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Assessment of Ecological Change Due To Cyclone Using Remote Sensing Technique

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Abstract

Ecology in coastal area of Bangladesh is affected by several natural hazards like cyclones, coastal flooding, tidal surges, salinity and other phenomenon. The ecological change of this area is mainly attributed to the periodic cyclones caused by deep depression formed over the Bay of Bengal. This research is carried out to measure the ecological change of cyclone affected costal area in Bangladesh using two key factors, named vegetation and temperature. To assess it, MODIS Global Disturbance Index (MGDI) method has been used for considering recent cyclone SIDR and AILA using time-series terra MODIS data between the periods 2005 to 2011. Raw MODIS data has been processed by re-projection and atmospheric correction. Enhanced Vegetation Index (EVI) and Land Surface Temperature (LST) have also been derived to determine the MGDI analyzing the variation of vegetation and temperature. It is found from the research that cyclones cause ecological change in the coastal area. Severe ecological disturbance has been found on the Sundarban area of Khulna, because of SIDR in 2007. It also had effects in Bagerhat, Barguna, Patuakhali and Pirojpur. In 2009, another cyclone, AILA causes severe ecological disturbance on Satkhira district and some part of Khulna district. However, this study provides a baseline to prioritize measures for reducing the ecological disturbance due to cyclone.

Introduction

Bangladesh, a cyclone prone coastal country bounded by Bay of Bengal on its south covers with 47211 km² coastal area which faces severe cyclone and storm surge every three year due to its geographic location and its tropical monsoon climate (Barua et al., 2010: 218; Rahman, 2011: 9). According to the previous record of last 100 years, among the 508 cyclones originated in the Bay of Bengal, 17% have hit in this coastal area of Bangladesh and during last 35 years nearly 900,000 people died due to catastrophic cyclones (Rahman, 2011: 9). Moreover, unique geographical location, high population density and low per capita income are the main structuring factors that are contributing to increase its vulnerability (Saha, 2014:63).

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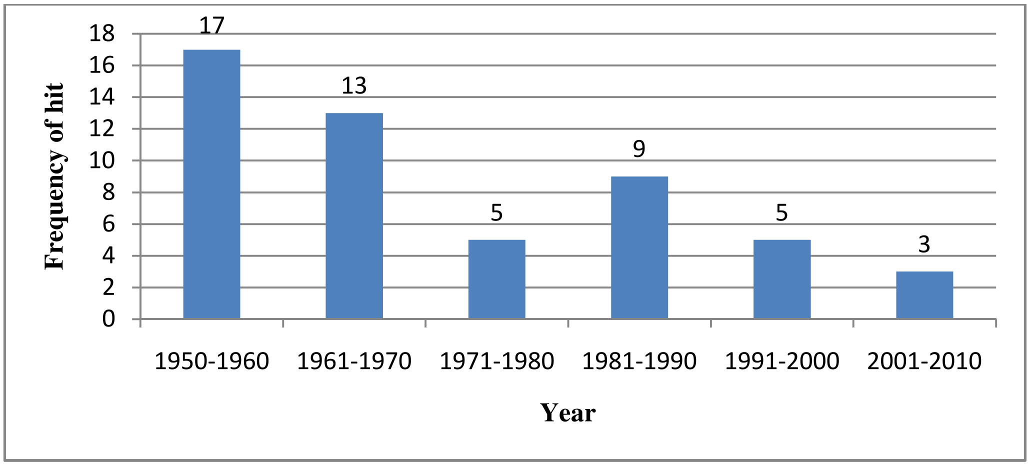

Source: Saha, 2014 : 69

Fig. 1: Frequency of cyclone hit in Bangladesh in the last 50 years

Cyclone causes not only the physical damage but also change the ecological balance of the coastal area which is considered as interfaces of land and ocean balancing geosphere, atmosphere and biosphere where major biological activity occurs for easy living (Rahman, 2010: 1). It contains many ecosystems, e.g. mangrove, marine, estuary, islands, coral and sandy beaches thus renowned as a treasure house of wetland resources and bio-diversity (Chowdhury, n.d :1).This kind of above substance are the important sources of food and raw materials, energy, minerals, recreation, transport, and trade thus makes the zone highly productive (Rahman, 2010: 1). This all kinds of substances makes the ecology which is affected by tropical cyclone thus causes widespread defoliation of rainforest canopy trees, removal of vines and epiphytes, along with the breakage of crown stems and associated tree falls that result in significant changes in forest microclimates and canopy, and complex vegetation and faunal responses to newly created light, temperature and humidity regimes and damage to different micro-organism (Turton, 2007: 2)cyclone also affect the valuable habitats with an equally extraordinary collection of species (Rahman, 2010: 1). Mangrove also provides environmental supports fort the community as well as serve as a protection for a myriad of juvenile aquatic species, functioning as a habitat for a variety if terrestrial fauna and a source of nutrients that helps to sustain many complex food chain (Sarkar, 2010: 1187).Tropical cyclones have devastating impacts on the floristic diversity pattern of tropical mangrove forests; sometimes it takes a significant amount of time for the forest to regenerate which influences the environmental sustainability of the area (Bhowmik, 2013: 62). Baldwin et al. (2001) state that the time required for the regeneration of mangrove forests following cyclones depends on the different pathways which are produced by the complex interactions between representing capability, seedling survival, post-hurricane seedling recruitment, and colonization by herbaceous vegetation. The time required for regeneration also depends on the degree of damage. Salinity and tidal surges that are considered as major determinants of the vegetation is affected by accumulation of salts from inundated sea water caused by cyclone (Dutta et al., 2014: 555). Inundation of land during high tide of tropical cyclone with saline causes salinization of the soil which is responsible for declining growth of vegetation. Lack of safe drinking water is the prime issue in nowadays in the coastal area which as a result creates pressure on ground water which is decreasing gradually due to excessive exploitation (Haque, 2006: 1362). Nowadays the timing, location and magnitude of vegetation disturbance, change in temperature in the environment and salinity in the soil is presently a major uncertainty in understanding ecological balance. So it is very much important to analyze the above mention factors to measure the ecological disturbance so that its negative impact on environment could be mitigate in the cyclone prone coastal area of Bangladesh.

The study enables to help in assessment of ecological disturbance. It is expected that the study will provide useful information that serve as a strong foundation toward assessment of ecological disturbance and adaptive nature of the environment and thus will help to take necessary steps to reduce the disturbance and save the ecology.

Earth Observation satellites like MODIS Terra satellite image is capable of viewing of inaccessible and protected areas for monitoring earth surface processes with high temporal resolution proposed a new index called MODIS Global Disturbance Index (MGDI) for assessing the large scale ecological disturbance (Dutta et al., 2014: 555-556). The concept of MGDI is based upon the fact that surface temperature decreases with an increase in vegetation density through latent heat transfer. The Two input variables such as land surface temperature (LST) and enhanced vegetation index (EVI) respond to different biophysical processes, thereby enriching the information content of indices (Mildrexler et al., 2009: 2105).In the present study, the MGDI approach was utilized to assess the ecological disturbance caused by two major cyclones (SIDR and AILA) occurred in the last for better management of mangrove ecosystem.

Objectives of the Study

The aim of the study is to assess the scenario of ecological balance due to the impact of cyclone in the cyclone affected coastal area of Bangladesh between the years of 2005 to 2010. The specific objectives of the research are (1) to identify cyclone affected coastal area of Bangladesh according to the previous cyclone data between the years 2005 to 2010; and (2) to analyze the ecological change in cyclone affected coastal area of Bangladesh using remote sensing techniques.

Study Area

The study area for this research is coastal area of Bangladesh. Geographically, the coastal zone lies within the tropical zone between 21-23° N and 89-93° E with total area of 2.85 million hectares where 0.83 million hectares are arable lands shown in Figure 2 (HAQUE, 2006:1359). The coastline of Bangladesh broadly is divided into three regions: the deltaic eastern region (Pacific type), deltaic central region and the stable deltaic western region (M.H. Minar, 2013: 114). The coastal area consists of 147 Thanas (sub-districts) of 19 districts of the southern part of the country (NAJNIN, 2014: 6). Topographically, most of the areas are low-lying and have elevation about 1.5 to 11.8m above the mean sea level (HAQUE, 2006:1360). These areas are subject to flooding in the monsoon season and water logging in parts of the basin areas in the dry season. The most considerable characteristic of hydrology in relation to agricultural development is the seasonal shallow flooding (up to 90 cm) which affects about 64 % of the total area. (M.H. Minar, 2013: 115)Population density in the coastal area is slightly higher than national average(NAJNIN, 2014: 31). A total of 35.1 million people live in the coastal zoneofBangladesh in 2001, increasing from only 8.1 milliona century earlier(M.H. Minar, 2013:114). It is anticipated that, thecoastal population will be growing to about 41.8 million in2015 and 57.9 million in 2050 (M.H. Minar, 2013:114).

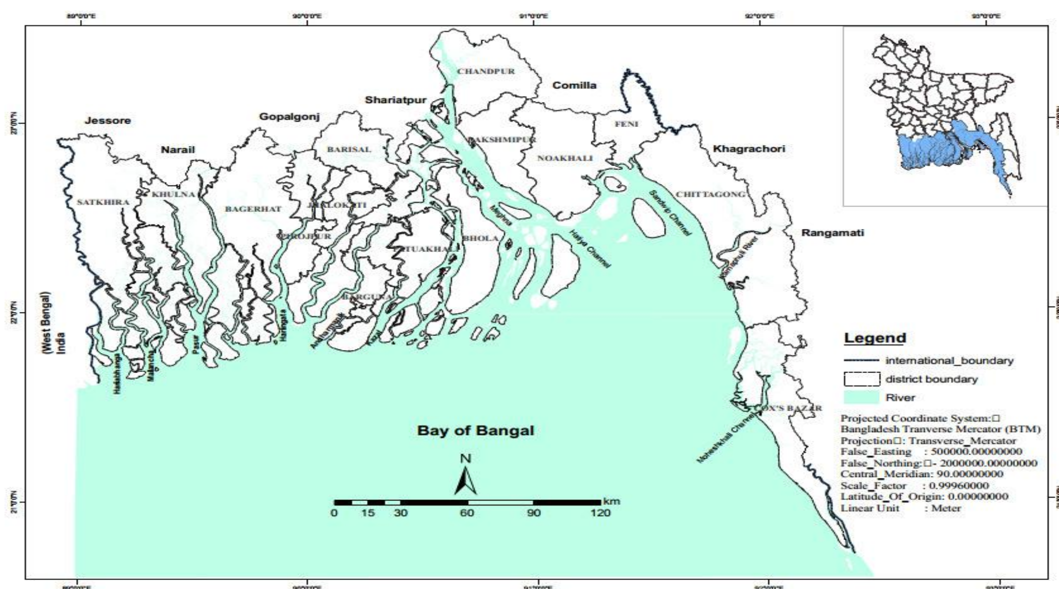

Fig. 2: Location map of study area.

Data and Methodology

To assess the ecological impact on cyclone affected area, some influential key factors of ecological change such as vegetation change, temperature variation, salinity level in soil and number of animals change in the communities are found from literature review to measure it. In this research, vegetation and temperature are considered to assess it using MGDI method. At first the cyclone affected area has been identified according to the damage data of previous cyclone named SIDR and AILA occurred in 2007 and 2009 respectively. After that The MGDI has been calculated through the value of EVI & LST. Then the ecological change of the cyclone affected area has been assessed through the value of MGDI. The methodology of the research is described step by step in the following and it has been chosen because of available in free public-domain MODIS web site and its spatial resolution.

The Terra MODIS data has been used in this research shown its characteristics in the table 1.

Table 1: Terra MODIS image used in the research

Data Name	Data type	Duration	Re-projection System	Source
Terra MODIS	The MODIS 250 m vegetation indices product (16 day composite)	2005,2006,2007, 2008,2009,2010	Geographic co-ordinate system	Goddard Space Flight Center(LAADS Web) http://ladsweb.nascom.nasa.gov/
	1 km Land Surface Temperature product (8 day composite)	2005,2006,2007, 2008,2009,2010	Geographic co-ordinate system	

The collected data is in HDF-EOS format and Sinusoidal projection with the WGS84 datum. MODIS Swath tool has been used to re-project this MODIS data from sinusoidal projection to geographic projection. HDF-View software has been used for browsing and viewing the contents of HDF files.

Changing Vegetation and temperature variation has been determined through the methods of Enhanced Vegetation Index (EVI) and Land surface temperature (LST) respectively. EVI are calculated from the following equation (1)(Matsushita et al., 2007: 2638).

$$EVI = G \times \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + (C_1 \times \rho_{red} - C_2 \times \rho_{blue}) + L} \dots\dots\dots\dots\dots (1)$$

Where, G is a gain or scaling factor. The coefficients adopted in the EVI algorithm are, L=1, C1=6, C2=7.5, and G=2.5.If blue reflectance (Band 3 of MODIS) is equal to or greater than 0.2, it is considered as cloudy pixel.

The further image processing needed for determining Land Surface temperature (LST). Raw data convert to radiance/reflectance, brightness temperature computation, water vapor content estimation, atmospheric correction, land surface albedo computation and Land surface emissivity computation has been done with the ILWIS software. The LST has been calculated in the following equation (2) (Zhao, 2009: 346).

$$LST = T31 + a1 + a2\,(T31 - T32) + a3\,(T31 - T32)2 + (a4 + a5W)\,(1 - \varepsilon) + (a6 + a7W)\,\Delta\varepsilon \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Where, $LST$is land surface temperature; $T31$ and $T32$ represent brightness temperature of bands 31 and 32; $a1$, $a2$, $a3$, $a4$, $a5$, $a6$ and $a7$ are split-window coefficients acquired through simulation with values of 1.02, 1.79, 1.20, 34.83, −0.68, −73.27 and −5.19 respectively .Water vapour content of the atmosphere; ε [$\varepsilon = (\varepsilon31 + \varepsilon32)/2$] is the mean effective emissivity of MODIS channels 31 and 32; and $\Delta\varepsilon$($\Delta\varepsilon = \varepsilon31 - \varepsilon32$) is the spectral emissivity difference.

MODIS Global Disturbance Index (MGDI) is an approach towards detection of ecological disturbance which also need to calculate the above vegetation index and land surface temperature data (Dutta et al., 2014: 556).

MGDI can be calculated in the following equation (3) (Dutta et al., 2014: 556).

$$MGDI_{inst} = \frac{(LST_{max}/EVI_{max-post})current\ year(y)}{(LST_{max}/EVI_{max-post})multiyear\ mean(y-1)} \ldots\ldots\ldots\ldots (3)$$

Here, $MGDI_{inst}$ = Instantaneous MGDI value, LST_{max} = Maximum 16-day composite LST (°C) in a year, $EVI_{max-post}$ = Maximum EVI value that occurs after the annual maximum LST (LST_{max}) during the same year for every pixel, $EVI_{max-post}$ = Maximum 16-day composite EVI following the $LST_{max,}$ Current year (y) = year being evaluated for disturbance and Multi-year mean (y−1) = the mean of the ratios excluding the current year.

The Percentage change in MGDI for the instantaneous disturbance has been calculated using the following equation (4).

$$\%\ \text{change in MGDI current year (y)} = \frac{MGDI\ current\ year}{MGDI\ multi-year\ mean} \times 100 \ldots\ \ldots\ \ldots\ \ldots\ (4)$$

Around fifty spatially distributed homogeneous clusters of affected pixels have been selected across the affected region and the mean value of %MGDI change for each cluster is computed. The inter-cluster mean value plus one standard deviation of the %MGDI change are considered to be the threshold, and the value has been used for discrimination of the disturbed pixels. Vegetation change/non-change was detected using the change detection method. For analyzing the change detection the following equation (5) has been used.

$$\text{Change Detection} = (\text{present year data} - \text{past Year data}) \times 100 \ldots\ \ldots\ \ldots\ \ldots\ (5)$$

Results and Findings

Cyclone Prone Coastal Area in Bangladesh

The cyclone prone coastal area has been selected on the basis of number of people death and damage caused by two devastated cyclone named SIDR and AILA which occurred in 2007 and 2009 shown in Figure 3. AILA hit the South-Western coastal region of Bangladesh on 25 May 2009. The sustained wind speed of the Cyclone AILA was about 65-75 mph (USS, 2009: 4). About 2.3 million people were affected by AILA and cause economic loss of 141 million and many of them stranded in flooded villages as they had no alternative to save themselves (USS, 2009: 4). The Cyclone AILA furiously hit the Satkhira and Khulna Districts of Bangladesh, entrancing immediate death of about 325 people including massive infrastructure damages (USS, 2009: 4).

Moreover, damage information has also been noticed from Bagerhat, Pirojpur, Barisal, Patuakhali, Bhola, Laksmipur, Noakhali, Feni, Chittagong and Cox's Bazar (USS, 2009:5). On November 15, 2007, the super cyclone SIDR hit the south western coast of Bangladesh with driving rain and high wave (MFDM, 2008: 9). Height of storm surge reached about 20 feet in certain areas, which causing extensive physical destruction, causalities, damages of crops, livestock and flooding low lying lands. The cyclone's attained winds up to 220 km per hour causing further destruction to buildings and uprooting trees that in turn destroyed housing and other infrastructures (MFDM, 2008: 9). The devastating cyclone also disrupted communication network and electricity supplies at south western coastal region. Government has classified four districts as 'worst' affected – Bagerhat, Barguna, Patuakhali and Pirojpur and eight districts as 'badly' affected – Khulna, Madaripur, Sariatpur, Barisal, hola, Satkhira, Jhalukhati and Gopalganj of the total 30 affected districts. Total damage has been estimated to 1.6 billion US dollars (MFDM, 2008: 9).

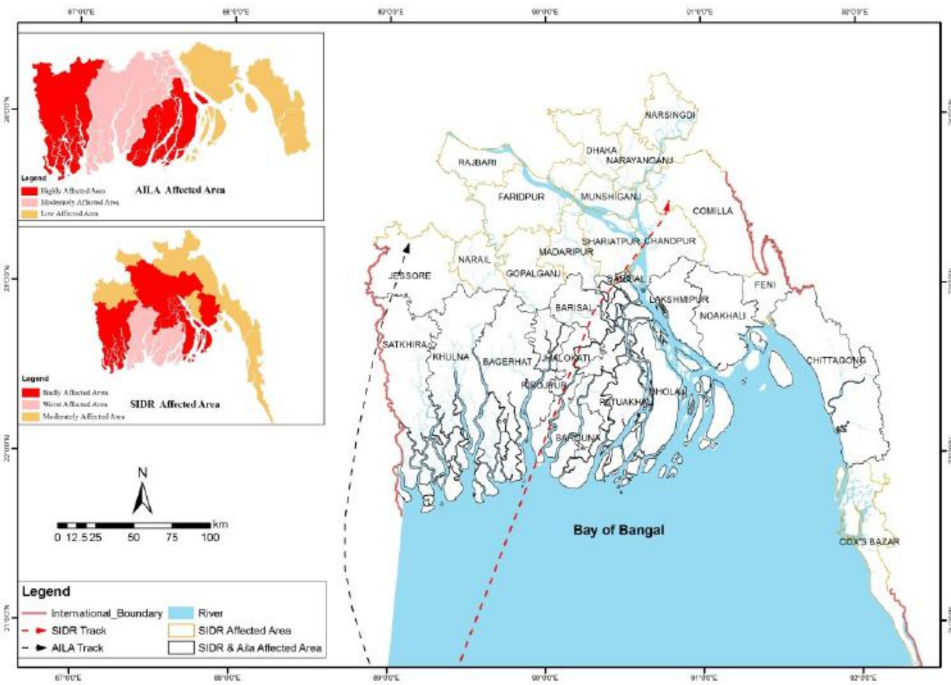

Fig. 3: Cyclone prone coastal area of Bangladesh

Vegetation Change Caused by Cyclones

Figure 4 represents the change of vegetation due to Cyclone SIDRon 2007. Here the negative value represents the reduction of vegetation and positive value represent the generation of vegetation. It has observed that after the cyclone SIDR 0-20% vegetation

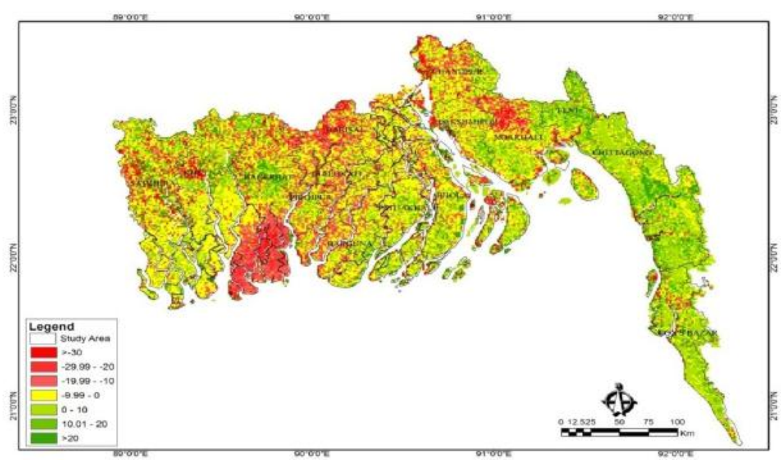

Fig. 4: Vegetation change due to SIDR

change in major part of the coastal zone which include Sariatpur, Barisal, Bhola, Satkhira, Jhalukhati, Gopalganj and higher value(>30%) indicate highly disturbed area which include Khulna, Bagerhat, Barguna, Patuakhali and Pirojpur. The positive value (>20%) is highin Chittagong and Cox'sbazar area where there are high regeneration of vegetation in 2007. SIDR slightly affect in some portion of the Cox'sbazar.

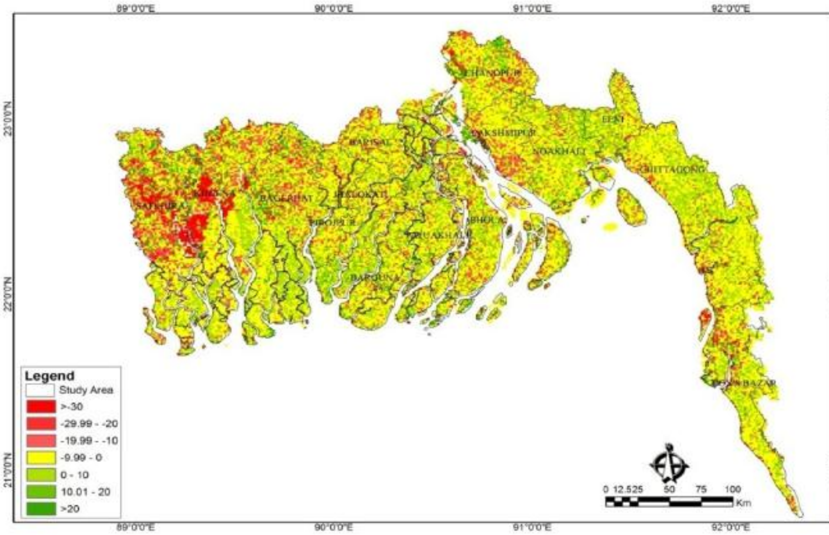

Fig. 5: Vegetation change due to AILA

Figure 5 presents the vegetation change after AILA on 2009. It has been found the most vegetation change in 2009 is happened in Satkhira district and Khulnadistrict where the value (>30%) is high. On the other part of the coastal area there are low vegetation change in 2009 which include Bagerhat, Pirojpur, Barisal, Patuakhali, Bhola, Laksmipur, Noakhali, Feni, Chittagong and Cox's Bazar.

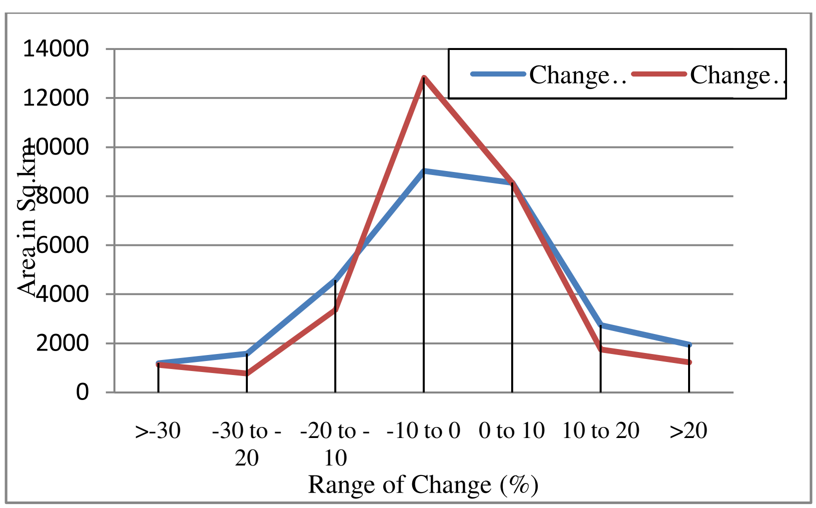

Fig. 6: Comparison of vegetation change due to cyclone in different years

Figure 6 presents a comparison about vegetation disturbance between year 2007 and 2009 where the positive value indicates the generation and negative value indicates the reduction. It has observed that 0-10% vegetation reduction occurs in most of the area in 2009 than 2007. Because AILA mainly hit the Satkhira and Khulna district and affect much on that area. So in the other area it causes less reduction of vegetation but SIDR hit badly on Khulna, Bagherhat, Barguna, Patuakhali and Pirojpur and causes reduction of vegetation (0-30%) in most of the area. But different scenario has been found in the Chittagong and Cox's Bazar area where the vegetation have been increased as not affected by cyclone.

Ecological Change Caused by Cyclones

The percentage change in MGDI (%$MGDI_{change}$) for each pixel was analyzed from temporal mean MGDI value. The concept of MGDI is based on the fact that the extreme events which causes ecological disturbance will lead to an increased surface temperature and reduced vegetation vigor. The % MGDI change above 90% of the temporal mean has been considered as the disturbance threshold for discrimination of the disturbed areas caused by cyclones from the non-disturbed areas.

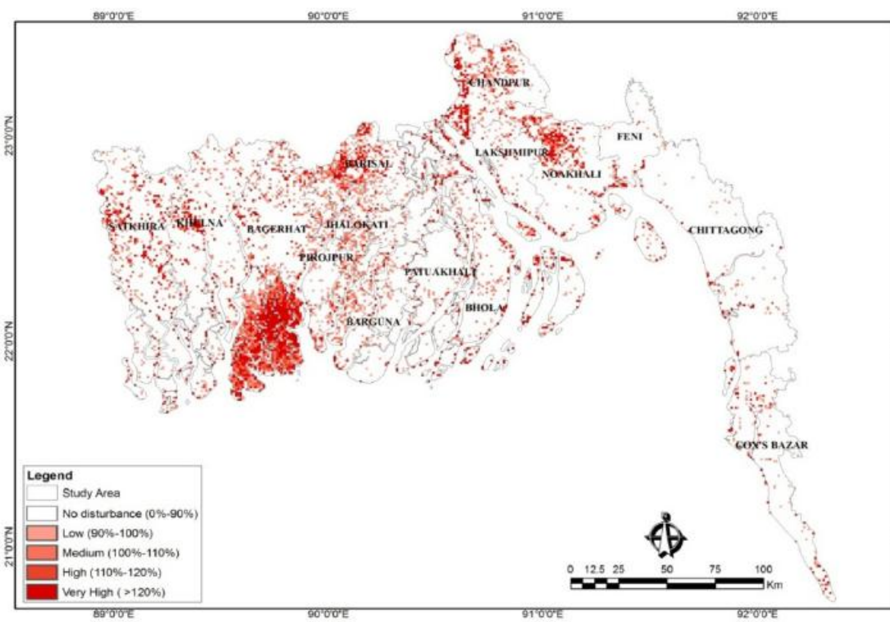

Fig. 7: Ecological change caused by SIDR on 2007

Figure 7 describes the ecological change caused by Super-cyclone 'SIDR' on the coastal area where the red mark indicate the disturbance.It has observed that SIDR causes severe disturbance on the Sundarban area of Khulna where the value(>120%) is high and also on the Bagerhat, Barguna, Patuakhali and Pirojpur and causes disturbance on the Bhola, Feni, Chandpur, Barisal, Jhalukhati and slightly effect on the Chittagong and Cox's bazar.

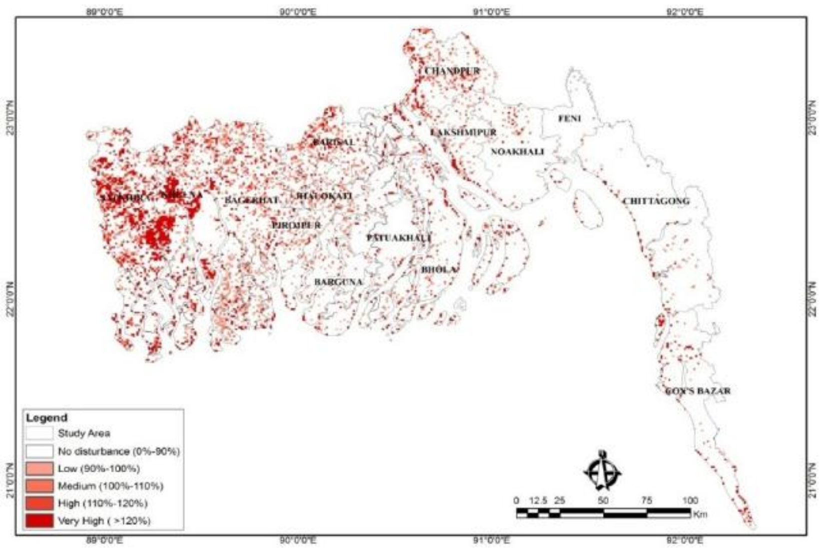

Fig. 8: Ecological change caused by AILA on 2009

Figure 8 presents the change in the ecology due to AILA which occurred on 2009. AILA causes severe ecological disturbance on Satkhira district and some part of Khulna district and also in Sundarban. It has also observed that it causes medium disturbance in the surrounding area of Satkhira and Khulna include Bagherhat, Pirojpur, Jhalukhati, Barisal, Chandpur.

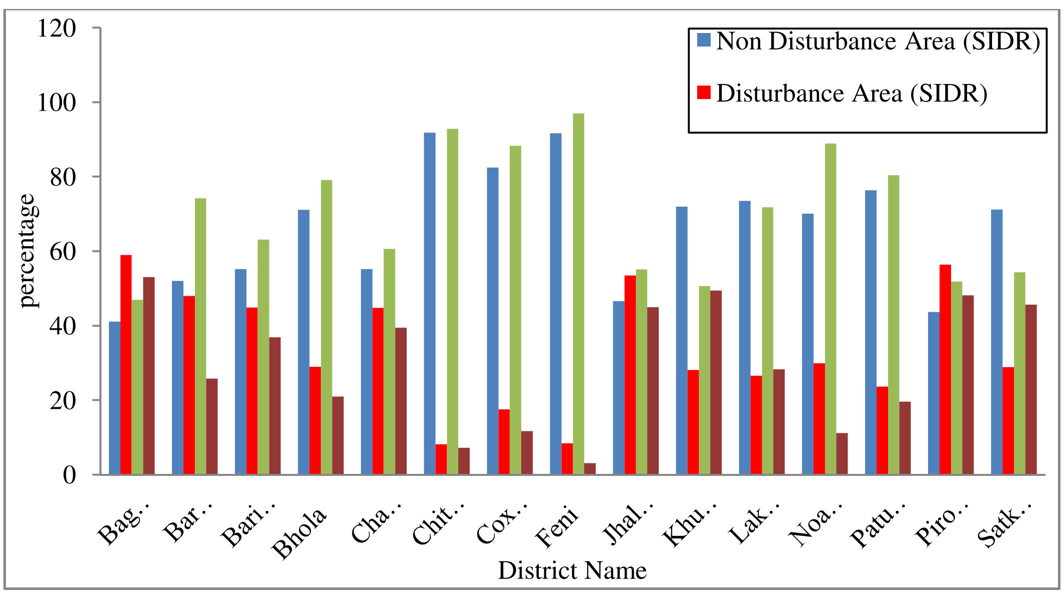

Fig. 9: District wise disturbance area due to cyclone SIDR and AILA

Figure 9 presents the District wise disturbance due to Cyclone SIDR and AILA. It is observed that there are some districts, which are affected badly on both cyclones. These districts are Bagherhat, Satkhira, Khulna.

If comparative analysis is made between the cyclone data which has been collected through the literature review and the output of MGDI, it is observed that there is a similarity on both data. From the literature review, it has been found that SIDR caused physical damage on Bagherhat, Khulna, Barguna, Patuakhli and Pirojpur as well as from the output of MGDI, it can be said that the high ecological disturbance occurs in these areas. The outcome is same in the case of AILA. AILA hit badly on Satkhira and Khulna and from the output of MGDI, it is found that ecological disturbance mostly occurred in Satkhira and some parts of Khulna. From the analysis in the research, it is observed that Satkhira, Khulna, Bagerhat, Pirojpur are the most vulnerable ecological areas. Both SIDR and AILA occured in these areas, and the areas are also ecologically potential.

Conclusion

Without better earth's ecosystem living things are not able to survive. Everything is interrelated. Over the last 50 years, human has changed the ecosystem through their activities. The ecology of the coastal area is very much important for the survival of the inhabitants, which are effected by cyclones thus causing the ecological disturbance. The aim of the research was to assess the ecological disturbance caused by two cyclones of varying intensity and occurring at different times and it is found that the ecology of the coastal area has been greatly disturbed by cyclones. The research output can be used to reduce the negative impact of the ecology and management plan to protect the environment for the survival of the inhabitants.

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