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SPATIOTEMPORAL DYNAMICS OF LAND USE AND CROPPING SYSTEMS IN THE YOUNG MEGHNA ESTUARINE FLOODPLAIN

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Abstract

To explore long-term changes in land use and land cover (LULC), cropping systems, and driving forces of LULC change, a study was carried out in Subarnachar upazila under the Young Meghna Estuarine Floodplain in Bangladesh. For studying LULC change and cropping systems, images from Landsat (TM) of 1989, Landsat (ETM+) of 2000 and 2010, and Landsat (Oli) of 2019 were used. A focus group discussion (FGD) was conducted to gather information on actors driving LULC changes. In the study area, five LULC categories—cropland, accreted land, settlements, mangrove forests, and water bodies were found. It reveals that cropland increased by 0.20% annually, while water bodies, accreted land, and mangrove forest decreased by 0.29, 0.17, and 0.23%, respectively. Settlements grew relatively at a faster rate (0.49%). The major land conversions between 1989 and 2019 were cropland to settlement (10.2%), mangrove forest to settlement area (3.2%), and mangrove forest to cropland area (4.0%). Other transformations included the shifting of accreted land to cropland and water bodies to settlements. From 1989 to 2019, double cropland increased by 0.71% annually due to the conversion of single to double cropland. Increased population pressure, especially for those displaced by the threat of river erosion, was a major factor in the conversion of cropland and mangroves into settlements. Due to the high demand for food in the study area, mangrove forests were converted to cropland and single cropland to double cropland more rapidly. These findings will assist farmers, stakeholders, and planners in developing and implementing optimal land use planning and sustainable agricultural production strategies in the region.

Keywords: LULC change, cropping pattern, climate change, focus group discussion, Bangladesh.

Introduction

Bangladesh is a deltaic plain cris-crossed by the Ganges, Brahmaputra, and Meghna (GMB) river systems and their tributaries. It comprises an area of 147,570 km^2, of which 5.13% consists of rivers and water bodies (BBS, 2021). The seasonal and annual variations in rainfall, temperature and humidity of the country are noticeably more prominent. The landscape also varies, resulting in 30 Agroecological zones (AEZ) based on land, soil, hydrology, and climate. The Young Meghna Estuarine Floodplain (AEZ 18) is situated in proximity to the Bay

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of Bengal. It is a tidally impacted fluvial landform that covers 18.0% of the coastal region and 6.3% of the country (Islam *et al*., 2016; Akter *et al*., 2015). Land use in coastal regions is generally at risk because of population pressure (Neumann *et al*., 2015; Kurt, 2013), sea level rise (Bell *et al*., 2021), accretion-erosion (Emran *et al*., 2017; Islam *et al*., 2016), land degradation (Xie *et al*., 2007), and extreme weather events (Abdullah *et al*., 2020). The area, like many other sea-exposed countries, is threatened by several factors, including salinity, cyclones, storm surges, and riverbank erosion (Mojid, 2020; Ghosh *et al*., 2015). The land areas outside the embankment are frequently flooded during high tide and significantly contribute to the formation of saline soils during the dry season (February–May). Additionally, the land is highly dynamic, with simultaneous processes of erosion and accretion that either cause the formation of char land or wash those new and old lands into the rivers and seas (Islam *et al*., 2016; Sarwar and Islam, 2013). It has an adverse effect on agroecosystems, hydrological conditions, and agricultural output during the dry season.

In the past, the region hardly received any attention. Since food demand increased significantly due to the expanding and migrating population in the area and the decline in the amount of arable land, it has recently been attempted to investigate the potential of the land for improving agricultural production (Naher *et al*., 2015; Hasan *et al*., 2013). The possible ways of increasing the cropland area are protection of the mainland from riverbank erosion and stabilizing new land created through accretion processes (Abdullah *et al*., 2019). Therefore, it needs an assessment of how the area has changed over time regarding land use, hydrology and cropping systems. Updated information on the processes and forces behind land-use change and how this affects crop productivity is still elusive. Therefore, it is vital to assess the magnitude of land-use changes, their underlying causes, and the accompanying production technologies.

Data on shifting land use and land cover in the area are not readily available and the existing information is mostly outdated. Therefore, it is vital to assess how intensive cropping, which constantly experiences erosion and accretion, changes the dynamics of land use and land cover. For resource management and sustainability in the region, such updates and development of information on land, soil, and water resources must be accessible to scientists, extension professionals, students, and policymakers. Geographic information systems (GIS) and remote sensing (RS) techniques are comparatively adventitious for determining the spatiotemporal dynamics of land use and land cover (Barakat *et al*., 2019; Vibhute and Gawali, 2013). The RS approach provides valuable multitemporal data for tracking land-use patterns, and GIS enables the analysis and mapping of these patterns (Xie *et al*., 2007; Giri *et al*., 2003). Decision-makers can be benefitted from the information provided by these time-series analyses of land-use change and the identification of its driving forces for the sustainable management of land resources and regional development (Sajid *et al*., 2023; Abd El-Hamid, 2020). Considering the above mentioned concerns, the study aims at quantifying land use and land cover changes (LULC) in the Lower Meghna Estuarine Floodplain using RS and GIS techniques, detecting the driving forces of changing LULC and cropping systems, and recommending sustainable crop production strategies in the future.

Materials and Methods

Location of the Study area

The study was carried out in Subarnachar, Noakhali district, Bangladesh, which covers an area of 382.12 km^2 and is located between 22° 28' and 22° 44' N latitude and 90° 59' and 91° 20' E longitude (Fig. 1). The area belongs to the Young Meghna Estuarine Floodplain under Agroecological Zone (AEZ) 18. The Meghna Estuary embraces the active river mouths of the Ganges-Brahmaputra (Jamuna)-Meghna (GBM) Mega Delta. Sedimentation and erosion are most common in the area, which eventually alter the shape of the coastline. The soils are silty, stratified, and slightly calcareous, with varying degrees of salinity during the dry period. Saline water intrusion occurs on the land margins during high tides in the monsoon and also during the tidal surge associated with a tropical cyclone. The estuary floodplain area is generally level, with low ridges and broad depressions. The dynamic change of land, river, and hydrology makes the study area vulnerable to agricultural production (Crawford *et al*., 2021).

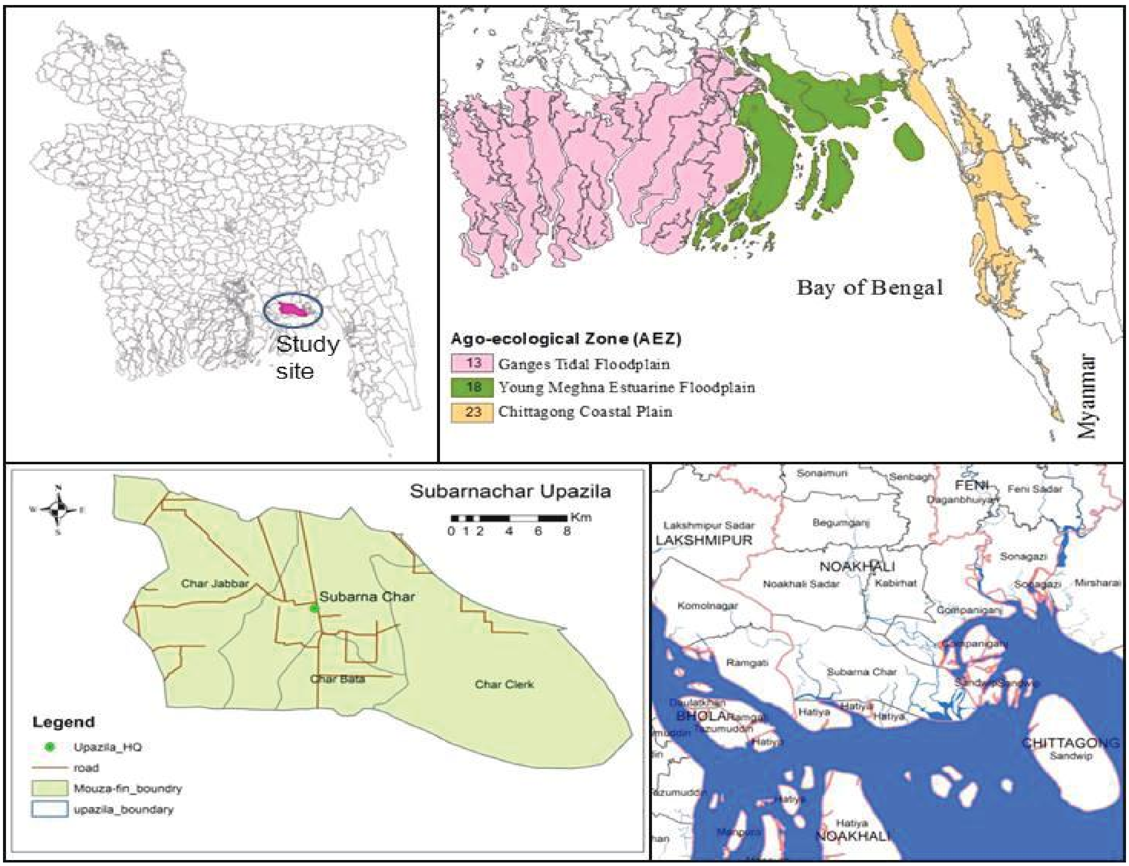

Fig. 1. Location map of the study area.

Satellite data acquisition

For analysis of LULC change, time-series Landsat satellite images of 1989, 2000, 2010, and 2019 were used. Images were obtained from the United States Geological Survey website (http://earthexplorer.usgs.gov). They consist of the Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS), with Path 136 and Row 44. The images had a 30 m spatial resolution and less than 10% cloud cover. The dry season images were considered to lessen the influence of cloud cover and seasonal variation (February–March) on the classification results. Details of the characteristics of the satellite images and their acquisition time are illustrated in Table 1.

Image classification

An unsupervised classification technique was employed for image classification. The ISODATA clustering algorithm was used in this classification method to divide the photos into 46 classes. The maximum number of iterations allowed for unsupervised classification was 15, and a convergence threshold of 0.95 was used for class determination. For Landsat 4 and 7, we used 4-3-2 to detect pixels for each category, and for Landsat 8, we used 5-4-5 FCC. Pixels were divided into five categories based on land cover: single-cropping land, double-cropping land, accreted land (recently formed coastal mudflats with some vegetation), settlement (orchards and trees, homestead area, ponds, and transportation infrastructure), mangrove (mainly forest and reserved forest), and water bodies (major rivers, lakes, ponds, and water reservoirs). Double-cropping lands are mainly double-cropped area with some triple-cropped and single-cropped areas that are classified into LULC classes based on existing crops like cereals, pulses, oilseed crops, vegetables, and other crops. Single-cropping lands are predominantly single-cropped area with some double-cropped and fallow areas that are classified as no cropping during image classification. Such classification was also based on historical land use maps produced by Soil Resource Development Institute (SRDI).

Accuracy assessment and ground-truthing

First, a training or test area (TTA) mask was created to test the classification accuracy. A confusion matrix was created for each image and the overall accuracy and kappa coefficient of agreement were calculated. Overall accuracy for all sites varied from 0.81 to 0.90, from 0.73 to 0.88, from 0.84 to 0.91 and from

Table 1. Details of acquired satellite imagery with acquisition date, spectral band and spatial resolution

Satellite ID	Acquisition date	Spectral band	Path/row	Spatial resolution (m)
Landsat 4-5 TM	18-03-1989	7	136/44	30 m
Landsat 7 ETM+	13-02-2000	8	136/44	30 m
Landsat 7 ETM+	08-02-2010	8	136/44	30 m
Landsat 8	24-02-2019	11	136/44	30 m

TM - thematic mapper; ETM+ - Enhanced Thematic Mapper Plus

0.86 to 0.93 for 1989, 2000, 2010, and 2019, respectively, with kappa coefficient of 0.78 to 0.87, 0.72 to 0.86, 0.84 to 0.91, and 0.85 to 0.92. Second, secondary data were used to support satellite imagery analysis. Soil and Landform Maps of 1987 obtained from Soil Resource Development Institute (SRDI) were used to obtain basic information on LULC as well as crops and cropping patterns. The classified images were verified through field surveys and aerial photographs at the randomly selected sites. All units of LULC classes were visited and verified through interviews with local people and field observations.

LULC change detection assessment

LULC change detection was calculated for the periods 1989–2000, 2000–2010, 2010–2019, and 1989–2019. It was done through post-classification comparisons (Lu *et al.*, 2004), which give the size and distribution of changed areas and the percentages of land cover classes. For this, conversion matrix tables between land use classes for the above four periods were prepared using ERDAS IMAGINE 14. The crosstabulation table illustrates the rates of change for each land use category from the earlier classified image to the later by comparing pixels.

Dynamic degree index of LULC

The dynamic degree index (K) of LULC depicts the speed of land use change over a period of time, which was estimated following a standard formula (Li *et. al.*, 2017):

$$K (\%) = (Wb - Wa)/Wa \times 1/T \times 100$$

where, K is the unit dynamic index, Wa, Wb represent the area of LULC before and after the study period, T is the study period length.

Focus group discussion

A Focus Group Discussion (FGD) was organized with 21 participants from the study area who are involved in agricultural research, development, and extension. The participants included a scientist from the SRDI, a scientist from the Bangladesh Institute of Nuclear Agriculture (BINA), a field officer from ASA, DUS (NGO), Upazila Nirbahi Officer (UNO) and five local progressive farmers. Among others, the Upazila Agriculture Officer (UAO) and Sub-Assistant Agriculture Officers (SAAO) were from the Department of Agricultural Extension (DAE). Respondents were asked to identify the dominant cropping patterns used by farmers in 2018-2019 and 15 years ago and to identify the variables that contributed to the conversion of cropland to settlement or other uses, mangrove forest to settlement, mangrove timber to cropland, and eventually from single cropland to double cropland. They were also asked to rank the causes that led to such conversions.

Feedback and validation

Data on land use and land cover classification, including maps and questionnaire survey data and information, were compiled, and a draft report was prepared. It was then presented at a review workshop in Subarnachar upazila of Noakhali district to receive validation and feedback from scientists (BINA and BADC), extension agents (SAAO), and concerned personnel (Upazila Nirbahi Officer). The workflow and steps followed for assessing LULC change and conversion are illustrated in Figure 2.

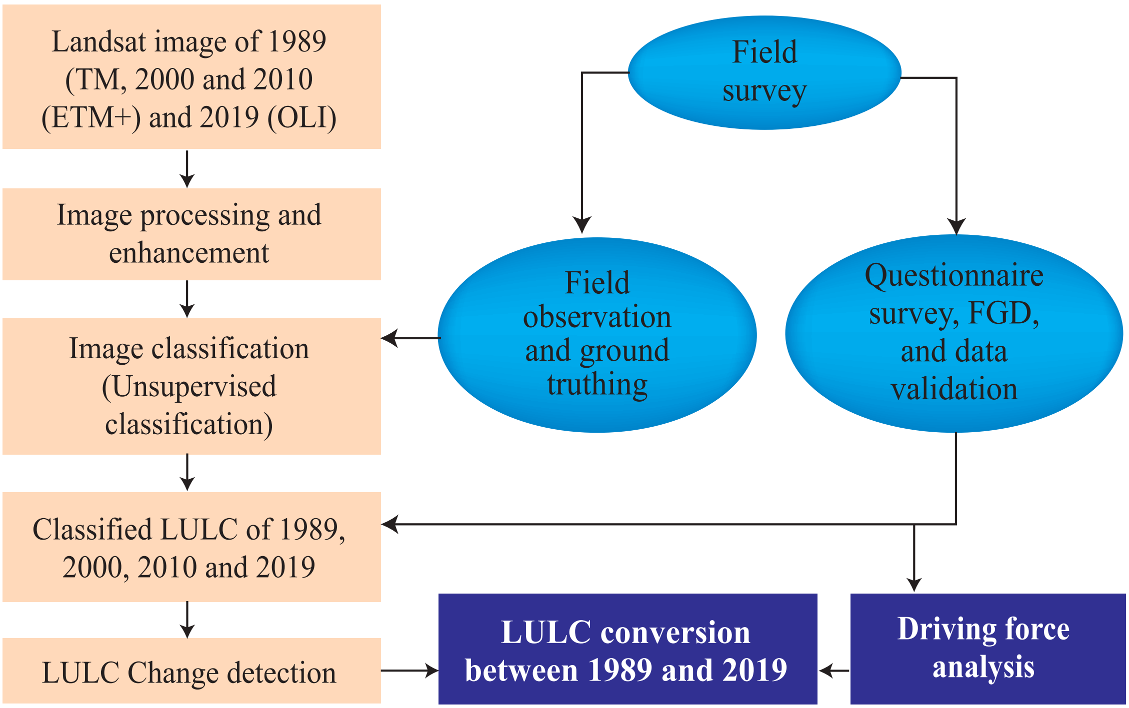

Fig. 2. Flowchart of land use land cover (LULC) change assessment, and overall approach to study.

Data analysis

All data obtained were verified and cross-checked, compiled, coded, and entered into the computer for analysis and interpretation using the SPSS program. Data were described and interpreted using descriptive statistical techniques such as range, mean, number and percentage distribution, standard deviation, and t-test.

Results and Discussion

Spatiotemporal LULC changes

The LULC change during 1989–2000, 2002–2010, and 2010–2019 were summarized in Table 2 and Figure 3. The annual loss to non-cropland was 0.17% and 0.62% during 1989–2000 and 2010–2019, respectively, while it increased by 1.33% during 2000–2010. In terms of cropland changes, the overall annual change between 1989 and 2019 is positive (0.20%). The loss of cropland between 2010 and 2019 was nearly four times the area lost between 1989 and 2000. It is important to note that despite the loss of accreted land, mangrove forests and water bodies, the increase in cropland has been so remarkable that between 2010 and 2019 there was a significant annual increase (0.20%) in cropland. The settlement has grown steadily throughout, which is remarkable. The fluctuating cropland growth rates show how dynamic the region is. These results are in accordance with the observations made by Islam *et al.* (2016) in the same study area (AEZ 18) where there has been a significant increase in cropland. It was reported that built-up, agricultural land and forest are the land use categories modified by

Table 2. Area and annual change of the different land use and land cover (LULC) types of Subarnchar in 1989, 2000, 2010, and 2019

LULC types	Area (ha)				Annual change (%)			
	Year 1989	Year 2000	Year 2010	Year 2019	1989-2000	2000-2010	2010-2019	1989-2019
Cropland	26366 (58.5)	25517 (56.6)	31515 (69.9)	29005 (64.3)	-0.17	1.33	-0.62	0.20
Non- cropland:	18734 (41.5)	19583 (43.4)	13585 (30.1)	16095 (35.7)	0.17	-1.33	0.62	-0.20
Accreted land	2703 (6.0)	4373 (9.7)	1391 (3.1)	428 (0.9)	0.34	-0.66	-0.24	-0.17
Settlement	2750 (6.1)	4314 (9.6)	6552 (14.5)	9418 (20.9)	0.32	0.50	0.71	0.49
Mangrove forest	3915 (8.7)	4590 (10.2)	1135 (2.5)	842 (1.9)	0.14	-0.77	-0.07	-0.23
Water bodies	9366 (20.8)	6306 (14.0)	4507 (10.0)	5407 (12.0)	-0.62	-0.40	0.22	-0.29
Total	45100	45100	45100	45100	0	0	0	0

Annual data without parentheses is the estimated area under each land use category and the percentage of total area with parentheses

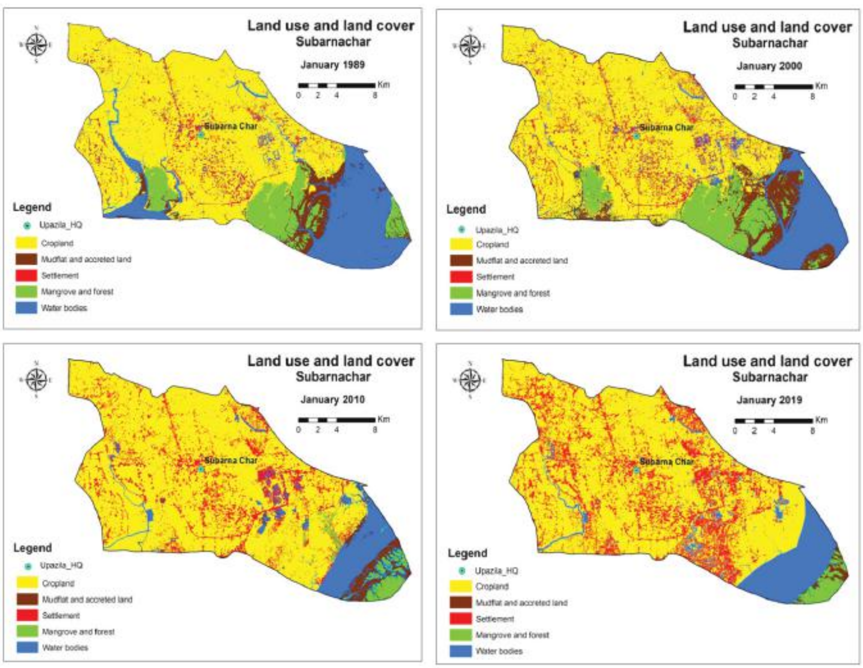

Fig. 3. Land use land cover (LULC) maps of Subarnachar in 1989, 2000, 2010, 2019.

natural and anthropogenic activities (Nath *et al.*, 2018; Li *et al.*, 2016).

Land conversion between 1989 and 2019

During the period 1989-2019, the major changes in land use were the conversion of cropland to settlement (10.2%), accreted land to cropland area (4.0%), mangrove forest to cropland area (4.0%) and settlement (3.2%), water bodies to cropland (7.3%) and settlement (2.3%) (Table 3). Despite the conversion of cropland to various land use categories, especially settlement, 17.0% cropland was acquired from water bodies, accreted land, and mangrove forest. Interestingly, almost all accreted land was transformed into other land use categories. The settlement area increased greatly, mainly from cropland, mangrove forests and water bodies. Also, mangrove forests disappeared and were replaced by new forest areas whereas the total area of water bodies increased.

LULC dynamic degree index

The LULC dynamic degree index (K) was positive and much high in settlement (8.08), followed by cropland (0.32) during 1989–2019 (Table 4). This means that the rate of settlement change was much faster. Accreted land, mangrove forests, and water bodies had negative values and ranged from 1.41 to 2.81, indicating that these types of land use declined at a relatively low rate. However, such increases and decreases are not consistent across different time scales. Only the degree of LULC dynamics was consistently increased for settlement. The increase in cropland shows the LULC dynamic index as high as 2.35 during 2000–2010. Accreted land and mangrove forests had positive indexes for 1989–2000, but they declined dramatically during the other two decades. Water bodies decreased in the first two decades and then increased. During 1989–2000, the degree of water bodies decline was related to an increase

Table 3. Land use and land cover conversion of Subarnachar between 1989 and 2019

LULC type	Year 1989					Year 1989 Total
	Cropland	Accreted land	Settlement	Mangrove forest	Water bodies	
Cropland	21353 (47.3)	2 (0.001)	4588 (10.2)	3 (0.001)	420 (0.9)	26366 (58.5)
Accreted land	1799 (4.0)	38 (0.1)	530 (1.2)	32 (0.1)	304 (0.7)	2703 (6.0)
Settlement	747 (1.7)	77 (0.2)	1807 (4.0)	64 (0.1)	55 (0.1)	2750 (6.1)
Mangrove forest	1792 (4.0)	112 (0.2)	1446 (3.2)	85 (0.2)	480 (1.1)	3915 (8.7)
Water bodies	3314 (7.3)	199 (0.4)	1047 (2.3)	658 (1.5)	4148 (9.2)	9366 (20.8)
Year 2019 total	29005 (64.3)	428 (0.9)	9418 (20.9)	842 (1.9)	5407 (12.0)	45100 (100.0)

The values in parenthesis indicate the percent conversion in respect of total land area

Table 4. Dynamic degree index (K) of different LULC types of Subarnachar

LULC types	Dynamic degree index (K) value			
	1989-2000	2000-2010	2010-2019	1989-2019
Cropland	-0.29	2.35	-0.70	0.32
Accreted land	5.62	-6.82	-7.69	-2.81
Settlement	5.17	5.19	4.86	8.08
Mangrove forest	1.57	-7.53	-2.87	-2.62
Water bodies	-2.97	-2.85	2.22	-1.41

in accreted lands, whereas during 2000–2010, it was related to an increase in cropland.

Change in cropping systems

The primary crop in the region was transplanted Aman (T. Aaman) rice, which was grown during the rainy season (Kharif II) between July and November. The land transformed into a double cropping system when rabi crops or Boro rice were produced in succession with T. Aman during the dry period. According to the satellite image classification, the single cropping area decreased from 44.4 to 29.0% with an average annual decrease of 0.52% during the study period, while the double cropping area gradually increased from 14.0 to 35.3% with an annual increase of 0.71% (Table 5). After 2000, the growth rate of double-cropped areas was substantially higher (about 1.0%). The conversion of single cropland to double cropland is the primary reason for the increasing rate. However, from 2000 to 2010, single cropping did not decrease while double cropping increased, primarily as a result of the conversion of accreted land to single cropland and also single cropland to double cropland (Fig. 4). Islam *et al*. (2016) reported that annual increase in single and double cropland during 1989-2010 was 0.91 and 0.48%, respectively, in other location of the same agro-ecological region.

Driving force of land conversion

Focus group discussion (FGD) indicated the factors that caused land use to shift from one category to another. The main reasons for shifting from cropland to settlements include increasing population pressure, and housing

Table 5. Area and annual change of double- and single-cropped land of Subarnchar in 1989-2019 periods

LULC types	Area (ha)				Annual change (%)			
	1989	2000	2010	2019	1989-2000	2000-2010	2010-2019	1989-2019
Double cropping	6321	7100	11897	15941	0.16	1.06	1.00	0.71
	(14.0)	(15.7)	(26.4)	(35.3)				
Single cropping	20045	18417	19618	13064	-0.33	0.27	-1.61	-0.52
	(44.4)	(40.8)	(43.5)	(29.0)				

The values in parenthesis indicate the per cent conversion of the total land

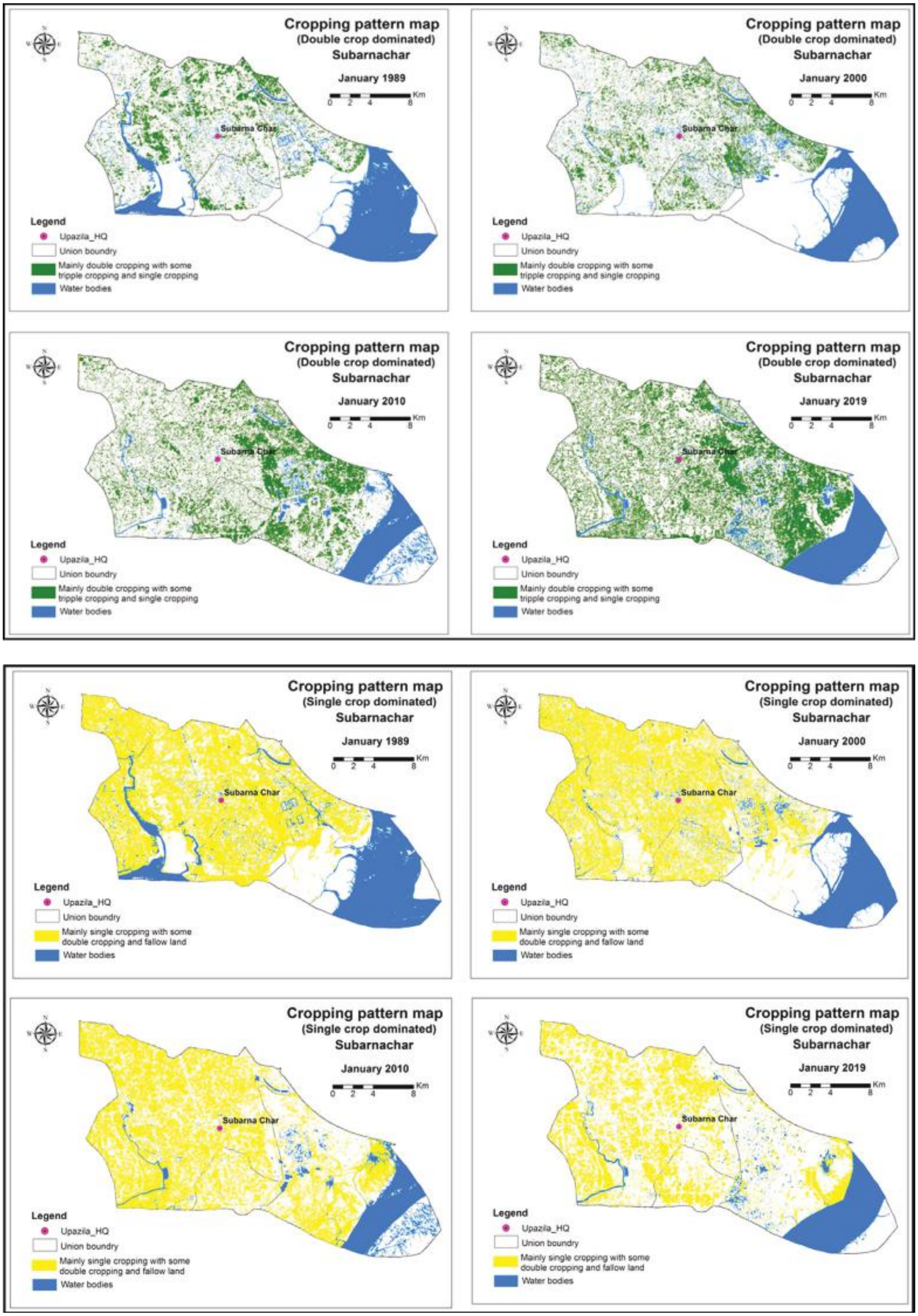

Fig. 4. Trend of changing double crop and single crop dominated area.

demand with adverse effects of abiotic stresses such as salinity, waterlogging and fluctuating market prices (Table 6). The main driving force behind the shifting of mangrove forests to settlements was the need for accommodation for the growing population. People are displaced from their homes due to river erosion, and they move largely to mangrove forests, which locals consider stable land and somewhat safe to live in. Rai *et al.* (2017) described a general global trend involving the conversion of cropland and forest land to urban areas. The primary driver behind the conversion of mangrove forests to cropland was the need for food due to the rising population. Farmers' ability to convert mangrove forests into cropland was further aided by development of marketing facilities and the accessibility of agricultural inputs. The mangrove forest, despite having a much higher economic value than crop production, is reportedly being turned into cropland (Chauhan *et al.,* 2017).

One of the main reasons for the conversion of single cropland to double cropland was the increase in food demand due to positive population growth. The transition from single cropland to double cropland, however, was sped up by the introduction of new crops, the development of high-yielding varieties, and the accessibility of agricultural inputs such as seeds, fertilizers, and agrochemicals. Such land-use transformations were facilitated

Table 6. Driving force scores for LULC change in Subarnachar

Driving forces*		Score (out of 10)	Standard deviation
From cropland to settlement	Increased population pressure	8.39	1.85
	Increased demand of housing	8.06	2.48
	Land degradation due to salinity/waterlogging	5.78	2.71
	Uncertainty of agricultural production and price	4.67	3.27
From mangrove forest to settlement	Increased population pressure	8.94	1.39
	Increased demand of housing	8.00	1.78
	River bank erosion	4.22	3.34
	Safe for dwelling (stable land)	3.72	2.30
From mangrove forest to cropland	Increased demand of food/cropland	8.27	2.25
	Increased population pressure	8.20	2.08
	Marketing facilities developed	5.73	2.49
	Availability of agricultural inputs	5.33	1.63
From single cropland to double cropland	Increased demand of food	8.00	2.76
	Increased population pressure	7.33	2.87
	Development of crop variety	7.33	1.87
	Availability of agricultural inputs	7.08	2.11
	Favorable govt. policy	5.83	2.66

*Listed only the main drivers of various land use transformations by government policies, including subsidies for agricultural inputs that improved crop production. The construction of flood-protected dams, the reduction of soil and water salinity, and the expansion of marketing facilities encouraged farmers to convert from single cropping to double cropping. Mechanization and expanded irrigation supported this transformation. Multi-cropping or double cropping strategies are most commonly used to intensify cropping systems (Borchers *et al*., 2014).

Change in cropping patterns

During 2018–2019, the major cropping pattern was Watermelon-Fallow-T. Aman (52.3%), closely followed by Soybean-Fallow-T. Aman (50.0%). Other dominant cropping patterns were Boro-Fallow-T. Aman and Groundnut-Fallow -T. Aman (Table 7). In contrast, the major cropping pattern during the 2000–2005 periods was Soybean- Fallow - T. Aman (40.9%), followed by Groundnut- Fallow - T. Aman (36.4%). Other dominant cropping patterns were Boro- Fallow - T. Aman and mungbean- Fallow - T. Aman. Results indicate that watermelon is a newly introduced crop in the study area, whereas soybean has been a predominantly cultivated crop for a long time in the area. More interestingly, 22.7% of farmers practiced only T. Aman in their cropping patterns during 2000–2005, which reduced to 2.3% during 2018–2019. It indicates that a significant amount of land has been transformed to double cropping from single cropping (Fallow- Fallow - T. Aman). The cropping patterns have generally changed in 68.2% of the land area. Floodplain aquaculture is now practiced in some areas in the dry season in combination with Boro rice.

Conclusion

The study quantifies land use and land cover (LULC) changes and analyses the rate of land conversion from one use to another, with the loss of mangrove forests and water bodies followed by a rise in cropland. Erosion and accretion, a dynamic process of land use change in the area, results in periodic LULC changes anomalies. Population pressure and

Table 7. Major cropping patterns followed by the farmers during 2000-2005 and 2018-2019

Sl.	2000-2005	% farmers	2018-2019	% farmers
1.	Soybean-Fallow-T. Aman	40.9	Watermelon-Fallow-T. Aman	52.3
2.	Groundnut-Fallow-T. Aman	36.4	Soybean-Fallow- T. Aman	50.0
3.	Fallow-Fallow-T. Aman	22.7	Boro-Fallow- T. Aman	27.3
4.	Mungbean-Fallow-T. Aman	18.2	Groundnut-Fallow- T. Aman	27.3
5.	Sweet potato-Fallow-T. Aman	11.4	Bean-Fallow- T. Aman	9.1
6.	Boro-Fallow-Fallow	6.8	Boro-Fish-Fish	6.8
7.	Chickpea-Fallow-T. Aman	6.8	Mungbean-Fallow- T. Aman	4.5
8.	Soybean-Aus-T. Aman	4.5	Chickpea-Fallow- T. Aman	4.5
9.	Groundnut-Aus-T Aman	4.5	Sweet potato-Fallow-T. Aman	2.3
10.	Chili-Fallow-T. Aman	2.3	Fallow-Fallow- T. Aman	2.3

Source: Questionnaire survey with the farmers human intervention contributed to the LULC dynamics, where a rapid increase of settlement and conversion of single cropland to double cropland is most common. The cropping systems and crop production scenarios experienced remarkable alterations because of all these changes.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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