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Application of Remote Sensing and GIS Techniques for Monitoring Water Quality Parameters of River Brahmani †

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Abstract: Monitoring condition and quality indicators within river water systems has emerged as a pressing priority due to the decline in water quality. This decline is primarily a result of improper disposal of household waste and the discharge of partially treated or untreated sewage and industrial effluents into the neighboring water bodies connected to the river systems. Conventional techniques for assessing water quality are costly and intricate and demand significant labor. Instead of relying on traditional field sampling methods, utilizing cost-effective satellite imagery holds considerable potential for the foreseeable future. This study employs LANDSAT-8 OLI imagery to assess the Brahmani River's water quality parameters over five years, from 2017 to 2021. The selected water quality parameters encompass Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), pH levels, Total Coliform (TC), and Fecal Coliform (FC). To determine the reflective values of all bands relevant to the aforementioned water quality parameters at their respective sampling sites, the Sentinel Application Platform (SNAP) tool was employed. Valuable insights were gained by establishing linear correlations between the water quality parameters and the reflective values of the bands and band ratios. Notably, the Pearson Correlation Coefficients revealed strong associations, with values of 0.892 for pH and B3/B7, 0.746 for DO and B1/B2, 0.814 for BOD and B7/B6, and 0.875 for FC and B6/B3. However, no robust correlation was observed between TC and any of the band ratios. The coefficients of determination for pH, DO, BOD, FC, and the corresponding band ratios (B3/B7, B1/B2, B7/B6, B6/B3) were calculated to be 0.796, 0.765, 0.772, and 0.766, respectively. Utilizing the outcomes of the linear regression analysis for pH, DO, BOD, and FC, predictions were made for the water quality parameters in the years 2020 and 2021. Impressively, a strong alignment was evident between the projected and observed values. This led to the conclusion that the established equations exhibited a noteworthy capacity to predict the water quality parameters for the Brahmani River accurately.

Keywords: water quality monitoring; remote sensing; satellite sensors; spectral signatures; geographic information system

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1. Introduction

Water is a critical natural resource essential for both human survival and the well-being of ecosystems [1]. Unfortunately, the rapid growth in population and industrial activities has led to contamination of surface and subsurface water quality due to the discharge of household and industrial waste into water bodies, resulting in various waterborne diseases [2]. To address these challenges, it is imperative to conduct regular water quality monitoring and management [3]. Present in-situ measurement methods for assessing water quality parameters are often laborious and need more accuracy and insight into the condition of water bodies [4].

Traditional water quality monitoring techniques are expensive, time-consuming, and unsuitable for large-scale analyses, thus constraining their spatial and temporal coverage [5,6]. Developing nations, in particular, face resource constraints when employing these methods [7]. Remote sensing (RS) emerges as a cost-effective solution, offering extensive spatial and temporal coverage of water bodies [8]. RS sensors capture water constituents' spectral signatures, enabling qualitative and quantitative estimation of water quality parameters [9]. Various RS sensors like Landsat, MODIS, and Sentinel-2 have successfully quantified water quality parameters in inland and coastal water bodies [10]. RS proves to be a valuable tool for effectively monitoring and managing water resources, often enhancing predictive capabilities through the development of remote sensing techniques [11]. This approach significantly surpasses the capabilities of traditional methods, making RS an ideal and cost-effective means of assessing water quality [12]. Furthermore, the availability of many satellite images to users at no cost further enhances its accessibility and utility [13].

A Geographic Information System (GIS) is a computer system that stores, analyzes, and visualizes the data referred to on Earth’s surface. This conceptualized framework enables us to capture and analyze geographic spatial data. ArcGIS software is a platform for creating, analyzing, managing, and sharing geographic information for GIS professionals [14]. In this software, the Mosaicking of bands, the Representation of shape files of specific areas, and the river's flow direction can be known. It is built around a geodatabase, which uses an object-relational database to store spatial data. SNAP Tool expands for Sentinel Application Platform Tool, which is widely used for processing and analysis of Earth Observation comprising a rapid image display and map reading even of giga-pixel images, and it is advantageous in new overlay addition and manipulation due to its advanced layer management. For the extraction of digital number/Reflectance values of pinned locations, there is a tool called Pin Manager in the SNAP tool.

Limited efforts have been made to utilize Land Sat-8 OLI data for assessing water quality parameters in Indian river systems [15]. Most research has focused on smaller water bodies such as lakes and creeks, often relying on limited in-situ measurements for water quality parameters [16]. To overcome this research gap, the main objective of our study is (i) to understand the relationship between in situ water quality measurements and reflectance values that are obtained from Landsat-8 OLI imagery, (ii) to derive the algorithms by regression analysis using in-situ field data of various water quality parameters, (iii) to use the generated algorithm for mapping of water quality parameters and (iv) to validate the final map results with field data and suggest which single band will be the most accurate one to predict the water quality parameter.

2. Study Area and Data Collection

The study area taken for measuring the water quality parameters is river Brahmani, which has a length of 799 km and is one of the second largest rivers in Odisha after Mahanadi. The coordinates of the river are 22°14′45′′N and 84°47′02′′E. Size of the basin is 39,033km^2. The selected study area is shown in Figure 1. To measure the water quality parameters, 13 sampling stations were selected, as shown in Figure S1, and the required data was downloaded from the State Pollution Control Board, Odisha website. The data have been downloaded for 2017 to 2021, in which 2017 to 2019 is taken for calibration and 2020 to 2021 is taken for validation, Table 1.

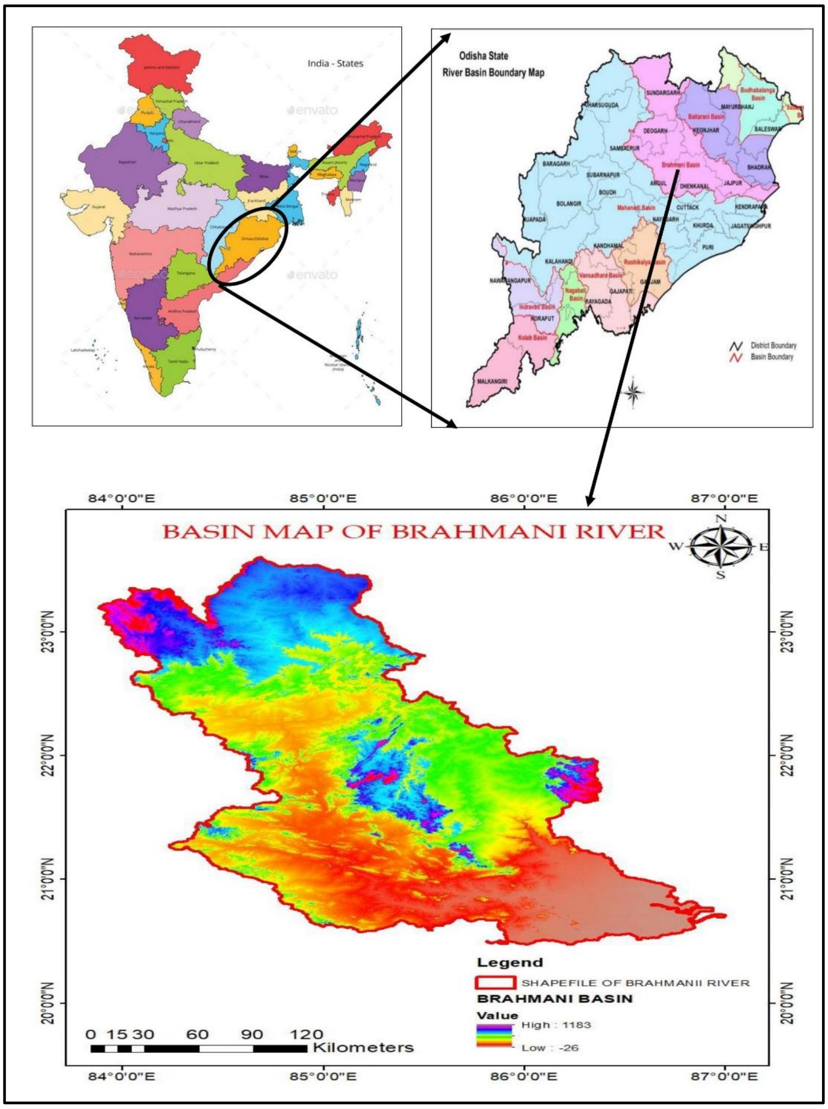


Figure 1. Study Area and Sampling Points along the Brahmani River, Odisha, India.

Table 1. Sources of various datasets utilized in the study.

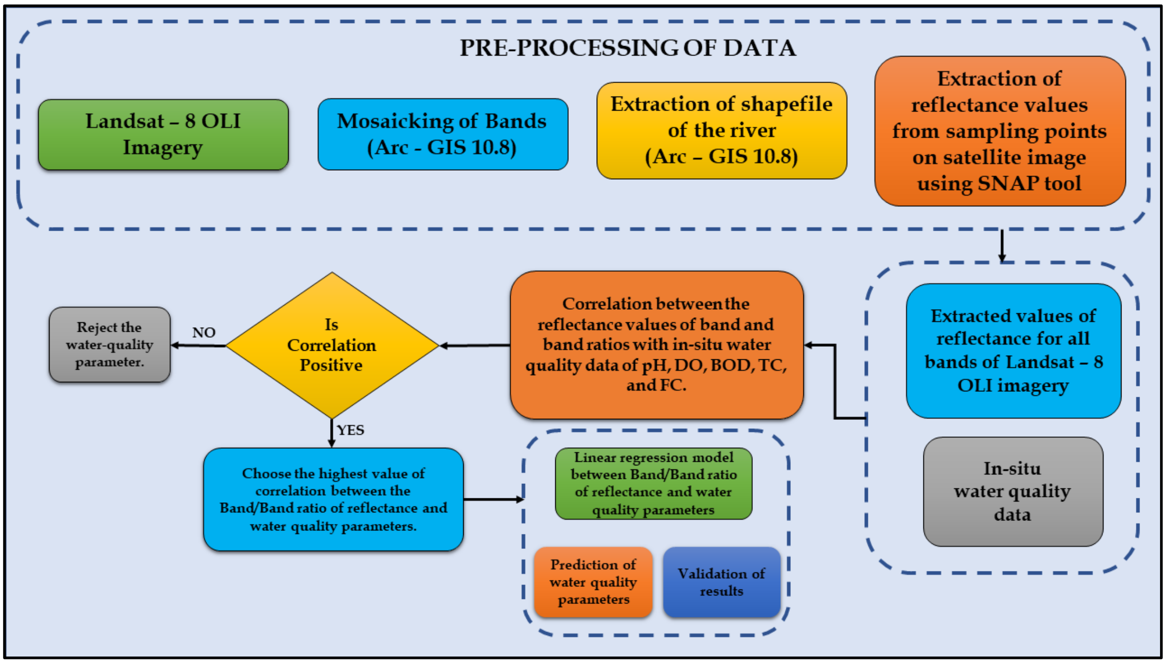
S. No	Data Set	Source	Year
01	Land Sat-8 OLI	USGS Earth Explorer	2017-2021
02	Brahmani River Shapefile	Google Earth Pro	-
03	Water Quality data	State Pollution Control Board, Odisha	2017-2021

3. Methodology

Figure 2 shows the flow chart illustrating the methodology adopted in monitoring the water quality parameters. To begin with, Landsat-8 OLI data is collected from the USGS Earth Explorer website, and the field data is collected from the State Pollution Control Board, Odisha. After downloading the Landsat data, it would be represented as a tile consisting of 7 bands in each tile, so combining all the tiles, Arc-GIS software is used. Then, the shape file of the river was extracted from Google Earth Pro using the polygon tool, and the selected sampling stations' reflectance values were extracted from the SNAP tool using the Pin Manager tool in which the coordinates are inserted of a particular station. By using the Arc-GIS software, converting the Excel sheets to CSV files, with the help of

IDW and extraction by masking the distribution of parameters like the potential of Hydrogen (pH), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), and Fecal Coliform (FC) are displayed. Spectral band combinations in remote sensing, such as those applied to Landsat-8 imagery, are specific groupings of different wavelengths of light captured by sensors onboard Earth-observing satellites. These combinations are carefully designed to enhance certain features or characteristics of the Earth's surface for various applications. Table S1 shows the combination of spectral bands applied to Landsat-8.

Figure 2. Methodology adopted in monitoring the water quality parameters**.**



4. Results and Discussion

The results from classified images were compared with the field data collected from the State Pollution Control Board, Odisha. The linear regression equations to predict the water quality parameters were obtained from the classified Landsat 8 image, and field data are summarized in Table 2. Pearson correlation matrix calculates the correlation between two variables, and a Pearson correlation coefficient value greater than 0.5 shows a strong correlation. Here, the dependent variables are water quality parameters, and the independent variables are reflectance values. The relation is developed between water quality parameters and reflectance values for 2017, 2018,2019,2020, and 2021. For the parameters pH, DO, BOD, and FC strongly correlate with the band ratios B3/B7, B1/B2, B7/B6, and B6/B3, respectively. The Pearson Correlation matrix for the existing dataset has been given in supplementary documents, Table S2.

Table 2. Regression equations of Water Quality Parameters.

S.No.	Water Quality Parameters	Pearson Correlation Coefficient(R)	R^2	Band /Band ratio	The equation for determining WQPs
1	pH	0.892598928	0.796	B3/B7	y = 2.073x + 6.197
2	DO	0.74661853	0.765	B1/B2	y = 3.910x + 5.058
3	BOD	0.814278408	0.772	B7/B6	y = 0.921x + 1.970
4	FC	0.87521998	0.766	B6/B3	y = 2621.x - 1077

Regression analysis was carried out for the reflectance values and parameters, coefficient of determination R^2, by which the proportion of variation in dependent variables can be predicted from the independent variables. R^2 value greater than 0.75 shows the highest coefficient of determination value. Graphs were plotted for the reflectance values and parameters to know the R^2 value. The coefficients of determination for pH, DO, BOD, FC, and the corresponding band ratios (B3/B7, B1/B2, B7/B6, B6/B3) were calculated to be 0.796, 0.765, 0.772, and 0.766, respectively. **Figure S2.** Shows the Regression plots between the reflectance values and water quality parameters: (a) pH, (b) DO, (c) BOD, and (d) FC. Using the obtained regression equations (Table 2), the water quality parameters such as pH, DO, BOD, and FC were predicted for 2020 and 2021. The results indicated a good correlation between the observed and predicted values, with values of 0.73 for pH, 0.78 for DO, 0.82 for BOD, and 0.82 for FC. The values were normalized by a factor of 0.017 (i.e., 1/60) for representation, and Figure 3 shows the plots for the normalized data.

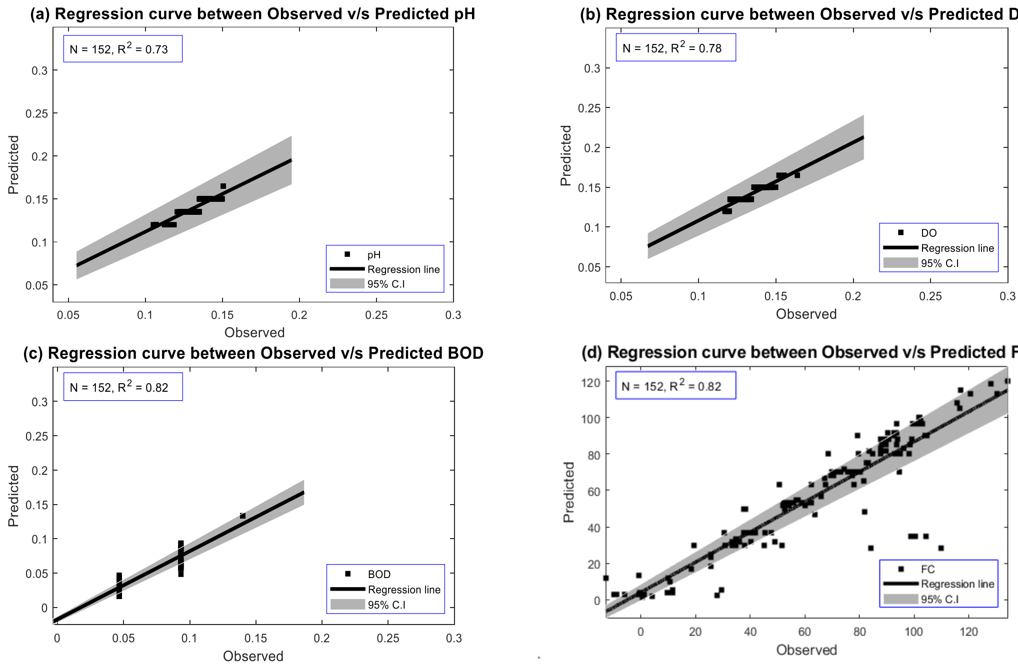


Figure 3. Regression plots between the Observed and Predicted water quality parameters of (**a**) pH, (**b**) DO, (**c**) BOD, and (**d**) FC.

4. Conclusion

In our current study, we have employed the Landsat-8 OLI satellite imager to assess water quality parameters in the Brahmani River in Odisha. Our primary objective was to ascertain the most precise band ratio for estimating water quality parameters, including pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), and fecal coliforms (FC). Moreover, following a comprehensive analysis involving regression techniques applied to the relationship between water quality parameters and reflectance values, we can draw the following conclusions based on the comparison between predicted weights and actual field measurements:

- The band ratio, i.e., Band 3/ Band 7, has a high Pearson correlation coefficient (R) = 0.8925, where R^2 = 0.796, for pH.
- The band ratio i.e., Band 1/Band 2 has the highest Pearson correlation coefficient (R) = 0.7466 and R^2 = 0.765, for DO.
- The band ratio, i.e., Band 7/ Band 6, has the highest Pearson correlation coefficient (R) = 0.8142 and R^2 = 0.772 for BOD.
- The band ratio Band 6/ Band 3 has the highest Pearson correlation coefficient (R= 0.875) and R^2 = 0.766 for FC.
- The results indicated a good correlation between the observed and predicted values, with values of 0.73 for pH, 0.78 for DO, 0.82 for BOD, and 0.82 for FC.

The findings from this study suggest that remote sensing-based water quality monitoring offers a promising approach for the future, enabling a dependable assessment of water quality by utilizing emerging remote sensing techniques.

Supplementary Materials: The following supporting information can be downloaded at www.mdpi.com/xxx/s1, Figure S1: Basin map along with Water Quality stations of Brahmani river; Figure S2: Shows the Regression plots between the reflectance values and water quality parameters:(a) pH, (b) DO, (c) BOD, and (d) FC; Table S1**:** Combination of spectral bands; Table S2: Pearson Correlation matrix.

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