic matter into environmentally benign chemicals, while also mitigating unpleasant odors [60]. The study in Hajjaj yielded results showing that the highest values (6–7 mg/L) were reached in February and March, respectively, while the lowest value (5 mg/L) was recorded in April. In Al-Baiji, the concentration reached 6.6 mg/L in February, followed by 6 mg/L in March and 6.2 mg/L in April. The results in Tikrit indicated that dissolved oxygen concentrations were 7 mg/L in February, 6.4 mg/L in March, and 5 mg/L in April, as shown in Figure 8. The results of this research indicate a marked variation in dissolved oxygen levels in river water samples over the study months. This relative variation in prediction arises from the influence of several variables on oxygen levels and concentrations, including river depth, temperature and barometric pressure fluctuations, and the presence of aquatic microorganisms.

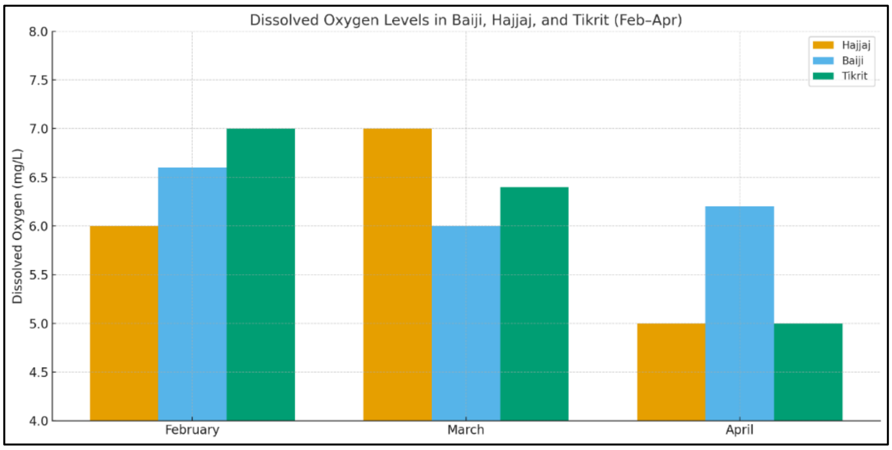

Figure 8. Dissolved Oxygen during the study months

Total Hardness and Ca, Mg Hardness

Total hardness is not a component but rather a mixture of several salts or components, most of which are calcium and magnesium salts [61]. The current study showed that the lowest values of total hardness in the Baiji area were recorded during March, reaching 540 mg/L of calcium carbonate, while they reached 600 and 580 during February and April respectively. This decrease may be due to the presence of aquatic plants in that area, which use a large amount of carbon dioxide for photosynthesis, leading to high pH values and, consequently, calcium carbonate precipitation [62] The highest site was Al-Hajjaj in February, at 2100 mg/L $CaCO_3$, and it reached 2000 and 1980 mg/L during March and April, respectively. This effect may be due to the direct influence of waste discharged from lands near the river, especially waste containing calcium and magnesium ions. Heavy rainfall in that month may also have caused the erosion of salts from the saline lands adjacent to the river.

February was the most challenging month, with a $CaCO_3$ concentration of 2,100 mg/L. The calcium content of natural waters depends on the quality of the soil and the river flow. The calcium values were recorded in Tikrit during February (1,020 mg/L $CaCO_3$), while the lowest values were recorded in March and April (510 and 480 mg/L $CaCO_3$), respectively. In general, calcium values were higher than magnesium values. This phenomenon may be due to carbon dioxide reacting more readily with calcium than with magnesium, thereby converting large amounts of calcium to dissolved bicarbonate. [63]. As for magnesium, the highest values were recorded in Hajjaj during February (430 mg/L $CaCO_3$), while during March and April, they reached 400 and 390, respectively. In Baiji, the percentage appeared during February, March, and April as follows: 405, 380, and 310. Finally, the percentage in the city of Tikriuring February, March, and April reached 455, 500, and 565, respectively, as shown in figure (9). The increase may be attributed to the leakage of magnesium from adjacent agricultural lands and water drains into the river, the decomposition of living organisms that contain magnesium, or increased evaporation, which has led to a higher concentration of magnesium [63,64].

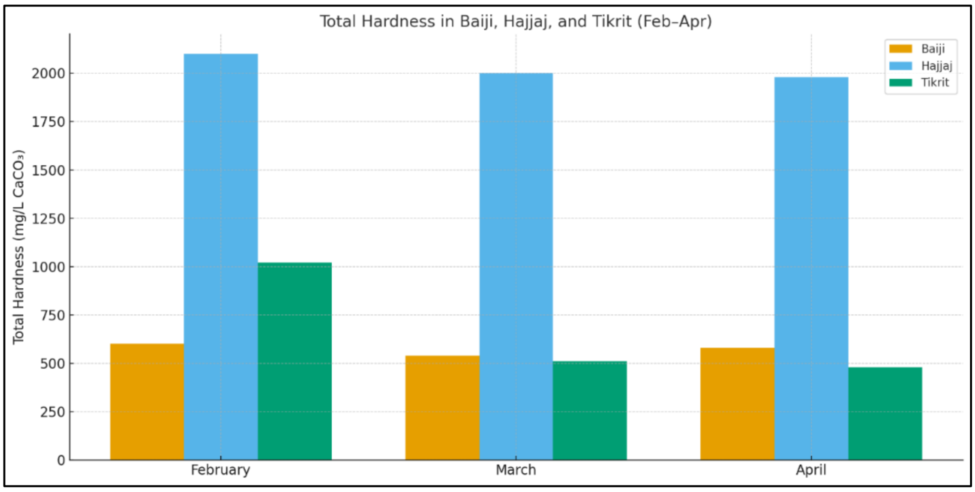

Figure 9. Total Hardness and Ca, Mg Hardness during the study months.

Conclusion

The study revealed that the physicochemical properties of the Tigris River in the areas of Baiji, Al-Hajjaj, and Tikrit are significantly influenced by both climatic conditions and anthropogenic activities. Seasonal variations played a major role in altering water quality parameters, with the highest values of temperature, turbidity, electrical conductivity, salinity, and total dissolved solids generally recorded during February, while relative declines were observed in April due to increased river flow and dilution effects. The results showed that industrial and petroleum discharges, in addition to agricultural runoff and urban waste, directly contribute to the observed fluctuations in water properties. It is worth noting that some parameters, such as pH, dissolved oxygen, and water hardness, exceeded natural limits in several cases, potentially posing environmental risks and negatively impacting aquatic biodiversity. Overall, the study results emphasize the importance of continuous monitoring of the Tigris River to monitor environmental changes, assess the suitability of the water for domestic and agricultural purposes, and protect aquatic life. Furthermore, implementing stricter waste disposal regulations and adopting sustainable management strategies are essential steps to conserve this vital water resource. management strategies are necessary steps to preserve this vital water resource.

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