



Original Research Paper

Seasonal Limnological Assessment of the Kho River in Bijnor, Western Uttar Pradesh (India): Evaluating River Health through Physicochemical Parameters and Pollution Indicators

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ABSTRACT

Rivers are vital freshwater resources, but industrialization, urbanization, and agricultural runoff increasingly threaten their quality. This study assessed seasonal variations in 16 physicochemical parameters of the non-perennial Kho River in Bijnor district, Western Uttar Pradesh, and evaluated water quality against Bureau of Indian Standards (BIS) and World Health Organization (WHO) guidelines. Monthly samples were collected from four sites, Benipur Kopa, Sherkot Kho Beraj, Sherkot Atmali, and Dhampur, from February 2023 to January 2024. Parameters including temperature, pH, turbidity, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), hardness, chloride, alkalinity, calcium, magnesium, iron, fluoride, nitrate, and sulphate were analyzed using standard American Public Health Association (APHA) methods. Turbidity and nitrate peaked during the monsoon at 508.1 NTU and 13.50 mg/L, respectively, likely due to runoff and soil erosion, while summer showed elevated BOD (6.3 mg/L) and COD (21.69 mg/L), indicating increased organic loading. Overall, pH ranged from 5.73 to 7.85, TDS from 88 to 288 mg/L, and DO from 6.8 to 8.11 mg/L. Most parameters remained within BIS and WHO limits, indicating generally acceptable water quality. However, seasonal deterioration underscores the need for continuous monitoring and effective pollution-control measures to protect the ecological health of the Kho River.

Keywords: Kho River; Limnological Assessment; Water Quality; Physicochemical Parameters; Seasonal Variation

INTRODUCTION

Water is one of the most important natural resources and is essential for the survival of all living organisms. Freshwater resources, particularly rivers, play an important role in maintaining aquatic ecosystems and supporting human activities [1]. Rivers provide water for domestic, agricultural, industrial, and recreational purposes and have historically contributed to the development of human settlements and economies [2]. However, rapid urbanization, industrialization, population growth, and agricultural activities have placed increasing pressure on river ecosystems, leading to deterioration of water quality in many regions [3]. In India, surface-water resources such as rivers, reservoirs, and dams are particularly important for meeting agricultural and domestic water requirements [4,5]. Rivers can broadly be classified as perennial and non-perennial based on their flow characteristics. Perennial rivers maintain flow throughout the year, whereas non-perennial rivers show substantial seasonal variations in discharge and may partially or completely dry during periods of low rainfall [6].

Seasonal changes in flow, rainfall, temperature, and runoff can influence the physical, chemical, and

biological characteristics of river water. Physicochemical parameters such as temperature, pH, turbidity, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), hardness, major ions, and nutrients are therefore useful indicators of water quality. DO is particularly important for aquatic life and is influenced by temperature, photosynthetic activity, and the decomposition of organic matter [7]. Regular assessment of these parameters is essential for identifying changes in water quality and preventing further degradation of aquatic resources [8].

The Kho River is a non-perennial river that flows through Pauri Garhwal, Kotdwar, and Bijnor before joining the Ramganga River. In Bijnor district of Western Uttar Pradesh, its flow and water characteristics vary considerably with seasonal conditions and surrounding land-use activities. However, information on the seasonal water quality of the Kho River in this region remains limited. Therefore, the present study assessed the seasonal variation in selected physicochemical parameters of the Kho River using monthly samples collected from four sampling sites over a one-year period.

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The study also examined pollution-related variations in key parameters, particularly turbidity, nitrate, BOD, COD, and DO, to provide an overall assessment of the river's physicochemical condition and identify periods of increased environmental stress.

MATERIALS AND METHODS

Study Area and Site Selection

The present study was conducted along the Kho River in Bijnor district, Western Uttar Pradesh, India. The Kho River flows through Pauri Garhwal, Kotdwar, and Bijnor before joining the Ramganga River. Four strategically selected sampling sites, namely Benipur Kopa, Sherkot Kho Beraj, Sherkot Atmali, and Dhampur, were selected to assess variations in water quality under different geographical and anthropogenic influences. Sherkot is located at an elevation of approximately 260 m (850 ft) above sea level, at 29.3228° N latitude and 78.5746° E longitude. The geographical coordinates of all sampling sites are presented in Table 1, while the spatial distribution of the study area is shown in Figure 1.

Sample Collection

Water samples were collected on a monthly basis from February 2023 to January 2024. To maintain consistency, sampling was carried out between 7:30 AM and 9:00 AM at all sites. Grab water samples were drawn from approximately 30 cm below the surface using clean plastic jerry cans. The containers were submerged, opened below the water surface to fill, and sealed underwater to prevent air bubble entrapment and avoid floating debris such as leaves or twigs. Temperature and other field-sensitive parameters were measured immediately on-site, while the remaining samples were safely transported to the laboratory for detailed physicochemical analysis.

Table 1. Geographic Coordinates of the Sampling Sites along the Kho River, Bijnor District, Western Uttar Pradesh, India

S. No	Sampling Site	Geographic Coordinates
1	Benipur Kopa	29.4360° N, 78.4982° E
2	Sherkot Kho Beraj	29.2100° N, 78.3500° E
3	Sherkot Atmali	29.3228° N, 78.5746° E
4	Dhampur	29.3080° N, 78.5033° E



Figure 1. Map showing the Kho River and the four selected sampling sites

Physicochemical Analysis and Data Processing

The collected water samples were analyzed for selected physical, chemical, and organic parameters following standard procedures described in the Limnology Workbook [9] and the methods of the American Public Health Association (APHA) [10]. The parameters analyzed included water temperature, pH, turbidity, TDS, DO, BOD, COD, total hardness, total alkalinity, chloride, calcium, magnesium, nitrate, sulphate, iron, and fluoride. Field-sensitive parameters, including temperature and pH, were measured on-site, whereas the remaining parameters were determined in the laboratory using standard analytical procedures. The analytical data were systematically tabulated and cross-checked for consistency. Unreliable or anomalous observations identified during quality checking were excluded from further analysis, and the validated data were used for graphical representation and subsequent assessment. The physicochemical parameters, analytical methods, and corresponding units of measurement are presented in Table 2.

Table 2. Physicochemical Parameters, Analytical Methods, and Units Used for Assessment of Kho River Water Quality

S. No	Parameter	Analytical Method/Instrument	Unit of Measurement
1	Temperature	Water thermometer	°C
2	pH	pH meter	pH
3	Turbidity	Turbidimeter	NTU
4	TDS	TDS meter	mg/L
5	Chloride	Argentometric	mg/L

S. No.	Parameter	Analytical Method/Instrument	Unit of Measurement
		titration	
6	Total alkalinity	Titration method	mg/L
7	Total hardness	EDTA titration	mg/L
8	Calcium	Argentometric titration	mg/L
9	Magnesium	Calculation/EDTA titration	mg/L
10	Nitrate	Spectrophotometric method	mg/L
11	Sulphate	Turbidimetric method	mg/L
12	Iron	Spectrophotometric method	mg/L
13	Fluoride	Ion-selective electrode/ion analyzer	mg/L
14	Biochemical oxygen demand	Incubation method	mg/L
15	Dissolved oxygen	Winkler's method	mg/L
16	Chemical oxygen demand	Titrimetric method	mg/L

RESULTS AND DISCUSSION

The monthly and seasonal variations in the physicochemical parameters of the Kho River water recorded across the study period are presented in Table 3 and discussed below.

Temperature

Temperature is an important environmental parameter that significantly influences the physical, chemical, and biological processes of aquatic systems [11]. It affects various natural processes in water bodies as well as the physiological functions and metabolic activities of aquatic organisms. In

the present investigation, water temperature ranged from 16.2°C to 39.1°C. Monthly observations revealed that water temperature increased from May to August, mainly due to higher solar radiation intensity and elevated ambient temperatures, whereas the lowest temperatures were recorded from December to January due to lower ambient temperatures during winter. The monthly variation in water temperature is depicted in Figure 2A.

pH

pH indicates the concentration of hydrogen ions and is an important parameter for assessing the acid-base status and overall quality of water. It influences various chemical and biological processes in aquatic systems and is associated with parameters such as DO, alkalinity, and nutrient availability [12]. As reported by Bouslah et al. (2017), pH is an important indicator of water pollution, as changes in pH can influence the toxicity, solubility, and biological effects of several contaminants [13]. In the present study, pH values ranged from 5.73 to 7.85, with the highest value recorded in February and the lowest in September. The lower pH observed during September may be associated with increased runoff and the decomposition of organic matter during the monsoon season. The monthly fluctuations in pH across the sampling period are shown in Figure 2B. According to Dewangan et al. (2023), a pH range of 6.7–8.4 is generally suitable for aquatic organisms, whereas values below 4.0 and above 9.6 may be harmful to aquatic life [14]. Thus, the observed pH values were generally within a range suitable for aquatic ecosystems, although the minimum value indicates slight acidic conditions that warrant monitoring.

Turbidity

Turbidity is an important water-quality parameter that affects light penetration and consequently influences photosynthesis and biological processes at different trophic levels. It is primarily caused by suspended and colloidal particles in water, which scatter and absorb light [15]. During the study period, monthly turbidity values ranged from 2.91 to 508.1 NTU. The lowest monthly average turbidity was recorded in June (2.91 NTU), whereas the highest was observed in August (508.1 NTU). The markedly higher turbidity during the monsoon season may be attributed to increased rainfall and surface runoff in the mountainous Kotdwar region, where the Kho River originates, resulting in greater soil erosion and the transport of suspended sediments into the river. The temporal variation in turbidity levels is illustrated in Figure 2C.

Total Dissolved Solids (TDS)

TDS represent the concentration of dissolved inorganic salts, minerals, and small amounts of dissolved organic matter present in water. TDS can

influence the taste, palatability, and overall suitability of water and may also reflect changes in the ionic composition of aquatic systems [16]. In the present study, TDS values ranged from 88.0 to 288.0 mg/L, with comparatively higher values observed in September. Variations in TDS may be associated with the influx of dissolved minerals and salts through surface runoff, soil leaching, and other anthropogenic inputs. TDS is often considered an indicator of changes in water chemistry and may increase with the addition of dissolved substances from natural and anthropogenic sources [17]. The observed TDS concentrations were within the permissible limits specified for drinking water, indicating a relatively low dissolved-solids load in the study area. However, TDS alone cannot be used to establish the potability of river water, as microbiological and other water-quality parameters must also be considered. The monthly variation in TDS concentration is presented in Figure 2D.

Total Alkalinity (TA)

Total alkalinity ranged from 75.0 to 210.3 mg/L during the study period. The highest value was recorded in April (200.0 mg/L), whereas the lowest value was observed in December (75.0 mg/L), indicating considerable seasonal variation. The higher alkalinity observed during the warmer months may be associated with increased bicarbonate and carbonate concentrations resulting from enhanced mineral dissolution and changes in biological activity. Similar seasonal variations in alkalinity have been reported by Kumar and Thomas (2019), who attributed higher alkalinity during summer to increased photosynthetic activity [18]. The monthly variations in the physicochemical parameters of the Kho River are presented in Table 3, while the monthly variation in alkalinity is shown in Figure 2F.

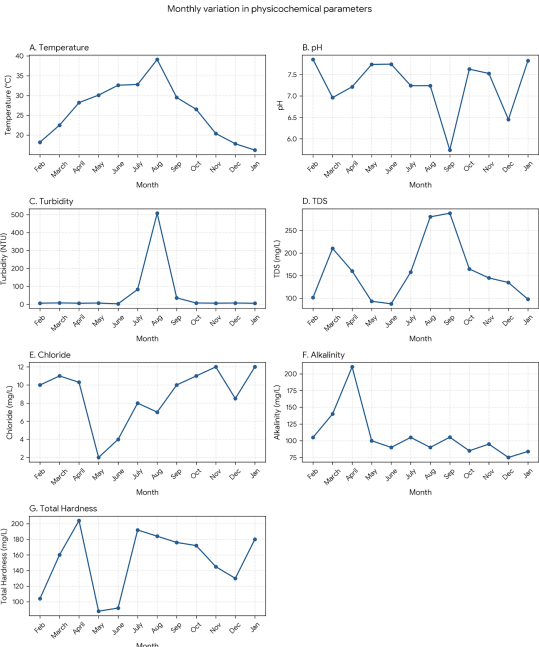


Figure 2. Monthly variations in physicochemical parameters (Temperature, pH, Turbidity, TDS, Chloride, Total Alkalinity, and Total Hardness) of the Kho River.

Table 3. Monthly Variations in Physicochemical Parameters of the Kho River (February 2023 to January 2024)

Pa	M	A										
ra	F	a	p	M	J	J	A	S	O	N	D	J
me	e	r	r	a	u	u	u	e	c	o	e	a
ter	b	c	i	y	n	l	g	p	t	v	c	n
s		h	l		e	y						
Te												
m	1	2	2	3	3	3	3	2	2	2	1	1
pe	8	2	8	0	2	2	9	9	6	0	7	6
rat	.	.	.	.	.	.	.	.	.	.	.	.
ur	2	5	2	1	6	8	1	5	5	4	8	2
e												
		7	6	7	7	7	7	5	7	7	6	7
	.	.	.	.	.	.	.	.	.	.	.	.
P	8	9	2	7	7	2	2	7	6	5	4	8
H	5	6	1	3	4	4	3	3	2	2	5	2
	0	1	4	5	1	1	9	7	5	5	2	2
Tu	6	7	5	6	2	8	5	3	7	6	6	5

rbi	.	.	.	.	.	2	0	5	.	.	.	.
dit	1	9	9	9	9	.	8	.	1	2	9	8
y	1	3	3	3	1	9	.	8	7	5	5	9
	8	5	5			8	1	8			2	0
	1	2	1	9		1	2	2	1	1	1	
T	0	1	6	3	8	5	8	8	6	4	3	9
DS	2	0	0	.	8	8	0	8	5	5	5	8
	.	.	.	4	.	.	.	.	.	.	.	.
	0	3	3	4	0	0	0	0	0	0	0	0
	9											
Ch	.	1	1	1	3			1	1	1		1
lor	9	1	0	.	.	8	7		0	1	2	8
ide	9	.	.	9	9	.	.	.	.	.	.	2
	6	0	3	9	9	0	0	.	.	.	5	.
						0	0	0	0	0		0
	1	1	2	1		1		1				
Al	0	4	1	0	9	0	9	0	8	9	7	8
ka	5	0	0	0	0	5	0	5	5	5	5	4
lin	.	.	.	.	.	.	.	.	.	.	.	.
ity	0	0	3	0	0	0	0	3	0	0	0	0
	1	1	2			1	1	1	1	1	1	1
T.	0	6	0	8	9	9	8	7	7	4	3	8
Ha	4	0	4	8	2	2	4	6	2	5	0	0
rd	.	.	.	.	.	.	.	.	.	.	.	.
ne	0	0	0	0	0	0	0	0	0	0	0	0
ss	0	0	0			0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
Fl	.	.	.	.	.	.	.	.	.	.	.	.
uo	4	6	5	2	1	2	2	2	1	2	5	3
rid	0	5	5	8	8	2	0	1	3	5	0	4
e	0	0	0	0	0	0	0	0	0	0	0	0
	.	.	.	.	.	.	.	.	.	.	.	.
Ir	0	4	3	7	8	1	5	4	8	4	6	3
on	3	5	6	1	6	8	5	8	8	0	4	5
	0	6	4	1	1	1	7	1	1	8	9	8
Ni	.	.	.	.	.	.	.	1	3	.	.	.
tra	9	0	0	5	6	2	2	.	.	6	6	3
te												

	8	5	5	6	1	6	5	5	5	5	5	4
								1	0			
Su	4	3	2	1	1	1	2	3	3	3	1	1
lp	0	0	8	0	0	4	4	2	8	0	4	5
ha	.	.	.	.	.	.	.	.	.	.	.	.
te	6	1	6	1	0	2	1	2	2	2	3	2
	4	8	5	1	6	8	8	8	4	5	5	5
M	7	2	2			2	2	2	2	2	1	2
ag	.	4	0	3	4	6	3	5	6	6	8	1
ne	7	.	.	.	.	.	.	.	.	.	.	.
siu	7	4	2	8	3	2	3	2	4	4	3	3
m	6	5	5	8	7	4	2	7	2	8	6	4
	2	3	2	2	3	3	3	2	3	3	2	2
Ca	9	2	8	9	2	4	5	9	6	4	4	8
lci	.	.	.	.	.	.	.	.	.	.	.	.
u	3	1	4	0	2	1	8	3	1	5	1	3
m	0	8	4	1	4	8	1	0	4	0	0	2
	8											
D	.	7	7	7	7	7	6	7	7	7	7	8
O	1	.	.	.	.	.	.	.	.	.	.	.
	1	9	6	4	6	2	8	0	1	3	4	2
	2											
B	.	2	3	4	6	5	5	5	4	3	2	2
O	0	.	.	.	.	.	.	.	.	.	.	.
D	3	1	5	6	3	8	4	1	8	2	8	5
C	5	7	1	1	2	1		1	1	1	1	4
O	.	.	0	5	1	1		6	8	7	5	.
D	2	5	.	.	6	7		.	.	.	.	7
			0	0	9	4		5	0	0	0	8
												4

Total Hardness (TH)

Total hardness is an important water-quality parameter primarily associated with the presence of dissolved calcium and magnesium ions. It is mainly contributed by their bicarbonates, carbonates, sulphates, and chlorides and influences the suitability of water for drinking, domestic, and industrial purposes. During the study period, total

hardness values ranged from 88.0 to 204.0 mg/L. The lowest monthly average value was recorded in May (88.0 mg/L), whereas the highest was observed in April (204.0 mg/L). The observed seasonal variation may be related to changes in the concentration of dissolved minerals and variations in runoff and groundwater contributions to the river. A similar pattern was reported by Bhutiani et al. (2017) [6]. The monthly variation in total hardness is shown in Figure 2G.

Dissolved Oxygen (DO)

Dissolved oxygen (DO) is an important parameter for assessing water quality and provides an indication of the physical and biological processes occurring within an aquatic system [19]. The major sources of DO in water are atmospheric diffusion and photosynthetic activity. Adequate DO is essential for the survival of aquatic organisms and supports the microbial decomposition of organic matter [20]. In the present investigation, DO concentrations ranged from 6.8 to 8.11 mg/L. The highest DO concentration was recorded in February, whereas the lowest was observed in August. The lower DO concentration during August may be associated with higher water temperature and increased microbial activity during the monsoon season. The monthly temporal variation in DO is presented in Figure 3A.

Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) represents the amount of DO required by microorganisms to decompose biodegradable organic matter in water and is an important indicator of organic pollution [21]. In the present study, BOD values ranged from 2.03 to 6.3 mg/L. The lowest BOD value was recorded in February, whereas the highest was observed in June. The higher BOD during summer may be associated with increased microbial activity and the greater availability of biodegradable organic matter under favorable environmental conditions. The monthly variation in BOD levels during the study period is illustrated in Figure 3B.

Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is an important water-quality parameter that measures the amount of oxygen required to chemically oxidize oxidizable organic and inorganic substances present in water. It is widely used as an indicator of organic pollution and the overall oxygen-demanding load of a water body [22]. In the present investigation, COD concentrations ranged from 4.78 to 21.69 mg/L. The highest COD concentration was recorded in June, whereas the lowest was observed in January. The higher COD levels during June may be associated with increased organic matter and other oxidizable substances in the river, potentially resulting from enhanced biological activity and surface runoff during the warmer months. The temporal variation in COD concentrations is depicted in Figure 3C.

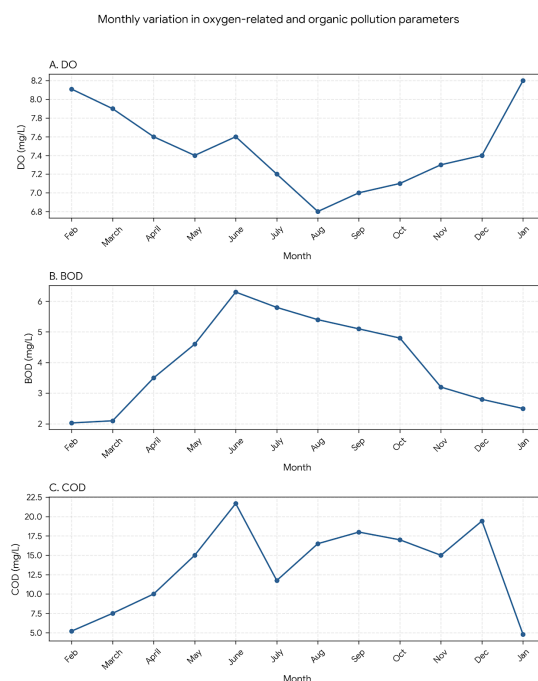


Figure 3. Monthly variations in oxygen-related and organic pollution parameters (DO, BOD, and COD) of the Kho River.

Chloride (Cl⁻)

Chloride is a major inorganic anion commonly present in natural waters and is associated with the dissolution of minerals, atmospheric deposition, and anthropogenic inputs. Although chloride is not generally harmful at concentrations commonly found in freshwater, elevated levels can impart a salty taste and may indicate increased mineral dissolution or pollution from domestic, agricultural, or other sources [23]. In the present investigation, chloride concentrations ranged from 1.99 to 12.0 mg/L. The highest chloride concentration was recorded in January, whereas the lowest was observed in May. The observed seasonal variation may be associated with changes in runoff, evaporation, and the contribution of dissolved salts to the river. The seasonal trend in chloride concentration is shown in Figure 2E.

Fluoride (F⁻)

Fluoride occurs naturally in water mainly through the dissolution of fluoride-containing minerals. At optimal concentrations, fluoride contributes to dental health, whereas prolonged exposure to elevated concentrations may increase the risk of dental and skeletal fluorosis [24]. In the present study, fluoride concentrations ranged from 0.13 to 0.65 mg/L. The highest concentration was recorded in March, whereas the lowest was observed in October. The observed variation may be associated with differences in mineral dissolution, groundwater contribution, and seasonal hydrological conditions. The monthly variation in fluoride concentration is illustrated in Figure 4A.

Nitrate (NO₃⁻)

Nitrate is an important inorganic form of nitrogen and an essential nutrient required for plant growth. However, excessive nitrate concentrations in aquatic systems can promote the growth of algae and aquatic macrophytes, contributing to nutrient enrichment and eutrophication [25]. In the present investigation, nitrate concentrations ranged from 0.98 to 13.50 mg/L. The observed variation may be associated with agricultural runoff, surface drainage, and the decomposition of nitrogen-containing organic matter entering the river. The temporal variation in nitrate concentration during the study period is presented in Figure 4C.

Sulphate (SO_4^{2-})

Sulphate is one of the major anions naturally present in surface and groundwater and originates primarily from the weathering of sulphate-containing minerals and other natural and anthropogenic sources. Elevated sulphate concentrations in drinking water may impart a bitter taste and, at sufficiently high levels, can produce a laxative effect [26]. In the present investigation, sulphate concentrations ranged from 10.6 to 40.64 mg/L. The highest concentration was recorded in February, whereas the lowest was observed in June. The observed seasonal variation may be associated with changes in mineral dissolution, surface runoff, and the dilution effect of rainfall. The monthly variation in sulphate concentration is depicted in Figure 4D.

Magnesium (Mg)

Magnesium is an important naturally occurring cation in freshwater and is primarily derived from the weathering and dissolution of magnesium-containing minerals [27]. During the study period, magnesium concentrations ranged from 3.88 to 26.48 mg/L. The lowest monthly average concentration was recorded in May (3.88 mg/L), whereas the highest was observed in November (26.48 mg/L). The observed seasonal variation may be associated with differences in mineral dissolution, surface runoff, and the contribution of groundwater to the river. Similar seasonal trends in magnesium concentrations have been reported by Bhutiani et al. (2018) [6].

Calcium (Ca)

Calcium is an important major cation in natural waters and primarily enters aquatic systems through the weathering and dissolution of calcium-containing minerals such as limestone, gypsum, and dolomite [28]. During the study period, calcium concentrations ranged from 24.10 to 36.14 mg/L. The lowest monthly average concentration was recorded in December (24.10 mg/L), whereas the highest was observed in October (36.14 mg/L). The observed variation may be associated with seasonal changes in mineral dissolution, runoff, and groundwater contribution to the river. A broadly similar seasonal pattern was reported by Bhutiani et al. (2016) [6]. The monthly variation in Magnesium

and Calcium concentrations is presented in Figure 4E and Figure 4F, respectively.

Iron (Fe)

Iron is an essential trace element naturally present in river water, primarily entering aquatic systems through the weathering of rocks and soils. However, elevated iron concentrations can affect water quality by imparting an undesirable taste, causing staining of laundry and plumbing fixtures, and promoting the growth of iron-oxidizing bacteria [29]. In the present study, iron concentrations ranged from 0.30 to 0.88 mg/L. The highest concentration was recorded in October, whereas the lowest was observed in February. The observed seasonal variation may be associated with differences in runoff, mineral weathering, and the availability of iron from surrounding soils and sediments. The monthly variation in iron concentration is shown in Figure 4B.

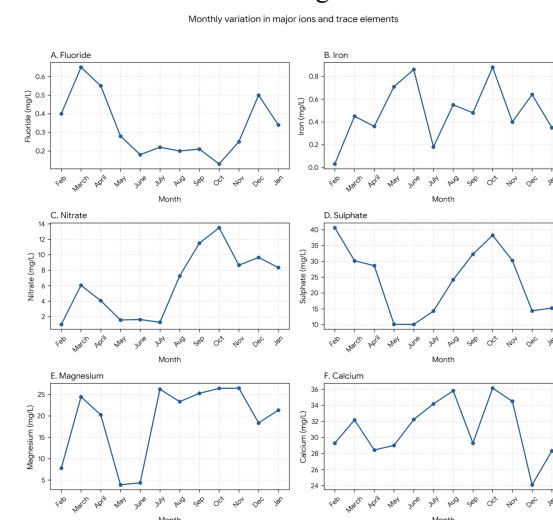


Figure 4. Monthly variations in major ions and trace elements (Fluoride, Iron, Nitrate, Sulphate, Magnesium, and Calcium) of the Kho River.

Overall Water Quality Assessment Using Standardized Parameters

To provide an integrated overview of seasonal variation in water quality, a standardized monthly heatmap based on Z-scores was generated for all physicochemical parameters across the twelve months of the study period (Figure 5). Standardization placed parameters with different units and numerical ranges on a common scale, allowing seasonal patterns and deviations from their respective means to be compared effectively. The heatmap highlights months with relatively higher or lower parameter values and provides an integrated visualization of the seasonal variation in the physicochemical characteristics of the Kho River.

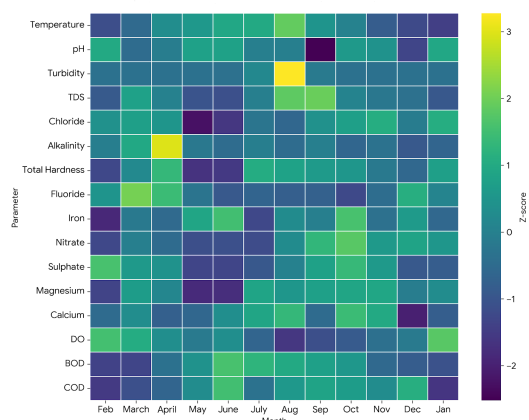


Figure 5. Heatmap depicting the standardized monthly variation (Z-score) of water quality parameters of the Kho River.

CONCLUSION

The one-year limnological assessment of the Kho River revealed clear seasonal variations in water quality, reflecting the combined influence of climatic conditions, runoff, and changes in river flow. Most physicochemical parameters remained within the permissible limits, indicating generally acceptable water quality during the study period. However, marked increases in turbidity and nitrate during the monsoon, particularly the peak turbidity of 508.1 NTU in August, indicate increased sediment and nutrient inputs associated with rainfall and surface runoff. Elevated BOD and COD during the warmer months, reaching 6.3 and 21.69 mg/L, respectively, suggest increased organic loading and microbial activity. In contrast, DO concentrations remained relatively high (6.8–8.11 mg/L), indicating adequate oxygen availability for aquatic life. The observed seasonal fluctuations, particularly in turbidity, nutrients, and oxygen-demanding parameters, highlight periods of increased environmental stress in this non-perennial river. Regular seasonal monitoring, control of runoff and other pollutant inputs, and appropriate conservation measures are therefore recommended to maintain the ecological health and sustainable use of the Kho River.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

CONSENT AND ETHICAL APPROVAL

This study involved the collection and analysis of environmental water samples and did not involve human participants, animals, or identifiable personal data. Therefore, informed consent and ethical approval were not required.

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