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Satellite-Based Chlorophyll-a Analysis of River Tapi: An Effective Water Quality Management tool with Landsat-8 OLI and Acolite Software

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ABSTRACT

Most pollutants found in rivers come from the discharge of raw sewage from both point and non-point sources. So, monitoring the pollution levels in surface water sources is essential. River pollution monitoring is a real challenge. Using remote sensing, precise outcomes can be achieved with the help of the selection of the right combination of satellite images and algorithms. Generally, established available algorithms are site-specific, indicating that they may not work at all areas on Earth's surface due to differences in altitude, cloud cover, and sun glint. The present work determined Chlorophyll-a concentrations in the Tapi River at various locations using Landsat-8 satellite images and Acolite software from 2017 to 2021 Period. The outcomes reveal that applying the dark spectrum fitting with sun glint correction when processing Landsat-8 satellite images is needed. In the present study, water quality results were obtained very precisely for the months of January, February, November, and December after processing and analysing satellite images. Due to factors such as sun glare, cloud cover, cloud shadow, and haze, the desired effect could not be achieved in the remaining months of the study period. This research provides a solid foundation for estimating the impact of eutrophication in the water body by estimating chlorophyll-a concentration from satellite images.

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INTRODUCTION

Nowadays, every country in the world faces the problem of river pollution. The problem arises due to the rapid growth in industrialization and urbanization. Discharging untreated wastewater from points and nonpoint sources is the leading cause of river pollution. Also, Insufficient plastic waste management is the foremost factor contributing to river pollution from a technical perspective(Padervand et al., 2020). Excessive discharge of untreated sewage and agricultural runoff, which contain pesticides, increases the concentration of pollutants such as total nitrogen and phosphorus, resulting in the eutrophication of the receiving water body. Sewage treatment plants in developing countries like India are mainly designed to remove solids and organic load. Also, the increased loads of nutrients may lead to the problem of eutrophication in most of the water bodies. Within the spectrum of organic and inorganic pollutants encountered in wastewater, the contamination stemming from dyes and heavy metals is a substantial and globally prevalent concern(Naderahmadian et al., 2023). Hence, utilizing a dependable and swift approach for eliminating organic and inorganic contaminants from wastewater becomes crucial(Padervand, Ghasemi, et al., 2021; Padervand, Rhimi, et al., 2021).

Various researchers have used satellite images and algorithms to predict water quality in

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different parts of the world where the past data of water quality is not available. Monitoring the nutrients available in the water body and pollutants in the large water body is time-consuming. The result obtained from the analysis may have laboratory and sampling errors (Gholizadeh et al., 2016). Looking at this, remote sensing is the most suitable technique for monitoring the level of contaminants in the water body on the Earth's surface. With Remote sensing, the pollutant with optical properties such as Chlorophyll-a, Colour dissolved organic matter (CDOM), suspended particulate matter (SPM), and Turbidity can be obtained accurately. Determination of Chlorophyll-a can predict the parameters such as total nitrogen and total phosphorous (Kärcher et al., 2020), as phosphorus and nitrate are the responsible nutrients for the growth of algae (Bhattacharjee et al., 2022). Chlorophyll-a is the indicator of the ecological state of the water body, so the accurate concentration of Chlorophyll-a helps to understand the water quality (Guo et al., 2016). Chlorophyll-a is a proxy for algal biomass (Boucher et al., 2018). The factor responsible for algal bloom is nutrient concentration, low flow, warm water, and high solar radiation (Bowes et al., 2020).

Various algorithms and satellites are available for determining Chlorophyll-a concentration in an inland water body, coastal water, and seawater. Sometimes, this algorithm only suits that particular region (Cheng et al., 2013). Using the spectral index is essential for determining Chlorophyll-a in the turbid lake.

The Google Earth engine has been used for Sentinel-2 images to monitor the Chlorophyll-a in the Ganga River (Bhattacharjee et al., 2022). The normalized difference chlorophyll index (NDCI) is proposed to predict the Chlorophyll-a concentration, especially for estuarine water. It gives the best result for Medium Resolution Imaging Spectrometer (MERIS) images (Mishra & Mishra, 2012) (Le et al., 2013). The 2-band approach was the best choice for MERIS data for an optically complex estuary. They are using concurrent Sentinel 2A MSI imagery (S2A) with a green-red band ratio suitable for lake water to determine the concentration of Chlorophyll-a (Ha, Thao, et al., 2017). The bio-optical model can be applied to Sentinel and Landsat-8 images for mapping Chlorophyll-a to the lake (Bresciani et al., 2018). Using Landsat-8 imagery, the Slope index can estimate the Chlorophyll-a (Jang et al., 2022). Hence, the proper selection of an algorithm and satellite is necessary to determine the accurate concentration of a parameter. Landsat-8 and Sentinel 2 satellites best suit aquatic applications (Maciel & Pedocchi, 2022). Assessing the effectiveness of several atmospheric correction techniques for high-resolution images like Landsat-8 requires extensive investigation (Ilori et al., 2019).

Thus, the present study is a comprehensive approach using Landsat-8 OLI, Acolite software, and the dark spectrum fitting algorithm for assessment of Chlorophyll-a concentration in the River Tapi. This comprehensive analysis is useful for its potential applications for water quality management and data integration. The study identifies optimal seasonal windows for reliable analysis, pinpoints specific high-Chlorophyll-a locations in the River Tapi. Finally, present analysis of the study is helpful for practical river management applications.

MATERIAL & METHOD

Tapi and Narmada are the two west-flowing rivers in India. The origin of Tapi is in Multai (Baitul, Madhya Pradesh) and meets the Arabian Sea at Surat (Gujarat), having a total length of 724 Km (Timbadiya et al., 2011). It lies between 72°33' to 78°17' east longitudes and 20°9' to 21°50' north latitudes at an elevation of 752m. One hundred kilometers upstream of Surat City, the Ukai Dam on the Tapi River was built for flood control and agriculture (Waghwala & Agnihotri, 2021). The stretch of Tapi River (Kamrej to Causeway) has been chosen as a study area, which is approximately 24 km long. The entering point of river Tapi starts from Kamrej village in Surat. The drinking water treatment plant available at Sarthana, Varacha, Katargam, and Rander, having an intake source of Tapi, fulfills the domestic water demand of Surat City

(Chander et al., 2018). The geolocation map of the study region is shown in Figure 1.

The methodology adopted for the present study is shown in Figure 2. There are two options

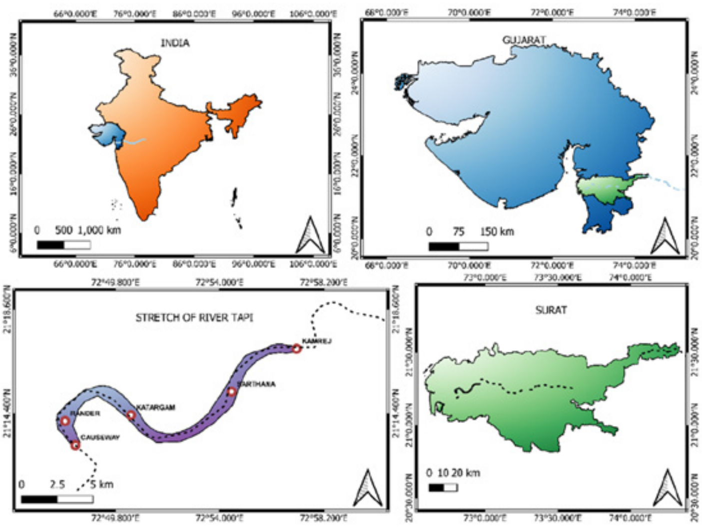


Fig. 1. Geospatial Analysis of Tapi River Strech: Mapping the Study Area in Surat District, Gujarat, India

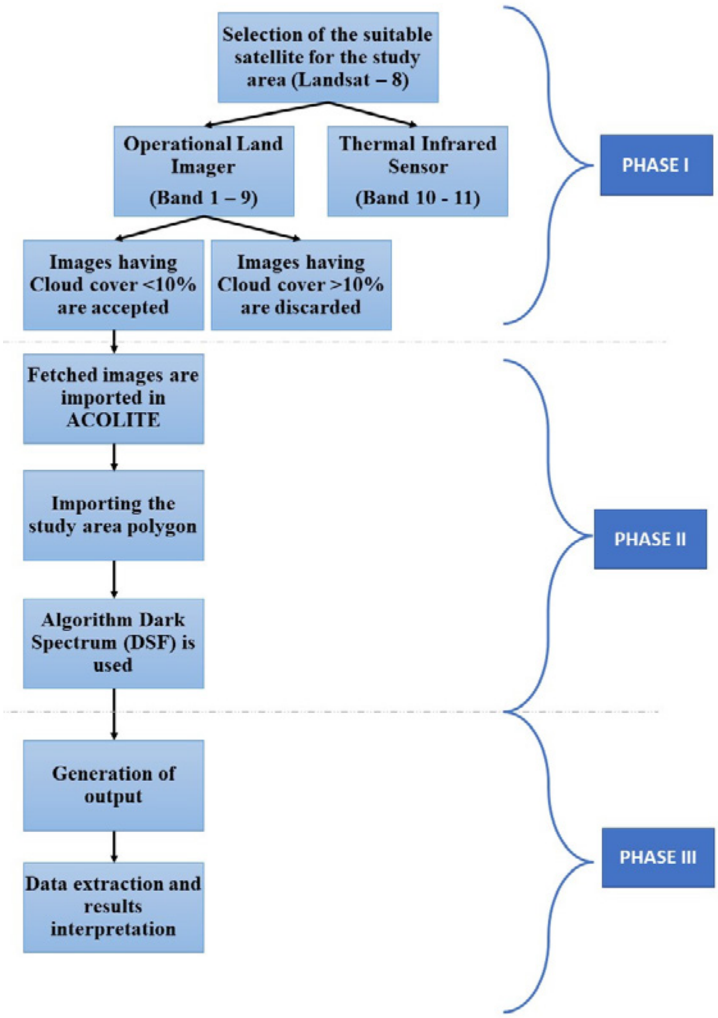


Fig. 2. Methodology Diagram: Acolite Software-Assisted Satellite Image Analysis across Three Phases

for selecting the study area in the present methodology; either a polygon should be chosen, or coordinates should be added. The region of interest in the current study is a stretch of the river Tapi. Since combining all the coordinates for a study area is challenging, a polygon was chosen.

Chlorophyll is a pigment found in green plants, which helps them to prepare their food through photosynthesis. There are two types of Chlorophyll, i.e., Chlorophyll a and b. Chlorophyll-a is the primary indicator of phytoplankton biomass which is used to assess the eutrophic condition of the water body, which will give an idea about the water quality (Moses et al., 2009). A significant environmental stressor worldwide is the eutrophication of freshwater habitats brought on by nitrogen and phosphorus pollution (Bennett et al., 2021). Chlorophyll-a and total phosphorus in freshwater were first correlated in the 1960s (Stow & Cha, 2013). Chlorophyll-a relates to the total nitrogen and phosphorus; hence, the approximate value of total nitrogen and total phosphorus in the water body can be estimated (Filstrup & Downing, 2017).

The Landsat-8 OLI (operational land images) images were downloaded from the United States Geological Survey (USGS) earth explorer site (https://earthexplorer.usgs.gov/), which is freely available. The images in which the cloud cover less than 10% has been downloaded and processed to get the output accurately. It is essential to select the proper method for atmospheric correction because a suitable atmospheric correction method can correctly estimate the reflectance value. Also, for particular land cover categories, different atmospheric correction techniques produced varied outcomes (Lantzanakis et al., 2016). Various methods are available for atmospheric correction, including Dark object subtraction, image correction for atmospheric effect (iCOR), and Landsat-8 surface reflectance algorithm (L8SR) (Bernardo et al., 2017; De Keukelaere et al., 2018). Acolite uses the default dark spectrum fitting algorithm for the atmospheric correction of satellite images (Vanhellemont, 2019; Vanhellemont & Ruddick, 2018). Acolite software which converts the raw digital number to radiance value and later converts this radiance value into the top-of-atmosphere reflectance value (Aswathy et al., 2021) for the area.

Acolite has two groups of methodology: short-wave infrared (SWIR) based exponential extrapolation (EXP) and dark spectrum fitting (DSF). The dark spectrum fitting DSF is the default method of atmospheric correction adapted to the Landsat and sentinel satellite images. DSF constructs a dark spectrum using multiple dark targets in the subscene and estimates the atmospheric path reflectance (ρ_{path}). This fully automated atmospheric correction process gives the lowest atmospheric path reflectance and avoids amplifying glint and adjacency effects. DSF is based on the two assumptions to measure the atmospheric path reflectance.

1) The atmosphere is homogeneous to a certain extent.
2) The scene contains pixels with surface reflectance's $\rho_s \approx 0$ in at least one of the sensor bands.

A single ρ_{path} can be used to process an entire scene. The tile size for Landsat 6×6 km is used. DSF computes the aerosol optical depth (τ_a) and removes the tile having the cloud shadow, and the tile with less than 10%-pixel coverage is also removed as the Landsat archive is affected by sun glint on the water surface. The advantage of DSF is it selects the band, giving the lowest estimate of atmospheric path reflectance, pixels, and band to avoid the sun glint (Vanhellemont, 2019). The DSF is not sensitive to the region of interest (ROI), ancillary information on gas concentration, atmospheric pressure, and wavelength spacing in the lookup tables (Vanhellemont, 2020).

The DSF algorithm in the present study finally gives Chlorophyll-a concentrations in $mg/m^{3,}$ which is the Blue/Green ratio for the Landsat-8 imagery for inland water bodies (Ha, Koike, et al., 2017). Blue (Band 2) has a wavelength of 0.45 to 0.51 micrometers and a resolution of 30 m, and Green (Band 3) has a wavelength of 0.53 to 0.59 micrometers and a resolution of 30 m.

RESULTS AND DISCUSSION

For the study area, Landsat-8 images of the years 2017 to 2021 for January, February, November, and December have been processed as described in the methodology in Figure 2 for the estimation of the Chlorophyll-a in the study region. Thus, the estimation of chlorophyll-a at the different locations in the stretch of river Tapi of the study area is finally obtained. Table 1 to Table 4 represents the summarised data of chlorophyll-a concentration at various locations for the study area for January, February, November, and December month from 2017 to 2021.

Spatiotemporal variation of Chlorophyll-a concentration for the selected stretch of river Tapi from 2017 to 2021 is shown in Figure 3 to Figure 6. Figure 3 represents the chlorophyll-a concentration for January, figure 4 for February, figure 5 for November, and figure 6 for December, respectively. The red indicates the high chlorophyll-a concentration, whereas the blue represents the low concentration values at different locations in the selected stretch. The

Table 1. January chlorophyll-a concentrations in mg/m^3 from 2017 to 2021

Sr.no	Date	Minimum	Maximum	Mean	S D
1	30 January 2017	1.29	43.54	4.43	2.75
2	1 January 2018	1.39	7.29	2.03	0.48
3	17 January 2018	1.34	10.08	2.54	0.86
4	20 January 2019	1.74	25.15	3.35	1.34
5	7 January 2020	1.49	4.55	2.17	0.42
6	23 January 2020	1.51	6.24	2.30	0.51
7	25 January 2021	1.34	18.99	4.63	1.58

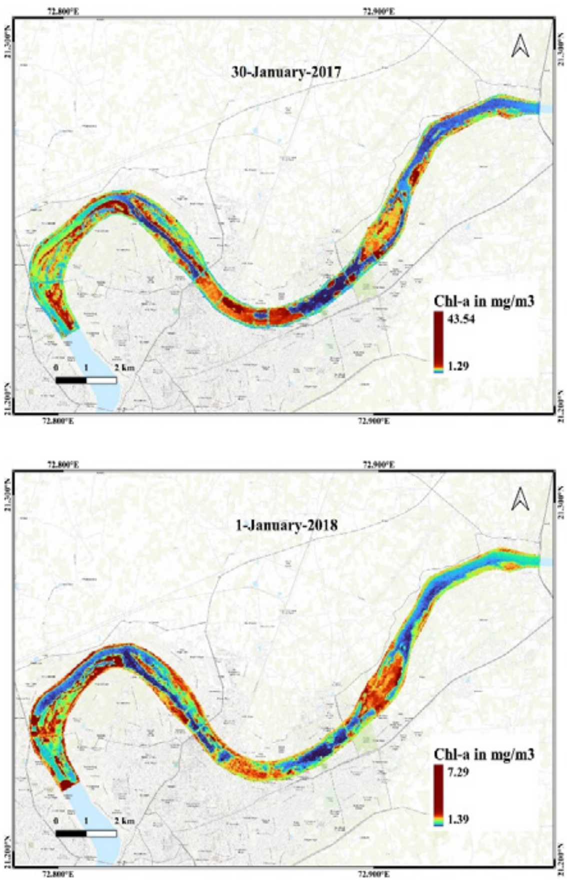
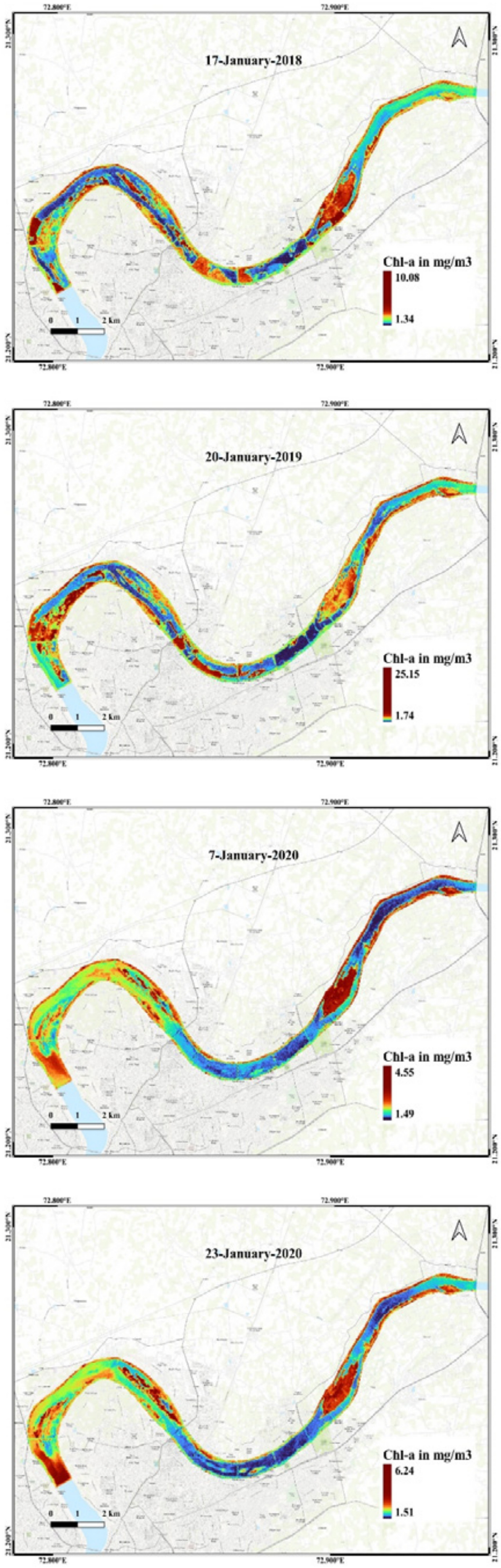


Fig. 3. Spatio-temporal Variations in Chlorophyll-a Concentration in mg/m^3 of January months for the period of 2017-2021.



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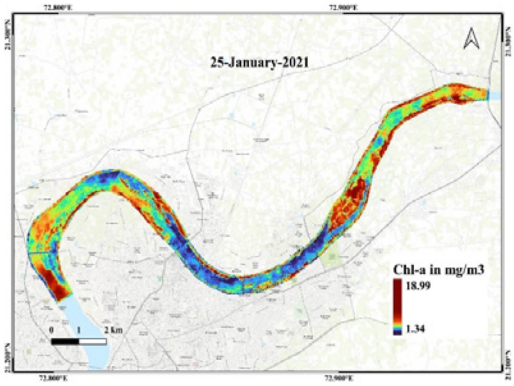

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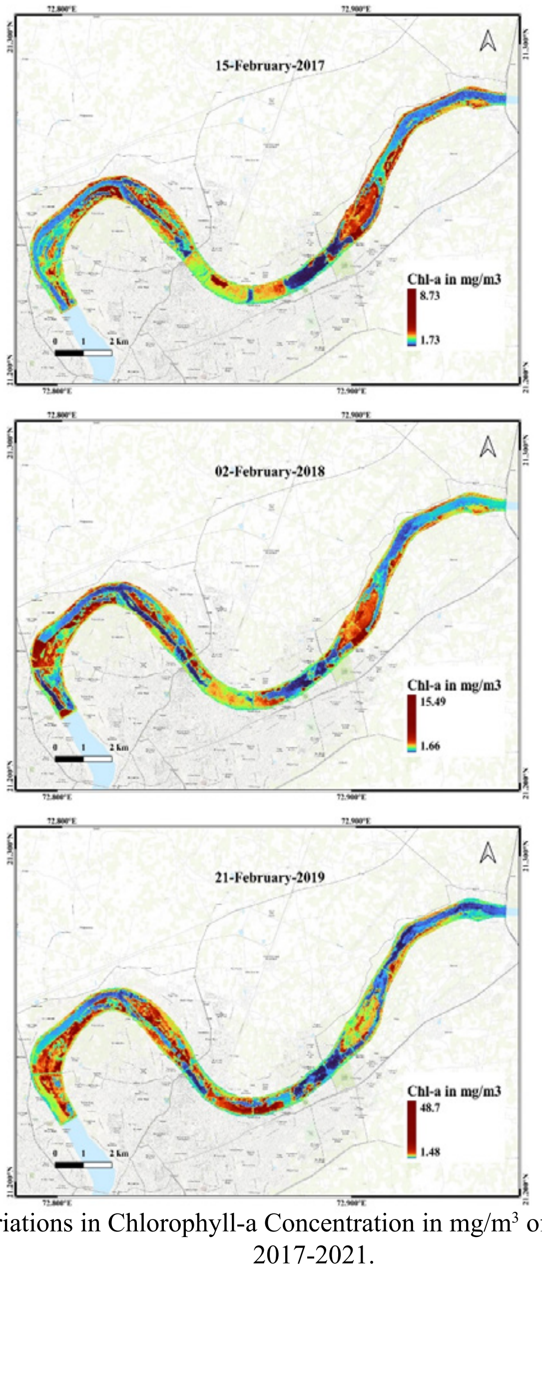
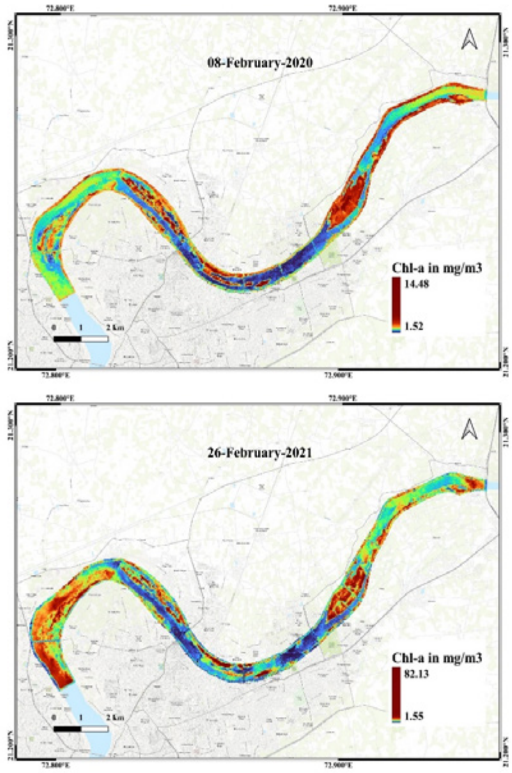


Fig. 4. Spatio-temporal Variations in Chlorophyll-a Concentration in mg/m^3 of February months for the period of 2017-2021.



Continued Fig. 4. Spatio-temporal Variations in Chlorophyll-a Concentration in mg/m^3 of February months for the period of 2017-2021.

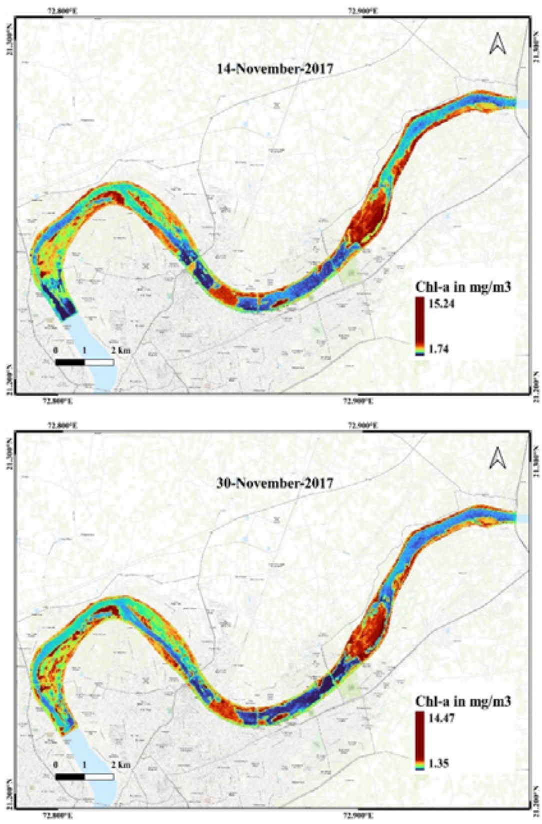
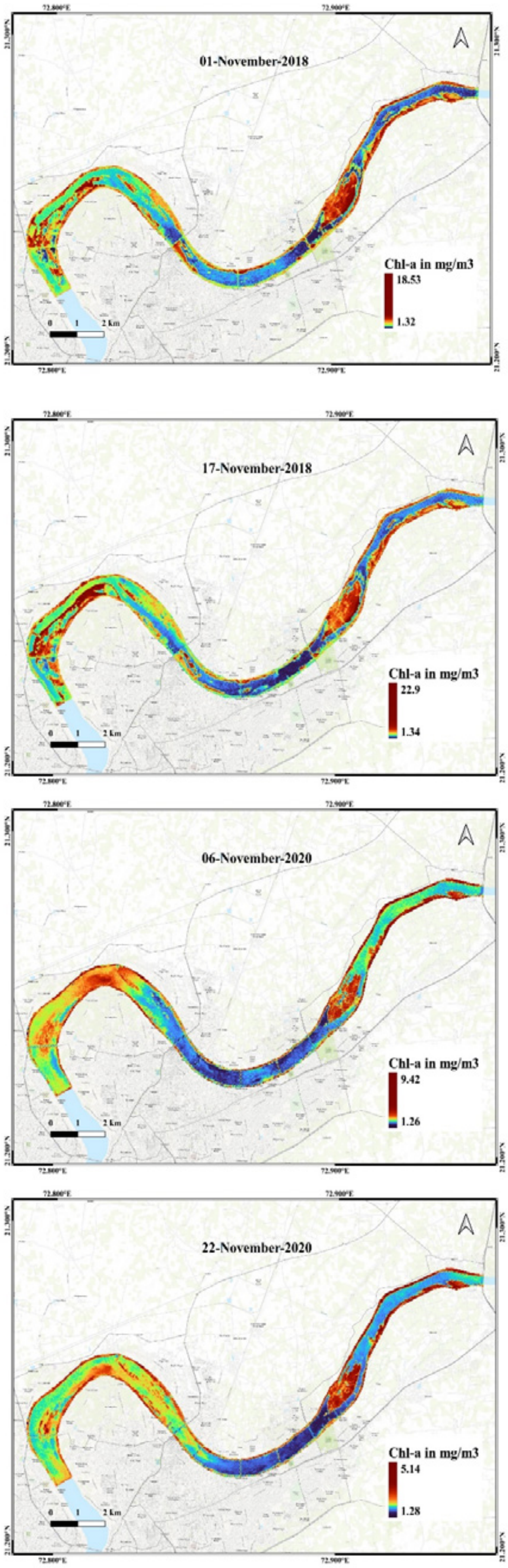
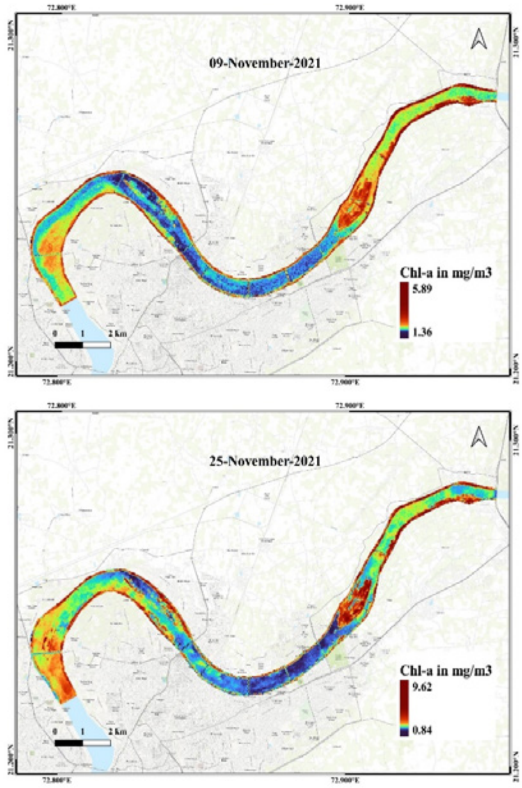


Fig. 5. Spatio-temporal Variations in Chlorophyll-a Concentration in mg/m^3 of November months for the period of 2017-2021.



Continued Fig. 5. Spatio-temporal Variations in Chlorophyll-a Concentration in mg/m^3 of November months for the period of 2017-2021.



Continued Fig. 5. Spatio-temporal Variations in Chlorophyll-a Concentration in mg/m^3 of November months for the period of 2017-2021.

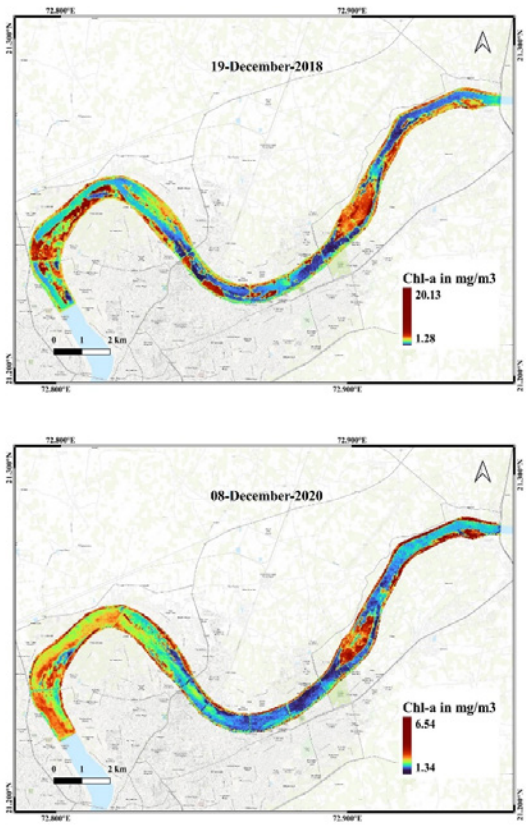
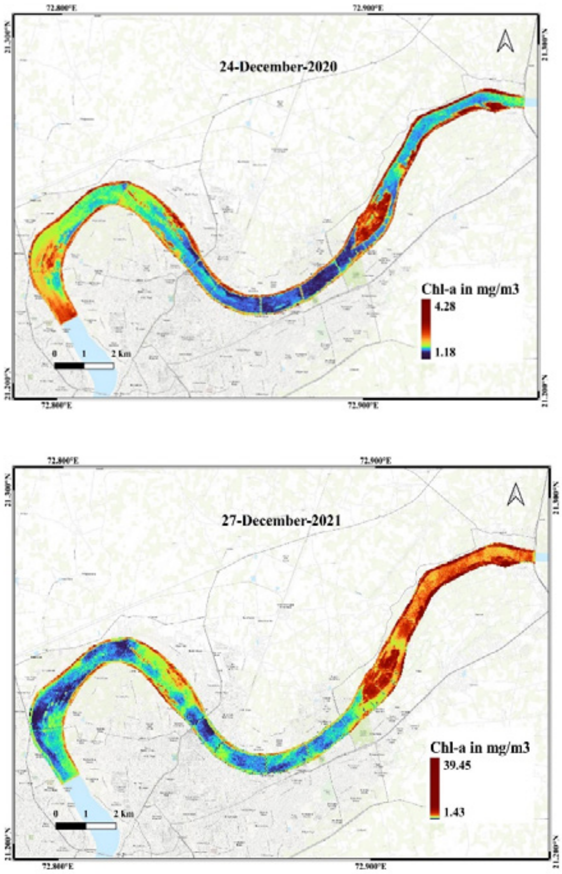


Fig. 6. Spatio-temporal Variations in Chlorophyll-a Concentration in mg/m^3 of December months for the period of 2017-2021.



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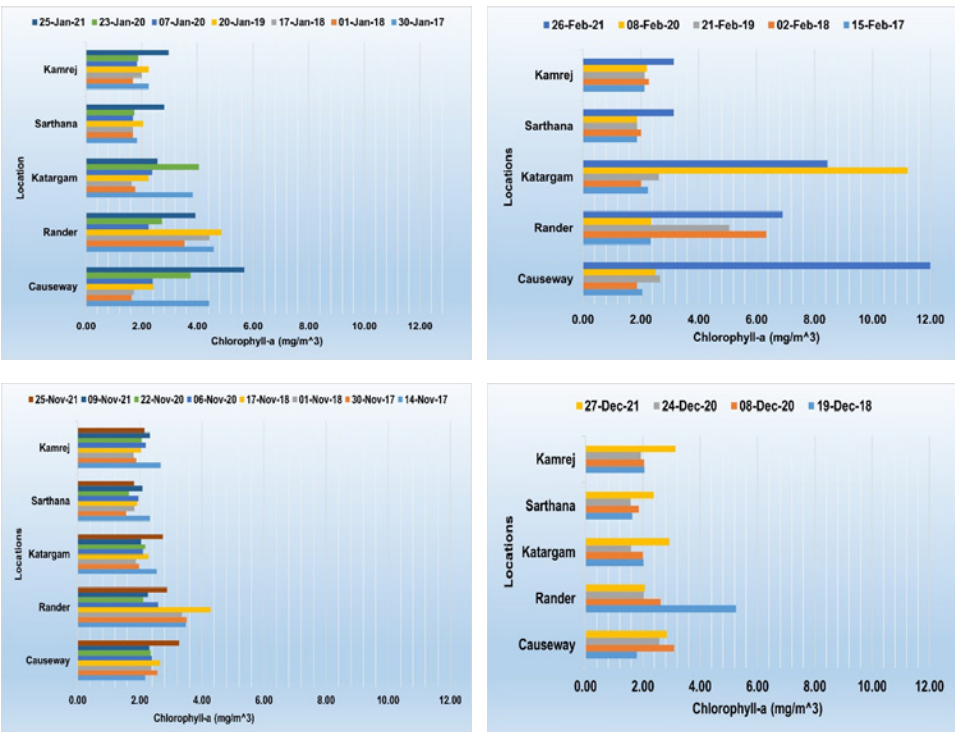

Fig. 7. Comparative Bar Graphs of Chlorophyll-a Concentration (January, February, November, December) at Five Tapi River Locations Over a Five-Year Span (2017-2021)

highest chlorophyll-a concentration has been observed at Causeway downstream of river Tapi in most of the cases in the study area. The observed highest chlorophyll-a level might be due to the water retention at the site (Jeong et al., 2010).

Considering the same methodology, the concentration of chlorophyll-a has been obtained for the February month of the period 2017-2021. Table 2 summarises chlorophyll-a concentrations in the study area from February 2017 to 2021. Figure 4 displays February chlorophyll-a concentrations from 2017 to 2021.

Table 3 summarizes the chlorophyll-a concentration at several locations in the study area for November 2017 to 2021. Figure 5 depicts the variation in chlorophyll-a concentration from November 2017 to 2021.

Table 4 presents chlorophyll-a concentration from December 2017 to 2021. Figure 6 illustrates chlorophyll-a concentration in December 2017-2021.

The highest mean Chlorophyll-a concentration of 5.71 mg/m^3 was observed in February 2021, followed by January 2021 (4.63 mg/m^3) and January 2017 (4.43 mg/m^3). The surface water temperature and the minimum discharge from the upstream dam might be the reason for a higher chlorophyll-a concentration.

The variation of chlorophyll-a concentration during the study period might be due to the

Table 2. February chlorophyll-a concentrations in mg/m^3 from 2017 to 2021

Sr.no	Date	Minimum	Maximum	Mean	SD
1	15 February 2017	1.73	8.73	2.86	0.74
2	02 February 2018	1.66	15.49	3.25	1.35
3	21 February 2019	1.48	48.71	4.62	3.30
4	08 February 2020	1.52	14.48	2.78	0.97
5	26 February 2021	1.55	82.13	5.71	3.32

Table 3. November chlorophyll-a concentrations in mg/m^3 from 2017 to 2021

Sr.no	Date	Minimum	Maximum	Mean	SD
1	14 November 2017	1.74	15.24	3.24	1.00
2	30 November 2017	1.35	14.47	2.57	0.93
3	01 November 2018	1.32	18.53	2.82	1.22
4	17 November 2018	1.34	22.90	3.48	1.71
5	06 November 2020	1.26	9.42	2.64	0.62
6	22 November 2020	1.28	5.14	2.31	0.49
7	09 November 2021	1.36	5.89	2.40	0.47
8	25 November 2021	0.84	9.62	2.80	0.80

Table 4. December chlorophyll-a concentrations in mg/m^3 from 2017 to 2021

Sr.no	Date	Minimum	Maximum	Mean	SD
1	19 December 2018	1.28	20.13	3.23	1.59
2	08 December 2020	1.34	6.54	2.58	0.59
3	24 December 2020	1.18	4.29	2.04	0.42
4	27 December 2021	1.43	39.45	3.61	1.83

hydrodynamic conditions, nutrients, and Lighting conditions (Bu et al., 2022). This may be due to the mixing of the macrophyte area and the algal bloom area (Liu et al., 2022). The obtained results were compared with the studies conducted on the Tapi River and other rivers in India. For example (Chander et al., 2018) found the Chlorophyll-a concentration at Kamrej, Sarthana, and Causeway locations as 13.92 mg/m^3, 29.40 $mg/m^{3,}$ and 16.76 $mg/m^{3,}$ respectively, in the year 2018, which is matching with the range of obtained results.

(Premkumar et al., 2021) analyzed the concentration of Chlorophyll-a in the Hooghly river which can be in a similar trend of Tapi river. (Prasad et al., 2020) estimated the concentration in the upper Ganga River and found a range between 14.32 mg/m^3 and 82.51 mg/m^3.

CONCLUSION

The study has demonstrated that Landsat-8 OLI, with its suitable characteristics, is an effective tool for measuring the optical properties of water bodies. When coupled with the Acolite software and the default setting of the dark spectrum fitting algorithm, it becomes a valuable resource for coastal and inland water bodies, especially those with sediment-rich water. By processing high spatial resolution Landsat-8 imagery, Chlorophyll-a concentrations could be assessed in the water. Applying the dark spectrum fitting algorithm to Landsat-8 satellite images proved to be a robust method for measuring water reflectance. Notably, Present research revealed significant variations in Chlorophyll-a concentration along the selected stretch of the Tapi River. The Causeway location was particularly interesting, which exhibited the highest Chlorophyll-a concentration for the study period. This finding suggests the influence of water retention, elevated temperature, and stagnant flow on Chlorophyll-a levels in this area. This study adds significant scientific value by establishing that Landsat-8 scenes, in conjunction with Acolite software and the dark spectrum fitting algorithm, are well-suited for assessing Chlorophyll-a concentrations during the winter season in India, particularly in January, February, November, and December. The occurrence of cloud cover in June, July, August, and September, along with the complexities arising from Sun glint and adjacency effects in March, April, and May images, underscores the significance of considering seasonal variations and technical challenges.

Thus, the present study offers an effective alternative for assessing river water quality where scientific and reliable water quality data is not available. From the present study, the higher chlorophyll-a concentration indicates where eutrophication effects are maximum in river stretch. This location also shows where nutrients accumulate in the river stretch, and biological activity will be most dominant. The research contributes to understanding water quality assessment and provides practical insights for managing water resources. It also represents a valuable addition to remote sensing and water quality assessment, offering a foundation for future research and applications in the domain of water quality management.

NOVELTY STATEMENT

This research pioneers a cutting-edge methodology by harnessing Landsat-8 OLI data, Acolite software, and the dark spectrum fitting algorithm for precise Chlorophyll-a measurement, unveiling seasonal variations and technical complexities. This innovative approach not only enhances water quality assessment without traditional monitoring but also advances the application of remote sensing technology in environmental science, particularly during India's winter months.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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