Remote Sensing Based Study on Channel Changes and Wetland Ecosystem Dynamics of Brahmaputra River in India

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ABSTRACT:

The study in this paper focuses on two major issues. Firstly, the study of morphology of fluvial landform through a combination of remote sensing, GIS analysis and field observation to better understand the morphological characteristics and dynamics of the Brahmaputra river with particular emphasis on bank line and width changes. Secondly, to map the dynamics of wetland ecosystem and its turbidity pattern of Deeper Beel of Brahmaputra basin using multi-temporal satellite imagery. In addition, this paper highlights the application of Rule-Based Decision Tree classifier for wetland identification and its extraction for further analysis. An attempt has also been made to link the wetland changes with the turbidity pattern observed from satellite imagery.

From the channel change analysis, it is found that the average northing for right bank line of the Brahmaputra river moved about 0.47 km to the north between 1990 and 2002, while that for the left bank moved about 0.48 km to the south. The river has radically avulsed just upstream side of the Dibrugarh town and excised areas of floodplain to create new bars. The river mean width has increased from 7.99 km to 8.94 km in the total length of the river; whereas the minimum width at Pandu is slightly constricted due to the presence of the bridge. The study further revealed that the total area within the two bank-line increased by 12.10% between 1990 and 2002 due to erosion process causing channel widening.

The wetland areas have rapidly shrunk from 33.5% in 1990, 21.1% in 1997 and 19.4% in 2002. The study has brought out that there is a rapid decline of wetland areas from 1990 to 1997. In addition, the study has concluded that the aquatic vegetation growth is very fast during 1990 to 1997 i.e. 0 to 6.33%, whereas its growth is steady from 1997 to 2002. Overall the wetland ecosystem has declined to 14.1 %(405 ha) from 1990 to 2002. High Turbidity in almost entire study area is recorded in 1997 as compared to 1990 and 2002. In 2002, the spatial extent of Deeper Beel wetland area has registered decrease while at the same time, pattern of low and medium turbidity has increased. The extent of wetland area mapped in 1997 was relatively more when compared to that of 2002, with more high turbid water pattern distribution in the prominent wetland Deepor Beel of the Brahmaputra basin. The wetland area is significantly shrinking from 1990 to 2002, which clearly indicates an imperative need for restoration of wetland health and its dynamic ecosystem.
The study highlights the need for satellite remote sensing for monitoring and dynamic assessment of fluvial ecosystem changes which facilitate planning for ecosystem restoration.

KEYWORDS:
Fluvial landform, Wetland ecosystem, Aquatic vegetation, Turbidity, Multi-temporal, Deepor Beel, Brahmaputra
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1. INTRODUCTION

1.1 Brahmaputra River and it's Morphology:

The Brahmaputra is a major transboundary river covering a drainage area of 580,000 sq. km., 50.5 percent of which lie in China, 33.6 percent in India, 8.1 percent in Bangladesh and 7.8 percent in Bhutan. Its basin in India is shared by provinces of Arunachal Pradesh (41.88%), Assam (36.33%), Nagaland (5.57%), Meghalaya (6.10%), Sikkim (3.75%) and West Bengal (6.47%). Originating in a great glacier mass at an altitude of 5,300 m just south of the lake Konggyu Tso in the Kailas range about 63 km southeast of Mansarovar lake in southern Tibet, the Brahmaputra flows through China (Tibet), India and Bangladesh for a total distance of 2880 km before emptying itself into the Bay of Bengal through a joint channel with the Ganga. Its total length comprises of 1625 km in Tibet, 918 km in India and 354 km in Bangladesh. Records show that devastating floods occurred in 1954, 1962, 1966, 1972, 1973, 1977, 1978, 1983, 1984, 1987, 1988, 1991, 1993, 1995, 1996, 1998 and 2004. Upwards of 9600 km^2 land, that is 12.21% of the geographic area of Assam, is annually affected by floods. In 1998, the flood which came in four frightening waves, deluged 38,200 km^2 or 48.65% geographic area of the state, putting in peril the lives and properties of 12.5 million people (Goswami, 1998).

The study on river morphology with the use of remote sensing data is a relatively new development, and has been in practice for not more than the last 20 to 25 years in India. Murthy, 1990 studied the flood plain of Brahmaputra river using satellite imageries. Hussain, 1992 carried out morphological studies of river Brahmaputra with the help of satellite imageries. Oak, 1998 worked on the prediction of bank erosion of the Brahmaputra river on Gumi-Alikash reach (down stream of Pandu). Some erosion studies using satellite imageries in the vicinity of Majuli island and Kaziranga National Park was been studied by Space Application Centre, Ahmedabad. Singh, 2003 studied the spatio-temporal morphological analysis using satellite data for a reach of river Brahmaputra.

1.2 Wetland ecosystem of Brahmaputra Valley- *Deepor Beel*

Assam has 3,512 wetlands each having areas over 2.25 ha and 1,120 wetlands each having areas less than 2.25 ha. Most of the wetlands in the Brahmaputra valley are oxbow lakes and hence bigger in sizes. During the period of 30s and 40s many wetlands known as Beels, marshes and swamps were seen in the rural areas. These wetlands were found to be very productive (Patar, 2005). In the fringe areas of the wetlands, different species of plants of economic importance grew. The Deepor Beel of Assam (Kamrup District) is one of the 21 national wetlands, which have been declared so far. The Deepor Beel wetland is a permanent, freshwater lake, in a former channel of the Brahmaputra river, to the south of the main river south-west of Guwahati city. It is a large natural wetland having great biological and environmental importance besides being the only major storm water storage basin for the Guwahati city. This wetland is endowed with rich floral and faunal diversity. In addition to huge congregation of residential water birds, the Deepor Beel ecosystem harbours large number of migratory waterfowl each year. The Deepor Beel has been designated as a Ramsar Site in November 2002.

There are eight different categories of wetlands in India differentiated by region. The flood plain of the Brahmaputra (Beels) and the marshes and swamps in the hills of North East and the Himalayan foot hills are such two categories (Prasad, 2002). For a country like India, with its vast biological and cultural diversity, a comprehensive use of remote sensing, GIS and other related technologies will be of great use in conservation. Classifying and mapping wetlands based on geomorphology, water quality and other biological attributes can lead to qualitative assessment. Results obtained could be used in planning, inventorying and monitoring wetlands in the country. Due to the large extent of wetlands, the use of ground survey methods for wetland mapping and regular updating of information is not a pragmatical approach. 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 that can map wetlands in a convinent manner over a larger area. This study has highlighted the importance to monitor the physical extent of wetlands in Assam using multi-temporal satellite imagery. Hence the dynamic nature changes of wetlands necessitate the widespread and consistent use of satellite-based remote sensors and low-cost, affordable GIS tools for effective management and monitoring.

Wetlands are areas, which are submerged under water or water-saturated land permanently or for part of the year. The water table is usually at or near the surface or the land is covered by shallow water. These include marshes, swamps, flood plains, bogs, peat lands, shallow ponds and littoral zones of large water bodies. Wetlands are formed when the excess of water accumulate on the surface of soil and make water-logging on the land during major part or whole year. This water accumulation on this surface of soil is due to impeded drainage conditions. The Ramsar Convention defines wetlands as areas of marsh, fen, peat land or water whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or saltish, including areas of marine water the depth of which at low tides does not exceed six metres. Ramsar further incorporates into its consideration for listing riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands. Ramsar categorises wetlands into (i) estuaries, mangroves and tidal flats; (ii) flood plains and deltas; (iii) freshwater marshes; (iv) lakes; (v) peatlands and (vi) forested wetlands.

Wetlands harbour a wide variety of flora and fauna, all of great economic, aesthetic and scientific importance. Wetlands are suitable habitats for fish, tortoise and some endangered and rare species of birds. As an ecosystem, wetlands are useful for nutrient recovery and cycling, releasing excess nitrogen, removing toxins, chemical and heavy water through absorption by plants. Wetlands help in mitigating floods, recharging aquifers and reducing surface run off and consequent erosion. During times of floods, they act as sponge which hold water and release it slowly, allowing ground water to recharge. Also, they are excellent cleansers of pollutants discharge into the water. Mangrove wetlands act as buffer against devastating storms. Some of the wetlands provide valuable areas for education research and recreation and tourism. Wetlands are a valuable natural resource for ground water recharge, flood control and water quality improvement (Rundquist et al. 2001). They provide critical habitat to a large number of wildlife species, including many endangered species, and support a rich biodiversity

(Ozesmi and Bauer, 2002). Wetlands also play an important role in global carbon and methane cycles, and thus could strongly feed back to, as well as being affected by, climate change (IPCC 2001).

1.3 Objectives of the Study

In this paper morphological study of fluvial landform is made through a combination of remote sensing, GIS analysis and field observation to better understand the characteristics and dynamics of the Brahmaputra river with particular emphasis on bank line and width changes. Attempt has been made towards wetland ecosystem dynamics assessment in the Deepor Beel area using rule based decision tree classification technique. In addition to this, turbidity pattern identification from satellite imagery has been attempted and the results are presented here with.

2. STUDY AREA AND DATA USED

In the study, digital satellite images of Indian Remote Sensing (IRS) Linear Imaging Self Scanner (LISS)-III sensor, comprising of 32 scenes for the years 1990, 1997, 2000 and 2002 are used for the study area. This area was covered by seven image frames made into a single mosaic for each period i.e.1990,1997 and 2002. In order to bring all the images under one geometric co-ordinate system, these are geo-referenced with respect to Survey of India (1:50,000 scale) toposheets using second order polynomial. A root means square error less than 0.5 pixel has been obtained and nearest neighbourhood re-sampling is adopted.

2.1. Dataset used and study area for extraction of channel form:

Satellite images of the Brahmaputra river corridor were identified and selected for the study. The images selected were taken during the dry season (February) when cloud-free imagery was available and when water level, vegetation cover and other ground conditions were relatively consistent. The focused extent of the area for this analysis covered the entire Brahmaputra River from Kobo to the border with Bangladesh, a distance of 622.73 km as shown in Figure1 (a). Considering the river flows, the confluence of river tributaries, and for convenience in computing the segments, the study area of 622.73 km from Dhubri (cross section 2 at chainage 17.34 km from Bangladesh border) to Kobo (cross section 65 at chainage 640.07 km) has been divided into seven reaches as shown in Figure 1(a) and the distances between the reaches are outlined in Table 1. The bank line of the Brahmaputra river is demarcated from each set of imageries and the channel patterns are digitized using Arc Info software.

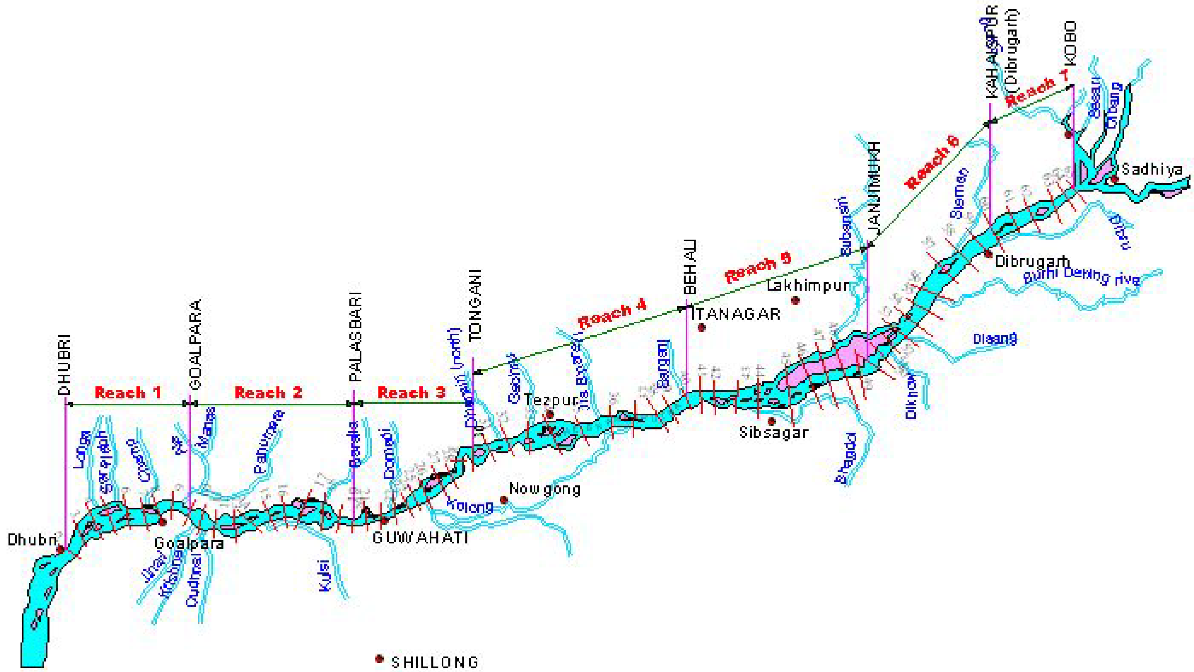


Figure 1(a): Brahamputra River- from Dhubri (cross section 2 at chainage 17.34 km from Bangladesh border) to Kobo (cross section 65 at chainage 640.07 km)

Table 1: Description of different reaches

Reach No	cross -section No		Distance in km.
	From	To	
1	2	10	65.28
2	11	20	89.76
3	21	30	79.57
4	31	40	120.88
5	41	50	107.6
6	51	60	98.44
7	61	65	51.00

2.2 Study area and dataset used for wetland dynamic assessment and turbidity pattern identification:

Deepor Beel is one of the largest and most important wetlands in the Brahmaputra valley of lower Assam and is a representative wetland type found within the biogeographic domain of Assam. It is located south of the Brahmaputra river in Kamrup district, 10 km south west of Guwahati, Assam. The geographical coordinates of Deepor Beel is around 91^0 35'- 91^0 43' E longitude, 26^0 05' - $26^0$11'N latitude Figure 1(b). The wetland category of Deepor Beel is Inland wetlands and wetland type includes permanent freshwater lake (over 8 ha), which is a large oxbow lake. Seasonal/intermittent freshwater marshes/pools on inorganic soil; includes sloughs, potholes, seasonally flooded meadows, sedge marshes.

The lake supports threatened species of birds like spotbilled pelican, lesser adjutant stork, greater adjutant stork, blacknecked stork, and large whistling teal. The lake is one of the staging grounds on the migratory flyways for several species. Some of the largest congregations of aquatic birds in Assam can be seen here, particularly in winter. It supports 50 fish species belonging to 19 families. The diversity and concentration of indigenous freshwater fish species is very high. Natural breeding of some of these species takes place within the wetland itself. Phytoplankton is one of the major components of the lowest level of the producers in the Deepor Beel ecosystem. The past two decades have seen a lot of transformation in the ecological and social character of Deepor Beel and near by areas. It has been observed that natural and anthropogenic problems include:

1. Disturbance from transport artery i.e. construction of railway line along the southern boundary of the Deepor Beel;
2. Industrial development within the periphery of the Beel;
3. Large scale encroachment within the Deepor Beel area;
4. Allotting the government vacant land to private party by government settlement department;
5. Brick making factory and soil cutting within the Beel ecosystem and erosion;
6. Hunting, trapping and killing of wild birds and mammals within and in the adjoining areas of Deepor Beel;
7. Commercial scale forest exploitation
8. Unplanned fishing practice without controlling mesh size and using water pump, etc.

2.3 Physical Features: (e.g. geology, geomorphology; origins - natural or artificial; hydrology; soil type; water quality; water depth water permanence; fluctuations in water level; tidal variations; catchment area; downstream area; climate) The Deepor Beel is set in a unique physiographic framework and is characterised by its active hydrologic regime. Geomorphologically, its origin and development are intimately linked with the geologic and tectonic history of the region, hydrology and channel dynamics of rivers and pattern and intensity of land use in the area. It is commonly believed that the Beel together with those adjoining it represents an abandoned channel of the Brahmaputra system.

2.4 Hydrological Values: (groundwater recharge, flood control, sediment trapping, shoreline stabilization, etc.). Deepor Beel acts as a natural stormwater reservoir during the monsoon season for the Guwahati city. At maximum flooding, it is about four metres deep: during the dry season, the depth drops to about one metre. The main sources of water are Basistha and Kalmani rivers and local monsoon run off between May and September. The Beel drains into the Brahamputra river five km. to the north, through the Khonajan channel.

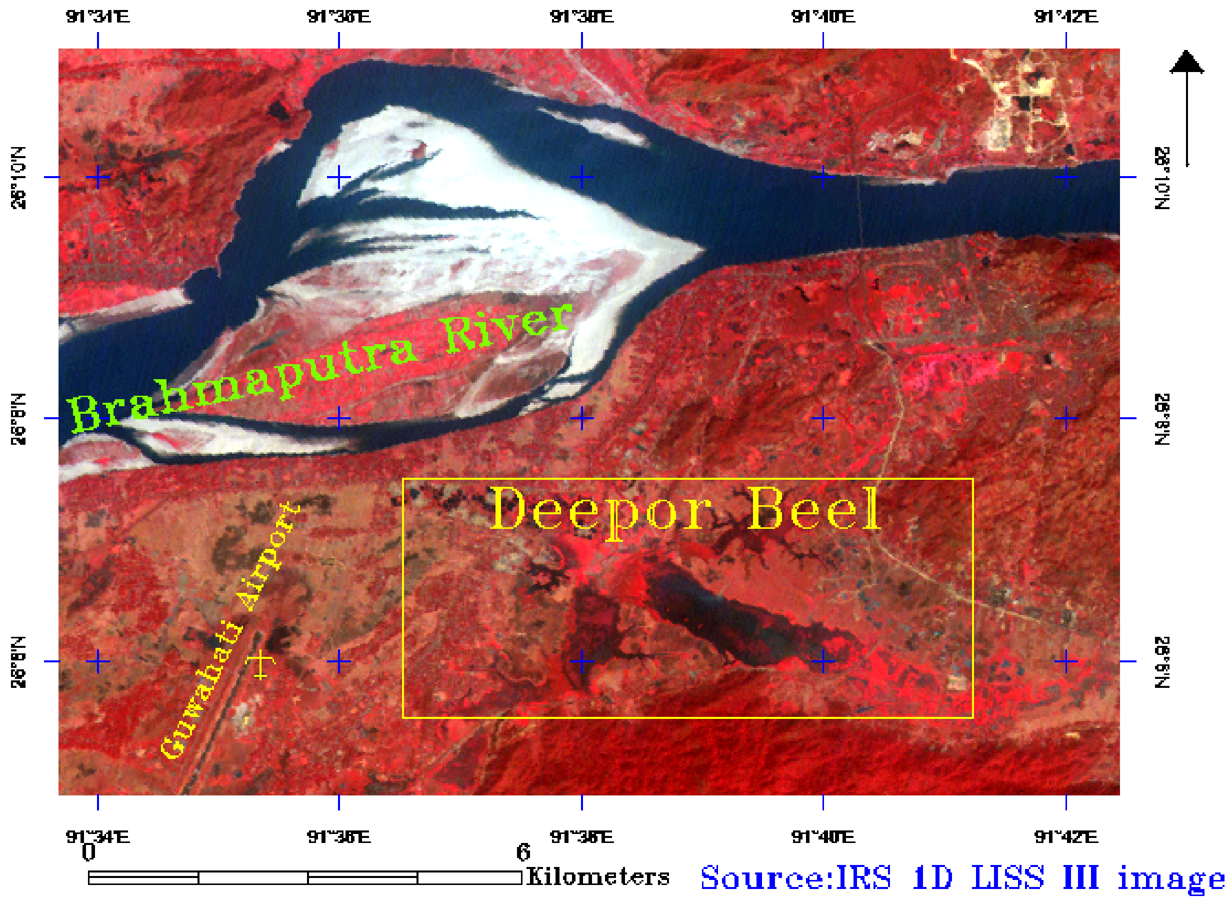


Figure 1(b): Deepor Beel-wetland ecosystem dynamics (study area)

IRS-1A, 1C, 1D satellite data have been used to delineate the wetland ecosystem from a long-term data i.e. from 1990 to 2002. From the IRS series, LISS I and LISS III data have been used, which is having different spatial and spectral resolution. For the year 1990, the sensor used is LISS I and for the year 1997 and 2002, LISS III data have been used for analyzing the wetland ecosystem dynamics in Deepor Beel.

Table 2: 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	1990	72.5	0.45 - 0.52 µm(B1) 0.52 - 0.59 µm (B2) 0.62 - 0.68 µm (B3) 0.77 - 0.86 µm (B4)
IRS-1C	LISS III	1997	23.5	0.52 - 0.59 µm (B2) 0.62 - 0.68 µm (B3) 0.77 - 0.86 µm (B4) 1.55 - 1.70 µm (B5)
IRS-1D	LISS III	2002	23.5	0.52 – 0.59 µm(B2) 0.62 - 0.68 µm (B3) 0.77 - 0.86 µm (B4) 1.55 - 1.70 µm (B5)

3. METHODOLOGY

3.1. Brahmaputra River bank-line shifting and its physical extent determination from muti- temporal satellite images:

For convenience in computation and determination of bank migration, 26^0 N latitude has been chosen as the permanent reference line, from which all the offsets to baseline location on the digitized maps have been made. Offsets have been measured at every cross section. After digitization of the above data, the offsets measurement to left and right banks using 26^0 N latitude line as the base line have been carried out from cross-section 2 to 65. The X distance i.e. chainage distance of cross-section 2 to 65, have been also measured from the base line i.e. 90^0 E longitude line. While comparing the boundary migration for any two years (both left & right boundary) -ve sign indicates boundary migration towards south and +ve sign indicates boundary migration towards north. For left bank –ve migration shows deposition, while +ve migration shows erosion whereas for right boundary +ve migration shows deposition and –ve migration shows erosion.

3.2. Wetland Dynamics monitoring using Rule-Based classification Technique:

The satellite data used to delineate the wetland ecosystem dynamics in Deepor Beel areas of Assam are IRS 1A, 1C and 1D. This has been taken from multi-temporal data set i.e. during 1990 as LISS I and 1997, 2002 as LISS III sensors. These satellite data have been used to identify the wetlands and aquatic vegetation of the Deepor Beel. GCP (Ground Control Points) collected from SOI (Survey of India) toposheets as well as from GPS (Global Positioning System) were used as bases to register on the images and were geometrically corrected. The satellite image was transformed with a standard defaulted 72.5, 23.5 m resolution i.e. default for IRS LISS I and LISS III images respectively and projected to polyconic coordinate system using nearest neighbourhood resampling in ERDAS Imagine software. From the entire scene, the whole study area was extracted using subset option in ERDAS Imagine software and FCC (False Colour Composite) displayed with the band combination of 3, 2, 1 Figure 1(b).

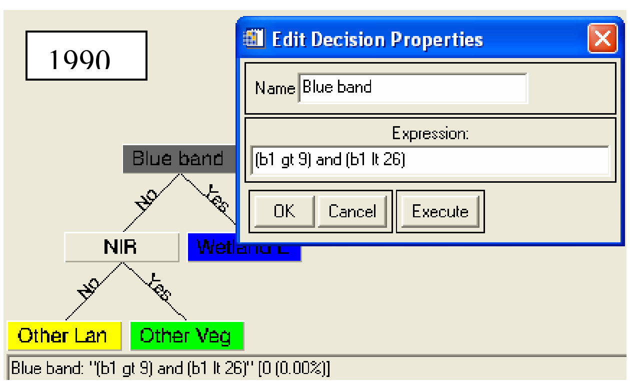
To delineate the wetland areas the Normalized Difference Water Index (NDWI) indicator has been used for the year 1997 and 2002 and on the contrary the blue band of LISS I data is used for the year 1990. The NDWI which is obtained using the function (Green – NIR)/ (Green + NIR), is useful to demarcate the land–water boundary (McFeeters, 1996) and mathematically it can be represented as-

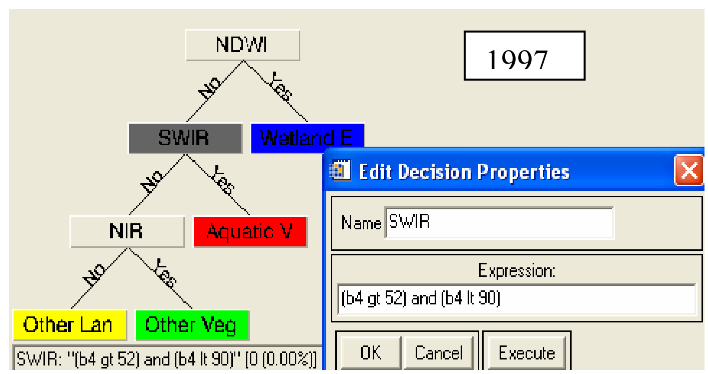
NDWI= (Green –NIR)/ (Green + NIR)

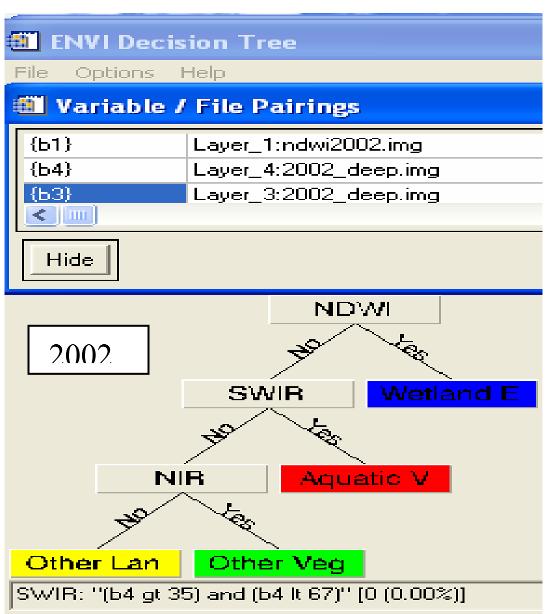
Where green is band2 (0.52-0.59µm) and NIR is band 4 (0.77-0.86µm)

Application of this indicator for a multi-spectral satellite image, results in positive values for water features and zero or negative values for soil and vegetation (Chatterjee et.al. 2003). When the NDWI is applied using Band 2 (green) and Band 4 (NIR) data of the LISS-III image of the Deepor Beel region, the wetland boundaries were distinct as compared to the original image.

All the images like NDWI and different bands of LISS I and LISS III are used in decision tree classifier to delineate the wetland ecosystem and aquatic vegetation in the study area using ENVI software. Traditional methods for wetlands mapping with satellite data have generally focused on the use of unsupervised classification and supervised classification. Wetland classification is difficult because of spectral confusion with other land cover classes and among different types of wetlands, but can be improved by using multi-temporal and multi-scale satellite data as well as ancillary soil and topography data. A decision tree classifier is an efficient form for representing decision processes for classifying patterns in data (Parmuchi et al. 2002). It employs tree-structured rules that recursively divide that data into increasingly homogeneous subsets based on splitting criteria. At each split, the values of each explanatory variable are examined and the particular threshold value of a single variable that produces that 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 trees is that they are less sensitive to non-linearities in the input data than are methods that require assumptions of Gaussian distributions (Townsend, 2001).







The decision tree classification has been done based on the pixel criteria for each year using NDWI and LISS I and LISS III data. However during 1990 the NDWI indicator has not been used for wetland ecosystem extraction because of poor result as compared to blue band (Band 1) of LISS I data. 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

3.3 Turbidity areas/pattern identification and their spatial distribution within the identified wetland area:

Turbidity patterns were best reflected and can be observed by the band 1,i.e. Green Band of IRS 1C, LISS III image data. The higher the DN value in band 1, the higher is the turbidity. The turbidity classification is a subjective one 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 needs to be carried out by examining the major (large-sized) water bodies in the area. (Prasad S.N., Ramachandra, et.al, 2002).

Here in this study, multi-date LISS sensor satellite data namely 1990, 1997 and 2002 are used for identifying area of High, Medium and Low Turbidity within the Deepor Beel. This helps to link the spatial distribution of wetland with respect to the turbidity pattern within the identified/mapped region. The quantitative turbidity ratings viz., low, moderate and high were also assigned based on the hue manifested on the false colour composites and it has been extracted/delineated using Isodata algorithm (unsupervised classification) in ERDAS Imagine.

Then, the spatial turbidity patterns on three different dates are mapped, which indicate the influence of turbidity on the spatial distribution of wetland areas from 1990 to 2002. This type of preliminary investigation is necessary to assess the health and the dynamic nature of wetland region. In addition, the potential utilization of multi-temporal, synoptic coverage satellite data is highlighted in this context.

4. RESULTS AND DISCUSSIONS

4.1. Channel shifting and migration pattern of Brahmaputra river course:

The offsets of the digitized satellite data of 1990, 1997, 2000 and 2002 are shown in Table 3. The shift patterns of bank of various years with respect to year 1990 imageries are graphically represented in Figure 3 to 8. The positive values indicate that the stream bank has shifted northward from 1990 imagery and negative values show vice-versa.

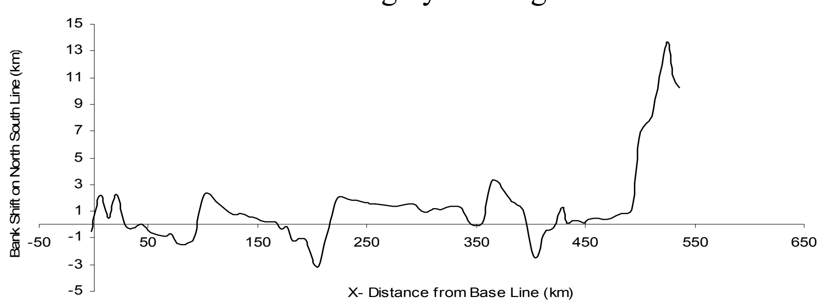


Figure 3 Shift of Left Bank Between 1990-1997

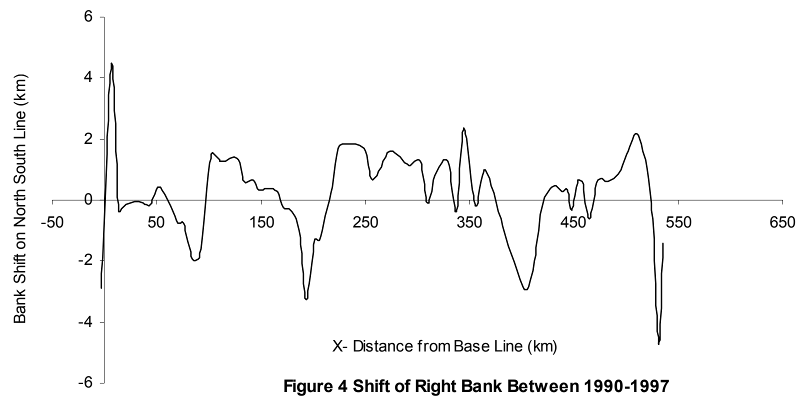


Figure 4 Shift of Right Bank Between 1990-1997

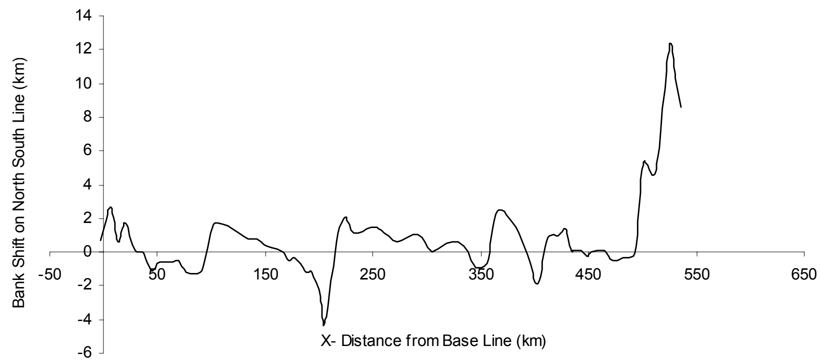


Figure 5 Shift of Left Bank Between 1990-2000

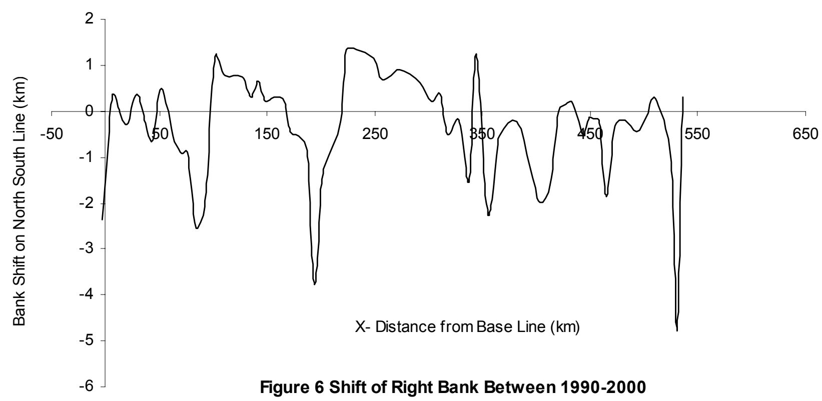


Figure 6 Shift of Right Bank Between 1990-2000

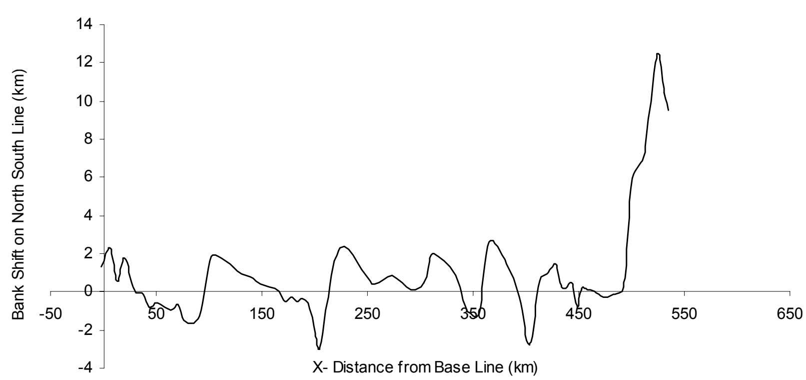


Figure 7 Shift of Left Bank Between 1990-2002

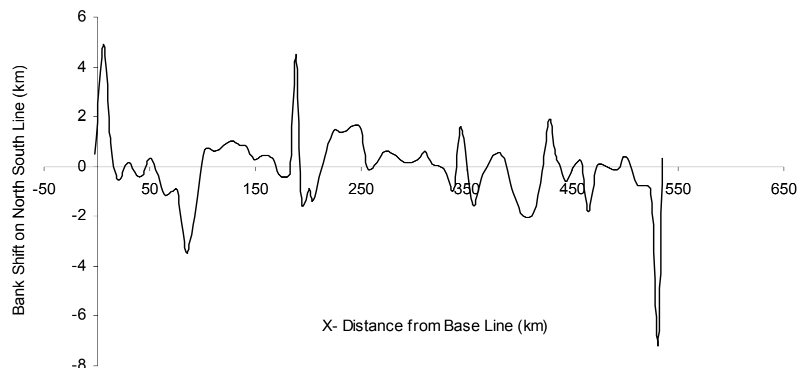


Figure 8 Shift of Right Bank Between 1990-2002

Table 3: Offsets of Satellite data in Km from baseline

C/S No.	Chainage (X)	Year -1990		Year -1997		Year -2000		Year -2002	
		Z_L	Z_R	Z_L	Z_R	Z_L	Z_R	Z_L	Z_R
2	-2.592	-12.528	8.96	-11.968	11.856	-13.184	11.312	-13.872	8.464
3	6.144	-0.672	14.848	-2.88	10.416	-3.312	14.496	-3.008	9.952
4	13.04	4.832	13.184	4.336	13.536	4.208	13.184	4.256	12.208
5	20.096	8.72	15.808	6.48	15.968	6.976	16.096	6.912	16.368
6	29.264	11.344	19.968	11.52	20.016	11.28	19.6	11.264	19.824
7	37.808	11.488	26.88	11.744	26.992	11.536	27.136	11.632	27.232
8	43.552	17.264	26.544	17.232	26.672	18.336	27.168	18.112	26.88
9	51.872	19.952	23.472	20.528	23.024	20.56	22.976	20.528	23.12
10	63.952	11.568	27.36	12.48	27.552	12.144	28.016	12.544	28.496
11	70.192	10.576	25.296	11.28	26.048	11.056	26.224	11.248	26.272
12	76.512	9.488	26.928	10.944	27.68	10.688	27.808	10.944	27.872
13	84.4	6.576	20.128	8.096	22.08	7.856	22.672	8.24	23.552
14	91.584	9.04	21.168	10.032	23.072	10.128	23.248	10.288	23.504
15	101.712	16.64	26.192	14.416	24.672	14.992	25.008	14.8	25.488
16	111.264	15.856	26.432	14.144	25.152	14.224	25.648	14.08	25.792
17	127.216	9.872	27.856	9.104	26.496	8.816	27.12	8.752	26.848
18	134.56	10.432	27.824	9.568	27.2	9.664	27.52	9.568	26.944
19	142.304	11.344	16.864	10.8	16.224	10.544	16.208	10.608	16.08
20	148.304	12.24	16.4	11.808	16.064	11.824	16.192	11.856	16.144
21	156.224	14.032	20.496	13.856	20.112	13.792	20.192	13.776	20.048
22	166.096	16.528	18.352	16.352	18.064	16.512	18.128	16.496	18.032
23	171.488	19.264	24.016	19.584	24.272	19.76	24.448	19.76	24.32
24	176.8	20.672	23.36	20.848	23.664	21.008	23.872	20.944	23.792
25	182.256	21.2	30.608	22.4	31.136	21.92	31.216	21.712	30.928
26	187.792	23.936	36.064	24.976	37.28	25.152	36.928	24.272	31.552
27	193.584	26.96	35.488	28.08	38.736	28.144	39.264	27.552	36.992
28	201.264	27.44	45.136	30.448	46.4	30.096	46.608	29.648	46.016
29	205.392	29.776	46.736	32.88	48.048	34.016	47.84	32.704	48.096
30	217.776	43.936	51.184	43.28	50.752	42.784	51.408	42.672	50.576
31	223.68	49.76	57.552	47.744	55.84	47.712	56.224	47.488	56.112
32	232.64	51.088	61.568	49.152	59.728	50	60.24	48.864	60.176
33	248.768	54.176	67.456	52.512	65.776	52.704	66.304	53.328	65.824
34	257.184	55.344	67.088	53.792	66.432	54.08	66.416	54.944	67.248
35	273.024	59.888	66.096	58.544	64.512	59.312	65.184	59.008	65.504

36	291.632	65.728	69.536	64.144	68.416	64.72	68.928	65.648	69.376
37	303.008	62.512	71.488	61.584	70.224	62.4	71.28	62.048	71.232
38	310.064	66.08	70.88	64.864	70.96	65.904	70.512	64.144	70.24
39	317.616	70.016	78.768	68.88	77.856	69.52	79.28	68.144	78.64
40	328.544	76.016	82.592	74.624	81.312	75.408	82.784	74.72	82.64
41	337.76	77.376	83.232	76.224	83.616	77.36	84.752	77.104	84.16
42	344.832	76.592	84.944	76.592	82.576	77.552	83.712	77.6	83.36
43	355.44	71.248	83.408	71.152	83.6	71.92	85.632	72.4	84.944
44	365.152	77.184	84.992	73.872	84.016	74.768	85.52	74.608	85.28
45	382.16	82.816	99.952	81.072	100.816	81.36	100.176	81.376	99.408
46	393.36	87.376	97.216	86.272	99.264	87.52	98.416	87.664	98.288
47	403.376	88	97.68	90.496	100.608	89.856	99.664	90.784	99.664
48	412.512	90.608	98.528	91.2	100.512	89.776	100.128	90.064	100.384
49	421.008	92.72	97.52	92.928	97.632	91.76	97.536	91.696	97.712
50	428.544	98.848	110.208	97.568	109.776	97.424	110.032	97.376	108.336
51	433.216	103.12	114.416	103.008	113.952	103.024	114.192	102.864	113.936
52	438.096	106.88	120.448	106.592	120.144	106.816	120.576	106.704	120.368
53	443.36	111.52	121.936	111.264	121.6	111.44	122.432	111.056	122.544
54	448.256	115.44	132.208	115.344	132.544	115.68	132.336	116.256	132.432
55	452.944	123.376	139.536	122.96	138.896	123.36	139.696	123.2	139.408
56	457.824	128.224	147.12	127.76	146.512	128.144	147.312	128.112	146.896
57	465.12	142.496	154.864	142.112	155.456	142.4	156.736	142.448	156.688
58	473.12	151.824	163.984	151.344	163.328	152.32	164.304	152.096	163.952
59	482.336	160.416	171.392	159.616	170.768	160.752	171.6	160.512	171.408
60	492.8	165.008	179.184	163.904	178.352	165.12	179.632	164.784	179.312
61	500.496	172.416	184.24	165.504	182.72	167.104	184.416	166.432	183.84
62	510.976	174.976	187.632	166.896	185.504	170.32	187.36	167.888	188.384
63	524.624	182.96	195.664	169.376	195.744	170.8	196.784	170.528	196.528
64	530.768	184.032	203.024	173.024	207.744	173.728	207.792	173.616	210.24
65	535.36	186.224	212.288	175.984	213.712	177.616	211.968	176.672	211.968

4.2. Analysis of Reach-1 to Reach-7 as per shifting pattern observed in Multi-temporal Imagery:

The discussions of the results pertaining to various reaches are as detailed follows:

Reach – 1

During the years 1990, 1997, 2000 and 2002, there is a mixed trend of erosion and deposition occurrence along the left bank of this lowermost reach. From cross-section 2 to cross-section 6, it shows deposition, while from cross-section 7 to cross-section 10, erosion is observed.

In the case of right bank, there is a trend of erosion between cross-section 2 to cross-section 4 and deposition in between cross-section 5 to cross-section 10.

Reach – 2

In this reach, left bank of river displayed migration towards North. It shows that it has deposition tendency. In the case of right bank also, deposition is observed. Thus the whole reach having the length of 89.76 kms is influenced by deposition. River is changing its course towards North over this reach. However the width of the river is decreased.

Reach – 3
This reach has a length of 79.5 km. For the left bank, over 9 km length, there is deposition. The remaining 70 km length channel bank is affected by erosion tendency and it is migrating towards South. In the case of right bank, mixed trend of deposition and erosion has been observed. Maximum deposition occurs in between chainage 224.91 km to chainage 251.95 km i.e., from cross-section no 26 to cross-section no 29. River width also is varying. It varies at different cross-sections of this reach. However river width does not change significantly.

Reach – 4
In this reach, all cross-sections on left bank except at cross-section 37 and 40, shows trend of erosion and are migrating towards South. In the case of right bank, there is deposition tendency and it is migrating towards South. Thus left bank shows erosion while right bank shows deposition for the whole reach. River width is decreasing between cross-section 31 to cross-section 33 and where as it is increasing between cross-section 34 to cross-section no 36.

Reach - 5
During the period 1997, 2000 and 2002 the left bank has deposition tendency between cross-section 40 to cross-section 42 and also between cross-sections 46 to cross-section 49. Other remaining cross-sections show erosion along this bank. Similarly right bank has erosion tendency in between cross-section 40 to cross-section 43 and cross-section 45 to cross-section 47. Deposition also takes place along right bank in between cross-section 48 to cross-section 50. River width varies at different cross-sections.

Reach – 6
Deposition is observed along left bank during the period 1990 and 2000 while there is erosion on right bank. During the period 1997 and 2000, cross-section 51 to cross-section 52 and cross-section 55 to cross-section 56, show tendency of deposition whereas cross-section 53 to cross-section 54 and cross-section 57 to cross-section 60 show tendency of erosion along the left bank. On the right bank, cross-section 52 to cross-section 54 and cross-section 56 to cross-section 58, there is erosion. For the duration 1990, 1997, 2000 and 2002, the river width is increased at cross-section 51 to cross-section and cross-section 55 to cross-section 56 while it is decreased at cross-section 54 and cross-section 58 to cross-section 59.

Reach – 7
During the period 1990 and 2000 left bank has displayed mixed nature of both deposition and erosion while along right boundary there is erosion. During the period 1997 and 2000 there is deposition along left bank and erosion along right bank.
During the period 1990 to 2000, the width of the river has increased at some cross-sections while it has decreased at others but during the period 1997 to 2000, the river width has increased.

4.3. Deepor Beel wetland distribution and Assessment of its changes:

The analysis deals with the status and distribution of wetland water body and its shrinkage. It also provides an overview of the Remote Sensing and Geographic Information System (GIS) tools in change analyses of surface water bodies, aquatic vegetation and wetlands. The review provides a methodology and action plan for evolving a nationwide network of conservation preserves of wetlands. The major elements of this methodology involve use of IRS LISS I and LISS III sensors for investigating turbidity, aquatic vegetation and major geomorphological classes of wetlands using different year satellite data i.e. 1990, 1997 and 2002.

The design of decision rules is the critical part of the rule-based method. By combining the information from LISS data and expert knowledge, knowledge-based decision rules within a GIS framework were designed. In this study the rule-based classification techniques have been used for identification of four major landuse/landcover classes namely wetland ecosystem, aquatic vegetation, other vegetation and other landuse. The decision rules were described as follows:

Table 4(a): A rule based method and its critical pixel values for decision tree classifier for 1990

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

Where b1 is blue band, b4 is NIR, 'lt' is less than and 'gt' is greater than

Table 4(b): A rule based method and its critical pixel values for decision tree classifier for 1997

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

Where b1 is NDWI, b3 is NIR, b4 is SWIR, 'lt' is less than and 'gt' is greater than

Table 4(c): A rule based method and its critical pixel values for decision tree classifier for 2002

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

Where b1 is NDWI, b3 is NIR, b4 is SWIR, 'lt' is less than and 'gt' is greater than

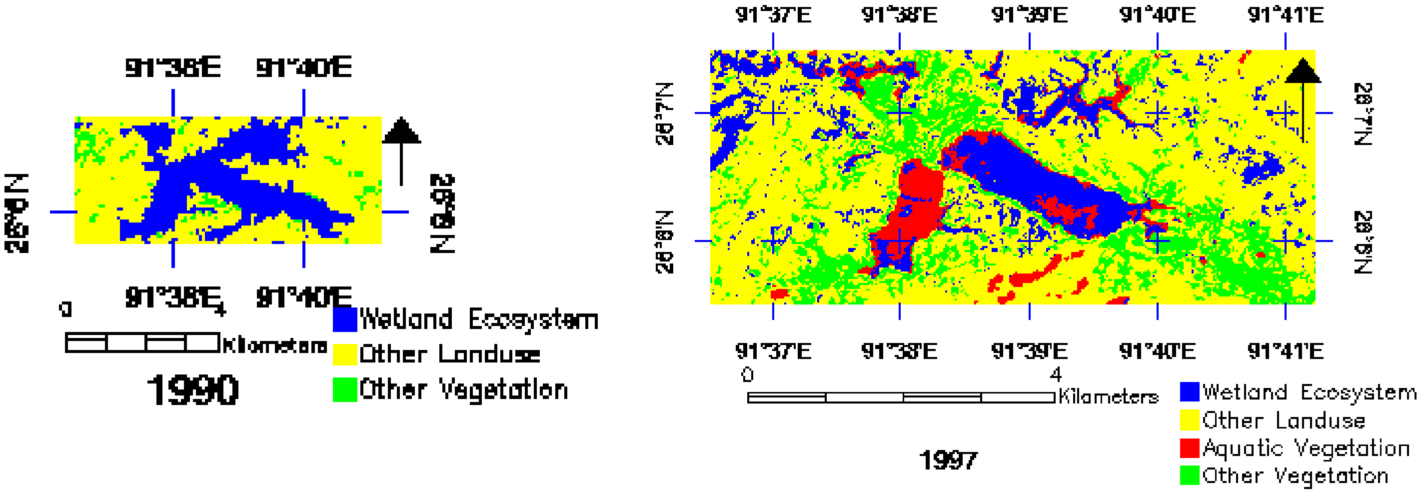


Figure 9(a): Rule based wetland ecosystem classification during 1990 and 1997

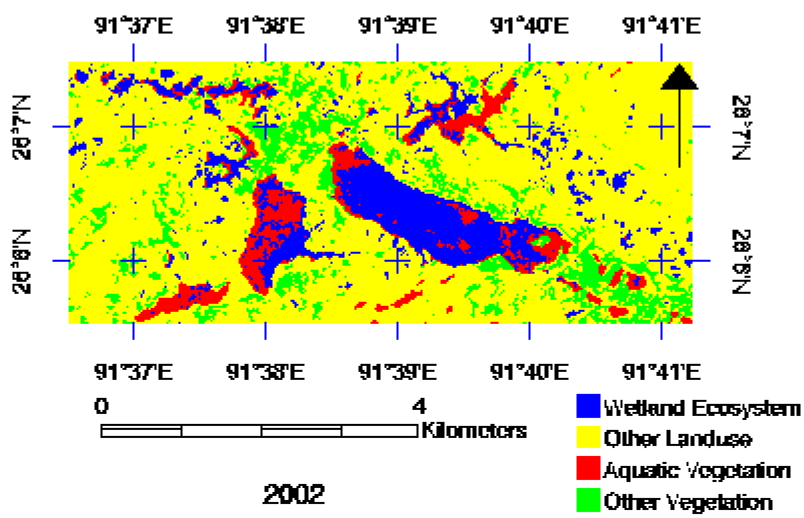


Figure 9(b): Rule based wetland ecosystem classification during 2002

From the accuracy Table 5(a), it has been shown that the overall accuracy in the classified image is 93.58, 91.91 and 94.21% for 1990, 1997 and 2002 respectively. The Kappa coefficient is 0.89, 0.89 and 0.91 for 1990, 1997 and 2002 respectively. The producers and users accuracy for the wetland ecosystem class is relatively good then other class for each year. During 1990 the aquatic vegetation doesn't have producer and user accuracy because the study found there is no aquatic vegetation in the Deepor beel ecosystem. Thus accuracy assessment helps to assess the efficiency of the remote sensing data to detect the landuse classes.

Table:5 (a) Accuracy assessment for Deepor Beel ecosystem

Accuracy (%)	1990		1997		2002	
Landuse category	Producer Accuracy	User Accuracy	Producer Accuracy	User Accuracy	Producer Accuracy	User Accuracy
Wetland Ecosystem	100	100	99.19	90.44	99.42	99.42
Aquatic Vegetation	**No class**	**No class**	90.16	100	98.39	98.39
Other vegetation	84.62	78.57	83.3	99.21	94.32	88.30
Other Landuse	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**	

The analysis of satellite data from 1990-2002 reveals that the wetland ecosystem is shrinking from year to year and this can be clearly seen in the Figure 9 (a & b). Spatially it has been observed that the wetlands are adjoined during 1990 and as the time progresses (1997), the wetlands have started fragmenting by detachment from each other due to vegetation growth, encroachment etc. The detachment rate has increased during 2002. The detachment of the wetlands resulting in its fragmentation causes major hindrance to the smooth flow of water body in Deepor Beel ecosystem. This study has found the development of interesting phenomena that is the growth of the aquatic vegetation. There was no aquatic vegetation growth during 1990, while aquatic vegetation has increased substantially from 1990 to 2002. This phenomenon of the progressive shrinkage of the wetland can be vividly seen from a perusal of the Table 5(b, c, d).

Table 5(b): Wetland areas during 1990

Landuse category	Area in ha	Percentage of area	Remarks
Wetland ecosystem Aquatic Vegetation	**961.7** **-**	**33.5** **-**	**33.5 %**
Other vegetation	144	5.0	-
Other Landuse	1765.4	61.48	-
Total	2871.1	99.48	-

Table 5(c): Wetland areas during 1997

Landuse category	Area in ha	Percentage of area	Remarks
Wetland ecosystem Aquatic Vegetation	**424.3** **182.0**	**14.77** **6.33**	**21.1 % (606.3)**
Other vegetation	506	17.61	-
Other Landuse	1760	61.29	-
Total	2872.3	100	-

Table 5(d): Wetland areas during 2002

Landuse category	Area in ha	Percentage of area	Remarks
Wetland ecosystem	**356.3**	**12.4**	**19.4 % (559.6**

Aquatic Vegetation	**203.3**	**7.0**	**ha)**
Other vegetation	329	11.45	-
Other Landuse	1983.7	69.15	-
Total	2872.3	100	-

In a nutshell, wetland ecosystem and aquatic vegetation has been analyzed for the Deepor Beel wetland during 1990 to 2002. The study indicated that during 1990, wetland ecosystem was 33.5% and there was no aquatic vegetation growth in that year. However the aquatic vegetation growth has been observed in subsequent years, that is 1997 and 2002. Moreover the aquatic vegetation growth has taken place in the wetland waterbody area and thereby there is a decreasing trend of wetland areas in the Deepor Beel areas. As the aquatic vegetation growth has taken place in the wetland area, this class has been merged with the wetland area to know the decreasing trend of wetland areas from 1990 to 2002. From the Table 5(b, c, d) it can be seen that the wetland area has decreased from 33.5% (1990) to 21.1% (1997) and then to 19.4% (2002). Hence the study has brought out that there is a significant decline of wetland areas from 1990 to 1997, however the decline rate is less from 1997 to 2002.

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 2002. Overall, the wetland ecosystem has declined to **14.1%(405 ha)** from 1990 to 2002, which is indication of major threats to the wetland ecosystem due to anthropogenic causes such as encroachment or due to any natural hazards.

4.4 Turbidity pattern within the 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 within the period 1990 to 2002. In this study, the qualitative turbidity of Deepor Beel has been recorded based on hue as manifested on the FCC. The turbidity classification using satellite imagery is based on the system proposed by Space Application Centre, Ahmedabad in India. It's seen that the turbidity of water in Deepor Beel wetland is varied and it can be spatially visualized from Figure 10. High Turbidity has been recorded in almost the entire wetland area in 1997 as compared to 1990 and 2002. In 2002, the spatial extent of wetland area decreased while pattern of low and medium turbidity increased. The extent of wetland area mapped in 1997 was relatively more compared to that of 2002, with more high turbid water pattern distribution in main Deepor Beel area. From this analysis it is seen that the intensity and pattern of high turbidity decreased from 1997 to 2002. The wetland area is shrinking from 1990 to 2002, which clearly indicates an imperative need for restoration of the wetland ecosystem. Moreover, it is seen that there is a significant development of aquatic species in the Deepor Beel wetland from 1990 to 1997 due to eutrophication. In the surrounding areas of Deepor Beel, the farmers are using more quantity of fertilizers, pesticide/herbicide to get more agricultural production; as a result the wetland ecosystem health is adversely affected and it indirectly can be inferred about increase in high turbidity pattern in 1997 from 1990.

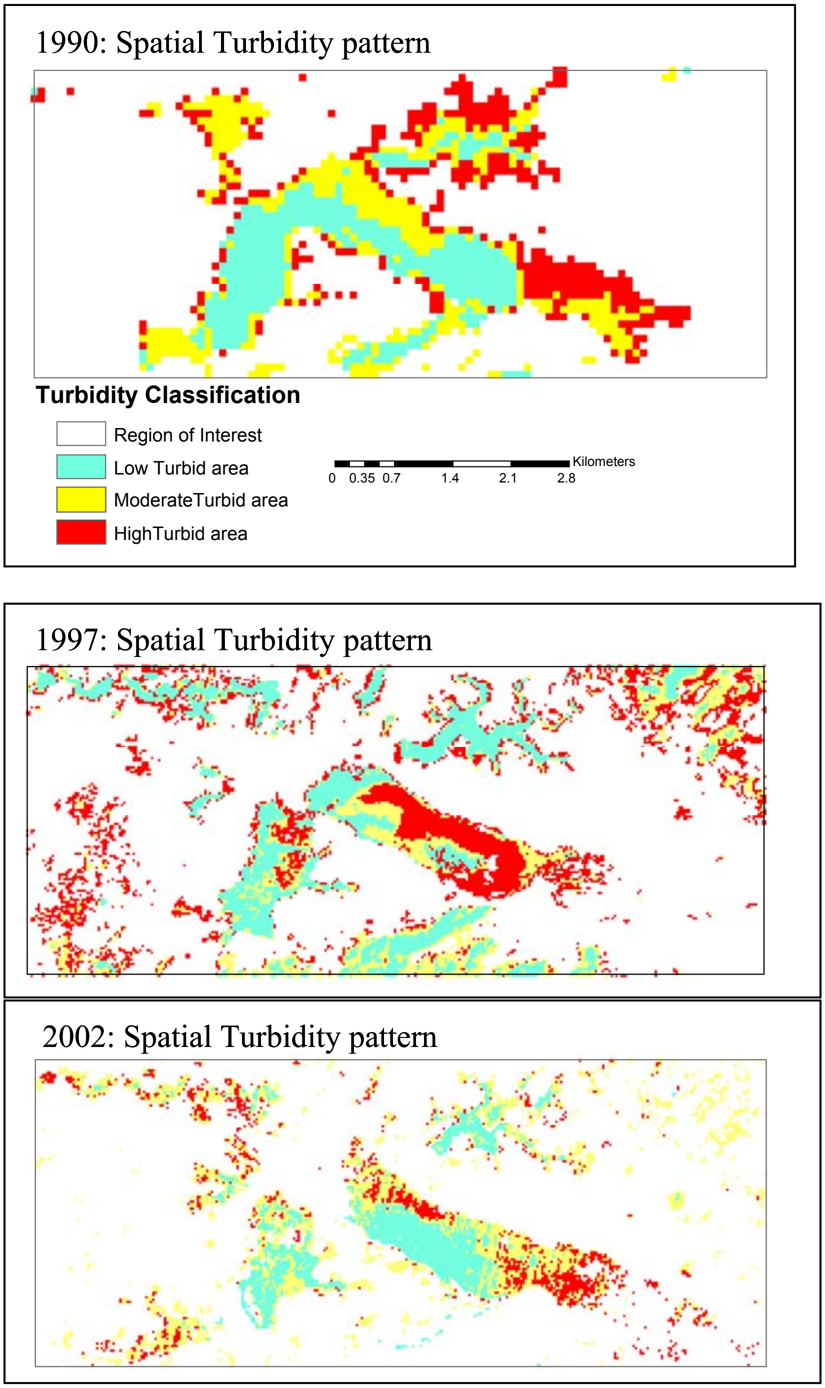


Figure 10: Spatial turbidity pattern from multi-temporal IRS LISS imagery

5. FINDINGS

1. The river Brahmaputra has a trend of channel boundary migration towards north and south directions depending upon nature of riverbank and local flow pattern. However it is observed that the general tendency of river migration is somewhat towards south.
2. The average northing for right bank line of the Brahmaputra river moved about 0.47 km to the north between 1990 and 2002, while that for the left moved about 0.48 km to the south. The river has avulsed just upstream side of the Dibrugarh town and excised areas of floodplain to create new bars.
3. The river mean width has increased from 7.99 km to 8.94 km in the total length of the river; where as the minimum width at Pandu is slightly constricted due to the presence of the bridge. The maximum width has marginally increased from 18.11 km in 1990 to 18.13 km in 2002 at downstream side of Pandu at cross section 18 near Gumi.
4. The satellite based study brought to the fore on the ongoing major avulsion processes of the confluence zone of mainstreams of the Brahmaputra near Sadiya.The total area within the stream bank increased by 12.10% between 1990 and 2002 due to erosion process causing channel widening. Expansion of the river had taken place primarily through floodplain erosion and excision coupled with bar or island growth. Trends of expansion showed no sign of slacking and the expansion process appears to continue. The degree of braiding of individual reaches fluctuates in the short-term due to morphological response to the magnitude and duration of monsoon runoff events.

5. Deepor Beel is a Ramsar site, and one of the important wetland ecosystem in the Brahmaputra Basin.It is encroached upon by various agencies including BSF camp, railways, nursing homes, brick kilns and is swamped by water hyacinth. Apart from a storm cushion, it is a major migratory centre and breeding ground for birds. Those are being disrupted. The dynamic nature of wetlands necessitates the widespread and consistent use of satellite-based remote sensors and low-cost, affordable GIS tools for effective management and monitoring.

6. The study revealed that wetland ecosystem of the Deepor Beel comprised 33.5% in 1990 and there was then no aquatic vegetation. However the aquatic vegetation has been observed in subsequent years namely 1997 and 2002. The wetland area has decreased from 33.5% (1990) to 21.1% (1997) and then to 19.4% (2002). Overall the wetland ecosystem has been reduced to **14.1% (405 ha)** from 1990 to 2002, which poses major threats to the wetland ecosystem due to anthropogenic factors.

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