IMPACT ASSESSMENT OF CYCLONIC STORM SURGES ON ECOYSTEM SERVICES IN THE SOUTHWEST COASTAL ZONE OF BANGLADESH

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ABSTRACT

Two of the most devastating cyclones experienced lately by Bangladesh are Sidr and Aila, both of which hit the southwest coast of Bangladesh on November 15, 2007 and May 25, 2009 respectively. Both the cyclones slammed the coastal areas of Bangladesh and several rivers broke through embankments, causing widespread flooding. It took several months to repair these broken embankments and draining out the excess rain & surge waters trapped inside the polders. This caused long-term flooding which affected the ecosystem services in the coastal area. This paper explores the temporal variation of wetlands before & after the two cyclonic events and its impact on ecosystem services of coastal zone. The study area covers the southwest coastal zone of Bangladesh, which includes the Satkhira, Khulna and Bagerhat districts. Important ecosystem services in the study area include agricultural lands and wetlands which support fisheries resources. To assess the impact of cyclonic storm surges in the study area, four Landsat scenes of 2007, 2008, 2009 and 2010 are analyzed using ILWIS. Supervised land cover classification has been conducted using maximum likelihood classification algorithm. Land cover classes included agricultural lands and wetlands. Secondary data on crop and fisheries production has been collected from BBS.

Keywords: Ecosystem services, storm surge, coastal zone, land cover classification and remote sensing

1. INTRODUCTION

The coastal area of Bangladesh is extremely vulnerable to cyclone-induced storm surge. In fact, UNDP had identified Bangladesh to be the most vulnerable country in the world to tropical cyclones (UNDP, 2004). There are mainly three reasons behind it. The first one is that the continental shelf is long and shallow and the funnel shape of the coast tends to concentrate and amplify the surge in the northern part of the Bay. Secondly the coastal zone is low-lying with 62% of the land having an elevation of up to 3 meters and 86% up to 5 meters from the mean sea level (IWM, 2009). The third reason is that the coastal area is densely populated, accommodating about 50 million people, nearly one-third of the total population of Bangladesh (Miyan, 2009).

About one-tenth of the global total cyclones forming in different regions of the tropics occur in the Bay of Bengal. About one-sixth of the tropical storms generated in the Bay of Bengal usually hit the Bangladesh coast. Historical record shows that more than 15 severe cyclones are generated in the Bay of Bengal in every ten years. During 1960-2007 about 18 severe cyclones hit the coast of Bangladesh (IWM, 2009). During the period 1582 to 1997 there were 82 cyclones that devastated the coastline of Bangladesh (Jacobson et al. 2006). These cyclones originated mainly in Indian Ocean or Bay of Bengal generally form in the months just before and after the monsoon and typically move to north to northeastern direction towards the land (SMRC, 1998). It is seen that the eastern coast experiences maximum inundation between 4-6 m and western coast experiences inundation within the range of 3-5 m (IWM, 2009).

Two of the most devastating cyclones experienced lately by Bangladesh are Sidr and Aila, both of which hit the southwest region of Bangladesh on November 15, 2007 and May 25, 2009 respectively. Cyclone Sidr formed in the central Bay of Bengal, and quickly strengthened to reach peak 1-minute sustained winds of 260 km/h (160 mph), making it a Category-5 equivalent tropical cyclone on the Saffir-Simpson Scale. It slammed the coastal areas of Bangladesh with heavy rain, strong winds and a storm surge. At least 3,447 deaths were caused by the storm. Again, Cyclone Aila with a storm surge of 3 m (10 ft) impacted the western coastal zone of Bangladesh, submerging numerous villages. Several rivers broke through embankments, causing widespread inland flooding. Torrential rains from Aila resulted in at least 190 fatalities from flooding (DMB, 2009). It took several months to repair these broken embankments as well as draining out the excess rain & surge waters trapped inside the polders. These caused long-term water-logging and inland flooding during high tides which affected the ecosystem services in the coastal area.

Ecosystems form the life-supporting system of the earth. Ecosystems are very important as they provide the basis for human civilization and natural capital for green economy and sustainable development. Ecosystems provide four types of potential services such as supporting services, regulating services, provisioning services and cultural services. Ecosystem services are components of nature. Ecosystem components include resources such as surface water, oceans, vegetation types and species. Ecosystem process and functions are the biological, chemical and physical interactions between ecosystem components (Boyd and Banzhaf, 2007). Ecosystem services may range from crops, fish, freshwater to those that are harder to see such as erosion regulation, carbon sequestration, and pest control. Ecosystem services are getting attention to the environmental community for conservation missions because the protection of ecosystem services is vital in securing the long-term livelihood of people.

The southwest coastal zone of Bangladesh consists of Satkhira, Khulna and Bagerhat districts. Important ecosystem services in this area include agricultural lands and wetlands which support fisheries resources and shrimp farming. The agricultural sector of Bangladesh contributes to 17.5% of GDP (2012 est.; CIA, 2013). It dominates both land use and the national economy. It supports people's lives and livelihood in this region. The performance of agricultural production has an overwhelming impact on major macroeconomic objectives like employment generation, poverty alleviation, human resources development and food security. However, The farmers in Satkhira-Bagerhat-Khulna area have switched over to shrimp culture from traditional agriculture, allowing more and more salt-water in the land. There are 37,400 bagda (saltwater shrimp) fields with an operated area of 170000 ha (PDO-ICZMP, 2003). A large proportion of delta populations experience extremes of poverty and are highly vulnerable to the environmental and ecological stress and degradation that is occurring (ESPA-Deltas, 2013). Certain changes (i.e. adaptation) are necessary as people in the coastal zone of Bangladesh face multiple threats (extreme poverty, food insecurity due to population increase, sea level rise, salinization, cyclones, etc.). In this context, this paper explores the variation of wetlands before & after the two major cyclonic events Sidr and Aila, using remote sensing techniques and, the subsequent effects on ecosystem services in the western coastal zone of the country.

2. STUDY AREA

The study area is located in the southwest coastal zone of Bangladesh. It includes three districts of Khulna division – Satkhira, Khulna and Bagerhat. The study area lies between latitudes 21o39´00´N to 23o05´00´N and longitudes 88o54´00´E to 90o00´00´E. The Sundarbans, world's largest mangrove forest is the southern part of the area. Khulna district has an area of 4394 km². The total population of Khulna district is 2,318,527. It is one of the important industrial and commercial areas of the country. 75% of shrimp exported from Bangladesh are cultivated in the Khulna zone. It is also known for its lobster, prawn, catfish, and crab. Satkhira district has an area of 3858 km². The total population of Satkhira district is 1,843,194. Most of the peoples of southern part of Satkhira depend on pisciculture. The main exports are shrimp, paddy, jute, wheat, betel leaf, leather and jute goods. Bagerhat district has a total area of 3959 km². The total population of Bagerhat district is 1,476,090 (BBS, 2012). Rampal and Fakirhat - two Upazillas of Bagerhat, is known for its huge production of shrimp.

3. METHODOLOGY

3.1 Data Collection

The study used satellite images downloaded from webpage of United Sates Geological Survey (http://www.earthexplorer.usgs.gov) and secondary data collected from national agencies such as Bangladesh Bureau of Statistics and Department of Fisheries, Bangladesh. In order to assess the impact of cyclonic storm surges in the study area, four Landsat scenes of 2007, 2008, 2009 and 2010 are analyzed using ILWIS 3.4. Supervised landcover classification has been performed using maximum likelihood classification algorithm for 7,4,2 Landsat TM band combination. Landcover classes include agricultural lands and wetlands. The images represent dry season of Bangladesh as all of them have been captured in the month of January. The images have been These images are taken at four tiles: Path of 137 with Row of 44, Path of 137 with Row of 45, Path of 138 with Row of 44 and Path of 138 with Row of 45, which cover the entire study area. Details of the images are presented in Table 1.

Table 1: Details of Landsat satellite images

Image No.	Acquisition Date	Satellite	Sensor	Spatial Resolution (m)
1	January, 2007	Landsat 5	TM	30
2	January, 2008	Landsat 5	TM	30
3	January, 2009	Landsat 5	TM	30
4	January, 2010	Landsat 5	TM	30

Secondary data include crop, fish and shrimp production at the study area for fiscal years 2006-07, 2007-08, 2008-09 and 2009-10 which are later compared with image analysis results for 2007, 2008, 2009 and 2010 respectively.

3.2 Satellite Image Processing and Land Cover Classification

Integrated Land and Water Information System (ILWIS, 2012) has been used to process the Landsat images and conduct spatial analysis. Land cover and land use classification using satellite image analysis includes several steps such as image importing, image gluing, sub setting, sample set preparation, supervised classification etc. While preparing the land use map for any particular year, firstly, the downloaded images of band 2, band 4 and band 7 from different tiles were imported individually. For each of these bands, images of the particular band at different tiles were glued to prepare a mosaic of the tiles. The combined image covers the entire study area. However, it also had portions beyond the study area. Thus, a sub-map was created which contained only the study area. In total three such maps (one for each of the bands 2, 4 and 7) were prepared. These images of band 2, 4 and 7 were used in the later part of land cover mapping. The 7,4,2 band combination was then selected for land cover classification. Four classes of land cover were considered. These are: (1) Agricultural lands, (2) Wetlands, (3) Forestry and (4) Settlements. A sample set was prepared using the selected band combination and a reasonable number of pixels were trained for each of the land cover categories.

The sample set was then used for supervised classification of land cover in the study area. The classification technique used was maximum likelihood classification algorithm. A land cover map of the study area for the particular year was obtained in the process where the study area was classified into the four land cover categories as mentioned earlier. In the classification process, agricultural lands typically included croplands and fallow lands. Forestry primarily included the Sundarbans and other areas with large trees. As the houses and road networks in the rural areas are typically surrounded by large trees, in this study, forestry excluding the Sundarbans was considered as rural settlements and road networks. Settlements primarily included urban settlements, mudlands and barren lands. But the area of rural settlements and road network were also added up to it which has been earlier separated from forestry. This combined area of urban, rural, mudland, barren land and road network has been considered as settlements in this study. Wetlands primarily included shrimp farms, ponds, rivers and the Bay of Bengal. But, rivers and the Bay of Bengal are not among wetlands. Thus, in order to exclude the rivers and the Bay of Bengal, a shape file of rivers in Bangladesh was used. Because the river shape file had some inaccuracies, parts of some rivers were still present in the image alongside the wetlands. These river pixels were also removed. Thus the land cover category ‘wetlands’ was left only with shrimp farms, ponds. However, in case of post-cyclone images (2008 and 2010), wetlands also included flooded land due to the cyclones, the area of which can be estimated from the difference in wetlands area between the pre- and post-cyclone land cover maps. Table 2 provides the details of Land Cover Classes.

Table 2: Details of Land Cover Classes

Land Cover Classes	Included Land Covers
Agricultural Lands	Croplands and Fallow Lands
Wetlands	Waterbodies excluding Rivers and the Bay of Bengal
Forestry	The Sundarbans
Settlements	Urban and Rural Area, Road Networks, Barren Lands and Mudlands

3.3 Estimation of Agriclutural Lands Affected by Post-Cyclone Flooding

In order to estimate the agricultural lands affected by the flood following the cyclone Sidr, the land cover maps of 2008 and 2007 were analyzed. The wetlands area from the 2008 land cover map in excess to that from the 2007 land cover map was identified and replaced by the land covers of the preceeding year. This resulted in an estimation of agricultural lands and other land cover types being flooded subsequent to cyclone Sidr. The same process was repeated to estimate the agricultural lands being flooded due to cyclone Aila, by comparing the land cover maps of 2010 and 2009.

3.4 Identification of Production Loss due to Post-Cyclone Flooding

Two different rule based techniques has been developed to identify crops and fisheries productions affected by each event of flooding followed after the cyclone Sidr and cyclone Aila. To identify production loss due to post-Sidr flooding, the production of different crops and fisheries in 2006-07 (P07), 2007-08 (P08) and 2008-09 (P09) were analyzed. If the temporal variation of production followed the pattern: P07>P08<P09, then the production was considered to be affected by the subsequent flooding. Again, in case of post-Aila flooding, the production of different crops and fisheries in 2007-08 (P08), 2008-09 (P09) and 2009-10 (P10) were analyzed. If the temporal variation of production followed the pattern: P08<P09>P10, then the production was considered to be affected by the long-term flooding due to cyclone Aila.

4. RESULTS AND DISCUSSION

The main focus of the study is to assess the long-term flooding due to the two major cyclonic events Sidr and Aila and its impacts on certain ecosystem services such as agricultural lands, crop production and fisheries production. Therefore, the temporal variations of all land cover classes have been quantified and presented in Figure 1, but only the wetlands and agricultural land cover changes are shown in Figure 2. Discussion over forestry (The Sundarbans) is omitted as its area has been found to be almost constant throughout the period.

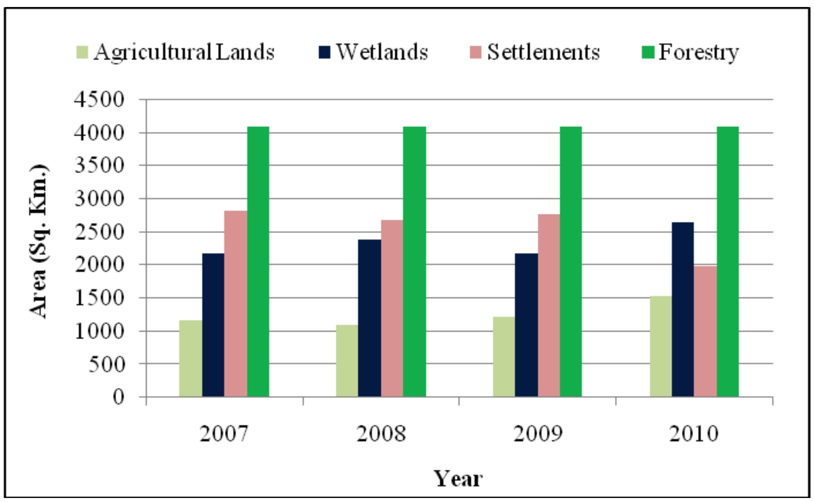

Figure 1: Temporal variations of different land cover classes in the study area

It has been assessed that in January 2008 the wetlands area in the study area increased by 11% from that in January 2007. However, in the following year it decreased by 12% but in January 2010, it again increased by 25%. Such sudden and sharp changes in wetlands area can be largely attributed to the widespread inland flooding caused by the cyclonic storm surges in 2007 and 2009 and the excess waters can be recognized as flooded areas. It has been also found that the study area consists of more wetlands than agricultural lands and also that a lagre portion of it is settlements. Thus, most of the flooded areas has been identified to be settlements and wetlands specially shrimp firms. However, significant agricultural land area is also found to be affected by the floodings after cyclone Sidr and cyclone Aila. As a result, production of several crops in the study area decreased significantly in the subsequent year of each of the cyclonic events. Table 3 shows the estimated agricultural lands flooded after the cyclones and Table 4 presents crop productions lost due to post-cyclone floodings. The post-Aila flooding also affected the production of shrimps significantly. However, it has been found that cyclone induced floods rarely affected the fisheries production. The only exception has been the fisheries production of Baors. Table 5 furnishes fisheries production affected by cyclone Sidr & cyclone Aila.

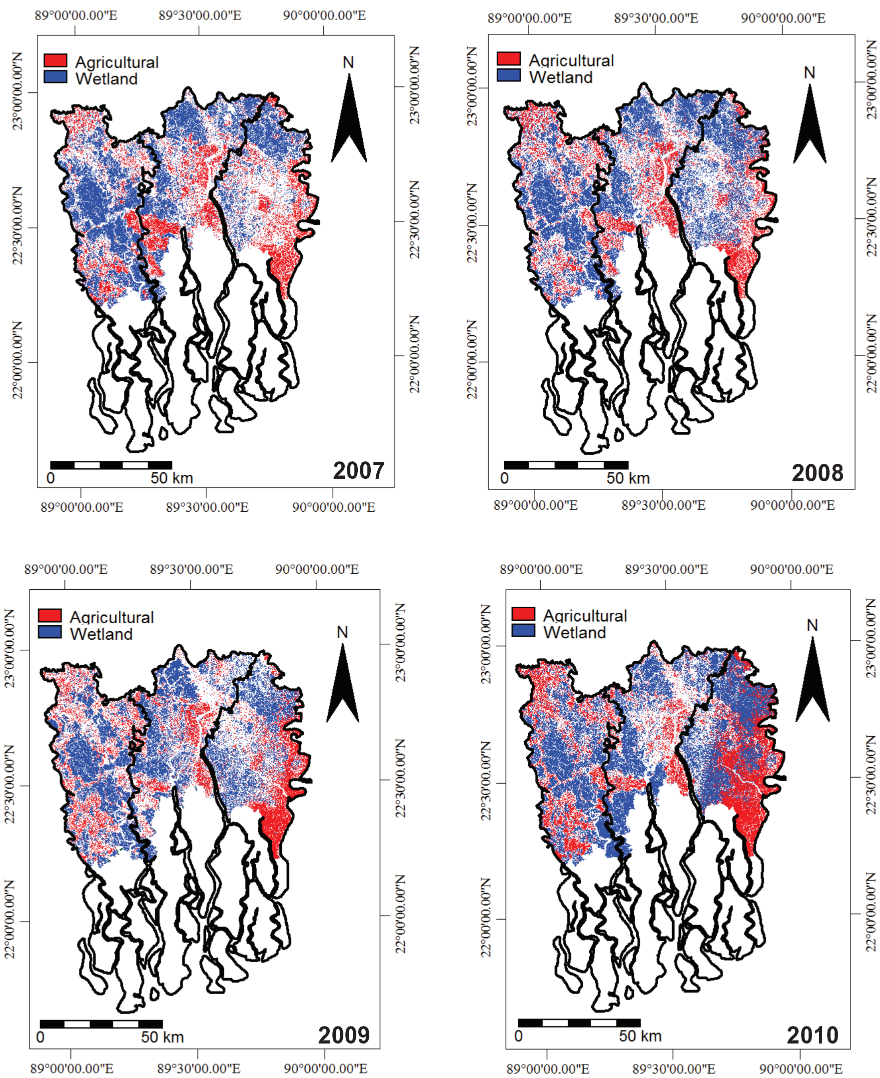

Figure 2: Spatial coverage of agricultural lands and wetlands in the study area at different years

Table 3: Estimated Agricultural Lands Flooded after the Cyclones

	Area (sq. km.)	% Agricultural Land
Post-Sidr (2008)	30	2.7
Post-Aila (2010)	110	6.7

Table 4: Crop Production Affected by Cyclone Sidr & Cyclone Aila

Production Decrease (%)			
Post-Sidr (2008)		**Post-Aila (2010)**	
Aus	8.6	Aus	10.9
Aman	14.9	Aman	11.8
Rice (Total)*	1.8	Rice (Total)*	1.2
Rabi Brinjal	3.7	Rabi Brinjal	19.7
		Wheat	16.1
		Jute	22.6
		Tomato	3.5

*Rice (Total) = Aus+Aman+Boro

Table 5: Fisheries Production Affected by Cyclone Sidr & Cyclone Aila

Production Decrease (%)			
Post-Sidr (2008)		Post-Aila (2010)	
Baor	15.4	Baor	37.0
		Shrimp	9.2

5. CONCLUSIONS

Results of this study reveal that both cyclone Sidr and cyclone Aila significantly affected the production of several ecosystem services in the southwest coastal zone of Bangladesh. In most cases the impact of cyclone Aila has been more severe than that of cyclone Sidr. Interestingly, the top wind speed of cyclone Sidr was more than twice than that of cyclone Aila. But Aila impacted during the high tide while Sidr made landfall during low tide. This indicates that the tide situation during a cyclonic event governs the damage intensity by the cyclone more than its top wind speed. Among the major varieties of rice, production of Aus and Aman rice decreased by 10.9 and 11.8 percent respectively from 2009 to 2010. However, production of Boro rice increased by 13.1% during this period. Such contrast can be attributed to technological advancements and better management practices which resulted in much increased production in spite of decreased command area. Another reason could be that, the cultivation area of such crops was not flooded or damaged by the storm surges. Similarly, significant decrease in shrimp production from 2009 to 2010 has been found which can be attributed to the shrimp firms being washed out by the storm surge induced floodings. Production data of more years can be analyzed to estimate production loss more accurately. Further research should be conducted to identify factors other than cyclone flooding that may have caused the sudden increase in wetlands so that the impact of cyclones can be estimated more precisely. Also, cyclone impacts can be attempted to correlate with storm properties, which may help to estimate production loss due to cyclones in advance. Proper structural and non-structural measures should be taken to reduce the impacts of cyclonic storms in the country.

REFERENCES

BBS (2012). "Bangladesh Household and Population Census 2011 – Community Report". Bangladesh Bureau of Statistics. Statistics and Informatics Division, Ministry of Planning, Government of Bangladesh.

Boyd, J., and Banzhaf, S. (2007). "What are ecosystem services? The need for standardized environmental accounting units." Ecological Economics, Vol. 63(2), 616-626.

CIA (2013). "The World Factbook: Bangladesh." Central Intelligence Agency, United States of America, https://www.cia.gov/library/publications/the-world-factbook/geos/bg.html.

DMB (2009). "Summary of Cyclonic Storm AILA." Disaster Management Bureau, 10 June 2009, Dhaka, Bangladesh.

ESPA-Deltas (2013). Assessing Health, Livelihoods, Ecosystem Services and Poverty Alleviation in Populous Deltas, http://www.espadelta.net/.

ILWIS (2012). Integrated Land and Water Information System, http://52north.org/.

IWM (2009). "Preparation of Inundation Map Considering the Decay Factors for Landuse, Geomorphology and Slope." Report submitted to Comprehensive Disaster Management Programme, Ministry of Food and Disaster Management, Government of the People's Republic of Bangladesh, Dhaka.

Jackobsen, F., Azam, M.H., Ahmed, M.M.Z. and Kabir, M.M. (2006). "Cyclone Storm Surge Levels along the Bangladeshi Coastline in 1876 and 1960-2000." Coastal Engineering Journal, Volume 48, No. 3.

Miyan, M.A. (2009). "Monsoon in Bangladesh." Proceedings of the Changes and Adaptation: Asian Monsoon Years AMY-6, Kunming, China, November 30-December 01, 2009.

PDO-ICZMP (2003). "A System Analysis of Shrimp Production (WP 014)." Program Development Office for Integrated Coastal Zone Management Plan, Water Resources Planning Organization, Government of Bangladesh.

SMRC (1998). "The Impact of Tropical of Cyclone on the Coastal Regions of SAARC Countries and Their Influence in the Region." SAARC Meteorological Research Center Report No. 1.

UNDP (2004). "Reducing Disaster Risk: A Challenge for Development – A Global Report." United Nations Development Programme, Bureau for Crisis Prevention and Recovery, New York.