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Analytic study of physico-chemical parameters in a selected stretch of the river Mahanadi in Odisha

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Abstract

The Mahanadi River, the largest river in Odisha, traverses approximately 851 km through the state before discharging into the Bay of Bengal. The present study assessed the physico-chemical characteristics of the river water from April 2023 to May 2025 across three seasons: pre-monsoon, monsoon and post-monsoon to evaluate its suitability for domestic, agricultural, and ecological purposes. Water samples were collected from seven locations: Hirakud at Sambalpur district. (R1), Thengo Dam at Sonepur district. (R2), the Mahanadi River near the Rameswar temple in Boudh district. (R3), Satakosia Gorge at Angul district. (R4), Mahanadi River near Dhableswar temple in Cuttack district. (R5), Naraj Dam in the Cuttack district. (R6), the Mahanadi River in Jagatsinghpur district. (R7). A total of sixteen key physicochemical parameters were analysed, i.e., water temperature, turbidity, pH, turbidity, electrical conductivity, dissolved oxygen, biological oxygen demand, Free CO_2. The seasonal variations indicated higher turbidity during the monsoon due to runoff and suspended sediments, while DO and pH were relatively higher during winter, reflecting enhanced aeration and lower biological activity. Spatially, upstream sites (R1–R3) showed better water quality compared to downstream stations (R6–R7), which exhibited higher BOD levels, indicating moderate organic pollution from urban and agricultural inputs. Overall, the Water Quality Index (WQI) ranged from 65.4 to 78.2, signifying good to moderately polluted conditions. The results suggest that while the Mahanadi River water remains largely suitable for irrigation and general domestic use after treatment, localised anthropogenic pressures in downstream stretches require effective management and continuous monitoring to sustain river health.

Keywords: Physico-chemical parameters, mahanadi river, water quality

Introduction

Lakes, rivers, and streams constitute fundamental components of freshwater ecosystems and serve as indispensable resources for human civilisation, providing drinking water, irrigation support, fisheries, and hydroelectric power generation (Iscen *et al*., 2008; Wetzel, Robert G., 2001 [10, 26]; Allan, J. David & Castillo, María M., 2007) [1]. Despite their immense ecological and socio-economic importance, these freshwater bodies are increasingly subjected to severe degradation due to escalating anthropogenic pressures. Rapid population growth, unplanned urbanisation, expanding industrial activities, and intensified agricultural practices have collectively contributed to the continuous discharge of untreated or partially treated wastewater into natural water systems (World Health Organisation, 2017; Chapman and Deborah, 1996) [6, 27]. Consequently, such inputs have led to a progressive decline in water quality, thereby posing serious threats to both ecosystem integrity and public health (United Nations Environment Programme, 2016; Boyd, Claude E., 2015) [5, 25].

The deterioration of water quality is primarily attributed to a wide spectrum of pollutants, including organic wastes, pathogenic microorganisms, excessive nutrient loads—particularly nitrogen and phosphorus—and a variety of toxic chemical substances. These contaminants not only alter the physicochemical composition of water but also disrupt the ecological balance of aquatic ecosystems (Boyd 2015; Chapman 1996) [5, 6]. Nutrient enrichment, for instance, often leads to eutrophication, which is characterised by excessive algal growth followed by the depletion of dissolved oxygen, thereby adversely affecting aquatic biota (Wetzel 2001; Allan and Castillo 2007) [1, 26]. Similarly, the accumulation of organic matter increases biochemical oxygen demand (BOD), reducing the availability of dissolved oxygen necessary for the survival of aquatic Water quality is governed by a complex interplay of external and internal factors, both of which are intricately linked within aquatic environments (Davis and Cornwell 2013; Dodds and Whiles 2020) [8, 9]. External factors encompass meteorological conditions such as temperature fluctuations, precipitation patterns, and seasonal variations, as well as anthropogenic influences including pollutant inputs and land-use changes (Allan and Castillo 2007; Singh *et al*. 2014) [1, 23]. These factors significantly influence key physico-chemical parameters such as temperature, pH, dissolved oxygen (DO), turbidity, and electrical conductivity (APHA 2017; Chapman 1996) [6]. Among these, temperature regulates metabolic and biochemical reaction rates, pH controls chemical equilibria and biological functioning, while dissolved oxygen serves as a critical indicator of the ecological health of aquatic systems (Wetzel 2001; Boyd 2015) [5, 26]. Any abrupt or significant variations in these parameters often reflect environmental disturbances and may indicate ecological stress or pollution events (Dodds and Whiles 2020 [9]; United Nations Environment Programme 2016) [25].

In contrast, internal factors are primarily associated with biological and biochemical processes occurring within aquatic systems (Dodds and Whiles 2020 [9]; Jordaan and Bezuidenhout 2024). These include interactions among microbial communities, phytoplankton, zooplankton, and higher trophic levels, all of which play a fundamental role in ecosystem functioning (Allan and Castillo 2007) [1].

Microbial decomposition of organic matter, nutrient recycling, and primary productivity are key processes that regulate water quality from within the system (Boyd 2015; Dodds and Whiles 2020) [3, 5]. The dynamic relationships between bacterial populations and planktonic organisms are crucial for maintaining ecological balance and regulating nutrient dynamics, as microbial communities drive biogeochemical cycling and respond sensitively to environmental changes (Jordaan and Bezuidenhout 2019 [14]; Jordaan and Bezuidenhout 2024). Furthermore, these internal processes often respond to and, in turn, modify external environmental conditions, thereby creating feedback mechanisms that govern the overall functioning of aquatic ecosystems (United Nations Environment Programme 2016; Pandey *et al.* 2014) [20, 25].

The physico-chemical characteristics of various freshwater systems, including rivers and streams, have been extensively investigated by numerous researchers over the years (Sahu *et al.* 1991; Chapman 1996; Wetzel 2001; Allan and Castillo 2007 [1, 6, 17, 26]; Shukla and Singh 2020). These studies have significantly contributed to understanding the dynamics of water quality and its relationship with ecological processes (Boyd 2015; APHA 2017; Dodds and Whiles 2020 [5, 9, 27]; Kumar *et al.* 2021). Several researchers have also highlighted the importance of seasonal variability in influencing water quality parameters, particularly in tropical river systems (Singh *et al.* 2014; Mishra and Tripathi 2021; Jena *et al.* 2022) [13, 19, 23]. However, despite the availability of such studies, there remains a lack of comprehensive and systematic investigation focusing specifically on the seasonal variability of physicochemical parameters in the Mahanadi River (Behera *et al.* 2020; Panda *et al.* 2021; Mohanty *et al.* 2023) [3, 16, 19].

The Mahanadi River, being one of the major river systems in India, plays a crucial role in supporting agriculture, fisheries, and domestic water requirements in the region. Different stretches of the Mahanadi River are influenced by both natural processes and anthropogenic activities, especially vulnerable to fluctuations in water quality. Seasonal variations, driven by monsoonal patterns, temperature changes, and runoff dynamics, can significantly alter the physico-chemical properties of the river, thereby influencing its ecological health and suitability for various uses.

The present study was undertaken during the period 2023–2025 with the objective of assessing seasonal variations in key physicochemical parameters of the Mahanadi River water. The study aims to generate baseline data and provide insights into temporal changes in water quality, which may further help in understanding the impact of environmental and anthropogenic factors on the river ecosystem. Such information is essential for the development of effective water resource management and conservation strategies.

Materials and Methods

1. Study Area

The study was carried out along the longitudinal gradient of the Mahanadi River, Odisha, India, extending from the upper stretch at Sambalpur to the lower estuarine segment at Jagatsinghpur. Seven representative sampling stations were selected. These are Hirakud at Sambalpur district(R1), Thengo Dam at Sonepur district (R2), Mahanadi River near Rameswar temple in Boudh district(R3), Satakosia Gorge at Angul district(R4), Mahanadi River near Dhableswar temple in Cuttack district (R5), Naraj Dam in the Cuttack district (R6) and Mahanadi River in Jagatsinghpur district(R7)

These sites represent reservoir inflow areas, stretches, midstream sections, and estuarine transitional zones, ensuring comprehensive ecological coverage. (Fig.1, Table-1)

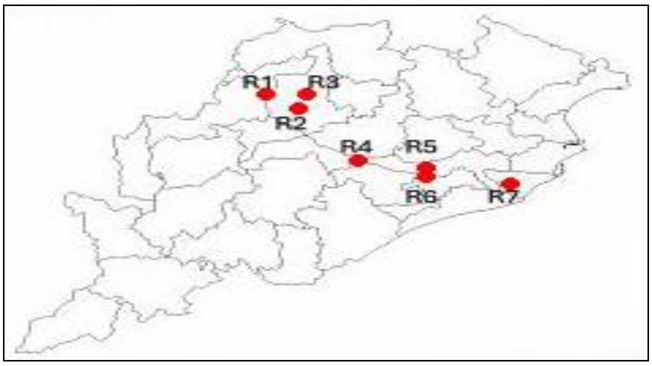


Fig 1: Seven sampling sites

Table 1: Study area and geographic details of sampling sites along the Mahanadi River

Site Code	Location	District	Coordinates
R1	Hirakud	Sambalpur	*21°27′N,83°58′E*
R2	Thengo Dam	Sonepur	*20°75′N,83°75′ E*
R3	Boudh	Boudh	*20°87′ N,84°20′ E*
R4	Satakosia Gorge	Angul	*20°34′ N; 84°48′ E*
R5	Dhableswar	Cuttack	*20°21′ N; 85°25′ E*
R6	Naraj	Cuttack	*20°29′ N; 85°25′ E*
R7	Jagatsinghpur	Jagatsinghpur	*20°16′ N; 86°10′ E*

1. Method

Water samples were collected (in 2-litre PVC containers) from each site and brought to the laboratory for further analysis. Important physical and chemical parameters, such as the water temperature, pH, conductivity, dissolved oxygen and free carbon dioxide of the river water at each sampling site, were determined using standard techniques (APHA 2017) [2].

Water temperature, pH and conductivity were measured on site with the help of a portable water analysis kit (Systronic Water analyser 371). Dissolved oxygen was estimated by the modified Winkler's method. The titrimetric method recommended by APHA (2017) was used for free carbon dioxide estimation.

Result

1. Temperature

The Temperature of water was measured by using a Water Analyser (Systronic Water Analyser 371). The analysis of water temperature along different stretches (R1–R7) of the Mahanadi River during the study period (Fig. 2 and Table-2) revealed a clear seasonal pattern with comparatively minor spatial intraseasonal variations.

A compatible seasonal trend is evident across all sites and both years. Values peak during the pre-monsoon period, reflecting higher concentrations before rainfall. During the monsoon, values decline (31.8–34.1). The lowest values occur in the post-monsoon season (16.3–19.9).

Spatially, slightly higher mean values are observed at downstream or enriched locations such as R6 and R7, with a maximum of 30.73 at R7 (2023–24). In contrast, R4 shows comparatively lower mean values (28.66 in both years), suggesting reduced concentration levels or variability. Other sites (R1, R2, R3, and R5) display similar mean values (~29.2–29.7), indicating relatively uniform environmental conditions.

Inter-annual variation between study periods is minimal, demonstrating temporal stability. Minor fluctuations at certain sites (e.g., a slight increase at R5) reflect natural variability rather than significant environmental change.

Standard deviation values (≈9.16–11.14) indicate moderate variability, primarily driven by seasonal changes. Higher variability at R1 and R4 suggests greater seasonal influence, whereas lower values at R3 and R7 indicate more stable conditions.

The results highlight a strong seasonal effect, moderate spatial variation, and stable inter-annual patterns.

2. P^H

The pH of water was measured using a Systronic Water Analyser (Model 371) at seven sampling stations along the Mahanadi River during the study periods (Fig. 3 and Table-3). Mean and standard deviation (SD) were calculated to assess central tendency and variability.

The pH ranged from 7.1 to 8.5, indicating a narrow and stable range across sites and seasons. A clear seasonal trend was observed, with the highest values during pre-monsoon likely due to evaporation and reduced water volume, and lowest values during monsoon (7.1–7.6) due to dilution from rainfall and increased discharge. Post-monsoon values (7.3–8.3) showed moderate recovery, reflecting gradual stabilisation of the system.

Spatial variation was minimal, suggesting uniform conditions along the river stretch. Slightly higher mean pH was recorded at R3 (~8.0), while R1 and R5 showed relatively lower values (~7.6–7.7). Other sites exhibited intermediate levels (~7.7–7.9).

Inter-annual differences were minor (<0.2 units), indicating temporal stability, with a consistent seasonal pattern (pre-monsoon > post-monsoon > monsoon) across both years. SD values (0.32–0.64) were low, confirming limited variability, though slightly higher fluctuations were noted at R5 and R7.

The water remained slightly alkaline (average 7.5–8.0), which is favourable for aquatic life. The observed seasonal changes reflect monsoonal influence, while the overall stability indicates a healthy and resilient aquatic environment.

3. Conductivity

Electrical conductivity varied widely across stations (R1–R7) and seasons (Fig.4 and Table-4), ranging from 199 to 623 µS/cm, indicating differences in dissolved ionic content along the river.

Seasonally, values were highest in pre-monsoon, lowest in monsoon due to dilution, and moderate in post-monsoon. A clear upstream–downstream gradient was observed, with lower values at R1–R2, moderate at R3–R4, and highest at R5–R7, reflecting cumulative inputs from runoff, waste discharge, and natural weathering.

A slight increase in conductivity was noted in 2024–25 at most sites, suggesting rising anthropogenic influence, though some local variations occurred. SD values indicated moderate variability, higher downstream and lower upstream.

Overall, conductivity remained within acceptable limits but showed increasing trends downstream and over time, highlighting the influence of seasonal hydrology and human activities.

4. Dissolved Oxygen

The Dissolved Oxygen (DO) of water was measured by Wrinkler's method. The dissolved oxygen (DO) concentration was recorded across the seven sampling sites (R1–R7) during the study period (Fig.5 and Table-5). Dissolved oxygen (DO) showed moderate seasonal and spatial variation across the sampling sites. Mean DO values ranged from 6.36 to 7.70 mg/L, indicating well-oxygenated conditions suitable for aquatic life. SD values (0.20–0.65) suggest low to moderate variability and overall stability.

Seasonally, DO was highest during monsoon (6.7–8.3 mg/L) due to increased flow and aeration, moderate in post-monsoon (6.3–8.0 mg/L), and lowest in pre-monsoon (5.8–7.5 mg/L) due to higher temperature and reduced flow.

Spatially, DO declined from upstream to downstream. Higher values at R1 and R4 indicate better aeration and lower pollution, while lower values at R6 and R7 suggest higher organic load and reduced flow. Intermediate conditions were observed at R2, R3, and R5.

Inter-annual variation was minimal, with only slight changes between years, maintaining the same seasonal pattern.

DO remained stable and within a favourable range, reflecting good ecological conditions, though slightly lower levels downstream indicate localized organic stress.

5. Free CO_2

The Free Carbon dioxide concentration of water was measured by the titrimetric method using phenolphthalein as an indicator (APHA, 2017) [2]. Free carbon dioxide (CO_2) showed significant seasonal, spatial, and yearly variation across the Mahanadi River. (Fig.6 and Table-6) Values ranged from 4.2 to 19.6 mg/L, indicating considerable differences in carbon dynamics.

Seasonally, CO_2 was lowest in pre-monsoon, increased in post-monsoon, and peaked during monsoon.

A clear upstream–downstream increase was observed. Upstream sites (R1–R2) showed lower values (≈5.7–7.0 mg/L), midstream sites moderate levels, and downstream sites (R5–R7) the highest (≈11.5–14.8 mg/L), Inter-annual comparison indicates a general rise in CO_2 at most sites, especially downstream, suggesting increased organic loading and biological activity, while upstream remained relatively stable.

SD values (1.06–4.75) show moderate variability, higher downstream due to fluctuating inputs and hydrological changes.

CO_2 dynamics are driven by seasonal hydrology and anthropogenic inputs. Elevated levels downstream, particularly during the monsoon, may lower pH and stress aquatic life, highlighting the need for regular monitoring and effective management of organic pollution.

6. Alkalinity

Alkalinity was determined using the titrimetric method (APHA, 2017). The study showed clear seasonal variation, spatial trends, and moderate to high variability across all sampling sites (Fig.7 and Table-7). Mean values ranged from 45.66 to 77.00 mg/L, indicating moderate buffering capacity, while SD values (22.22–38.11) reflect noticeable seasonal fluctuations.

Seasonally, alkalinity was highest during monsoon (85–129 mg/L), moderate in pre-monsoon (33–67 mg/L), and lowest in post-monsoon (19–41 mg/L).

Spatially, alkalinity increased from upstream to downstream. Lower values at R1 and R4 (~45–52 mg/L) indicate relatively stable conditions, while higher values at R5–R7 (≈65–77 mg/L), especially at R7.

SD values were higher at downstream sites (R5–R7), indicating greater seasonal variability due to fluctuating runoff and inputs, while lower values at R3 suggest more stable conditions.

Inter-annual differences were minor, with a consistent seasonal pattern across both years, showing that alkalinity is mainly controlled by hydrological cycles.

The river exhibits moderate buffering capacity, with increasing downstream mineralisation and strong monsoonal influence, making alkalinity a key indicator of water chemistry and ecosystem stability.

Table 2: Temperature Variation along the study sites

Sample site	Year	Pre-monsoon	Monsoon	Post monsoon	Mean	SD
R1	2023-24	39	32	18	29.66	10.69
	2024-25	38.6	33.3	17.2	29.70	11.14
R2	2023-24	37.8	32.2	19.2	29.73	9.54
	2024-25	37.2	31.8	18.6	29.20	9.56
R3	2023-24	36.9	33.5	18.8	29.73	9.61
	2024-25	36.6	32.9	19.2	29.56	9.16
R4	2023-24	35.8	33.9	16.3	28.66	10.75
	2024-25	35.4	34.1	16.5	28.66	10.55
R5	2023-24	37.2	32.9	17.9	29.33	10.13
	2024-25	37.8	33.3	18.1	29.73	10.32
R6	2023-24	37.8	34.1	19	30.30	9.95
	2024-25	37.4	33.8	18.7	29.96	9.92
R7	2023-24	38.4	33.9	19.9	30.73	9.64
	2024-25	38.3	33.5	19.6	30.46	9.71

Table 3: pH Variation along the study sites

Sample site	Year	Pre monsoon	Monsoon	Post Monsoon	Mean	SD
R1	2023-24	8.2	7.1	7.5	7.60	0.55
	2024-25	8.3	7.2	7.7	7.73	0.55
R2	2023-24	8.5	7.4	7.9	7.93	0.55
	2024-25	8.3	7.6	7.8	7.90	0.36
R3	2023-24	8.5	7.4	8.2	8.03	0.56
	2024-25	8.3	7.3	8.3	7.96	0.57
R4	2023-24	8.3	7.6	7.9	7.93	0.35
	2024-25	8.2	7.5	7.8	7.83	0.35
R5	2023-24	8.1	7.2	7.5	7.60	0.45
	2024-25	8.3	7.1	7.3	7.56	0.64
R6	2023-24	8.2	7.5	7.7	7.80	0.36
	2024-25	8.1	7.4	7.6	7.70	0.36
R7	2023-24	8.4	7.3	7.5	7.73	0.58
	2024-25	8.2	7.6	7.7	7.83	0.32

Table 4: Conductivity Variation along the study sites

Sample Site	Year	Pre-monsoon	Monsoon	Post-monsoon	Mean	SD
R1	2023-24	334	199	271	268.00	67.54
	2024-25	319	207	267	264.33	56.04
R2	2023-24	345	229	300	291.33	58.48
	2024-25	358	242	323	307.66	59.50
R3	2023-24	403	259	340	334.00	72.18
	2024-25	415	265	365	348.33	76.37
R4	2023-24	478	309	397	394.66	84.52
	2024-25	464	342	411	405.66	61.17
R5	2023-24	489	348	412	416.33	70.59
	2024-25	513	357	471	447.00	80.74
R6	2023-24	576	423	448	482.33	82.07
	2024-25	559	411	448	472.66	77.02
R7	2023-24	604	440	511	518.33	82.24
	2024-25	623	460	531	538.00	81.72

Table 5: DO(Mg/L) Variation along the study sites

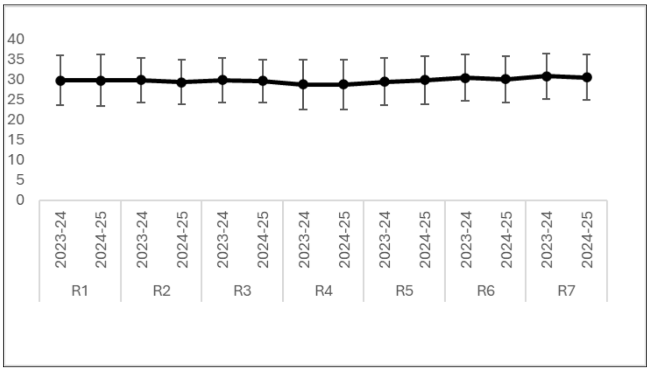
Sample Site	Year	Pre-monsoon	Monsoon	Post-monsoon	Mean	SD
R1	2023-24	7.5	8.3	7.3	7.70	0.52
	2024-25	7.1	7.9	8	7.67	0.49
R2	2023-24	6.6	7.2	7.1	6.96	0.32
	2024-25	7.2	7.3	6.9	7.13	0.20
R3	2023-24	6.2	7.1	7.4	6.90	0.62
	2024-25	6.6	7.6	7	7.06	0.50
R4	2023-24	6.8	7.5	7.3	7.20	0.36
	2024-25	7.4	7.9	7.7	7.66	0.25
R5	2023-24	6.8	7.4	6.3	6.83	0.55
	2024-25	6.3	7.6	6.9	6.93	0.65
R6	2023-24	6	6.9	6.7	6.53	0.47
	2024-25	6.5	7.4	7.2	7.03	0.47
R7	2023-24	5.8	6.7	6.6	6.36	0.49
	2024-25	6.3	6.2	6.9	6.46	0.37

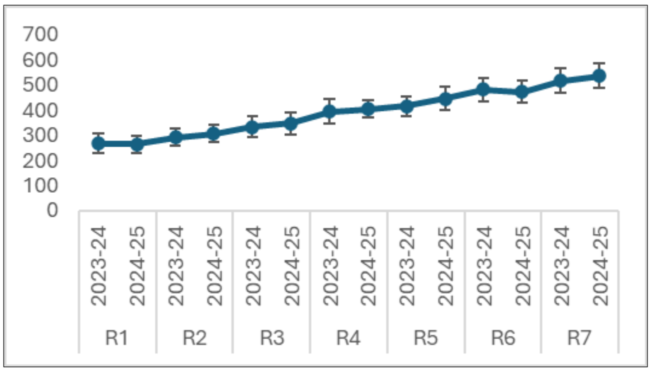
Table 6: Free CO_2 (Mg/L) Variation along the study sites

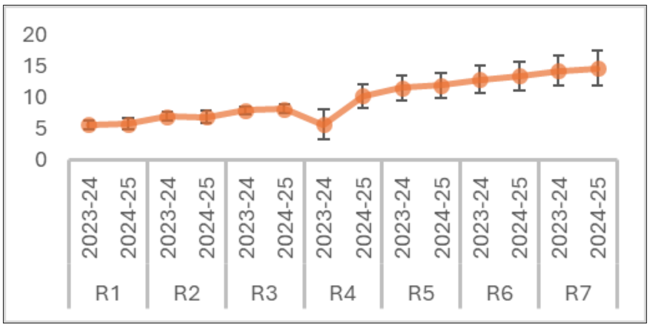
Sample Site	Year	Pre-monsoon	Monsoon	Post-monsoon	Mean	SD
R1	2023-24	4.8	7.1	5.2	5.70	1.22
	2024-25	4.2	7.5	5.7	5.80	1.65
R2	2023-24	5.9	8.3	6.8	7.00	1.21
	2024-25	5.2	8.5	7.1	6.93	1.65
R3	2023-24	6.8	8.9	8.2	7.96	1.06
	2024-25	6.9	9.1	8.6	8.20	1.15
R4	2023-24	7.2	1	8.9	5.70	4.15
	2024-25	7.1	13.8	9.9	10.26	3.36
R5	2023-24	8.4	15.1	11.2	11.56	3.36
	2024-25	8.7	15.7	11.7	12.03	3.51
R6	2023-24	9.2	16.9	12.6	12.90	3.85
	2024-25	9.8	17.6	13.1	13.50	3.91
R7	2023-24	10.3	18.8	14	14.36	4.26
	2024-25	10.1	19.6	14.6	14.76	4.75

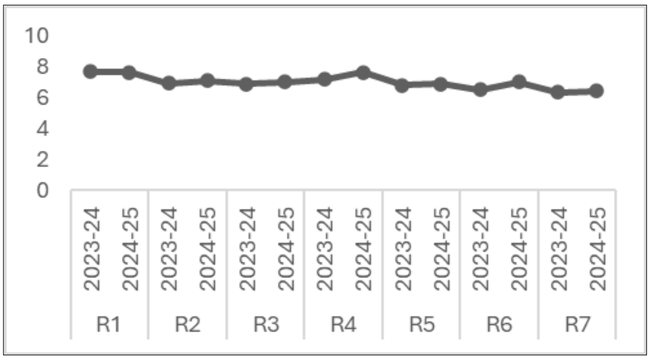
Table 7: Alkanity Variation along the study sites

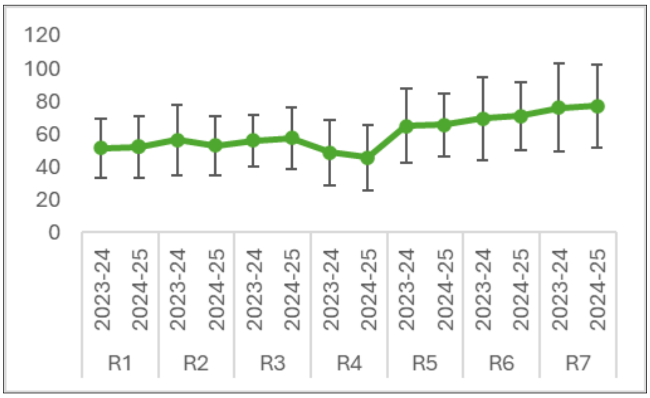
Sample Site	Year	Pre-monsoon	Monsoon	Post-monsoon	Mean	SD
R1	2023-24	46	85	23	51.33	25.59
	2024-25	39	89	28	52.00	26.54
R2	2023-24	48	97	24	56.33	30.37
	2024-25	42	88	29	53.00	25.31
R3	2023-24	45	87	36	56.00	22.22
	2024-25	47	94	32	57.66	26.41
R4	2023-24	38	87	21	48.66	27.98
	2024-25	33	85	19	45.66	28.39
R5	2023-24	53	109	33	65.00	32.16
	2024-25	55	103	39	65.66	27.19
R6	2023-24	59	117	32	69.33	35.46
	2024-25	64	110	39	71.00	29.40
R7	2023-24	58	129	41	76.00	38.11
	2024-25	67	125	39	77.00	35.81











Discussion

The present study reveals that the physico-chemical characteristics of the Mahanadi River are strongly influenced by seasonal hydrology, spatial gradients, and, to a lesser extent, inter-annual variation. Such patterns are consistent with earlier studies on tropical river systems, where monsoonal dynamics play a dominant role in regulating water quality (Panda *et al.,* 1991; Singh *et al.,* 2004) [22, 24].

Water temperature exhibited a clear seasonal trend, with higher values during pre-monsoon and lower values in post-monsoon, reflecting the influence of atmospheric conditions and solar radiation. Temperature is a key factor controlling chemical reactions and biological processes in aquatic systems, thereby influencing other parameters such as dissolved oxygen and metabolic rates (Iscen *et al.,* 2008) [10].

The pH remained within a narrow alkaline range (7.1–8.5), indicating stable conditions across sites and seasons. Slight alkalinity is typical of river systems with good buffering capacity and is generally favourable for aquatic organisms. The minor seasonal fluctuation, with lower values during monsoon due to dilution, agrees with previous findings (APHA, 2017; Sahu *et al.,* 1991) [17].

Electrical conductivity showed a clear seasonal and spatial pattern, with higher values in pre-monsoon and downstream regions. This reflects the concentration of dissolved ions during low flow and cumulative input from natural weathering and anthropogenic sources such as agricultural runoff and domestic waste. Similar downstream increases in conductivity have been widely reported in river systems subjected to human activities (Singh *et al.,* 2004; Ghose *et al.,* 2009) [11, 24].

Dissolved oxygen (DO) levels indicated generally healthy conditions, remaining within a range suitable for aquatic life. Higher DO during monsoon is attributed to increased turbulence and aeration, while lower pre-monsoon values result from higher temperature and oxygen consumption. The gradual decline in DO towards downstream sites suggests increased organic load and microbial activity, a trend commonly observed in impacted river stretches (Sinha, 1986).

Free carbon dioxide (CO_2) exhibited an inverse relationship with DO and showed higher concentrations during the monsoon and at downstream sites. This is mainly due to increased decomposition of organic matter and reduced photosynthesis under turbid conditions. Elevated CO_2 levels in downstream regions indicate higher metabolic activity and organic pollution, which may influence pH and overall ecosystem balance (Bezuidenhout *et al.,* 2002) [4].

Alkalinity demonstrated strong seasonal variation, with maximum values during monsoon due to runoff and weathering, and minimum values during post-monsoon. The increasing trend from upstream to downstream reflects cumulative mineral input and anthropogenic influence. Moderate alkalinity indicates good buffering capacity, helping maintain pH stability in the river system (APHA, 2017; Panda *et al.,* 1991) [15, 22].

The study suggests that the river maintains relatively good water quality with moderate seasonal fluctuations and clear spatial gradients. However, increasing trends in conductivity, CO_2, and alkalinity, along with decreasing DO in downstream areas, indicate growing anthropogenic pressure. These findings highlight the importance of continuous monitoring and effective management strategies to preserve the ecological integrity of the river system.

Conclusion

The study shows that the physico-chemical characteristics of the Mahanadi River are strongly influenced by seasonal hydrology, with dilution during monsoon and concentration during pre-monsoon, followed by stabilisation in post-monsoon.

Water quality declines gradually from upstream to downstream, where higher conductivity, alkalinity, and free CO_2, along with slightly lower dissolved oxygen, indicate increasing anthropogenic influence.

Despite this, most parameters remain within suitable limits for aquatic life, suggesting overall moderate ecological health. However, rising trends in downstream pollution highlight the need for continuous monitoring and effective management to maintain river stability.

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