Evaluating Water Quality In Indian Sundarban Estuaries Using Remote Sensing

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ABSTRACT
This study uses in-situ data analysis and remote sensing to examine the water quality of the Indian Sundarban estuaries. Along the main estuarine channels, it continuously measures salinity, turbidity, suspended sediment concentration, and chlorophyll-a concentration, among other crucial water quality parameters. The water quality parameters were retrieved using atmospheric and geometric correction techniques, where Landsat 8 and Sentinel-2 satellites' remote sensing data were used input which were then processed using established algorithms and empirical models. Existing field campaigns served as validation with in-situ measurements for remote sensing estimates. To evaluate the relationship between in-situ data and estimations acquired from satellites, correlation analysis was done. A high spatial-temporal variability of water quality was observed. In river discharge and tidal current affected areas, turbidity and suspended sediment concentrations were higher, especially through the monsoon season. Enhanced productivity was observed in the western and central regions, with chlorophyll-a concentrations peaking in pre- and post-monsoon season. Strong correlations (R2 > 0.78) between in-situ measurements and remote sensing estimates were found by the estimation accuracies. The study emphasizes how crucial the tidal cycle is, seasonal variability, and anthropogenic effects on estuarine water quality. Such an integrated approach is informative when it comes to conservation and sustainable management of the Sundarbans.

Keywords: *Indian Sundarbans; Water quality; Remote sensing; Estuaries; Turbidity.*

1. INTRODUCTION

Background

One of the most important locations of the Indian Sundarbans, its UNESCO World Heritage Site status, makes up the world's largest contiguous mangrove forest and is a deltaic environment created by the Ganges, Brahmaputra and Meghna. This distinctive environment sustains and enriches the rich biological diversity including endangered species such as the Bengal tiger, Gangetic dolphin, and many avian populations. The Sundarbans are also important for ecosystem services delivery (including coastal protection, carbon sequestration and fisheries that support millions of people across the region). However, the water quality of Sundarban estuaries is increasingly threatened by a range of anthropogenic pressures, such as industrial and agricultural runoff, sewage disposal and unsustainable fishing practices. These actions release effluents, nutrients and sediment into water which can result in eutrophication, habitat alteration and human health risks.

Water quality monitoring is a vital process to assess the ecosystem health of the Sundarban and to plan its management. Conventional monitoring methods involving field collection and laboratory analyses are typically too sparse spatially and temporally and are not practical or sustainable for recurring monitoring. Remote sensing is a potential approach, which have the synoptic and cost-effective characteristics to study water quality in extensive areas at hierarchical intervals. Using satellite imaging and analytical methods, it also offers useful

information on the temporal and spatial distribution of key water quality metrics (such as turbidity, chlorophyll-a concentration, and suspended sediment concentration).

Research Objectives

The purpose of this study is to use remote sensing methods to assess the water quality in the Indian Sundarban estuaries. The particular goals are:

- **Assess and map key water quality parameters:** to calculate quantitative estimates of the concentrations of suspended sediment, chlorophyll-a, and turbidity throughout the research region using satellite photos.
- **Analyze spatial and temporal variations:** to identify regions and times of concern by examining the temporal dynamics and spatial distribution of various water quality characteristics.
- **Evaluate the accuracy of remote sensing techniques:** to compare water quality estimations obtained from remote sensing with in-situ observations in order to evaluate their precision and dependability.
- **Analyze the relationship between remote sensing and in-situ data:** To investigate the relationship between field observations and data from remote sensing, as well as how remote sensing might enhance and supplement conventional monitoring techniques.

Research Questions

The following research questions are intended to be addressed by this study:

- What are the turbidity's temporal and geographical patterns, chlorophyll-a concentration, and suspended sediment concentration in the Indian Sundarban estuaries?
- How accurately can remote sensing techniques estimate these water quality parameters in this complex estuarine environment?

Significance of the Study

This research holds significant implications for the conservation and management of the Indian Sundarbans. By providing a comprehensive assessment of water quality using remote sensing, this study can contribute to:

- **Improved understanding of water quality dynamics:** Identifying areas and periods of water quality degradation can help guide targeted interventions and management strategies.
- **Enhanced monitoring capabilities:** Remote sensing can complement traditional monitoring efforts, providing a more spatially and temporally comprehensive assessment of water quality.
- **Early warning system:** Detecting changes in water quality through remote sensing can provide early warnings of potential pollution events or ecosystem degradation.
- **Informed decision-making:** The data produced by this study can help with well-informed decision-making for conservation and sustainable resource management initiatives in the Sundarbans.

Lastly, our work highlights the viability of using remote sensing as a useful tool for water quality monitoring in delicate ecosystems, particularly in areas with little information where conventional monitoring techniques might not be able to function well. This study demonstrates how successful remote sensing is in the Sundarbans and may encourage other areas to use similar methods for environmental preservation and water resource management.

2. METHODOLOGY

Study Area

A UNESCO World Heritage Site, the Indian Sundarbans are a huge and intricate estuarine environment situated in the Bay of Bengal, in the delta region of the Ganges, Brahmaputra, and Meghna rivers. This distinctive environment features a web of connecting channels, creeks, and mangrove forests, forming a dynamic and vulnerable ecological zone. The study area includes the main estuarine channels and water bodies of the Indian Sundarbans region — the Hooghly estuary, Saptamukhi estuary, Matla estuary, and the Thakuran estuary. They are influenced by a complex mix of freshwater inflow from rivers, tidal effects from the Bay of Bengal, and human activity in the nearby regions. The interplay of these factors creates a complex hydrological regime and modulates the water quality dynamics in the Sundarbans.

Data Acquisition

This project will use both in-situ data and remote sensing to evaluate the water quality in the Indian Sundarbans. Open-access satellite images, primarily from Landsat 8 (Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)) and Sentinel-2 (MultiSpectral Instrument (MSI)), will make up the remote sensing data. Such multispectral data with adequate spatial and temporal coverage can monitor the highly variable spatio-temporal patterns of estuarine water quality. Field campaigns will collect in-situ data on key water quality parameters at multiple locations in the study area. The parameters of interest are turbidity, chlorophyll-a concentration, suspended sediment concentration and salinity. Analyzing portable multi-parameter water quality probes and laboratory of water samples. The dataset will be longitudinal in nature, covering multiple seasons to account for seasonal variability in water quality.

Data Processing and Analysis

Preprocessing procedures will be applied to the remote sensing data to correct it and make it comparable to each other. The nature of the problems as you will see in the course the data will go through include atmospheric correction. The images will be geometrically corrected for accurate spatial registration. Using standard algorithms and empirical models, the parameters of water quality will be derived from the pre-processed satellite data. For example, turbidity will be predicted relying on algorithms through the reflectance of visible and near-infrared bands. Band ratio algorithms or machine learning models (trained on in-situ data) will allow derivation of chlorophyll-a concentration. The spatial distribution of water quality metrics within the research region will be mapped and visualized using geospatial analysis techniques. Point measurement will be used for continuous maps building by using the interpolation methods. Common statistical methods will be used for verifying interdependencies between the different water quality parameters, as well as to detect trends and patterns in the data. Compiling you the validation, correlation analysis will be conducted to assess the agreement between remote sensing-derived observations and in-situ measurements at each location.

3. DATA ANALYSIS

Table 1: Summary of In-situ Water Quality Measurements

Parameter	Mean	Standard Deviation	Minimum	Maximum
Turbidity (NTU)	25.5	8.2	12.1	42.8
Chlorophyll-a (µg/L)	12.3	4.5	5.6	21.9

Suspended Sediments (mg/L)	35.7	11.4	18.2	58.5
Salinity (psu)	22.8	3.6	18.5	28.1

The mean turbidity (25.5 NTU) is high with a standard deviation (8.2 NTU), which indicates significant variability of water clarity within the Sundarban estuaries, which might be particularly determined by the tide, river discharge, and sediment resuspension. The comparatively high chlorophyll-a levels (mean 12.3 µg/L) suggests that the waters are productive, thus providing space for diverse phytoplankton communities to thrive. While high levels of chlorophyll-a are also associated with nutrient loading and algal blooms, necessitating further investigation. This broad spectrum of salinity (18.5 to 28.1 psu) indicates an abundance of mixing between freshwater and saltwater in the estuarine setting and affects both the distribution of faunal species and ecological interactions.

Table 2: Accuracy Assessment of Remote Sensing-Derived Water Quality Parameters

Parameter	**Algorithm/Model**	**R^2**	**RMSE**
Turbidity	Empirical Relationship (Band Ratio)	0.85	4.2 NTU
Chlorophyll-a	Three-Band Model	0.78	2.8 µg/L
Suspended Sediments	Empirical Relationship (Reflectance)	0.82	6.5 mg/L

All parameters exhibit high R^2 values (greater than 0.78), suggesting that the chosen algorithms adequately captured the combination of data utilized for water quality variability observed in the in-situ measurements. The RMSE values also indicate slight differences between the estimated and measured values. For example, the RMSE of 4.2 NTU for turbidity indicates that the remote sensing estimates are probably uncertain, particularly in very turbid water. Compared with turbidity and suspended sediments, the relatively lower accuracy for estimating chlorophyll-a ($R^2 = 0.78$) was most likely attributed to the complex optical properties of chlorophyll-a and the interference of other optically active substances in the water."

Table 3: Correlation between Remote Sensing and In-situ Measurements

Parameter	**Pearson's Correlation Coefficient (r)**
Turbidity	0.92
Chlorophyll-a	0.88
Suspended Sediments	0.9

The importance of using remote sensing to monitor the water quality of the Sundarban estuaries is demonstrated by the strong positive correlations ($r > 0.88$) between the estimates obtained from remote sensing and in-situ observations of every parameter. The extremely strong correlations show that the remote sensing models are capable of accurately representing temporal and spatial variations in water quality, which may be gradually used in environmental monitoring and management. It's crucial to keep in mind, though, that correlation does not imply causality. The factors mediating the observed connections between the in-situ measurements and the remote sensing data require further investigation."

4. RESULT AND DISCUSSION

Analysis of Data the Indian Sundarban estuaries' water quality indicators varied significantly across time and space, according to remote sensing study. Spatial patterns of turbidity signified different higher values

connected with river discharge and tidal currents, especially during the monsoon season. Chlorophyll-concentrations were generally high in the western and central studio area, suggesting higher primary production in these zones. Similar seasonal fluctuations in chlorophyll-a were noted, Analysis of Data The Indian Sundarban estuaries' water quality indicators varied significantly across time and space, according to remote sensing study. Suspended sediment concentrations exhibited both spatial and temporal patterns consistent with turbidity, indicative of the high correlation between these two parameters.

The evaluation of model accuracy for remote sensing-based water quality quantities indicated that the chosen algorithms and models were successful in accounting for the variability seen in in-situ data. All parameters exhibited strong statistical correlations between the remote sensing estimates and in-situ data ($R^2 > 0.78$ for turbidity, chlorophyll-a, and suspended sediments). The results demonstrate the strong potential for utilizing remote sensing approaches for water quality monitoring of Sundarban estuarine systems, offering a relatively low-cost and spatially extensive alternative to more traditional data collection approaches of field sampling. By merging remote sensing and in situ data, this research produced a comprehensive view of Sundarbans water quality fluctuations. Furthermore, in-situ measurements revealed a spatiotemporal mismatch in the remote sensing data, demonstrating the accuracy of remote sensing as a source of information. The results revealed the significance of natural processes like tidal fluctuations, river flow and seasonal effects in regulating water quality across the Sundarbans. Moreover, the study identified some potential problems for the system, including site-specific hotspots of turbidity and suspended sediments that may be related to human influence. These learnings will help to plan management strategies and conservation practices to ensure the ecological integrity of the Sundarban estuaries.

5. CONCLUSION

The examination of remote sensing data showed that the water quality metrics in the Indian Sundarban estuary region varied significantly in both space and time. It showed clear spatial patterns, with predominantly higher turbidity in areas under the influence of river discharge in monsoon season and tidal currents. Chlorophyll-a concentrations were also higher in the western and central portions of the study area, representing greater phytoplankton productivity in these areas. The spatiotemporal patterns of chlorophyll-a were also identified, with high values observed during pre-monsoon and post-monsoon periods ascribed to nutrient enrichment and light promotion. Suspended sediment concentrations exhibited comparable spatial and temporal trends to turbidity, which can be attributed to the strong coupling between these two variables.

The accuracy evaluation of remote sensing-derived water quality parameters indicated the ability of the algorithms and models employed in this study to explicate the variability recorded by the in-situ measurements. The correlation between the trophic state parameters derived from remote sensing and in-situ data was consistent and high for all variables ($R^2 > 0.78$ for turbidity, chlorophyll-a and suspended sediments). All things considered, these findings suggest that current remote sensing methods can be effective instruments for tracking the water quality in the Sundarbans estuaries and can offer affordable and geographically extensive substitutes for expensive field sampling strategies. To get a comprehensive picture of the dynamics of water quality in the Sundarbans, remote sensing and in-situ data are combined. The variation both spatially and temporally in the remote sensing data were in agreement with those observed in the in-situ samples, hence further validating the reliability of the remote sensing approach. The study also emphasizes how natural factors, including tidal

cycles, discharge of rivers and seasonal variation affect water quality in the Sundarbans. The investigation also showed some local increases in turbidity and suspended sediments that may have a man-made cause. These discoveries can help guide management strategies and conservation initiatives to preserve the ecological health of the Sundarban estuaries.

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