Seasonal Variations in Physiochemical Properties of the Sone and Gopad Rivers in Sidhi District, Madhya Pradesh, India: Implications for Ecological Health and Anthropogenic Impacts

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Abstract- This study looks at how the seasonal changes affect the physical and chemical properties of the Sone and Gopad rivers in Sidhi District, Madhya Pradesh, India. It assesses their ecological health in light of increasing human pressures. We chose seven sampling sites along the two rivers, representing a mix of urban, agricultural, and untouched areas in the tehsils of Churhat, Sihawal, Bahri, Majhauli, and Madwas. We collected water samples during three seasons: pre-monsoon (March to June), monsoon (July to September), and post-monsoon (October to February). We analyzed these samples for key parameters such as temperature, turbidity, pH, total dissolved solids (TDS), total hardness, conductivity, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (NH3-N), nitrates (NO−3), and total phosphate (TP). We followed standard protocols for both on-site and lab measurements. For example, we used Winkler titration for DO, EDTA titration for hardness, and spectrophotometry for nutrients. The results showed clear seasonal patterns. During the monsoon, turbidity reached higher levels (up to 70 NTU at Sone River sites), with TDS reaching up to 600 mg/L and higher nutrient levels, all due to increased runoff and sediment flow. In pre-monsoon conditions, DO levels were lower (as low as 6.0 mg/L) while hardness was higher (up to 150 mg/L), which indicates evaporation and concentration. Post-monsoon values generally returned closer to baseline levels. Sone River sites (A1 to A4) consistently showed higher pollution levels than Gopad River sites (B1 to B3). This reflects greater human impacts from urbanization and agriculture. These results highlight how vulnerable river ecosystems are to seasonal water changes and human activities, especially in sensitive areas like the Son Gharial Sanctuary. Higher BOD and COD during the monsoon indicate organic pollution from agricultural runoff and domestic waste, which can threaten aquatic life, including endangered gharials. The study stresses the importance of integrated water management strategies, such as creating buffer zones and monitoring pollution, to reduce degradation. By providing a solid baseline dataset, this research aids in sustainable river conservation in central India, showing how natural processes and human actions influence water quality.

Keywords: Water quality, River ecosystems, Seasonal variations, Physiochemical parameters, Anthropogenic impacts, Sidhi District.

1 INTRODUCTION

Rivers are integral to an ecosystem as they uphold life forms, facilitate farming, and support human settlements. In addition, they assist with water supply and waste management [1,2]. In India, river systems are crucial for social and economic development [3-5]. They, however, face the constant threat of water pollution due to urbanization, industrial growth, and increased agriculture [6,7]. An example of this are the Sone and Gopad rivers located in Madhya Pradesh's Sidhi District. The Sone river is one of the primary tributaries of the Ganges. Its journey starts at the Amarkantak plateau, from where it passes through different geographical regions including the forest, agricultural land, and urban centers. It contains important ecosystems such as the Son Gharial Sanctuary, which protects endangered species including the gharial (Gavialis gangeticus). The Gopad River, a smaller tributary of the Sone, also traverses similar regions, but is less impacted by human activity because some of its tributaries are less accessible.

Sidhi District is one of the eastern districts of the state of Madhya Pradesh. The district also has a tropical climate as it has distinct pre-monsoon, monsoon, and post-monsoon seasons. Temperature rise and a drop in water levels leads to a concentration of pollutants from early to mid June which brings in the pre-monsoon period. This is followed by the monsoon season in which rains are received from July to September. This also brings a lot of water which causes run off both from agricultural fields as well as urban centers which add on a lot of Pollutants to the rivers.

Assessing water quality is essential for understanding ecosystem health and guiding conservation efforts [8]. Physiochemical parameters provide insights into pollution sources and ecological stressors. For instance, elevated turbidity and BOD indicate sediment and organic loading, while high nitrates and phosphates signal eutrophication risks from agricultural practices. Previous studies in Indian rivers, such as the Ganges and Yamuna, have documented similar seasonal patterns, linking them to land-use changes and climate variability [9,10]. However, data on the Sone and Gopad rivers remain limited, particularly in Sidhi District, where rapid development threatens pristine sites.

This study addresses this gap by examining seasonal variations in key physiochemical parameters across seven sampling sites along the Sone and Gopad rivers. The sites were chosen to represent a spectrum of environmental conditions: from urban-influenced areas near Sidhi town to protected zones in the Son Gharial Sanctuary and remote forested regions. Objectives include: (1) documenting baseline water quality across seasons; (2) identifying spatial differences between the two rivers; (3) evaluating anthropogenic impacts on ecological integrity; and (4) recommending management strategies for sustainable river health.

By integrating field sampling with standardized laboratory analyses, this research provides a holistic framework for monitoring riverine systems in central India. It highlights the importance of seasonal considerations in water quality assessments, as hydrological shifts can amplify or mitigate pollution effects. Ultimately, the findings aim to inform policymakers, environmental managers, and local communities on preserving these rivers, which are crucial for biodiversity conservation, irrigation, and potable water supply in a region facing water scarcity and climate change pressures.

2 METHODS

2.1 Sampling Sites: A Framework for Study

This study focuses on seven strategically selected sampling sites along the Sone and Gopad rivers, designed to capture the ecological and anthropogenic diversity of Sidhi District's riverine systems. These sites, located in the villages of Patpara, Tariha, Dadiya, Khadbadha, Parshilee, Bharuhi, and Tikri, span the tehsils of Churhat, Sihawal, Bahri, Majhauli, and Madwas. Each site represents a unique combination of environmental conditions and human activities, providing a comprehensive framework for assessing the rivers' ecological health. The following table summarizes the sampling locations:

Table 1: Sample Collection Locations – Sidhi District

Sample Code	Sample Collection Source	Village	District	State
A1	Sone River	Patpara	Sidhi	MP
A2	Sone River	Tariha	Sidhi	MP
A3	Sone River	Dadiya	Sidhi	MP
A4	Sone River	Khadbadha	Sidhi	MP
B1	Gopad River	Parshilee	Sidhi	MP
B2	Gopad River	Bharuhi	Sidhi	MP
B3	Gopad River	Tikri	Sidhi	MP

2.1.1 Site Descriptions

1. Patpara (A1, Sone River, Churhat Tehsil): Located near Sidhi town, Patpara is a bustling villagewith significant agricultural and urban activity. The Sone River at this site is influenced by upstream inputs from Sidhi town, including domestic waste and runoff from nearby fields. The site's proximity to human settlements makes it ideal for studying the impacts of urbanization on river ecosystems.

2. Tariha (A2, Sone River, Sihawal Tehsil): Tariha is a rural village surrounded by agricultural lands,where the Sone River flows through a relatively undisturbed stretch. The site is characterized by fertile plains and riparian vegetation, offering insights into the river's ecological health in a predominantly agrarian context.
3. Dadiya (A3, Sone River, Bahri Tehsil): Situated within the Son Gharial Sanctuary, Dadiya isan ecologically sensitive site with minimal human disturbance. The Sone River here supports diverse aquatic life, including gharials, making it a critical location for studying pristine riverine ecosystems.
4. Khadbadha (A4, Sone River, Sihawal Tehsil): Khadbadha is a village with moderate human activity, including fishing and small-scale farming. The Sone River at this site is influenced by upstream agricultural runoff, providing a context for examining the interplay between human land use and water quality.
5. Parshilee (B1, Gopad River, Majhauli Tehsil): Parshilee, located near the Gopad's confluence withthe Sone, is part of the Son Gharial Sanctuary. The site's sandy banks and forested surroundings make it ideal for studying the Gopad's role in supporting endangered species and riparian ecosystems.
6. Bharuhi (B2, Gopad River, Bahri Tehsil): Bharuhi is an agricultural village where the GopadRiver flows through fertile plains. The site is exposed to runoff from farming activities, offering a perspective on the impacts of agriculture on smaller river systems.
7. Tikri (B3, Gopad River, Madwas Tehsil): Tikri is a remote village surrounded by forests, where theGopad River remains relatively pristine. The site's isolation from major human activities makes it a benchmark for studying undisturbed riverine environments.

These sampling sites collectively provide a robust framework for understanding the environmental dynamics of the Sone and Gopad rivers, capturing the interplay between natural processes and human influences across Sidhi District.

2.2 Physiochemical Properties

Water quality testing procedures for the Sone and Gopad rivers in Sidhi District were conducted across pre-monsoon (March–June), monsoon (July–September), and post-monsoon (October–February) seasons at the seven sampling sites. Parameters measured included temperature (°C), turbidity (NTU), pH, total solids (TS, mg/L), total hardness (mg/L), conductivity (µS/cm), dissolved oxygen (DO, mg/L), biochemical oxygen demand (BOD, mg/L), chemical oxygen demand (COD, mg/L), ammoniacal nitrogen (NH_3-N, mg/L), nitrates (NO^-_3 , mg/L), and total phosphate (TP, mg/L). Standardized protocols ensured consistency and accuracy, with measurements conducted on-site or in the laboratory as appropriate.

2.2.1 Temperature (°C)

Temperature was measured on-site using a calibrated digital thermometer (±0.1°C accuracy). A 1-liter water sample was collected at a 0.5-meter depth in a sterile container, avoiding turbulent areas during monsoon to minimize runoff effects. The probe was submerged for 30 seconds, and three readings were taken 5 minutes apart between 8:00 AM and 10:00 AM to standardize conditions. The probe was cleaned with distilled water between sites to prevent contamination, especially during monsoon due to sediment loads. Ambient air temperature was recorded post-monsoon to contextualize data.

2.2.2 Turbidity (NTU)

Turbidity was assessed on-site using a calibrated portable turbidimeter. A 500-mL sample was collected at 0.5 meters, gently mixed to suspend particles, and poured into the turbidimeter's sample cell. Three readings in Nephelometric Turbidity Units (NTU) were recorded between 8:00 AM and 10:00 AM, with the cell cleaned using distilled water between measurements. During monsoon, samples avoided debrisheavy areas to ensure accurate readings, and the turbidimeter was recalibrated to account for high sediment loads.

2.2.3 pH

pH was measured on-site using a portable pH meter (±0.01 pH units), calibrated with buffer solutions (pH 4.0, 7.0, 10.0). A 500-mL sample was collected at 0.5 meters, and the electrode was rinsed with distilled water before submersion. After 30 seconds of stabilization, three readings were taken between 8:00 AM and 10:00 AM, with the electrode cleaned between measurements. Monsoon measurements avoided turbulent zones to minimize runoff-induced pH fluctuations, and the meter was recalibrated before each session.

2.2.4 Total Solids (mg/L)

Total solids were measured in the laboratory. A 1-liter sample was collected at 0.5 meters, stored at 4°C, and filtered (100 mL) through a pre-weighed 0.45 μm glass fiber filter using vacuum filtration. The filter was dried at 105°C for 24 hours, cooled in a desiccator, and weighed. Total solids (mg/L) were calculated as the weight difference divided by 0.1 L. Three subsamples were analyzed per site, with equipment cleaned using distilled water to prevent contamination, particularly during monsoon due to sediment.

2.2.5 Total Hardness (mg/L)

Total hardness was determined in the laboratory using EDTA titration. A 500-mL sample was collected at 0.5 meters, stored at 4°C, and 50 mL was mixed with 2 mL ammonia buffer (pH 10) and Eriochrome Black T indicator. Titration with 0.01 M EDTA until a red-to-blue color change yielded hardness (mg/L $CaCO_3$) as (mL EDTA × 1000) / 50 mL. Three titrations per site were conducted, with glassware cleaned using distilled water, especially during monsoon to avoid sediment interference.

2.2.6 Conductivity (μS/cm)

Conductivity was measured on-site using a portable conductivity meter (±1 μS/cm), calibrated with potassium chloride solution. A 500-mL sample was collected at 0.5 meters, and the probe was rinsed with distilled water before submersion. After 30 seconds of stabilization, three readings were taken between 8:00 AM and 10:00 AM, with the probe cleaned between measurements. Monsoon measurements avoided runoff-heavy areas, and the meter was recalibrated before each session.

2.2.7 Dissolved Oxygen (mg/L)

DO was measured using the Winkler titration method. A 300-mL sample was collected at 0.5 meters in a BOD bottle, avoiding air bubbles. On-site, 2 mL manganese sulfate and 2 mL alkali-iodide-azide reagent were added, mixed, and allowed to settle. After adding 2 mL concentrated sulfuric acid, a 200-mL aliquot was titrated with 0.025 N sodium thiosulfate using starch indicator until the blue color disappeared. DO (mg/L) was calculated as (mL thiosulfate × 0.025 × 8 × 1000) / 200 mL. Three titrations per site were conducted, with glassware cleaned to avoid monsoon sediment contamination.

2.2.8 Biochemical Oxygen Demand (BOD, mg/L)

BOD was determined in the laboratory. A 300-mL sample was collected at 0.5 meters in a BOD bottle, stored at 4°C. Initial DO was measured using the Winkler method, followed by 5-day incubation at 20°C in a dark BOD incubator. Final DO was measured, and BOD (mg/L) was calculated as the DO difference, adjusted for dilution. Three subsamples per site were analyzed, with equipment cleaned using distilled water to prevent contamination.

2.2.9 Chemical Oxygen Demand (COD, mg/L)

COD was measured in the laboratory using the closed reflux titrimetric method. A 500-mL sample was collected at 0.5 meters, stored at 4°C. A 50-mL aliquot was mixed with 5 mL potassium dichromate and 15 mL sulfuric acid-silver sulfate reagent, refluxed at 150°C for 2 hours, cooled, and titrated with 0.1 N ferrous ammonium sulfate using ferroin indicator until a blue-green to reddish-brown color change. COD (mg/L) was calculated as [(blank mL – sample mL) × 0.1 × 8 × 1000] / 50 mL. Three tests per site were conducted, with glassware cleaned.

2.2.10 Ammoniacal Nitrogen (NH_3-N, mg/L)

Ammoniacal nitrogen was measured in the laboratory using the Nesslerization method. A 500-mL sample was collected at 0.5 meters, stored at 4°C. A 50-mL aliquot was mixed with 1 mL Nessler's reagent, left for 10 minutes for color development, and absorbance was measured at 425 nm using a spectrophotometer against a blank. NH_3-N (mg/L) was calculated using a calibration curve. Three tests per site were conducted, with cuvettes cleaned to avoid contamination.

2.2.11 Nitrates (NO^-_3, mg/L)

Nitrates were measured in the laboratory using the UV-spectrophotometric method. A 500-mL sample was collected at 0.5 meters, stored at 4°C. A 50-mL aliquot was filtered (0.45 μm), mixed with 1 mL 1 N hydrochloric acid, and absorbance was measured at 220 nm and 275 nm. Nitrate concentration (mg/L) was calculated using a calibration curve, correcting for organic matter by subtracting twice the 275 nm absorbance. Three tests per site were conducted, with cuvettes cleaned.

2.2.12 Total Phosphate (TP, mg/L)

Total phosphate was measured in the laboratory using the ascorbic acid method. A 500-mL sample was collected at 0.5 meters, stored at 4°C. A 50-mL aliquot was mixed with 5 mL ammonium molybdateantimony potassium tartrate reagent and 2 mL ascorbic acid solution, left for 10 minutes for blue color development, and absorbance was measured at 880 nm against a blank. TP (mg/L) was calculated using a calibration curve. Three tests per site were conducted, with cuvettes cleaned.

3 RESULTS

The analysis of physiochemical parameters across the Sone (A sites) and Gopad (B sites) rivers revealed significant seasonal variations, reflecting the influence of hydrological cycles and anthropogenic activities. Data are presented as ranges for each parameter, aggregated by site group and season, to highlight trends. Temperature data, although measured, are not tabulated here but showed typical seasonal patterns: highest in pre-monsoon (25–32°C across sites) due to low water levels and solar heating, moderate in monsoon (22–28°C) with dilution from rainfall, and lowest in post-monsoon (18–25°C) under cooler ambient conditions.

Table 2: Seasonal Alterations in Physiochemical Properties in the Sone and Gopad Rivers of Sidhi District

Season	Site Group	Turbidity (NTU)	pH	TDS (mg/L)	Hardness (mg/L)	Conductivity (µS/cm)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	NH_3-N (mg/L)	NO_3^- (mg/L)	TP (mg/L)
Pre-Monsoon	A Sites	[5–20]	[7.2–7.7]	[240–350]	[110–150]	[320–450]	[6.0–7.5]	[2.2–4.0]	[14–25]	[0.2–0.6]	[4.2–8.0]	[0.06–0.13]
	B Sites	[3–12]	[7.3–7.5]	[210–300]	[100–130]	[300–370]	[6.7–8.1]	[1.5–2.9]	[12–18]	[0.05–0.3]	[3.0–5.2]	[0.02–0.08]
Monsoon	A Sites	[10–70]	[7.5–8.2]	[300–600]	[125–200]	[360–650]	[5.3–7.0]	[2.8–5.5]	[18–35]	[0.3–0.8]	[5.2–11.0]	[0.09–0.20]
	B Sites	[7–52]	[7.5–7.9]	[230–490]	[106–160]	[315–500]	[5.8–7.8]	[1.8–4.1]	[14–26]	[0.07–0.6]	[3.6–8.2]	[0.03–0.15]
Post-Monsoon	A Sites	[4–25]	[7.1–7.8]	[250–450]	[108–170]	[320–550]	[6.5–7.9]	[1.9–4.0]	[13–25]	[0.2–0.6]	[4.0–8.0]	[0.05–0.14]
	B Sites	[2–20]	[7.2–7.5]	[210–390]	[100–145]	[300–450]	[6.4–8.1]	[1.5–3.0]	[12–19]	[0.05–0.4]	[3.0–6.0]	[0.02–0.09]

In the pre-monsoon season, A sites (Sone River) exhibited higher turbidity (5–20 NTU) compared to B sites (3–12 NTU), likely due to reduced water flow concentrating suspended particles from urban and agricultural sources. pH remained slightly alkaline across both groups (7.2–7.7 for A, 7.3–7.5 for B), within natural ranges for tropical rivers. TDS and conductivity were elevated in A sites (240–350 mg/L and 320–450 µS/cm), reflecting mineralization from evaporation and human inputs, while B sites showed lower values (210–300 mg/L and 300–370 µS/cm). Hardness followed a similar pattern, with A sites at 110–150 mg/L indicating moderate hardness from calcium and magnesium ions. DO levels were adequate but lower in A sites (6.0–7.5 mg/L) than B sites (6.7–8.1 mg/L), suggesting minor oxygen depletion from organic matter. BOD and COD were higher in A sites (2.2–4.0 mg/L and 14–25 mg/L), pointing to organic pollution, whereas B sites had lower organic loads (1.5–2.9 mg/L and 12–18 mg/L). Nutrient parameters like NH_3-N (0.2–0.6 mg/L in A, 0.05–0.3 in B), NO^-_3 (4.2–8.0 mg/L in A, 3.0–5.2 in B), and TP (0.06–0.13 mg/L in A, 0.02–0.08 in B) indicated agricultural influences, particularly in A sites near farmlands.

Monsoon season showed the most pronounced changes, with turbidity spiking dramatically in A sites (10–70 NTU) due to runoff carrying sediments, and moderately in B sites (7–52 NTU). pH increased slightly (7.5–8.2 in A, 7.5–7.9 in B), possibly from dilution and alkaline soil erosion. TDS, hardness, and conductivity rose across both groups, with A sites reaching 300–600 mg/L, 125–200 mg/L, and 360–650 µS/cm, respectively, attributed to dissolved ions from surface runoff. DO decreased (5.3–7.0 mg/L in A, 5.8–7.8 in B) amid higher turbulence and organic inputs, while BOD and COD escalated (2.8–5.5 mg/L and 18–35 mg/L in A; 1.8–4.1 mg/L and 14–26 mg/L in B), signaling increased biodegradable and non-biodegradable pollutants. Nutrients peaked, with NH_3-N (0.3–0.8 mg/L in A), NO^-_3 (5.2–11.0 mg/L in A), and TP (0.09–0.20 mg/L in A) higher than in B sites, reflecting fertilizer and waste leaching during rains.

Post-monsoon results indicated recovery, with turbidity dropping to 4–25 NTU in A sites and 2–20 NTU in B sites as sediments settled. pH stabilized (7.1–7.8 in A, 7.2–7.5 in B), and TDS, hardness, and conductivity moderated (250–450 mg/L, 108–170 mg/L, 320–550 µS/cm in A; lower in B). DO improved (6.5–7.9 mg/L in A, 6.4–8.1 in B), supporting aquatic life recovery. BOD and COD decreased (1.9–4.0 mg/L and 13–25 mg/L in A; 1.5–3.0 mg/L and 12–19 mg/L in B), though still elevated in A sites. Nutrients declined but remained notable in A sites (NH_3-N 0.2–0.6 mg/L, NO^{-}_{3} 4.0–8.0 mg/L, TP 0.05–0.14 mg/L), suggesting persistent pollution.

Overall, A sites consistently showed higher parameter values, underscoring greater anthropogenic stress on the Sone River compared to the more pristine Gopad River. These ranges represent averages from triplicate measurements, with variations within sites linked to local factors like proximity to settlements.

4 DISCUSSION

The results demonstrate clear seasonal and spatial variations in the physiochemical properties of the Sone and Gopad rivers, driven by a combination of natural hydrological processes and human-induced factors. During the pre-monsoon season, the concentration of parameters like TDS, hardness, and conductivity in A sites highlights the effects of low water volumes and evaporation, which amplify pollutant density from upstream urban sources such as Patpara (A1). This aligns with patterns observed in other Indian rivers, where dry periods exacerbate mineralization. In contrast, B sites, particularly Tikri (B3), maintained lower values, benefiting from forested buffers that mitigate inputs.

Monsoon dynamics introduced the highest variability, with elevated turbidity, nutrients, and oxygen demand reflecting runoff from agricultural lands and domestic waste. The spike in NO^{-}_{3} and TP in A sites (up to 11.0 mg/L and 0.20 mg/L) suggests eutrophication risks from fertilizer use in tehsils like Sihawal and Bahri, potentially leading to algal blooms that threaten gharial habitats in the Son Gharial Sanctuary. Higher BOD and COD in A sites indicate organic pollution, possibly from untreated sewage in urban-adjacent areas, reducing DO to levels (as low as 5.3 mg/L) that could stress fish and other aquatic organisms. B sites, while affected, showed attenuated impacts due to less intensive land use, emphasizing the protective role of natural landscapes.

Post-monsoon recovery, with declining turbidity and nutrients, indicates the rivers' resilience through dilution and sedimentation. However, persistent elevations in A sites for parameters like COD and nitrates imply chronic pollution, not fully alleviated by seasonal flows. This spatial disparity underscores anthropogenic gradients: Sone River sites, influenced by urbanization and agriculture, exhibit greater degradation than Gopad sites, which are more isolated or protected.

These findings have implications for ecosystem management. Elevated nutrients and oxygen demand during monsoons could disrupt biodiversity, particularly in sensitive areas like Dadiya (A3) and Parshilee (B1). Compared to permissible limits (e.g., WHO standards for DO >5 mg/L, BOD <3 mg/L), some values exceed thresholds, signaling potential health risks for human use. Strategies such as afforestation, wastewater treatment, and seasonal monitoring are recommended to curb impacts. Future research should incorporate biological indicators and long-term trends to enhance understanding.

5 CONCLUSION

This study reveals significant seasonal physiochemical variations in the Sone and Gopad rivers, with monsoon exacerbating pollution and A sites showing higher impacts. Findings advocate for targeted conservation to safeguard these vital ecosystems.

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