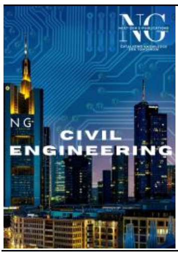

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Research Article

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Surface Water Quality Appraisal and Suitability Assessment for Designated Uses along the Brahmani River Basin, Odisha, India

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HIGHLIGHTS

- Water quality of the Brahmani River was assessed from 2017 to 2024.
- Urban wastewater caused a local water quality decline near Rourkela.
- River water is fit for irrigation; quality improved post-monsoon

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ABSTRACT

The Brahmani River in Odisha supports regional agriculture, industry and domestic supply but human activities are mounting pressures on the water quality of the river. The paper measures the spatio-seasonal variability in the surface-water quality between 2017 and 2024 by using the samples obtained in 12 monitoring stations during pre- and post-monsoon periods. The main parameters that were examined to describe hydrochemistry and their suitability for use were core physico-chemical parameters (pH, dissolved oxygen, biochemical and chemical oxygen demand, total dissolved solids, major cations, and anions). The overall status was calculated in terms of the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI), and agricultural usability was assessed using common irrigation indices, which are sodium adsorption ratio (SAR), soluble sodium percentage (SSP), permeability index (PI), Kelly ratio (KR), magnesium adsorption ratio (MAR) and residual sodium carbonate (RSC). It was observed that some quality deterioration occurred locally and was in line with the discharge of urban and industrial wastewater into the basin. The type was predominant and the hydrochemical facies was characterized by carbonate weathering with minor evaporite effects.

1. INTRODUCTION

Water is a prime natural resource fundamental to ecosystem stability and human development, supporting agriculture, industry, and domestic life (UN-Water, 2021). The quality of surface water is increasingly threatened by both natural processes and anthropogenic activities such as industrial discharge, agricultural runoff, and domestic waste disposal (Kumar et al., 2022). Regular monitoring and

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assessment are therefore critical for the integrated management and protection of water resources.

The Brahmani River, the second largest river in Odisha, India, is a crucial water source for the region. Despite its importance, there is a lack of comprehensive and reliable information on its water quality status and trends, leading to unchecked usage. Previous studies on Indian rivers have successfully employed Water Quality Indices (WQI) and geospatial tools to simplify complex data and communicate water status effectively (Tripathi & Singal, 2019; Singh et al., 2020). Similarly, irrigation water quality indices are vital for assessing the long-term viability of water for agriculture, preventing soil degradation, and ensuring crop productivity (Adimalla, 2021).

This study aims to bridge the knowledge gap by conducting a detailed spatiotemporal assessment of the water quality of the Brahmani River. The specific objectives are to: (1) analyze the physicochemical and biological characteristics of the river water; (2) evaluate its overall quality using the CCME WQI; (3) determine its suitability for irrigation using established indices; and (4) identify the primary hydrochemical processes and pollution sources influencing water quality through statistical and graphical methods.

2. MATERIALS AND METHODS

2.1 *Study Area*

The Brahmani River is formed by the confluence of the Sankh and South Koel rivers near Rourkela, Odisha. It flows southwards through the Gangpur Basin and forms a delta along with the Baitarani River before draining into the Bay of Bengal. The basin covers nine revenue districts of Odisha, representing diverse land-use patterns from forested uplands to urban, industrial, and intensive agricultural zones 0.8H depths (where H is the total flow depth), averaged as;

2.2 *Data Collection and Sampling*

A total of twelve sampling stations (P1 to P12) were selected along the river stretch to represent upstream, midstream, and downstream locations, including points downstream of major urban and industrial centres (e.g., Rourkela, Talcher). Grab water samples were collected seasonally (pre-monsoon and post-monsoon) over Seven years (2017-2024) following standard protocols (APHA, 2017). The precise geographic coordinates of each station were recorded using a GPS device.

2.3. *Analytical Methods*

The samples were analyzed for a comprehensive set of parameters: pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Coliform (TC), Total Alkalinity (TA), Total Dissolved Solids (TDS), Total Hardness (TH), Electrical Conductivity (EC), Boron (B), Fluoride (F^-), and major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}). All analyses were performed as per standard methods outlined in APHA (2017).

Factor 1: F1 (Scope)

Scope assesses the extent of water quality guideline non-compliance over the time of interest, which means the number of parameters whose objective limits is not met. It has been adopted directly from the British Columbia WQI:

F1 = (Number of failed variables/Total number of variables) *100

Where the variables indicate those water quality parameters whose objective values (threshold limits are specified, and observed values at the sampling sites are available for the index calculation.

Factor 2:

The frequency (i.e., how many occasions the tested or observed value was off the acceptable range)

limits) with which the objectives are not met, which represents the percentage of the individual

tests that do not meet the objectives (“failed tests”):

F2 = (Number of failed tests/Total number of variables) * 100

The formulation of this factor is drawn directly from the British Columbia WQI.

Factor 3: F3 (Amplitude)

The amount by which the objectives are not met (amplitude) represents the amount by which the failed test values do not meet their objectives, and is calculated in three steps. The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an “excursion” and is expressed as follows.

When the test value must not exceed the objective.

$\text{Excursion}_i = (\text{Failed test value}_i / \text{Objective}_j) - 1$

For the cases in which the test value must not fall below the objective:

$\text{Excursion}_i = (\text{Objective}_j / \text{Failed test value}_i) - 1$

The collective amount, by which the individual tests are out of compliance, is calculated by summing the excursions of individual tests from their objectives and then dividing the sum by the total number of tests. This variable, referred to as the normalized sum of excursions (NSE) is calculated as:

$$NSE=\sum_{i=1}^{N} excursion/Number\ of\ tests \quad (1)$$

F3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (NSE) to yield a value between 0 and 100.

$$F3= \left(\frac{NSE}{0.01NSE+0.01}\right) \quad (2)$$

The CWQI is finally calculated as

$$CWQI = 100- ([F1^2 + F2^2 + F3^2]^{0.5}/1.732)$$

The factor of 1.732 has been introduced to scale the index from 0 to 100. Since the individual index factors can range as high as 100, it means that the vector length can reach a maximum of 173.2 as shown below:

$$(100^2 + 100^2 + 100^2)^{0.5} = 173.2 \quad (3)$$

The above formulation produces a value between 0 and 100 and gives a numerical value to the state of water quality. Note a zero (0) value signifies very poor water quality, whereas values close to 100 signify excellent water quality. The assignment of CCME WQI values to different categories is a somewhat subjective process and also demands expert judgement and the public's expectations of water quality. The water quality is ranked in the following five categories, shown below.

a) Excellent: (CCME WQI values 95 – 100)
b) Good: (CCME WQI values 80 – 94)
c) Fair: (CCME WQI values 60 – 79)
d) Marginal: (CCME WQI values 45 – 59)
e) Poor: (CCME WQI values 0 – 44)

A WQI map was created with the help of CCME WQI classification to understand the surface water quality in the study area.

2.4. Data Analysis

Water Quality Index (WQI): The overall water quality was assessed using the CCME WQI model (CCME, 2001), which incorporates scope (F1), frequency (F2), and amplitude (F3) of exceedances. Irrigation Water Quality Indices: Suitability for agriculture was determined by calculating Soluble Sodium Percentage (SSP), Sodium Adsorption Ratio (SAR), Permeability Index (PI), Kelly's Ratio (KR), Magnesium Adsorption Ratio (MAR), and Residual Sodium Carbonate (RSC) using standard formulas.

Statistical and Geospatial Analysis: Pearson's correlation analysis was conducted to identify relationships between parameters. Piper trilinear diagrams and Gibbs plots were used for hydrochemical characterization. Spatial distribution maps for all parameters and indices were generated using the Inverse Distance Weighted (IDW) interpolation technique in ArcGIS 10.3.

3. RESULTS

3.1. Physicochemical Characteristics

The results of the physicochemical analysis are summarised in Table 1 (see below). Most parameters, including pH, DO, BOD, COD, TDS, and major ions (except HCO_3^- post-monsoon), were within permissible limits set by WHO (2008) and BIS (2012). Notable exceptions include high Total Coliform counts at stations P3 (Panposh D/s) and P4 (Rourkela D/s), indicating faecal contamination. Total hardness classified the water as "very hard." Alkalinity (HCO_3^-) exceeded desirable limits at most stations during the post-monsoon season.

3.2. Irrigation Water Quality

The calculated irrigation indices confirmed the general suitability of the water for agricultural use. All SAR values were low (0.18-2.41), classifying the water as excellent (S1) with low sodium hazard. Similarly, SSP values were within safe limits (<60%). However, MAR values exceeded the 50% threshold at several stations (P1, P4, P5, P6, P7, P9, P10, P12 in pre-monsoon), indicating a potential magnesium hazard for soil structure. Kelly's Ratio was <1 at all stations except P9 in pre-monsoon, confirming low sodium levels. RSC values indicated an alkaline hazard during the post-monsoon season at over 80% of the stations.

3.3. Hydro-chemical Facies and Processes

Piper trilinear diagrams revealed that the water type across all stations and seasons is predominantly Ca^{2+}-Mg^{2+}-HCO_3^-, suggesting dominance of weathering of carbonate and silicate minerals. Gibbs plots indicated that rock-water interaction is the primary mechanism controlling the river's hydrochemistry.

3.4. Spatial Distribution and CCME WQI

The CCME WQI results showed clear spatial and temporal variations (Table 2). Water quality was poorest at stations P3 and P4 (downstream of Rourkela), classified as "Poor" in pre-monsoon and "Marginal" in post-monsoon. The water quality generally improved from upstream to downstream in the lower basin and showed improvement post-monsoon due to the diluting effect of rainfall (fig:2). Stations in less impacted areas (P1, P6, P7, P8) consistently showed "Good" water quality.

.**Table 1**: Statistical Summary of Water Quality Parameters (2017-2024)

Water Quality Parameter	**Pre-Monsoon Season (2017-2024)**			**Post-Monsoon Season (2017-2024)**		
	Min	**Max**	**Avg ± SD**	**Min**	**Max**	**Avg ± SD**
pH	6.60	8.40	7.26 ± 0.43	7.00	8.10	7.57 ± 0.37
DO (mg/L)	6.80	8.30	7.50 ± 0.52	6.90	8.30	7.58 ± 0.49
BOD (mg/L)	0.75	4.50	1.80 ± 1.14	0.75	4.50	1.73 ± 1.18
TC (MPN/100ml)	1310.00	13222.00	3548.5± 3637.2	1310.00	13222.00	3618.0±3602.8
COD (mg/L)	6.30	18.30	11.82 ± 3.81	6.30	18.30	13.22 ± 3.67
TA (mg/L)	40.00	250.00	170.83± 66.29	50.00	660.00	559.17±243.40
TDS (mg/L)	150.00	1200.00	591.67± 277.94	74.00	622.00	262.25±140.30
TH (mg/L)	48.00	244.00	149.67± 53.71	55.00	365.00	206.67 ± 62.53
EC (µS/cm)	55.00	590.00	262.33± 137.19	90.00	240.00	189.25 ± 44.41
B (mg/L)	0.00	0.17	0.08 ± 0.08	0.03	0.17	0.08 ± 0.08
F^- (mg/L)	0.08	0.66	0.30 ± 0.20	0.20	0.66	0.33 ± 0.16
Ca^{2+} (mg/L)	6.70	57.10	28.18 ± 14.53	12.60	109.20	49.00 ± 25.91
Mg^{2+} (mg/L)	7.60	31.60	20.55 ± 7.67	3.20	30.40	20.53 ± 7.97
Na^+ (mg/L)	8.00	66.00	31.17 ± 21.13	7.00	111.00	33.51 ± 33.12
K^+ (mg/L)	0.20	1.32	0.63 ± 0.46	0.70	5.30	2.46 ± 1.68
Fe^{2+} (mg/L)	0.01	0.20	0.10 ± 0.07	0.02	0.09	0.04 ± 0.02
CO_3^{2-} (mg/L)	0.01	36.00	7.01 ± 10.80	0.00	180.00	38.00 ± 54.63
HCO_3^- (mg/L)	48.80	292.80	194.15± 77.42	61.00	1073.00	608.93± 66.40
Cl^- (mg/L)	15.00	179.90	41.66 ± 46.75	15.00	129.90	37.85 ± 34.18
SO_4^{2-} (mg/L)	0.50	45.70	7.64 ± 12.85	0.70	48.80	7.93 ± 13.59

Note: DO = Dissolved Oxygen; BOD = Biochemical Oxygen Demand; TC = Total Coliform; COD = Chemical Oxygen Demand; TA = Total Alkalinity; TDS = Total Dissolved Solids; TH = Total Hardness; EC = Electrical Conductivi

Table 2: CCME Water Quality Index Values and Status for Sampling Stations

Location No.	**Station**	**Pre-Monsoon WQI**	**Pre-Monsoon Status**	**Post-Monsoon WQI**	**Post-Monsoon Status**
P1	Sankh U/s	80.48	Good	81.49	Good
P2	Koel U/s	70.98	Fair	74.87	Fair
P3	Panposh D/s	39.32	Poor	45.11	Marginal
P4	Rourkela D/s	43.48	Poor	53.16	Marginal
P5	Bonagarh	79.44	Fair	82.84	Good
P6	Rengali	85.47	Good	84.88	Good
P7	Samal	84.60	Good	81.20	Good
P8	Talcher U/s	85.19	Good	84.82	Good
P9	Dhekhanal U/s	77.66	Fair	52.52	Marginal
P10	Bhuban	73.18	Fair	83.85	Good
P11	Dharmasala	85.08	Good	73.71	Fair
P12	Pottamundai	82.02	Good	60.46	Fair

Note: U/s = Upstream; D/s = Downstream. WQI Status: Excellent (95–100), Good (80–94), Fair (60–79), Marginal (45–59), Poor (0–44).

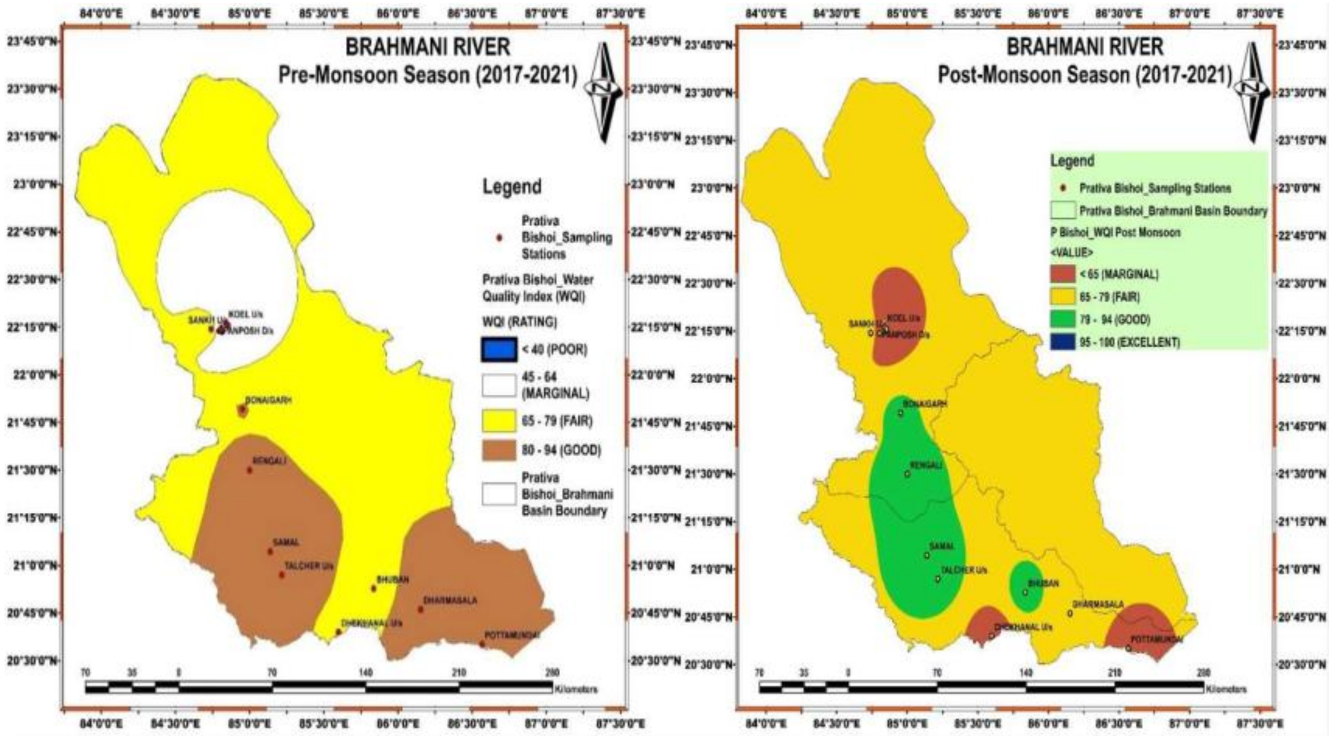

Figure 2. Spatial distribution of CCME WQI in the pre-monsoon and post-monsoon periods

4 DISCUSSION

The findings of this study are consistent with global research on river systems impacted by anthropogenic activities. The deterioration of water quality downstream of urban centers (Rourkela) is a common phenomenon, primarily driven by the discharge of untreated or partially treated municipal and industrial wastewater (Kumar et al., 2022). The high coliform counts at these locations pose a significant health risk and highlight a critical failure in wastewater management infrastructure.

The Ca^{2+}-Mg^{2+}-HCO_3^- hydrochemical facies is typical of river waters in regions with carbonate rock geology and aligns with findings in other Indian peninsular rivers (Adimalla, 2021). The positive correlations between Na^+ and Cl^-, and between Ca^{2+} and SO_4^{2-}, suggest dissolution of halite and gypsum/anhydrite minerals as significant contributors to the ionic load.

The assessment for irrigation suitability yields largely positive results. The low SAR and SSP values indicate that long-term use of this water for irrigation is unlikely to cause soil sodicity and permeability issues. However, the elevated MAR at multiple stations is a concern, as high magnesium can adversely affect soil structure, making it compact and impermeable (Ravikumar et al., 2011). This necessitates careful soil management practices, such as the application of gypsum, in areas using this water for irrigation. The high RSC values post-monsoon further indicate a potential for increasing soil alkalinity.

The CCME WQI effectively synthesized complex multi-parameter data into a simple, communicative tool for policymakers. The spatial maps generated through GIS are invaluable for identifying pollution hotspots and prioritizing areas for remedial action.

5 CONCLUSION

The overall water quality of the Brahmani River is acceptable for most uses but is significantly impaired near urban and industrial areas, particularly downstream of Rourkela. The hydrochemistry of the river is primarily controlled by rock-water interactions, yielding a calcium-magnesium-bicarbonate water type. The river water is generally suitable for irrigation with low sodium hazard, but potential magnesium hazard and residual alkalinity require attention and management. The integration of traditional water quality analysis with WQI, irrigation indices, and GIS techniques provides a robust framework for holistic water resource assessment and management. The discharge of untreated wastewater is the primary cause of water quality degradation, underscoring the urgent need for improved wastewater treatment infrastructure and stricter enforcement of environmental regulations throughout the basin.

Author Contributions:

Prativa Priyadarsini Bishoi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software. Chitaranjan Dalai: Validation, Visualization, Writing – original draft. Dr. Deba Prakash Satapathy: Supervision, Project administration, Resources, Validation, Writing – review & editing.

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