



Assesment of the microbiological, physicochemical quality of Diyala River water, with emphasis on regulatory roles of coliform bacteria

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Surface water bodies are essential sources of water for human consumption, residential use, agriculture, industrial operations, as well as for aquatic life and ecosystems. The aim of this article is to appraise the microbiological, physical, and chemical quality of the water of the Diyala River. Water samples were collected from nine various sites along the Diyala River, during the period from winter (December) 2023 to summer (May) 2024. The total count of aerobic bacteria, total coliforms (TC) and fecal coliforms (FC), *E. coli* bacteria and physico-chemical parameters are evaluated. The results show that the water from the Diyala River is contaminated with coliform organisms in all sites. Regarding pathogens, which include bacteria *Salmonella* spp., *Shigella* spp., *Klebsiella pneumoniae*, *Enterobacter ludwigii*, and *Staphylococcus* spp., the results specify that there is no clear difference in abundance of pathogens between the two seasons. The mean, of maximum and minimum value for temperature, electrical conduction, turbidity, BOD, DO, calcium, magnesium, nitrate concentration are all greater than the permitted values of the World Health Organization (WHO). However, pH, chloride concentration and total dissolved solids (TDS) in the water samples are all within the permitted levels set by the WHO. The water quality index (WQI) and comprehensive pollution index (CPI) score for all sites indicate that the river water quality is poor. The study indicates that the water in the study area is heavily polluted and poses significant health risks because of fecal and emerging pathogens in the samples. Therefore, there is a need for an immediate treatment for reuse.

Keywords: coliform bacteria; microbial pollution; fecal contamination; water pollution; bacterial contamination.

Introduction

Regardless of an object's size, shape, or form, it cannot survive without water, which makes it essential to all biological and industrial activities. One of the biggest issues facing the world today is water pollution in all of its manifestations, which has an impact on different parts of the globe (Chaudhry et al., 2017; Some et al., 2021). As water has been exposed to pollution, its properties have deteriorated in many areas of the world. Water is considered polluted when the composition of its elements changes beyond the limited values issued by global health organizations (Alsarayreh et al., 2020). Indeed, the quality of water changes due to natural and human-induced factors such as climate change, geological processes, biological activity, human activity, and industrial applications (Al-Obaidi et al., 2017; Bhutiani et al., 2018; Essa et al., 2024). This makes this water a source of many pathogenic bacteria and fecal coliform bacteria, which are utilized as a sign of fecal pollution in water (Mohammad et al., 2024). The proliferation of some epidemics and diseases, such as typhoid, bacterial dysentery, and cholera, is further intensified when drinking water pipes become contaminated with sewage. The intake of contaminated water is associated with a rise in water-borne diseases and mortality rates globally (Al-Obaidi et al., 2017; Kılıç, 2020). Therefore, pollution is one of the main dangers that threatens all living organisms, especially humans. There must be no physical, chemical, or biological impurities in drinking water. The water must also be devoid of color, flavor, and odor (Al-Obaidi et al., 2017). The microbial contamination of the water of the Diyala River was investigated by Hassan et al. (2017), who indicated the presence of high levels of *Escherichia coli* bacteria. Also, Hadi (2023) assessed the water quality of the Diyala River by evaluating the physical and microbial parameters. The results indicated that the pH, EC, and TDS exceeded the permissible limit. Also, the water was classified as undesirable for drinking due to the existence of fecal bacteria (*Escherichia coli* and enterococci) in high proportions.

The utilization of bacteria as indicators of water quality serves to specify the presence of fecal contamination. As a result, it can be used to identify the root causes of the contamination, assess its level of severity, and choose the best course of action to eliminate it. Therefore, it is crucial to remember that the amount of indicator bacteria strongly correlates with the degree of fecal contamination, increasing the risk of water-borne illnesses (Sood et al., 2008; Mao et al., 2021). Referring to these principles, the current study attempts to analyse the state of pollution in the Diyala River system (Diyala Governorate, Iraq) by taking advantage of its cultured bacterial diversity and physicochemical factors. In turn, this would provide a comprehensive understanding of all aspects of pollution in the Diyala River system. Specifically, the current study would evaluate the appropriateness of its water for human consumption and aquatic life relying on measuring the water quality index (WQI) and comprehensive pollution index (CPI).

To identify the existence of fecal contamination, bacteria are used as water quality indicators. As a result, it can be used to identify the root causes of the contamination, assess its level of severity, and choose the best course of action to eliminate it. Thus, it is crucial to remember that the amount of indicator bacteria closely correlates with the degree of fecal contamination, increasing the risk of waterborne illnesses. Referring to these principles, the current study attempts to analyse the state of pollution in the Diyala River system (Diyala Governorate, Iraq) by studying its cultured bacterial diversity and physicochemical factors.

Material and methods

Eighteen samples were collected from different areas of Diyala Governorate. Sample collection began in winter (December 2023) and continued to summer (May 2024). The water samples were taken from well water, river water, filter water, and tap water from different areas. From Diyala Governorate, the water samples were collected from nine main sites with 4 replicates for each site. Table 1 shows the

description of the associated sites, while Figure 1 introduces a map of the studied area and the locations of water samples.

For this investigation, water samples were taken in triplicate at each station using screw-cap tubes that had been sterilized with radiation. 15 tubes were used to collect samples to isolate bacteria, and 50 mL tubes were provided by Tarson, India, to determine the most probable number (MPN) value. The water sample was collected in a polypropylene bottle with a capacity of 1 L. According to the guidelines provided by the American Public Health Association, all of the tubes and bottles were immediately transferred to a cooling pack after the collection of samples. Then, they were transported to the laboratory within a period of two to three hours for analysis (Malik et al., 2025).

Table 1
Depiction of sampling sites

Site	Description	Coordinates
S1	The Muqdadiya district, Shahrban district	33°57'25.8"N 44°55'14.5"E
S2	The Wajihya district, Abu Jisra district	33°55'02.9"N 44°48'54.5"E
S3	The village of Abu Khuraibish	33°55'23.5"N 44°49'04.4"E
S4	Al-Aswad village	33°50'32.2"N 44°31'42.3"E
S5	The Khuraisan River	33°37'51.1"N 44°41'04.4"E
S6	Al-Abara village northeast of Baquba	33°48'57.2"N 44°39'24.1"E
S7	Baladruz district	33°42'01.6"N 45°04'12.6"E
S8	Hadd Maziyad	33°48'17.4"N 44°44'10.5"E
S9	Al-Ghalibi in Baquba district	33°43'54.6"N 44°29'14.9"E



Fig. 1. The study area

The plate pour method mentioned in APHA (Kadhum et al., 2025) was utilized to calculate the total count of aerobic bacteria (TCAB). A series of dilutions was prepared from the water sample, withdrawing 1 mL from each dilution using a sterile glass pipette. It was placed in a sterile dish and then poured into the medium. The nutrient (15 mL) was cooled to a temperature of -45°C and was stirred clockwise and counterclockwise several times, and left to solidify. Then the dishes were placed upside down in the incubator at a temperature of 37°C for 24–48 hours according to the number of colonies forming bacteria units per ml in the water samples. The bacterial colonies were measured and expressed as \log_{10} CFU/mL, or colony forming units per milliliter.

The study of total coliforms (TC) and fecal coliforms (FC) was achieved via the membrane filtering approach, as elucidated by (Köster et al., 2003). The main concept of this approach is the filtration of a specific volume of water using specialized membranes. Afterward, the filter and the residual bacteria were transferred onto specialized media to enable bacterial proliferation. The medium was incubated with the filter for one to two days at 37°C , after which the colonies undergoing growth were counted. This technique stands out from other methods due to its quickness and ability to produce effects within 18–24 hours. The bacterial colonies were measured and reported logarithmically as \log_{10} colony-forming units per milliliter (\log_{10} CFU/mL).

The microbiological media used were obtained from Hi-media. The MPN test is a commonly utilized method for evaluating potable water quality by identifying total coliform bacteria within the water specimen. The use of this test is prevalent as a means of assessing water contamination. Oblinger & Koburger's (1975) method was employed to conduct the five-tube MPN test. In brief, 10 mL of MacConkey broth with the necessary concentration was generated. Each set of five tubes was then supplemented with 0.1, 1.0, and 10.0 mL of water samples. The mixture was then incubated at a temperature of 37°C for 48 hours. A positive result was observed when the color transitioned from purple to yellow.

The enriched samples obtained from positive MPN tubes were cultured by the standard techniques to determine the presence of *E. coli*, bacteria that cause urinary tract infections (UTI), *Salmonella* spp., *Shigella* spp., *Klebsiella pneumoniae*, *Enterobacter ludwigii*, and *Staphylococcus* spp. (Kumar et al., 2020; Mohammad et al., 2024). Following the acquisition of selective media from HI media Pvt. Ltd., the samples were inoculated on eosin methyl blue agar (EMB agar) and thiosulfate citrate bile salts. The experiment contained sucrose agar (TCBS agar), *Salmonella Shigella* agar (SS agar), *Aeromonas* selective agar supplemented with ampicillin, *Listeria* selective agar enhanced with *Listeria* supplement, and Baird Parker agar (Mohammad et al., 2025). The documentation of bacterial pathogens was accomplished by analyzing their morphological and biochemical characteristics, which were then confirmed using Bergey's manual of determinative bacteriology. The individual colony of each pathogen was chosen from the agar plate and subsequently applied to newly equipped nutrient agar slants. The slants were then preserved at a temperature of -20°C in trypticase soy broth, which contained a stock solution consisting of a mixture of thirty percent glycerol.

The World Health Organization, the US Environmental Protection Agency, and many other health institutions have paid attention to diseases resulting from water pollution and controlling them (WHO, 2021). Following these organizations, standards and determinants were set by the Iraqi Department of Standardization and Quality Control (Song et al., 2021). The recognized Iraqi standards for the presence of bacteria stipulate that there should be no coliform bacteria in drinking water. In contrast, the total number should not exceed 10 cells/100 mL (Chowdhary et al., 2020; Othman et al., 2020).

This study involved the analysis of water samples, where the physicochemical parameters were studied. The pH was evaluated using a pH meter from Eutech. As temperature can affect the abundance of bacteria, water temperature at the sampling sites was measured using a mercury thermometer. Turbidity and electrical conductivity (EC) were identified using a Turbidity meter and a conductivity device, respectively. The gravimetric technique was utilized to determine the total dissolved solids (TDS). Biological oxygen demand (BOD) and dissolved oxygen (DO) were appraised using the Winkler calibration approach, for five days of incubation in dark conditions and 20°C at aerobic conditions (for BOD samples). In addition, magnesium (Mg^{+2}) and calcium (Ca^{+2}) were measured using the titration approach. Nitrate (NO_3^{-1}) was also determined using a titrimetric method, and chloride (Cl^{-1}) levels were determined using Mohr's method (Kaur et al., 2022).

The recommended values of all the physicochemical indicators are listed in Table 2 based on the regulations of the WHO. The water quality index was utilized in this study to assess the overall water quality by using physico-chemical and biological characteristics for a variety of applications. By the computed results, water samples were classified into a number of categories. The lower the water quality index score, the higher the level of water pollution and the greater the health risk (Pham, 2020). Standard ranges of water quality index based on the CPCB criteria, as described by Sharma et al. (2020): 0–25 – excellent, 25–50 – good, 51–75 – poor, 76–100 – very poor, and above 100 – unsuitable for drinking.

A comprehensive pollution index (CPI) was utilized in this study to investigate the comprehensive pollution load of aquatic environments. The calculation is determined based on the equation provided below (Mishra et al., 2016).

Table 2
CPI, water quality cataloging and uses (Pramanik et al., 2020)

CPI	Status	Use
0.00–0.20	very clean	Good and suitable for consumption drinking purpose
0.21–0.40	sub clean	Good and suitable for usage in the home environments
0.41–0.80	qualified	Some contaminants have been identified, their concentrations are within the acceptable range, allowing them to be utilized for irrigation and industrial purposes
0.81–1.00	basically qualified	The concentrations of some pollutants are higher than the standard, which indicates that the water is of low quality and can only be utilized for irrigation purposes
1.01–2.00	polluted	The concentrations of certain contaminants are higher than the standard, which means that the water is of very low quality and can only be utilized for irrigation in limited quantities
≥2.01	seriously polluted	These pollutants have concentrations that are higher than the standard, which means that they are of an extremely contaminated quality and require treatment before they can be used

The data was elucidated as the mean ± standard deviation (SD). The data was subjected to analysis using the SPSS software provided by SPSS Inc. (version 16.0). All experiments were in triplicate (Awad et al., 2025).

Results

The analysis of the total count of aerobic bacteria (TCAB) is based on the pouring plate method; this method counts only live cells. The results are presented in Figure 1a, which indicates that TCAB ranges between 8.90 ± 0.12 to 6.89 ± 0.01 in winter. However, the TCAB values increase in summer and range between 10.70 to 9.12. In winter, the highest value of TCAB of 8.90 was registered in Al-Abara Village, northeast of Baquba District (S6), if compared to the lowest value of 6.89 that was registered in the village of Abu Khuraybish (S3). In summer, the highest value of TCAB was registered in the Wajihya District (S2) of 10.7, and the lowest value of 9.12 was registered in the village of Abu Khuraybish (S3).

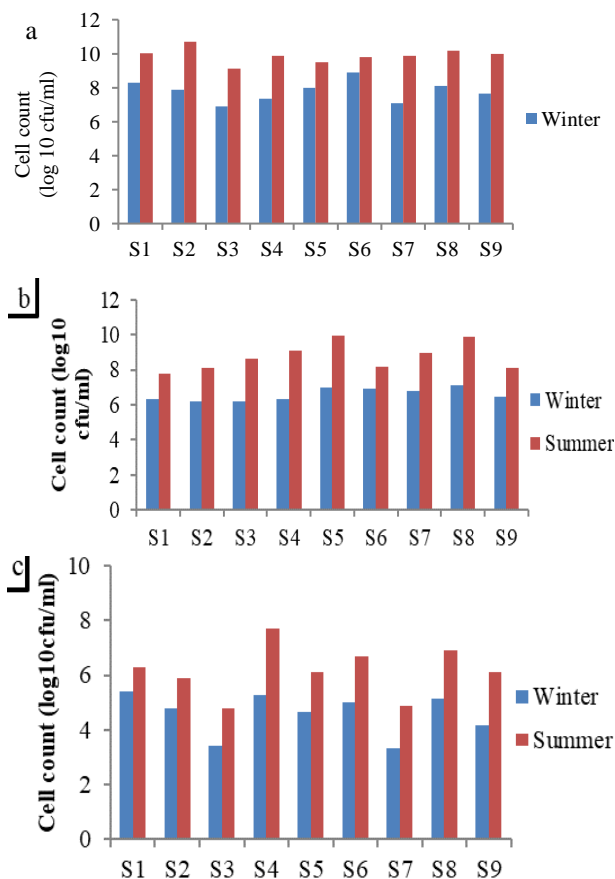


Fig. 2. Bacterial, cell count (log₁₀ CFU/mL) of different locations (a) total count of aerobic bacteria (TCAB); b – TC and c – FC in different seasons

The levels of total coliforms (TC) and fecal coliforms (FC) in water samples are exhibited in Figures 2b and 2c. The samples ascertain-

ned significant contamination by coliform bacteria, suggesting the existence of waterborne pathogens in the water. The highest log₁₀ values were recorded for TC and FC, 9.89 ± 0.01 in the Khuraisan River (S5) and 7.70 ± 0.03 in Al-Aswad Village (S4), respectively. Specifically, these values were registered in the summer during the period of study. More importantly, the results of Figures 2b and 2c indicate that the water from the Diyala River is contaminated with coliform organisms in all sites.

Table 3 shows the number of isolates of water pathogen organisms in the tested water samples of different sites along the Dayala River. The results indicate that the highest relative abundance of *E. coli*, is reached in the summer of 31%, in comparison to 24% in the winter.

The findings shown in the Table 3 indicate that *Salmonella* spp., *Shigella* spp., *Klebsiella pneumoniae*, *Enterobacter ludwigii*, and *Staphylococcus* spp. were found during both seasons. Six primary emerging pathogens were found when the water samples were taken during the summer and winter. In this aspect, the maximum relative abundances of bacteria that cause disease, including *Salmonella* spp., *Shigella* spp., *Klebsiella pneumoniae*, *Enterobacter ludwigii*, and *Staphylococcus* spp., were determined in the summer months to be 31.1%, 14.1%, 12.4%, 13.6%, and 11.2%, respectively.

During the winter season, the highest levels of *Salmonella* spp., *Shigella* spp., *Klebsiella pneumoniae*, *Enterobacter ludwigii*, and *Staphylococcus* spp. were found to be 31.9%, 15.1%, 12.9%, 6.1%, 14.8%, and 11.5%, respectively (Table 4). Although some of the pathogens detected in this study were less abundant, they still pose a threat if consumed water is not properly treated.

Table 3
Number of isolates of water pathogens at different sites in the summer season

Site of samples	<i>E. coli</i>	<i>Salmonella</i> spp.	<i>Shigella</i> spp.	<i>K. pneumoniae</i>	<i>E. ludwigii</i>	<i>Staphylococcus</i> spp.
S1	31	13	20	25	15	10
S2	25	12	18	21	11	9
S3	27	10	15	22	12	6
S4	20	9	12	18	10	4
S5	23	11	15	29	7	5
S6	28	8	10	21	6	8
S7	22	13	8	25	9	6
S8	25	9	8	18	11	5
S9	26	10	9	16	14	6

Table 4
Number of isolates of water pathogens at different sites in the winter season

Site of samples	<i>E. coli</i>	<i>Salmonella</i> spp.	<i>Shigella</i> spp.	<i>K. pneumoniae</i>	<i>E. ludwigii</i>	<i>Staphylococcus</i> spp.
S1	24	11	17	22	12	8
S2	22	10	15	19	8	7
S3	23	8	13	17	9	4
S4	18	8	11	15	6	3
S5	21	10	14	24	4	4
S6	24	6	9	19	2	7
S7	19	12	7	23	5	5
S8	23	7	6	15	7	3
S9	24	8	7	13	9	4

The physicochemical parameters of the water samples gathered from different sites along the Dayala River are displayed in Tables 5 and 6. The results indicate that the pH levels at various sites ranged between 7.11 to 9.01 in the winter season and 7.7 to 9.9 in the summer season. This variation can be related to changes in the levels of inorganic and organic contaminants. The highest pH values of 9.01 and 8.86 are registered in winter in Muqadadiya district, Shahrban district (S1) and Wajihya district, Abu Jisra district (S2), respectively. Also, 9.90, 9.22, and 9.55 are the highest pH values registered in summer in S1, S2, and Baladruz district (S7), respectively. More importantly, the pH values of summer are greater than the permissible limits of (6.5–8.5) that were set by the WHO in 2011.

It is observed that the solubility of oxygen in water decreases as the temperature increases. In this study, the water temperature in the winter ranges between 20.5 to 27.0 °C, and the highest values exceeded the permissible limit in S1 and S2, where the temperature reaches 27 °C. In the summer season, the water temperature for all the studied sites exceeded the permissible limits of 25 °C.

Turbidity refers to the state of suspended solids in the water, encompassing various substances such as waste materials, sewage, and plankton. In the current study, it is observed that the turbidity exhibited high values during the summer season compared to the winter season. Specifically, the highest value of 7.8 NTU was recorded in S1, while the lowest value of 4.1 NTU was recorded in Al-Aswad village (S4). In other words, all the readings exceeded the acceptable limit of the WHO. The elevated turbidity levels noted in the current analysis can be attributed to the presence of sediments and sewage loads originating from the adjacent regions. On top of this, the elevated turbidity levels render the water unfit for consumption, bathing, and the optimal survival of aquatic organisms.

The electrical conductivity (EC) obtained in this study ranges between 1111 to 2220 µs/cm in winter and 1123 to 2068 µs/cm in summer (Tables 5 and 6). Specifically, these results are greater than the acceptable limit of the WHO of 300 µs/cm. This is additional supportive evidence of the poor water quality of collected water samples from different sites.

Biological oxygen demand (BOD) is also employed to estimate the quantity of biochemically degradable organic matter found in the water samples. The laboratory analyses show that the BOD value fluctuates in winter between 6.33 mg/L in Al-Abara village northeast of Baquba (S6) and 13 mg/L in S1. In summer, the BOD varies between 14.27 mg/L in S7 and 23.75 mg/L in S5. The rise in BOD levels can be ascribed to elevated microbial activity during the decomposition of organic materials in the presence of oxygen.

The nitrate content in the current study ranges between 1.12 mg/L in S1 and 3.21 mg/L in S2 in the winter season and ranges between 5.98 mg/L in Hadd Mazyad (S8) to 5.71 mg/L in (S2) in the summer season. Thus, the nitrate concentration is within the permissible threshold of 50 mg/L as specified by the WHO.

The hardness of water is quantified based on the concentration of calcium (Ca) and magnesium (Mg) present. Referring to the WHO (2011), the acceptable thresholds of Ca and Mg levels in water must not surpass 500 mg/L. Tables 5 and 6 present that the concentrations of Ca and Mg are below the recommended thresholds.

Chlorides and total dissolved solids (TDS) of the water samples in the winter season ranged between 8.22 mg/L in S1 to 23 mg/L in Al-Ghalibi in Baquba district (S9) and 124 mg/L in the village of Abu Khuraibish (S3) to 390 mg/L in Baladruz district (S7), respectively. However, in the summer season, chlorides and TDS ranged between 9.21 mg/L in S1 to 24.45 mg/L in S4 and 188 mg/L in S3 to 410 mg/L in S7, respectively.

Table 5

Physicochemical characteristics and water quality analysis of water samples gathered from various sites in the winter season

Winter	S1	S2	S3	S4	S5	S6	S7	S8	S9	Standard value of WHO
pH	8.86	9.01	7.15	7.5	7.6	7.3	7.31	7.11	7.78	6.5–8.5
Temperature, °C	27	25	20.5	22.5	22.5	22.5	27	25	25	25
Turbidity, NTU	6.2	5.1	4.4	3.9	4.9	6.2	5.1	4.09	4.78	5
EC, µs/cm	1357	1088	2220	1823	1425	1447	1285	1111	1210	300
DO, mg/L	4.41	3.53	3.0	5.4	5.6	5.5	4.11	4.24	3.88	4–6
BOD, mg/L	13.0	9.8	10.5	10.5	9.75	6.33	9.87	8.23	7.98	5
NO ₃ ⁻¹ , mg/L	1.12	3.21	1.40	1.28	1.00	1.07	1.20	2.02	2.76	50
Ca ²⁺ , mg/L	48.2	35.4	37.1	35.4	40.2	46.6	47.7	45.3	38.8	75
Mg ²⁺ , mg/L	45.12	30.17	33.12	33.90	37.18	44.19	44.11	42.77	35.01	50
Cl ⁻¹ , mg/L	8.22	19.01	18.17	22.44	14.14	19.90	17.11	16.60	23.0	250
TDS	243	239	124	323	289	225	390	234	344	500

Table 6

Physicochemical characteristics and water quality analysis of water samples gathered from various sites in the summer season

Summer	S1	S2	S3	S4	S5	S6	S7	S8	S9	Standard value of WHO
pH	9.9	9.22	7.9	8.1	7.9	7.7	9.55	8.01	8.72	6.5–8.5
Temperature, °C	30	33	37	31	30	32.5	39	35	40	25
Turbidity, NTU	7.8	5.8	4.2	4.1	5.6	6.7	5.8	5.49	4.99	5
EC, µs/cm	1457	1123	2235	2068	1711	1575	1525	1421	1460	300
DO, mg/L	5.8	5.13	4.5	5.4	5.1	4.5	5.02	4.24	4.21	4–6
BOD, mg/L	18.0	16.8	19.5	20.5	23.75	18.33	14.27	22.23	14.91	5
NO ₃ ⁻¹ , mg/L	2.88	5.71	3.40	2.28	1.33	1.77	1.24	5.98	4.76	50
Ca ²⁺ , mg/L	48.2	35.4	37.1	35.4	40.2	46.6	47.7	45.3	38.8	75
Mg ²⁺ , mg/L	45.12	30.17	33.12	33.90	37.18	44.19	44.11	42.77	35.01	50
Cl ⁻¹ , mg/L	9.21	23.01	19.1	24.45	18.14	23.90	18.11	19.60	25.0	250
TDS	343	236	188	403	299	325	410	234	444	500

Calculating the water quality index (WQI) offers a thorough evaluation of the overall quality of water. The weights presented in Table 7 indicate the importance of the parameter and its influence on water quality. Determining the water quality index is based on the CPCB criteria. The primary objective of this assessment is to measure the overall quality of the river water, encompassing its appropriateness for consumption and household purposes, as well as its influence on the overall welfare of aquatic creatures.

The results indicate the WQI, which is determined by analysing the physio-chemical and biological characteristics of water samples

collected throughout the period study. The categorization of water quality into distinct levels was derived from VEA 2011. According to the WQI evaluation, the river water from all sites falls into categories D and E, which indicates that it is not fit for drinking. The findings of Figure 4 specify that the water of the Diyala River is inappropriate for home or irrigation usage due to its significant public health hazards if it has not been subjected to the appropriate treatment and disinfection.

The CPI calculation is performed to deliver a thorough understanding of the total pollution burden in the river. According to the CPI values, it can be stated that the water quality is significantly com-

promised in the majority of places (Fig. 4). It is possible to attribute the high levels of CPI to the high values of BOD, TDS, and turbidity measured in the water.

Table 7
Unit weights of chemical properties

Parameter	Weight (Wn)
pH	3
Temperature, °C	2
Turbidity, NTU	2
EC, µs/cm	3
DO, mg/L	3
BOD, mg/L	3
NO ₃ ⁻¹ , mg/L	4
Ca ⁺² , mg/L	2
Mg ⁺² , mg/L	1
Cl ⁻¹ , mg/L	1
TDS	3

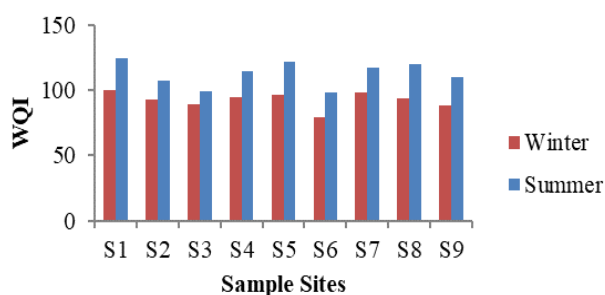


Fig. 3. Water quality index of the considered sites along the Diyala river using CPCB standards

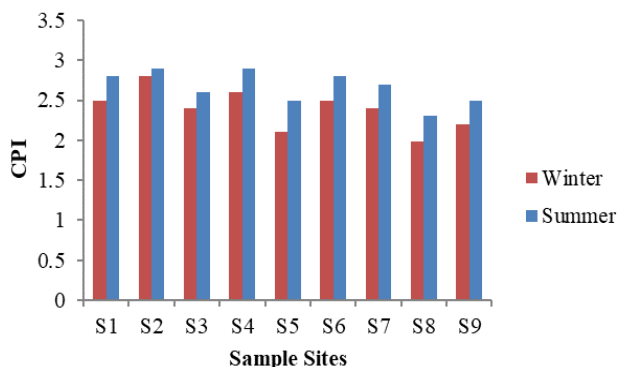


Fig. 4. CPI of the considered sites along the Diyala River utilising CPCB standards

Discussion

The appearance of these types of bacteria and pollutants, isolated and diagnosed in samples of the governorate's drinking water, gives an indication of unsafe drinking water. Microbial variation at sites is attributed to changes in temperature, availability of nutrients, and extent of contamination. Undoubtedly, the investigation of total coliform, thermotolerant coliform, and *E. coli* in the treated waters is important, as an increase of these indicators would signify insufficient treatment. Coliform bacteria are commonly known as "indicator organisms" because they serve as an indication of the existence of fecal pollution and enteric pathogens within the water system. The elevated concentration of coliform bacteria is caused by the densely populated region surrounding the Diyala River, as well as the contamination of water by domestic and sewage effluent. Thus, it is fair to admit that the sewage water is not properly treated before returning it to the riverbed. Furthermore, it should be noted that the regions covered in the current study are predominantly cultivated, with a possibility of disposing of deceased animals in the riverbed, which might cause the contamination of river water with these bacterial strains. These results are in agreement with what was stated by Attia et al. (2023) and Purgar

et al. (2023), who considered that the presence of these bacteria is an indicator of the contamination of drinking water, making it unfit for consumption. All the samples of Attia et al. (2023) and Purgar et al. (2023) were determined to be unsuitable for drinking due to the presence of industrial waste, which promotes the growth and survival of bacteria.

Referring to the World Health Organization (WHO), *Escherichia coli* cannot be present in any water suitable for human consumption. Furthermore, *E. coli* serves as a surrogate bacterium to evaluate water quality. It is a signal of the existence of fecal contamination. An examination of the samples was performed to determine the presence of *E. coli*. The relative abundance of the bacteria was determined during the summer and winter seasons. Thus, it can be said that the prevalence of *E. coli* in the Diyala River is affected by seasonal variation. Undoubtedly, emerging pathogens have become a significant cause for concern in terms of public health. *Vibrio cholera*, *Klebsiella pneumoniae*, *Enterobacter ludwigii*, and *Staphylococcus aureus* are examples of emerging pathogens (Pramanik et al., 2020).

The high pH level of water can indicate the presence of chemical or heavy metal contamination. Thus, high pH values in the water are a clear sign of pollution and make it unfit for consumption. Climate change and disposal of hot industrial effluent into water supplies can cause temperature fluctuations at various locations. The second physicochemical property is the temperature of water, which is one of the most essential aspects of an aquatic system because it directly influences the levels of DO, as well as the chemical and biological activities that occur in the water (Bhatia et al. 2018).

Dissolved oxygen (DO) is another important metric that can be used to assess the quality of water and plays a vital role in the sustenance of aquatic life. Moreover, dissolved oxygen has a significant impact on many water parameters, such as biological elements and visual properties such as taste, clarity, and odor. According to a study of water samples, dissolved oxygen levels were 4–6 mg/L in both seasons, which is below the limit set by the World Health Organization (Saari et al., 2018).

Nitrate is the primary nitrogen source for aquatic plants. Nevertheless, excessive nitrate levels can be detrimental and result in eutrophication in aquatic environments. Specifically, an increase in the nitrate concentration in water resources can be an indicator of serious water pollution. Nitrate contamination often occurs due to the presence of fertilizers in irrigation water (Craswell, 2021).

Conclusions

The current study intended to appraise the water quality of the Dayala River via inspecting the microbiological, physical, and chemical indicators of water samples collected from various regions along the river. The results revealed that the summer season is more polluted than the winter season. Levels of BOD, COD, nitrate, phosphate, pesticides, and MPN index for *E. coli* and fecal coliforms were relatively higher during the summer than in the winter. The variation of these properties is attributed to the mixing of raw/semi-processed sewage from urban areas, open defecation, agricultural runoff, and industrial effluent. WQIs and CPI values were also measured, and the results indicated poor water quality from upstream to final sampling sites.

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