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Investigation of the principal vectors of wetland loss in Barind tract of West Bengal

Rajib Tarani Das · Swades Pal

Abstract In last few decades flood plain wetland loss in the Barind tract of West Bengal has become a serious threat to the hydro-ecological setup and livelihood security. Out of total study area (6790.38 km^2), only < 1% is covered with riparian wetland of different kinds. Moreover there is no definite wetland map in meso and micro spatial scale which is crucial for managing wetland. Therefore, present paper attempts to systematic mapping of riparian wetland, monitoring, estimating loss and investigating associated vectors of wetland loss. The result demonstrates that since 1988–2016, about 65% wetland has either lost or at the verge of loss. Heavy anthropogenic pressures like reclamation of 4% wetland to agriculture land, 35–50% dwindling of peak flow in Tangon, Punarbhaba and Atreyee rivers, average 3–4 m lowering down of ground water level, delinking of Tista system from off shoots channel as mentioned are the prime vectors of wetland transformation. Such disappointing incidents may invite shrinking of valuable biodiversity rich natural capital and precious habitat.

Keywords Barind tract · Water presence frequency · Wetland loss · Vectors of wetland loss · Hydrological regime and stress on wetland

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Introduction

Wetland loss and associated degradation is a serious environmental problems and it is a vital issue to the environmentalist for last 5 decades in all over the World (Zedler and Kercher 2005; Gopal 2013; Rees and Reed 2014). This highly productive, diverse wetland (10% of the earth's surface and 15% out of which flood plain wetland) (Tockner et al. 2008) ecosystem provides a number of goods and services which possess immense importance to the society (Brander et al. 2006). The global extent of wetland losses in the twentieth century were 64–71% and for some areas it is even higher and loss of natural wetlands continues in the twenty-first century even faster rate (Davidson 2014) especially in the developing countries. The scenario is almost similar in everywhere for example, at present, global coastal wetlands eliminating at a rate of 1% per year. Nicholls et al. (1999) predicted that a global sea level rise of 20 cm by 2080 s would result in substantial damage while a 1 m rise would eliminate 46% of the world's coastal wetlands. In the United States (for 1986–1997), the annual rate of wetland loss is about 80% lower than in the preceding 200 years (Zedler and Kercher 2005; Dahl 2000; Dahl and Watmough 2007, 2013). Current estimates on wetland loss indicate that up to 70% of wetlands have been lost or degraded in India (Panigrahy et al. 2012).Flood plain wetlands are rather vulnerable and about to extinction (Mandal and Pal 2016; Talukdar and Pal 2017).These

large scale losses insist various stresses on ecosystems and hardship in socioeconomic conditions as country's 21% of total people is dependent directly or indirectly on such natural capital (MoEF 1990; Gopal 2013; Borro et al. 2014).

India, with its varying topography and climatic regimes, covers 58.2 million hectare (18.4% of total land)wetland and it supports diverse and unique wetland habitats (MoEF 1990; Prasad et al. 2002). In a developing country like India, management of wetlands has received inadequate attention from society and it is still considered as fallow waste land (Mandal and Pal 2016).Seasonal flood plain wetlands are time specific, neglected and even not found in the wetland maps sometimes due to their seasonal appearance; smaller sizes but hydro-ecologically they have immense importance (Ramsar Convention on Wetlands 2002; Li et al. 2015). Ramsar Convention on Wetlands (2002) designated such wetland as a temporary pool of natural resources and flood plain ecosystem. Agricultural encroachment is the principal cause behind wetland transformation. More that 27% wetland has lost due to draining of wetland for agriculture (OECD 1996; Gordon et al. 2010).In Gangetic flood plain more than 50% wetland is lost due to agricultural encroachment (Panigrahy et al. 2012). Perennial wetland is also affected by the agricultural invasion in terms of fragmentation and transformation. Mondal and Pal (2017) clearly reported this studying Ahiron wetland of Gangetic flood plain. Pal and Akoma (2009) carried out one research on Hizole wetland of the moribund deltaic West Bengal and documented that the seasonal nature allures people to infiltrate in the wetland during the summer period and cultivate summer rice. Implementation of intensive agriculture in this region during lean season using groundwater often lowers down the ground water level. It is again withstanding against the vertical interaction of wetland and groundwater. It causes transformation of perennial wetland into semi-perennial (Pal and Akoma 2009) and affects the biodiversity of the hyphoreic zones. Das and Pal (2016) also reported that the ground water level in the Barind tract is declined by 3–4 m since 1996–2016.

Natural hydrological regime and its seismotectonic modification are largely responsible for the river course modification and alteration of discharge volume (Chatterjee and Majumdar 1972). It causes loss of riparian wetland in one tract and formation in another

region. Additionally, flow modification through the dam and embankment play crucial role in ringing death sentence to the riparian wetlands (Pal 2016; Junk et al. 1989). Pal (2016) reported that due to dam construction in the Atryee river in 2012, flow volume is reduced by 53% and incidents of flood plain inundation are attenuated by 50% which are certainly cause for squeezing flood plain wetlands. Pal (2015) reported that erecting embankment has artificially raised the flood wall and therefore, flood plain doesn't get watered regularly from the river. Mondal and Pal (2016) also reported the phenomenon of the isolation of Hizole wetland complex from river Mayurakshi and Kuya. Flow regulation has immense impact on timing, frequency, duration and magnitude of wetland inundation on which biological species are sensitively reacting (Ward and Stanford 1995). Hydrological alteration of flood plain wetland is strongly introduced through irrigation practices as reported by Behera et al. (2012). Loss of connectivity between river and wetland via a good number of tie channels in the flood plain prevents the exchange of water and nutrient between them, which invites isolation of wetland ecosystems and gradual qualitative and quantitative degradation of the wetland (Junk et al. 1989; Ward and Stanford 1995; Li et al. 2015). Urban expansion is not only responsible for squeezing the size of the wetland but also exerts impacts on modifying structure, composition, the function of biota mainly altering the hydrological, sedimentological, toxicological components of the wetland (Yuanbin et al. 2012; Mandal 2017; Narula et al. 2000; Singh and Singh 1989). Aggressive wetland based tourism practices are also responsible for exploitation of ambient wetland environment (Bassia et al. 2014).

The Barind Tract is an uplifted old alluvial block covers 7163.27 ha. wetlands (Das and Pal 2016). Wetlands in this region are falling under three major groups, namely wetlands from channel remnants or riparian wetlands, depressed wetland and man-induced inland wetlands. The main source of water in these wetlands is rain water and inundated water from river because maximum natural wetlands are located along the course of rivers Atreyee, Tangon, Punarbhaba, Kulik, Nagar, Mahananda etc. flowing over this region (Rashid and Islam 2015; Das and Pal 2016).The Origin of these wetlands and their characteristics are deeply conditioned by the present rainfall status and hydrological regime of the river concerned in this

region (Das and Pal 2017). The area has already lost a massive wetland area and today only less than one-third of the area's original wetlands remain quite as usual. Intensive anthropogenic disturbances have affected the wetland condition even some natural drivers are also associated with wetland loss.

Successful wetland management requires accurate wetland inventories and monitoring them properly (Li and Chen 2005). Geographical information system and satellite remote sensing data provide valuable support monitoring wetland. Wetlands of Barind tract are dynamic in nature, and a large part of wetlands are ephemeral and seasonally flooded wetlands. Therefore the actual area of wetlands is highly fluctuating due to having a high degree of seasonality. No meso and micro level wetland inventories are available; there is no specific boundary of wetlands. Continuously, wetland is getting lost over time. In this condition wetland delineation is very essential but difficult and continuous monitoring within a certain period need to be performed to solve this problem (Yang et al. 2016). Only one or 2 years' image analysis does not provide any scientific base for the delineating wetland area. Water presence frequency method is a very good technique for the identification of such types of seasonal wetlands where multi-date high recurrence satellite imagery are used for monitoring (Baker et al. 2006; Dvorett et al. 2016, Mondal and Pal 2016). Under this circumstance the present study attempts to identify wetlands in multi-temporal scale to create a continuum of wetland presence with scientific manner. Trend of wetland change is also to be detected in the recent past (1988–2016). This work also wants to investigate is the change of wetland is majorly regulated by anthropogenic forces? Is there any role of drainage evolution even outside of this basin for historical change of the drainage and wetland set up?

Study area

The Barind tract of West Bengal is a neo-tectonically uplifted elevated physiographic unit in comparison to the surrounding floodplain (Rashid and Islam 2015) covering 6831.50 km^2 (679,038.39 ha in West Bengal, India) (Fig. 1). Rivers Atreyee, Tangon, Punarbhaba, Kulik, Nagar, Mahananda etc. dissected the region. Geomorphologically, it is divided into the active flood plain, inactive flood plain, extended flood plain, uplands, piedmont and fan, swampy water logged

area etc. (Das and Pal 2016). The area falls into two major physiographic surfaces, namely Pleistocene Barind Tract and Holocene channel floodplain complexes and predominantly composed of alternating sand, silt and clay layers with an average elevation of 35–50 m. above mean sea level (amsl). This region initially formed in Pleiocene era (5.33 mya) and later on experienced neo-tectonic upliftment of older alluvium block (Chakraborty and Ghosh 2010; Alam and Paepe 1996; Monsur 1990). Upper part of the region partially overlaid with eroded materials from Swilik part of Himalayan mountain commonly known as Teesta/Tista mega fan. Table 1 depicts the geological succession of Barind region and proximate Malda Tal, Diara and Rajmahal part (Alam 1995; Fergusson 1863). Average annual rainfall of this region is 1250 mm occurring mainly from late June to October and temperature ranges from 10° to 38 °C. The rivers of this region frequently used to inundate the proximate area and constructions of the dam over the major rivers have altered the hydrological regime.

Table 1 Geological succession of Barind tract and proximate regions; mya = million year ago.

Materials

Data set used here and their relevant sources have been shown in Table 2.

LANDSAT TM and LANDSAT 8 OLI have been used as a primary data source for detection of the water body. Imageries are obtained from the US Geological Survey (USGS) Global Visualization Viewer. The obtained Landsat data (Level 1 Terrain Corrected (L1T) product) were pre-geo referenced to UTM zone 45 North projection using WGS-84 datum. Detail specification of the satellite imageries is mentioned in Table 2. The other necessary corrections of the images have been carried out before image transformation. Arc GIS 10.1 and ERDASIMAGINE 9.2 have been used for the entire study.

Methods

Water body identification

Normalized Difference Water Index (NDWI) is selected to detect water body from Landsat imagery (McFeeters 1996) because this method represents
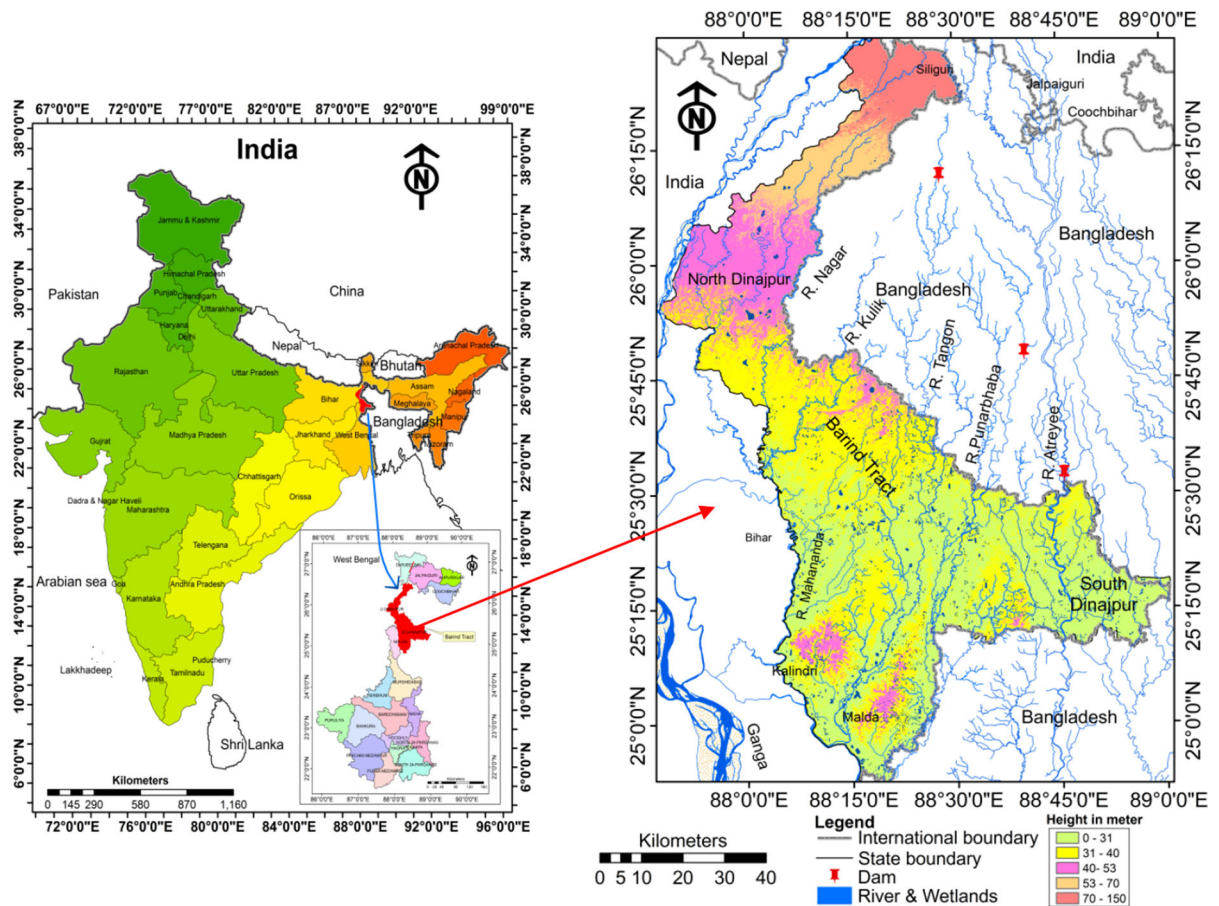
Fig. 1 Study area indicating parts of Barind tract, location of dam in different rivers

good accuracy for delineating wetland for this region (Das and Pal 2016). The Optimum threshold for separating water body from non water body from a histogram by analyzing the frequency distribution of grey levels in the image can be done. Procedure of NDWI calculation is,

$$NDWI = \frac{Green - NIR\,band}{Green + NIR\,band}$$

Each NDWI image consists of DN (Digital Number) value ranges between -1 and $+1$ where water body is denoted by the positive value. Binary wetland layers have been generated from all images by considering the theoretical threshold and defined 1 as water body and 0 as non water body (Borro et al. 2014).

Classification of wetlands

Frequency based approach is used for delineation and classification of wetlands. It is very useful for this region because water presence character is highly dynamic. It helps in the identification of wetlands, which are seasonal or ephemeral because it counts the frequency of water presence in every pixel over a considered period of time (Borro et al. 2014; Mondal and Pal 2016). More density of imageries can provide more credible result, but in our region, we have compelled to admit it in data sparse condition. For doing this work, the total frequency of images has been grouped into three major phases based on the anthropogenic interferences through damming over the rivers passing through. Phase I: before 1992, time of dam construction over river Punarbhaba; Phase II: 1993–2011, before the construction of dam over Atreyee (2011–12); and Phase III: 2012 onward, after

Table 1 Geological succession of Barind region and proximate Malda Tal, Diara and Rajmahal part. *Source:* Modified from Monsur et al. (2001), Ahmed et al. (2004), Ravenscroft et al. (2005), Rashid and Islam (2015)

Era	Epoch	Age (year starts on mya)	Quaternay Malda and adjoining	Lithology	Morphological unit(s)
	Holocene	Upper (0.0117)	Alluvium Diara Formation	Newer alluvium	Tal and Diara
	Pleistocene	Lower	Barind formation	Light olive brown with light brownish gray, sticky, mottled, moderately to very hard and compact, clay with silty clay. Few places filmy iron coating and iron concretions and pedogenic soil carbonate nodules are present. Mica is also present	Barind
	Plio-Pleistocene	Upper (0.126)	Barind formation	Compact and sticky clay with silty clay	Barind
Unconformity					
	Pleiocene	5.333	DupiTila formation		Barind
Unconformity					
Mesozoic	Cretaceous	Upper (100.5)	Rajmahal hills (trap), composed of basalt flows of volcanic origin (60–65 m.y.)	Basalt and associated sediments (tholeiitic basalt, quartz tholeiite, olivine tholeiite and alkali basalt)	Diara and Rajmahal transition
	Cretaceous	Lower (145)	Condowana fossil	Plant fossil of Cladophlebis indica, Dictyozamites indicus, Taeniopteris spatulata, Brachyphyllum rhombium	Diara and Rajmahal transition
Proterozoic	Pre Cambrain	(4000)	Achaean basement	Granitic rock complex (about 210 m below surface as per the drilling records of Mandilpur)	Basement of Rajmahal trap and surroundings

the construction of dams. Frequency structures of images used for this work are illustrated in Table 3.

$$WPF_j = \frac{\sum_{i=1}^{n} I_j}{n} \times 100$$

WPFj = Water presence frequency of jth pixels in a time period; I_j = jth pixel having water in the selected NDWI images; n = number of images. This value ranges from 0 to 100%. Value near to 100% indicates high frequency water body with greater stability and value near to 0 shows low frequency water body with greater chance of instability or conversion.

Estimation of wetland loss

For estimation of wetland loss, we have subdivided entire time series data for each season into three phases

in reference to the construction of dam as mentioned in Table 3. For the change detection, composite image of 2nd phase is deduced from 1st phase, 3rd phase is deduced from 2nd phase etc. This process is carried out after classifying each image into three classes e.g. high WPF (> 66%), moderate WPF (33–66%) and low WPF (< 33%) wetland.

Method for preparing different vectors dataset

In our study area, wetland degradation is inextricably interlinked with some vectors. In 1st vector, for analysis of role of flow modification in river, the flow regime of pre and post dam condition is being illustrated and a seasonal gap of water level between pre and post dam condition has been calculated for both the seasons. For instability analysis, year wise total water presence areas for both pre-monsoon and post-monsoon seasons have been considered. Least

Table 2 Details of study material

Purpose	Data used	Data sources
Administrative boundary delineation (State and International Boundary)	Malda District Map of Census of India, North and South Dinajpur District Map of Census of India. 2011	District Bureau of Statistics Office, Topographical Map, 1991
River and wetland Boundary Delineation (Atreyee, Punarbhaba, Tangon, Kulik, Nagar, Fulhar and Mahananda river)	Google Earth Imagery of 2015	Google Earth Imagery
Review of past drainage system	Old historical map	Map generated by James Rennel 1764–1777
		J.B. Tassin (1841) etc
Water-body Identification	Landsat TM imagery of TM and OLI_TIRS 8 satellite imageries	USGS Earth Explorer
Climatic condition analysis	Rainfall, Temperature, Humidity(1901–2011)	Indian Meteorological Department, District Bureau of Statistics Office, malda
Ground Water condition	Ground water level data (1996–2014)	Central ground water dept. New Delhi, http//www.India-WRIS.nrsc.go, State Water Investigation Directorate (SWID), West Bengal
Cropping intensity	Gross cropped area, Net sown area (2000–2010)	Bureau of Economics and Applied Statistics, Malda District

Table 3 Frequency structure of the dataset in different phases

Season	Phase-I	Phase-II	Phase-III	Total year
Pre-monsoon (March–May)	1988, 1989, 1990,1991, 1992 Total frequency = 5	1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011 Total frequency = 18	2013, 2014, 2015, 2016 Total frequency = 4	26
Post-monsoon (October–December)	1988, 1989, 1990, 1991, 1992 Total frequency = 5	1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011 Total frequency = 18	2013, 2014, 2015, Total frequency = 3	25

square regression models have been developed for phase-I, II and III with the concerned coefficient of determination (R^2). Finally instability is being calculated with the following equation of Cuddy and Valle (1978).

$$IX = CV \times \sqrt{1 - R^2}$$

where R^2 is coefficient of determination and CV is Coefficient of variation of selected time series water

presence area. Less IX value indicates less instability and vice versa. Supervised classification has been done for preparation of land use/land cover map from Landsat imageries of three different temporal resolutions (1991, 2001 and 2011). For minute observation land use classification has been done only for some selected area of interest where wetlands concentration is high. It is done for understanding the nature of land use transformation and consequent wetland loss. Three notified areas were selected (Segment-I, II and

III) where wetland concentration at initial phase was very high. Agricultural intensity has been calculated from data published by Statistical hand book of the Bureau of Economics and Applied Statistics. Agricultural intensity has been calculated following the method of Doi (1959).

$$AI = \frac{GCA}{NSA} \times 100$$

where AI = Agricultural intensity; GCA = Gross cropped area; NSA = Net sown area

For investigation of historical river system, old historical maps of Rennel (1767), Tassin (1841), toposheet of USGS (1951), toposheet of Survey of India (1991), Landsat imageries etc. have used. From these maps it is tried to find out the delinking or new connection of the rivers with surrounding major river systems. Previous literatures have also been corroborated for justifying the results coming out from the historical map series study.

Inverse distance weighted (IDW) method is used for preparation of thematic layers of ground water level distribution in different periods. Ground water monitoring stations of Central Ground Water Board (CGWB), India and State Water Investigation Directorate (SWID), West Bengal have been taken into consideration for such mapping.

Results and analysis

Nature of wet land loss of Barind tract of West Bengal

Figure 2a–c respectively represent the composite inundation frequency maps of wetlands for phase I, II and III, pre-monsoon and Fig. 2d–f show the same for post-monsoon period. Total estimated wetland areas at the 1st, 2nd and 3rd phases are respectively 20,274.83, 13,327.92 and 7163.27 ha during post monsoon season. Wetland areas for the same phases during pre-monsoon season are respectively 9006.4, 5156.01 and 2557.93 ha. This information clearly states that water body expansion is maximum in post monsoon season and seasonal gap of wetland area is very noteworthy. Comparative analysis reveals that total 13,206.94 ha water body areas have been lost since 1st to 3rd phase, 7042.29 ha since 1st to 2nd phase during post monsoon season. Loss of water

presence area is not uniform in every year and every part of the river basins. Based on the composite wetland of individual years, total high, moderate and low water presence frequency area were 1343.29, 2923 and 4741.44 ha respectively in pre-monsoon season for phase-I (1988–92). But in phase-II, water presence area has reduced significantly to 1086.31, 1655.05 and 2412.69 ha in respective classes in same season (Table 4).The scenario of the post-monsoon season differs from pre-monsoon as WPF area is 3 times higher in former season almost in every phase (Fig. 2d–f). In post-monsoon season of phase-I, water presence area were recorded as 45.85% (high frequency), 32.94% (moderate frequency) and 21.16% (Low frequency) to the total WPF area correspondingly which is much higher than pre-monsoon season. If phase wise total wetland loss is calculated, it is 34.73% from phase I to phase II, 46.25% from phase II to III, 65.14% from phase I to III in post monsoon season.

From year wise variability study of the water presence area, it is found that it varies from 25 to 52% (Fig. 3a, b). The core part of wetland is relatively stable, but average water presence area continues to decrease over phases. In phase-I for pre-monsoon, average water presence area was 11,083.6 ha and it has lowered down in phase-II (8942.29 ha) and phase-III (4535.18 ha). Continuous declining trend is prominent in both the seasons (Table 5). Areal instability of wetland has increased from phase I to phase III in both the seasons but its degree is high during pre monsoon season (8.74–42.50). In phase II, degree of instability is so high that some of the cases it has crossed the threshold limit of 3rd quartile.

Sensitivity analysis of wetland mapping

It is highly essential to assess the sensitivity of the prepared wetland images. This analysis is carried out for (1) water presence frequency maps and (2) wetland loss maps

1. For assessing accuracy of the wetland maps (WPF maps), 131 wetland plots were selected for phase I, 153 for phase II and 168 for phase III. It is investigated that whether water body were there in the respective phase and the frequency of water body appearance. Public opinion of the concerned plots are also taken into consideration for making
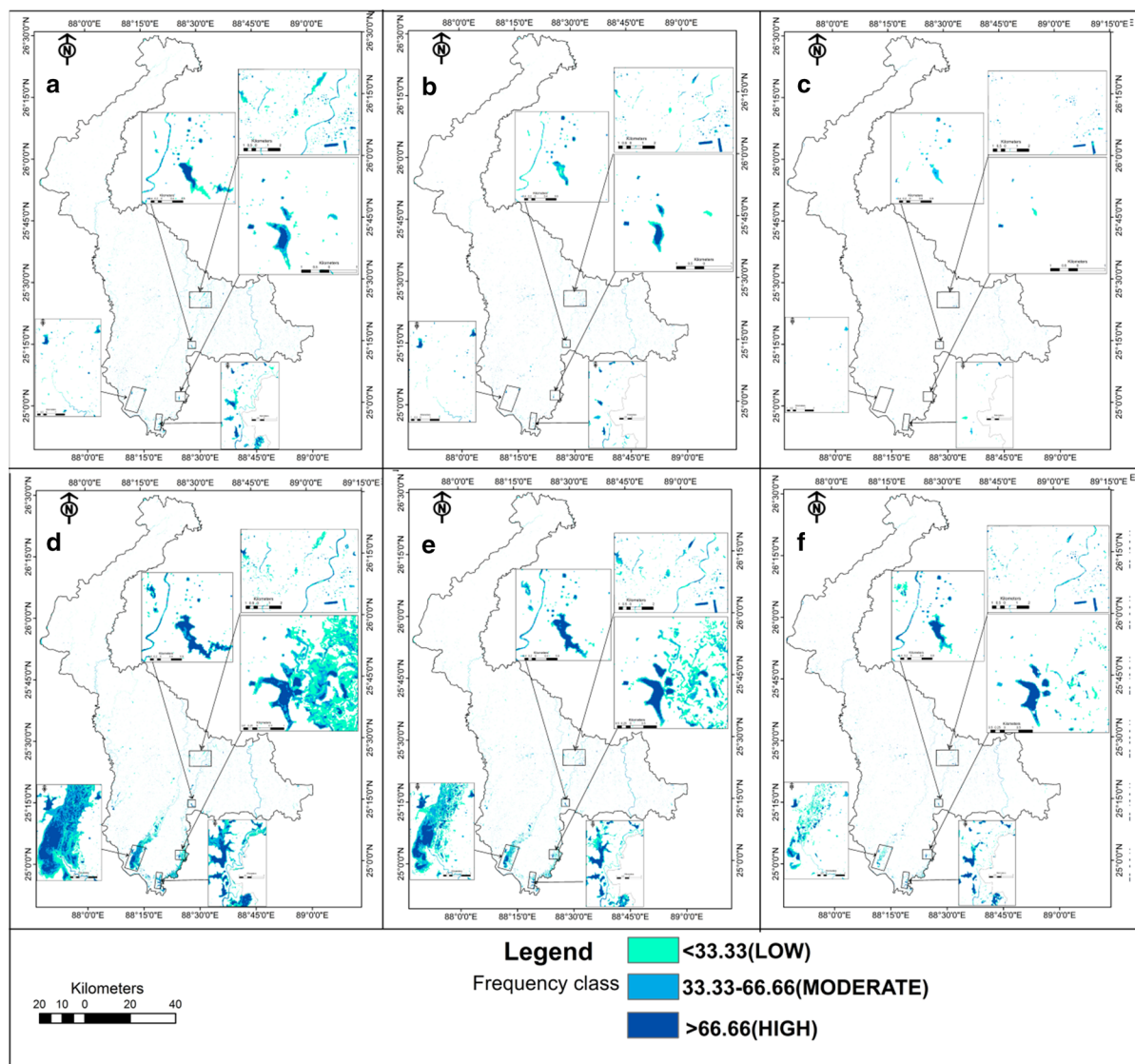
Fig. 2 Water presence area in different seasons and phases. **a** Phase-I, **b** Phase-II, **c** and Phase-III in pre-monsoon season and water presence area of **d** Phase-I, **e** Phase-II and **f** Phase-III in post-monsoon season

Table 4 Water presence area (hectare)under different water presence frequency classes (area in hectare)

Phase	Inundation frequency, pre-monsoon season			Inundation frequency, post-monsoon season		
	Low (< 33%)	Moderate (33–66%)	High (> 66%)	Low (< 33%)	Moderate (33–66%)	High (> 66%)
Phase-I (1988–1992)	4741.44	2923.15	1343.29	9295.823	6678.963	4298.208
Phase-II (1993–2011)	2412.69	1655.05	1086.31	5515.603	5245.573	2457.128
Phase-III (2012–2016)	1052.93	996.06	508.65	3145.757	2419.896	1598.027

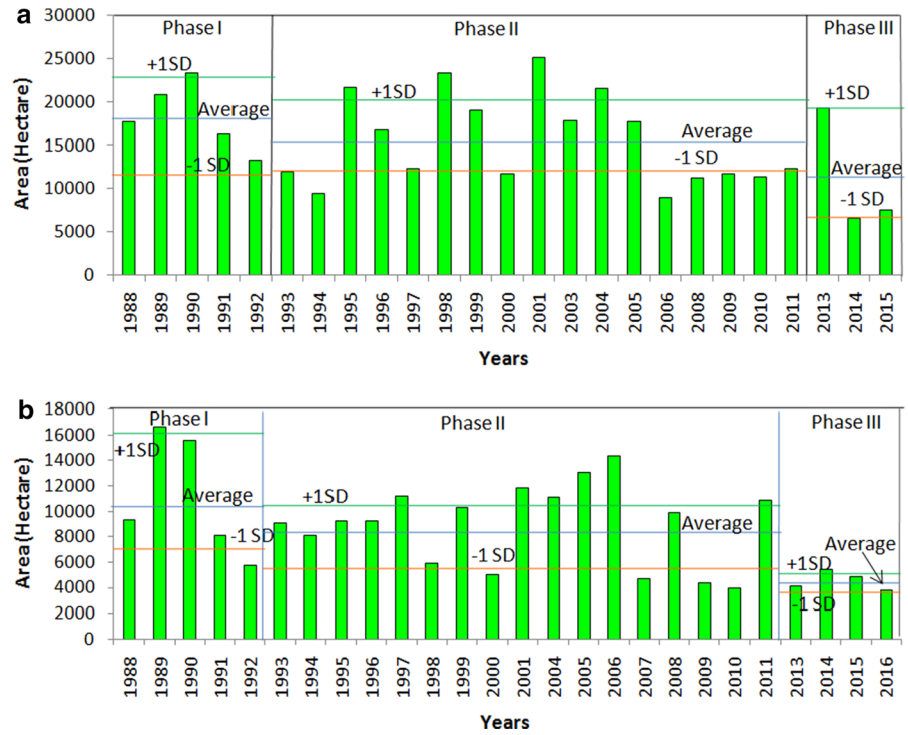**Fig. 3** Trend of water presence area in different seasons and deviations. **a** Pre-monsoon season and **b** post-monsoon season

Table 5 Instability analysis of seasonal wetland in different phases

Phase	Season	Y = a + bx	r^2	CV (%)	IX	Remarks
I	Pre-monsoon	Y = − 0.143x + 285.7	0.654	51.85	30.49	High instability due to inconsistent water presence
	Post-monsoon	Y = − 0.080x + 160.1	0.882	25.47	8.74	Low instability due to heavy rainfall
II	Pre-monsoon	Y = − 0.009x + 18.40	0.072	47.82	46.06	High instability due to squeezing of wetted area
	Post-monsoon	Y = − 0.002x + 5.378	0.015	35.91	35.63	High instability due to reduction of wetted area
III	Pre-monsoon	Y = 0.003x − 6.209	0.023	43.01	42.50	High instability due to reduction of wetted area
	Post-monsoon	Y = − 0.033x + 67.67	0.135	43.06	40.06	High instability due to reduction of wetted area

the fact confirm. From the investigation, it is noted that over all accuracy is 86.57% in phase I, 89.62% in phase II and 92.38% in phase III.

2. For accuracy assessment of the wetland loss map, 131 wetland plots were selected in respect to the wetland of phase I. Same sites were investigated for immediate next phase (Phase II). Out of total, 43% cases wetland is transformed into other land use mainly agriculture land. Rest 75 sites were taken as reference sites for phase II for analyzing the wetland loss status for phase III. In phase III, 55% wetland sites have converted into other land uses. In both the cases, > 90% sites are identified

from the given reference sites where existence of wetland is lost in immediate next phase. From these statistics, wetland loss trend can be apprehended.

Vectors of wetland loss

Reduction of stream flow and water supply inconsistency in wetland due to dam construction

The study reviews that how dams, diversion and river management have affected floodplain wetlands

because these wetlands are highly dependent on flows of rivers. Dams and diversions have reduced flooding to wetlands, altering their ecology and causing poor health of aquatic biota (Kingsford 2000; Jiang et al. 2014). After construction of the dam over the rivers in different periods, flow has reduced by 36.55% in Punabhaba river, 47.39% in Tangon river and 53% in Atreeye river. Percentage of discharge reduction in the post reservoir period are 30.97, 66.86 and 64.01% respectively during pre-monsoon, monsoon and post-monsoon in Atryee river and intra-season discharge variation has also reduced from 23.70 to 9.64% in pre-monsoon, from 76.33 to 32.53% in monsoon and from 77 to 23.41% in post monsoon (Pal 2016). As a result, permanent and seasonal wetlands have reduced respectively from 9007.88 and 11,268.43 to 5154.05 and 8171.91 ha from phase-I to phase-II. It has further reduced to 2557.93 and 4605.34 ha at phase III after construction of the dam over river Atreyee in 2012. Steady decline of the seasonal wetland area over time clearly exhibits the fact that the magnitude of flood has also reduced. A total wetland area in respect to the total geographical area of the basin has reduced from 2.99 to 1.05% in the last 28 years (Table 6). This fact is really alarming. Figure 4a, b respectively show the lost wetland at different phases during pre and post monsoon periods.

From the result it is clear that both seasonal and permanent wetland areas have declined with very steady manner in consequence of the reduction of rivers flow in post dam period. Dam disrupts longitudinal and lateral connectivity and creates barriers to easy water flow in the riparian wetlands. Flood frequency is reduced considerably in the rivers and water supplies to the flood plain wetlands become more inconsistent. Wetland located at the distant part of the flood plain from main river started suffering from flood water. But inundation water is not only the

main source of water of the wetland but it also supplies valuable nutrients to the wetland ecosystem significant for sporting survival. Moreover, return flood water washes out the pollutants of the wetland but lack of regular flooding may aggravate the qualitative degradation of the wetland. Irregular flood increases chance of conversion of wetland to other land uses (Das and Pal 2017).

Loss of external water course connectivity

Most of the natural wetlands are located along the course of rivers flowing over this region mainly associated with lower reach of Tangon and Punarbhaba rivers and their confluence parts. It has been assessed that the morphology of the major river system in the study area tremendously changed over the last three centuries. Examination of a number of old maps published between 1760 to tilldate reveals that during that period the drainage system of the entire region has altered significantly. Shifting of the channel, reorientation of major drainage direction, beheading, reallocation of flow among the major rivers etc. are some evident expression of drainage transformation. Such alteration of fluvial system has strong impacts of wetland transformation in this area. River Teesta first flowed south from Jalpaiguri (India) in three channels, namely the Karotaya to the east, the Punarbhaba to the west and the Atreyee to the center. It was the principal source of water to the Karatoa, Atreyee, Jobuneshwari and other rivers till 1787. Considerable structural changes triggered by neo-tectonic activities in the physiographic setup of the Barind region affected the drainage characters and volume of flow (Rashid and Islam 2014). In every year the Teesta with a large amount of water could not pass down the Atreyee without causing flooding. The excessive rains of 1787 suddenly brought down a huge amount of sand and

Table 6 Wetland area in different phases

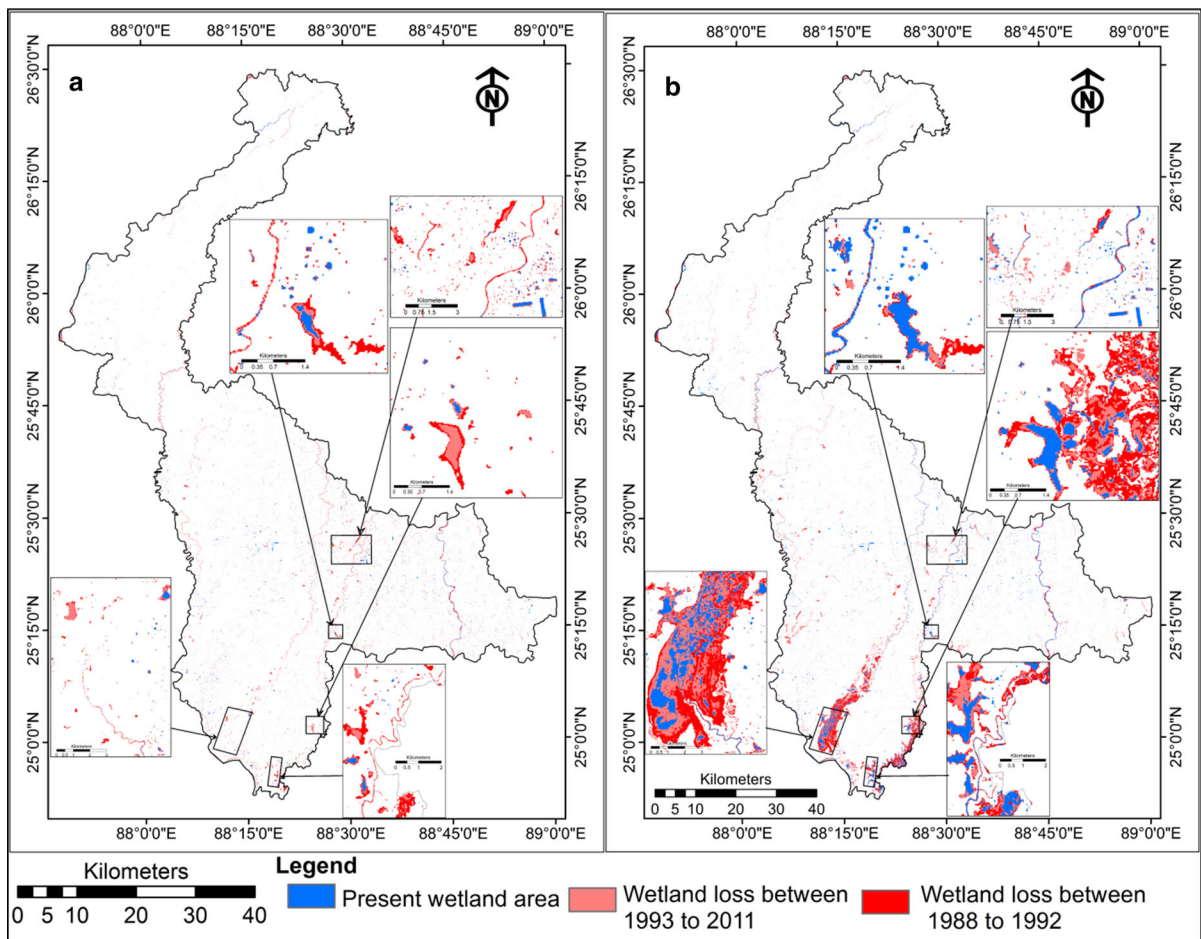| Phase	Wetland area (hectare)			% to total geographical area of the basin		
	Permanent	Seasonal	Total	Permanent	Seasonal	Total
I (1988–1992)	9006.4	11,268.43	20,274.83	1.33	1.66	2.99
II (1993–2011)	5156.01	8171.91	13,327.92	0.76	1.2	1.96
III (2012–2016)	2557.93	4605.34	7163.27	0.38	0.68	1.05

Fig. 4 Wetland loss in different seasons. **a** Pre-monsoon season and **b** post-monsoon season

choked the channel of Atreyee, with the result that the Teesta started flowing into the very small Ghaghat river, and not finding a sufficient outlet. So, Teesta found a new outlet for itself. After this tectonic movement in the eighteenth century, the Teesta river has started to shift continuously eastward and pour ultimately to the river Brahmaputra (Debnath 2007). In another opinion, the Teesta river flowed into the Ganga river up to the end of the eighteenth century but after the 1787 destructive flood the Teesta river changed its old channel and rushing south-east ward and poured into the Brahmaputra river (Agarwal and Narain 1991). The drainage map of entire the Bengal basin was first prepared by James Rennel during the period of 1764–1777 has become an important evident and supports the above statement of river linkage among the rivers (Fig. 5a). Another map published by J.B. Tassin in 1841 represents the same fact (Fig. 5c).

It is clear from the old historical maps that rivers Punarbhaba, Atreeye, Tangan and Kulik were once interlinked with Teesta river and they were used to receive an enormous amount of water from Teesta river. Therefore, these rivers were flooded frequently and wetlands along these rivers were inundated naturally. These rivers also interconnected to each other by several tributaries and distributaries for example, Punarbhaba is linked with Atreyee by Dipar river, Tangan and Punarbhaba, Nagar and Dauk and Kulik and Tangan etc. rivers were once interlinked and shared their water to each other which is evident from these old maps (Fig. 5a). but the linkages of Punarbhaba, Atreyee, Karatoya have gradually become disconnected from Teesta system and became completely non-perennial isolated rivers. Due to disconnection of such linkages among these rivers, water supply from Teesta is halted and a big
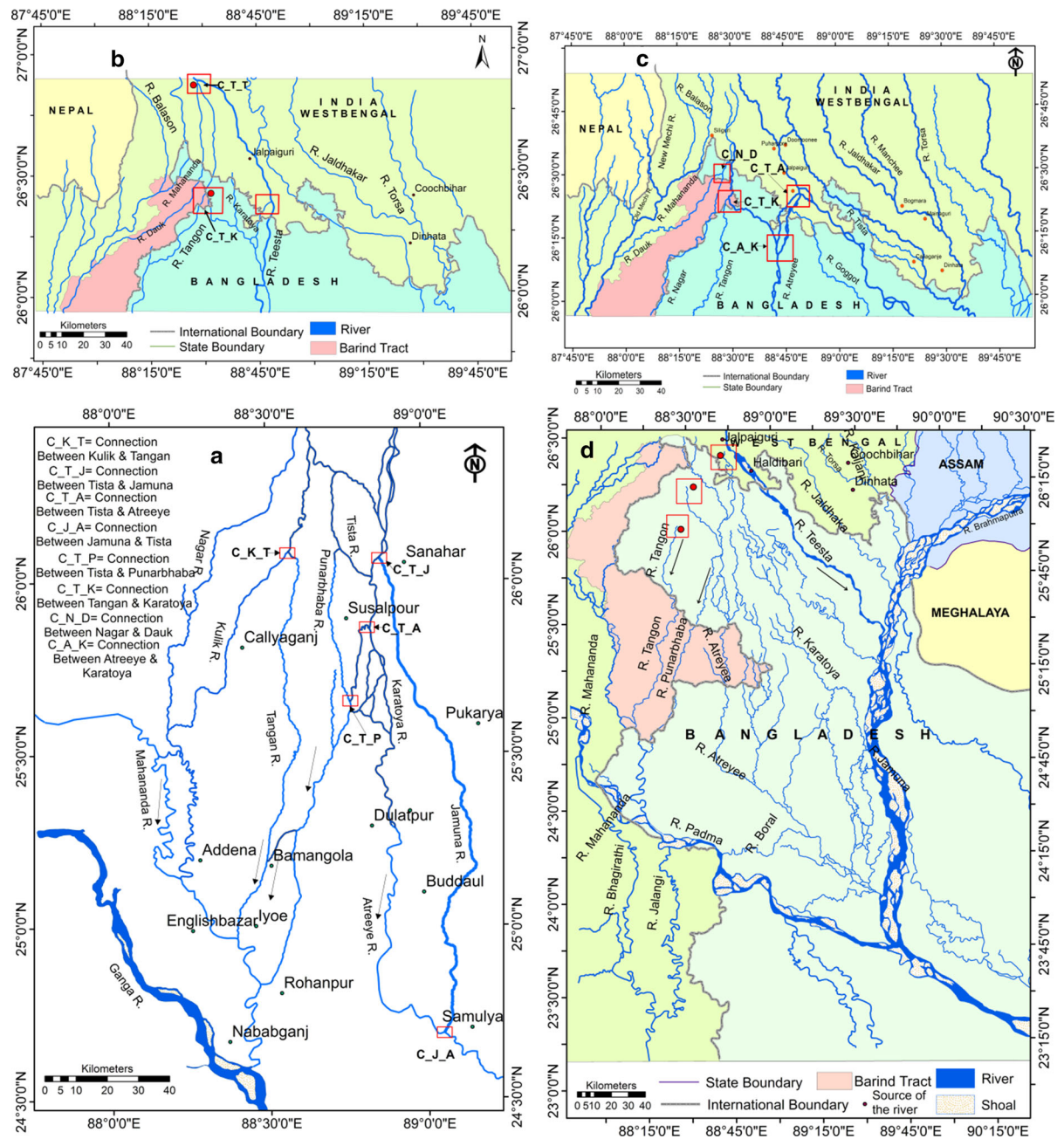
Fig. 5 Historical drainage network evolution of Barind tract. a Drainage map by J. Rennel, 1767, b Rennel's map with present administrative boundary, c drainage network by J.B. Tassin, 1841 and d drainage network generated from landsat imagery, 2016

hydrological paradigm shift is occurred in river as well as in riparian wetlands. Upliftment of older Barind tract of Pleistocene era and incision of rivers concerned for readjustment has artificially raised the height of the bank wall of the rivers. It is caused for

gradual detachment of the ox bow lakes from the rivers and reduction of flood (Rashid and Islam 2015). Rashid and Islam (2015) also mentioned that some of the wetlands of Barind tract are also formed due to regional neo-tectonic depression.
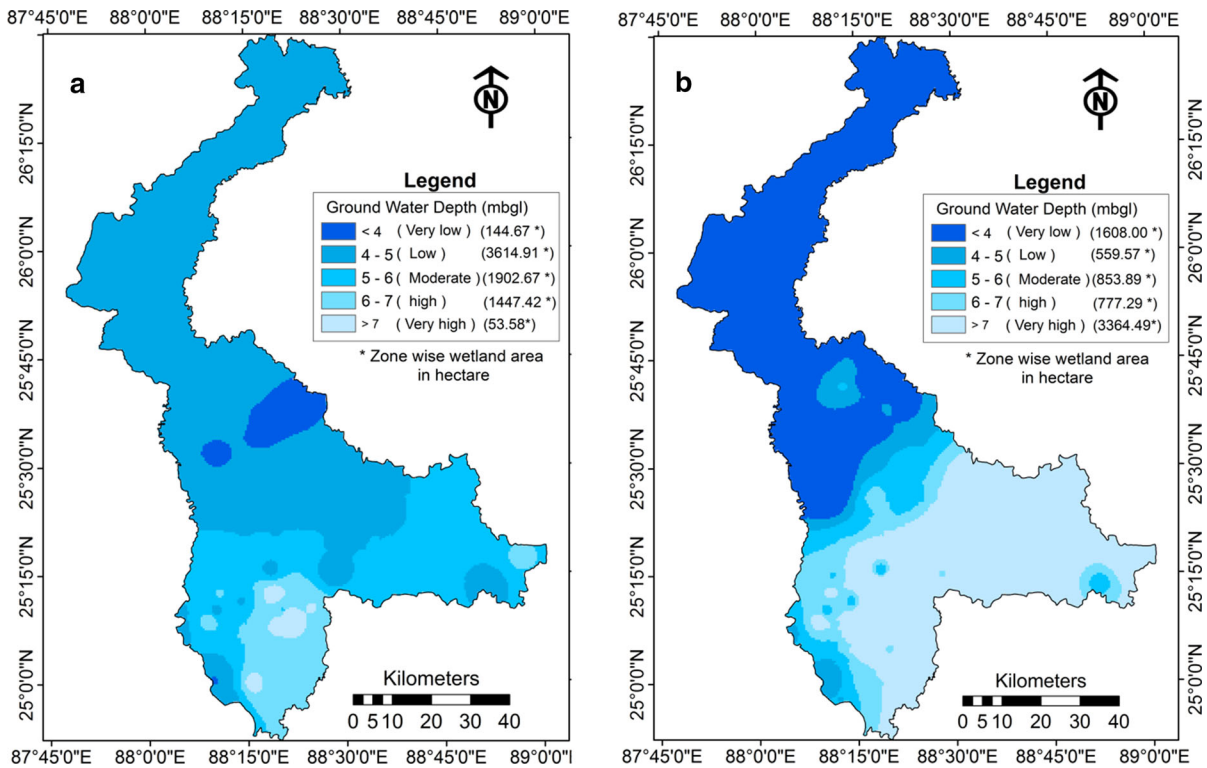
Fig. 6 Average depth of ground water level in **a** 1996–2000 and **b** 2011–2014

Changes in ground water level

Ground water has a profound influence on sustaining perennial/semi perennial wetland and ecology of the wetlands (Kirkman et al. 2000). Presence of water level very nearer to the surface supports stagnation of water and wetland formation and as much as ground water levels near to surface depression, creates effulent condition and provides continuous water support to wetland (Hoque and Burgess 2012). The average ground water level of this region is 5–6 mbgl. Lowering of vadose layers of soil intensifies seepage from the surface water body, which results reduction of water from wetlands. Average ground water level is calculated from the data received from different public health and engineering centers of the region in two different periods (1996–2000 and 2011–2014) and the results show that high fluctuation in ground water level exists. Spatio-temporal changes in the ground water for the period 1996–2014 reveals that maximum ground water depletion occurred in southern and south-eastern part. Drop of ground water is also high in Tangon-Punarbhaba interfluves region. Rigorous

abstraction ground water for irrigation is attributed to the rapid declining trend in ground water level. Estimated ground water level lowering since 1996–2014 is 30–40% in the southeastern part. It may intensify the seepage process from the surface water body in pre-monsoon season. Spatial distribution of wetlands in response to different ground water level zones represents the high variability of wetlands area in two different periods. In the period of 1996–2000, only 53.58 ha area of wetland was under > 7 (mbgl) zone but, it was 3364.495 ha area during 2011–2014 in the same zone and total wetland loss is also high in this ground water level zone for the same periods (Fig. 6a, b). Decrease in ground water level may be a cause of wetland loss in the study area.

Conversion of wetlands into agricultural fields

Land use analysis has become a prerequisite to detect the changes of anthropogenic landscape and overlay of it on the natural landscape. The impact of changing land use relies on the prevailing surface and subsurface hydrologic conditions and the dynamics of
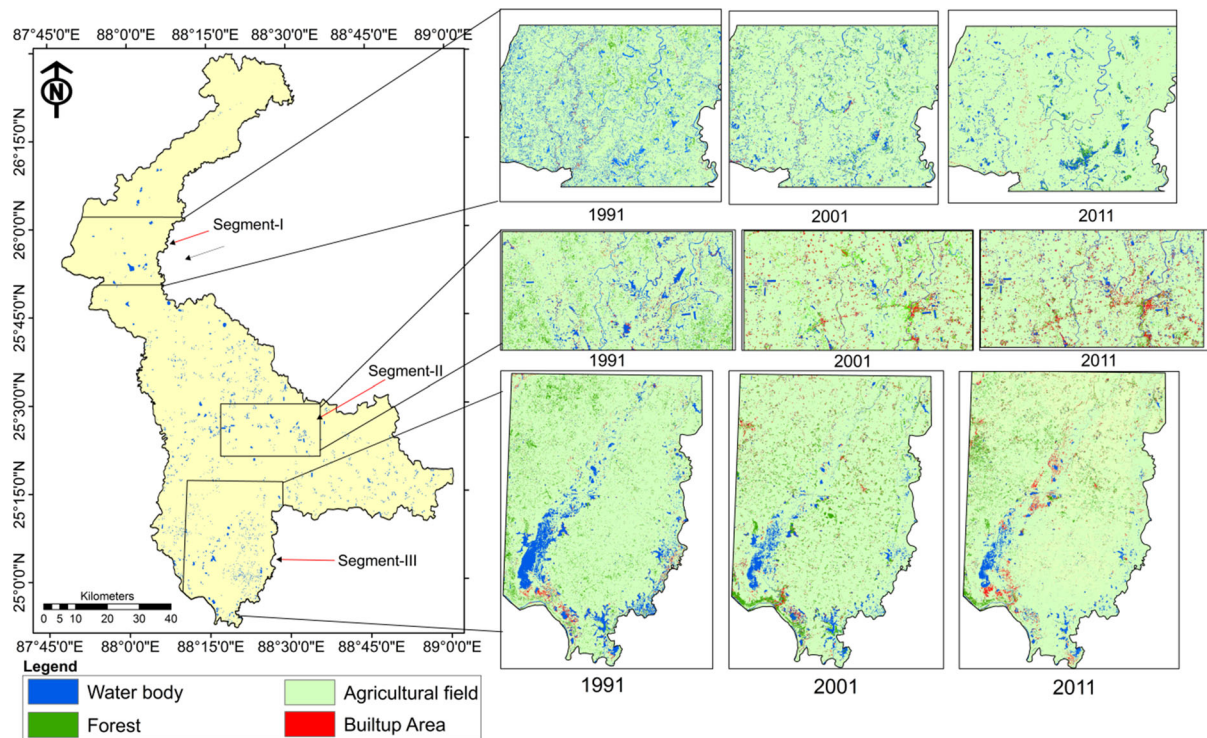
Fig. 7 LULC map of 1991, 2001 and 2011

hydrologic processes. Intensive subsistence agriculture is practiced here and more than 75% of people are engaged in this occupation. Due to high demand of land they used to take the advantages of seasonal drying out or shallow wetlands and use those for seasonal agriculture purpose. The agricultural intensity of this study area is about 150%. From the image classification in three phases (1991, 2001 and 2011) (Fig. 7), it is seen that the most salient changes in land use has been the quick augmentation of agricultural land, replacing wetlands area in and around the major wetland patches. A total agricultural field area in the segment I was 53749.62 ha in 1991, 55,677.80 ha in 2001 and 56,911.78 ha in 2011 which proves the increase of agricultural lands and similar phenomena is also recorded in segment-II and III (Table 7). Conversely, wetland area at segment I is reduced from 5189.55 ha in 1991 to 2095.78 ha in 2011. Conversion to agricultural fields and draining of wetland for agriculture is one of the primary reasons of wetland loss in the projected area.

Validation of LU/LC maps

For assessing Land use/land cover of the classified image, Kappa coefficient (K) has been calculated. For accuracy assessment total 71 ground control points (GCPs) and 150 random sites from google image (for 2011) have been taken into consideration. The overall accuracy for segment-I, II andIII are 81.79, 80.61 and 83.54 respectively. So, it can be stated that there is an excellent agreement between classified images and actual ground reality. It is also to be mentioned that accuracy assessment for phase I and phase II are entirely based on GCPs.

Conclusion

The present work delineated the wetland of Barind tract and explained how the wetlands on Barind tract have been continuously degrading and what the reasons behind such wetland loss are. The study also has highlighted competent mapping of seasonally flooded wetlands of immense hydro-ecological importance based on water presence frequency approach.

Table 7 Extent and relative land cover (in hectare) for the years 1991, 2001 and 2011

Segments	1991				2001				2011			
	Built-up area	Water body	Forest	Agriculture field	Built-up area	Water body	Forest	Agriculture field	Built-up area	Water body	Forest	Agriculture field
I	286.41	5189.55	855.53	53,749.62	404.82	3218.07	780.42	55,677.80	502.62	2095.78	570.94	56,911.78
	(0.48)	(8.64)	(1.42)	(89.46)	(0.67)	(5.36)	(1.30)	(92.67)	(0.84)	(3.49)	(0.95)	(94.72)
II	983.25	3518.55	2503.66	44,411.34	1350.47	2729.26	2249.02	45,088.06	2014.28	2554.93	1904.93	44,942.67
	(1.91)	(6.84)	(4.87)	(86.38)	(2.63)	(5.31)	(4.37)	(87.69)	(3.92)	(4.97)	(3.70)	(87.41)
III	1178.17	5874.68	4255.67	98,430.67	1710.86	3712.92	4314.46	100,000.96	2014.28	2554.93	1904.93	44,942.67
	(1.07)	(5.35)	(3.88)	(89.70)	(1.56)	(3.38)	(3.93)	(91.13)	(1.98)	(2.30)	(2.79)	(92.94)

Values in parenthesis are the corresponding percentage values

Based on the vector study, it is found that anthropogenic pressure plays vital role in deteriorating wetland and increasing vulnerability of wetlands. River regulation projects through the dam emerge as adominant factor in altering drainage and wetland hydrological conditions. Rapid encroachment of agricultural activities in seasonal wetted parts fully destructed ecological functions of wetlands fragmented the ecological integrity. Excessive harvesting of ground water has also converted effluent wetlands into influent. India is a signatory to the Ramsar convention on Wetlands and adopted many of protective measures but, still no significant progress has been made on the conservation and wise use of such seasonal wetlands at micro level. Lack of proper awareness about the viable goods and services of the wetland, paucity of resource generation attempts compel wetland as wasteland. Very least attempt of nourishing wetland as done to other crop lands can make the wetland productive. Conflict between agriculture and wetland should immediately be avoided. The priority areas need to be determined based on watershed process and environmental degradation or restoration. In this connection present findings can support for decision making regarding wetland preservation and management.

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