Research Article

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Impact of Industrial Wastewaters on the Physicochemical Characteristics of Chambal River at Nagda, M. P., India

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• Pollution load (TDS
BOD
COD
Hardness) rises 2–5× in Winter/Summer compared to Monsoon
• DO consistently drops outside Monsoon showing oxygen stress
• Chloride & Sulphate spike in Summer at Stn3–Stn5
indicating industrial/agricultural discharge.
• Hardness ratios are extreme (up to 4.75×) suggesting heavy mineralization in Summer.

ABSTRACT

The study investigated the impact of effluents from chemical and textile industries on the physicochemical characteristics of the Chambal River over a one-year period. Water samples were collected quarterly across three seasons from five designated stations along the river, selected based on proximity to major industrial discharge points. Stations 2, 3, and 4, which received direct effluent inputs, exhibited slight increases in pH, BOD, and COD values. Statistical analysis using the t-test revealed significant differences in turbidity, TDS, TSS, electrical conductivity, DO, chloride, sulphate, and hardness among the sampling stations. In contrast, the upstream (Station 1) and downstream (Station 5) reference sites recorded comparatively lower values for these parameters. Seasonal variation had minimal influence on most parameters, except for chloride, sulphate, and TDS, which showed significant differences across sampling periods. The findings highlight the urgent need for remediation programs to mitigate the deteriorating water quality in affected sections of the river.

INTRODUCTION

Freshwater ecosystems are among the most valuable natural resources because they support drinking water supplies, agriculture, fisheries, industrial development, and aquatic biodiversity. Rapid industrialization and urbanization, however, have resulted in substantial deterioration of river water quality worldwide through the discharge of untreated or partially treated industrial effluents. Textile, chemical, pharmaceutical, pulp and paper, and fertilizer industries contribute large quantities of organic matter, suspended solids, nutrients, salts, heavy metals, and other toxic contaminants that significantly alter the physicochemical characteristics of receiving water bodies. Continuous discharge of industrial wastewater reduces dissolved oxygen, increases biochemical oxygen demand (BOD) and chemical oxygen demand (COD), and disrupts the ecological balance of aquatic ecosystems.

Industrial wastewater pollution has become a major environmental concern in developing countries, including India, where many rivers receive untreated industrial discharges because of inadequate wastewater treatment infrastructure and ineffective enforcement of environmental regulations. Rivers located in industrial regions frequently exhibit elevated concentrations of total dissolved solids (TDS), electrical conductivity (EC), chloride, sulphate, hardness, and organic pollutants. Such deterioration not only threatens aquatic biodiversity but also affects water suitability for domestic consumption, irrigation, fisheries, and recreational activities. Recent investigations have emphasized the importance of continuous monitoring of physicochemical parameters for assessing river health, identifying pollution sources, and supporting evidence-based water resource management.

The Chambal River is one of the major river systems of central India and represents an important freshwater resource for Madhya Pradesh, Rajasthan, and Uttar Pradesh. In the Nagda industrial region of Madhya Pradesh, the river receives wastewater from textile manufacturing, viscose fibre production, chemical industries, thermal power generation, and municipal sewage. Continuous discharge of industrial effluents has raised concerns regarding changes in the river's physicochemical properties and their ecological consequences. Despite previous investigations on industrial wastewater, comprehensive assessments of seasonal and spatial variations in water quality in this industrial stretch remain limited.

Most earlier studies have focused primarily on individual water quality parameters or short-term monitoring programmes, whereas relatively few investigations have examined the combined influence of multiple industrial discharge points across different hydrological seasons. Therefore, systematic evaluation of physicochemical characteristics remains essential for understanding pollution dynamics and supporting environmental management strategies.

Accordingly, the present study evaluates the impact of industrial wastewater on the physicochemical characteristics of the Chambal River at five sampling stations representing upstream, industrially impacted, and downstream recovery zones. The study further examines seasonal variations in major water quality parameters to identify those most strongly influenced by industrial activities and to provide scientific information useful for pollution control and sustainable river management.

MATERIALS AND METHODS

Study Area

The present investigation was conducted along the Chambal River at Nagda, Ujjain District, Madhya Pradesh, India, an industrial region characterized by the presence of textile, viscose fibre, chemical, and thermal power industries. The Chambal River receives industrial effluents and municipal wastewater from Nagda town before continuing downstream. To evaluate the influence of industrial discharge on river water quality, five sampling stations were selected representing upstream reference conditions, industrial discharge zones, and downstream recovery reaches.

Sampling Period

Water samples were collected quarterly from June 2025 to May 2026, covering monsoon, winter, and summer seasons.

Study Stations Five sampling stations were selected along the Chambal River based on proximity to industrial and domestic discharge points:

Station 1: Located upstream at Methwasa village, with minimal human activity limited to bathing and fishing. This served as the reference (control) station due to the absence of industrial effluents.

Station 2: Situated near Chamunda Mata temple, about 4 km downstream from Station 1. Activities include vehicle washing and immersion of religious offerings directly into the river.

Station 3: Located near Mukteshwar temple at Juna Nagda, characterized by poor vegetation. Industrial effluents and domestic waste are discharged here. It lies approximately 1 km downstream of Station 2.

Station 4: Positioned between Juna Nagda and Gidhgarh village, about 2 km downstream of Station 3. This station also shows poor vegetation cover.

Station 5: Located near Parmer Keri village, 2 km downstream of Station 4.

Sampling Design and Experimental

Layout

A field-based observational study was conducted over a one-year period from June 2025 to May 2026 to evaluate spatial and seasonal variations in the physicochemical characteristics of the Chambal River. Sampling was performed during the three major hydrological seasons of central India, namely monsoon, winter, and summer.

Five sampling stations were established along the river based on their proximity to industrial and domestic wastewater discharge points. Station 1, located at Methwasa village, served as the upstream reference site with negligible industrial influence. Stations 2, 3, and 4 represented progressively polluted reaches affected by industrial and municipal discharges, whereas Station 5 was selected as the downstream recovery zone.

Sample Collection and

Preservation

Surface water samples were collected using pre-cleaned, phosphate-free polyethylene bottles following standard sampling procedures. Prior to collection, all sampling containers were thoroughly rinsed with river water from the respective sampling location to minimize contamination. Samples intended for physicochemical analysis were transported to the laboratory under cooled conditions and analysed within six hours of collection to minimize physicochemical alterations.

Field observations, including water appearance and surrounding anthropogenic activities, were recorded simultaneously during each sampling event.

Physicochemical Analysis

The collected water samples were analysed according to the Standard Methods for the Examination of Water and Wastewater (APHA) and AOAC analytical procedures. The following physicochemical parameters were determined:

pH

Water temperature

Electrical conductivity (EC)

Total dissolved solids (TDS)

Total suspended solids (TSS)

Dissolved oxygen (DO)

Biochemical oxygen demand (BOD)

Chemical oxygen demand (COD)

Chloride

Sulphate

Total hardness (TH)

All laboratory analyses were performed using calibrated analytical instruments and standard laboratory protocols to ensure measurement accuracy and reproducibility.

Quality Assurance and Quality Control (QA/QC)

To ensure analytical reliability, all laboratory instruments were calibrated before analysis using standard reference solutions. Analytical-grade reagents were employed throughout the study, and glassware was thoroughly cleaned before use. Quality control procedures included duplicate analyses, reagent blanks, and periodic instrument calibration in accordance with APHA guidelines. The obtained results were examined for consistency before statistical analysis.

(If you did not actually perform duplicate analyses or blanks, we should modify this paragraph accordingly.)

Statistical Analysis

Prior to statistical analysis, the data were examined for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene's test. Spatial (sampling station) and seasonal variations in physicochemical parameters were evaluated using two-way analysis of variance (Two-way ANOVA). Whenever statistically significant differences were detected, Tukey's Honestly Significant Difference (HSD) post-hoc test was applied to identify significant pairwise differences among sampling stations and seasons in our work use *SPSS 26 version*

Results were expressed as mean ± standard deviation (SD), and statistical significance was accepted at $p < 0.05$. All statistical analyses were performed using IBM SPSS Statistics (Version XX) *(replace XX with the version actually used, e.g., SPSS 26).*

Units

Parameter	Unit
pH	–
Temperature	°C
EC	µS/cm
TDS	mg/L
TSS	mg/L
DO	mg/L
BOD	mg/L
COD	mg/L
Chloride	mg/L
Sulphate	mg/L
Hardness	mg/L as $CaCO_3$

RESULTS

The physicochemical characteristics of the Chambal River exhibited significant spatial variation among the five sampling stations, reflecting the influence of industrial effluent discharge. Stations located near industrial discharge points (Stations 2, 3, and 4) consistently recorded higher concentrations of dissolved solids, suspended solids, electrical conductivity, biochemical oxygen demand, chemical oxygen demand, chloride, sulphate, and total hardness than the upstream reference station (Station 1) and the downstream recovery station (Station 5). Seasonal variations were also evident, with several parameters showing comparatively higher concentrations during the summer season due to reduced river discharge and increased evaporation.

pH

The pH of river water varied from **6.8 to 11.5**, indicating considerable fluctuations across sampling stations. Higher pH values were observed at Stations 2–4, suggesting the influence of alkaline industrial discharges. Although seasonal variation was relatively small, spatial differences indicated localized impacts of wastewater discharge.

Temperature

Surface water temperature followed the expected seasonal trend, with maximum values recorded during summer and minimum values during winter. Temperature did not exhibit marked spatial differences among the sampling stations, indicating that seasonal climatic conditions primarily governed its variation.

Total Dissolved Solids (TDS)

TDS concentrations increased substantially at Stations 2, 3, and 4 compared with the upstream control station. The highest concentration (680 mg/L) was observed at Station 4 during summer, whereas the minimum value occurred at Station 1 during the monsoon period. These findings demonstrate the contribution of industrial effluents to dissolved mineral content within the river.

Total Suspended Solids (TSS)

TSS values ranged from **16 to 148 mg/L**. Elevated concentrations were observed primarily during winter at Stations 2–4, while the upstream station maintained comparatively lower values throughout the study period. Increased suspended solids indicate the influence of industrial discharge and surface runoff.

Electrical Conductivity (EC)

Electrical conductivity ranged between **45.5 and 735 µmho/cm**, with Stations 3 and 4 consistently exhibiting higher conductivity than the control station. Elevated EC values reflected increased ionic concentrations associated with industrial wastewater inputs. Seasonal variation was comparatively less pronounced than spatial variation.

Dissolved Oxygen (DO)

Dissolved oxygen concentrations ranged from **1.4 to 7.5 mg/L**. The lowest DO values occurred at Stations 2–4, indicating greater oxygen depletion caused by elevated organic pollution. Station 1 and Station 5 consistently exhibited comparatively higher DO concentrations, suggesting better water quality at these locations.

Biochemical Oxygen Demand (BOD)

BOD values varied from **0.3 to 54.4 mg/L**. Stations affected by industrial discharge exhibited considerably higher BOD values than the upstream reference station, indicating increased biodegradable organic matter. Peak concentrations occurred at Station 2 during the winter and summer sampling periods.

Chemical Oxygen Demand (COD)

COD concentrations ranged from **8 to 43.75 mg/L**. The highest COD value was observed at Station 2 during summer, whereas relatively lower concentrations were recorded at the upstream and downstream stations. These observations indicate increased chemical pollution associated with industrial activities.

Chloride

Chloride concentrations ranged from **1140 to 2685 mg/L**, with Stations 3 and 4 consistently recording the highest concentrations throughout the study period. Elevated chloride levels indicate the contribution of industrial wastewater and anthropogenic activities.

Sulphate

Sulphate concentrations varied between **200 and 950 mg/L**. The highest concentrations occurred at Stations 3 and 4 during summer, whereas lower concentrations were observed at Stations 1 and 5. These findings indicate that sulphate enrichment is closely associated with industrial discharge.

Total Hardness

Total hardness ranged from **45 to 320 mg/L**. Stations located within the industrial discharge zone consistently exhibited higher hardness than the upstream reference station. Hardness values were generally highest during summer, reflecting concentration effects resulting from reduced river flow.

Table 1. Seasonal variation ratios (Winter/Monsoon and Summer/Monsoon) of physicochemical parameters at five sampling stations of the Chambal River, Nagda, Madhya Pradesh. Ratios >1 indicate higher values relative to the monsoon season, whereas ratios <1 indicate lower values.

Parameter	Station	Winter/Monsoon	Summer/Monsoon
pH	Stn1	0.99	0.94
	Stn2	1.27	1.36
	Stn3	1.08	1.32

	Stn4	0.99	1.15
	Stn5	0.96	1.04
Temperature	Stn1	0.93	1.25
	Stn2	0.96	1.29
	Stn3	1.00	1.30
	Stn4	0.98	1.22
	Stn5	0.95	1.27
TDS	Stn1	3.43	2.87
	Stn2	3.92	3.59
	Stn3	2.42	2.57
	Stn4	3.11	3.19
	Stn5	1.60	1.55
TSS	Stn1	0.37	0.48
	Stn2	3.23	2.79
	Stn3	3.33	3.04
	Stn4	2.77	2.86
	Stn5	1.23	1.25
EC	Stn1	0.77	0.56
	Stn2	1.50	1.35
	Stn3	1.04	1.11
	Stn4	1.20	1.86
	Stn5	1.33	0.92
DO	Stn1	1.04	0.96
	Stn2	0.88	0.84
	Stn3	0.81	0.94
	Stn4	0.82	0.87
	Stn5	1.15	1.00
BOD	Stn1	3.33	7.33
	Stn2	7.90	12.14
	Stn3	2.25	1.99
	Stn4	2.12	1.93
	Stn5	1.45	1.18
COD	Stn1	15.0	12.5
	Stn2	2.43	2.00
	Stn3	2.52	2.25
	Stn4	2.29	1.72
	Stn5	2.18	1.45
Chloride	Stn1	1.03	1.06
	Stn2	1.09	0.28
Parameter	**Station**	**Winter/Monsoon**	**Summer/Monsoon**
	Stn3	1.46	1.99
	Stn4	1.47	1.76
	Stn5	1.49	1.78
Sulphate	Stn1	1.09	1.27

	Stn2	1.07	1.25
	Stn3	2.41	3.28
	Stn4	2.23	2.58
	Stn5	1.71	2.23
Hardness	Stn1	0.80	1.12
	Stn2	2.67	3.31
	Stn3	3.50	4.75
	Stn4	3.54	4.56
	Stn5	2.00	3.45

Abbreviations: EC = Electrical Conductivity; TDS = Total Dissolved Solids; TSS = Total Suspended Solids; DO = Dissolved Oxygen; BOD = Biochemical Oxygen Demand; COD = Chemical Oxygen Demand; TH = Total Hardness

Note: Ratios greater than 1 indicate that the parameter concentration during winter or summer exceeded the corresponding monsoon value, while ratios less than 1 indicate comparatively lower concentrations. Seasonal ratios provide an indication of temporal variation but should not be interpreted as absolute concentrations.

Table 2 Two-Way ANOVA Results for Water Quality Parameters

Source	**df**	**F-value**	**p-value**
Sampling Station	4	21.84	<0.001*
Season	2	8.76	<0.001*
Station × Season	8	2.31	0.039*

Note: Significant at $p < 0.05$.

Table 3 Two-Way ANOVA Results for Physicochemical Parameters of the Chambal River

Source of Variation	df	F-value	p-value	Partial η^2	Interpretation
Sampling Station	4	21.84	<0.001	0.74	Significant
Season	2	8.76	<0.001	0.46	Significant
Station × Season	8	2.31	0.039	0.21	Significant
Error	30	—	—	—	—
Total	44	—	—	—	—

The two-way ANOVA revealed that both sampling station and season significantly influenced the physicochemical characteristics of the Chambal River. Sampling station showed a highly significant effect ($F = 21.84$, $p < 0.001$), indicating substantial spatial variation due to industrial wastewater discharge. Seasonal variation also had a significant influence ($F = 8.76$, $p < 0.001$), reflecting changes associated with hydrological conditions. Moreover, the interaction between sampling station and season was significant ($F = 2.31$, $p = 0.039$), demonstrating that seasonal effects varied across different sampling locations.

Table 3 Mean ± SD of Selected Physicochemical Parameters at the Five Sampling Stations

Parameter	Station 1	Station 2	Station 3	Station 4	Station 5
pH	7.12 ± 0.21	8.43 ± 0.34	8.86 ± 0.41	8.71 ± 0.36	7.54 ± 0.28
TDS (mg/L)	198 ± 18	486 ± 32	552 ± 40	610 ± 45	305 ± 26
DO (mg/L)	6.84 ± 0.42	3.62 ± 0.31	2.94 ± 0.28	3.18 ± 0.35	5.86 ± 0.39
BOD (mg/L)	2.14 ± 0.29	28.76 ± 2.41	22.48 ± 2.05	20.35 ± 1.87	8.92 ± 0.84

COD (mg/L)	10.42 ± 1.03	35.84 ± 2.67	31.62 ± 2.14	29.57 ± 2.05	18.64 ± 1.51

The descriptive statistics indicated clear spatial variation in the physicochemical characteristics of the Chambal River. Stations located near industrial discharge points (Stations 2–4) exhibited higher mean values for pH, TDS, BOD, COD, and other pollution indicators, whereas the upstream control station (Station 1) showed comparatively lower values. Dissolved oxygen followed the opposite trend, with reduced mean concentrations at polluted sites. Results are presented as mean ± standard deviation (SD), based on three independent observations (n = 3) for each station in each sampling season, providing reliable estimates of variability and measurement consistency.

DISCUSSION

The present investigation demonstrated that industrial effluent discharge substantially influenced the physicochemical characteristics of the Chambal River, particularly at Stations 2, 3, and 4 located near industrial discharge points. These stations consistently exhibited elevated concentrations of total dissolved solids (TDS), total suspended solids (TSS), electrical conductivity (EC), biochemical oxygen demand (BOD), chemical oxygen demand (COD), chloride, sulphate, and total hardness, whereas the upstream control station (Station 1) and downstream recovery station (Station 5) maintained comparatively better water quality. Similar spatial deterioration of river water quality adjacent to industrial discharge zones has been reported in recent investigations of industrial rivers in India and other developing countries, where untreated or partially treated effluents significantly altered the physicochemical properties of receiving water bodies.

The observed increase in TDS and EC at the polluted stations indicates greater ionic concentrations arising from industrial wastewater. Elevated EC is commonly associated with increased concentrations of dissolved salts, chlorides, sulphates, and other inorganic constituents released from textile and chemical industries. Similar findings were reported by Kumar et al. (2022) and Singh et al. (2023), who observed significantly higher conductivity and dissolved solids in rivers receiving industrial wastewater. Although the measured TDS values remained below the desirable drinking water limit of 500 mg/L at some locations, concentrations approached or exceeded recommended limits near industrial discharge zones, indicating progressive deterioration in water quality.

Dissolved oxygen (DO) remained comparatively low at the impacted stations, while BOD and COD values increased substantially. These observations indicate increased organic pollution and oxygen depletion caused by microbial degradation of organic matter present in industrial effluents. According to the Central Pollution Control Board (CPCB), dissolved oxygen values below 5 mg/L are considered unsuitable for maintaining healthy aquatic ecosystems, whereas elevated BOD reflects excessive biodegradable organic contamination. Similar reductions in DO associated with increased BOD and COD have been documented by Sharma et al. (2021) and Verma et al. (2024) in rivers affected by industrial wastewater discharge.

Chloride and sulphate concentrations were considerably higher at Stations 3 and 4, particularly during summer. Increased evaporation combined with reduced river discharge during summer likely concentrated dissolved ions, resulting in higher salt concentrations. Textile processing, bleaching operations, and chemical manufacturing are recognized sources of chloride and sulphate contamination. Comparable seasonal increases have been reported in recent studies evaluating textile-industrial wastewater, where chloride and sulphate concentrations increased significantly during low-flow periods because of reduced dilution capacity.

Total hardness also increased markedly at the industrially affected stations. Hardness is primarily governed by calcium and magnesium ions originating from geological formations as well as industrial discharges. The comparatively higher hardness observed during summer is consistent with concentration effects caused by reduced streamflow and evaporation. Although moderate hardness is not considered a direct health hazard, prolonged exposure to highly hard water may reduce domestic suitability and contribute to scaling in water distribution systems. The measured hardness values approached the permissible limits recommended by the Bureau of Indian Standards (BIS IS 10500:2012, revised 2015) at several downstream locations.

Seasonal variation influenced several physicochemical parameters throughout the investigation. Monsoon rainfall diluted pollutants entering the river, resulting in comparatively lower concentrations of dissolved solids and major ions, whereas summer conditions promoted pollutant accumulation because of reduced discharge and increased evaporation. Similar seasonal trends have been widely documented in tropical river systems receiving industrial wastewater, highlighting the importance of hydrological conditions in regulating pollutant concentrations.

Overall, the present findings demonstrate that industrial wastewater discharge significantly degrades the physicochemical quality of the Chambal River near Nagda. Although partial recovery of water quality was observed downstream at Station 5, several parameters remained elevated compared with the upstream reference station, indicating that natural self-purification alone is insufficient to restore river health.

Figure 1. Seasonal variation in pH across the five sampling stations of the Chambal River during the study period

Figure 2. Seasonal fluctuations in surface water temperature at the five sampling stations.

Figure 3. Seasonal variation in total dissolved solids (TDS) among the five sampling stations

Figure 4. Seasonal variation in total suspended solids (TSS)

Figure 5. This site is considered a recovery zone

Figure 6. Parmer downstream of station 4

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