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Research Article

Preliminary Application of Space-Based Remote Sensing and Geospatial Technology for Investigation on the Geo-Environmental Consequences of Cyclone Aila 2009 in the Bangladesh

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Abstract

Climate change has become a great concern in the context of global change and increased frequency and magnitude of natural disasters throughout the world. Natural disasters like cyclones, storm surges, floods etc. often cause significant losses of life, large-scale economic and social impacts, and considerable environmental damages. This paper dealt with the overall methodological development to investigate the consequences of climate change extremities particularly, the after effects of cyclone using Remote Sensing (RS) and Geographic Information System (GIS) technology. In this context, individual functional components have been investigated, tested and verified. Time series multi-sensor satellite data particularly of Landsat, World view (from Google origin) have been utilized to infer information on the consequences of Cyclone Aila 2009 hitting part of Southwestern Bangladesh as a pilot study. Information retrieval mechanism utilized is based on specially designed methodological framework using satellite-based RS technology along with GIS. Developed technical approach consists of a three-fold components – (i) Establishment of input foundation layer with high spatial details to support characterization, recognition and identification of important surface features using high resolution satellite data; (ii) Effective operational procedure to process, analyze, interpret and finally to archive the retrieved information; (iii) Functional computations were made using spatial modeler language (SML) programming environment under ERDAS Imagine image processing software. Satellite image processing, analysis operation together with image-based spectral characterization of surface features under different stressing conditions etc. have been exercised to derive useful surface information. Specially designed geospatial database has been established in GIS using ArcGIS operational platform. Varieties of geospatial data from diverse sources have been incorporated categorically as column-based attributes in GIS. Dual spatial data layers have been generated in GIS for two different dates representing the pre-cyclone and post-cyclone time sequences utilizing appropriate high spatial resolution satellite images. Finally, a geospatial image-based combinational technique has been utilized employing high temporal and moderate spatial resolution time series satellite data with low temporal and high spatial resolution satellite data. Such an operation results in an improved spatial and temporal resolution of output products enabling capture of dynamics of surface features in the spatiotemporal domain providing more precision and details in the output. This study has been supplemented with necessary Ground Position System (GPS)-guided ground truthing, selected field data collection and field-based group discussions outcomes.

Keywords: Geospatial techniques, GIS, Remote sensing, Landsat, Disaster.

Introduction

Bangladesh is one of the largest deltas in the world, which is highly vulnerable to natural disasters due to its unique geographical location, flat and low-lying landscape, population density, poverty, illiteracy, lack of institutional setup etc. The coastal areas of Bangladesh are particularly disaster prone because of their geographical location, land characteristics and the proximity to the funnel-shaped feature (which reduces the width and increases the height of storm induced waves) of the Northern Bay of Bengal (UNEP, 2001). This coastal zone forms the lowest landmass (in cases 0-30 cm mean sea level), part of a delta of the extended Himalayan drainage ecosystem, and is exceedingly prone to multiple threats like cyclones, storm surges, floods, tsunamis, and climate change (Bishawjit et al., 2017). Government (GoB, 2005) identified the coastal zone as an “agro-ecologically disadvantaged region”. The dense population in Bangladesh results in a high human-to-land ratio of about 520 people per km2 (BBS, 2012a). This density has a significant influence on land use/land cover. According to the Long-Term Climate Risk Index (CRI) 2017 of German Watch, Bangladesh has been ranked as the sixth most affected country in the period of 1996-2015 regarding climatic disasters of the world (Kreft et al., 2016). All the adverse effects have aggravated the overall economic development scenario of the country largely. The combined effect of natural and anthropogenic activities further intensifies the damage to the ecosystem and hamper the economy, livelihood, migration (Rowsell et al., 2013) and development of the coastal areas of Bangladesh (MWR, 2005). Planning to mitigate the impact of such incidents has become even more critical, given the prediction of increased climatic extremes associated with an "enhanced greenhouse effect." UN stressed the need for special attention to be given to planning for natural disasters and to reducing long-term vulnerability in those countries at highest risk. Eventually, the threatening consequences of global climate change phenomena powered by increasingly hazardous natural disasters principally cyclones, storm surges, floods, Earthquake, landslides etc. with cascading effects of tidal floods, water logging, intrusion of salinity, enhanced drought, land-use and land-cover changes etc. imposed great challenges to the living community worldwide.

It is obvious that space technology inputs are crucial for disaster monitoring, management etc. as it is the only means to obtain required real-time data in remote and inaccessible areas. Recent advancements in remote sensing (RS) and its application technologies enabled the use remotely sensed imagery data for assessing vulnerability of urban areas and for capturing damage distribution due to natural disasters (Shinozuka & Rejaie, 2000). RS imagery derived from airborne digital and earth observation satellite systems (Visser and Darwood, 2004) provide valuable sources of information about the location and severity of damages following major disasters (Islam et al., 2016; Stryker and Jones, 2009; Akyüz, 2021).

Integrated Geographical Information Systems (GIS) and RS technology constitute a useful and effective tool in disaster monitoring and management operation. These technologies have been the object of substantial interest for all countries and bodies concerned with space and in exacting emergency services and disaster management. The objectives of the disaster experts are to monitor and analyze the situation with good precision to come up with better prediction models, suggest appropriate contingency plans and prepare spatial databases. Remotely sensed data can be used effectively for assessing severity and impact of damage due to, earthquakes, landslides, flooding, forest fires, cyclones and other disasters in a short period of time (Sharma et al., 2010).

When both pre-disaster and post-disaster data are available, optical data can be used to detect changes. A good number of methodologies is presently available that could be used to extract damage on a pixel-by-pixel basis from optical images, depending on the resolution and the time difference between the images. Moreover, spectral as well as spatial (e.g., textural) features may be considered as input to the selected change detection method. Final damage detection and evaluation is done at some object level (buildings or blocks), the analysis can be directly obtained at the object level or is first performed at the pixel level, and the results are jointly considered within a spatially defined area. GIS has a graphic database of geo-referenced information system, which is linked to the descriptive database. It uses high-powered graphic and processing tools that are equipped with procedures and applications for inputting, storing, analyzing and visualizing geo-referenced information. Various disasters like cyclones, floods, earthquakes, tsunamis and other natural hazards that end with significant losses of human lives, properties and infrastructures. Remotely sensed data can be used to assess the impact of damages due to these disasters. In the disaster relief phase, GIS, grouped with global positioning system (GPS) is extremely useful.

This research examines the utility of RS technologies for damage assessment in disasters and presents a framework for the application of RS technologies specifically to the disaster. Space technology has significant influence in the decision-making processes in almost all social spheres. It encompasses information generation on natural resource viz., land use, agriculture, climate, urban systems for better management of resources and in protecting humans from the impact of natural calamities like cyclone, flood, drought, forest fire, landslide etc.

The goal of this research is to provide a comprehensive perspective on the rationale and end-to-end design of time-sensitive remote sensing systems (TSRSS) that are able to provide timely information on extent of damage and volume of debris immediately following hazard events in support of decision making by emergency managers. The research focuses on the region hit by Cyclone Aila, covering the Khulna and Satkhira districts. This study demonstrated the capability of a RS approach for assessing multiple damages produced by the cyclone using object-based classification from multi-sensor images. Multi-date images have been utilized for mapping pre- and post-cyclone land covers in the study area with a high degree of accuracy.

The study was conducted with the following objectives:

- Application of RS technology for inferring biophysical information over the study area.
- Preparation of spatial database in GIS with relevant surface parameters as retrieved through.
- Analysis of TSRSS of different resolutions to study the land use and land cover changes under pre and post Aila scenarios.
- Characterize the changes due to cyclone Aila.

Materials and Method

Study area

The study area includes part of the coastal zone situated in the southern side of Bangladesh as shown in Figure 1. The area includes six Upazilas under two districts of the country. It is to be mentioned that Upazila is the smallest administrative unit in Bangladesh. Koyra, Dacope and Paikgachha Upazila are under Khulna district. Tala, Assasuni and Shyamnagar Upazila are under Satkhira district. Study area is located between 21°37'54.99" and 22°17'24.80" north latitudes and between 89°38'1.55" and 88°59’37.14" east longitudes. The breakup of the study area falling under different administrative units is given in Table 1. A total of about 1481058 people live in these six Upazila (BBS, 2012a, b). The area is located in the Western Coastal Region of Bangladesh coast.

The study area has tropical monsoon climate. The summer, rainy and winter are the three characteristically contrasted most important seasons among the six seasons in the country. The rainy season extends from May to October, the winter season extends from November to February and the summer extends from March to April. Maximum rainfall is recorded in rainy season, and the maximum temperature observed in summer season.

In the present context of global climate change and frequent natural disasters worldwide, there has been a global concern to undertake effective and timely measures in reducing and mitigating the impacts of disasters through appropriate disaster management procedure. Information requirements of emergency response organizations need to be specified to develop a TSRSS that provides appropriate information in a sufficiently reliable and timely fashion.

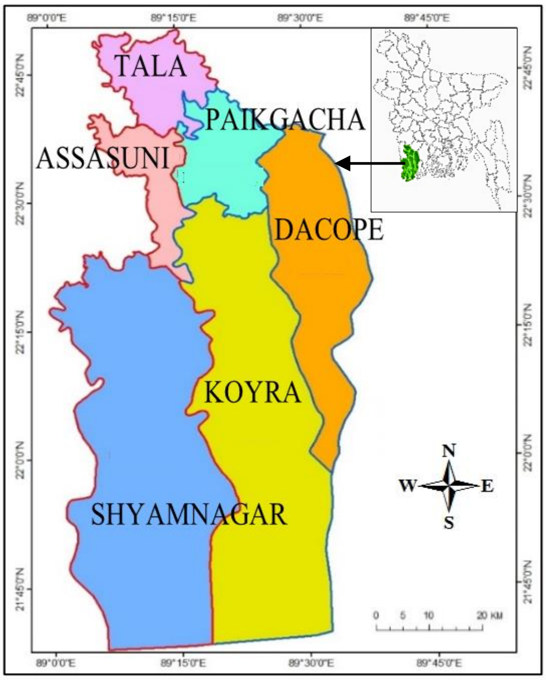

Fig. 1. Study area covering six Upazilas under Khulna and Satkhira Districts of Bangladesh.

Satellite Data Utilized

Table 2 provides a list of the satellite data used in the study. Landsat 5 Thematic Mapper of 2008, 2009 and 2010 along with Google images of 2001, 2008 and 2011 have been utilized to study the geo-environmental consequences of cyclone Aila in the area. Multi-date Landsat TM satellite data have been obtained from Earth explorer site (http://earthexplorer.usgs.gov/) and Google images from Google Earth (Table 2).

Table 1: Upazila areas and populations

District	Upazila	Area (Sq. km.)	Population
Khulna	Dacope	992	152316
	Koyra	1,775	193931
	Paikgachha	411	247983
Satkhira	Assasuni	375	268754
	Shyamnagar	1,968	318254
	Tala	337	299820
	Total	**5858**	**1481085**

**Source: BBS, 2012a, 2012b*

Table 2: Specification of Satellite Data.

Satellite	Sensor	Path/ Row	Acquisition Date	Resolution
Landsat 4-5	TM	138/44	October 30, 2008 February 3, 2009 May 10, 2009 June 11, 2009 October 17, 2009 February 6, 2010	30 M
		138/45	February 19, 2009	
Google Image	-	-	January 25, 2001 November 27, 2008 March 01, 2010 February 11, 2011	-

**Data Source: USGS GloVis*

Methodological Approach

Figure 2 shows the methodological framework as adapted for implementation of the present research study. The study area has been extracted from satellite images by using vector GIS boundary layer. Digital data processing, analysis and interpretation have been cariied out to identify the surface features over the area. Thematic data layers were generated following procedural flowchart as mentioned. This research work extensively utilized the ERDAS Imagine and ArcGIS software for various geospatial application under the study theme.

Data Analysis, Interpretation and Classification

Landsat TM images were formatted into ERDAS Imaging IMG format. DN values were transformed into reflectance values. Necessary atmospheric corrections have been performed utilizing Simplified Method for Atmospheric Correction (SMAC) of satellite images (Rahman and Dedieu, 1994) to normalize the differences in radiative values of surface features between images acquired under different dates under different atmospheric conditions. Necessary corrections have been carried out for scattering due to atmospheric aerosols and molecules and absorption due to gaseous components. Post-processing of the images has been carried out following digital techniques in the ERDAS Imagine image processing software and ArcGIS. Class-wise spectral characterization of classified images has been carried out and class properties have been investigated in terms of amplitude and pattern of spectral signature of individual class categories. Relatively insignificant class elements specially in terms of cluster size have been merged with the other relevant class category in order to keep mainly the distinct and meaningful class elements. Finalized thematic layers have been transformed into vector format in ArcGIS Necessary attributes have been assigned to individual class elements.

Ground truthing and filed data incorporation

Analysis of time series satellite data with subsequent image-based GPS-guided ground truthing, verification and data collection operation have been carried out. In addition, ground information and field data collected just after the cyclone Aila-2009 by Bangladesh Space Research and Remote Sensing Organization (SPARRSO) as a regular event-based activity have been utilized from SPARRSO archival. A series of vector layers has been produced in ArcGIS platform from each of the thematic raster layers. Necessary Arc correction and post processing operation have been carried out for each of the vector layers. Specific attributes have been assigned to each of these vector layers. In the next step, statistics have been generated on LULC and its changes over the study area. Finally, individual map products have been produced.

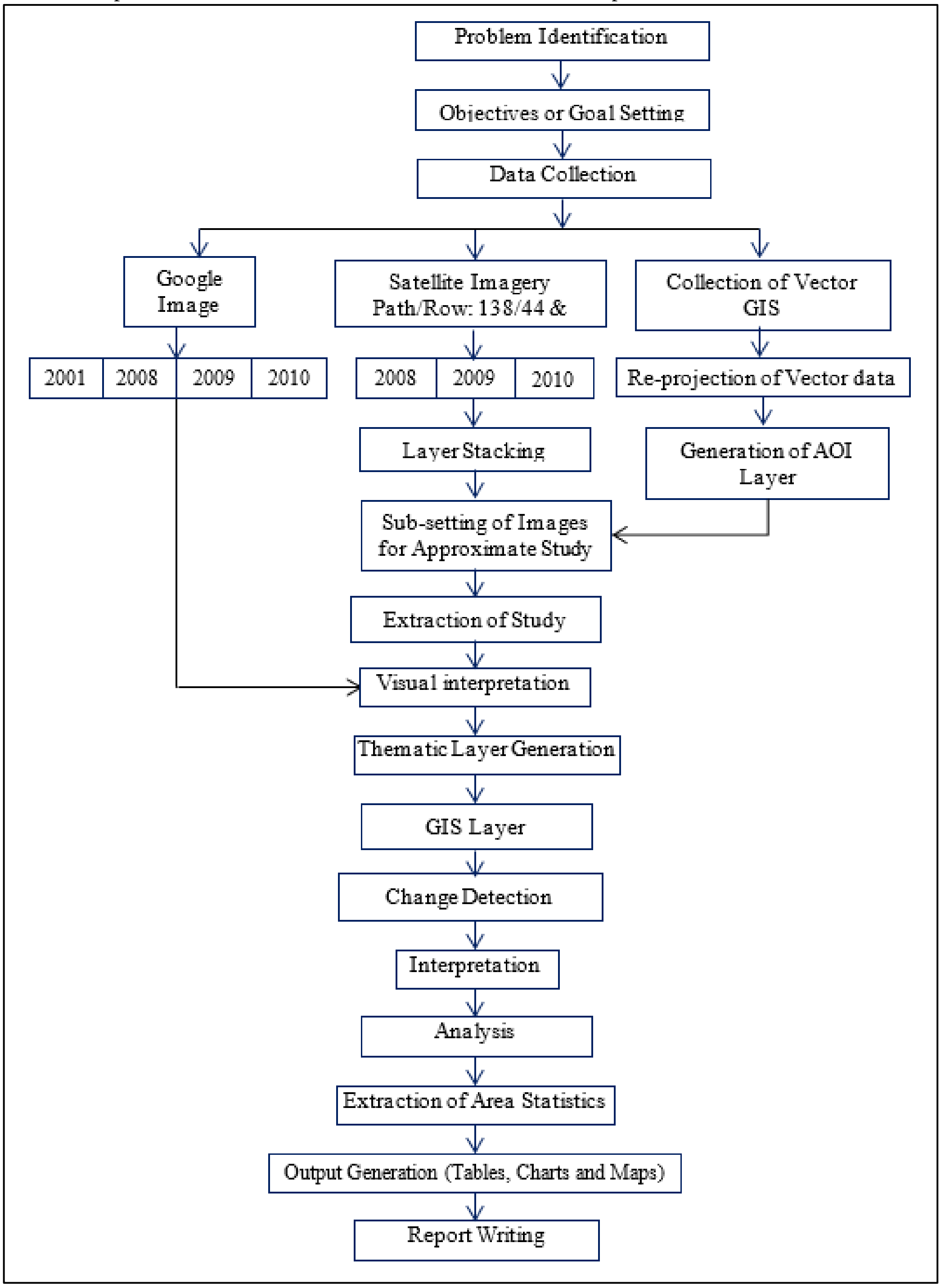

Fig. 2. Flow chart of the working methodology under the present work.

Towards Change Detection and Damage Assessment

Integration of GIS and RS technologies has been the object of substantial interest in producing and providing emergency services supporting disaster management (Mas, 1999) initiatives. Remotely sensed data have proven to be effective for rapid assessment of severity and in analyzing damaging impacts due to cyclones and other disasters (Ali et al., 1998; Rahman, 1999). Accurate and timely detection of event-based changes of surface features is extremely important to promote better decision making. Many change detection techniques have been developed (Lu et al., 2004). In practice, different algorithms are often compared to find the best change detection results for a specific application. Change detection approach detects the differences in the state of a land-surface before and after a disaster event using pre- and post-disaster images. All the geospatial data layers including satellite images of pre- and post-disaster event must have the same geometry and wavelength, and have to be well co-registered. Change detection can be implemented by using shape analysis, brightness value comparison, image differencing etc. Characterization of the differences between color, spectra, texture, and other features extracted from the registered images provide viable way to discriminate surface features under the category of damaged and undamaged object classes.

Results and Discussions

RS Analysis on the Radiometry of the Landscape

Figure 3 shows the Landsat TM spectral images of February 3, 2009 and February 6, 2010 representing (a) pre-Aila and (b) post-Aila situation respectively in the Koyra Upazila under Khulna district. Landsat TM bands 3, 4 and 5 have been loaded in the B, G and R plains respectively of the display device. Spatial profiles have been drawn along a straight line (XY) over the two images. The readily noticeable bluish characteristics of the post-Aila-2009 image as compared to that of pre-Aila-2009-time sequence provide the evinces of storm surge driven water coverage over the area.

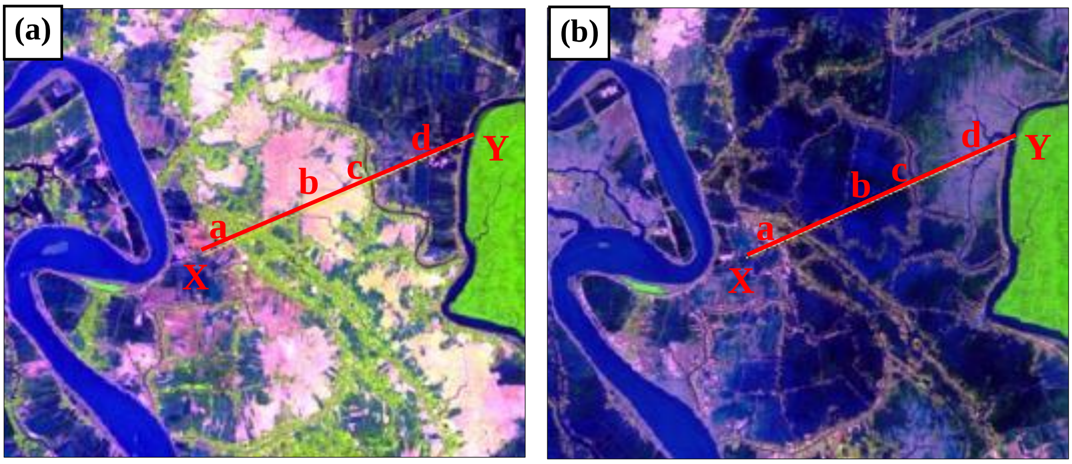

Fig. 3. Images dated (a) February 3, 2009 representing pre-Aila and (b) February 6, 2010 representing post-Aila time sequences respectively in the Koyra Upazila under Khulna district.

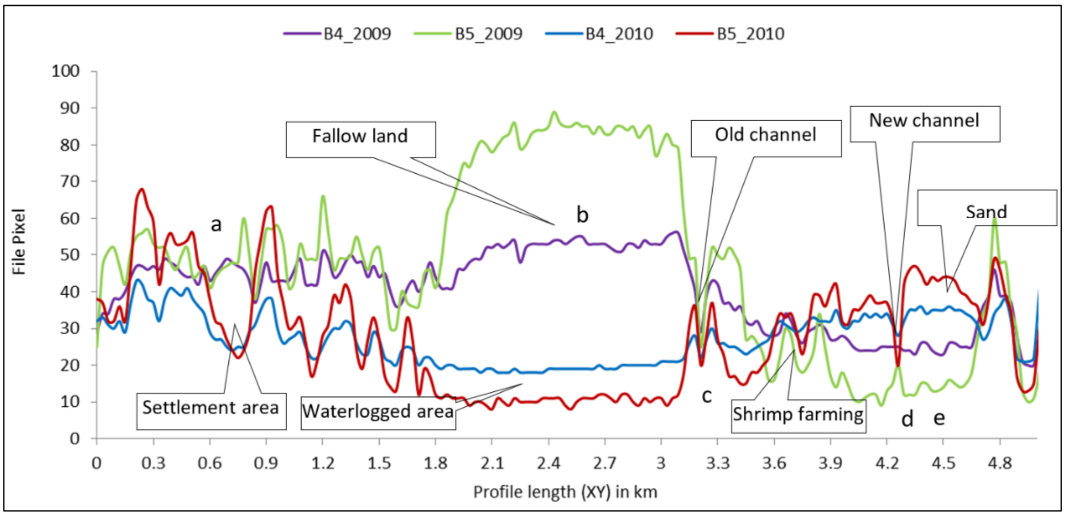

Fig. 4. Linear spatial profiles corresponding to three spectral bands (5, 4, and 3) of Landsat TM spectral color images on the two different dates 3 February, 2009 and 6 February, 2010 representing pre-Aila and post-Aila situation respectively in the Koyra Upazila. The profile line has been shown in Figure 17 starting from position X to position Y and passing through the points a, b, c, and d.

Figure 4 shows the variation of spectral reflectance values in bands 4 and 5 of Landsat TM along a linear profile on two different dates as mentioned. Along the profile a number of specific locations e.g., a, b, c and d has been considered over both the images. Dynamic variation of reflectance values along the profiles on two dates have been interpreted in terms of surface category, its condition and transformation into another category. Profile lines as a function of distance exhibit significant variation of surface radiative intensity over the profiling direction.

Presence of water along the profile line, vegetation and soil radiative properties together determined the intensity of the signal in different spectral bands of Landsat Thematic Mapper (TM) sensor. The optical and architectural properties of vegetation and its density, moisture content of the soil particularly important in relatively low-density vegetation cover collectively determine the overall radiative characteristics of the vegetation canopy system (Rahman et al., 1999). The evolving condition of a landscape with surface components consisting of primary surface classes e.g., soil, vegetation and water is principally dependent on the dynamic changes of surface variables that result in modification in their radiative response properties. In such deterministic processes of surface radiative responses, vegetation phenology, land physiography and condition, amount of incident solar radiation, dynamic soil moisture condition plays important role (S. Rahman, 2007, Rahman 2001). The role of overspreading water has a dual role to play in this regard. Water itself influences the overall canopy radiative characteristics. In addition, presence of salinity in the water affects the vegetation bringing a degradation of vegetation condition with respect to time. In the present work, atmospheric effects in the multi-date satellite images have been removed through application of atmospheric correction procedure with consideration of atmospheric aerosol and molecular scattering. The presence of homestead vegetation as appeared in green color in Figure 3(a) is not visible in the post-cyclone image as in Figure 3(b), though both the images correspond to almost same seasonal time of the year.

Referring to location 'a' corresponding to settlement area in 2009 was affected by Cyclone Aila and presence of flood water is readily visible in 2010 after the cyclone Aila. Thus, the spectral value corresponding to position 'a' dropped down significantly in 2010 as compared to that in 2009 prior to the cyclone Aila. Location 'b' represents fallow land in 2009 with high reflectance value, while, the value significantly dropped in 2010 due to water logging in the area causing high absorption of radiative value. Location 'c' represents the old channel in 2009 with low reflectance value, while, the value dropped down a little in 2010 due to water logging in the area causing more absorption of radiative value. Location 'd' represents new channel in 2010 with low reflectance value, while, the value in 2009 indicate presence of mixed environment of sand and water. Again, the increasing trend of radiative value represents sand deposition in 2010, while low radiative value in 2009 represents the possible presence of water over the area under study.

Under the present research work, five land-use/cover (LULC) types have been identified in the study area. These are barren land, crop, water, vegetation and others. ArcGIS analysis tool was used to portray the dynamics of land cover changes that have been taken place after cyclone Aila. The tool measures the transition of a given land cover class into another class category at a given spatiotemporal extent. Nine unique classes have been introduced as a change factor between the two-time spans. At the final stage, two specific output files have been generated. The first one is change vector file (Figure 2) and the final output consist of change statistics (will be provided in the later section). Finally, the resulting information was analyzed to assess the impacts of cyclone Aila-2009 on the study area.

The temporal change detection map has been prepared from two Landsat imageries of pre- and post-cyclone time sequences to detect and quantify the aerial extent of changes in the study area. The composite data layers of study year have been overlaid to generate a multi-temporal composite data layer. The composite data layer contains identification of each thematic data layer, which was used for addressing it in order to generate area statistics as well as for assigning unique color for a particular feature in the map. The attribute table of this composite data layer was rebuilt to generate multi-temporal change-class with appropriate identification of each change class.

Object-based approach for image classification

An object-based approach has been employed to classify land cover from moderate resolution satellite images of the study area of pre- and post-cyclone Aila time sequences. Five land cover classes were used: (i) barren land; (ii) crop; (iii) water bodies; (iv) vegetation; (v) others. An object-based approach to incorporate multiple spatial scales in the analysis through multi-scale segmentation process was essential to classify the land covers more accurately. The spatial pattern of LULC of six different Upazilas under the study area for before and after cyclone Aila is shown in Figures 5-10. All the products have been generated through digital processing and analysis of Landsat TM images following specific methodologies as mentioned under the present work.

LULC statistics of six Upazila under the study area before and after the cyclone Aila-2009 have been given in table 3. From figure 10, it is revealed that in the Shyamnagar Upazila, crop area has been decreased from 6,234 hectares to about 2,021 hectares while vegetation area has been decreased from 1,10,707 hectares to 107894 hectares after the cyclone Aila-2009 (Table 3). In contrary, water area has been increased from 61,695 hectares to 62,139 hectares. In the Assasuni Upazila, crop area has been decreased from 3494 hectares to 2,339 hectare and vegetation area has been decreased from 6,220 hectare to 6,056 hectares after the cyclone Aila-2009. But water area increased from 10,513 hectares to 13,367 hectares. Similar scenarios have been observed for the rest of the Upazilas under the present study. Crop and vegetation areas were decreased in each Upazilas whereas water area was increased significantly.

A decreasing trend in case of barren land area has been observed in each Upazila except Shyamnagar after cyclone-2009 hit the area.

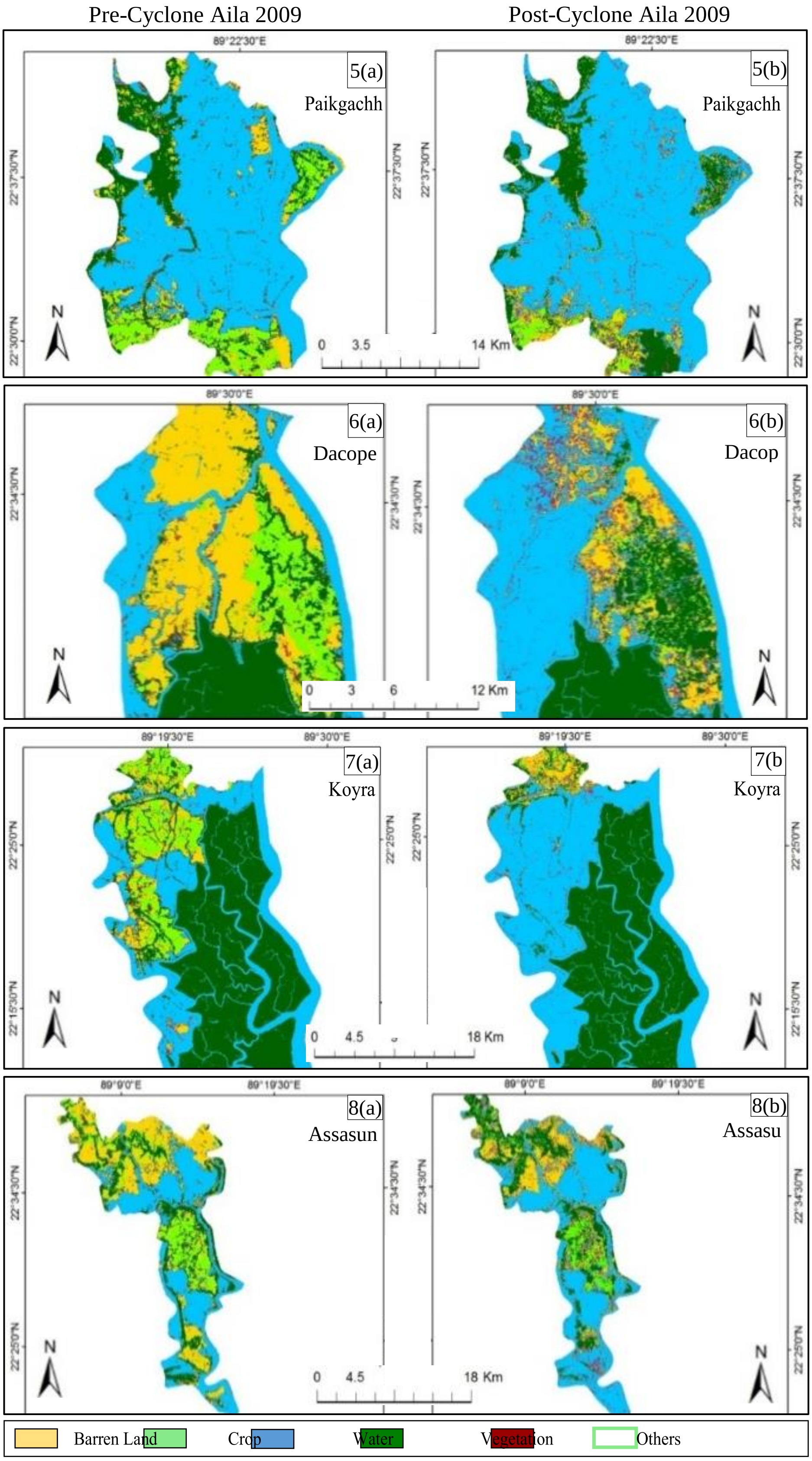

Fig. 5-8. LULC maps for part of (5) Paikgachha; (6) Dacope; (7) Koyra; (8) Assasuni Upazilas. Here ‘a’ and ‘b’ refer to the pre- and post-cyclone condition respectively. All the products have been generated through processing and analysis of Landsat TM images following methodologies as mentioned under the present work.

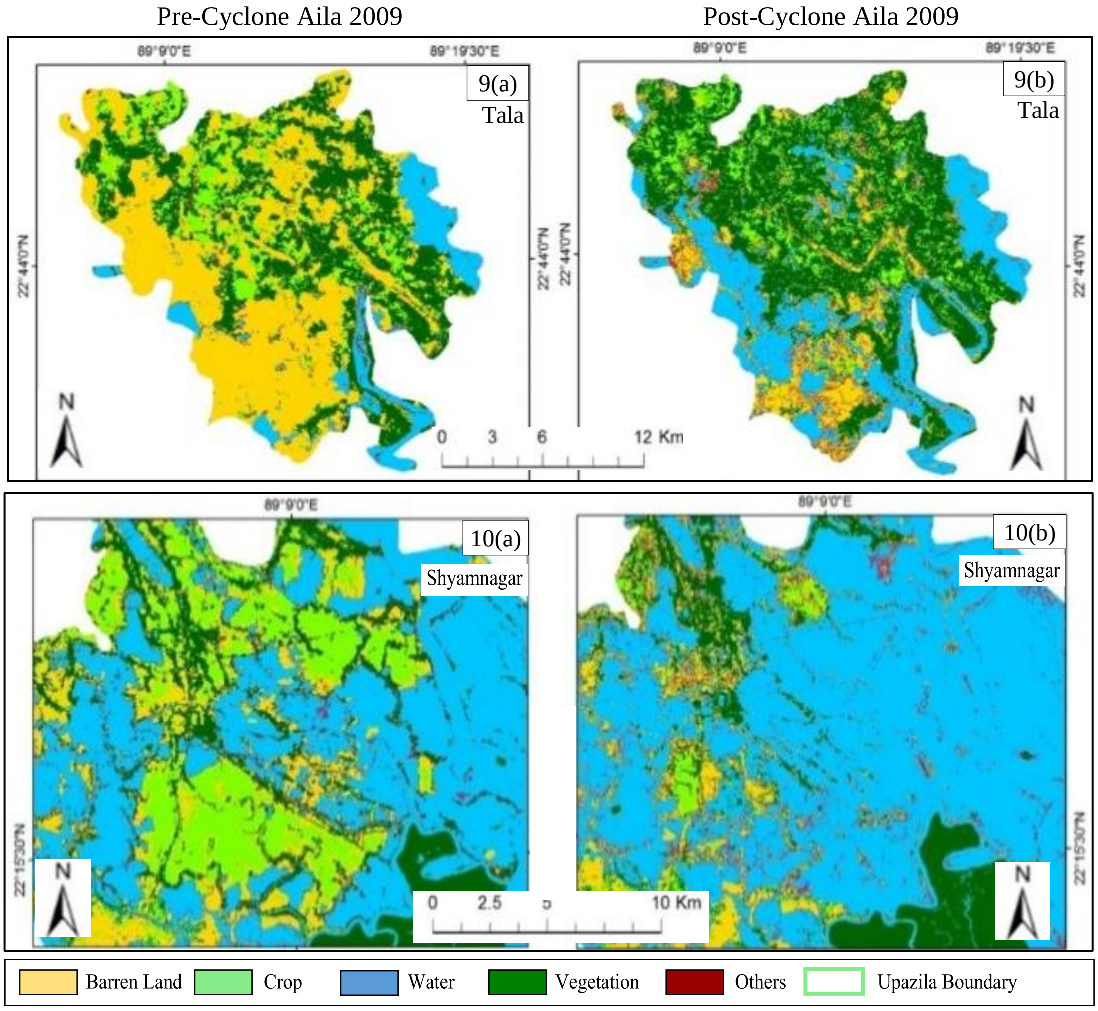

Fig. 9-10. LULC maps for part of (9) Tala and (10) Shyamnagar Upazilas. Here 'a' and 'b' refer to the pre- and post-cyclone condition respectively.

Table 3: Landuse/Cover Statistics of six different Upazilas in the study area.

Landuse Category	Shyamnagar		Assasuni		Tala		Paikgachha		Koyra		Dacope	
	Area		Area		Area		Area		Area		Area	
	Hectare	%	hectare	%	hectare	%	hectare	%	hectare	%	hectare	%
Landuse/Cover Statistics for pre-cyclone-Aila-2009.												
Barren land	31170.08	5.21	7294.77	1.22	15408.10	2.58	2655.54	0.44	6091.20	1.02	12623.10	2.11
Water	61694.50	10.32	10512.81	1.76	3298.14	0.55	24932.89	4.17	83430.50	13.95	19948.64	3.34
Crop	6233.94	1.04	3493.71	0.58	3978.09	0.67	3644.64	0.61	5683.68	0.95	3762.81	0.63
Vegetation	110707.00	18.52	6220.53	1.04	10468.40	1.75	6305.58	1.05	98646.10	16.50	50333.10	8.42
Other	3094.74	0.52	1289.34	0.22	685.08	0.11	1287.18	0.22	2009.70	0.34	1024.29	0.17
Landuse/Cover Statistics for post-cyclone-Aila-2009.												
Barren land	36433.39	6.09	3944.79	0.66	3706.47	0.62	1713.60	0.29	3341.79	0.56	4100.49	0.69
Water	62139.20	10.39	13367.47	2.23	8455.32	1.41	27335.18	4.57	93472.20	15.63	28642.60	4.79
Crop	2021.22	0.34	2338.65	0.39	4386.87	0.73	1459.62	0.24	849.42	0.14	851.85	0.14
Vegetation	107894.00	18.04	6056.37	1.01	14600.60	2.44	5987.07	1.00	96194.20	16.08	50919.70	8.51
Other	4375.35	0.73	3096.90	0.52	2706.12	0.45	2337.48	0.39	2191.50	0.37	3212.55	0.54

Change Detection

Spectral response characteristics of Earth's surface are principally governed by the processes of absorption and reflection of solar radiation through radiative interaction at the soil-vegetation-atmosphere (SVA) interface. Eventually, the radiometric measurements as performed by a specific sensor on board the satellite demonstrates systematic and distinct variation for a given landscape depending on the surface cover characteristics and its associated changing dynamics particularly in terms of spatial coverage and density of vegetation, their optical and architectural properties together with vegetation phenology, plant health, green vigor along with other environmental factors collectively determine the radiative intensities and nature of vegetation radiative responses.

The dynamics of vegetation cover particularly in terms of condition, density, growth, leaf chlorophyll content, photosynthetic activity under exposure to salinity, condition and properties of background soil, existence of water over soil etc. govern the overall vegetation canopy radiative responses leaf structural and optical properties. The biochemistry of photosynthesis and biophysical processes that constrain it are intrinsically linked within the landscape of the inner leaf (Adams and Terashima, 2018; Earles et al., 2019).

Post-classification comparison change detection algorithm was used to investigate the land cover changes between pre- and post-cyclone Aila-2009 classified images for damage assessment. Post classification has been successfully used by a number of researchers for tropical cyclone impact assessment (Dewan & Yamaguchi, 2009). Cross tabulation analysis was performed to analyze the spatial distribution of land cover changes. The comparison of post-classification results provided cyclone land cover classes to assess the damages. It was assumed that within 30 days interval between two images, the changes occurred in the study area land covers just only for tropical cyclone Aila. The descriptive statistical analysis has been performed from the change matrix to quantify the degree and extent of damages of a particular land cover type due to cyclone in the study area. LULC statistics of six Upazilas under the study area before and after the cyclone Aila-2009 have been given in tables 3.

The results indicate that mainly barren land, cropland and vegetation of the study area were damaged moderate-to- high by the impacts of tropical cyclone Aila. This was indicated by class transitions from barren land, cropland and vegetation to water bodies. Major damage was identified for cropland, vegetation and barren land. Around 8,163 hectares cropland area was flooded by cyclone induced surge water and totally damaged which is 1.37% of total area.

The reliable knowledge about how the land cover in such areas actually respond to environmental changes and disaster-driven modifications are prerequisite to making effective decisions in response to these environmental problems. Lack of such knowledge is a major impediment to the design of sustainable development strategies. Recent techniques of studying such changes depend on identifying differences in the state of objects or phenomena by observing them at different dates (Lu et al., 2004)

In the present work, information extraction and detection processes exploit two characteristically different technical algorithm-based approaches leading to land cover characteristics and their geospatial configuration. The first one is the *pixel-to-pixel approach* (Nemmour and Chibani, 2004) which is a simultaneous radiometric spatiotemporal analysis of multispectral images and the second one includes *post classification approach* which is the comparative analysis of independently produced classifications for multi-date time sequences (Alagu Raja et al., 2013). The fundamental consideration in change detection protocol assume that a change in surface cover or surface material will produce a corresponding change in the radiometric surface response characteristics of the study area. Among the presently available change detection techniques, the most commonly used are image differencing, principal component analysis and post-classification comparison (Macleod and Congalton, 1998; Lu et al., 2004). The post-classification change detection technique was chosen for use in this study, because it does not only give the size and distribution of changed areas, but it also gives the percentages of other land cover classes that share in the change in each land cover class individually.

The cyclone had caused significant casualties in the area. It damaged and destroyed a large number of houses, roads, embankments, rural structures and washed away shrimp farms (USAID, 2015; Ahmed *et al.*, 2016 and Bishawjit *et al.*, 2017, Roy *et al.,* 2009).

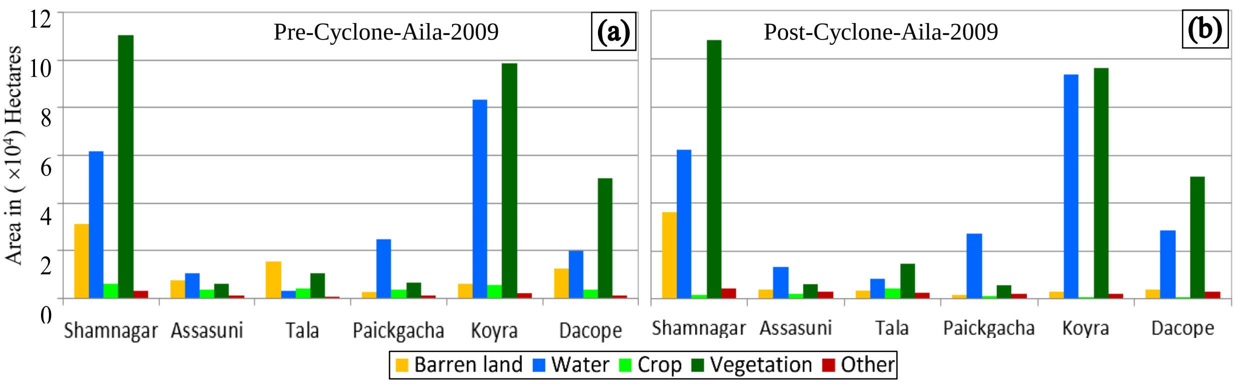

Fig. 11. Landuse/Cover statistics in six different Upazilas of the study area for (a) pre- and (b) post-cyclone Aila-2009. Results have been obtained through processing and analysis of Landsat TM images following methodologies as mentioned earlier under the present work.

Satellite-imaged-based time series observation over the area reveals that the cyclone affected area remained waterlogged for a considerable time period. The situation caused salinization of soil and inland water. As a result, agricultural activities in the region were under serious threat. Radiation-interception characteristics of a green vegetation canopy is determined principally by the wavelength of radiation, surface roughness and optical properties of the canopy components, biochemical contents of the leaves, leaf thickness, leaf structure, chlorophyll content of leaves, distribution of yellow foliage etc. (Ross, 1981). This variation in spectral response characteristics can be utilized for acquiring useful information on the surface properties, vegetation and its condition (Widlowski et al., 2001; Rahman 1996). The effective use of these characteristics requires a thorough understanding of the radiative transfer through vegetation canopy in relation to their morphological and optical properties and on the environmental and other associated factors as well.

In the present study, a direct change detection approach has been adapted using two sets of images acquired before and after the cyclone event to produce a principal component composite image and a set of image difference bands. Techniques in the comparison include supervised classification, unsupervised classification, and object-oriented classification approach with a nearest neighbor classifier. GPS-based ground truthing operation has been carried out for selected features at specific geographical locations.

The spatial pattern of LULC changes corresponding to various land cover categories in the study area due to cyclone Aila-2009 is shown in Figure 11. Table 3 summarizes the results of analysis of the pre- and post-Aila condition as obtained through classification of Landsat TM image followed by necessary pre-processing. While, Table 4 provides the Change Matrix of water area in the study site after the cyclone Aila-2009. Results reveal that, after cyclone Aila-2009, 3.53% of barren land area has been changed into water area; 1.37% cropland area flooded and 2.06% of vegetation land changed into water area (Table 4). Water bodies increased significantly in spatial extent due to cyclone-driven surge water flooding of various land covers. The water area has been found to be about 36.69% including contributions from all other class categories.

Table 4. Change Matrix of water area in the study site after the cyclone Aila-2009.

Class name	Area (hectare)	Area (%)
Barren Land to Water	21,047	3.53
Crop to Water	8,163	1.37
Other to Water	4,427	0.74
Vegetation to Water	12,278	2.06
Water to Barren Land	848	0.14
Water to Crop	74	0.01
Water to Other	3,013	0.50
Water to Vegetation	4,140	0.69
Water to Water	2,18,991	36.69

The spatial distribution pattern of class-to-class area transformation due to cyclone Aila-2009 storm surge for post- cyclone time sequence condition is shown in

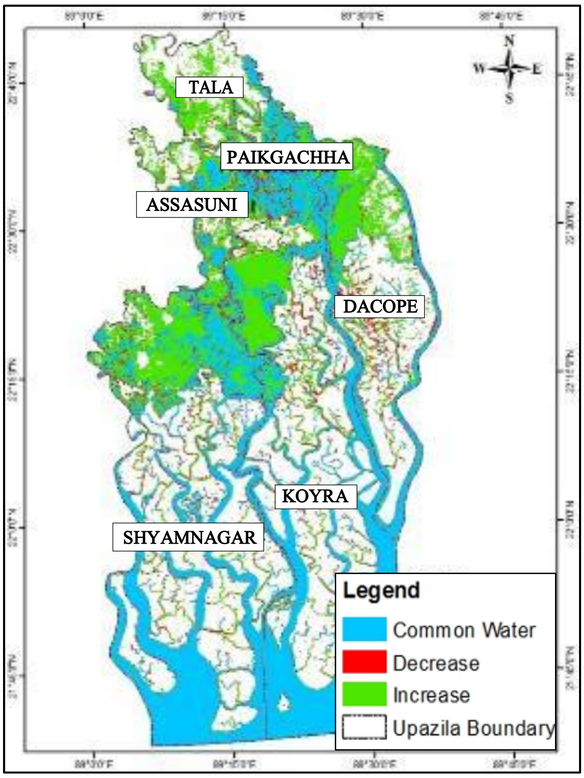

Fig. 12. Landsat satellite derived map of six different Upazilas covering the study area after the cyclone Aila in 2009 representing map of water area increase-decrease.

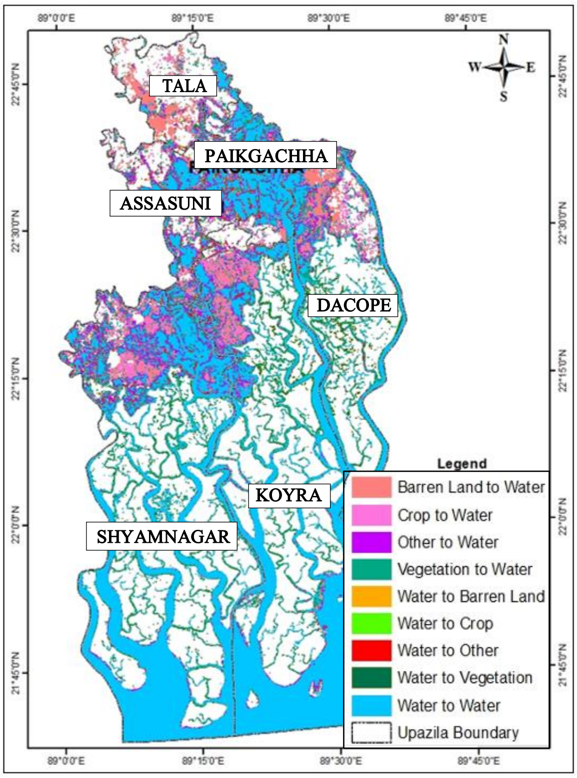

Fig. 13. Landsat satellite derived map of six Upazilas covering the study area after the cyclone Aila in 2009 representing map of water area change due to transformation from different class categories into water class.

Figure 12. While, Figure 13 shows the Landsat satellite derived spatial map of six different Upazilas covering the study area after the cyclone Aila-2009 representing map of area transformation from different class elements

into water category. Interpreted RS data through proper processing and analysis has passed through GIS analysis that provided an area of about 37,839 hectares of land as flooded after cyclone hit.

RS-GIS Analysis of Geo-Environmental Consequences

Cyclone Aila-2009 introduced dynamic changes in the geo-environmental configuration and composition of surface features over the study area with different cascading effects of parameters and processes. RS spectral measurements are principally controlled by the interaction of radiative signal with different earth's surface materials. Figures 14a and 14b represent part of Koyra union under Koyra Upazila, Khulna District as observed in Google images of 2009 and 2011 corresponding to pre- and post-cyclone Aila respectively. Comparison of these two figures provides important differences in surface feature configuration over the area. From post-Aila image of 2011 (Figure 14b) existence of a newly created canal (named as Pabna canal) has been noticed. In the pre-Aila image (Figure 14a), the existence of the canal was not evident. The length of this canal has been estimated to be about 2 km and the canal width varies from place to place over a range of about 80 m to about 300 m along the canal direction.

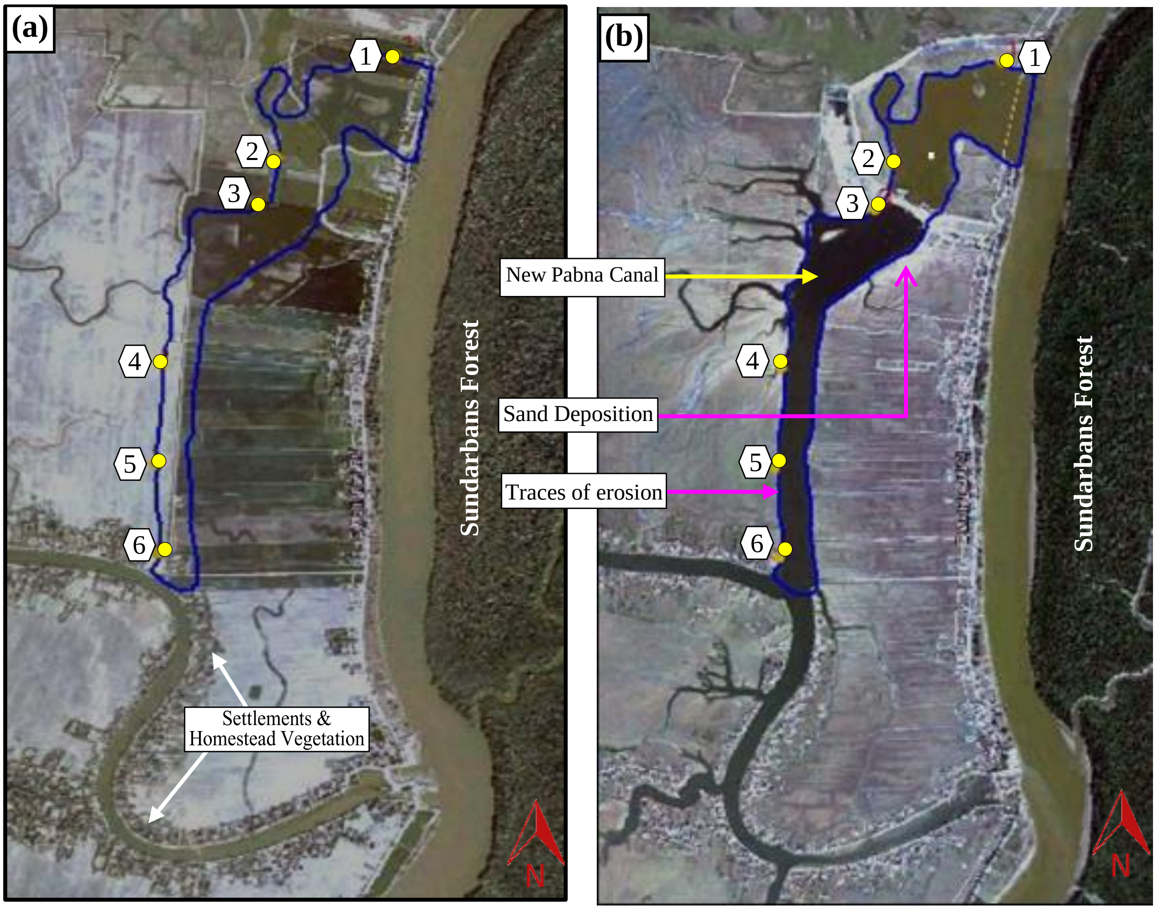

Fig. 14. Image show the (a) pre-Aila 2009 condition and (b) post-Aila 2011 condition.

Referring to Figure 14b, it is to be noted that deposition of sand has been observed along the bank of the Pabna canal. After the landfall of the cyclone Aila, inundation over large area has been observed from the upper part of the post Aila image of 2009. Eventually this inundated area forms the newly developed Pabna canal. Erosion occurs along the Sakbaria River and increase River width of about 17 km along its right bank has been noticed.

Damages of Embankments

Analysis of time series satellite data indicates that devastating Cyclone Aila bleached nearby embankments, roads and settlements, damaged *Ghers* and agriculture fields, increased the widths and depth of channels, developed new channels. Here it should be mentioned that *Gher* farming is a traditional agriculture system in Bangladesh in which a pond is dug into a rice field to use for fish farming, with the dugout soil used to create dykes around the pond for growing vegetables.

Figure 15 represents an enhanced view covering a small part of the study area as appeared in the high-resolution color composite Google Earth image showing the river side along with the area around damaged embankment corresponding to March 1, 2010 i.e., same seasonal time but after one year of cyclone Aila-2009. In this high-resolution optical image damages of the embankment are clearly visible. Damaged embankment allowed storm surge-driven flood water to spread up towards the surrounding areas. Ground data collection at selected location and discussion with the local people therein provided important information on certain aspects of the cyclone Aila-2009.

Fig. 15. Color composite image (Worldview, Google) of March 1, 2010 (Post Aila-2009) shows enhanced view (inset) covering a small part of the present study area: Damaged embankment allowing river water to spread up over the nearby land areas.

As a whole, cyclone Aila hit the southern part of Bangladesh and eastern India on the 25th May 2009, caused widespread damages and largely affected the population living over the area under the present study. In southern Bangladesh, the cyclone accompanied by a tidal surge caused significant damages to the coastal embankments. In the south-western districts, especially in Satkhira and Khulna, people living in the coastal villages were forced to flee to nearby embankments as their houses became submerged under water.

Comparison of satellite images with existing maps after rasterization through scanning and geo-referenced have been utilized for identification and positioning of the affected embankments in the study area. Cyclone Aila-driven surge water exerted pressure to the embankment on its way to move forward and caused damages and casualties. At certain locations surge water washed away part of the embankment network. The incidence had resulted in a prolonged flooding with periodic aggravation during daily high tides.

Flooding and Water Logging

The landscape of the present study site is very much fragile as the site is under storm surge due to tropical cyclone, sea-level rising, tidal excursion and back water effect, thus intrusion of saline water from the Bay of Bengal is common. Water-logging is a pressing concern that becomes worsens for the people of southwest Bangladesh. Bangladesh is a low-lying deltaic country with most of the coastal parts and associated inland of Khulna lie within 1-3 m from sea level. Figures 16a and 16b represent a subset of the affected area as pre- and post-Aila condition as derived through processing and analysis of Landsat TM satellite sensor data. These figures principally demonstrate the water area in part of Koyra and Dacope Upazilas under Khulna district at a date 10th May, 2009, just before the cyclone Aila and 11th June, 2009 immediately after the cyclone.

Comparison of these two images show extended water area under inundation due to cyclone Aila 2009. Comparison of the images show significant increase in water covered areas in the post-cyclone time sequence as compared to that of post-Aila time sequences. Extended spatial coverage of water has been noticed during post-Aila period. Cyclone Aila accompanied by storm surges, flooded the villages and crop fields with saline water from the Bay of Bengal. The incoming seawater caused two-fold effects in the area e.g., (i) water logging in areas at different locations depending on the surface topography and (ii) growing salinity due to incoming surge water had affected most of the vegetation area causing destruction and disappearances of vegetation. A number of scientific studies reported that salinity affects production in crops, pastures and trees by interfering

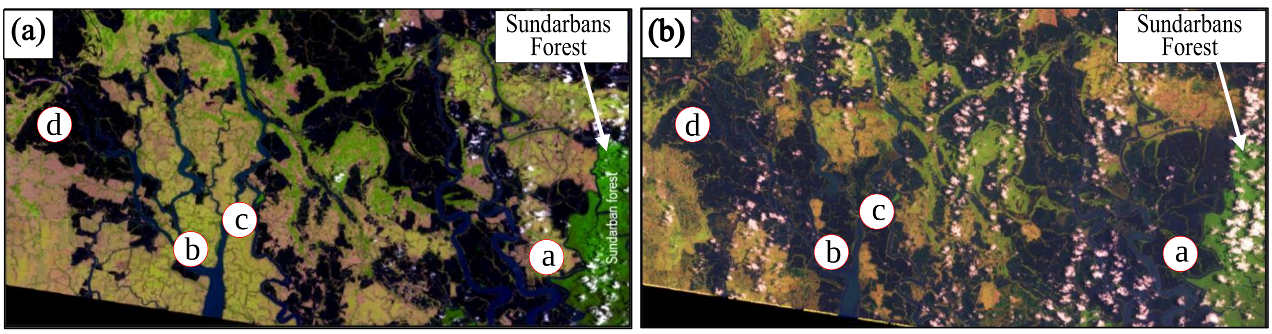

Fig. 16. Landsat TM spectral color composite images RGB (5, 4, 3) of dated (a) May 10, 2009 (Pre Aila) and (b) June 11, 2009 (Post Aila) representing the changes of surface features within the image area.

with nitrogen uptake, reducing growth and stopping plant reproduction. The prolonged water-logging has caused humanitarian challenges in safe water supply, sanitation, shelter, food security etc. In such a context, water logging has had a major impact on the possible rural livelihood options.

Damages of Vegetation and Cropland

Figures 17a and 17b exhibit images of (a) November 27, 2008 and (b) March 1, 2010 representing pre-Aila and post-Aila situation respectively in part of the Koyra Upazila under Khulna district. The presence of water covering the settlement areas is very much visible in image of (b) as compared to that in image (a). The presence of trees and vegetation in Figure 15(a) as textured elements are readily visible over the settlement areas; whereas, such texture is almost absent in Figure 15(b) indicating probable destruction of trees and vegetation.

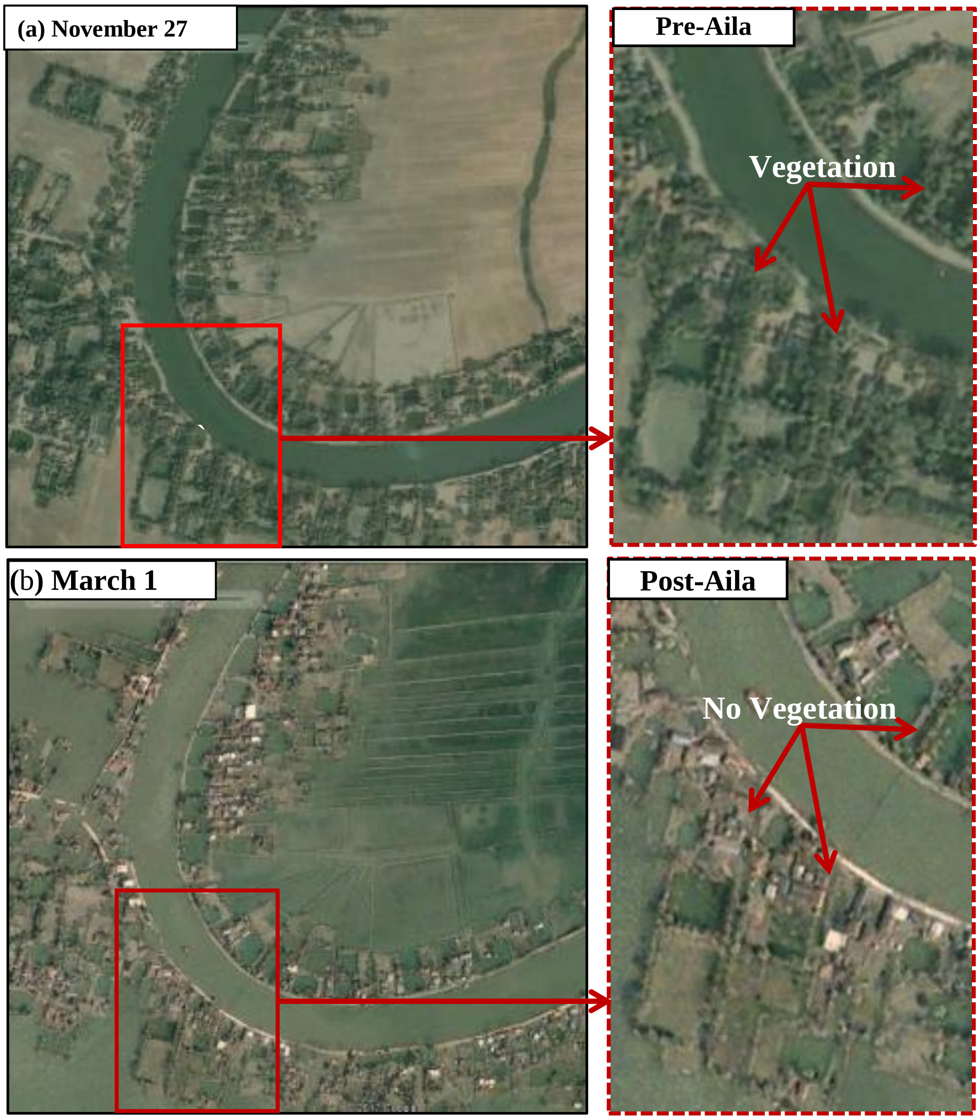

Fig. 17. Images of part of the Koyra Upazila under Khulna district dated (a) November 27, 2008 and (b) March 1, 2010 representing pre-Aila and post-Aila situation respectively.

Cyclone Aila-2009 accompanied by high intensity winds, storm-water surges, tidal inundation, saline water invasion and flash floods caused significant damages to the people dependent on the fragile landscape for their life and livelihood generation activities in addition to the deaths of an appreciable number of populations residing in this area. Plants die when the salinity is above the tolerance threshold; hence biodiversity within the region correspondingly decreases as the essential survival environments are damaged by the high salinity. Severe environmental and ecological problems are caused by saltwater intrusion (Duan, 2016). Resulting effects at the surface level due to land cover changes significantly affected the biophysical and radiative properties of the land-surface over the area as demonstrated through the satellite-derived radiative response properties.

Salinity intrusion by surge water caused significant negative impacts on vegetation and agricultural crops. Presence of excess salts in the soil where plants are present tend to drastically affect the plant yield, growth and its metabolic activities (Lutts et al. 1995; Zeng and Shannon, 2000). Salt stresses affect the crop germination rate, destruct chloroplast structure and reduces photosynthesis to nearly zero and also decrease the grain yield (Asch et al. 2000; Yamane et al. 2015). Plants die when the salinity is above the tolerance threshold essential survival environments are damaged by the high salinity. As a follow up action, environmental and ecological problems are caused by saltwater intrusion (Duan, 2016).

Biophysical characterization of spectral radiative measurements provides enhanced capability and precision for radiative data interpretation. The dynamic changes in landcover characteristics over the area in the post-cyclone time period caused noticeable modification of radiative transfer properties as demonstrated through the satellite-derived surface albedo, and surface temperature in the area under exposure of cyclone Aila-2009. Satellite image analysis and interpretation with GPS-guided ground-based observation, correction and verification operation together with discussion at local level led to finalization of the satellite image It has been found that almost all the agriculture land (>90%) and homestead gardens (>70%) were flooded and 70% of the green vegetation were damaged. Much of the natural vegetation of salt-affected areas has been destroyed or damaged. This has caused major changes to the landscape in the area.

Figure 18 represents images dated (a) October 30, 2008 of Pre-Aila and (b) 17 October 2009 of Post-Aila time sequences. Figures represent changes of cropping activities and inundation respectively in the Koyra and Dacope Upazilas under Khulna district due to cyclone Aila. The whitish cluster followed by an adjacent dark shadow generally represents cloud clusters over the Landsat images. The figure demonstrate that relatively large areas were under water in the post-Aila time, which had been previously under Aman crop areas in the pre-Aila image. This area usually shows excess salt content. Such a situation largely limits the crop cultivation in the area.

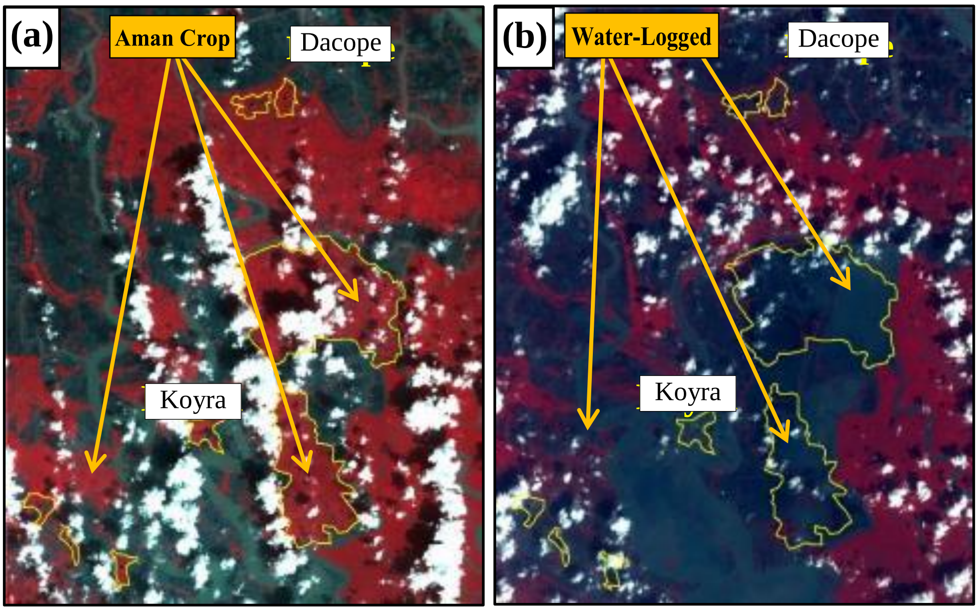

Fig. 18. Landsat TM spectral images (a) October 30, 2008 (Pre Aila) and (b) 17 October 2009 (Post Aila) representing changes of cropping activities and inundation respectively in part of the Koyra and Dacope Upazilas.

It may be mention that Intergovernmental Panel on Climate Change (IPCC) AR4 notified about the future storm surges and related floods in all over the Word and Bangladesh with their thought that Bangladesh will likely to be more severe as future tropical cyclones has possibility to increase in intensity (IPCC, 2007; Ülker et al., 2018, 2020) which is in conformity with the present results.

Conclusions

Threatening consequences of global climate change, increased natural disasters causing losses of lives and properties, disturbing large scale agricultural productivity creating various geo-environmental crises altogether put serious challenges to the living community the world over. Situational gravidity demands focused and harmonized effort for undertaking necessary mitigation measures. Effective monitoring system empowered by (i) satellite-based effective data acquisition system together with (ii) proper methodological framework and operational guideline for fruitful application is a crucial issue in generating, providing and maintaining useful and timely disaster information support services.

This research dealt with the application of satellite-based time series data in characterizing and analyzing the effects of cyclone Aila of 25th May 2009 on the geo-environmental condition of the study area partly covering Satkhira and Khulna districts – the two most badly affected areas in Bangladesh. A two-stream technical approach has been adapted and applied to comprehend and assess damages and destruction caused by tropical Cyclone Aila-2009 in Bangladesh using time series, multi-sensor satellite data. Necessary methodological framework based on satellite-based RS coupled with appropriate ground RS technology platform and eventually guided by GPS-based positioning system has been developed.

The first approach includes feature-based spectral characterization of radiative responses. Following spectral pattern recognition protocol in conjunction with spatial data analysis procedure has been exercised for targeted information retrieval. Digital image based spectral characterization of radiative response pattern of individual surface features in relation to feature specific radiative signature library under the information retrieval process has been employed. Results demonstrated dynamic variation in radiative response properties in the area over time for pre- and post-cyclone time sequences. In relation, a distinct feature type dependency of radiative responses is also evident. Storm surge water caused soil extended water coverage, soil moisture variability, salinity intrusion that ultimately led to evolving vegetation condition, their destruction and finally disappearances. Evolving geo-environmental conditions are being manifested in the spectral radiative response properties in time series satellite-based observation.

The second approach consists of object-based image classification technique application for mapping cover categories corresponding to pre- and post-cyclone multi-sensor satellite data. Post classification change detection technique has been applied for characterization and identification of types of land cover changes due to disaster induced devastation. The technique takes into account various surface features and generates products using high resolution multiple satellite raster images. Major numerical and functional operations have been accomplished using Spatial Modeler Language (SML) in ERDAS Imagine in combination with ArcGIS. The complete setup has been encapsulated in GIS operational platform.

Analysis depicts that around 37,839 hectares area was flooded after cyclone hit. About 60% of the study area was significantly damaged by Aila. Near about 8,163 hectares of croplands were flooded by storm surges and with vegetation, settlements and infrastructure of the area all being completely or partially damaged. Analysis depicts that around 37,839 hectares area was flooded after cyclone hit. About 60% of the study area was significantly damaged by Aila. Near about 8,163 hectares of croplands were flooded by storm surges and with vegetation, settlements and infrastructure of the area all being completely or partially damaged.

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