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Impact of Seasonal variations in Physico-chemical and Bacteriological Characteristics of Mandakini River water at multiple locations of Chitrakoot

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ABSTRACT
The Mandakini River, a sacred water body flowing through Chitrakoot in the Bundelkhand region of India, faces increasing pollution due to mass bathing during religious events, untreated urban wastewater, and agricultural runoff. This study assessed seasonal variations in the physicochemical and bacteriological parameters of the river at eight selected sites during pre-monsoon (July 2024), post-monsoon (September 2024), and winter (January 2025). Key parameters including pH, turbidity, total dissolved solids (TDS), dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD), and microbial counts (Total Coliform and Fecal Coliform) were analyzed using standard APHA methods. Results revealed significant seasonal and spatial variations, with downstream stations (Ram-Ghat and Bharat-Ghat) showing higher pollution loads. Pre-monsoon samples exhibited poor water quality due to reduced flow and concentrated pollutants, while post-monsoon rains temporarily improved physicochemical parameters but not microbial contamination. The findings underline the urgent need for effective wastewater treatment, pollution control measures, and regular monitoring to safeguard the water quality and public health.

INTRODUCTION:
River in India regarded as sacred from times immemorial. A dip in a holy river is believed to wash all sins being obsessed by such faith people take bath in these rivers **(Tripathi et al., 2016)**. The River Mandakini is one of the holy rivers of India, which flows across the Chitrakoot area of the eastern part of Bundelkhand region. Its water is shared by the Indian states of Uttar Pradesh and Madhya Pradesh. Sati Anusuiya is a perennial reach of Mandakini River where a large number of small and big springs feed to the river. It originates in the Western upland of Majhgawan N lock in district Satna MP and travels 39km, before reaching Sati Anusuiya Ashram site. In these 35 km, it is seasonal stream flowing only in monsoon. At Sati Anusuiya Ashram a number of springs from nearby hillocks enter into the river and convert it into perennial one with the minimum flow recorded as 1.2 m^3/sec **(Gupta et al., 2014).**

Many people visit here with spiritual emotions on the occasion of Amawasya (no moon day), Purnima (full moon day), Ram Navami, Deepawali (festival of lights), etc. and take holy baths in the river. Thus, Mandakini receives large quantity of pollution due to the mass bathing **(Kannan, 1995).** Besides the above, the discharge of wastewater from nearby urban settlements also deteriorates the water quality of river Mandakini.

The River serves as a crucial source of water for domestic, agricultural, and industrial purposes. However, the increasing water demand coupled with reduced supply due to low rainfall and monsoon failures has severely stressed the river ecosystem. Wastewater drains continue to enter the river, polluting it beyond its natural self-purification

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capacity. As a result, many water borne diseases such as typhoid, hepatitis, jaundice, cholera, diarrhea dysentery have become wide spread any they account for 2/3 of illness in India **(Sabhapandit et al., 2011)**.

This study, therefore, aims to evaluate the seasonal changes in physico-chemical and bacteriological parameters of the Mandakini River, providing insights into the extent of anthropogenic impacts and guiding future water quality management strategies.

MATERIAL AND METHODS:

Sample collection:
For the purpose of study, river water samples were collected from eight different stations: Sati-Ansuiya (S1), Mohkmgarh (S2), Sphatik-Shila (S3), Arogyadham (S4), 2 km south; Jankikund (S5), Pramod-Van (S6), Bharat-Ghat (S7), and Ram-Ghat (S8) during the pre-monsoon, post-monsoon, and winter seasons in July, September 2024, and January 2025, respectively.

Samples were aseptically collected in sterile brown bottles (1000 ml capacity), transported to laboratory. The containers were labeled with masking tape containing samples number, date and time and were kept in the laboratory refrigerator at 4ºC prior the analysis. The water samples for bacteriological analysis were collected in sterilized neutral glass bottles of 120ml capacity with stoppers and kept in the refrigerator pending the analysis **(Manila and Njoko, 2009)**.

Physicochemical Analyses:
Parameters assessed included temperature (T), transparency, pH, total dissolved solids (TDS), electrical conductivity (EC), Turbidity, Alkalinity, Total Hardness (TH), Calcium, Magnesium. Chloride and salinity. Dissolved Oxygen (DO) was determined by azide modification method as described by APHA **(APHA, 2005).** The biological oxygen demand (BOD), chemical oxygen demands (COD) were further analyzed. Additionally five-day Biological Oxygen Demand (BOD) was estimated **(APHA, 1998).**

Bacteriological Analyses:
Spread plate method was used for detection and enumeration of Total Viable Bacterial Counts (TVBCs) at 37°C and 22°C. Samples were examined for enumeration of classical indicators including; Total Coliform (TC), and Fecal Coliform (FC) using a membrane filtration technique **(APHA, 2005).** Briefly, water sample (100 ml) was filtered through a gridded sterile cellulose-nitrate membrane filter (0.45 µm pore size, 47 mm diameter, Sartorius type filters) under partial vacuum (Millipore, Befrid, UK) **(Leong et al., 2018)**.

RESULTS:

Water Testing Report of Mandakini River, Chitrakoot of Pre-Monsoon Session (July 2024)

S. No.	Parameter	S1	S2	S3	S4	S5	S6	S7	S8
1.	**Ambient Temp (°C)**	33.0	35.0	34.2	34.1	35.0	35.0	35.0	35.2
2.	**Water Temp (°C)**	29.2	29.2	29.2	31.0	31.0	31.2	31.0	30.0
3.	**Colour**	Turbid	Turbid	Turbid	Turbid	Turbid	Turbid	Turbid	Turbid
4.	**Odor**	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless
5.	**Taste**	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
6.	**Turbidity**	45	35	45	40	35	34	45	50
7.	**Transparency**	Transparent	Transparent	Transparent	Transparent	Transparent	Transparent	Transparent	Transparent
8.	**Flow (m³/s)**	2.0	2.8	2.0	2.0	1.8	1.5	1.5	1.0
9.	**pH**	7.42	7.51	7.0	7.6	7.7	7.2	7.8	7.9
10.	**Alkalinity (mg/l)**	152	148	169	168	170	175	180	198
11.	**Total Hardness (mg/l)**	105	138	208	210	208	209	210	206
12.	**Calcium (mg/l)**	58.8	50.4	75.6	52.5	65.1	58.8	50.4	60.9
13.	**Magnesium (mg/l)**	11.27	21.37	32.10	38.43	34.86	36.64	38.94	35.40
14.	**Chloride (mg/l)**	35.45	28.36	35.45	35.45	21.27	14.18	28.36	28.36
15.	**DO (mg/l)**	4.2	4.4	5.2	4.7	4.7	5.0	5.4	5.7
16.	**BOD (mg/l)**	1.9	2.4	2.1	2.0	2.2	2.1	2.2	1.8
17.	**COD (mg/l)**	62	63	60	62	61	62.1	63	66
18.	**TDS (mg/l)**	596	870	875	1012	625	622	605	645
19.	**Salinity (ppt)**	0.2 ppt	0.2 ppt	0.1 ppt	0.3 ppt	0.1 ppt	0.1 ppt	0.1 ppt	0.1 ppt

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20.	**EC (ms/cm)**	150	212	210	220	134.7	135.7	137.6	139.0

Water Testing Report of Mandakini River, Chitrakoot Post-Monsoon Session (September 2024)

S. No.	Parameter	S1	S2	S3	S4	S5	S6	S7	S8
1.	**Ambient Temp. (°C)**	29.2	29.2	30.2	29.2	28.6	28.6	28.6	29.2
2.	**Water Temp. (°C)**	27.2	27.2	29.0	29.0	28.0	28.0	28.0	27.0
3.	**Colour**	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
4.	**Odor**	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless
5.	**Taste**	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
6.	**Turbidity**	4	4	5	6	6	6	8	8
7.	**Transparency**	Transparent	Transparent	Transparent	Transparent	Transparent	Transparent	Transparent	Transparent
8.	**Flow (m³/s)**	1.0	1.8	1.0	1.0	2.0	1.0	1.2	1.0
9.	**pH**	7.60	7.89	8.70	7.61	7.86	7.96	7.69	7.65
10.	**Alkalinity (mg/l)**	402	388	392	396	496	604	514	492
11.	**Total Hardness (mg/l)**	252	264	252	284	310	362	352	284
12.	**Calcium (mg/l)**	88.2	81.9	100.8	106	107.1	157.5	126	152
13.	**Magnesium (mg/l)**	39.96	44.43	36.89	43.43	49.53	49.97	55.14	32.04
14.	**Chloride (mg/l)**	28.36	28.36	35.45	35.45	35.45	28.36	35.45	42.54
15.	**DO (mg/l)**	7.2	6.8	7.8	8.0	9.2	7.2	6.8	7.2
16.	**BOD (mg/l)**	1.2	1.2	1.9	2.0	3.2	1.2	0.91	1.5
17.	**COD (mg/l)**	60	61	63	64.2	62.1	63	63	63
18.	**TDS (mg/l)**	202	194	173.3	201	232	232	241	248
19.	**Salinity (ppt)**	0.0	0.3	0.5	0.3	0.0	0.0	0.3	0.4
20.	**EC (ms/cm)**	434	424	378	436	506	509	527	541

Water Testing Report of Mandakini River, Chitrakoot of Winter Session (January 2025)

S. No.	Parameter	S1	S2	S3	S4	S5	S6	S7	S8
1.	**Ambient temp. (°C)**	8.0	8.06	10.0	10.02	10.3	10.3	10.2	11.0
2.	**Water temp. (°C)**	15.02	15.3	15.3	16.2	16.0	17.0	17.2	17.4
3.	**Colour**	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
4.	**Odor**	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless
5.	**Taste**	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
6.	**Turbidity**	3	2	5	4	4	5	7	7
7.	**Transparency**	Transparent	Transparent	Transparent	Transparent	Transparent	Transparent	Transparent	Transparent
8.	**Flow m³/s**	1.9	2.0	1.9	1.8	1.4	1.3	1.4	1.4
9.	**pH**	7.00	6.56	6.54	6.57	7.90	7.21	7.31	7.9
10.	**Alkalinity mg/l**	230	242	240	202	245	235	256	258
11.	**Total Hardness mg/l**	121	138	144	165	156	160	184	180
12.	**Calcium mg/l**	109	102.9	100.8	105	107.1	111.3	115.5	117.6
13.	**Magnesium mg/l**	2.92	8.565	10.54	14.64	11.93	11.88	16.71	15.22
14.	**Chloride mg/l**	21.27	35.47	21.27	35.47	35.47	35.47	42.54	42.54
15.	**DO mg/l**	6.9	6.5	7.0	7.1	5.1	5.6	5.4	5.5
16.	**BOD mg/l**	1.8	1.6	2.2	2.5	1.9	1.5	1.6	1.4
17.	**COD mg/l**	61.3	62.3	62.1	62	64.3	62.1	65.0	66.1
18.	**TDS mg/l**	240	254	245	265	255	295	302	303

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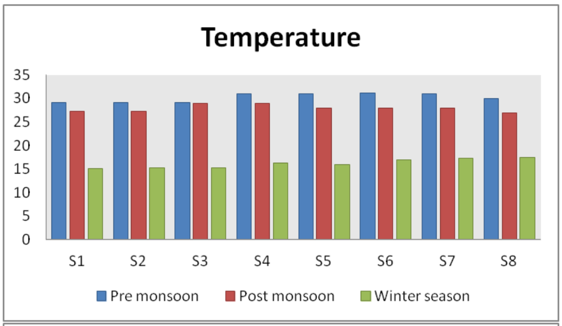
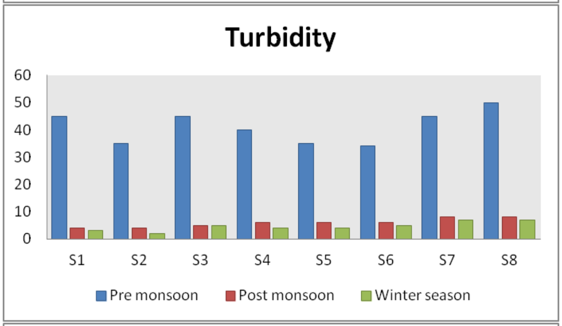
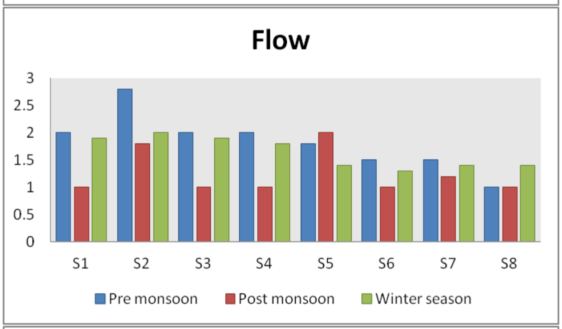
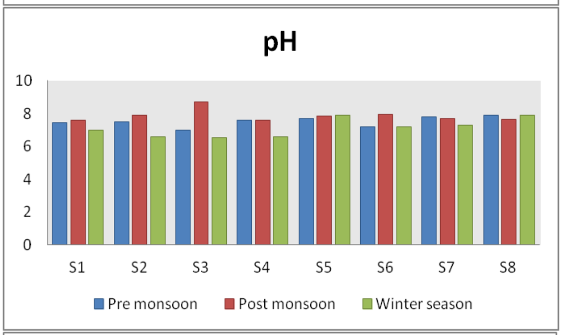
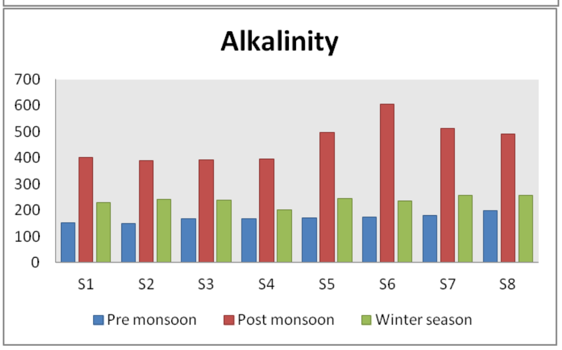
19.	**Salinity**	0.0	0.0	0.1	0.0	0.2	0.3	0.3	0.1
20.	**EC**	605	610	655	595	540	520	515	520

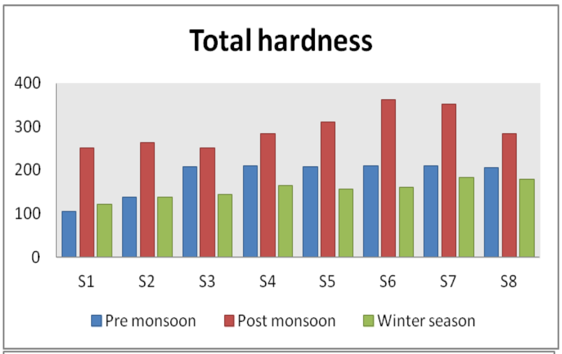


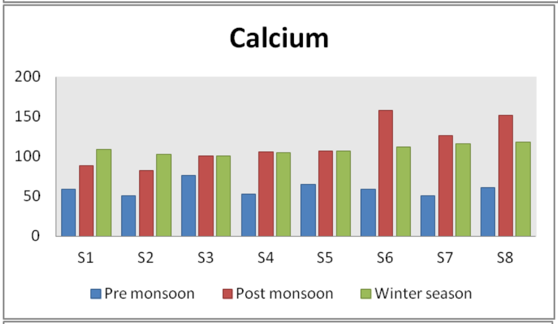


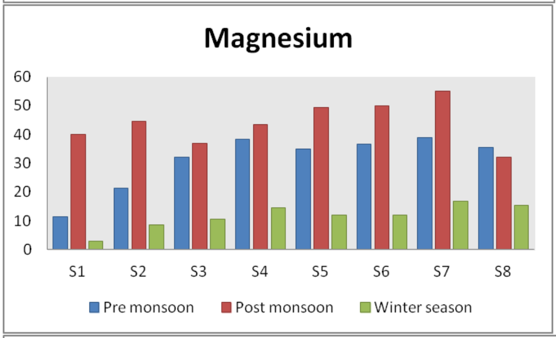


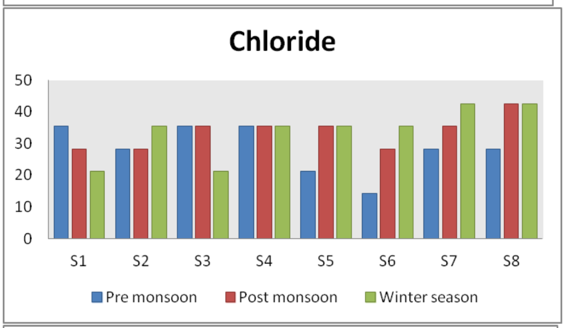


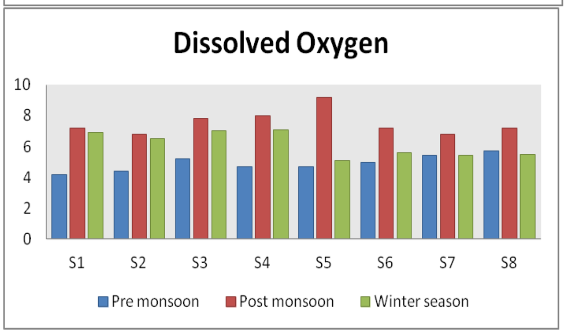












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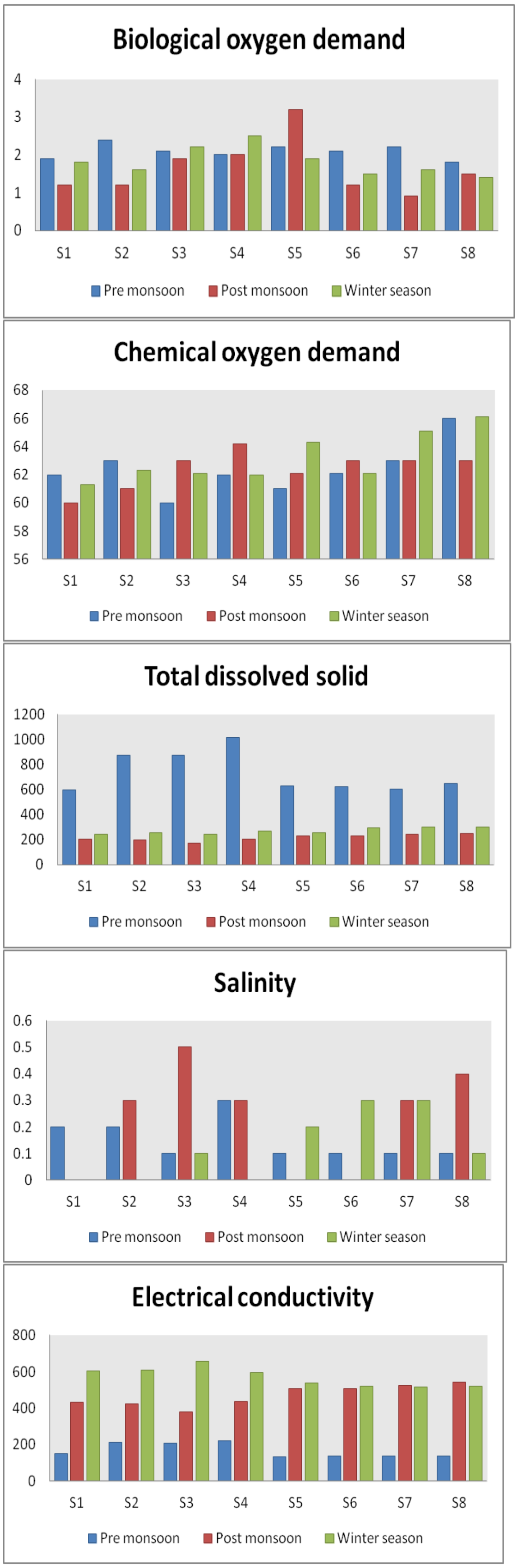


Graph 1 Comparative graph of physicochemical parameters during pre and post monsoon session and winter season

Assessment of Biological parameters: Total coliform (TC) and Fecal coliform FC) MPN/100ml in river Mandakini water in Pre, Post, and Winter Monsoon Period 2024-25

Table 1 Microbial analysis in Pre-Monsoon (July)

S. No.	Parameter	S1	S2	S3	S4	S5	S6	S7	S8
1	Total Coliform (MPN/100ml)	4	8	155	172	185	200	402	440
2	Fecal Coliform (MPN/100ml)	1	1	100	105	185	150	375	395

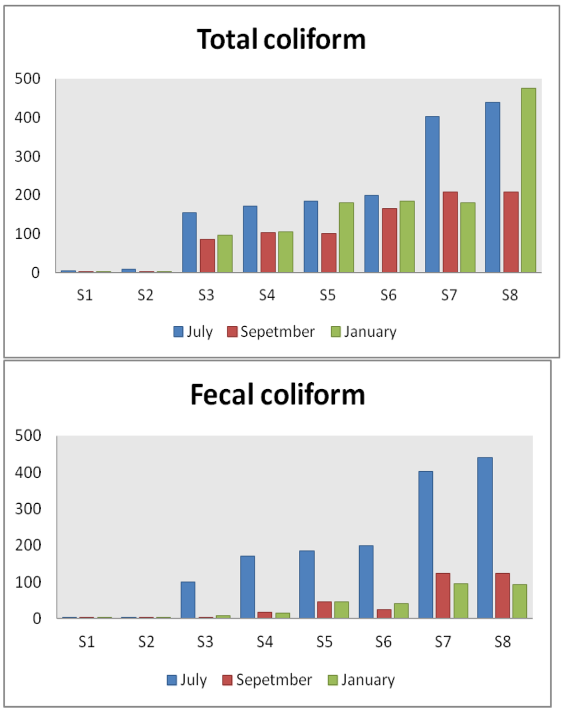
Table 2 Microbial analysis in Post-Monsoon (September)

S. No.	Parameter	S1	S2	S3	S4	S5	S6	S7	S8
1	Total Coliform (MPN/100ml)	2	1	85	102	101	165	207	209
2	Fecal Coliform (MPN/100ml)	0.1	0.1	0.1	18	45	25	125	123

Table 3 Microbial analysis in Winter–Monsoon (January)

S. No.	Parameter	S1	S2	S3	S4	S5	S6	S7	S8
1	Total Coliform (MPN/100ml)	3	3	96	105	180	185	180	476
2	Fecal Coliform (MPN/100ml)	0.3	0.5	9	14	45	42	95	92

Note: - MPN (Most Probable Number)/100ml



Graph 2 Comparative graph of Total coliform (TC) and Fecal coliform FC) during pre and post monsoon session and winter season

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DISCUSSION:

The present study evaluated the seasonal variation in the physicochemical and microbiological characteristics of the Mandakini River at eight selected stations (S1–S8) during pre-monsoon, post-monsoon, and winter-monsoon periods in 2024–2025.

The water temperature ranged between 15.02°C (S1, winter-monsoon) and 31.2°C (S6, pre-monsoon). According to APHA, temperature affects the solubility of oxygen and the metabolic activities of aquatic organisms. The pre-monsoon temperatures were relatively high, promoting microbial activity and organic decomposition, which may have contributed to the observed lower dissolved oxygen (DO) levels at some stations **(Rajendiran et al., 2023)**.

Turbidity levels were highest during pre-monsoon, peaking at 50 NTU (S8), well above APHA's recommended limit of 5 NTU for drinking water. Post-monsoon and winter-monsoon values declined significantly (minimum of 2 NTU at S2 in winter), likely due to dilution from monsoon rains and reduced suspended solids. High turbidity during pre-monsoon indicates significant surface runoff and anthropogenic discharges.

The pH values across all seasons ranged from 6.54 (S3, winter-monsoon) to 8.70 (S3, post-monsoon), remaining largely within APHA's acceptable range of 6.5–8.5, except for slight alkalinity at S3 post-monsoon. Fluctuations suggest influences of organic matter decomposition, agricultural runoff, and sewage inflow.

Alkalinity values showed seasonal variation, ranging from 148 mg/L (S2, pre-monsoon) to 604 mg/L (S6, post-monsoon). While no strict APHA limit exists for alkalinity, values above 500 mg/L (observed at S6 post-monsoon) can affect taste and buffering capacity, indicating possible input of bicarbonates from agricultural runoff and soil erosion **(Mazhar and Ahmad, 2020).**

Total hardness varied from 105 mg/L (S1, pre-monsoon) to 362 mg/L (S6, post-monsoon). APHA considers water with hardness >300 mg/L as "hard." Post-monsoon and winter-monsoon seasons showed elevated hardness at downstream stations (S6–S8), suggesting mineral leaching and urban wastewater contribution.

DO levels were lowest during pre-monsoon at 4.2 mg/L (S1) and highest post-monsoon at 9.2 mg/L (S5). APHA recommends DO ≥5 mg/L for aquatic life. Pre-monsoon values at several stations (S1, S2, S4) approached or fell below this threshold, indicating organic pollution and oxygen depletion due to increased microbial activity and reduced river flow **(Eriksen et al., 2022)**.

BOD ranged from 0.91 mg/L (S7, post-monsoon) to 3.2 mg/L (S5, post-monsoon). APHA recommends BOD ≤3 mg/L for drinking water. Slightly elevated BOD at midstream and downstream stations indicates organic pollution, likely from untreated sewage and bathing activities.

COD levels across all stations and seasons (60–66 mg/L) exceeded APHA's drinking water guideline (<10 mg/L). While still far below effluent discharge standards (≤250–500 mg/L), these values highlight the presence of oxidizable organic and inorganic pollutants in the river **(Lv et al., 2024)**.

TDS levels showed wide seasonal variation: highest in pre-monsoon (1012 mg/L at S4) and lowest in post-monsoon (173.3 mg/L at S3). APHA suggests ≤500 mg/L as desirable and ≤1000 mg/L as the maximum permissible limit. Pre-monsoon TDS at S4 exceeded this limit, reflecting concentrated pollutants due to reduced flow and high evaporation.

EC values ranged from 134.7 µS/cm (S5, pre-monsoon) to 541 µS/cm (S8, post-monsoon). While within APHA's acceptable limits (≤750 µS/cm), slightly higher values downstream suggest accumulation of ionic species from urban and agricultural sources.

In the pre-monsoon session, microbial contamination was highest, with TC and FC reaching 440 MPN/100 mL and 395 MPN/100 mL at Ram Ghat (S8), respectively. This is likely due to reduced river flow, direct sewage discharge, and mass bathing activities. The post-monsoon session showed a decrease in contamination, attributed to dilution from rainfall, though downstream stations like Bharat Ghat (S7) and Ram Ghat (S8) still showed high TC (209 MPN/100 mL) and FC (123 MPN/100 mL). In the winter-monsoon session, levels slightly increased again, particularly at downstream sites, suggesting pollutant accumulation due to reduced flow. Upstream stations (Sati Anusuiya - S1, Mohkmgarh - S2) consistently recorded lower counts, while downstream stations (S7, S8) showed the highest contamination throughout, reflecting anthropogenic pressure from urban settlements and religious activities.

CONCLUSION:

This study indicates that while the Mandakini River exhibits seasonal variation in water quality, several key parameters, particularly turbidity, TDS, COD, and microbial contamination, frequently exceed

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APHA permissible limits. Pre-monsoon water quality was poorest due to reduced flow and concentrated pollutants, while post-monsoon rains temporarily improved physicochemical parameters but failed to reduce microbial loads.

Downstream stations like Bharat Ghat (S7) and Ram Ghat (S8) consistently showed the highest pollution levels, reflecting cumulative impacts of domestic sewage, religious activities, and agricultural runoff. Upstream sites such as Sati Anusuiya (S1) and Mohkmgarh (S2) demonstrated comparatively better water quality, though occasional deviations from standards were noted.

Persistent fecal contamination across all seasons renders the river water unfit for direct human consumption without treatment and poses serious public health risks. There is an urgent need for implementing sewage treatment plants, regulating industrial and agricultural discharges, and increasing public awareness to safeguard water quality. Regular monitoring and effective pollution control measures are essential to restore and maintain the ecological and cultural integrity of the Mandakini River.

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