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Research Paper

Preparing turbidity and aquatic vegetation inventory for waterlogged wetlands in Lower Barpani sub-watersheds (Assam), India using geospatial technology

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A B S T R A C T

Wetlands play a significant role in maintaining environmental stability. These have a complex of values like food storage, water quality maintenance, livelihood and support species diversity, etc. Wetlands inventory is the pre-requisite process for conservation and management practices. The study makes an attempt to delineate wetlands and prepare inventory for turbidity and aquatic vegetation in Lower Barpani sub-watersheds (Assam), India. The study utilized Landsat 8 OLI (Operational Land Imager) data during pre- and post-monsoon seasons, 2014. Wetlands during pre- and post-monsoon were delineated using supervised classification and threshold method. Wetland inventory for turbidity and aquatic vegetation was prepared during pre- and post-monsoon seasons. Single-band turbidity retrieval algorithm and normalized difference vegetation index (NDVI) were used to assess the level of turbidity and aquatic vegetation in GIS environment. The study revealed that the variation in the extent of water logged wetlands in sub-watersheds was due to water spread variation during pre- and post-monsoon seasons. All the sub-watersheds were characterized by medium turbidity which was attributed to sediments and silts brought with runoff in wetlands. Aquatic vegetation showed variation in its distribution across sub-watersheds. High vegetation indicated high turbidity and presence of nutrients. The study shows usefulness of remote sensing data in mapping and characterization of wetlands for preparing inventory and monitoring seasonal variation.

1. Introduction

Wetlands are the ecosystems having water table at or near the surface (Mitsch and Gosselink, 1986). Globally the area under wetland ecosystem is estimated to be 917 million hectares (Lehner and Doll, 2004). Most of the natural water bodies including rivers, lakes, coastal lagoons, mangroves, coral reefs and man-made water bodies like canal, ponds, farm ponds, reservoirs, etc constitute the wetland ecosystems in India (Ramsar Convention, 2012). Wetland occupies an area of 15.2 million hectares in India which constitutes nearly 4.6 per cent of the geographical area of the country (Space Applications Centre, 2011). Wetlands as natural habitats are valuable resources for supporting biological diversity, ground water recharge, flood control, and water quality improvement (Rundouist et al., 2001; May et al., 2002; Ghermandi et al., 2008) and have a complex of values to local economy and society (Prasad et al., 2002; ten Brink et al., 2012). However in recent years, anthropogenic activities such as urban development and agricultural management have caused a significant change in the land use/land cover and subsequent loss and degradation of wetlands (Syphard and Garcia, 2001; Rodrıguez et al., 2005; Zhao et al., 2006; Central Pollution Control Board, 2008). Wetlands have been identified as one of the most threatened habitats and received increasingly greater attention for monitoring their ecological functions and conservation (Gopal and Sah, 1995; Kabii, 1996).

Various wetland classification schemes have been proposed by different researchers and agencies (Cowardin et al., 1979; Paijmans et al., 1985; Mitsch and Gosselink, 1993). Space Applications Centre (2010) classified wetlands into natural and man-made wetlands. As per this classification scheme, the wetlands of Lower Barpani watershed are under 'waterlogged' category due to the seasonal variation of water supply by rainfall and floods. These

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kind of natural wetlands are locally known as *Beel* (Baruah et al., 2000; Deka et al., 2011).

Wetland inventory are the combination of generic and site specific features including physical, chemical and biological properties describing a wetland area in the simplest and most objective possible terms (Turner et al., 2000). Inventory of wetlands on the basis of hydrologic regimes, physico-chemical parameters and socio-economic attributes is essential in a country like India. The erratic nature and unequal distribution of rainfall in India have a direct bearing on the nature of the wetlands (Space Applications Centre, 2011). The vagaries of the monsoon have been responsible for extensive human regulation of water resources throughout the country, primarily for irrigation and domestic supplies, and secondarily for fisheries, hydropower and other uses (Kumar et al., 2005). The continued interaction between wetlands and the humans in various ways keeps their characteristics always changing, often unpredictably. Remote-sensing plays an important role in studying the changing characteristics of lake, reservoir, lagoons and terrestrial wetlands due to developmental activities (El Gammal et al., 2010; El-Asmar et al., 2013). Development of hyperspectral remote sensing and hydrological inference from watershed analysis for water resource management are recent development in geospatial technology (El-Magd and El-Zeiny, 2014; Singh et al., 2014). Turbidity is strong indicator for monitoring and planning of wetlands. Water quality monitoring using optical remote sensing is essential for mapping the water turbidity (Nechad et al., 2009). Remote-sensing based turbidity map helps in measuring suspended particulate matter (SPM) concentration in sediment (Gippel, 1995). Various turbidity retrieval algorithms have been proposed for specific geographical regions but a single standard algorithm is widely and effectively used globally (Dogliotti et al., 2015). The aquatic vegetation status along with turbidity is significant aspect for studying eutrophic level of wetlands (Manju et al., 2005; Chopra et al., 2010; Ray et al., 2012).

The turbidity and aquatic vegetation are significant aspects for making inventory of wetlands for sustainable development and management. Inventory based on aquatic vegetation and turbidity can help in monitoring ecological sustainability and water quality of wetlands (Panigrahy et al., 2012). The turbidity level of the water is a good indicator for analyzing the health status of the wetland for maintaining its ecosystem. Spatial variability of suspended particulate matter (SPM) is an important and potential source of uncertainty for turbidity estimation. Hence it becomes imperative to have inventory of wetlands. The study makes an attempt to delineate waterlogged wetlands on the basis of seasonal variation and inventory for turbidity and aquatic vegetation.

2. Study area

The Barpani River is a tributary of *Kopili* River in central Assam. The river is originated in the Karbi Anglong district and it merged to *Kopili* River in Nagaon district. Lower Barpani is a watershed of Barpani River which flows mostly in Nagaon district and in some hilly terrain of Karbi Anglong district. The extent of the watershed is from 25° 52′ N to 26°11′ N latitudes and 92° 29′ E to 92° 44′ E longitudes (Fig. 1). Watershed code of Lower Barpani River is 3B2A5 (All India Soil and Land Use Survey, 1990). There are seven sub-watersheds of Lower Barpani watershed. Out of these, only three sub-watersheds contain waterlogged wetlands. These waterlogged wetlands were chosen for preparing inventory. Topography of the study area is mostly plain in Nagaon district and hilly terrains are found in Karbi Anglong district. Numerous wetlands are found in the plain region of Nagaon district which are surrounded by agricultural fields and settlements. The study area experiences monsoon-type climate. The average annual rainfall in the study area ranges from 1000 mm to 2000 mm. The study area receives about 68% of the rainfall from June to September, with July being the rainiest month of the year (Department of Agriculture Assam, 2012).

Wetlands during post-monsoon are filled with water through rainfall, flood and run off. Flooded water and surface run off bring many nutrients to the wetlands making them suitable habitat for aquatic vegetation and fauna. The extent of water in wetlands is reduced during pre-monsoon season and *Boro* paddy is cultivated during this period. Post-monsoon flora and fauna make wetlands fertile and suitable for cultivation (Ahmed and Sajjad, 2015).

3. Data and methodology

Landsat 8 OLI (Operational Land Imager) data of November 2014 (Post-Monsoon) and March 2014 (Pre-Monsoon) were used in the present study. Landsat-8 OLI data product is very useful in terrestrial study. It has spatial resolution of 30 m except band 8 (panchromatic band). The panchromatic band is very significant for enhancing spatial resolution of other bands into 15 m useful in land use/ land cover study. Spectral resolution of OLI consists of nine spectral bands and provides better accuracy for studying spectral characteristics of surface objects. The watershed was demarcated using Survey of India Topographical sheets (83 B/12 and 83 B/13) and sub-watersheds were curved out based on the area and stream flow direction. Twelve sampled wetland sites were surveyed through Garmin handheld GPS to validate its location with satellite data. It has an average accuracy of less than 3 m with WAAS (Wide Area Augmentation System) receiver. Pre-processing of the data was carried out for turbidity measurement from satellite data. It involved satellite calibration and atmospheric haze reduction by calibration constant of Landsat 8 and IDOS (Improved Dark Object Subtraction) method.

3.1. Wetland delineation

Wetlands were delineated using threshold technique. Spectral reflectance of twelve sampled coordinates of waterlogged wetlands collected through GPS was analyzed on image during pre- and post-monsoon seasons. In a 16-bit raster image, post-monsoon spectral reflectance (5000–6000 digital numbers) showed maximum absorption of water in shortwave infrared band (2.11–2.29 μm) of Operation Land Imager satellite data. Pre-monsoon spectral reflectance showed maximum reflectance (17,500–20,000 digital numbers) of paddy in wetlands in a near infrared band (0.85–0.88 μm). The threshold values were applied to extract and delineate water body from post-monsoon image (Fig. 2). Heavy cloud cover in the post-monsoon image was excluded in the delineation process based on spectral signature and GPS survey. The extent of the wetlands were also examined through monthly average of precipitation and No. of wet days of last fifty years data form Indian water portal (Meteorological Data, 2016). The effect of aquatic vegetation in the delineation of some wetlands was removed by masking of water and validated through maximum likelihood classifier (Fig. 3). Maximum likelihood classification method of supervised classification considers variances and co-variances of classes assigning in the training sets. As per this assumption every particular class was characterized through its mean and co-variance matrix. The statistical probability was calculated for every pixel of the image to determine its membership for a particular class. The overall accuracy of this classification for this study was calculated as 89.23%. User accuracy of this classification ranged from 75% to 92% where producer accuracy ranged from 74% to 93%. From these accuracies, the Kappa Coefficient was determined as 0.83 which is very much significant

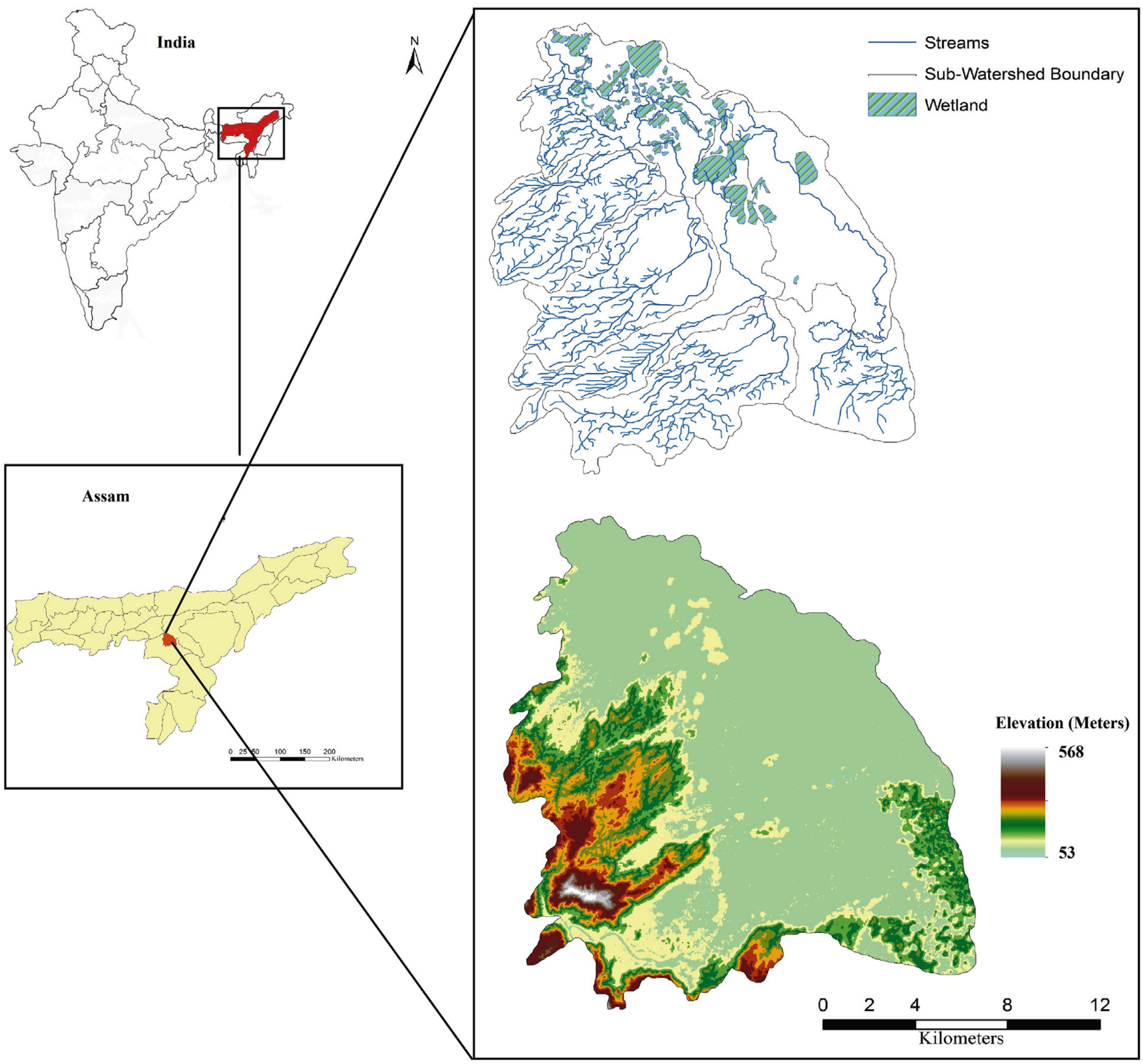

Fig. 1. Location Map of Study Area.

for this classification. Waterlogged wetlands and river were taken as separate classes for further validating the waterlogged wetlands delineated by threshold method.

3.2. Turbidity

For assessing spectral properties of water received by satellite is needed to be calibrated and corrected for atmospheric effect. For calibration of Landsat 8 OLI data was converted to Top of Atmosphere (TOA) planetary reflectance using reflectance rescaling coefficients which is provided in the image metadata. The following equation was used to convert DN values of band 4 to TOA reflectance.

$$\rho\lambda' = M\rho Q_{cal} + A\rho \tag{1}$$

Where $\rho\lambda'$ = TOA planetary reflectance, without correction for solar angle, $M\rho$ = Band-specific multiplicative rescaling factor (0.00002), $A\rho$ = Band-specific additive rescaling factor (−0.10000), Q_{cal} = Quantized and calibrated standard product pixel values (DN).

Calculation of TOA reflectance with a correction for the sun angle is expressed below.

$$\rho\lambda = \frac{\rho\lambda'}{cos(\theta_{SZ})} = \frac{\rho\lambda'}{sin(\theta_{SE})} \tag{2}$$

where $\rho\lambda$ = TOA planetary reflectance, θ_{SE} = Local sun elevation angle (42.62568548), θ_{SZ} = Local solar zenith angle; $\theta_{SZ} = 90° - \theta_{SE}$.

The atmospheric correction was carried out by Improved Dark Object Subtraction (IDOS) method using Ding et al. (2015), where final predicted haze value (FPHV) is subtracted from input digital number value of the dark object in each band. IDOS is expressed as:

$$IDOS = DN - FPHV \tag{3}$$

The Eqs. (1) and (2) were applied to convert image DN into object reflectance i.e. ρλ and Eq. (3) was applied to minimize the atmospheric haze effect on object reflectance. The single band suspended particulate matter retrieval algorithm was applied in the present study following Nechad et al. (2010). It relates turbidity and reflectance at wavelength 'λ'. Turbidity was calculated through radiative transfer simulation depends on the reflectance of dissolves particle in water. The variation of backscattering of water is observed in this model to examine the amount of dissolve particle present in wetlands. Turbidity can be expressed as:

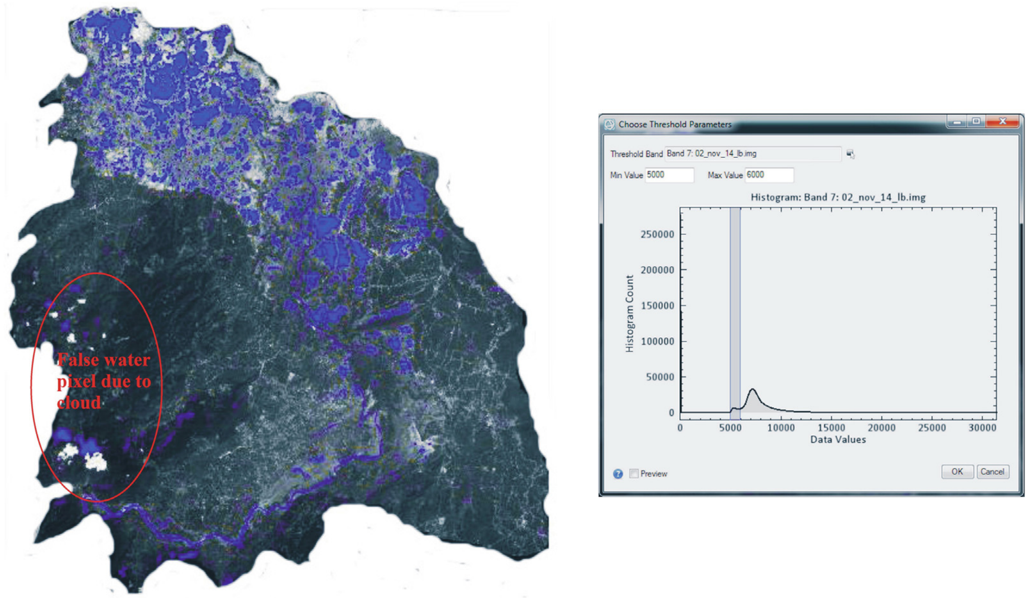

Fig. 2. Extracted water body by thresholding of water pixels.

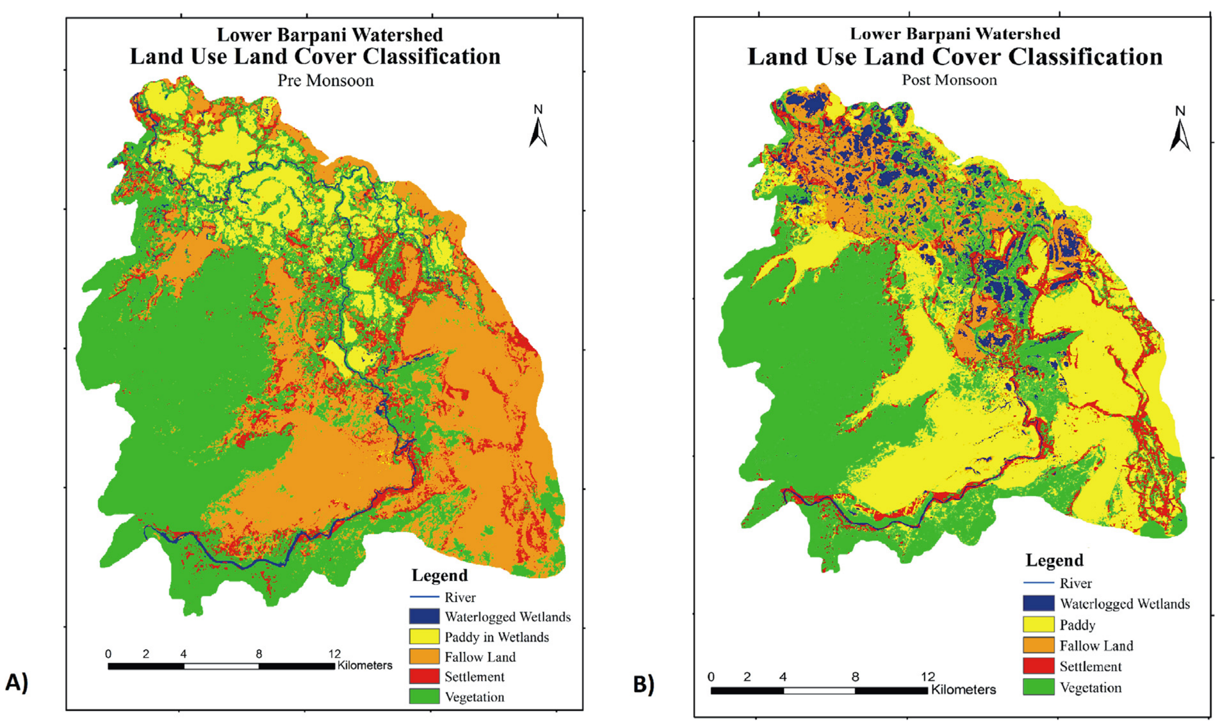

Fig. 3. Land Use/ Land Cover Classification (A. Pre-Monsoon, B. Post-Monsoon).

$$T = \frac{A_T^{\lambda}\rho_W(\lambda)}{\left(1 - \frac{\rho_W(\lambda)}{C_\lambda}\right)} \quad (4)$$

where A_T and C = wavelength-dependent calibration coefficients, (OLI band 4 the tabulated values for 655 nm are used: A_T = 289.29 - g m−3 and C = 0.1686).

To verify the turbidity due to aquatic vegetation was carried out by normalized difference vegetation index (NDVI) model. Reflectance capability of aquatic vegetation in near-infrared portion of electromagnetic spectrum (EMS) is very high due to near-linearity with increasing leaf area index and positive correlation with photosynthetic activity.

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (5)$$

where NIR = Near Infrared band of EMS (Band 5), Red = Red band of EMS (Band 4).

4. Results and discussion

The spatial distribution of wetlands in sub-watersheds were identified and mapped in 2014. Wetlands were concentrated in whole of 3B2A5a sub-watershed, north and south west portion of 3B2A5c sub watershed and northern portion of 3B2A5d sub watershed (Fig. 4). Remote-sensing derived area of wetlands and extent

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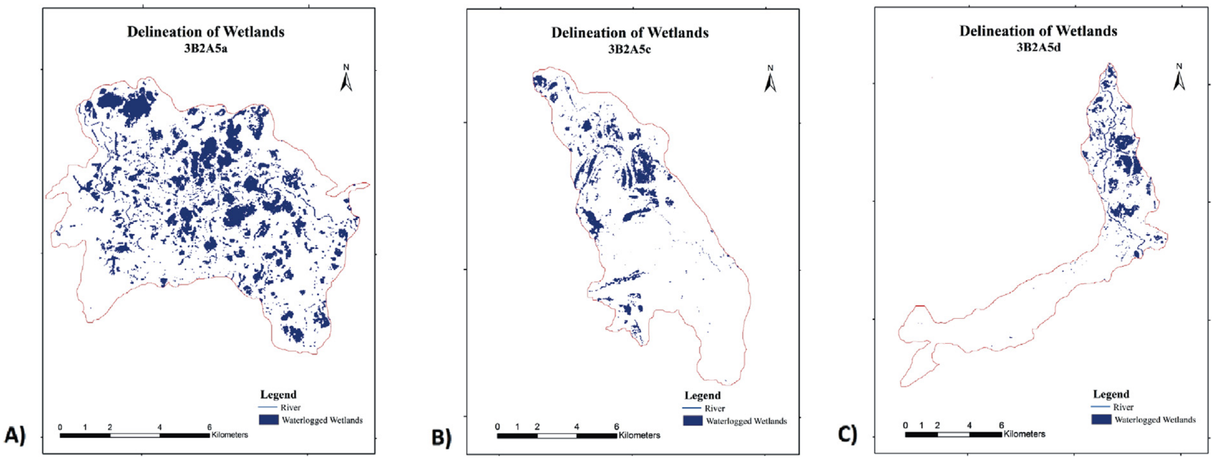

Fig. 4. Delineation of Wetlands (A. sub-watershed 3B2A5a, B. sub-watershed 3B2A5c, C. sub-watershed 3B2A5d).

Table 1
Areas of wetlands water spread in sub-watersheds during pre- and post-monsoon seasons.

Sub watershed	Extent of water spread (hectare)		Total Area of wetlands (hectare)
	Pre monsoon	Post monsoon	
3B2A5a	281.79	1552.70	4724.39
3B2A5c	145.53	601.13	1362.94
3B2A5d	100.71	619.2	1529.75

Source: Derived through remote sensing data.

of water spread in three sub watersheds is shown in Table 1. The largest area under wetland was found in 3B2A5a (4724 ha) followed by 3B2A5d (1530 ha) and 3B2A5c (1363 ha). It is also seen from the table that 3B2A5a and 3B2A5c were deep wetlands where the extent of water was large during pre-monsoon season while 3B2A5d sub-watershed was shallow wetland since the extent of water here was only 101 ha. Table 2 shows that the study area experiences monsoon climate where maximum precipitation occurs during May to September. This is termed as summer monsoon (south west monsoon) in Indian sub-continent. Average number of wet days is also high in monsoon season due to plenty of rainy days. Wetlands are filled with water during this period. Therefore the extent of wetlands area is higher in post-monsoon as compared to pre-monsoon season.

The radiative transfer simulation is analyzed in this study to measure the uncertainty at 655 nm. The turbidity in terms of backscattering was measured as water leaving irradiance depending on the concentration of suspended particulate matter (SPM). Turbidity levels for the wetlands of sub-watersheds have been qualitatively characterized into three levels namely, low, medium and high. It is observed that 83% of the area in 3B2A5c, 77% in 3B2A5d and 68% in 3B2A5a is under moderate to high turbidity (Table 3 and Fig. 5). The turbidity level in the post-monsoon data is attributed to the sediments and silt that have been transported into the wetlands along with runoff water and presence of aquatic vegetation in the wetlands.

The post-monsoon aquatic vegetation distribution for different wetlands shows that nearly 40% of the area of wetland in 3B2A5a corresponds to low vegetation density category. Moderate vegetation density coverage is found to be 42% of the wetland area in 3B2A5d 40% in 3B2A5c sub-watersheds respectively. Thus, a high level of aquatic vegetation density would indicate the possibility of the water being eutrophic. This may be attributed to the excessive growth of aquatic vegetation caused by excess input of organic and inorganic nutrients into a wetland. All the sub-watersheds have maximum area under high to moderate level of aquatic vegetation. The low aquatic vegetation status represents open water where surface vegetation cover is not available. This

Table 2
Monthly average for precipitation and number of wet days during last fifty years.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation*	13.3	29.2	100.4	248.0	475.3	772.6	715.2	537.4	381.6	209.4	35.2	9.2
No. of Wet Days	1	2	5	10	13	16	17	15	11	5	1	1

Source: India water portal.
* Precipitation (in millimeter).

Table 3
Average percentage of turbidity and aquatic vegetation status of wetlands in different Sub-watersheds (in percentage).

Sub watershed	High		Medium		Low	
	Surface turbidity	Aquatic vegetation	Surface turbidity	Aquatic vegetation	Surface turbidity	Aquatic vegetation
3B2A5a	28.96	30.31	39.30	29.13	31.74	40.56
3B2A5c	17.22	26.51	65.62	39.84	17.15	33.64
3B2A5d	20.9	24.81	56.31	41.96	22.78	33.22

Source: Authors' calculation from Turbidity and NDVI models.

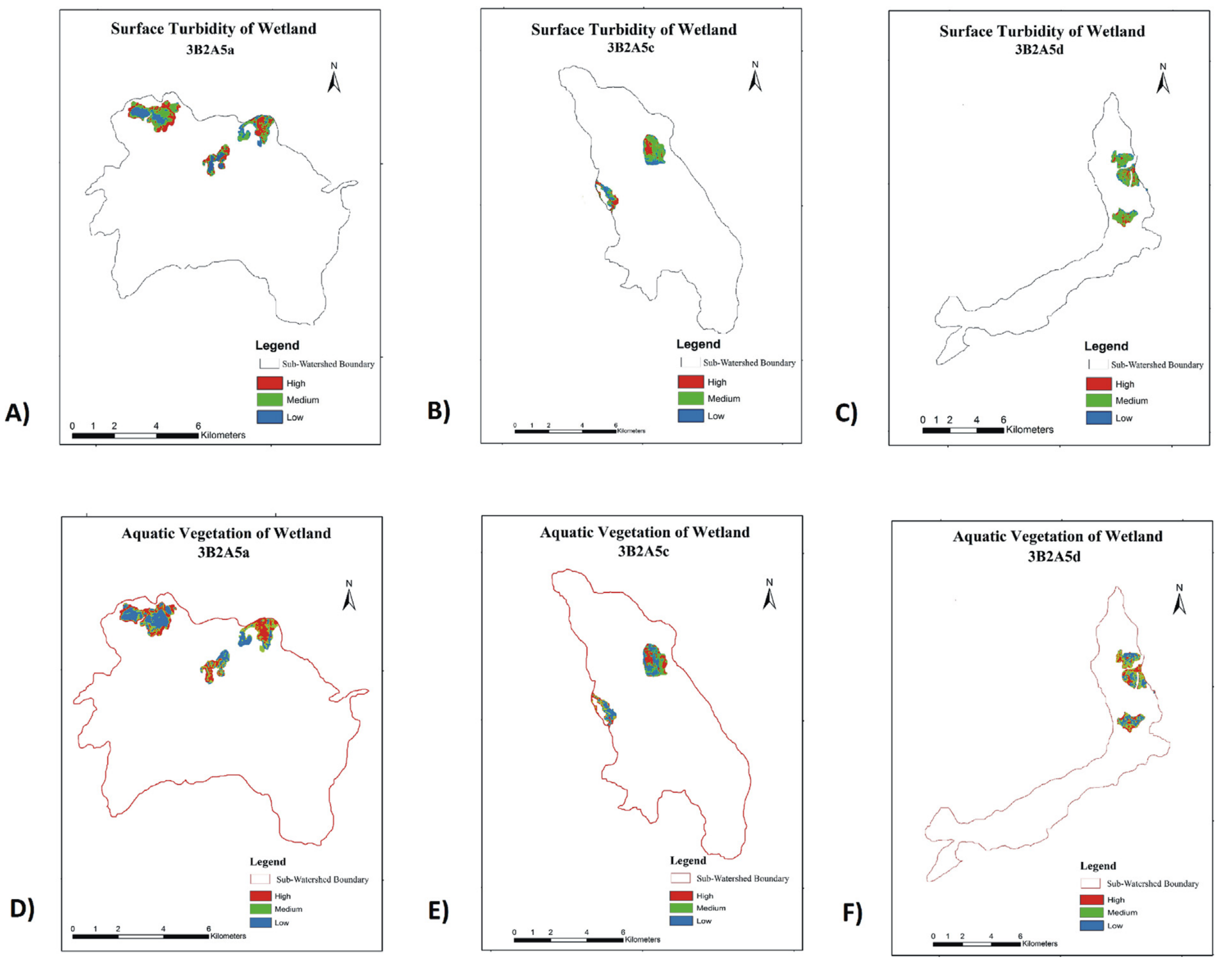

Fig. 5. A, B, C represent surface turbidity and D, E, F represent aquatic vegetation status of sampled wetlands for sub-watersheds.

analysis revealed that post-monsoon aquatic vegetation contributed to increased fertility of the soil of the wetlands. All the delineated wetlands of the sub-watersheds are important ecosystems for the cultivation of *Boro* paddy. The results revealed eutrophic status of the wetlands of the sub-watersheds during post-monsoon season. High surface turbidity of wetlands is attributed to dense aquatic vegetation cover on the water surface. This indicated eutrophic water rich in organic and inorganic inputs brought in by surface run off. Thus, pre-monsoon season offers ideal conditions for the cultivation of paddy in wetlands of sub-watersheds.

5. Conclusion

The paper explored the usefulness of remote sensing and GIS for preparing inventory of wetlands at sub-watershed levels. Wetlands were delineated using threshold model and supervised classification. Monsoon plays a significant role in the hydrology of wetlands in Lower Barpani sub-watersheds. Turbidity and aquatic vegetation were analyzed using single band algorithm and NDVI models. Pre- and post-monsoon remote sensing data enhances the research capability of preparing water spread, turbidity of water and aquatic vegetation inventories. The study emphasized the significance of the status of turbidity and aquatic plants in agriculture and supportive nature to aquatic fauna. Remote sensing derived turbidity, aquatic vegetation, water spread have proved to be significant indicators for assessing the ecological status of wetlands. These derived indicators can help in monitoring and preparing inventory of wetlands for planning and management for future uses.

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