

Assessing Wetland Landscape Dynamics in the Deepor Beel of Brahmaputra Basin Using Geospatial Tools

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Abstract

This work assesses wetland landscape dynamics in the Deepor Beel of Brahmaputra basin using multi-temporal satellite imagery. An attempt has also been made to link the wetland changes with the turbidity pattern observed from satellite imagery. In addition, this paper also highlights application of rule-based decision tree classification of satellite remote sensing data for monitoring and assessment of fluvial landscape dynamics. The wetland landscape has rapidly shrunk from 33.5% in 1990 to 21.1% in 1997 and 19.4% in 2007. The aquatic vegetation growth is very fast during 1990 to 1997, whereas it is relatively steady from 1997 to 2007. High turbidity in almost the entire study area was recorded in 1997 as compared to 1990 and 2007. In 2007, the spatial extent of Deepor Beel wetland area had decreased while at the same time the pattern of low and medium turbidity had increased. The significant shrinking of the wetland area clearly indicates an imperative need for restoration of the landscape.

Key words: Wetland, Turbidity, Remote Sensing, Rule-Based Decision Tree classifier, Landscape Dynamics.

1. Introduction

Wetland landscapes are permanently or seasonally submerged or water-saturated land. These include marshes, swamps, flood plains, bogs, peat lands, shallow ponds and littoral zones of large water bodies. These are formed due to excess water accumulation at a surface or water-logging on land during major parts, or the whole year. This water accumulation on this surface of soil is due to impeded drainage conditions. The Ramsar Convention in Iran (1971) defines wetlands as areas of marsh, fen, and peat land or water whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or, where marine, the water depth of

which does not exceed six meters at low tides. Ramsar further incorporates riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water. Ramsar categorizes wetlands into (i) estuaries, mangroves and tidal flats; (ii) flood plains and deltas; (iii) freshwater marshes; (iv) lakes; (v) peat lands and; (vi) forested wetlands.

Wetland landscapes harbor a wide variety of flora and fauna, all of great economic, aesthetic and scientific importance. These are suitable habitats for fish, tortoise and some endangered and rare species of birds. As an ecosystem, these are useful for nutrient recovery and cycling, releasing excess nitrogen, removing toxins, chemical and water through

absorption by plants (IPCC, 2001). Wetlands help in mitigating floods, recharging aquifers and reducing surface runoff and consequent erosion. During the time of floods, they act as sponge, which hold water and release it slowly, allowing groundwater to recharge. Mangrove wetlands act as a buffer against devastating storms. Some of the wetlands provide valuable areas for education, research, recreation and tourism. Wetlands are a valuable natural resource for flood control and water quality improvement (Rundquist *et al.*, 2001). They provide a critical habitat to a large number of wildlife species, including many endangered species, and support a rich biodiversity (Ozesmi and Bauer, 2002).

There are eight different categorizes of wetlands in India differentiated by region. The flood plain (locally called Beel) of the Brahmaputra river and the marshes and swamps in the hills of the northeast and the Himalayan foothills are such two categorizes (Ramchandra *et al.*, 2002). For a country like India, with its vast biological and cultural diversity, a comprehensive use of remote sensing, GIS and related technologies is obligatory in up-to-date conservation. Wetland's landscape characterization based on geomorphology, water quality and other biological attributes can lead to qualitative assessment. Results obtained from this type of analysis can be used in planning, inventorying and monitoring wetlands in the country. Due to the large extent of wetlands, the single use of ground survey methods is not a feasible approach for wetland mapping and temporal monitoring. Satellite remote sensing has many advantages including synoptic view, multi-spectral data collection, multi-temporal coverage and cost-effectiveness (Rundquist *et al.*, 2001). Therefore satellite remote sensing is arguably

the only practical approach for mapping wetlands in a convenient manner when covering large areas. This study highlights the importance of monitoring the physical extent of Deepor Beel wetland in Assam state of India using multi-temporal satellite imagery, as the changes in wetland nature and extent necessitate the widespread and consistent use of satellite-based remote sensors and low-cost, affordable GIS tools for effective management and monitoring.

2. Deepor Beel Wetland of Brahmaputra Valley

Assam state of India has 3,512 large wetlands (area > 2.25 ha) and 1,120 smaller wetlands. In the Brahmaputra valley most of the wetlands are oxbow lakes and hence bigger in size. These wetlands are locally known as Beels (Patar, 2005). Deepor Beel in the Kamrup District of Assam is one of the 21 national wetlands of India. The geographical coordinates of Deepor Beel are between 91°35' - 91°43' E longitude, 26°05' - 26° 11' N latitude (Figure 1). It is a natural, permanent, freshwater lake, in a former channel of the Brahmaputra located to the south of the present main river channel, oriented to the south-west of Guwahati city as a major storm water storage basin. It is set in a unique physiographic framework and is characterized by active hydrologic regime. At maximum flooding, it is about four meters deep; during the dry season, the depth drops to about one meter. The main sources of water are Basistha and Kalmani Rivers and local monsoon runoff between May and September. The Beel drains into the Brahmaputra River 5 km to the north-west, through the Khonajan channel.

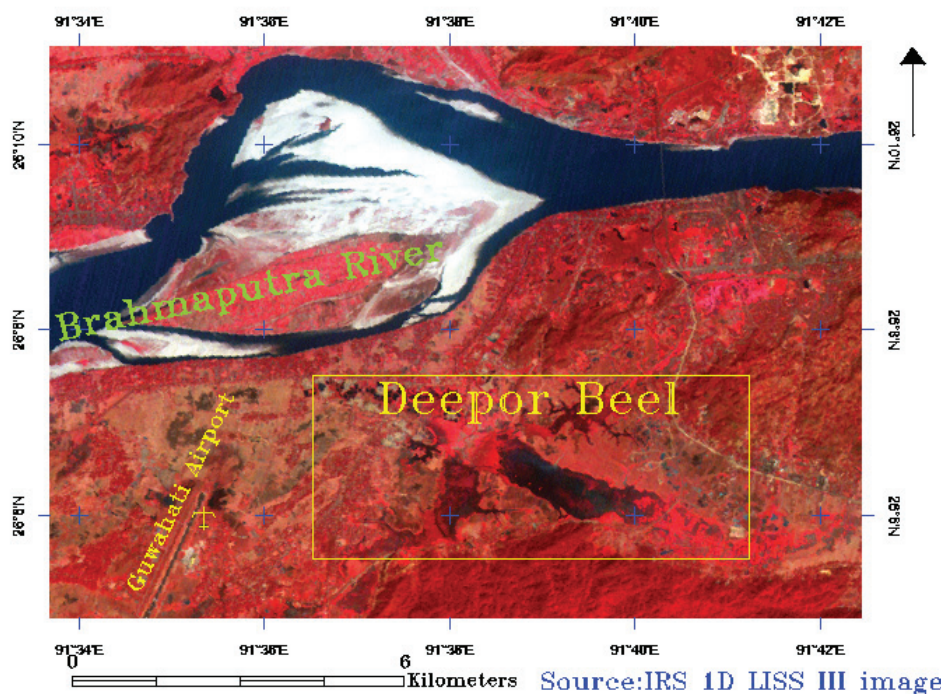


Figure 1. The Deepor Beel wetland ecosystem dynamics study area – False Color Composite (Band 3, Band 2, Band 1)

Deepor Beel, designated as a Ramsar Site, is habitat to a large number of migratory waterfowl each year in addition to a huge congregation of residential water birds. 219 species of birds including more than 70 migratory species are reported in the beel area. The lake supports globally threatened species of birds like Spotbilled Pelican (*Pelecanusphilippensis*), Lesser Adjutant Stork (*Leptoptilosjavanicus*), Baer's Pochard (*Aythya baeri*), Pallas' Sea Eagle (*Haliaeetusleucogaster*), Greater Adjutant Stork (*Leptoptilosdubius*), BlackneckedStork, and large Whistling Teal. It also supports 50 fish species belonging to 19 families (Saikia and Bhattacharjee, 1987).

The past two decades have seen considerable transformation in the ecological and social character of Deepor Beel and nearby areas. It has been observed that natural and anthropogenic problems i.e., (i) disturbance from transport artery i.e. construction of railway line along the southern boundary; (ii) industrial development within the periphery; (iii) large scale encroachment within the wetland; (iv) allotting government vacant land to private party; (v) brick making factory and soil cutting and erosion; (vi) hunting, trapping and killing of wild birds and mammals; (vii) commercial scale forest exploitation (viii) unplanned fishing practice without controlling mesh size and using water pump, etc. (Bezbaruah, 2007) are dominant. Incidentally not much work has been done to analyse the change in characteristics of this area. There is need to assess the wetland landscape using geospatial tools for effective monitoring and management of the beel area. The objective associated with this study is to characterize Deepor Beel wetland using geospatial tools. The study is intended to (i) assess wetland ecosystem dynamics using rule-based decision tree classification, (ii) assess spatio-temporal patterns in turbidity and (iii) changes in the landscape.

3. Datasets Used and Methodology

3.1 Datasets

Indian Remote Sensing (IRS) satellite's Linear Imaging Self Scanner (LISS) I and III sensor data were used (Table 1). The

satellite data were used to delineate wetland boundary from 1990 to 2007. For the year 1990, the LISS I data was used and for the year 1997 and 2007, LISS III data were used for analyzing the wetland landscape dynamics in Deepor Beel. Survey of India (SOI) toposheet 72N/12 was used in the study.

3.2 Data Pre-Processing

Radiometrically corrected satellite remote sensing data was obtained from National Remote Sensing Centre (NRSC/ISRO). For geometric correction, GCPs (Ground Control Points) collected from toposheet as well as using GPS (Global Positioning System) were used as reference locations. In order to bring all the images under one geometric coordinate system, these were geo-referenced with respect to SOI toposheet using second order polynomial and Polyconic projection system. A root mean square error less than 0.5 pixels has been obtained and nearest neighbour resampling was adopted. LISS I image has been resampled from spatial resolution of 72.5 m to 23.5 m. A standard false color composite image of study area is shown in Figure 1.

3.3 Rule Based Classification Technique

Decision tree classifier is more efficient over the traditional hard classifiers (Parmuchi *et al.*, 2002). It employs tree-structured rules that recursively divide the data into increasingly homogeneous subsets based on splitting criteria. At each split, values of each explanatory variable are examined and the particular threshold value of a single variable that produces the largest reduction in a deviance measure is chosen to partition the data (Rogan *et al.*, 2003). As a result, hierarchical, non-linear relationships within the data are revealed. The advantage of decision tree is that they are less sensitive to non-linearity in the input data than other methods that require assumptions of Gaussian distributions (Townsend, 2001).

3.3.1 Rule generation

In addition to conventional supervised and unsupervised approaches, several techniques integrating spatial

Table 1. The sensor characteristics for different satellite data used for wetland ecosystem assessment

Satellite	Sensor used	Year of Data acquisition	Spatial Resolution (m)	Spectral Bands
IRS-1A	LISS I	26-12-1990	72.5	0.45 - 0.52 μm (Blue band) 0.52 - 0.59 μm (Green band) 0.62 - 0.68 μm (Red band) 0.77 - 0.86 μm (NIR band)
IRS-1D	LISS III	08-02-1997	23.5	0.52 - 0.59 μm (Green band) 0.62 - 0.68 μm (Red band) 0.77 - 0.86 μm (NIR band) 1.55 - 1.70 μm (SWIR band)
IRS-P6	LISS III	14-12-2007	23.5	0.52 - 0.59 μm (Green band) 0.62 - 0.68 μm (Red band) 0.77 - 0.86 μm (NIR band) 1.55 - 1.70 μm (SWIR band)

environmental data with satellite imagery (Sader *et al.* 1995, Bolstad and Lillesand 1992, Lunetta and Barlogh 1999) have been developed to improve the accuracy of wetlands classification. Bolstad and Lillesand (1992) developed a rule-based model in which spatial data themes (i.e. roads, land cover, soil texture, terrain) and TM data was used for land cover classification. Sader *et al.* (1995) found that GIS rule-based methods with Landsat satellite images for forest wetland classification performed significantly better than traditional methods. Lunetta and Barlogh (1999) used a simple rule-based GIS model to classify wetland and upland vegetation types in Maryland and Delaware from SPOT satellite images. Their study showed that how a simple GIS rule-based model could be used after classification to improve accuracy. Therefore, a new rule-based wetland mapping method has been designed by integrating optical, radar and DEM data. For convenience, the new rule-based methods have been denoted as method 1, the decision tree classification method using optical data only as method 2, and the decision tree method using both optical data and radar data as method 3.

To delineate the wetland areas the Normalized Difference Water Index (NDWI) was calculated for all images in addition to individual band information (i.e., green, red, NIR). For 1990 image, blue wavelength information was included as well. The NDWI is useful to demarcate the land–water boundary (Gao, 1996; McFeeters, 1996) and mathematically it can be represented as follows:

$$NDWI = (NIR - SWIR) / (NIR + SWIR)$$

Where NIR is band 4 (0.77-0.86µm) and SWIR is band 5 (1.77-1.70µm) of LISS-III data.

Application of this indicator to a multi-spectral satellite image results in a positive values for water features and zero

or negative values for soil and vegetation (Chatterjee *et al.*, 2003). When the NDWI was applied using Band 4 (NIR) and Band 5 (SWIR) data of LISS-III image of the Deepor Beel region, the wetland boundaries were more distinct as compared to the original image.

3.3.2 Decision rules

All the images (NDWI and different bands of LISS I and LISS III) were used in decision tree classifier to delineate the wetland ecosystem and aquatic vegetation using ENVI software (Figure 2). Combining the information from IRS 1A, IRS 1D, IRS P6 satellite data, knowledge-based decision rules were designed within a GIS framework. The decision rules are described in Table 2a, 2b, 2c. For example (i) for

Table 2a. Rule based method and critical pixel values for decision tree classifier: 1990

Expression	Class	Remarks
(b1 > 9) and (b1 < 26)	Wetland ecosystem	If the condition is Yes
(b4 > 24) and (b4 < 29)	Other Vegetation	If the condition is Yes
Others	Other Land use	If the condition is No

Where, b1 is blue band, b4 is NIR

Table 2b. Rule based method and critical pixel values for decision tree classifier: 1997

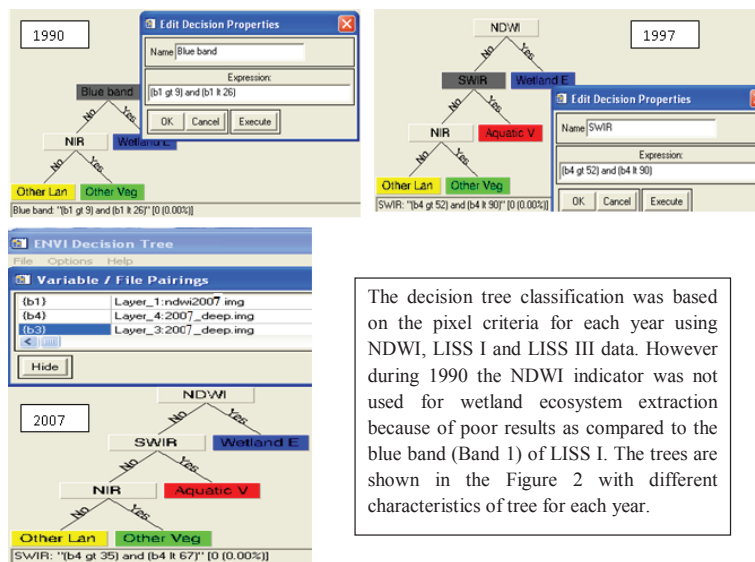
Expression	Class	Remarks
b1 > 0.20	Wetland ecosystem	If the condition is Yes
(b4 > 52) and (b4 < 90)	Aquatic Vegetation	If the condition is Yes
(b3 > 78) and (b3 < 110)	Other Vegetation	If the condition is Yes
Others	Other Land use	If the condition is No

Where, b1 is NDWI, b3 is NIR, b4 is SWIR

Table 2c. Rule based method and critical pixel values for decision tree classifier: 2007

Expression	Class	Remarks
b1 > 0.222	Wetland ecosystem	If the condition is Yes
(b4 > 35) and (b4 < 67)	Aquatic Vegetation	If the condition is Yes
(b3 > 70) and (b3 < 100)	Other Vegetation	If the condition is Yes
Others	Other Land use	If the condition is No

Where, b1 is NDWI, b3 is NIR, b4 is SWIR



The decision tree classification was based on the pixel criteria for each year using NDWI, LISS I and LISS III data. However during 1990 the NDWI indicator was not used for wetland ecosystem extraction because of poor results as compared to the blue band (Band 1) of LISS I. The trees are shown in the Figure 2 with different characteristics of tree for each year.

Figure 2. Schematic diagram for wetland delineation using Rule Based Decision tree classifier

wetland class, in 1990 data a condition pixel value of band 1 ranging between 9 and 26 is true, (ii) for other vegetation class, a condition pixel value of band 4 ranging between 24 and 29 is true, ELSE (condition = false), pixels other than 24 to 29 belong to other land use class. For the 1997 data, (i) for wetland class, a conditional pixel value of NDWI image (band 1) greater than 0.22 is true, (ii) for aquatic vegetation class, a conditional pixel value of band 4 ranging between 52 to 90 is true, (iii) for other vegetation class, a condition pixel value of band 3 ranging between 78 to 110 is true, ELSE (condition = false), pixels other than 70 to 110 belong to other land use class. For the 2007 data, (i) for wetland class, a conditional pixel value of NDWI image (band 1) greater than 0.22 is true, (ii) for aquatic vegetation class, a conditional pixel value of band 4 ranging between 35 to 67 is true, (iii) for other vegetation class, a condition pixel value of band 3 ranging between 70 to 100 is true, ELSE (condition = false), pixels other than 70 to 100 belong to other land use class.

3.4. Spatio-Temporal Characterization of Turbidity

Turbidity pattern was best reflected and observed using Green band of IRS 1D, LISS III image data. The higher the DN value in Green band, the higher is the turbidity. The turbidity classification is subjective as it is impractical to relate the quantitative values for turbidity (which are dynamic according to the season) with the reflectance. Thus,

determination of the threshold for different turbidity levels needed examining the major (large-sized) water bodies in the area (Prasad *et al.* 2002).

In this study, multi-date satellite data of 1990, 1997 and 2007 were used for identifying areas of high, medium and low turbidity within the Deepor Beel. This helped to link the spatial distribution of turbidity patterns within the mapped wetland. The quantitative turbidity ratings assigned are low, moderate and high based on the hue manifested on false color composites and extracted using ISODATA algorithm (unsupervised classification) in ERDAS Imagine. The spatial turbidity patterns on three different dates were mapped to indicate the influence of turbidity on the spatial distribution of wetland areas from 1990 to 2007. This type of preliminary investigation is necessary to assess the health and the dynamic nature of the wetland region.

4. Results and Discussion

4.1. Deepor Beel Wetland Distribution and Changes

Rule-based classification technique was used for identification of four major land use land cover classes: wetland ecosystem, aquatic vegetation, other vegetation and other land use (Figure 3a & 3b). Here, wetland ecosystem refers to the area covered by water within wetland area.

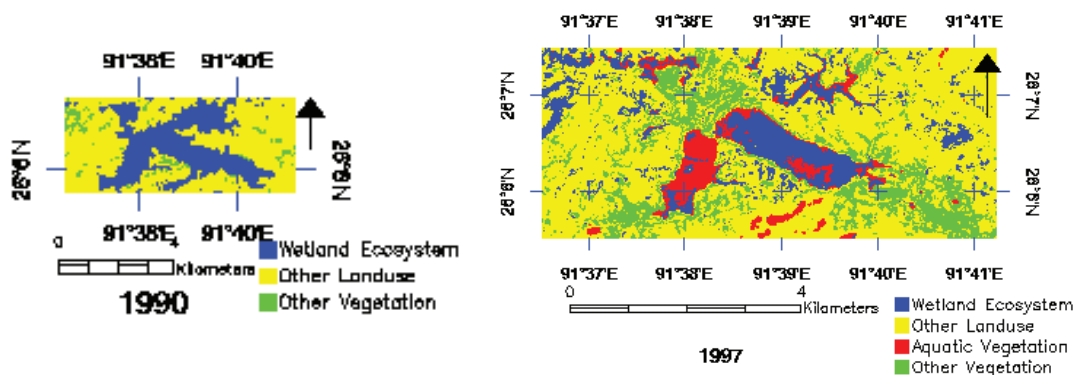


Figure 3a. Rule based wetland ecosystem classification for 1990 and 1997

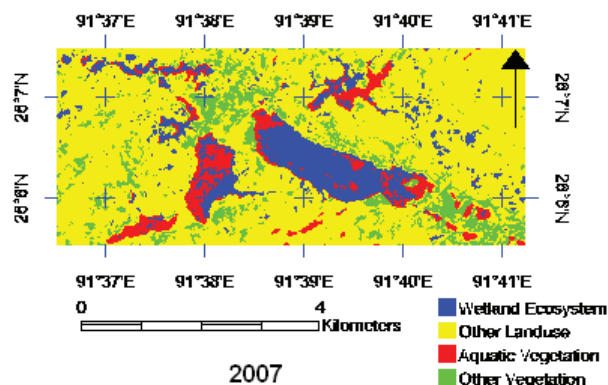


Figure 3b. Rule based wetland ecosystem classification for 2007

Aquatic vegetation also referred as hydrophytes or aquatic macrophytes, are plants that have adapted to living within aquatic environments. These plants require special adaptations for living submerged in water or at the water's surface. Aquatic plants can only grow in water or in soil that is permanently saturated with water. Remaining vegetation classes are grouped in 'other vegetation'. Other than these three classes, remaining pixels are grouped as 'other land use classes'.

The accuracy assessment (Table 3a) results show that the overall accuracy of the classified image is 93.58%, 91.91% and 94.21% for 1990, 1997 and 2007, respectively. The Kappa coefficient is 0.89, 0.89 and 0.91 for 1990, 1997 and 2007, respectively. For 1990 producer and user accuracy could not be calculated for the aquatic vegetation because no aquatic vegetation was recorded in the Deepor Beel ecosystem.

The analysis of satellite data from 1990-2007 reveals that the wetland ecosystem is shrinking, as shown in Figures 3a and 3b. The wetland was intact in 1990 and by 1997, the wetland had started fragmenting due to vegetation growth, encroachment, siltation etc. The detachment rate increased until 2007. The fragmentation is a major obstacle to the smooth flow of water in the DeeporBeel ecosystem. The phenomenon of progressive shrinkage of the wetland is shown in Table 3b.

The qualitative change analysis of wetlands indicates that during 1990, wetland ecosystem was 33.5% of the total study area. The aquatic vegetation growth has been observed in 1997 and 2007. As the aquatic vegetation growth has taken place in the wetland area, this class was merged with the wetland area to know the decreasing trend of wetland patches in the Deepor Beel area from 1990 to 2007. From Table 3b it can be seen that the wetland area has decreased from 33.5% of total area (1990) to 21.1% of total area (1997)

and then to 19.4% of total area (2007). Hence the study reveals that there is a significant decline of wetland areas from 1990 to 1997, however the decline rate is less from 1997 to 2007. Similarly the study has indicated that the aquatic vegetation growth is very rapid during 1990 to 1997 i.e., 0 to 6.33%, whereas the growth is steady from 1997 to 2007. Overall, the wetland ecosystem has declined by 14.1% (405 ha) from 1990 (33.5% of total area) to 2007 (19.4% of total area).

4.2. Turbidity Pattern within Deepor Beel

Turbidity pattern within the Deepor Beel has been mapped using the multi-temporal satellite images to assess the spatial extent of turbid water from 1990 to 2007 (Figures 4a, 4b, 4c). In this study, the qualitative turbidity of Deepor Beel record was based on hues as manifested on the FCC. The turbidity of water in DeeporBeel is variable as shown in Figure 4. During the period 1997 to 2007, the highest turbidity was recorded in 1997. In 2007, the spatial extent of wetland area has decreased while the pattern of low and medium turbidity was dominant. The extent of wetland area mapped in 1997 was larger as compared to that of 2007, and turbidity was higher in the main part of DeeporBeel. Shrinking of the wetland area clearly indicates an imperative need for restoration of the wetland ecosystem. In 1990, presence of aquatic vegetation could not be assessed quantitatively using information from satellite image due to inherent limitation of low spatial resolution (72.5 metres) of LISS I data. However, existence of some aquatic vegetation in 1990 could be inferred based on expert knowledge from field assessments in a qualitative manner, but in comparison to that much aquatic vegetation has been detected in 1997. In the surrounding areas of Deepor Beel, the farmers are using higher quantities of fertilizer and pesticides to increase the agricultural production; which may affect the wetland ecosystem.

Table 3a. Accuracy assessment of digital classification for DeeporBeel ecosystem

Accuracy (%)	1990		1997		2007	
	PA	UA	PA	UA	PA	UA
Wetland Ecosystem	100	100	99.19	90.44	99.42	99.42
Aquatic Vegetation	0	0	90.16	100	98.39	98.39
Other vegetation	84.62	78.57	83.3	99.21	94.32	88.30
Other Land use	89.29	92.59	97.98	78.86	87.64	93.98
Overall Accuracy	93.58		91.91		94.21	
Kappa Coefficient	0.89		0.89		0.91	

(PA - producer's accuracy, UA – User's accuracy)

Table 3b. Area Statistics of Wetland Area during 1990, 1997, 2007

Class Name	1990		1997		2007		Change % 1990-2007
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	
Wetland Ecosystem	961.7	33.5	424.3	14.77	356.3	12.4	-21.1
Aquatic Vegetation	-	-	182.0	6.33	203.3	7.0	7.0
Other Vegetation	144.9	5.0	506	17.61	329	11.45	6.45
Other Land Use	1765.7	61.5	1760	61.29	1983.7	69.15	7.65
Total	2872.3	100	2872.3	100	2872.3	100	0

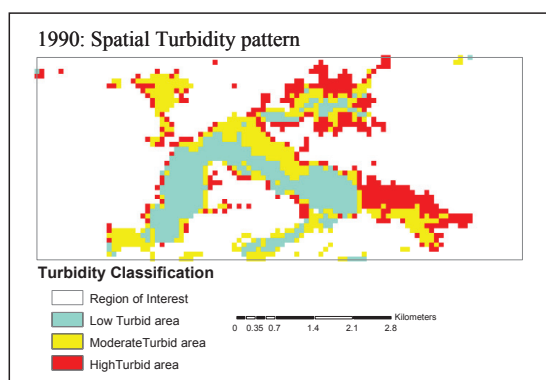


Figure 4a. Spatial turbidity pattern from multi-temporal IRS LISS imagery - 1990

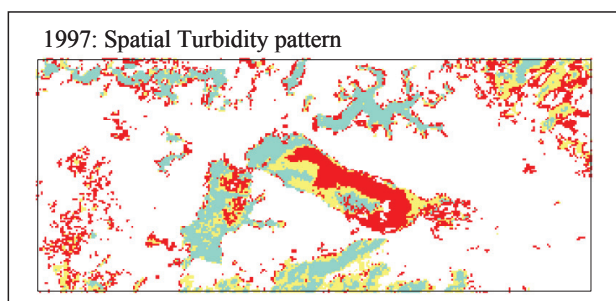


Figure 4b. Spatial turbidity pattern from multi-temporal IRS LISS imagery - 1997

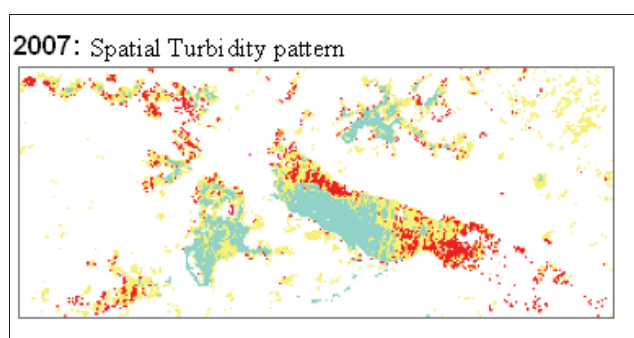


Figure 4c. Spatial turbidity pattern from multi-temporal IRS LISS imagery - 2007

5. Conclusion

The study revealed that the Deepor Beel wetland ecosystem comprised 33.5% of total study area in 1990, when presence of aquatic vegetation was almost missing. Subsequently the area of the wetland has reduced. In the survey period the wetland area decreased from 33.5% (1990) to 21.1% (1997) and then to 19.4% (2007) of the study area. In the total survey period the wetland ecosystem area is observed to be sharply diminished posing threat to its sustainability. Moreover, emergence of aquatic vegetation was observed in subsequent years.

Deepor Beel, a Ramsar site, and one of the important wetland ecosystems in the Brahmaputra Basin, is encroached upon by various agencies including Border Security Force (BSF)

camp, railways, nursing homes, brick kilns and is swamped by water hyacinth. Apart from acting as a storm water retention basin, it is a major migratory centre and breeding ground for birds. This opportunity is getting lost as a result of the present development, causing growth of water hyacinth and shrinkage of the wetland area. The dynamic nature of wetlands necessitates the widespread and consistent use of satellite-based remote sensing and low-cost, affordable GIS tools for effective management and long-time monitoring.

References

- Bezbaruah, A., 2007. Environmental Management Fall 2007 Case Studies. <http://www.ndsu.edu/pubweb/~bezbaruah/em/casestudies.html#Other>. (accessed on 16 Oct. 2010).
- Bolstad, P.V. and Lillesand, T.M., 1992. Rule-based classification models: flexible integration of satellite imagery and thematic spatial data, *Photogrammetric Engineering and Remote Sensing*, 58:965-971.
- Congalton, R.G., 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, 37 (1), 35-46.
- Chatterjee, C., Kumar, R. and Mani, P., 2003. Delineation of surface waterlogged areas in parts of Bihar using IRS-1C LISS III data. *J. Indian Soc. Remote Sensing*, 31, 57-65.
- Gao, B.C. 1996. NDWI - A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment* 58: 257-266.
- IPCC, 2001. Climate Change 2001, The Scientific Basis. *Contribution of working group 1 to the third assessment report of the intergovernmental panel on climate changes*, Cambridge University Press, New York, 524.
- Jensen J. R. 2004. Introductory digital image processing, 3rd edition, Pearson, 544.
- Lunetta, R. and Balogh, M., 1999. Application of multitemporal Landsat 5 TM imagery for wetland identification. *Photogrammetric Engineering & Remote Sensing*. V.65, N.11, 1303-1310.
- McFeeters, S.K., 1996. The use of normalized difference water index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*, 17, 1425-1432.
- Ozesmi, S.L. and Bauer, M.E., 2002. Satellite remote sensing of wetlands. *Wetlands Ecology and Management*, 10, 381-402.

- Parmuchi, M.G., Karszenbaum, H. and Kandus, P., 2002. Mapping wetlands using multitemporal RADARSAT-1 data and a decision-based classifier. *Canadian Journal of Remote Sensing*, 28, 175–186.
- Patar, K.C., 2005. Preservation of wetlands. Editorial. *The Assam Tribune*, Guwahati, Saturday, October 1, 2005.
- Prasad, S.N., Ramachandra, T.V., Ahalya, N., Sengupta, T., Alok Kumar, Tiwari, A.K., Vijayan V.S. and Lalitha, Vijayan (2002). Conservation of wetlands of India-a review. *Tropical Ecology*, 43(1): 173-186.
- Ramchandra *et al.*, 2002
- Rogan, J., Miller, J., Stow, D., Franklin, J., Levien, L. and Fisher, C., 2003. Land-cover change monitoring with classification trees using Landsat TM (Thematic Mapper) and ancillary data. *Photogrammetric Engineering and Remote Sensing*, 69, 793–804.
- Rundquist, D., Narumalani, S. and Narayanan, R., 2001. A review of wetlands remote sensing and defining new considerations. *Remote Sensing Reviews*, 20, 207–226.
- Sader, S.A., Ahl, D., and Wen-Shu, L. 1995. Accuracy of Landsat-TM and GIS Rule-Based Methods for Forest Wetland Classification in Maine. *Remote Sensing of the Environment*, 53:133-144.
- Saikia, P.K. and P.C. Bhattacharjee, 1987. A study of the Avifauna of DeeporBeel A Potential Bird Sanctuary in Assam. Parisah, D. and Prentice, R. C. (Eds) 1999. *Wetland and Waterfowls Conservation in Asia*. Asian Wetland Bureau/IWRB, Kuala Lumpur.
- Townsend, P.A., 2001. Mapping seasonal flooding in forested wetlands using multitemporal Radarsat SAR. *Photogrammetric Engineering and Remote Sensing*, 67, 857–864.