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Hydrochemical and Environmental Assessment of Sai River in Pratapgarh Region, Uttar Pradesh

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Abstract

This study presents a comprehensive assessment of the Sai River within the Pratapgarh region of Uttar Pradesh, India. The Sai River, a significant tributary of the Gomti River in the Ganga basin, plays a vital role in the agricultural, industrial, and domestic water requirements of the region. Water samples were collected from six strategic locations along the river course within Pratapgarh district during both pre-monsoon and post-monsoon seasons of 2024. These samples were analyzed for 22 physicochemical parameters including temperature, pH, electrical conductivity, total dissolved solids, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, major ions, nutrients, and heavy metals. Results indicate seasonal variations in water quality with significant deterioration observed near urban settlements and industrial zones. The Water Quality Index (WQI) calculations revealed that water quality ranged from "good" in upstream agricultural areas to "poor" in downstream segments receiving untreated effluents. Principal Component Analysis and Hierarchical Cluster Analysis identified anthropogenic pollution, agricultural runoff, and geogenic factors as the primary contributors to water quality variations. This study provides crucial baseline data for effective water resource management and pollution control strategies for the Sai River basin in the Pratapgarh region.

Keywords: Sai River, Pratapgarh, physicochemical parameters, seasonal variation, water quality index, multivariate analysis, pollution

sources

1. Introduction

Rivers are essential freshwater resources that support diverse ecosystems and human activities. In India, rivers hold cultural, religious, and economic significance while providing water for irrigation, industry, and domestic consumption. However, rapid urbanization, industrialization, and agricultural intensification have led to severe degradation of river water quality across the country (Singh et al., 2021). The Ganga basin, which covers approximately 26% of India's land area, has been particularly affected by these anthropogenic pressures (Rai et al., 2019). The Sai River, an important tributary of the Gomti River in the Ganga basin, originates in Hardoi district and flows through several districts of Uttar Pradesh including Pratapgarh before joining the Gomti River. The river holds significant importance for the region's agricultural productivity, serving as a primary irrigation source for thousands of hectares of farmland (Srivastava et al., 2020). The Pratapgarh region, situated in the eastern part of Uttar Pradesh, relies heavily on the Sai River for its agricultural, industrial, and domestic water requirements. Despite its importance, comprehensive studies on the water quality of the Sai River, particularly within the Pratapgarh region, are limited. Previous research has primarily focused on the main stem of the Ganga River or its larger tributaries, leaving gaps in our understanding of smaller yet significant rivers like Sai (Kumar et al., 2018; Tiwari et al., 2022). This lack of data hampers effective water resource management and pollution control efforts in the region.

The specific objectives of this research include:

1. Determination of key physicochemical parameters of Sai River water at selected sampling sites in Pratapgarh district
2. Assessment of seasonal variations in water quality during pre-monsoon and post-monsoon periods
3. Evaluation of the spatial distribution of pollutants along the river course
4. Calculation of Water Quality Index (WQI) to categorize water quality for different uses
5. Identification of major pollution sources using multivariate statistical techniques
6. Recommendation of appropriate mitigation measures for sustainable management of the river

This study provides valuable baseline data that can inform policy decisions, guide pollution control strategies, and facilitate sustainable water resource management in the region. The findings also contribute to the broader understanding of river water quality dynamics in agriculturally intensive regions of northern India.

2. Materials and Methods

2.1 Study Area

The study area encompasses the Sai River within the administrative boundaries of Pratapgarh district, Uttar Pradesh, India. Pratapgarh district (25°342N latitude and 81°192E longitude) is situated in the eastern part of Uttar Pradesh and covers an 3,717 km² area. The district has a population of about 3.2 million (Census 2011) with agriculture being the primary occupation. The climate of the region is subtropical with hot summers (maximum temperature reaching 45°C in May-June) and cold winters (minimum temperature dropping to 5°C in December-January). The average annual rainfall is about 1000 mm, with approximately 80% occurring during the July-September.

The Sai River flows for approximately 60 km through Pratapgarh district, primarily in a southeast direction. The river basin in this region is characterized by alluvial plains with fertile soil suitable for intensive agriculture. Major crops grown in the area include rice, wheat, pulses, and sugarcane. Several small-scale industries, primarily food processing units, textile mills, and brick kilns, are situated along the river course, particularly near urban settlements.

2.2 Sampling Strategy

Six sampling stations (S1-S6) were established along the Sai River within Pratapgarh district based on accessibility, proximity to potential pollution sources, and representation of different land use patterns. The geographical coordinates and characteristics of each sampling site are presented in Table 1.

Details of sampling locations along the Sai River in Pratapgarh district-

Water samples were collected during two seasons: pre-monsoon (May 2024) and post-monsoon (October 2024) to account for seasonal variations in water quality parameters. At each sampling site, three replicates were collected to ensure the reliability of the data.

2.3 Sample Collection and Preservation

Water samples collected from approximately 30 cm below of water surface in the middle of the river channel using pre-cleaned polyethylene bottles following standard procedures described in APHA (2017). For (DO) analysis, samples were collected in BOD bottles and fixed immediately with Winkler's reagents on-site.

We collected separate samples for heavy metal analysis using acid-washed polyethylene bottles, which were then acidified with concentrated HNO to keep the pH under 2. In the field, we measured temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) on-site with a multi-parameter water quality analyzer (Model: Hach HQ40d). All samples were properly labeled, stored in ice-filled cooler boxes, and transported to the laboratory within 6 hours of collection. In the laboratory, samples were stored at 4°C until analysis, which was completed within the recommended holding time for each parameter.

Analytical methods for water quality parameters

2.5 Quality Control

To ensure the reliability and accuracy of analytical results, strict quality control measures were implemented throughout the study.

These included:

1. Analysis of procedural blanks to check for contamination during sample processing
2. Analysis of duplicate samples (10% of total samples) to assess analytical precision
3. Use of certified reference materials for instrument calibration
4. Participation in inter-laboratory comparison exercises
5. Regular calibration of all instruments and equipment

The precision of analytical methods was evaluated by calculating the relative percent difference (RPD) between duplicate analyses, which was maintained below 10% for all parameters. The accuracy was assessed using percent recovery of known additions, which ranged from 90% to 105% for various parameters.

2.6 Water Quality Index (WQI) Calculation

The Water Quality Index (WQI) was determined to give a simple numerical representation of the overall quality of water by considering several water quality parameters. We calculated the WQI using the weighted arithmetic index method, which was originally outlined by Brown et al. (1970) and later adjusted by Tyagi et al. (2013).

The calculation involved the following steps:

1. Assignment of weight (wi) to each parameter based on its relative importance for aquatic ecosystem and human health
2. Calculation of quality rating scale (qi) for each parameter using the equation: $qi = [(Ci - Ci0) / (Si - Ci0)] \times 100$ where Ci is the concentration of each parameter, Ci0 is the ideal value (usually zero for all parameters except pH and DO), and Si is the standard permissible value as per Bureau of Indian Standards (BIS 10500:2012)
3. Calculation of sub-index (SIi) for each parameter: $SIi = wi \times qi$
4. Determination of WQI as the sum of all sub-indices: WQI = “SIi

The computed WQI values were categorized as: <50 (excellent), 50-100 (good), 100-200 (poor), 200-300 (very poor), and >300 (unsuitable for drinking).

2.7 Statistical Analysis

We carried out statistical analyses using IBM SPSS Statistics 26.0 and R software (version 4.1.0). For all the parameters, we calculated descriptive statistics. To check the data distribution, we used the Shapiro-Wilk test. To assess seasonal variations in water quality parameters, we utilized paired t-tests or Wilcoxon signed-rank tests depending on whether the data was normally distributed. For spatial variations, we implemented one-way ANOVA or Kruskal-Wallis tests, followed by the appropriate post-hoc tests.

3. Results and Discussion

3.1 General Physicochemical Parameters

The results of physicochemical parameters of the Sai River water at different sampling stations during pre-monsoon and post-monsoon seasons are presented in Table 3. The data represent the mean values of three replicates collected at each sampling site.

Mean values of physicochemical parameters at different sampling stations during pre-monsoon and post-monsoon seasons

3.1.1 Temperature

Water temperature exhibited distinct seasonal changes, reaching higher levels during the pre-monsoon season (31.2-32.8°C) compared to the post-monsoon season (24.7-26.3°C). This seasonal trend aligns with the local climate, which features warm summers and moderately chilly winters. Among all the sampling locations, S4 (Kunda) recorded the highest temperatures across both seasons, likely due to heated effluents from nearby small-scale industries. These temperature fluctuations impact the solubility of gases, chemical reactions, and the metabolic activities of aquatic organisms (Srivastava et al., 2018).

3.1.2 pH

In the Sai River, pH levels varied from 7.6 to 8.4 during the pre-monsoon season and 7.3 to 8.1 in the post-monsoon, suggesting slightly alkaline conditions. All readings fell within the acceptable range (6.5-8.5) set by BIS standards for drinking water. The slightly higher pH values during pre-monsoon may be linked to increased photosynthesis driven by higher solar radiation, which decreases CO levels in the water and raises pH (Kumar and Sharma, 2019). The highest pH values were noted at station S4, where industrial effluents containing alkaline substances are present.

3.1.3 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

Pre-monsoon EC values ranged from 425 to 1032 ìS/cm, while post-monsoon values spanned 315 to 785 ìS/cm. Similarly, TDS varied from 273 to 662 mg/L during the pre-monsoon and 202 to 503 mg/L in the post-monsoon period. There was a noticeable spatial trend where values increased from S1 to S4 and decreased again towards S6. The elevated readings at S3 and S4 suggest significant ionic contributions from urban and industrial areas. The lower values seen in the post-monsoon season can be attributed to dilution effects from increased river flow following the rains.

TDS exceeded the acceptable BIS limit (500 mg/L) at stations S3 and S4 in the pre-monsoon season, indicating moderate pollution in those areas. High TDS levels can affect water taste and potentially cause gastrointestinal discomfort in sensitive individuals (Verma et al., 2021).

3.1.4 Total Suspended Solids (TSS)

TSS showed an opposite trend, with higher values recorded during the post-monsoon season (87-224 mg/L) compared to the pre-monsoon period (42-157 mg/L). This is likely due to increased runoff during the monsoon, which carries a substantial amount of suspended materials into the river. The distribution of TSS mirrored that of EC and TDS, peaking at S4 due to cumulative upstream contributions and local discharges.

3.1.5 Dissolved Oxygen (DO)

DO levels ranged from 3.7 to 6.8 mg/L in the pre-monsoon season and from 4.8 to 7.5 mg/L after the monsoon. The lower DO levels seen in the pre-monsoon can be linked to higher temperatures (which reduce oxygen solubility) and increased microbial activity due to higher organic loads. During pre-monsoon, DO levels dropped below the 5 mg/L minimum requirement for drinking water at S3 and S4, and at S4 in the post-monsoon, indicating organic pollution at these locations.

There was a clear decline in DO from S1 to S4, followed by recovery towards S6, suggesting that pollution loads from urban (S3) and industrial zones (S4) have a negative impact, but natural recovery processes such as reaeration and self-purification are evident downstream.

3.1.6 Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

BOD values ranged from 2.3 to 12.7 mg/L during pre-monsoon and 1.8 to 9.8 mg/L post-monsoon. COD values varied from 8.2 to 42.3 mg/L in pre-monsoon and 6.4 to 34.9 mg/L afterward. BOD and COD were consistently above the safe limits for drinking water at S3, S4, S5, and S6 through both seasons, indicating substantial organic pollution.

The spatial pattern of BOD and COD resembled that of other pollution indicators, with the highest values recorded at S4. The elevated BOD and COD levels at S3 and S4 are likely due to untreated or partially treated domestic sewage from Pratapgarh city and industrial discharges from the Kunda area, respectively. The drop in values during the post-monsoon can be attributed to dilution and enhanced microbial breakdown, promoted by better conditions.

3.2 Major Ions and Nutrients

The concentrations of major ions and nutrients in the Sai River water at various sampling sites during the pre-monsoon and post-monsoon seasons are summarized in Table 4.

3.2.1 Hardness and Major Cations

The total hardness of the river water ranged from 148 to 308 mg/L during the pre-monsoon and from 112 to 232 mg/L post-monsoon. The increased values during the pre-monsoon may result from heightened evaporation and reduced flow, leading to more concentrated dissolved salts. While hardness levels surpassed the desirable limit (200 mg/L) at most sites, they remained well below the permissible threshold (600 mg/L), classifying the water as moderately hard to hard.

Calcium and magnesium, the main contributors to hardness, showed similar spatial and seasonal trends. Their concentrations were compliant with permissible levels across all sites in both seasons, except for a slight exceedance of calcium at S4 during the pre-monsoon. The order of dominant cations was $Ca^{2}z > Naz > Mg^{2}z > Kz$ at all locations, consistent with region-specific freshwater systems.

Sodium and potassium exhibited greater spatial variability than calcium and magnesium, being significantly higher at S3 and S4. This suggests anthropogenic inputs, mainly from domestic sewage rich in sodium and potassium.

3.2.2 Major Anions

Among the major anions, chloride concentrations were the highest, followed by sulfate. Pre-monsoon chloride levels varied from 28 to 112 mg/L and post-monsoon values ranged from 22 to 86 mg/L. Despite spatial variations, chloride levels remained well within the permissible limit (250 mg/L) at all sites. The elevated chloride at S3 and S4 likely results from domestic sewage contributions since chloride is a conservative indicator of sewage pollution.

Sulfate values followed a similar trend to chloride but were at lower levels (16-58 mg/L pre-monsoon and 12-44 mg/L post-monsoon). All values remained below the permissible limit (200 mg/L), showing minimal pollution from sulfate-rich sources.

Fluoride levels were relatively low (0.42-0.78 mg/L during pre-monsoon and 0.36-0.65 mg/L post-monsoon), which stayed within the permissible level (1.0 mg/L) at all sites, indicating mainly natural sources rather than anthropogenic ones.

3.2.3 Nutrients

Nitrate concentrations spanned from 3.6 to 11.4 mg/L during the pre-monsoon season and from 2.8 to 8.9 mg/L in the post-monsoon period. Although all measurements were below the permissible limit (45 mg/L), higher concentrations at S3, S4, and S5 hint at agricultural runoff and domestic sewage influences. The lower readings post-monsoon are likely due to dilution and uptake by aquatic plants during their growth phase.

Phosphate levels showed notable variations, ranging from 0.18 to 1.42 mg/L in pre-monsoon and 0.14 to 1.12 mg/L post-monsoon. The elevated values at S3 and S4 indicate that domestic sewage, typically high in phosphates from detergents and human waste, influences these readings. Though specific phosphate standards for drinking water do not exist, concentrations exceeding 0.1 mg/L generally indicate anthropogenic pollution. The heightened phosphate levels observed at numerous sampling sites signal a potential risk for eutrophication, particularly during low-flow conditions.

3.3 Heavy Metals

The concentrations of selected heavy metals in the Sai River water across various sampling sites during both pre-monsoon and post-monsoon seasons are shown in Table 5.

Among the analyzed heavy metals, iron had the highest concentrations, followed by zinc, copper, and lead. Iron levels exceeded the permissible limit (0.3 mg/L) at all sampling sites in both seasons, with higher concentrations observed during the post-monsoon period. This seasonal variation is distinct from many other parameters and likely relates to increased runoff during the monsoon, which carries iron-rich sediments from the surrounding area. The high iron levels may primarily result from natural geological features associated with the alluvial sediments in the region.

Zinc concentrations remained below the permissible limit (5.0 mg/L) at all sampling locations, ranging from 0.05 to 0.26 mg/L during pre-monsoon and post-monsoon measurements.

Zinc levels were clearly below the permissible limit (5.0 mg/L) at all sites, with readings of 0.05 to 0.26 mg/L during pre-monsoon and 0.04 to 0.20 mg/L post-monsoon. Spatially, higher concentrations were found at S3 and S4 due to inputs from industrial discharges and urban runoff.

Copper levels ranged from 0.012 to 0.064 mg/L during pre-monsoon and from 0.009 to 0.048 mg/L during post-monsoon. They surpassed the permissible limit (0.05 mg/L) only at S4 during the pre-monsoon period. Copper also exhibited a similar spatial pattern with elevated levels at S3 and S4, reflecting urban and industrial pollution.

Lead concentrations ranged from 0.004 to 0.023 mg/L in the pre-monsoon and from 0.003 to 0.018 mg/L in the post-monsoon period. Values exceeded the permissible limit (0.01 mg/L) at S3, S4, and S5 during the pre-monsoon and at S3 and S4 in the post-monsoon. The presence of lead above acceptable limits at various sites raises concerns, as lead is a harmful heavy metal with no known biological role and poses serious health risks even at low levels. Lead in the Sai River likely stems from industrial discharges, vehicular emissions that settle via atmospheric deposition, and leachate from nearby solid waste dumps.

3.4 Water Quality Index (WQI)

To provide a cohesive measure of water quality, the Water Quality Index (WQI) was calculated for each sampling site across both seasons. The results are detailed in Table 6 and depicted in Figure 1.

WQI values varied from 42.7 to 156.2 during pre-monsoon and from 36.5 to 126.8 in the post-monsoon season. Based on WQI rankings, water quality was classified as “Good” at stations S1, S2, and S6 throughout both seasons. Water quality shifted from “Poor” to “Good” at S3 and S5 from pre-monsoon to post-monsoon, illustrating the significant effect of seasonal flow fluctuations on water quality. S4 consistently exhibited “Poor” water quality during both seasons, highlighting ongoing pollution challenges.

The overall increase in WQI during the post-monsoon season can be attributed to higher river flows, which facilitate dilution and enhance self-purification. The spatial WQI pattern mirrors the cumulative effects of various pollutant sources along the river, showing a general decline from S1 to S4, followed by gradual recovery towards S6 due to natural processes.

3.5 Statistical Analysis

3.5.1 Correlation Analysis

To uncover relationships among different water quality parameters, Pearson’s correlation analysis was conducted. The correlation matrix for the pre-monsoon period is presented in Table 7 (the post-monsoon correlation matrix followed similar patterns and is not shown here).

Strong positive correlations ($r > 0.9$) were noted between EC, TDS, BOD, COD, and most nutrients and heavy metals, suggesting these parameters may stem from common origins or be affected by similar processes. A strong negative correlation between DO and various pollution indicators (BOD, COD, nutrients, and heavy metals) indicates that organic and inorganic pollutants deplete oxygen levels. This correlation pattern shows domestic sewage and industrial discharges as major contributors to water quality decline in the Sai River within the Pratapgarh region.

3.5.2 Principal Component Analysis (PCA)

PCA was employed on normalized data to identify the primary factors driving water quality variations. In the pre-monsoon season, three principal components (PCs) with eigenvalues exceeding 1 were extracted, accounting for 93.7% of the total variance in the dataset (see Table 8).

PC1, which accounted for 74.5% of the total variance, exhibited high loadings for EC, TDS, BOD, COD, chloride, phosphate, and most heavy metals. This component represents anthropogenic pollution from domestic sewage and industrial inputs. PC2, explaining 13.5% of the variance, had high loadings for TSS, iron, and nitrate, linked to agricultural runoff and soil erosion. PC3, contributing 5.7% to total variance, was influenced by temperature and fluoride, representing natural or geogenic factors.

The PCA results for the post-monsoon period revealed a similar pattern with some differences in variance distribution, highlighting seasonal shifts in pollution sources and water flow conditions.

3.5.3 Hierarchical Cluster Analysis (HCA)

HCA was utilized to classify sampling sites based on their water quality characteristics. The dendrogram for the pre-monsoon season (refer to Figure 2) indicated three distinct clusters:

Cluster 1: S1 and S2 (cleaner sites in upstream agricultural areas)

Cluster 2: S3, S5, and S6 (moderately polluted sites with mixed influences)

Cluster 3: S4 (heavily polluted site near the industrial zone)

This clustering reflects the spatial water quality variations, with a clear distinction between relatively pristine upstream locations, moderately polluted areas, and heavily contaminated industrial sites. The post-monsoon HCA results demonstrated consistent groupings, reaffirming prevailing spatial patterns despite fluctuations in pollution intensity across seasons.

4. Environmental Implications and Management Strategies

4.1 Environmental Implications

This study’s findings carry several environmental implications for the Sai River ecosystem and the communities that rely on it:

Water Quality Degradation: The ongoing decline in water quality from upstream to downstream, particularly near urban and industrial zones (S3 and S4), signals substantial anthropogenic pressure on the river ecosystem. Elevated levels of organic pollutants (BOD, COD), nutrients (nitrate, phosphate), and heavy metals (notably lead) at these sites threaten aquatic life and human health.

Potential for Eutrophication: High phosphate levels at multiple sampling sites, especially during the pre-monsoon season, highlight a risk of eutrophication. This could result in excessive algal blooms, oxygen depletion, and subsequent ecological imbalance within the river.

Heavy Metal Contamination: The detection of lead above permissible limits at several sites is alarming due to its toxic properties and potential for bioaccumulation in the aquatic food web. This can pose long-term health threats to both aquatic organisms and humans consuming river fish or using the water for domestic purposes.

Seasonal Vulnerability: Overall lower water quality during the pre-monsoon season points toward the river ecosystem's susceptibility during low-flow periods. Limited dilution during this time exacerbates pollution impacts, leading to conditions that may be critically harmful to aquatic life.

Impact on Water Uses: Given the WQI readings, water from stations S3, S4, and S5 during pre-monsoon, and S4 in post-monsoon, may be unsafe for direct domestic use without appropriate treatment. This situation affects the availability of safe water for local communities, particularly in rural areas with limited access to advanced treatment systems.4.2 Proposed Management Strategies

Based on the findings of this study, the following management strategies are proposed for sustainable management of the Sai River within the Pratapgarh region:

1.Source Control Measures:

- o Implementation of proper sewage treatment facilities in Pratapgarh city to reduce organic and nutrient loads entering the river at S3
- o Enforcement of stricter effluent standards for industries in the Kunda area (S4) with regular monitoring and compliance checks
- o Promotion of organic farming practices and controlled use of agrochemicals in the agricultural areas to reduce nutrient runoff

2.In-stream Management:

- o Installation of artificial aeration systems at critical locations (S3 and S4) to increase dissolved oxygen levels, particularly during the pre-monsoon season
- o Periodic dredging of sediments in heavily polluted stretches to remove accumulated contaminants
- o Development of riparian buffer zones with native vegetation to filter runoff and stabilize banks

3.Institutional and Policy Measures:

- o Establishment of a dedicated river basin management authority for the Sai River with representation from all stakeholders
- o Development of a comprehensive water quality monitoring program with real-time data acquisition and public dissemination
- o Implementation of the "polluter pays" principle to generate funds

for river restoration activities

4.Community Engagement:

- o Awareness programs for local communities regarding the importance of river conservation and sustainable water use
- o Involvement of local communities in monitoring and reporting pollution incidents
- o Promotion of traditional water conservation practices and cultural values associated with the river

5.Research and Innovation:

- o Detailed ecological assessment of the river to understand the impact of pollution on aquatic biodiversity
- o Investigation of innovative, low-cost water treatment technologies suitable for rural communities
- o Development of predictive models for water quality management, incorporating climate change scenarios

The implementation of these strategies requires coordinated efforts from government agencies, local authorities, industries, academic institutions, and community organizations. A phased approach with clear timelines, responsibilities, and monitoring mechanisms would be essential for effective implementation.

5. Conclusions

This comprehensive study of the Sai River within the Pratapgarh region has provided valuable insights into the spatial and temporal variations of various physicochemical parameters and their implications for water quality and environmental health. The key conclusions drawn from this research are:

1. The water quality of the Sai River shows significant spatial variations, with progressive deterioration from upstream agricultural areas to downstream urban and industrial zones, followed by partial recovery due to natural self-purification processes.
2. Seasonal variations in water quality are pronounced, with generally poorer conditions during the pre-monsoon season due to reduced flow and increased concentration of pollutants.
3. Based on the Water Quality Index, water quality ranges from “Good” in upstream agricultural areas (S1 and S2) to “Poor” in sections receiving urban sewage (S3) and industrial effluents (S4).
4. The principal sources of pollution in the river include domestic sewage from Pratapgarh city, industrial effluents from the Kunda area, and agricultural runoff from surrounding farmlands.
5. Heavy metal contamination, particularly of lead, at multiple sampling sites poses potential risks to both aquatic organisms and human populations dependent on the river.

6. Statistical analyses (PCA and HCA) revealed that anthropogenic pollution, agricultural runoff, and geogenic factors are the primary contributors to water quality variations in the river.
7. The current state of the Sai River calls for immediate implementation of comprehensive management strategies focusing on source control, in-stream management, institutional frameworks, community engagement, and innovative research.

This study provides a baseline for future monitoring and management efforts for the Sai River within the Pratapgarh region. The findings highlight the need for integrated water resource management approaches that balance development needs with environmental conservation objectives. Regular monitoring of water quality parameters, particularly during critical low-flow periods, would be essential to assess the effectiveness of management interventions and to ensure the long-term sustainability of this vital river ecosystem.

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