SPATIAL AND TEMPORAL VARIABILITY OF TOTAL SUSPENDED MATTER CONCENTRATION OVER SELECTED SITES IN GANGA RIVER USING RESOURCESAT-2 LISS-III DATA

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ABSTRACT

Total Suspended Matter (TSM) is one of the water quality parameter which is required to understand the eco-hydrological processes (soil erosion, runoff, discharge, mixing of water from tributaries, trophic state of an aquatic ecosystem etc.) in inland water bodies. Water quality measurements are essential for addressing the issues of Ganga river whose turbidity changes depending on low flow in dry summer to heavy discharge conditions in monsoon period. Paper reports TSM variability estimated from Resourcesat-2 Linear Imaging Self Scanning-III (RS2-LISS-III) sensor data at two sites in Ganga river (Allahabad and Patna) during 2012-2016. Analysis is based on (a) development of empirical relationship between TSM and water reflectance observed in Near Infra-Red (NIR) of LISS-III sensor band using radiative transfer model simulations and (b) atmospheric correction and estimation of TSM using RS2-LISS-III observations. These observations were analysed in pre-monsoon (March/April) and Post Monsoon (October/November) period. It was observed that TSM concentration in pre and post monsoon seasons ranges from 30 - 250 mg/L and 50-220 mg/L respectively at Allahabad. Similarly, TSM concentration in Patna ranged from 40 - 200 and 60 - 220 mg/L in pre and post monsoon seasons respectively. Post monsoon TSM values were found more as compared to pre monsoon TSM concentration in most of the cases at both sites. Mixing of water from tributaries (Yamuna in Allahabad and Gandak in Patna) plays important role in changing the TSM concentration of Ganga river. TSM values of Ganga was found relatively reduced after mixing with Yamuna in Allahabad whereas mixing of Gandak river water relatively increased the TSM values in Patna.

INTRODUCTION

Every year, 20 billion tons of sediments are brought to the oceans by the rivers (Milliman & Syvitski,J., 1992). Total Suspended Matter (TSM) carries nutrients and contaminants in the organic and inorganic form, which reduces the transmission of light through water column, that in turn influences the aquatic life which are living in that water system. Accurate spatial and temporal information on TSM distribution patterns are important for a better understanding of ecosystem dynamics and development of effective and quantitative monitoring of aquatic environments, in order to protect and improve water quality management (Grove et al., 2015; Cerco et al ., 2013; Skarbovik et al., 2012). Water turbidity, which exerts a major influence on the ecology of aquatic systems, is determined by the light-absorption and scattering processes that take place within the water column (Campbell et al., 2011) Observations on suspended TSM can be used in various numerical schemes to help characterize the trophic state of an aquatic ecosystem (Carlson, 1977; Zhang et al., 2002).

Satellite and airborne scanner data are useful in mapping some of the most important water quality parameters such as turbidity, TSM and chlorophyll-a (Koponen et al., 2002; Buttner et al., 1987; Khorram et al., 1991; Pulliainen, et al., 2001). Imaging Spectroscopy is well established method to assess water quality but there are limited airborne and space borne measurement over rivers. Multi spectral sensors on board LANDSAT and SPOT satellite series has been used to assess water quality related parameters over lakes, reservoirs and rivers using different band ratio techniques. Assessment of TSM involves development of empirical, semi empirical or radiative transfer models by taking satellite spectral characteristics into account. No such modelling scheme has been yet developed for Indian Remote Sensing multi spectral sensors like RS2-LISS-III for retrieval of TSM over inland water bodies. This paper reports the findings of TSM variability in Ganga river for the first time developing RS2-LISS-III specific TSM retrieval models incorporating the sensor's spectral characteristics (relative spectral response). Spatial and temporal variability was studied at two sites (Allahabad and Patna) over the span of five years (2012-2016).

STUDY AREA AND DATA USED

The Ganga river flows through the Srinagar, Rishikesh, Haridwar, Roorkee (in Uttarakhand), Bijnor, Narora, Kanauj, Kanpur, Allahabad, Varanasi, Mirzapur (In Uttar Pradesh), Patna, Bhagalpur (In Bihar) and Bahrampur, Serampore, Howrah and Kolkata (in West Bengal). Present Study was carried out at two sites viz. Allahabad and Patna (Figure.1). RS2-LISS III data were used from 2012 to 2016 during Pre monsoon (March/April) and post Monsoon (October/November) season. Detailed dates and path row of the remote sensing images are given in Table 1. Selection of date of acquisition of remote sensing data was based on availability of cloud free images in pre monsoon and post monsoon period over the selected sites. Study was carried out to study the mixing of tributary water in main stream of Ganga at two locations at each sites located after (A) and before (B) joining of tributaries. Geolocation of A site of Allahabad is $25^0$17'22.70"N, $82^0$7'52.77"E and B site of Allahabad is $25^0$30'11.67"N, $81^0$51'12.42"E. Similarly, Geolocation of A for Patna is ($25^0$31'52.72"N, $85^0$17'30.87"E) and B for Patna is ($25^0$39'59.68"N, $84^0$56'39.49"E). Region of interest Location (C) with corresponding latitude and longitude ($25^0$24'22.57"N, $81^0$54'23.24"E for Allahabad), ($25^0$37'5.81"N, $85^0$12'31.34"E for Patna) was used to analyse the seasonal and inter annual variations.

Table 1. Study area, Path, Row and period of data used in analysis.

Location	Path/Row	Acquisition Date (DD-MM-YYYY)	
		Pre monsoon	Post monsoon
Allahabad	104/054	06-04-2012	15-10-2012
		01-04-2013	27-11-2013
		27-03-2014	29-10-2014
		22-03-2015	24-10-2015
		16-03-2016	18-10-2016
Patna	104/053	28-03-2012	23-11-2012
		16-04-2013	18-11-2013
		11-04-2014	13-11-2014
		30-04-2015	08-11-2015
		24-04-2016	02-11-2016

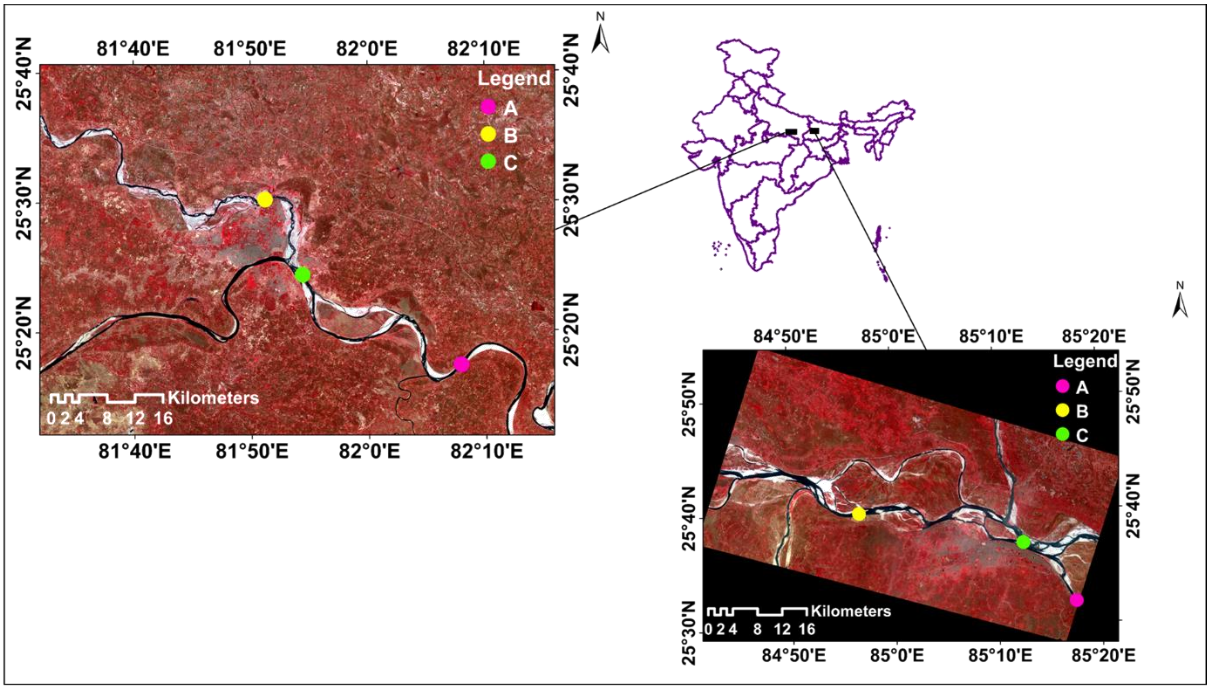

Figure 1. Location map of study area in India along the Ganga river. Pink (A) and Yellow (B) points are locations in Ganga river after and before the tributaries (Yamuna in Allahabad and Gandak in Patna) join the main stream Ganga river. The green point (C) shows the selected region of interest location.

METHODOLOGY

Resourcesat-2 LISS III data was acquired from NRSC (National Remote Sensing Centre, Hyderabad) in the Geo tiff format. Analysis involved pre-processing of raw data in terms of conversion of DN (Digital Number) to Radiance using radiometric calibration coefficients available in the metadata file followed by atmospheric correction, detailed methodology represented in flowchart (Figure 2). Atmospheric corrections were done by using FLAASH (Fast line-of-Sight Atmospheric Analysis of Spectral Hypercubes) inbuilt in ENVI 5.2 software (Nazeer et al., 2014). Water reflectance (ρ) was estimated using above mentioned atmospheric correction scheme. Necessary varying input of solar and viewing geometry for atmospheric correction was provided as details given in metadata file whereas atmospheric condition was considered fixed with 40 km visibility.

The MNDWI (Modified Normalised Difference Water Index) was calculated for each scene to generate water mask in the image. The MNDWI (Xu, 2006) is defined as

$$MNDWI = \frac{\rho_{Green}\,(B2) - \rho_{SWIR}\,(B5)}{\rho_{Green}\,(B2) + \rho_{SWIR}\,(B5)} \quad (1)$$

Where $\rho_{Green(B2)}$ is reflectance in green band and $\rho_{Swir(B5)}$ is reflectance in SWIR band.

To develop an analytical relationship between remote sensing reflectance of water in NIR band with TSM, a radiative transfer (RT) model was used.

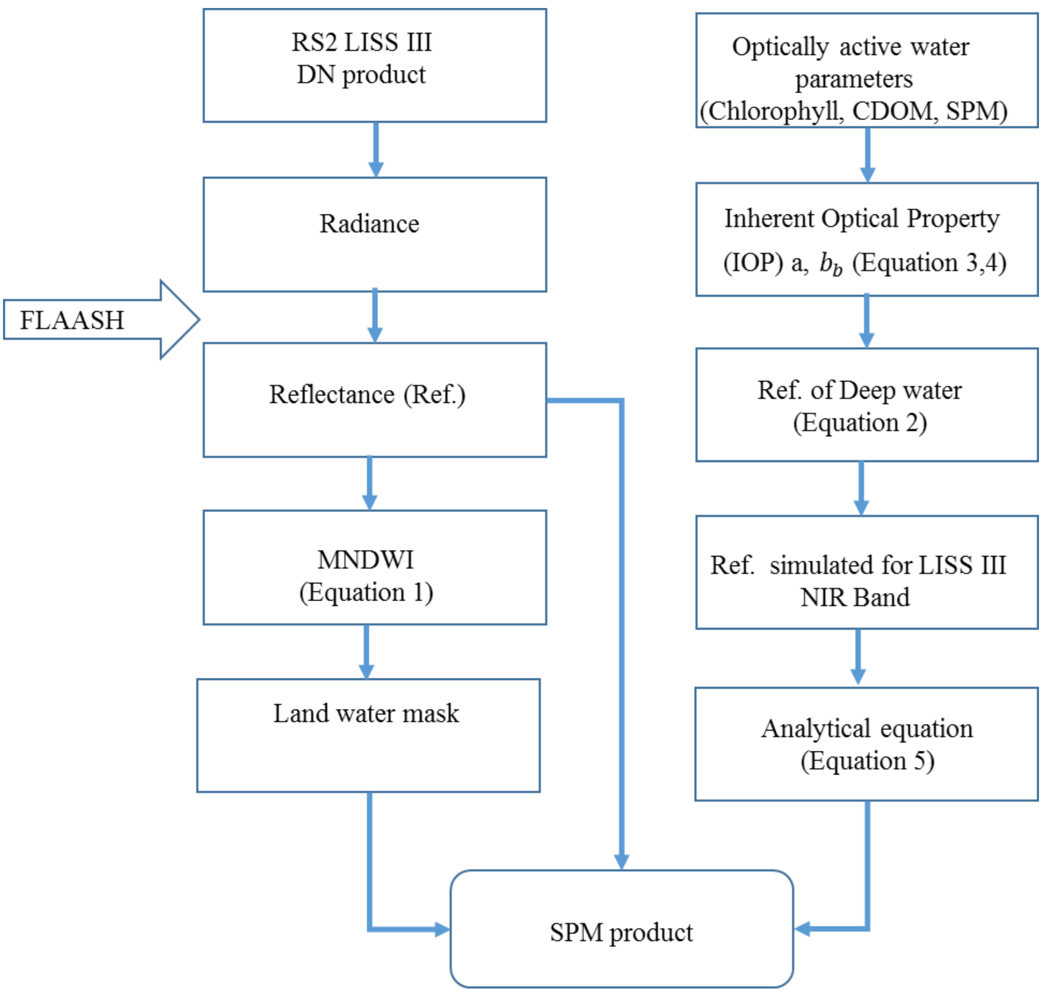

Figure 2. Systematic flow chart of methodology for explaining from initial stage to final stage.

The single channel NIR TSM model is based on the assumption that remote sensing reflectance in NIR region from the river is purely from the water column and suspended matter and no contribution is from the bottom substrate.

Remote sensing reflectance from optically deep water r_{rs}^{deep} is in relation with water parameters absorption a (λ) and backscattering coefficients b_b(λ) (Albert & Mobley, 2003).

$$r_{rs}^{deep} = f \frac{b_b}{a+b_b} \tag{2}$$

Where f is proportionality factor. Absorption due to water is sum of absorption due to its constituent particles.

$$a(\lambda) = a_w(\lambda) + Ca_c^*(\lambda) + Ya_Y^*(\lambda) \tag{3}$$

Where $a_w(\lambda)$ is absorption by pure water, C is phytoplankton concentration, $a_c^*(\lambda)$ is specific absorption coefficient and Y is CDOM (Coloured Dissolved Organic Matters) absorption at 400nm and $a_Y^*(\lambda)$ is specific absorption coefficient of CDOM normalized at 400nm.

Backscattering $b_b(\lambda)$ is the sum of backscattering by pure water, chlorophyll and suspended matter. Backscattering due to water is calculated as $b_{b,W}(\lambda)$ = $b_1(\lambda/\lambda_1)^{-4.32}$. where b1=0.00111 m^-1 for fresh water and b1=0.00144 m^-1 for oceanic water and λ_1=500 nm. Backscattering by chlorophyll particles is calculated as: $b_{b,C}^* = 0.0006 * C^{-0.37}$ Backscattering due to suspended particles (C_S) is calculated with $b_{b,S}^*$=0.0042, λ_S=500 and n=1 (Buiteveld et al., 1994; Gege P., 2014)

$$b_b(\lambda) = b_{b,W}(\lambda) + C.b_{b,C}^*. + C_S.b_{b,S}^*.\left(\lambda/_{\lambda_S}\right)^n \tag{4}$$

Remote sensing reflectance was simulated for various pigment concentrations. Chlorophyll concentration was varied from 0 to 100 µg/L at interval of 1 µg/L, CDOM absorption at 440nm was varied from 0 to 10 m^{-1} at interval of 0.1 m^{-1}, and Total suspended matter was varied from 0 to 1000 mg/L at interval of 10 mg/L. A million spectra was simulated to study the effect of various pigment concentrations on remote sensing reflectance of water. The simulation shows that TSM concentration is highly correlated with remote sensing reflectance value in NIR region. The spectra were then simulated for IRS-Resourcesat-2 LISS-III NIR band (B4) based on its spectral response ratio (RSR). An analytical relation was established based on NIR reflectance and TSM value, given by

$$TSM\ (mg/L)\ = 1120\ \rho_{NIR} - 9.5 \tag{5}$$

Where TSM is total suspended matter in mg/L unit and ρ_{NIR} is water reflectance in NIR band computed from atmospheric correction of data. Equation 5 was used to calculate TSM in different regions of Ganga using land water mask generated from MNDWI image.

Analysis was carried out to calculate the seasonal and inter annual mean and ranges of TSM in both the sites as well the study the role of mixing water of tributaries in Ganga river. TSM values at specified locations before and after tributaries join Ganga were analysed at both sites. Relative changes in TSM values of Ganga was studied with respect to Yamuna in Allahabad and Gandak in Patna.

RESULTS AND DISCUSSION

Seasonal and inter annual spatial distribution of TSM was studied for selected sites in Ganga river using 20 RS2-LISS-III atmospheric corrected scenes. Figure 3 shows variations in TSM in Allahabad during pre-monsoon as well as post monsoon period. TSM values in Ganga river in Allahabad region over entire image ranged between 30-250 mg/L during pre-monsoon period. Similarly, the TSM values over entire image ranged between 50-220 mg/L during post monsoon period. Figure 4 shows variations in TSM in Patna during pre-monsoon as well as post monsoon period. TSM values over entire image ranged between 40-200 mg/L in Pre monsoon period. TSM over entire image ranged between 60-220 mg/L during post monsoon period.

Analysis was carried out over selected region of interest near location (C) in Allahabad to assess the seasonal variations in TSM concentration. Five year mean TSM of Allahabad in pre monsoon period was observed as 83 ± 30.8 mg/L whereas mean TSM in post monsoon period was found as 97.8 ± 12.3 mg/L. Mean TSM was observed as 99.4 ± 25.9 mg/L in pre monsoon period and 107.2 ± 13.8 mg/L in post monsoon period when similar analysis in selected region of interest near location (C) was carried out in Patna.

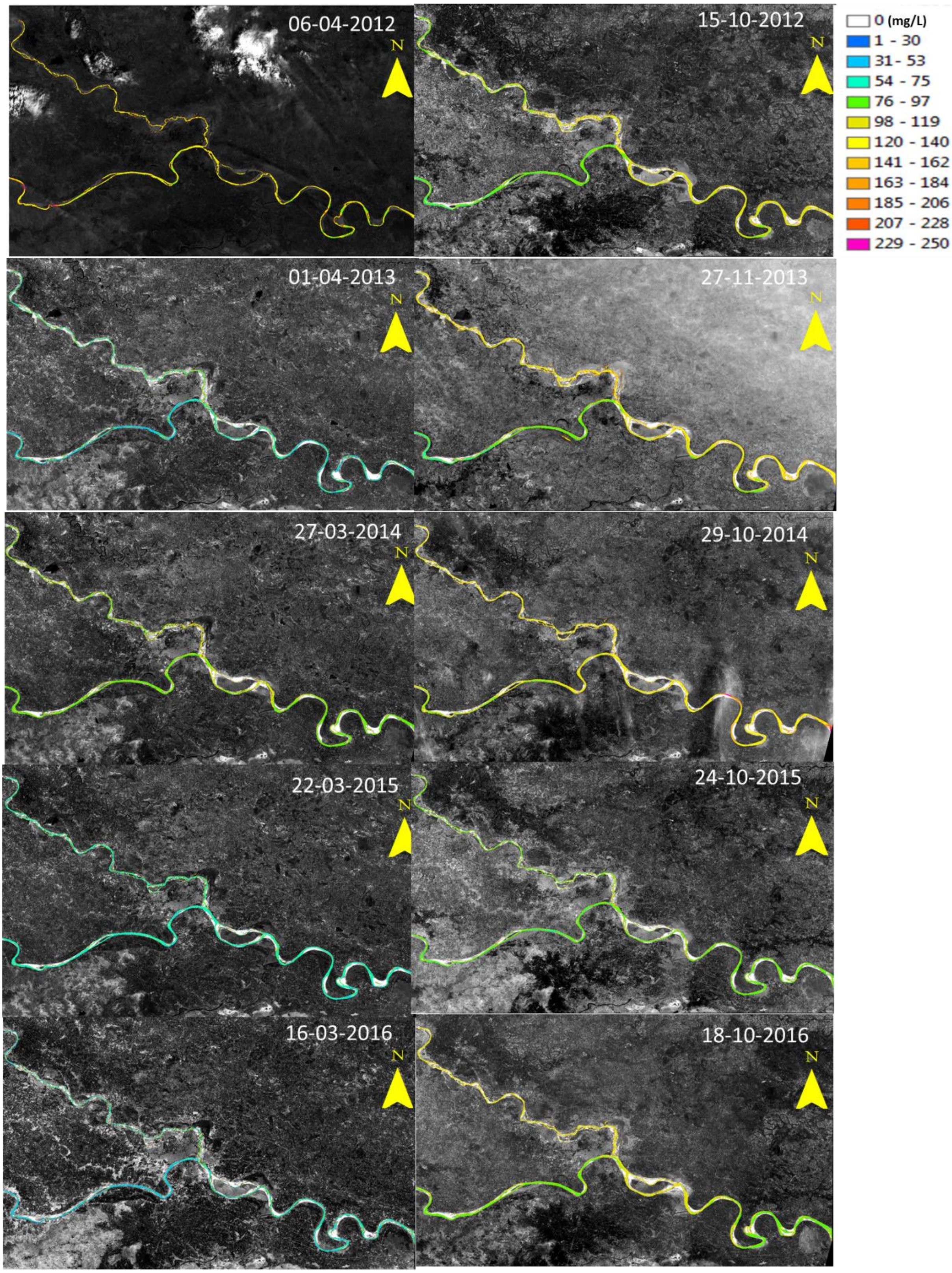

Figure 3. TSM (mg/L) variations in Ganga river from 2012 to 2016 in Allahabad during pre-monsoon and post monsoon period.

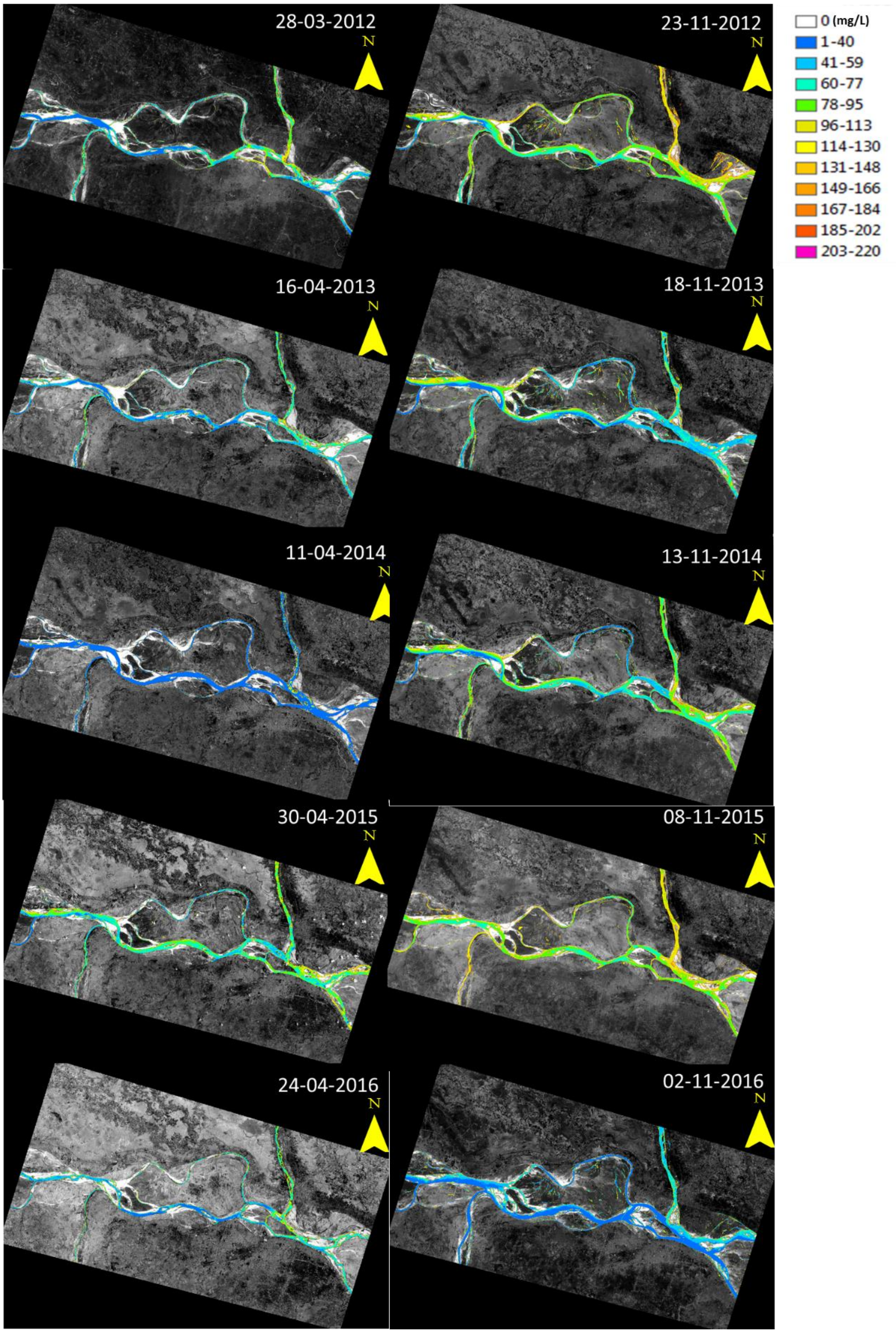

Figure 4. TSM (mg/L) variations in Ganga River from 2012 to 2016 in Patna during pre-monsoon and post monsoon period.

Scene level yearly average TSM variations in Ganga river in pre monsoon and post monsoon from 2012 to 2016 for Allahabad and Patna region is shown in Figure 5 and Figure 6 respectively. It can be seen that Post monsoon TSM are generally high as compared to pre monsoon season in most of the cases except 2012 in Allahabad and 2015 and

2016 in Patna. Partly cloudy conditions as observed in 2012 image of Allahabad or atmosphere with high aerosol conditions not properly accounted in atmospheric correction can influence and bias the TSM estimates.

Normally high turbidity is associated with wet monsoon season when surface runoff carries sediments from the soil to the river and also the more turbulent water during high flow conditions won't allow to settle down the suspended particles (Bhutiani et al., 2007; Maillard et al., 2008). The river system is associated with complex hydrological processes and understanding the turbidity variation is challenging because the sediments originates from multiple sources and also they vary spatially and temporally.

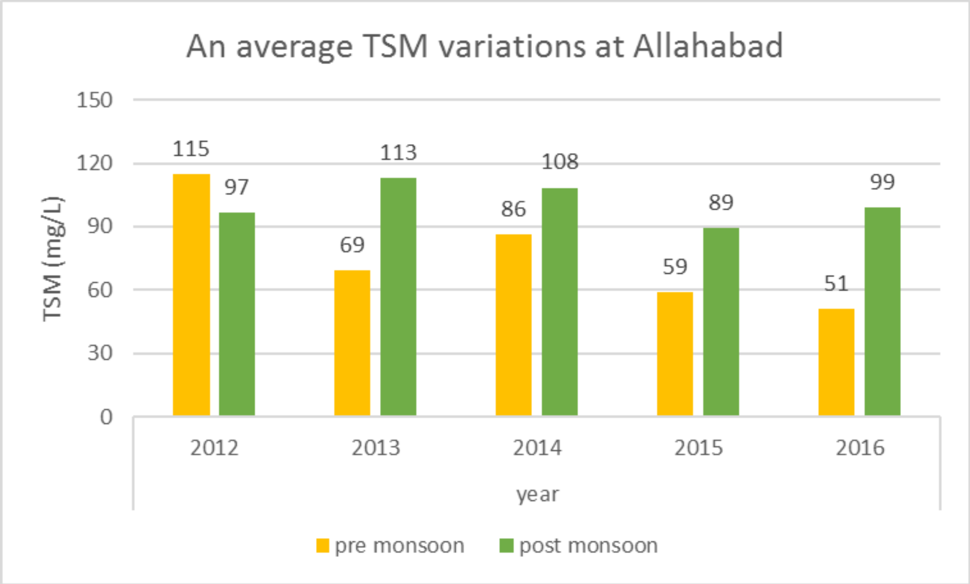

Figure 5. Scene level yearly average TSM variations in Ganga river in pre monsoon and post monsoon from 2012 to 2016 in Allahabad region

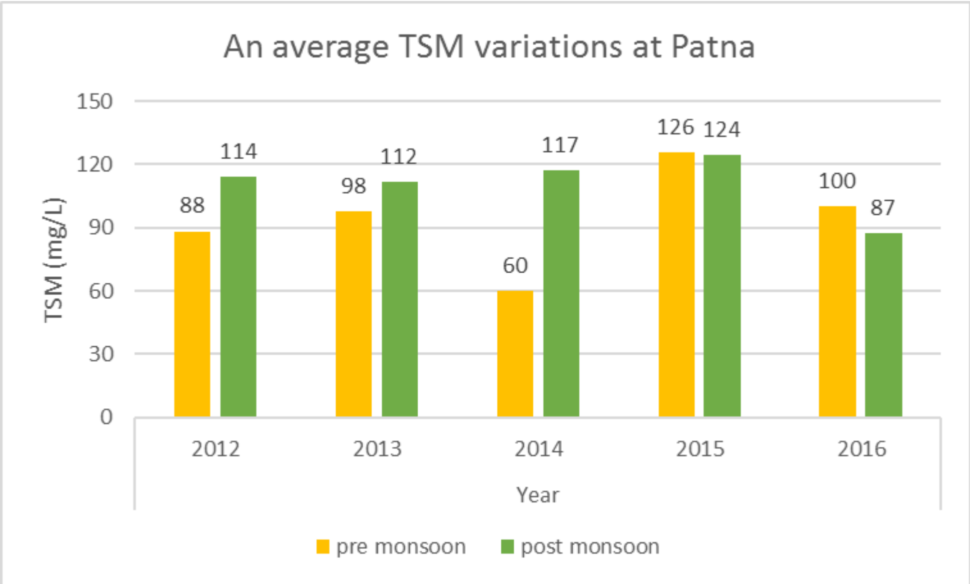

Figure 6. Scene level yearly average TSM variations in Ganga river in pre monsoon and post monsoon from 2012 to 2016 in Patna region

To understand the role of mixing of water from tributaries in Ganga river, analysis was carried out to study the TSM values in Ganga River at a specified location before the river meets the tributary and location after the joining of tributary in Ganga river at both the sites. Results of mixing of water of Ganga and Yamuna near Allahabad is given in Table 2 and Ganga and Gandak near Patna is given in table 3.

Table 2. Site level average TSM values for pre and post monsoon seasons Before joining of the tributary (B) and After Joining of the tributary (A) near Allahabad.

Acquisition Date (DD-MM-YYYY)	Average TSM ranges (mg/L)		Acquisition Date (DD-MM-YYYY)	Average TSM ranges (mg/L)	
Pre monsoon	B	A	Post monsoon	B	A
06-04-2012	139	87	15-10-2012	97	88
01-04-2013	58	44	27-11-2013	151	87
27-03-2014	91	80	29-10-2014	114	101
22-03-2015	69	52	24-10-2015	117	72
16-03-2016	59	47	18-10-2016	115	89

It was found that TSM values relatively decrease at location after Yamuna river joins Ganga River in comparison to TSM value at location before Yamuna joins the Ganga river in Allahabad in all the observations. But in case of Patna site, it was observed that Ganga river TSM values increase in location after Gandak river joins Ganga river in comparison to location before Gandak river joins Ganga river in most of the observations irrespective of pre and post monsoon conditions. Contrasting results on mixing of tributaries in Allahabad and Patna is due to different sediment load carried by Yamuna and Gandak and different water flow conditions. Low TSM (Average 73 mg/L) of Yamuna as compared to Ganga River caused reduction of TSM after mixing in Allahabad. Relatively high TSM of Gandak (average 117 mg/L) caused increase in TSM after mixing with Ganga river near Patna.

Table 3. Site level average TSM values for pre and post monsoon seasons Before joining of the tributary (B) and After Joining of the tributary (A) near Patna.

Acquisition Date (DD-MM-YYYY)	Average TSM ranges (mg/L)		Acquisition Date (DD-MM-YYYY)	Average TSM ranges (mg/L)	
Pre monsoon	B	A	Post monsoon	B	A
28-03-2012	84	85	23-11-2012	112	114
16-04-2013	89	103	18-11-2013	116	116
11-04-2014	57	64	13-11-2014	119	119
30-04-2015	116	131	08-11-2015	130	124
24-04-2016	88	101	02-11-2016	86	91

CONCLUSIONS

Spatial and temporal variations in TSM in Ganga river was analysed in Allahabad and Patna region using twenty atmospherically corrected Resourcesat-2 LISS-III data during 2012-2016. Atmospherically corrected NIR reflectance of water surface was used as satellite input for TSM estimation. The RT modelling scheme was used to develop the relationship between TSM and reflectance in NIR band tuned with relative spectral response of LISS-III sensor. Observations were taken in pre-monsoon (March/April) and Post Monsoon (October/November) period to avoid the cloud contamination and study the seasonal variation.

It was observed that Post monsoon TSM values were relatively higher as compared to pre monsoon TSM concentration in most of the cases in both seasons. Attempt was also made to study the role of Mixing of water from tributaries (Yamuna in Allahabad and Gandak in Patna) in changing the TSM concentration of Ganga river. Analysis carried out at specific locations before and after tributary meets Ganga showed that mixing of Yamuna water in Ganga at Allahabad results in relative reduction in TSM values of Ganga whereas mixing of Gandak water in Ganga at Patna results in relative increase in TSM values of Ganga.

This analysis is based on retrieval of TSM purely from theoretical RT model consideration and use of single channel (NIR) reflectance. Results need to further validated and calibrated with actual measurements. Present approach is also limited with atmospheric correction with fixed atmospheric visibility condition. It needs to be further improved by incorporating the variable atmospheric conditions in terms of aerosol optical thickness (AOT) in atmospheric correction scheme. Turbid atmosphere with higher AOT tends to increase the path radiance, an additive term in signal collection from satellite which can introduce error in TSM estimation. Field measurements of TSM and AOT values are required for improvement in accuracy of estimates. Over all it is a unique attempt to address the TSM variability in Ganga by developing sensor specific TSM retrieval algorithm for Indian RS2-LISS-III instrument.

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