Agricultural land availability in Bangladesh

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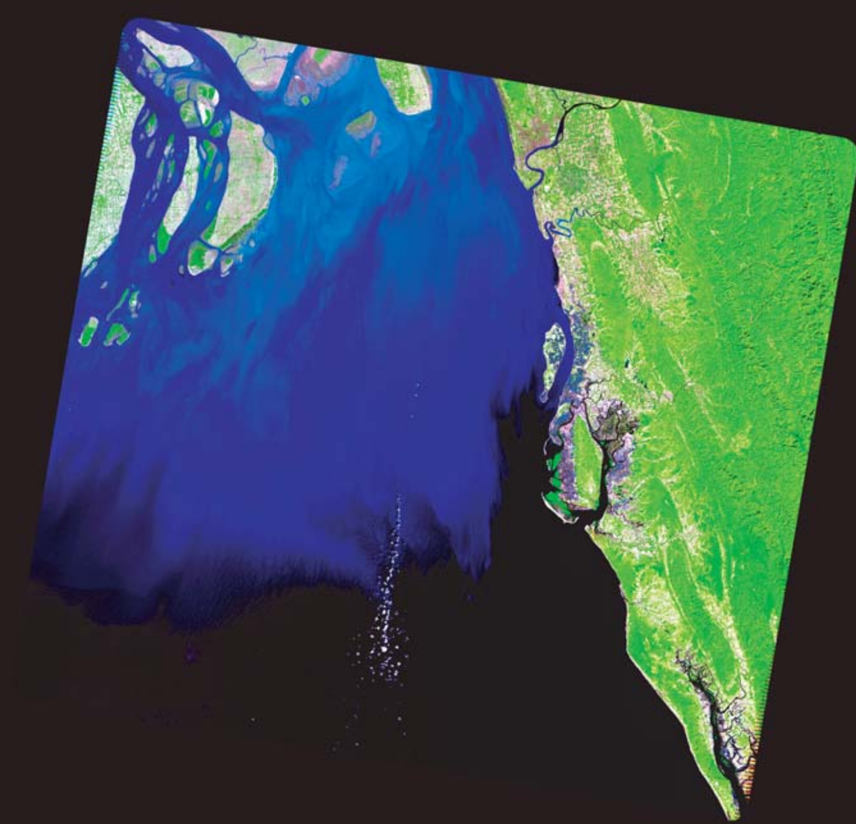

Landsat satellite imagery of path 136 and row 045 during December 2009, showing coastal ecosystem of Bangladesh

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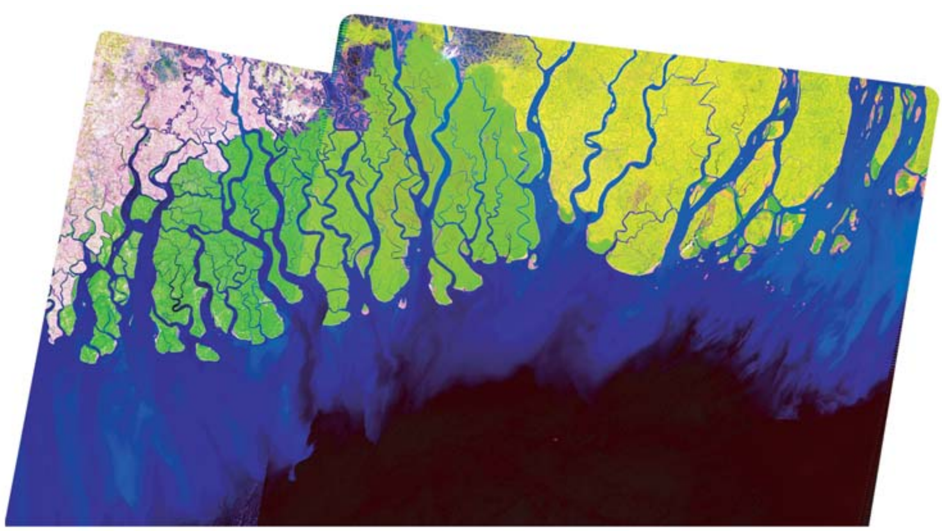

Landsat satellite imagery of path 137-138 and row 045 during 2010, showing Sundarbans mangrove ecosystem (source: http://glovis.usgs.gov/, accessed on January 2012)

EXECUTIVE SUMMARY

Bangladesh is principally an agricultural country, characterized by rice paddy agriculture dominated landscapes. So, land resource is the major asset contributing wealth and livelihood in rural areas, although land-man ratio is very low in the world, estimated to be 0.06 hectares (ha) per person (FAO, 2013). However, data on total available arable lands of the country is not conclusive and seem to be varying as suggested by different organizations. For example, the Soil Resource Development Institute, SRDI (2010) was reported a total 9.5 million ha of agriculture land compared to an estimate of 8.52 million ha by the Bangladesh Bureau of Statistics, BBS (2011) and 9.1 million ha by the Department of Agricultural Extension, DAE (2011). This difference in data is probably due to the methodology and time frame followed by the organizations to complete the survey. Statistics on the conversion rate of agricultural lands to non-agricultural activities also differ among the studies, i.e. an annual change of about 1% (UNDP 2003), 0.13% (Rahman and Hasan, 2003) or 0.27% was reported between the years of 1976-77 and 2010-11 (BBS 2011), however, this sort of information does not seem to have a solid scientific basis. Rahman (2010) estimated that the overall land area was increased 4% during 1948-2006 due to land accretion in coastal areas, i.e. reclamation of char lands, whereas 0.1% cultivable land was annually transformed to housing, road and industrial infrastructures in the same period. In a similar study, CEGIS (2008) reported that 156,780ha land were lost due to erosion along the Jamuna, Ganges and Padma rivers, and at the same time 45,520ha areas were accreted during 1973-2008.

However, the inventory, monitoring and surveys of land-use/cover change, especially in conventional way (e.g. extensive field survey) are very expensive and time consuming effort. As alternative, remote sensing satellite imagery that records data of the entire earth surface on a periodic basis can be used to measure the changes in land use patterns, including the cultivation period of paddy rice, even in remote areas. Incidentally, data on the trends of available agricultural lands is most important requirement for any land use planning (LUP) related to farming and food security. In this connection, the geographic information system (GIS), which is an excellent tool for data integration, analysis and visualization, may play a key role to support LUP approaches and natural resource management. The research aim is to detect land cover changes of Bangladesh using satellite remote sensing technology. More specifically the research objectives are to a) quantify how the availability of agricultural land has evolved since independence; b) quantify how the availability and allocation of land to

various uses has evolved at national and sub-national levels since independence; and c) quantify land lost and gained due to various factors.

This study was conducted through hybrid interpretation of satellite imagery, compare with secondary information and ground truthing (i.e. the process of verifying the remotely acquired data physically) in selected sites. A total of 14 Landsat scenes of path 135-139 and row 42-46 cover the entire Bangladesh. Thus, three sets of Landsat imagery (total 42 scenes) for the year of 1976, 2000 and 2010 were used in this study to identify land cover types and to quantify spatial changes. The 1976 mapping/images served as the 'base-year' for land cover mapping due to the accessibility on country-wide (14 scenes) satellite imagery right after the independence. Whereas, the year 2000 was chosen as the middle of land cover changes due to an increasing trend in annual growth rate (GDP) that maximized the rate of conversion of agricultural lands to non-agricultural lands. The satellite imageries were digitally interpreted with unsupervised and supervised classification to quantify total land area of the country with classifications of agriculture and non-agriculture lands, and also to measure the changes of agriculture land to other land use activities. Image analysis was done with ENVI software (version 4.3; developed by Research Systems, Inc., USA) and the ArcGIS software (version 9.3; developed by Environmental Systems Research Institute, USA) was used to digitize and analyze all the classified and other necessary maps. The required secondary data were taken from the Reconnaissance Soil Survey Report (RSS), the Semi-Detailed Soil Survey (known as 'Upazila/Thana Vumi Nirdeshika' or 'Land and Soil Resources Utilization Guide of Upazila/Thana'), the Detailed Soil Survey Reports, and various land capability and land use maps and reports produced by SRDI. The yearbook of Agricultural Statistics of Bangladesh published by BBS was also used in the study.

Results of this study indicated that the total area of Bangladesh has risen in the last few decades, i.e. an increase is noted from 144,873km^2 in 1976 to 145,306 and 145,778km^2 over the years of 2000 and 2010 respectively. The overall gain of land is 90,512ha primarily due to accreted lands in the southern coastal zone. The land resource of the country is divided into two categories, i.e. agriculture lands and non-agriculture lands. The agriculture lands include croplands, homestead and natural forests, mangrove forests, rivers, Kaptai lake, beels and haors, aquaculture farms, tea gardens/estates and saltpans. While, non-agriculture lands include rural settlements, urban and industrial areas, and accreted lands. However, a declining trend was observed for the total agricultural lands of the country, i.e. a decrease is noted from 91.83% in 1976 to 87.69% and 83.53% over the years of 2000 and 2010 respectively. A total of 561,380ha agricultural lands were decreased during 1976-2000 and this figure was increased to 565,370ha during 2000-2010. Yearly average loss of agriculture lands were 23,391ha and 56,537ha during 1976-2000 and 2000-2010 respectively. This indicates that agriculture lands were transforming to other activities in higher rates between the years of 2000 and 2010. The non-agriculture lands of the country were 8.17%, 12.31% and 16.47% during 1976, 2000 and 2010 respectively. The extent of non-agriculture lands were increased by 2.13% and 3.43% during 1976-2000 and 2000-2010 respectively. Annual land loss from crop agriculture is 68,700ha, where land gained in rural settlement, urban and industry, and aquaculture is 30,809ha, 4,012ha and 3,216ha respectively during 2000-2010. The geo-spatial model outputs were evaluated against field measurements/data and the accuracy level was 92%, indicating a good consistency with existing land use patterns of the country.

The results of the analysis produce science-based data on the availability of agricultural land including trends of land cover change since independence. This analysis can be used as a foundation for further research on the connection among human actions, spatial patterns in the landscape, and ecosystem functions. Better understanding of how socioeconomic and political processes impact the spatial patterns in the landscape may improve analysis and addressing of issues such as farming, housing, urbanization and habitat protection for particular species of plants and animals. This improved understanding will lead to better landscape management policies.

1. Introduction

Agriculture has a strategic function, because it is the main food supplier for the people in Bangladesh. Different estimation methods of agricultural production provide various data and information, so their reliability is questionable. One source of error lies in information on acreage of agriculture fields, which results in calculations of planting area and crop yields. According to official data from Soil Resources Development Institute (Land and Soil Statistical Appraisal Book of Bangladesh, SRDI, 2010) agriculture land covers 9.5 million ha in Bangladesh. Conversely, Bangladesh Bureau of Statistics (BBS) and Department of Agriculture Extension (DAE) stated about 9.1 million ha agriculture land in the Krishi (agriculture) Diary in 2011. The Yearbook of Agricultural Statistics of Bangladesh (BBS, 2011) mentioned the availability of cultivable land during 1976-77 to 2010-11 (Table 1.1).

Table 1.1 Availability of agricultural land during 1976-77 to 2010-11 (source: BBS, 2011).

Year	Land area of Bangladesh (million ha)	Cultivable land (million ha)	% cultivable land
1976-77	14.28	9.39	65.75
1980-81	14.29	9.38	65.64
1985-86	14.48	9.44	65.19
1990-91	14.84	9.72	65.50
1995-96	14.84	8.72	58.76
2000-01	14.85	8.40	56.57
2005-06	14.84	8.42	56.74
2010-11	14.84	8.52	57.41

Note: Agricultural land is the summation of cropped land, current fallow and culturable waste.

The difference between SRDI and DAE reports in the availability of agricultural land is about 0.4 million hectares, which may be due to the data collection techniques in both the institutions. SRDI generates data through aerial photographs analysis and ground truthing (soil survey) along with reviewing secondary information and maps such as the Reconnaissance Soil Survey (RSS) reports, topographic maps and DLR maps within a survey cycle of about 10 years. On the other hand, DAE collect information through their Sub-Assistant Agriculture Officers posted in every union of the country and the time period of survey is very short. BBS collects data through Upazila/Thana Statistical Officer in prescribed forms and questionnaires. After checking and compiling those data at regional office they are sent to the Agricultural Wing of BBS Head Quarter. BBS also uses secondary data collected from other organizations such as the Department of Forestry, Department of Fisheries, Bangladesh Meteorological Department (BMD), Bangladesh Agricultural Development Corporation (BADC), Department of Marketing and the DAE.

The shifting rate of agricultural land to non-agricultural use is said to be about 1% per year (Palning Commission, 2009), which is alarming in respect to the total crop production and food security in Bangladesh (Rahman and Hasan, 2003). This rate of shifting however does not seem to have a sound scientific basis. In fact, if this data were correct, at least one quarter of the country's agricultural land would have been lost since independence. In this connection, SRDI estimated approximately 0.13% land transfer from agriculture to non-agriculture sector per year during the period 1963 to 1983 (Rahman and Hasan, 2003). It is likely that the shifting rate may be much faster during the 2000s till date, because of faster economic growth and the infrastructure development implied.

Agricultural land is declined about 0.26% annually from 1976-77 to 2010-11 (34 years average), 0.42% annually from 1976-77 to 2000-01 (25 years average), 0.75% annually from 1983-84 to 1993-94 (10 years average) and 0.40% annually from 1993-1994 to 2003-2004 (10 years average). There is slight increase of agricultural land from 2000-2001 to 2010-2011 (average 0.14%) (Table-1.1). Rahman (2010) reported the overall land area of the country increased 4% during 1948 to 2006 due to reclamation of char lands and the cultivable land declined 0.10% annually, assuming transfer to housing, road and industrial infrastructures. Moreover, CEGIS (2008) estimated total land eroded 156,780ha and accreted 45,520ha along the rivers of Jamuna, Ganges and Padma during 1973 to 2008 (CEGIS, 2008). In recent years, significant advances have been made in remote sensing of Bangladesh, especially in mapping shrimp farming and agricultural areas (Shahid et al., 1992), detection of changes in Sunderbans mangrove forest (Islam et al., 1997), shrimp-farming development of coastal zone (Hossain et al., 2001), mapping suitable areas for saltpan development (Hossain et al., 2003a), mangrove afforestation (Hossain et al., 2003b), tilapia farming areas

(Hossain et al., 2007), assessing suitable carp-farming areas (Hossain et al., 2009; Salam et al., 2005) and giant prawn farming area (Hossain and Das, 2010). Considering these works, the present initiative is unique in the context of land cover mapping in Bangladesh.

As the world population increases and the global food supply-demand balance may become less stable, food production systems are now an important policy issue as a subject of intense research. Careful assessment of the changing agricultural system and environment is an essential first step to understand current and future food security issues. Thus, Bangladesh needs to collect its own intelligence about agricultural systems to develop a comprehensive strategy in order to ensure secure food supplies and maintain peace and stability. The land resource inventory, monitoring and updating of land use in the conventional way through a field survey is very expensive and the existing methods used to perform this work requires comparatively longer time. Remote sensing technology that records data periodically of the earth surface can be used as an alternative to support of field research mainly to measure the changes in land use, including the planting period in the paddy field. Hence, coverage of satellite data provides information of agricultural land even in remote areas.

For a sustainable crop production to ensure food security, land use planning (LUP) approach requires more and more data integration, multi-disciplinary and complex analysis, and need faster or more precise information. Data on the trends in the availability of agricultural land is most important requirement for any land use planning related to agriculture and food security. Geographic information system (GIS), which has strong capacity in data integration, analysis and visualization, becomes the main tool to support LUP approaches.

2. Objectives

The objective of this study is to quantify how the availability of agricultural land and other land use patterns has evolved since independence with land lost and gained due to various factors. The research questions are as follows:

a) What was the total area of agriculture land with geo-spatial distribution in Bangladesh during 1976, 2000 and 2010?

b) What was the allocation of the total land to various uses at national and sub-national level in Bangladesh during 1976, 2000 and 2010?

c) What are the trends of land use change between agriculture and non-agriculture practices over time (1976-2010)?

d) How much land is gained or lost due to various factors like erosion and accretion.

e) How the research outputs contribute in policy making?

3. Study Area

Present study was covered the administrative boundary of the People's Republic of Bangladesh. The geographical location is between latitude 20°45 and 27°00 N and longitude 88°00 and 92°45 E (Figure 3.1). A total of 14 scenes of Landsat MSS/TM/ETM imagery of path 135-139 and row 42-46 covering the entire Bangladesh (Figure 3.2) have been digitally analyzed. Three sets of satellite imagery represent the year of 1976, 2000 and 2010 were used in this study. Most of the images of January-March were used as inputs for the classification. This inclusion assisted in reducing attribution difficulties related to crop calendars.

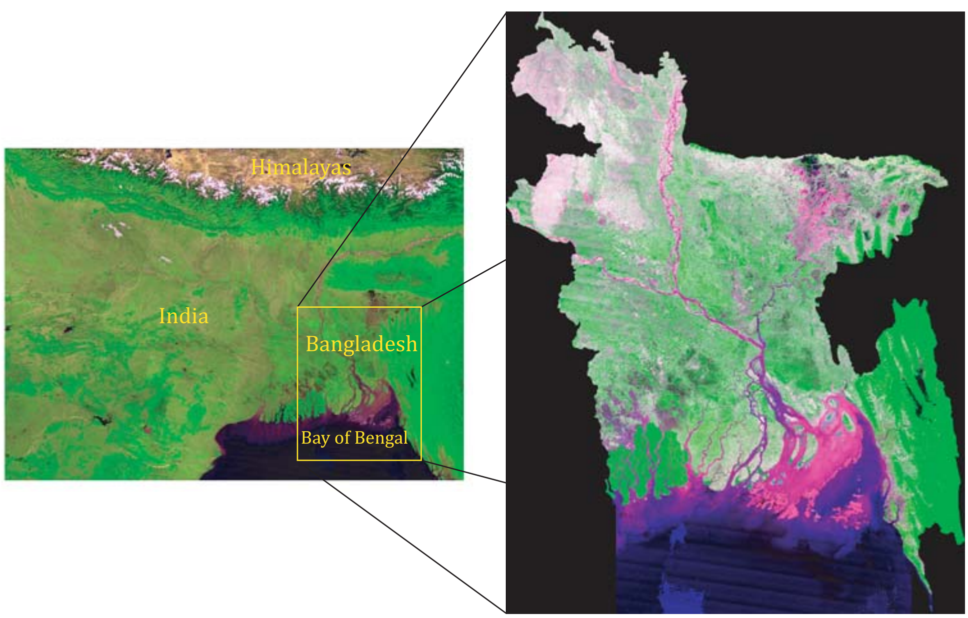

Figure 3.1 MODIS image of December 2010 shows geographical location of Bangladesh

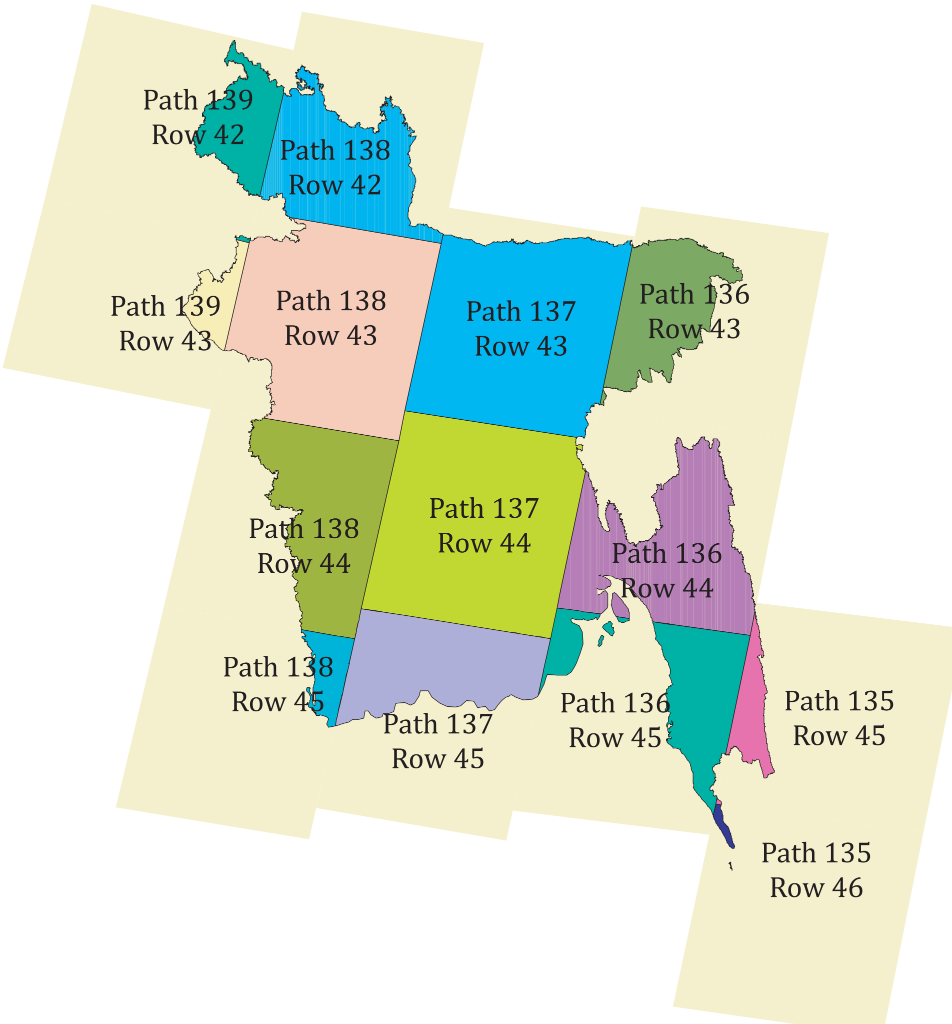

Figure 3.2 Path and row map of Landsat satellite over Bangladesh

4. Methodology

The study has been conducted through digital interpretation of satellite imagery, secondary information and ground truthing in selected locations of Bangladesh. The detail methodology of the digital interpretation of satellite image is presented in Figure 4.1.

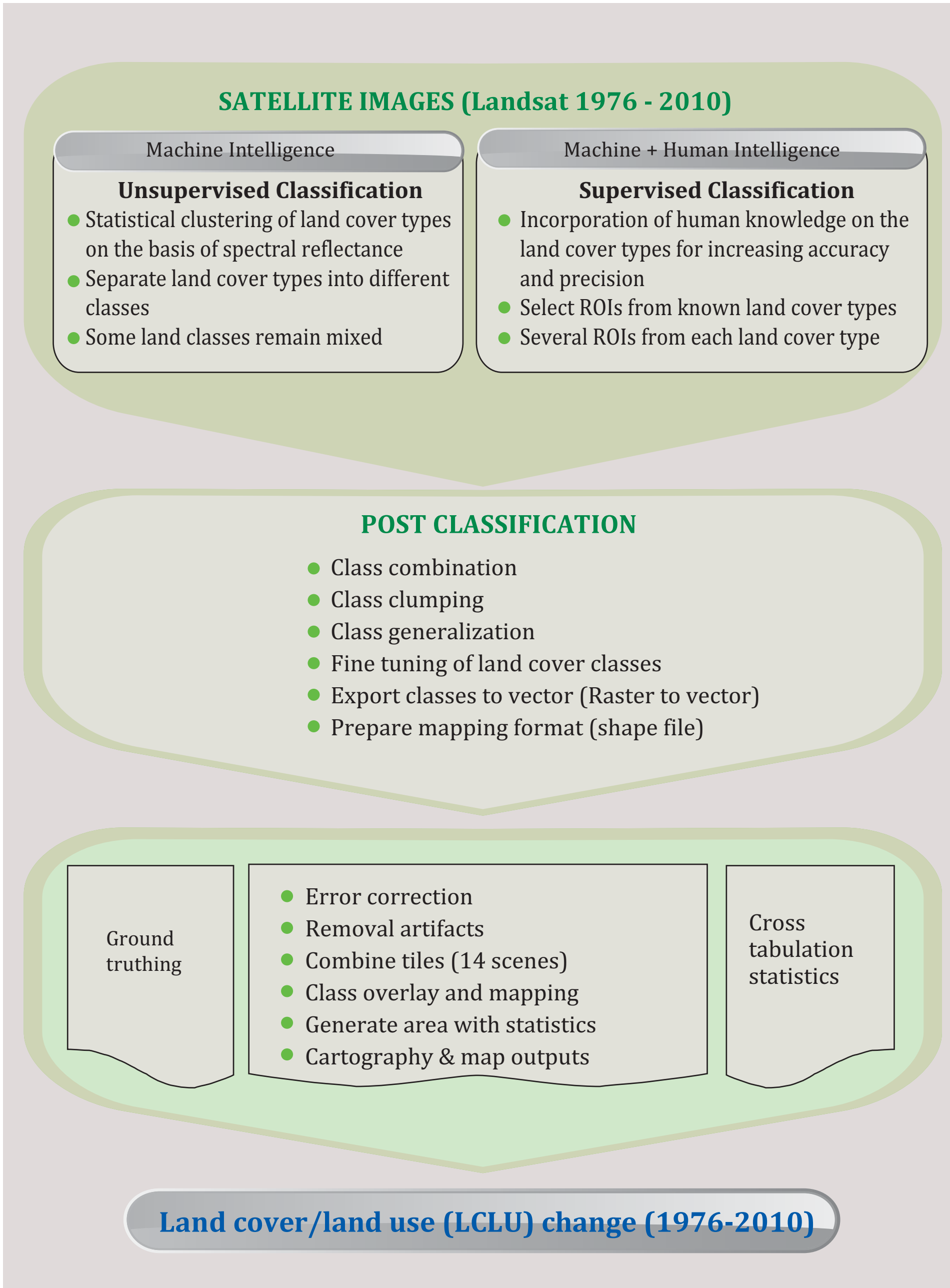

Figure 4.1 Hybrid interpretation of satellite image for land cover/land use classification in Bangladesh

4.1. Digital interpretation of satellite image

Space-borne satellite imageries (Landsat, MSS/TM/ETM) available for 1976, 2000 and 2010 were used to identify the types of land available through out the country and quantify the changes with geographical distribution of agricultural and non-agricultural land. More specifically, satellite imageries were digitally interpreted with unsupervised[1] and supervised[2] classification to quantify total land area of the country with the classification of agricultural and non-agricultural lands as well as measure the changes of agricultural land to other land use patterns since independence. Moreover, land lost due to river erosion, salinity intrusion and water logging areas were determined with geo-referenced maps, where land reclaimed from river and coastal sedimentation (e.g. char lands) were also mapped and measured. Qualitative and quantitative surveys as well as satellite imagery and GIS techniques were used for interlinking spatial and relevant data to get the outputs. Remote sensing image analysis was done using ENVI (version 4.3) developed by Research Systems, Inc, USA. ArcGIS software (version 9.3) developed by Environmental Systems Research Institute, USA applies to digitize and analyze all the classified and other necessary maps.

4.2. Secondary information

The relevant secondary data available in the Reconnaissance Soil Survey Report (RSS), the Semi-Detailed Soil Survey (end product as Upazila/Thana Nirdeshika or Land and Soil Resources Utilization Guide), Detailed Soil Survey Reports and various land capability and land use maps and reports produced by SRDI were used to validate the present database. Moreover, Bangladesh Bureau of Statistics (BBS) publications, such as Handbook of Agricultural Statistics of Bangladesh and Yearbook of Agricultural Statistics of Bangladesh have also used to compare outputs of satellite image interpretation. Besides, other relevant data sources i.e. Bangladesh Water Development Board (BWDB), Water Resources Planning Organization (WARPO), Bangladesh Inland Water Transport Authority (BIWTA), Bangladesh Meteorological Department (BMD), Space Research and Remote Sensing Organization (SPARRSO), Centre for Environmental and Geographic Information Services (CEGIS) and different universities have used to verify satellite image classification.

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1. Use of information from the image itself to identify spectral clusters, which are interpreted as classes

2. On the basis of Region of Interest (ROIs), where the training areas (collect during field investigation) are regions of terrain with known properties or characteristics

4.3. Ground truthing

The land cover change database created from the digital interpretation of satellite imagery and manual interpretation of aerial photographs were verified through ground survey in the randomly selected sites with the help of SRDI Field Offices. Moreover, ground truthing (verification) were done by the research team using GPS and available maps. The relevant secondary data collected from various sources were also useful for triangulation of the satellite image classification.

4.4. Cross-tabulation for error matrix analysis

The classification error matrix for the Landsat image was conducted to quantify the incorrectly classified sites, based on field verification sites. The Kappa Index of Agreement (KIA) was generated to determine the degree of agreement between the two outputs. Its values range from -1 to +1 after adjustment for chance agreement. A value of 1 indicated that the two outputs were in perfect agreement (no change has occurred), whereas if the two outputs were completely different from one another, then the Kappa value was -1. The Kappa (K) and Kendall's tau (T) coefficients were determined using SPSS software (version 11.5) to indicate the level of agreement between digitally interpreted land and existing land area of the country.

4.5. Land cover maps

The land cover mapping was carried out using the FAO Land Cover Classification System (LCCS) and the major land use patterns were extracted from satellite images using digital interpretation techniques. Practical operational definition of land categories are given in Table 4.1.

Table 4.1 Practical operational definition of land categories applicable for moderate resolution (30 m) satellite images

Land categories	Practical operational definition
Cropland	Cultivated crops i.e. paddy rice, field grown vegetable and other crops; seasonal (detected by examining seasonal pattern using multi-temporal images), orchard, wet meadow or pasture land, fellow land
Hill forest	Deciduous (seasonal) and evergreen (permanent) forest vegetation; detected by high NDVI and location in hilly terrain
Sal forest	High seasonal NDVI (deciduous) and confirmed by specific map location, Modhupur tract and Barind tract
Mangrove forest	Year-round high NDVI, located along the coastal belt and tidal flats, and in designated reserved forest

Aquaculture	Ponds, ditches, excavated wetlands for traditional fish farming detected by water logging and specific visual patterns
Coastal salt pan	Solar extraction of sea salt, located along the southeast coastal belt and tidal flats
Rivers and estuaries	Water body generally highly turbid and showing linearity
Flood plains	The extent of land flooded by river channels in high flow seasons due to over-bank flooding; characterized by temporary to seasonal water logging (except hills, Akhaura terrace, Modhupur tract and Barind tract)
Kaptai Lake	Clear deep water body created by drowning of valley; confirmed by shape of mountain valleys
Beel, haor	Water body surrounding rural settlements and perennial vegetation; seasonal expansion and contraction; confirmed by map locations, saucer shaped water bodies in the north-east regions
Urban centers	Built-up and paved areas characterized by high reflectivity, high surface temperature, very low vegetation and confirmed by geographic locations (cities, districts towns, rural townships)
Rural settlement	Concentration of perennial vegetation including orchards and trees, homestead gardens, small ponds and occasional rooftops connected by rural networks
Road network	Network of national highways, wide city streets, district highways, embankment cum roads and all other roads connecting townships: not extracted from image but superimposed from existing GIS data
Industrial zone	Characteristics similar to urban centers and situated in urban or peri-urban locations detectable by large civil structures; includes EPZs, industrials areas
Accreted coastal land / char	Recently formed coastal sandbars, mudflats and upstream chars showing active geomorphological changes over time; sometimes succeeded by vegetation
Braided river channel	Dynamically active point bars and mid-channel bars inside wide river channels generally separated by deeper active channels
Erosion-prone zone	Shore land showing active geomorphological changes over time characterize by recent or ongoing loss of land to the river or sea
Others	Land types not falling in any of the above classe

NDVI = Normalized Difference Vegetation Index

4.6. Survey and monitoring

The causes of land use change particularly transfer of agricultural land to non-agricultural land as well as identification of most potential lands those should be keep for agriculture were addressed by survey and monitoring with the help of focus group discussions (FGD), semi-structured interview and participatory field visit. The District Officer of SRDI, Co-Investigators and the Research Associates conducted the interviews. To produce useable outputs, observations were recorded as drawings and notes. A set of guidelines (checklist of topics) have been developed for the interviews in order to get the most complete information and to keep the team members on the same course.

4.7. Cartography and mapping

The outputs are presented in the form of digital maps of classified satellite image in GIS context with ground truthing and cross-tabulation validation. The GIS-based maps contained all the user-friendly information such as legend, direction and scale. Maps are interpreted using simple and understandable language for wider acceptance to the policy makers, extension managers and researchers. In addition, statistical tables and graphs are also generated using Microsoft Excel and/or SPSS software. The integration of map, graph, table and text is the innovation of this interdisciplinary research team from the recognized universities and research organization of Bangladesh. Landsat satellite image shows the Meghna river systems with neghbouring areas (Figure 4.2).

Figure 4.2 Landsat satellite imagery of path 137 and row 044 during November 2009 (source: http://glovis.usgs.gov/, accessed on January 2012)

5. Results and Discussion

5.1. Land use and land cover (LULC) at national level

The area of Bangladesh represents 144,873, 145,306 and 145,778km^2 during 1976, 2000 and 2010 respectively (Table 5.1.1). Overall land gain was 905km^2 (90,512ha) during 1976 to 2010 due to accretion in the southern coastal zone of Bangladesh. The land cover of the country was divided into two categories i.e. agricultural land and non-agricultural land.

Table 5.1.1 Total land area of Bangladesh, based on Landsat satellite data

Land cover type	1976		2000		2010	
	Area (ha)	% of total	Area (ha)	% of total	Area (ha)	% of total
Agricultural land	13,303,654	91.83	12,742,274	87.69	12,176,904	83.53
Non-agricultural land	1,183,605	8.17	1,788,307	12.31	2,400,867	16.47
Total	14,487,259	100.0	14,530,581	100.0	14,577,771	100.0

5.1.1. Trend of agricultural land availability

Agricultural land included cropland, forest, mangrove forest, river, lake, beel and haor, aquaculture, tea estate and saltpan. The agricultural land was 13,303,654ha in 1976 which constituted 91.83% of the country's total land area. The agricultural land decreased to 12,742,274ha in 2000 with yearly loss 23,391ha and further declined to 12,176,904ha in 2010 with yearly loss 56,537ha. Total agricultural land reduced 1,126,750ha during the past 34 years (1976-2010) with yearly average loss 33,140ha. Data analysis reveals that rapid decreasing trend of agricultural land found during the period of 2000-2010. Average yearly agricultural land lost were 0.18%, 0.44% and 0.25% during 1976-2000, 2000-2010 and 1976-2010 respectively (Table 5.1.2). Yearly average changes of major land cover types during 1976-2000 and 2000-2010 are shown in Figure 5.1.1.

Table 5.1.2 An analysis of major land cover types in Bangladesh during 1976-2010, derived from Landsat imagery

Land cover	Area (1976)		Area (2000)		Area (2010)		Yearly average change (ha)			Yearly average change (%)		
	ha	%	ha	%	ha	%	1976-2000	2000-2010	1976-2010	1976-2000	2000-2010	1976-2010
Agriculture	**13,303,654**	**91.83**	**12,742,274**	**87.69**	**12,176,904**	**83.53**	**-23,391**	**-56,537**	**-33,140**	**-0.17**	**-0.42**	**-0.24**
Cropland	9,761,450	67.38	9,439,541	64.96	8,751,937	60.04	-13,413	-68,760	-29,692	-0.10	-0.49	-0.22
Forest	1,754,917	12.11	1,311,121	9.02	1,434,136	9.84	-18,492	12,301	-9,435	-0.13	0.08	-0.07
Mangrove	452,444	3.12	486,791	3.35	441,455	3.03	1,431	-4,534	-323	0.01	-0.03	-0.003
River	911,819	6.29	888,441	6.11	939,073	6.44	-974	5,063	802	-0.01	0.03	0.004
Lake	50,829	0.35	58,261	0.40	51,739	0.35	310	-652	27	0.002	-0.005	0.0001
Beel-haor	239,977	1.66	251,774	1.73	250,727	1.72	492	-105	316	0.003	-0.001	0.002
Aquaculture	582	0.004	143,506	0.99	175,663	1.21	5,955	3,216	5,149	0.04	0.02	0.04
Tea	119,847	0.83	138,533	0.95	96,152	0.66	779	-4,238	-697	0.01	-0.03	-0.005
Salt pan	11,789	0.08	24,306	0.17	36,022	0.25	522	1,172	713	0.004	0.01	0.005
Non-agriculture	**1,183,605**	**8.17**	**1,788,307**	**12.31**	**2,400,867**	**16.47**	**25,196**	**61,256**	**35,802**	**0.17**	**0.42**	**0.24**
Rural settlement	885,637	6.11	1,458,031	10.03	1,766,123	12.12	23,850	30,809	25,897	0.16	0.21	0.18
Urban & Industrial	26,799	0.18	47,495	0.33	87,616	0.60	862	4,012	1,789	0.01	0.03	0.01
Accreted land	271169	1.87	282781	1.95	547128	3.75	484	26,435	8,116	0.003	0.18	0.06
Total	**15,670,865**	**108.17**	**16,318,888**	**112.31**	**16,978,638**	**116.47**	**27,001**	**65,975**	**38,464**	**0.17**	**0.42**	**0.24**

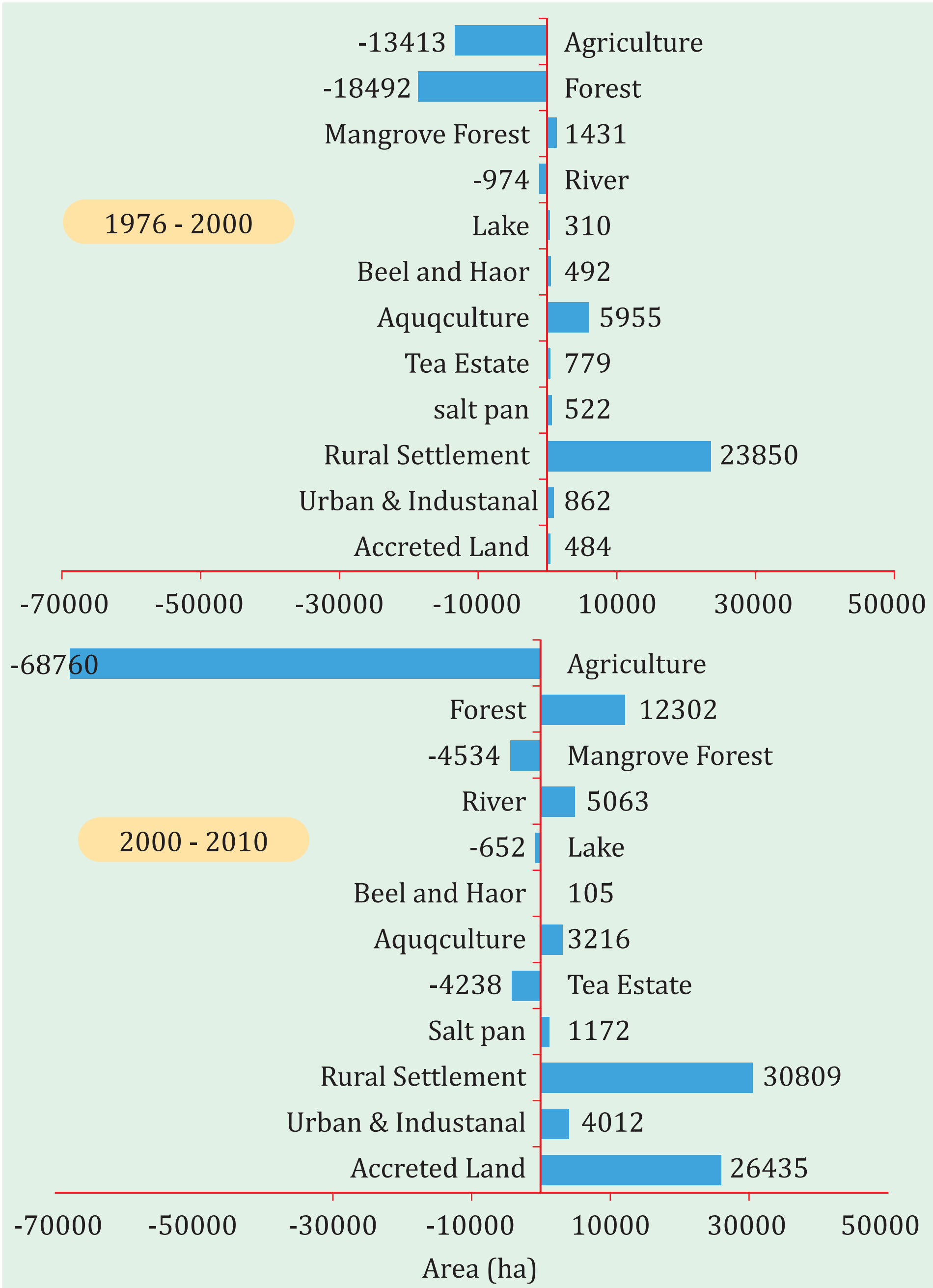

Figure 5.1.1 Annual loss and gain of different land cover types in Bangladesh during 1976-2000 and 2000-2010

5.1.1.1. Cropland

Cropland included land under cultivated, cultivable waste and current fallow. Total cropland was estimated 9,761,450ha, 9,439,541ha and 8,751,937ha in 1976, 2000 and 2010 corresponding to 67.38%, 64.96% and 60.04% of the total land area respectively (Table 5.1.2). This indicates that cropland decreased more rapidly during 2000-2010 compared to 1976-2000. Yearly average cropland decreased 13,413ha (0.14%) during 1976-2000, 68,760ha (0.73%) during 2000-2010 and 42,063ha (0.30%) during 1976-2010 (Table 5.1.2). Cropland shifting rate is alarming because food security is the main economic and political concern of Bangladesh. Geo-spatial extent of cropland cover maps of Bangladesh are given in Figure 5.1.2.

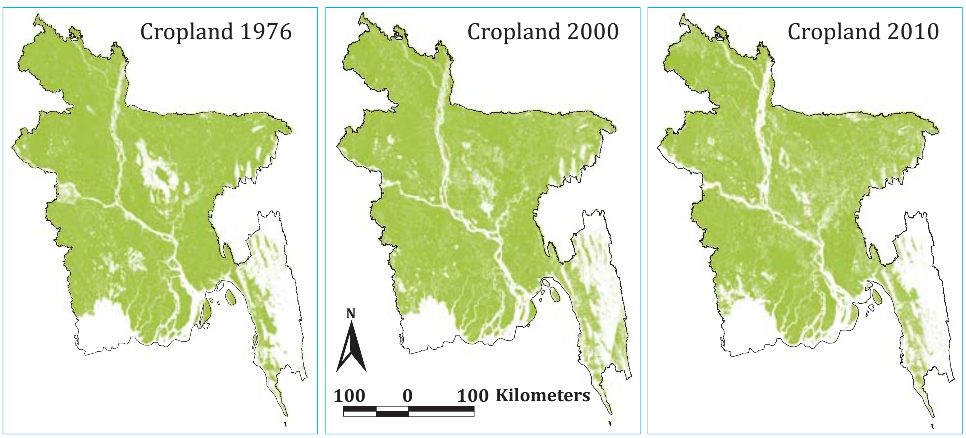

Figure 5.1.2 Cropland maps of Bangladesh in the years of 1976, 2000 and 2010, after satellite imagery interpretation

5.1.1.2. Forest

Forest land included deciduous/evergreen Hill forest and deciduous Sal forest of the country. Forest area was measured 1,754,917ha in 1976 representing 12.11% of the total land mass of the country. However, forest area decreased to 1,311,121ha (9.02%) in 2000 and then increased to 1,434,136ha (9.84%) in 2010. Yearly average decreasing trend of forest was 18,492ha (1.05%) and 13,366ha (0.76%) during 1976-2000 and 1976-2010 respectively. In contrary, yearly average increased 12,302ha (0.94%) during 2000-2010. FAO (2006) reported that forest cover in Bangladesh remained almost stable during the period of 1990-2005 and modified natural forest area was in decreasing trend, while tree plantations are increasing to offset the decrease. Forest cover maps of Bangladesh are shown in Figure 5.1.3.

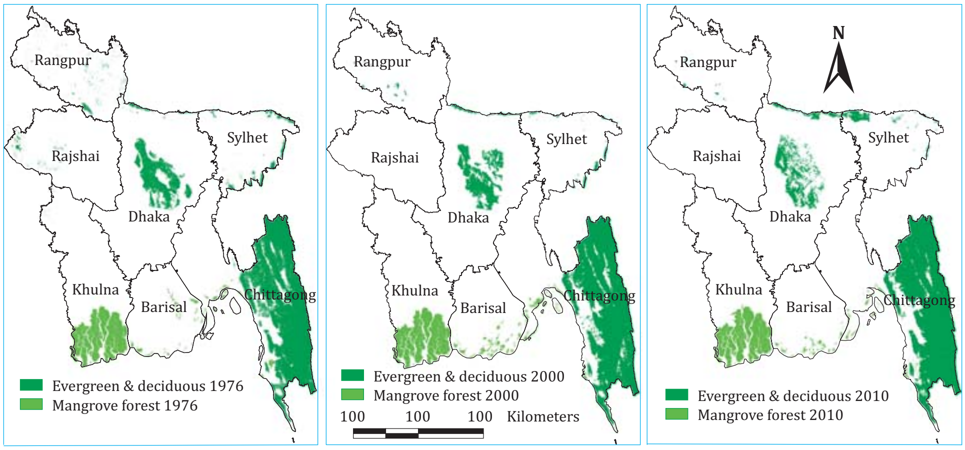

Figure 5.1.3 Landsat observations of forest maps of Bangladesh in the years of 1976, 2000 and 2010

5.1.1.3. Mangrove forest

Mangrove ecosystems are the salt tolerant forest located along the coastal belt and tidal flats. Mangrove forest was 452,444ha (3.12%) of the country in 1976. The present study revealed that mangrove increased to 486,791ha in 2000 with yearly average 1,431ha (3.35%) and thereafter decreased to 441,455ha in 2010 with yearly average 4,534ha (3.03%). It was estimated that mangrove increased 10,989ha during the past 34 years (1976-2010) with average yearly increasing of 323ha. The increasing trend of mangrove forest confirms the success of coastal afforestation programme. Yearly average mangrove forest increased 0.32% during 1976-2000, where the area decreased 0.93% during 2000-2010 and 0.10% during 1976-2010. Figure 5.1.4 shows mangrove forest maps of Bangladesh.

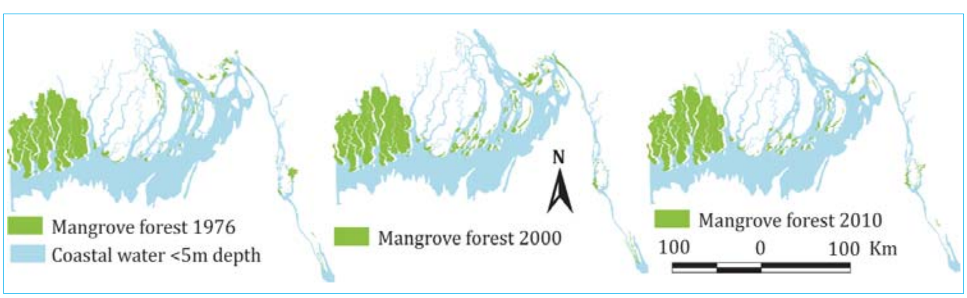

Figure 5.1.4 Maps of mangrove forests along the coast in 1976, 2000 and 2010, using Landsat satellite data

5.1.1.4. River network

The area of river network remained almost static during the past 34 years (1976-2010) with slight decreasing trends. River area was measured 911,819ha in 1976 that slightly decreased to 888,441ha in 2000 and further increased to 939,073ha in 2010 indicating 6.29%, 6.11% and 6.44% of the total area respectively (Table 5.1.2). Yearly average decrease and increase of river areas were 974ha and 5,063ha during 1976-2000 and 2000-2010 respectively. It is estimated that the rate of yearly decrease in river area was 0.007% during 1976-2000 and increase was 0.033% during 2000-2010 with overall increase 0.004% during 1976-2010. Figure 5.1.5 shows river network maps of Bangladesh.

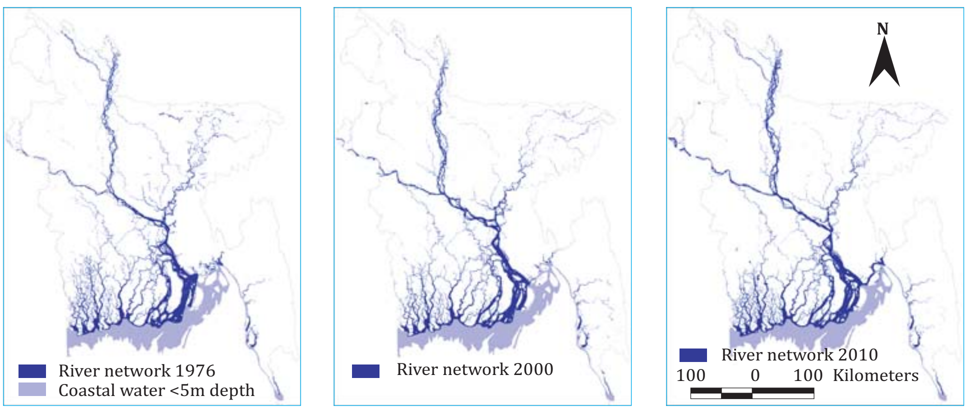

Figure 5.1.5 Satellite-borne remotely sensed river network maps of Bangladesh in 1976, 2000 and 2010

5.1.1.5. Lake (Kaptai Lake)

The Kaptai Lake characterize with clear deep water body created by

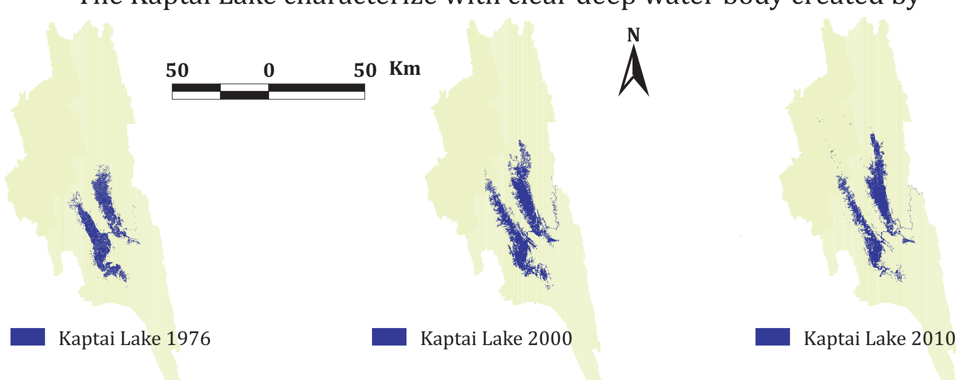

Figure 5.1.6 Kaptai Lake from Landsat imagery, during 1976, 2000 and 2010

drowning of valley and located in mountain valleys of Chittagong Hill Tracts. The lake area was measured 50,829ha in 1976 and remained the area almost unchanged with 51,739ha in 2010, representing about 0.35% of the country. However, lake area had been somewhat over estimated i.e. 58,261ha (0.40%) in 2000 probably due to higher seasonal precipitation and upland runoff. Figure 5.1.6 shows Kaptai Lake maps during 1976, 2000 and 2010.

5.1.1.6. Beel and Haor

Beel and haor area was calculated 239,977ha in 1976 that represents 1.66% of the total area of the country. With an increase of 11,797ha, the area raises 251,774ha with 1.73% in 2000. Thereafter, Beel and Haor decreased 10,750ha during the 34 years period (1976-2010). Yearly average increasing rate was 0.003% and 0.002% during 1976-2000 and 1976-2010 respectively, where the decreasing rate was 0.001% during 2000-2010. Increased area of Beel and Haor during 1976-2000 might be permanent water logging in some low-lying concave areas as the consequences of higher precipitation and faulty flood management. Moreover, influence of satellite image acquisition time can not be neglected in estimating Beel and Haor area. Figure 5.1.7 showing maps of Beel and Haor in Bangladesh.

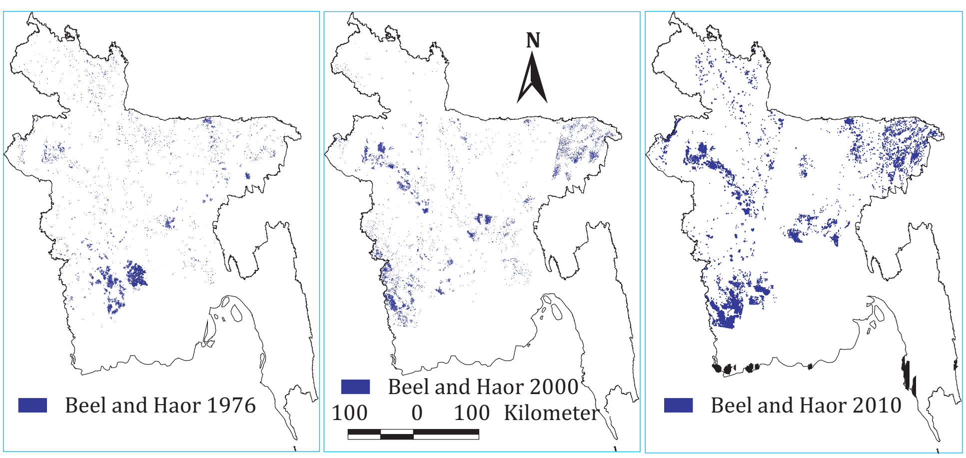

Figure 5.1.7 Mapping beel and haor of Bangladesh with Landsat images, during 1976, 2000 and 2010

5.1.1.7. Aquaculture

Aquaculture area was estimated only 582ha in 1976 which noticeably increased to 143,506ha in 2000, indicating 0.99% of the total area of the country. However, the increasing trends in aquaculture area extended to 175,663ha in 2010 signifying 1.21% of the country. Yearly average aquaculture area increased 5,955ha, 3,216ha and 5,149ha during 1976-2000, 2000-2010 and 1976-2010, representing 0.04%, 0.02% and 0.04% respectively. It is important to note here that small water bodies and ponds within the homestead were excluded from the estimation of aquaculture areas due to the low resolution of satellite images of this study.

5.1.1.8. Tea garden

Tea garden area was measured 119,847ha in 1976 that increased to 138,533ha in 2000 with the yearly average increase 0.01%. Thereafter, tea garden area declined to 96,152ha in 2010 with yearly average decreasing rate of 0.03%. However, yearly average decreasing rate was 0.005% during the past 34 years (1976-2010). Figure 5.1.8 showing maps of tea garden during 1976, 2000 and 2010.

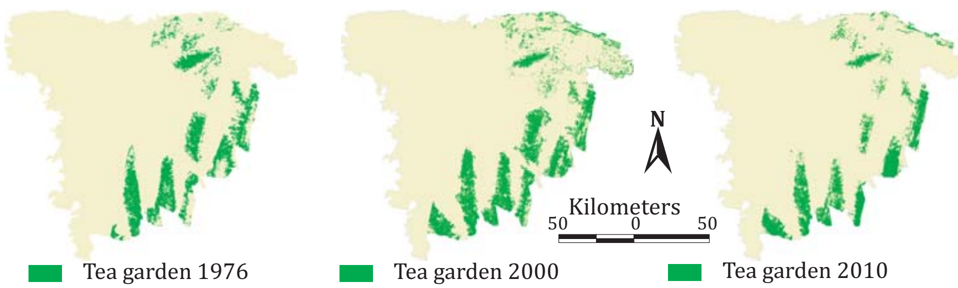

Figure 5.1.8 Tea garden maps in Sylhet division of Bangladesh using Landsat images, during 1976, 2000 and 2010

5.1.1.9. Salt pan

The sea salt extraction area has shown consistent increasing trends in the southeast coastal region of Bangladesh. Salt pan area was measured only

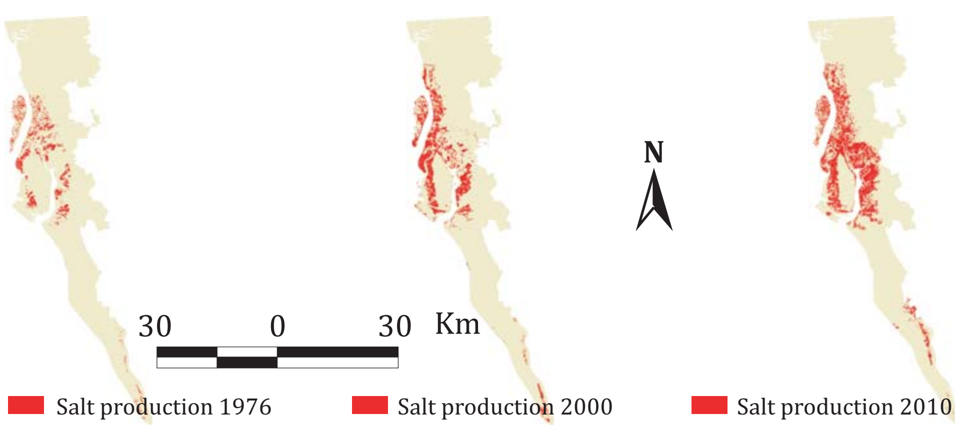

Figure 5.1.9 Mapping salt production areas in Cox's Bazar coastal zone of Bangladesh by satellite remote sensing, during 1976, 2000 and 2010

11,789ha in 1976, which increased to 24,306ha and 36,022ha in 2000 and 2010 respectively. Yearly average salt production area increased 522ha, 1,172ha and 713ha representing 0.004%, 0.01% and 0.005% during the 1967-2000, 2000-2010 and 1976-2010 respectively. Figure 5.1.9 showing sea salt production areas of Bangladesh during 1976, 2000 and 2010.

5.1.2. Trend of non-agricultural land availability

Non-agricultural land included rural settlement, urban and industrial estate and accreted land. The non-agricultural land was estimated 1,183,605ha, 1,788,307ha and 2,400,867ha, which correspond to 8.17%, 12.31% and 16.47% during 1976, 2000 and 2010 respectively (Table 5.1.2). Maximum increasing of 612,560ha was found during 2000-2010, representing 0.42% yearly average increasing rate.

5.1.2.1. Rural settlement

Rural settlement area was estimated 885,637ha in 1976 occupying 6.11% of the total area of the country. Rural settlement area consistently increased over time which grabbed 1,458,031ha (10.03%) in 2000 and 1,766,123ha (12.12 %) in 2010. Yearly average increasing rate were 0.16% and 0.21% during 1976-2000 and 2000-2010 respectively. The overall rate of increase in rural settlement was 0.18% during the 34 years period (1976-2010). From this study, it is revealed that rapid growth of rural settlement is the main driver in declining agricultural land of Bangladesh. It is estimated that yearly average 23,850ha land went to rural settlement during 1976-2000 and 30,809ha during 2000-2010. Figure 5.1.10 shows the maps of rural settlement of Bangladesh.

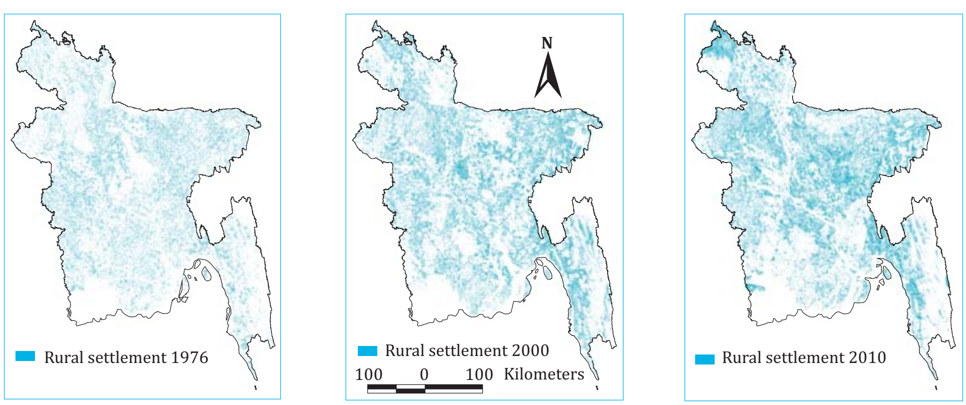

Figure 5.1.10 Rural settlements mapping using Landsat satellite imagery, during 1976, 2000 and 2010

5.1.2.2. Urban and industrial zone

There is significant increase in urban and industrial areas of the country during the period of 1976 to 2010. The total urban and industrial area was 26,799ha in 1976 that expanded to 47,495ha in 2000 and dramatically increased to 87,616ha in 2010 (Table 5.1.2). This trend indicates that urban and industrial areas increased almost double from 1976 to 2000 and more than three times from 1976 to 2010. The yearly increasing rate was higher (0.03%) during 2000-2010, followed by 0.01% during 1976-2000. Yearly average 4,012ha land was transferred to urbanization and industrialization sector during 2000 to 2010. Figure 5.1.11 shows the maps of urban and industrial zones of Bangladesh during 1976, 2000 and 2010.

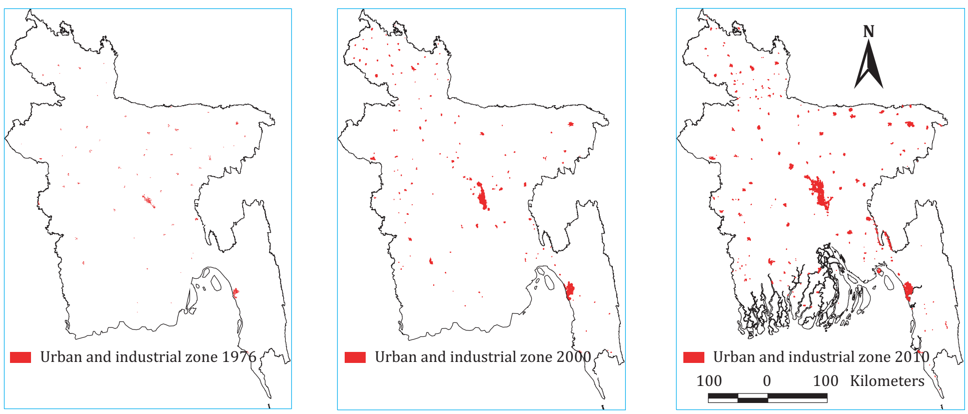

Figure 5.1.11 Urban and industrial zones of Bangladesh from satellite imagery data, during 1976, 2000 and 2010

5.1.2.3. Accreted land

Accretion of land area in the river system of Bangladesh was much faster during the period of 2000-2010 compared to the period of 1976-2000. The accreted land was estimated 271,169ha in 1976 and only 11,612ha land was added up to 2000, where as it was 264,347ha during 2000-2010. The accreted land was 1.87%, 1.95% and 3.75% in 1976, 2000 and 2010 respectively. It was estimated that yearly average rate of accretion was 0.003% during 1976-2000, 0.18% during 2000-2010 and 0.06% during 1976-2010. Subarna Char and Nijhum Dwip under Noakhali District are the best example of coastal accretion. Figure 5.1.12 shows the maps of accreted land in Bangladesh.

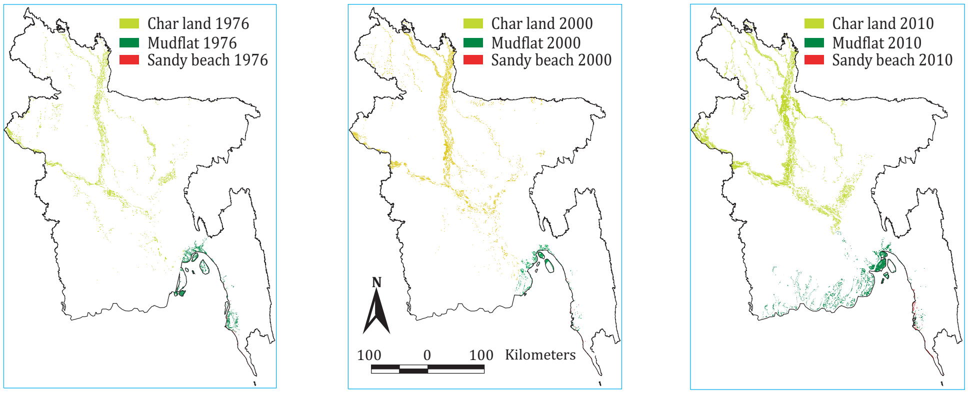

Figure 5.1.12 Maps of accreted char land, mudflat and sandy beach in Bangladesh based on remote sensing satellite data, during 1976, 2000 and 2010

Change in land coverage under different categories as plotted in log-log scale during 1976-2010 are shown in Figure 5.1.13.

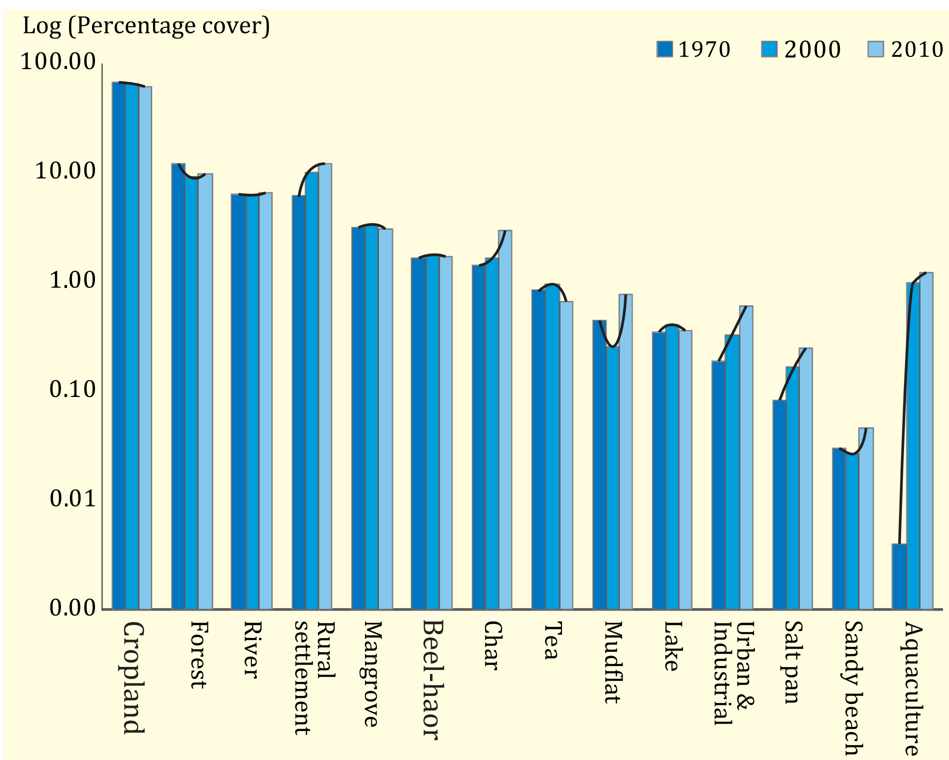

Figure 5.1.13 Land cover changes in log-log scale during 1976-2010

5.2. Land cover at sub-national level
5.2.1. Dhaka division

Agricultural land

Major land cover changes of Dhaka division during 1976-2010 are shown in Table 5.2.1. Most of the lands in Dhaka division have been used as cropland with declining trend of 2,313,751ha in 1976, 2,312,961ha in 2000 and 2,161,650ha in 2010. Average yearly loss of cropland was 33ha (0.001%) during 1976-2000, 15,131ha (0.65%) during 2000-2010 and 4,474ha (0.19%) during 1976-2010. Forest area is being estimated 300,753ha, 133,532ha and 91,930ha in 1976, 2000 and 2010 respectively. Yearly average decreased 6,968ha (2.32%) during 1976-2000, 4,160ha (3.12%) during 2000-2010 and 6,142ha (2.04%) during 1976-2010. The river area remains almost static during the study period (1976-2010). Yearly average rural settlement increased 2.25%, 4.78% and 3.75% during 1976-2000, 2000-2010 and 1976-2010 respectively.

Non-agricultural land

Among non-agricultural lands, rural settlement occupied the highest area that increased more than two-fold during 1976-2010. The data indicates that land gained in rural settlement was 5,077ha (2.25%), 16,626ha (4.78%) and 8,474ha (3.75%) annually during 1976-2000, 2000-2010 and 1976-2000 respectively. The area occupied by urban and industrial zone increased 10,190ha in 1976 to 22,795ha in 2000 and further 42,747ha in 2010. Land gained in urban and industrialization was much rapid during 2000-2010 compared to 1976-2000 and estimated 1,995ha annually.

Table 5.2.1 Remote sensing image-based analysis of major land cover changes in Dhaka division, 1976–2010

Year	Unit	Major land cover types				
		Cropland	Forest	River	Rural settlement	Urban & industrial
1976	ha	2,313,751	300,753	114,261	225,775	10,190
2000	ha	2,312,961	133,532	122,200	347,620	22,795
2010	ha	2,161,650	91,930	114,331	513,875	42,747
Yearly change 1976-2000	ha	-33	-6,968	331	5,077	525
	%	0.001	-2.32	0.29	2.25	5.15
Yearly change 2000-2010	ha	-15,131	-4,160	-787	16,626	1,995
	%	-0.65	-3.12	-0.64	4.78	8.75
Yearly change 1976-2010	ha	-4,474	-6,142	2	8,474	958
	%	-0.19	-2.04	0.002	3.75	9.40

5.2.2. Chittagong division

Agricultural land

Major land cover changes of Chittagong division during 1976-2010 are shown in Table 5.2.2. The highest area in Chittagong division is covered by cropland with declining trend of 1,366,983ha in 1976 to 1,365,756ha in 2000 and further to 1,186,076ha in 2010. Average yearly loss of cropland was 51ha (0.004%) during 1976-2000, 17,968ha (1.32%) during 2000-2010 and 5,321ha (0.39%) during 1976-2010. Forest land is estimated 1,380,402ha, 1,116,258ha and 1,316,104ha in 1976, 2000 and 2010 respectively. Yearly average forest area decreased 9,076ha (0.66%) during 1976-2000 but increased 15,358ha (1.32%) during 2000-2010 and again decreased to 1,891ha (0.14%) during 1976-2010. Yearly average river area increased 0.41%, 0.55% and 0.47% during 1976-200, 2000-2010 and 1976-2010 respectively.

Non-agricultural land

Among non-agricultural lands, rural settlement occupied the largest area that increased more than two-fold during 1976-2010. The data indicates that land gained in rural settlement was 7,266ha (4.61%), 1,233ha (0.37%) and 5,491ha (3.48%) annually during 1976-2000, 2000-2010 and 1976-2000 respectively. Urban and industrial area increased 2.31% during 1976-2010 and 5.73% during 2000-2010. The land gained in urbanization and industrialization was faster during 2000-2010 compared to 1976-2000 and estimated 765ha annually.

Table 5.2.2 Remote sensing image-based analysis of major land cover changes in Chittagong division, 1976–2010

Year	Unit	Major land cover types				
		Cropland	Forest	River	Rural settlement	Urban & industrial
1976	ha	1,366,983	1,380,402	127,738	157,628	8,599
2000	ha	1,365,756	1,162,580	140,435	332,004	13,362
2010	ha	1,186,076	1,316,104	148,200	344,337	21,012
Yearly change 1976-2000	ha	-51	-9,076	529	7,266	198
	%	-0.004	-0.66	0.41	4.61	2.31
Yearly change 2000-2010	ha	-17,968	15,352	777	1,233	765
	%	-1.32	1.32	0.55	0.37	5.73
Yearly change 1976-2010	ha	-5,321	-1,891	602	5,491	365
	%	-0.39	-0.14	0.47	3.48	4.25

5.2.3. Rajshahi division

Agricultural land

Major land cover changes of Rajshahi division during 1976-2010 are given in Table 5.2.3. Like other divisions, the major area has been used as cropland with declining trend of 1,552,558ha in 1976 to 1,436,307ha in 2000 and further declined to 1,276,861ha in 2010. Average yearly loss of cropland was 4,844ha (0.31%) during 1976-2000, 15,945ha (1.11%) during 2000-2010 and 8,109ha (0.52%) during 1976-2010. Forest area was only 9,834ha in 1976 which completely declined by 2000 and no forest land identified in 2010 images. Yearly average river area increased 1.58%, 1.62% and 1.77% during 1976-200, 2000-2010 and 1976-2010 respectively, indicating incessant riverbank erosion particularly along the river Padma.

Non-agricultural land

Among non-agricultural lands, lion-share occupied by rural settlement that increased more than two-fold during 1976-2010. Data analysis reveals that land gained in rural settlement was 3,033ha (2.59%), 7,021ha (3.70%) and 4,206ha (3.59%) annually during 1976-2000, 2000-2010 and 1976-2000 respectively. Urban and industrial area increased 0.06% during 1976-2010 and 7.41% during 2000-2010. The land gained in urbanization and industrialization was faster during 2000-2010 compared to 1976-2000 and estimated 180ha annually.

Table 5.2.3 Remote sensing image-based analysis of major land cover changes in Rajshahi division, 1976–2010

Year	Unit	Major land cover types				
		Cropland	Forest	River	Rural settlement	Urban & industrial
1976	ha	1,552,558	9,834	44.552	117,142	2,393
2000	ha	1,436,307	0	61,423	189,942	2,426
2010	ha	1,276,861	0	71,343	260,155	4,223
Yearly change 1976-2000	ha	-4,844	-410	703	3,033	1
	%	-0.31	-4.17	1.58	2.59	0.06
Yearly change 2000-2010	ha	-15,945	0	992	7,021	180
	%	-1.11	0.00	1.62	3.70	7.41
Yearly change 1976-2010	ha	-8,109	-289	788	4,206	54
	%	-0.52	-2.94	1.769	3.59	2.25

5.2.4. Khulna division

Agricultural land

Major land cover changes of Khulna division during 1976-2010 are given in Table 5.2.4. The major area is covered by cropland with declining trend of 1,330,485ha in 1976 to 1,322,039ha in 2000 and further declined to 1,234,229ha in 2010. Yearly average loss of cropland was 352ha (0.03%) during 1976-2000, 8,781ha (0.66%) during 2000-2010 and 4,011ha (0.21%) during 1976-2010. Geo-spatial data reveals that natural mangrove forest of Sunderban covers 409,646ha in 1976 which slightly increased to 415,047ha in 2000 due to natural regeneration but ever-increasing human interferences and natural disasters decreased forest to 400,021ha in 2010. Yearly average river area decreased by 0.26% during 1976-2000 but it increased by 0.38% during 2000-2010.

Non-agricultural land

Trends in the availability of rural settlement increased during 1976-2000 at the rate of yearly 517ha (0.37%) but it decreased annually 654ha (0.43%) during 2000-2010. Urban and industrial zone increased more than three fold in Khulna division during 1976-2010. Yearly land gained in urban and industrial area was 44ha (2.54%) during 1976-2000 and 249ha (8.94%) during 2000-2010.

Table 5.2.4 Remote sensing image-based analysis of major land cover changes in Khulna division, 1976–2010

Year	Unit	Major land cover types				
		Cropland	Mangrove	River	Rural settlement	Urban & industrial
1976	ha	1,330,485	409,646	209.591	139,404	1,727
2000	ha	1,322,039	415,047	196,629	151,819	2,779
2010	ha	1,234,229	400,021	204,138	145,276	5,264
Yearly change 1976-2000	ha	-352	255	-540	517	44
	%	-0.03	0.05	-0.26	0.37	2.54
Yearly change 2000-2010	ha	-8,781	-1,503	751	-654	249
	%	-0.66	0	0.38	-0.43	8.94
Yearly change 1976-2010	ha	-2,831	-283	-160	173	104
	%	-0.21	-0.07	-0.077	0.12	6.03

5.2.5. Barisal division

Agricultural land

Major land cover changes of Barisal division during 1976-2010 are presented in Table 5.2.5. The greatest area is covered by cropland with declining trend of 844,141ha in 1976 to 820,671ha in 2000 and further declined to 814,010ha in 2010. Yearly average loss of cropland was 978ha (0.12%) during 1976-2000, 666ha (0.08%) during 2000-2010 and 886ha (0.10%) during 1976-2010. The planted mangrove forest was 22,208ha in 1976 which increased to 37,132ha in 2000, indicating the pioneer success of coastal afforestation programmes in specific ecological zones on the islands, the coastal and riverine shorelines and in the upland locations. Human encroachment and climate extreme events are the drivers to decrease mangrove forest to 21,292ha in 2010. River area decreased annually by 0.28% during 1976-2000 but it increased annually by 0.14% during 2000-2010.

Non-agricultural land

Trends in the availability of rural settlement increased in Barisal division during 1976-2000 at the rate of annually 1,455ha (2.47%) but decreased at the rate of 386ha (0.41%) annually during 2000-2010. Urban and industrial zone increased more than fivefold during 1976-2010. Data analysis indicates that land lost in urban and industrial area at the rate of 11ha (3.11%) during 1976-2000 and again it gained at the rate of 176ha (201.72%) during 2000-2010.

Table 5.2.5 Remote sensing image-based analysis of major land cover changes in Barisal division, 1976–2010

Year	Unit	Major land cover types				
		Cropland	Mangrove	River	Rural settlement	Urban & industrial
1976	ha	844,141	22,208	352,172	58,838	342
2000	ha	820,671	37,132	328,660	93,752	87
2010	ha	814,010	21,292	335,449	89,895	1,842
Yearly change 1976-2000	ha	-978	622	-980	1,455	-11
	%	-0.12	0	-0.28	2.47	-3.11
Yearly change 2000-2010	ha	-666	-1,584	679	-386	176
	%	-0.08	0	0.21	-0.41	202.14
Yearly change 1976-2010	ha	-886	-27	-492	913	44
	%	-0.10	0	-0.140	1.55	12.89

5.2.6. Sylhet division

Agricultural land

Major land cover changes of Sylhet division during 1976-2010 are given in Table 5.2.6. Like other divisions, major area is covered by cropland which was 945,506ha in 1976 with a gradual decreased to 831,227ha in2000 and 839,371ha in 2010. Yearly average loss of cropland was 4,762ha (0.50%) during 1976-2000 and 814ha (0.10%) during 2000-2010. Overall yearly lost of cropland was 3122ha (0.33%) during 1976-2010. Yearly average forest area decreased 1,358ha (3.04%) during 1976-2000 and thereafter increased 1,138ha (9.42%) during 2000-2010. River area was decreased continuously by 0.58% annually during 1976-2000.

Non-agricultural land

Trends in the availability of rural settlement increased annually 4450ha (4.89%) during 1976-2000 and further increased 1,932ha (0.98%) during 2000-2010. The rate of increase was much higher during 1976-2000 compared to 2000-2010. However, a rapid increase of urban and industrial area was observed between 2000 and 2010.

Table 5.2.6 Remote sensing image-based analysis of major land cover changes in Sylhet division, 1976–2010

Year	Unit	Major land cover types				
		Cropland	Forest	River	Rural settlement	Urban & industrial
1976	ha	945,506	44,677	11,668	90,991	2,333
2000	ha	831,227	12,088	10,603	197,785	1,652
2010	ha	839,371	23,469	9,368	217,107	6,980
Yearly change 1976-2000	ha	-4,762	-1,358	-44	4,450	-28
	%	-0.54	-3.04	-0.38	4.89	-1.22
Yearly change 2000-2010	ha	814	1,138	-124	1,932	533
	%	0.10	9.42	-1.17	0.98	32.26
Yearly change 1976-2010	ha	-3,122	-624	-68	3,709	137
	%	-0.33	-1.40	-0.58	4.08	5.86

5.2.7. Rangpur division

Agricultural land

Major land cover changes of Rangpur division during 1976-2010 are shown in Table 5.2.7. The greatest area is covered by cropland with declining trend of 1,408,175ha in 1976 to 1,350,730ha in 2000 and further decreased to 1,239,768ha in 2010. Annual declination rate is much faster in 2000-2010 (0.82%) compared to 1976-2000 (0.17%). Forest land is being estimated 18,634ha, 2,921ha and 2,632ha in 1976, 2000 and 2010 respectively. Forest area decreased annually 655ha (3.51%) during 1976-2000 and 29ha (0.99%) during 2000-2010. Yearly average forest lost was observed 471ha (2.53%) during the past 34 years (1976-2010). Area under river showed fluctuating trends that decreased greatly from 1976 to 2000 and thereafter increased two folds from 2000 to 2010.

Non-agricultural land

Among non-agricultural lands, rural settlement occupied the greatest area that increased more than two-fold during 1976-2010. Data analysis shows that rural settlement increased 2,052ha (2.14%) and 5,044ha (3.48%) annually during 1976-2000 and 2000-2010 respectively. The area occupied by urban and industrial zone increased from1,217ha in 1976 to 4,395ha in 2000 which further increased to 5,549ha in 2010. Practically urban and industrial area increased more than four times during 1976 to 2010.

Table 5.2.7 Remote sensing image-based analysis of major land cover changes in Rangpur division, 1976–2010

Year	Unit	Major land cover types				
		Cropland	Forest	River	Rural settlement	Urban & industrial
1976	ha	1,408,175	18,634	44,874	95,859	1,217
2000	ha	1,350,730	2,921	28,503	145,114	4,395
2010	ha	1,239,768	2,632	56,268	195,550	5,549
Yearly change 1976-2000	ha	-2,394	-655	-682	2,052	132
	%	-0.17	-3.51	-1.52	2.14	10.88
Yearly change 2000-2010	ha	-11,096	-29	2,777	5,044	115
	%	-0.82	-0.99	9.74	3.48	2.63
Yearly change 1976-2010	ha	-4,953	-471	335	2,932	127
	%	-0.35	-2.53	0.75	3.06	10.47

Land lost and gained at sub-national level under cropland, rural settlement and urban and industrial zone are shown in Figure 5.2.1, Figure 5.2.2 and Figure 5.2.3 respectively.

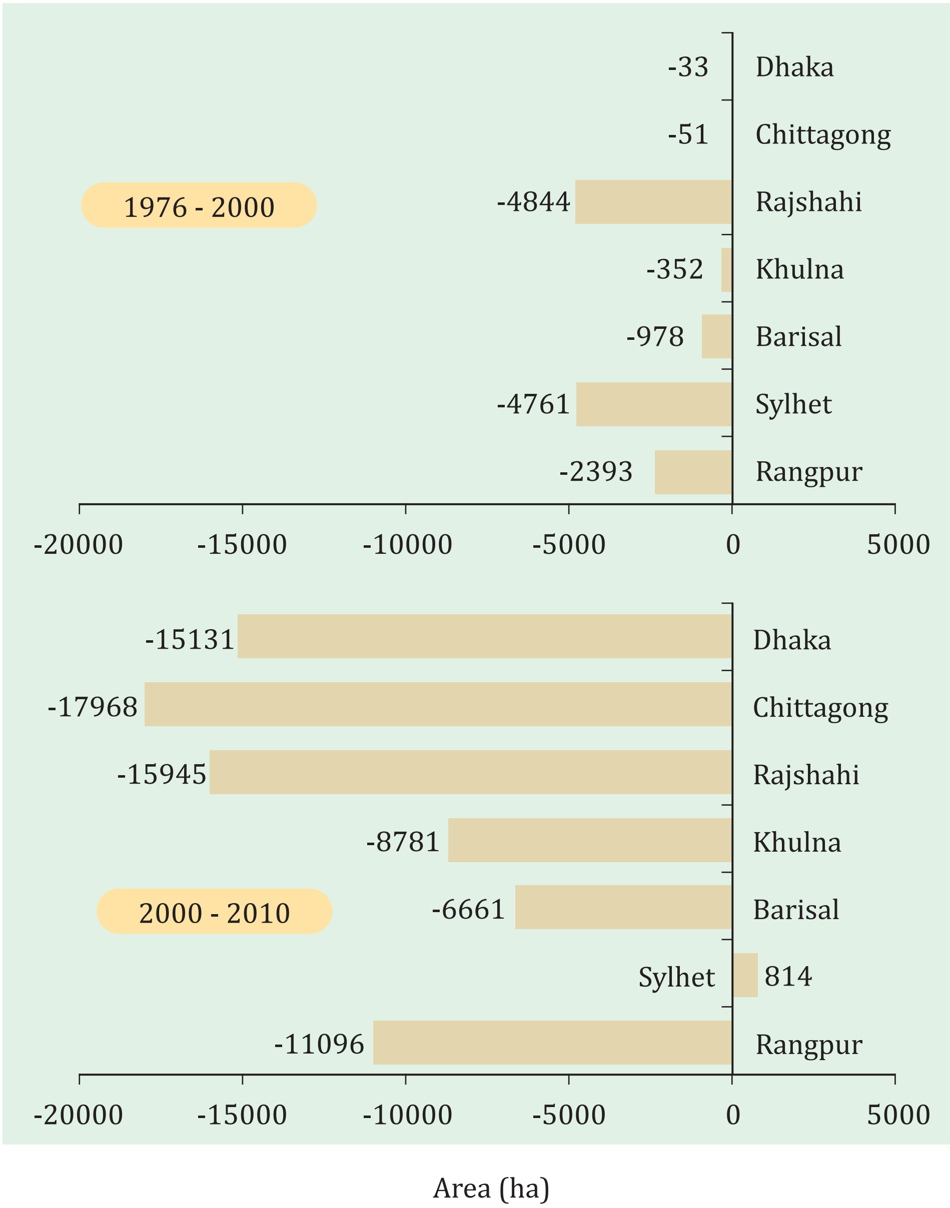

Figure 5.2.1 Cropland changes at sub-national level during 1976-2000 and 2000-2010

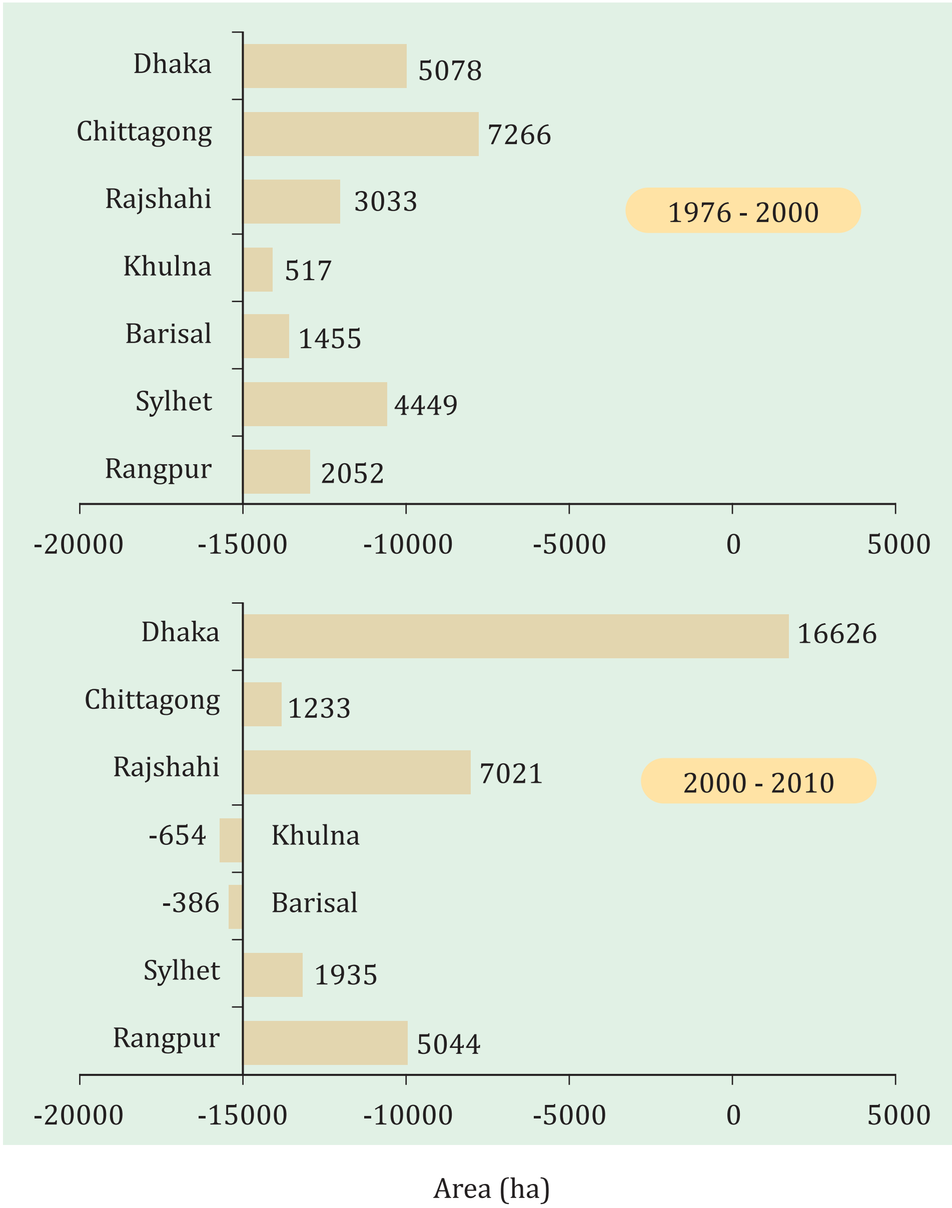

Figure 5.2.2 Changes in rural settlement at sub-national level during 1976-2000 and 2000-2010

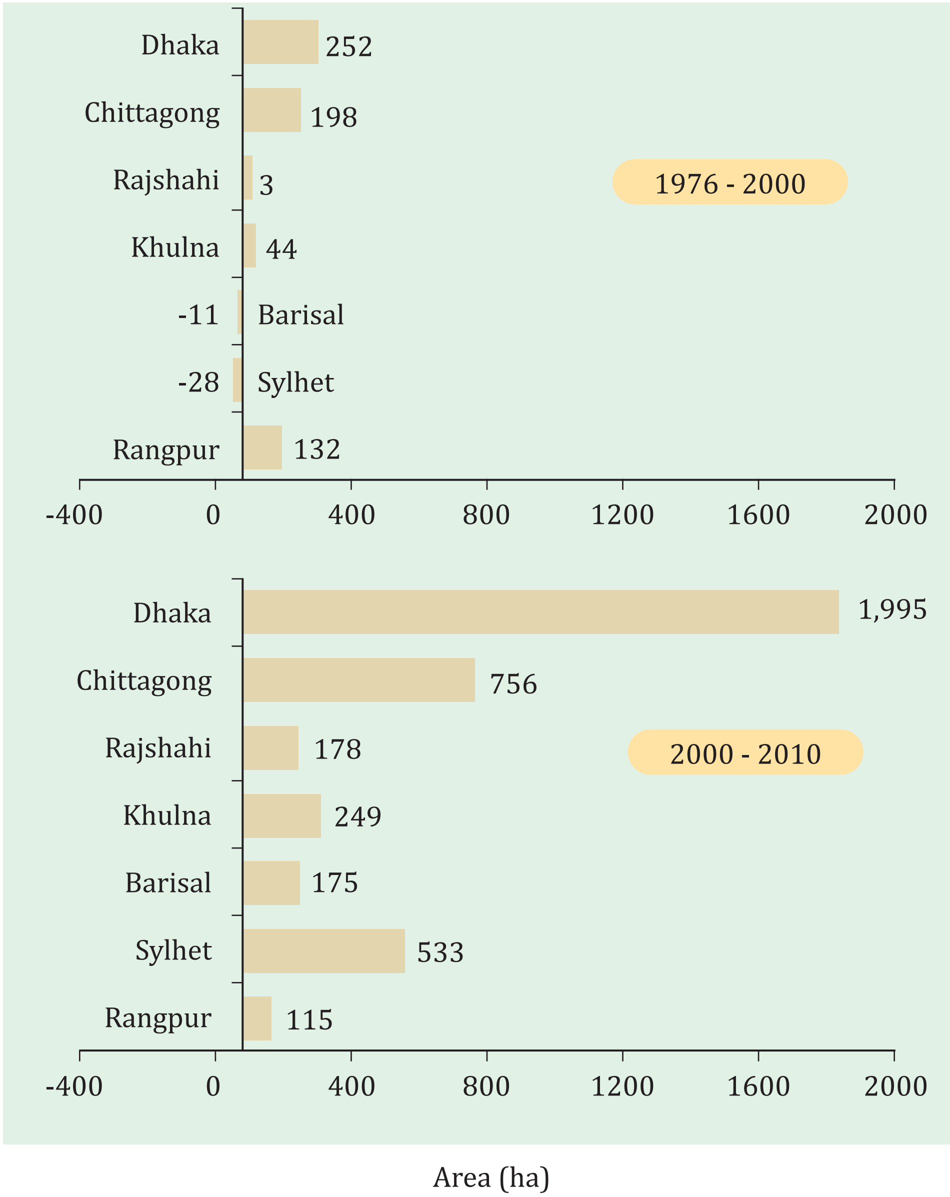

Figure 5.2.3 Change in urban and industrial zone at sub-national level during 1976-2000 and 2000-2010

5.3. Comparison of existing land covers versus geo-spatial model

Among the randomly selected 62 sites to verify existing land covers compared to the geo-spatial model 24, 14, 12, 7 and 5 sites were located in cropland, rural settlement, forest, river and mangrove ecosystem respectively (Table 5.3.1). In 57 sites the model provides accurate figures of land cover according to field verification, where only 1 site of cropland (# 12), 2 sites of rural settlement (# 32 and 37), 1 site of forest (# 49) and 1 site of mangrove (# 60) were incorrectly classified for the existing land covers. All the 3 sites of cropland and rural settlement in model prediction indicated as forest in field verification. On the other hand, both the forest and mangrove sites revealed as rice/paddy in field verification. Thus, 92% of the model output matched with the field verification (Table 5.3.1).

The geo-spatial modeling error matrix for different land covers shows the incorrectly classified sites, based on 62 field verification sites (Table 5.3.2). Most sites (57) were correctly classified, obtaining an overall accuracy of 92%. Model accuracy (MA) and field accuracy (FA) for each of the land covers showed that river had the highest values of MA (1.00) and FA (1.00) respectively. Cropland class was well discriminated from the rest of the class (MA= 0.92 and FA = 0.96). The Kappa Index of Agreement (KIA) was generated to determine the degree of agreement between the two outputs. Its values range from -1 to +1 after adjustment for chance agreement. A value of 1 indicates that the two outputs are in perfect agreement (no change has occurred), whereas if the two outputs are completely different from one another, then the Kappa value is -1. The Kappa (K) and Kendall's Tau (T) had the value of 0.891 coefficients and 0.865 at 95% confidence, indicating that there is very good agreement between geo-spatial model and existing land cover patterns. Statistical analysis concluded that very high percentage of the land cover characteristics was identified correctly, better than would be expected by a completely random classification.

Table 5.3.1 Comparison of field data against of model data for land covers change

Site #	Field information	Model prediction	Accuracy	
			Site #	%
1	Rice/paddy/vegetable	Cropland	57	91.94
2	Rice/paddy/vegetable	Cropland		
3	Rice/paddy/vegetable	Cropland		
4	Rice/paddy/vegetable	Cropland		

Site #	Field information	Model prediction	Accuracy	
			Site #	%
5	Rice/paddy/vegetable	Cropland		
6	Rice/paddy/vegetable	Cropland		
7	Rice/paddy/vegetable	Cropland		
8	Rice/paddy/vegetable	Cropland		
9	Rice/paddy/vegetable	Cropland		
10	Rice/paddy/vegetable	Cropland		
11	Rice/paddy/vegetable	Cropland		
12	Forest	Cropland		
13	Rice/paddy/vegetable	Cropland		
14	Rice/paddy/vegetable	Cropland		
15	Rice/paddy/vegetable	Cropland		
16	Rice/paddy/vegetable	Cropland		
17	Rice/paddy/vegetable	Cropland		
18	Rice/paddy/vegetable	Cropland		
19	Rice/paddy/vegetable	Cropland		
20	Rice/paddy/vegetable	Cropland		
21	Rice/paddy/vegetable	Cropland		
22	Rice/paddy/vegetable	Cropland		
23	Rice/paddy/vegetable	Cropland		
24	Rice/paddy/vegetable	Cropland		
25	Living house/yard	Settlement		
26	Community place	Settlement		
27	Living house/yard	Settlement		
28	Living house/yard	Settlement		
29	Living house/yard	Settlement		
30	Living house/yard	Settlement		
31	Living house/yard	Settlement		
32	Forest	Settlement		
33	Living house/yard	Settlement		

Site #	Field information	Model prediction	Accuracy	
			Site #	%
34	Living house/yard	Settlement		
35	Living house/yard	Settlement		
36	Community place	Settlement		
37	Forest	Settlement		
38	Living house/yard	Settlement		
39	Dense forest	Forest		
40	Dense forest	Forest		
41	Dense forest	Forest		
42	Dense forest	Forest		
43	Dense forest	Forest		
44	Dense forest	Forest		
45	Dense forest	Forest		
46	Dense forest	Forest		
47	Dense forest	Forest		
48	Dense forest	Forest		
49	Rice/paddy	Forest		
50	Dense forest	Forest		
51	River/canal	River		
52	River/canal	River		
53	River/canal	River		
54	River/canal	River		
55	River/canal	River		
56	River/canal	River		
57	River/canal	River		
58	Mangrove ecosystem	Mangrove		
59	Mangrove ecosystem	Mangrove		
60	Rice/paddy	Mangrove		
61	Mangrove ecosystem	Mangrove		
62	Mangrove ecosystem	Mangrove		

Table 5.3.2 Cross-tabulation for error matrix analysis of model data (columns) against field reference data (rows) for land covers change

Field reference data							
Model data	Cropland	Settlement	Forest	River	Mangrove	Row total	Field accuracy
Cropland	**23**	0	1	0	0	24	0.96
Settlement	0	**12**	2	0	0	14	0.86
Forest	1	0	**11**	0	0	12	0.92
River	0	0	0	**7**	0	7	1.00
Mangrove	1	0	0	0	**4**	5	0.80
Column total	25	12	14	7	4	62	
Model accuracy	0.92	1.00	0.79	1.00	1.00		

Diagonal sum (bold) = 57; Overall kappa = 0.891; Kendall's Tau = 0.865

6. Conclusion

Data analysis revealed that annual loss of cropland during 1976-2000 was 13,413ha which continues to 68,760ha during 2000-2010. Considering cropland irrespective of the percentage of total landmass of the country, the total land under cropland in 1976 was 9,761,450ha which reduces to 9,439,541ha in 2000, i.e., annual loss is 0.137%. This cropland further decreases to 8,751,937ha in 2010, i.e., annual loss of cropland during 2000 to 2010 is 0.728 %. Highest annual loss of crop land occurs in Chittagong Division and at the rate of 17,968ha. Annual loss of cropland in Rajshahi, Dhaka, Rangpur, Khulna and Barisal were 1,5945ha, 15,131ha, 11,096ha, 8,781ha and 6,661ha respectively. On the other hand annual increases of rural settlements were 23,850 and 30,809 ha per year during 1976-2000 and 2000-2010 respectively. Highest annual growth of rural settlement observed in Dhaka Division which is 16,626ha during 2000-2010. Rajshahi and Rangpur secure the second and third position. Annual increase of urban settlement and industrial area increases by 4,012ha per year during 2000-2010. There was significant loss of forest land observed during 1976-2000, but on the other hand forest land increases significantly during 2000-2010, this may be because of the initiatives by the government, awareness among the peoples especially of social forestry. Coastal plantation initiatives increased the mangrove area during 1976-2000 but it decreased largely during 2000-2010 due to human interferences and tropical cyclones. Annual increases in aquaculture during 1976-2000 were observed 5,955ha but for the period 2000-2010, the increase took place by 3216ha per year. Figure 6.1 shows land cover dynamics at national level during 1976-2010.

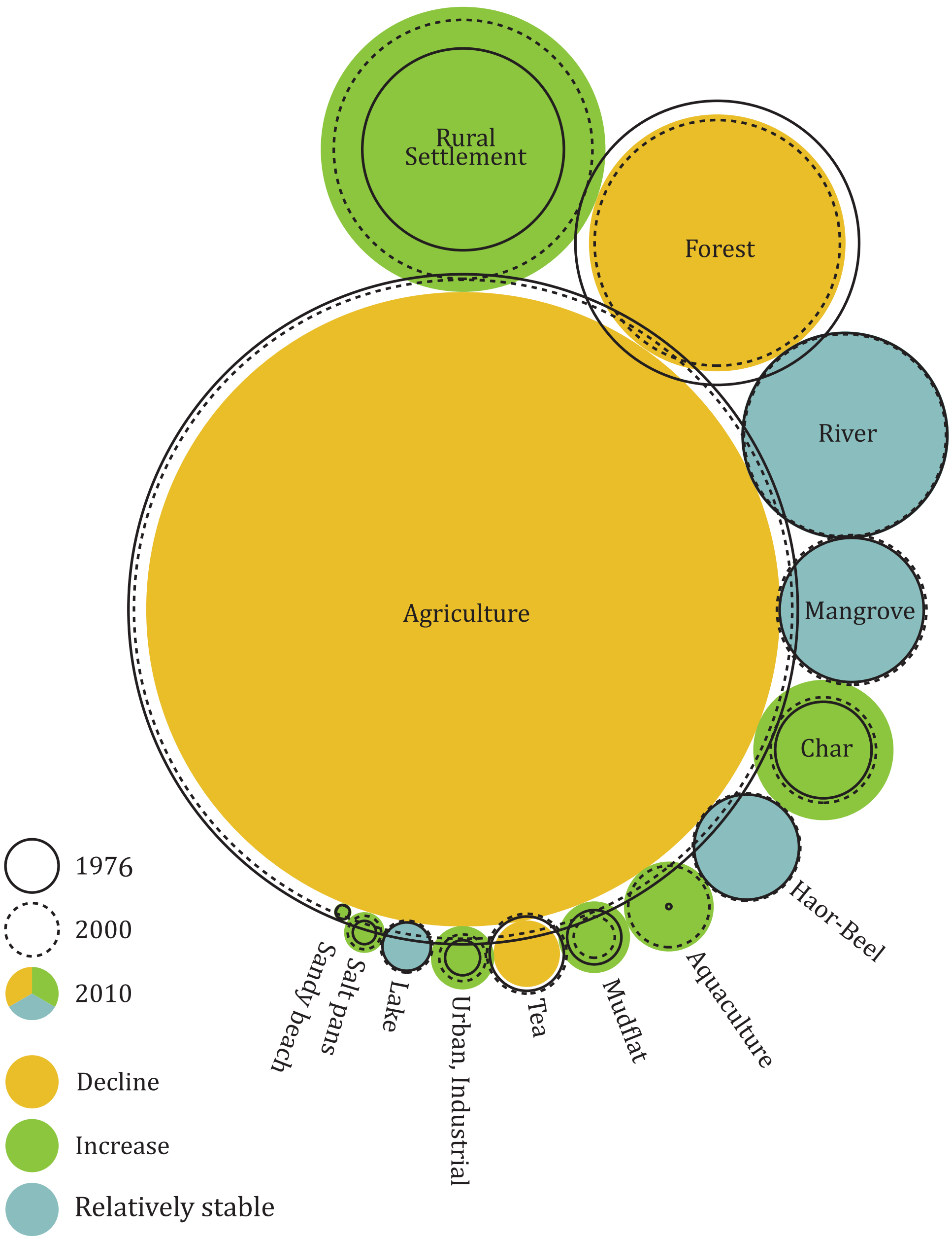

Figure 6.1 Land cover dynamics at national level during 1976-2010

7. Policy Implication

The growth of rural settlement is the main driver of the land lost from crop agriculture followed by urbanization and industrialization. Houses of ever increasing population in Bangladesh are expanding towards agricultural land. As the food security is the main concern of Bangladesh, necessary steps should be taken to conserve agricultural land from the shifting to non-agricultural uses. The concerned Ministry and Departments can address the findings of this study in the forthcoming policy documents to develop integrated house-cropland-industrial expansion for social, economic and food security.

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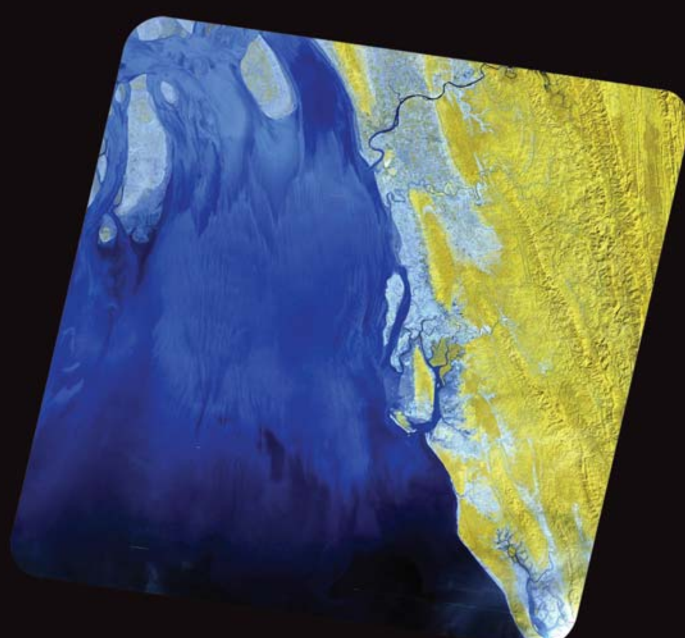

Landsat satellite imagery of path 136 and row 044 during January 2010 (above); path 146 and row 045 during January 1974 (below)

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