International Journal of Scientific & Engineering Research Volume 8, Issue 12, December-2017
ISSN 2229-5518

Impact of the tropical cyclone AILA along the coast of Bangladesh

Mst. Rupale Khatun, Goutam Chandra Gossami, Shamima Akter, Mrinal Chandra Barman, Gour Chandra Paul

Abstract— AILA, a category 1 cyclone, furiously hit south western coastal region of Bangladesh on 25 May 2009, killing 190 people, and left several injured. Even though AILA was a cyclonic storm by definition, but its impact was greater than that of the super cyclone SIDR that hit the coast of Bangladesh. Using information obtained from different sources, this study identified some reasons for the economic cost and sufferings for the coastal people resulting from storm surges. The casualties may be attributed to a number of physical characteristics of the cyclone such as duration of the storm and associated surges, landfall time and site, varied coastal ecology, and coastal embankment. This article recommends improvements to the cyclone warning systems and some measures for at least partial mitigation of storm surges along the coast of Bangladesh.

Index Terms— AILA; Bay of Bengal; Cyclone; Non-linear interaction; Storm surge

1 Introduction

Bangladesh is a low-lying country which is situated at the northern tip of the Bay of Bengal. The coastal region of Bangladesh is very complex, which is full of many small and big islands [1]. The geographical location makes the country vulnerable for the tropical cyclones and other hazards [2]. An increasing number of tropical cyclones with associated surges always cause a considerable loss of many lives and properties along the region of interest [3]. Mainly cyclones in November 1970, 1985, April 1991, 1997, SIDR 2007, and AILA 2009 caused a considerable death tools [4]. The cyclone AILA hit the southwestern part of Bangladesh in May 25, 2009 and caused about 190 deaths [5]. The residents, homesteads, roads and embankments were destroyed due to flood associated with the cyclone AILA. In total, over 3.9 million people were affected and nearly 350,000 acres of crop land were destroyed [6]. It is pertinent to point out here that fishing, agriculture, shrimp farming, salt farming and tourism are the main economic activities of this coastal area [7]. But cyclone AILA washed away all the houses, crops and agricultural land. The damage of the infrastructure was huge; it also destroyed the livelihoods of the people. The government of Bangladesh is not always fully successful in recovering the situation and gives a sustainable livelihood to the coastal people [8]. That is why we should take some proper policy to mitigate the resulting damages as we cannot prevent this natural phenomenon. Bearing this fact in mind, we have pointed out some reasonable steps to minimize the resulting damages from storm surges. But the mitigative measures are highly dependent on a proper warning system, which in turn depends on an efficient storm surge prediction model.

The present study attempts to emphasize on a proper cyclone warning system based on a model simulation so that a considerable loss of lives and properties can be reduced through it.

- *M. R. Khatun, Department of Mathematics, Rajshahi University of Engineering & Technology, Rajshahi 6204, Bangladesh, E-mail: rupalemathru@gmail.com*
- *G. C. Gossami , Department of Mathematics, University of Rajshahi, Rajshahi 6205, Bangladesh, E-mail: goutam.ru08@gmail.com*
- *S. Akter , Department of Mathematics, Bangabandhu Sheikh Mujibur Rahman Science & Technology University Gopalganj-8100, Bangladesh, E-mail: shamima.bsmrstu15@gmail.com*
- *G. C. Paul , Department of Mathematics, University of Rajshahi, Rajshahi 6205, Bangladesh, E-mail: pcgour2001@yahoo.com*
- *M. C. Barman , Department of Mathematics, Mawlana Bhashani Science & Technology University, Tangail-1902, Bangladesh, E-mail: mcbarman_math@yahoo.com*

2 Storm Statistics in Bangladesh

Storm surges associated with intense tropical cyclones originating in the Bay of Bengal (BOB) are responsible for major devastation along the coastal region of Bangladesh. Debsarma [9] notes that on average, 5-6 storms form in the BOB region each year, but with about 80% of the global casualties. However, the coast of Bangladesh situated at the northern tip of the BOB is treated as the word most venerable region. One of the major regions of vulnerability is its complex coastal geometry. Figure 1 is added here to clarify the fact. The region is also vulnerable due to some other factors found in [1]. However, the number of deaths caused by the most severe tropical cyclones originating in the BOB is shown in Fig. 1. The details of the number of deaths are also presented in tabular form in Table 1 for better understanding.

3 Life history of AILA

According to the Bangladesh Meteorological department (BMD), a low pressure area (low) was formed over southwest Bay and adjoining area at noon of 21 May 2009. It then moved northwards and intensified into a well-marked low over southwestern Bay and adjoining west central Bay at 0300 UTC of 23 May 2009. At 0900 UTC of the same day, the system intensified into a depression and moved northwards and after 2100 UTC of the same day, the system changed its movement direction and moved north-northeastwards and intensified further into a deep depression. Then the system moved northwards into northwest Bay and adjoining west central Bay, intensified into a cyclonic storm AILA at 1200 UTC of 24 May 2009its movement direction and moved north-northeastwards and intensified further into a deep depression. Then the system moved northwards into northwest Bay and adjoining west central Bay, intensified into a cyclonic storm AILA at 1200 UTC of 24 May 2009. After that AILA moved northwards till 0300 UTC of 25 May 2009 and then north-northwestwards and finally northwards to West Bengal-Khulna (Bangladesh) coast. At about 0800 UTC of 25 May, the system started crossing West Bengal-Khulna (Bangladesh) coast near Sagar Island of India and then moved continuously northwards. At about 1200 UTC, the central position of the system positioned over Kolkata (India) and adjoining areas of India and Bangladesh but the remaining part of AILA was still crossing the coast. During the next 3-4 hours, the system completed crossing the coast and lay centered at West Bengal and adjoining western parts of Bangladesh. Then the system moved northwards, weakened into a land depression by giving precipitation and positioned over West Bengal and adjoining northwestern parts of Bangladesh at 0600 UTC of 26 May 2009. The time series for the positions and the nature of the cyclone AILA is shown in Table 2. The track of the cyclone AILA is shown in Fig. 3 for better understanding, where the data were received from the BMD, whereas Fig. 4 shows AILA at peak intensity.

TABLE 1
NUMBER OF DEATHS ASSOCIATED WITH SEVERE TROPICAL CYCLONE ORIGINATING IN THE BAY OF BENGAL (SOURCE: BMD).

Year	Location	Deaths
1822	Bangladesh	40.000
1876	Bangladesh	100,000
1897	Bangladesh	175,000
1912	Bangladesh	40,000
1919	Bangladesh	40,000
1960	Bangladesh	5,149
1961	Bangladesh	11,468
1963	Bangladesh	11,520
1965(11 May)	Bangladesh	19,279
1965(31 May)	Bangladesh	12,000
1970	Bangladesh	500,000
1985	Bangladesh	11 069
1991	Bangladesh	138,868
2007	Bangladesh	5000-10000
2009	Bangladesh	190

4 DAMAGE DUE TO AILA IN BANGLADESH

The cyclone AILA hit south-western coastal region of Bangladesh frantically on 25 May 2009 and moved in northerly direction in course of its life period. Its intensification was prompt a few hours before landfall and retained that intensity even up to 15 hours after landfall [10]. The storm dissipated into low-laying districts, namely Khulna, Satkhira, Patuakhali, Jhalakathi, Laxmipur, Bagerhat, Barisal, Barguna, Pirojpur, Jessore and Bhola along the coastal region of Bangladesh having maximum sustained wind speed $120\ km h^{-1}$ [11]. It caused about 190 human deaths on coastal residents as well as a heavy loss of livestock's [5]. Standing crops on vast tracts of land were smashed, innumerable trees were uprooted. According to daily newspaper (The Daily Star, May 26, 2009), thousands of people were made homeless as tidal waves leaping up to 13 feet high Low-lying areas of the coastal districts, offshore islands and chars were inundated by the flood due to the storm associated surges. The tidal waves also spoiled river and flood-control embankments and dykes and submerged many villages of coastal districts of Bangladesh. Power supply snapped and the communication system was cut off between the capital and all affected southern districts. Recorded wind speed and direction in different observatories of the BMD during the passage of cyclone AILA is shown in Table 3. The cyclone AILA furiously hit the Satkhira and Khulna and the worst affected upazilas of Khulna district are Koyra and Dacope. According to the official statistics of Unnayan Onneshan about 545,954 people of 118,757 families are affected in Khulna while death toll stands on 45 as of 3 June 2009 [5]. The damage due to cyclone AILA is shown in Fig. 9-10. As of 29 May, government figures indicate

Fig. 1 A picture of the northern part of the BOB covering the area $15^o - 23^o$ N Latitudes and $85^o - 85^o$ E Longitudes (After Murshed [22]).

ISSN 2229-5518

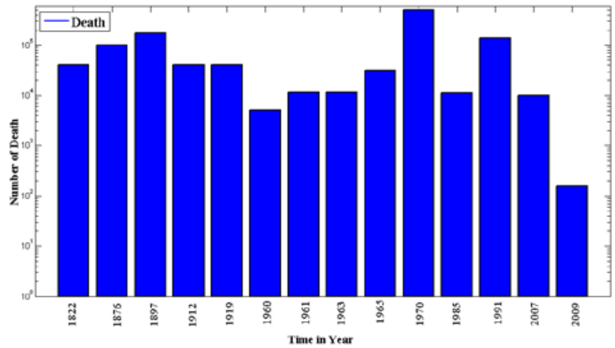

Fig. 2 Number of deaths associated with some severe tropical cyclones along the coast of Bangladesh (Fig. is constructed using the information of Table 1).

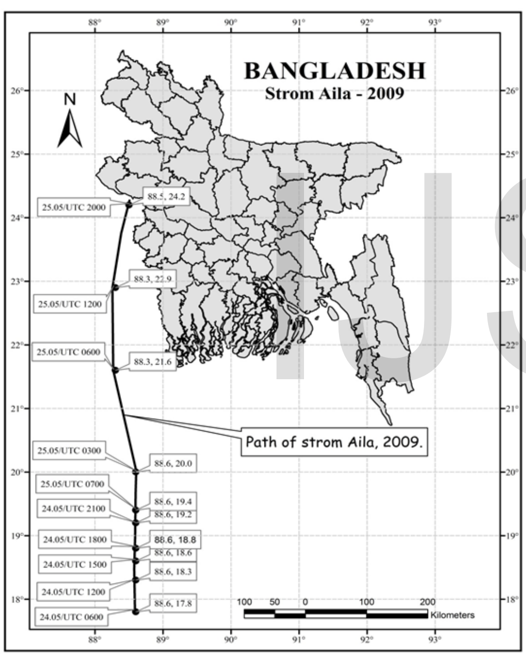

Fig. 3 Observed track of cyclonic Storm AILA (After Paul [18]).

TABLE 2
TIME SERIES FOR THE POSITIONS AND THE NATURE OF THE CYCLONE AILA, 2009. (SOURCE: BMD).

Date (2009)	Hour (UTC)	Latitude (°N)	Longitude (°E)	Nature of the storm
23 May	0900	16.0	88.0	Depression
23 May	1500	16.5	88.0	Depression
23 May	2100	16.7	88.0	Depression
24 May	0000	17.2	88.3	Depression
24 May	0600	17.8	88.6	Deep Depression
24 May	0900	17.8	88.6	Deep Depression
24 May	1200	18.3	88.6	Deep Depression
24 May	1500	18.6	88.6	Deep Depression
24 May	1800	18.8	88.6	Deep Depression
24 May	2100	19.2	88.6	Deep Depression
25 May	0000	19.4	88.6	Deep Depression
25 May	0300	20.0	88.6	Deep Depression
25 May	0600	21.6	88.2	Deep Depression
25 May	1200	22.9	88.3	Deep Depression
25 May	2100	24.2	88.6	Deep Depression

that 3,709,334 people have been affected in 15 coastal districts, with 147 dead and 1,131 missing. Up to 230,208 houses were reportedly destroyed while those partially damaged stand at 315,018. The amount of damaged crops is estimated to be 340,660 acres. A government report on 28 May 2009 indicates damage assessed as shown in the Table 4.

5 RELIEF MANAGEMENT AND RECOVERY ACTIVITIES

The government of Bangladesh, international and local non-governmental organizations, United Nations agencies had worked to provide relief goods and initial assessments helping AILA affected people. To help local administration and non-government organizations in rescue and relief operations, the government had deployed the armed forces, navy and the Bangladesh Rifles. Up to five navy ships had been working to bring people stranded in offshore islands for security. In rescue operations coast guards and the Bangladesh army continue their backing. The government administration distributed rice among the victim people through vulnerable group feeding (VGF) cards. The Bangladesh Red Crescent Society (BDRCS) distributed non-food relief items about 8,000 affected families within the first 48 hours of the cyclone taking support from the international federation. Besides these, some local and national Non-Government Organization (NGO) like as the Bangladesh Rural Advancement Committee (BRAC) was also very helpful in supporting for AILA affected people. They distributed food items and non-food items to families in the most affected districts.

6 HEALTH AND SANITATION

There was insufficiency of food, drinking water and medicines for victims in cyclone shelters [5]. Many water-borne diseases diarrhoea, dysentery and fever had broken out in AILA affected areas. To give helping hand to the helpless people a total number of 686 medical teams had been working in the districts of Satkhira, Kulna, Bagerhat, Barisal, Patuakhali, Bhola, Borguna and Pirojpur for providing emergency medical care reported by United nation world health organization. At least 95 percent of the affected and waterlogged areas were out of the safe sanitation coverage [5]. Toilets, bathrooms and other sanitary structures remain submerged because of the water was still staying well over ankle height in most of the affected areas. People taking refuge on the embankments were forced to defecate on open water and use the contaminated saline water for household use.

7 Environmental impact

Unluckily there were no official estimations of the loss of the Sundarbans due to cyclone AILA. The mangrove forest is a remote place to enter and it is much harder in the rainy season when the height of tide water reaches the highest. According to the media reports the Sundarbans was inundated with 20 feet of water [11]. The Sunderbans, a region which houses 265 of the threatened royal Bengal tiger and dozens of the tigers were gone down due to flood of storm surge AILA [11]. About 35 percent of forest camps in the west part of the Sundarbans totally destroyed according to statement from forest department of Bangladesh. There were uprooted a large number of trees and injured infrastructures by the cyclone AILA. Inside the forest there was the acute paucity of drinking water. The actual effect of AILA on flora and fauna in Sunderbans was made certain by various government and non-government agencies.

8 Cyclone warning system and preparedness

A detailed of the cyclone warning system and preparedness in Bangladesh is discussed in Paul [3]. However, a gist of it is presented here. As in Paul [3], BMD is the sole government organization and authority accountable for forecasting, preparing, issuing, and disseminating warnings for cyclones in Bangladesh. The storm warning center (SWC) of the BMD issues special weather bulletins after forming a depression in the BOB, to alert specially the country's coastal and island inhabitants through which a significant reduction in the loss of lives and properties can be made [12]. The SWC issues warnings in different stages of the formation of the cyclones depending on the wind speed (cyclone alert stage: when wind in a TC research 50 km h^{-1}; cyclone warning stage: when wind in a TC research between 51-61 km h^{-1}; cyclone disaster stage: when wind in a TC exceeds 61 km h^{-1}; cyclone great-danger stage: when wind in a TC exceeds 89 km h^{-1}) [13]. At the final stage, a warning message is usually disseminated every 15 minutes and the residents are urged to evacuate at this point. The warning message in this regard is initiated before 10 h of the predicted landfall. The National Disaster Management Council (NDMC) headed by the Honorable Prime Minister of the People's Republic of Bangladesh, then reviews disaster management policies and provides directives to all concerns for preparedness, disaster risk reduction, evacuation, response and recovery [3]. The CPP of Bangladesh Red Crescent Society (BDRCS) with its volunteers plays a leading and vital role in this regard. The volunteers also assist coastal people in executing rescue operation, distributing relief goods, providing first aid under the supervision of the Government of Bangladesh (GOB) local administration. However, as in Paul [3], the SWC meteorologists prepare warning messages based on both self-produced and accessed numerical model generated forecasts with weight on the prior one [13]. At this juncture it is to be pointed out that the SWC meteorologists do not have the necessary computational skills to modify the accessed models for forecasting precisely new TCs [12] and to run them in the existing resources available at the BMD [14]. Thus, predictions by the SWC meteorologists have often been criticized [15, 16]. These weaknesses in the TCs forecasts need to be rectified properly for having an improved warning system. Because, unnecessary evacuations following erroneous warnings are waste of wealth as well as infallibly cause the coastal people to ignore subsequent warnings of genuine danger [17]. Therefore, a model capable of running in the existing resources in the BMD for precise foreseeing of the TCs is urgent for the vulnerable region.

9 Numerical simulation of the cyclonic storm surge AILA in Bangladesh

In this section we have summarized the numerical simulation of the storm surge AILA and made a numerical simulation of it. Some studies, so far, have been conducted for the numerical simulation of the storm surge AILA. Worth mentioning of them are conducted due to Rahman [4], Paul and Ismail [18], Paul [19, 20]. Among them the first two groups of studies were conducted only to show the impact of surge on water level in the absence of astronomical tide. Paul [19] developed the model of Paul and Ismail [22] for attaining a prediction accuracy including surge affecting factors for the region of interest. . However, in all the studies it is concluded that for having a better predict tion of water levels all the factors affecting surge levels for the region having coastal complexities should property be taken into account. In our numerical estimation, we employed the codes used in the study of Paul and Ismail [1]. The only difference here is in meteorological inputs (e.g., storm track, maximum sustained wind radius and wind speed) as are discussed in the above sections. Firstly surge model is run using meteorological conditions only from the cold start. Tide model is also run from the cold start in the absence of wind stress. After having a stable tidal regime, surge model is then run for the results from non-linear interaction of tide and surge [3, 19, 20]. The results of our calculation are presented in section 5 for their discussion, comparison and validation, and to support our recommendations

Fig. 4 NASA's Terra satellite captured this true-color image of AILA on May 25, 2009 (After Paul and Ismail [18]).

10 Simulated Results

The results for the storm AILA 2009 are computed for 80 hours (from 1200 UTC of 22 May to 2000 UTC of 25 May) but they are presented for the last 48 hours (from 2000 UTC of 23 May to 2000 UTC of 25 May) at some representative coastal and island locations of Bangladesh. The obtained results of our computations are shown in diagrammatic forms through Figs. 5, 6, 7, and 8.

Figure 5 depicts our simulated results due to tide at eight coastal locations depicted in Fig. 1. The results can be found to agree well with the corresponding results found in Paul et al. (2016, 2018). Figure 6 depicts our computed water levels due to surge at the mentioned coastal locations. The peak surge values (in the absence of astronomical tide) can be found to range between 1.76-3.70 m (Fig. 6). According to a NASA report, there was a storm surge between 3.05-3.96 m high along the western coastline of Bangladesh during the time of landfall. Further, according to the Indian Meteorological Department (IMD), a storm surge of about 2-3 m above astronomical tide was realized over the West Bengal and adjoining Bangladesh coastal areas. Thus, our computed surge heights compare well with some reported data. Figure 7 shows our computed total water levels due to the nonlinear interaction of tide and surge with the observed ones at three stations, namely Hiron Point, Chittagong and Char Chenga. It can be inferred from Fig. 7 that our model simulated water levels agree well with observed data. Due to lack of observed time series of total water level data for other locations, we could not compare our simulated results with observed data, but our computed total water levels at some representative stations are presented in Fig. 8. Our computed peak total water levels came out to be 2.31−5.07 m (Figs. 7-8). Paul [20] simulated 2.63−5.62 m peak total levels along the coast of Bangladesh, whereas Paul [19] predicted 3.30-5.97 m high total water levels along these areas. In [5] it is reported that at the time landfall, the peak total water level was 4−5 m. According to the BMD, the cyclone AILA made landfall between 0800 to 0900 UTC of 25 May over Bangladesh coast (Khulna) when the local astronomical tide was at peak [20]. Our model simulated result presented in Fig. 7 justifies the fact. Also based on a report from the BMD, the central point of the storm positioned over Kolkata and adjoining areas of India and Bangladesh at about 1200 UTC 25 May (Fig. 3). Thus our computed total water levels (see Figs. 7-8) are found to be consistent with the sequence of events, data and landfall time mentioned above.

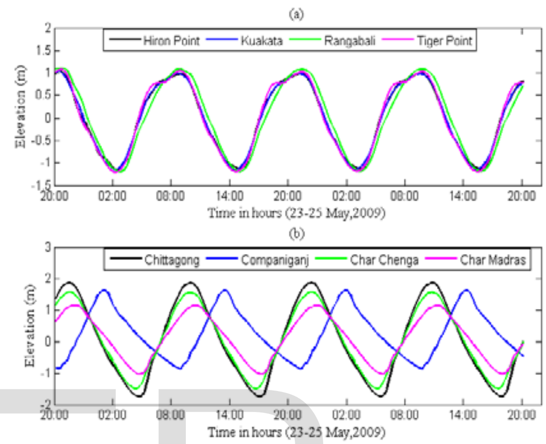

Fig. 5 Water levels with respect to the mean sea level (MSL) due to tide along the coast of Bangladesh during the storm AILA.

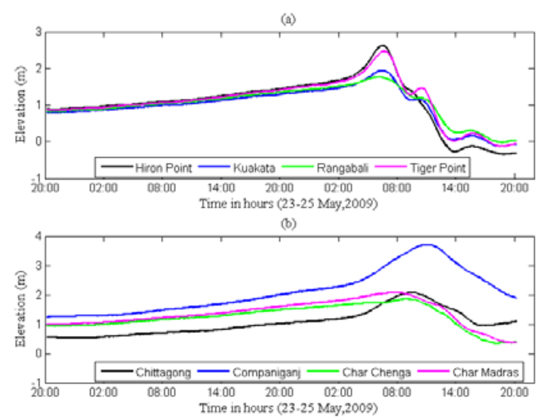

Fig. 6 Water levels with respect to the MSL due to surge along the coast of Bangladesh during the storm AILA (The results are presented in the absence of astronomical tide).

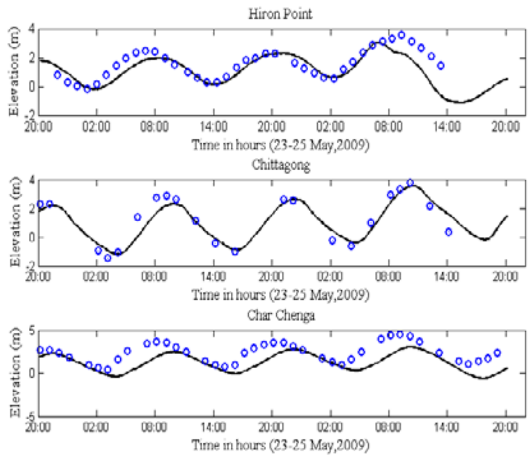

Fig. 7 Comparison of our computed results with observed data at Hiron Point, Chittagong and Char Chenga. In each case, a black solid line represents the configuration for our simulated tidal levels, and a blue circle represents an observed data, wherever available in the mentioned period of displaying results.

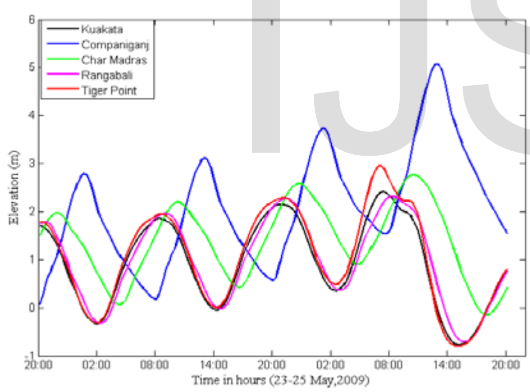

Fig. 8 Computed water levels with respect to the MSL due to tide, surge and the non-linear interaction of tide and surge associated with storm AILA along the coast of Bangladesh.

11 The Reasons of Large Impact of Storm Surges and Recommended Mitigation Steps

The reasons behind large impact of storm surges along the Bangladesh coast are as follows:
(i) Complex land sea interface,
(ii) Shallow continental shelf,
(iii) Triangular shape of the head bay of Bengal,
(iv) Complex warning system,
(iii) Indifference of warnings.
From the above reports obtained from different sources and discussion of simulated results, we can take the following steps to protect life and property against cyclone and storm surges. These are appended below:

(i) An effective cyclone warning system is the principal key to minimize loss of lives and properties. But an effective warning system is highly dependent on a numerical model that can predict water levels, land fall time with location, resurgent, etc. with considerable accuracy. However, a proper warning system should be informative but simple and understandable because literacy rate is low in rural areas people. Also, it should be reached each and every corner in affected coastal areas.

(ii) Public awareness activities are more important. In this regard various educational campaigns via radio and television or other media should play a vital role to create public awareness on the various aspects of the Cyclone so that they can understand what they should have done during disaster.

(iii) Sunderbans, the south-western part of Bangladesh covers a total area of 6,000 square km, is the world's largest single mangrove tract. This mangrove forest is of extreme importance since it provides efficient protection to life and property against cyclones and storm surges by reducing intensity of both the wind and storm surges. But due to deforestation, the width of the mangrove belt is being promptly decreased. Thus we lay emphasis on coastal afforestation. So, now it is high time to evolve a national strategy for its proper protection and development so that the entire coastal belt is planted as densely as possible.

(iv) Embankments along the coastal districts support agriculture and protect the lives and property of coastal residents during cyclones and storm surges. The embankments in the coastal area provide an effective defense during the storm surge. Lives are saved, and damages and property losses are much lower. Bangladesh government has constructed many embankments. Some of their condition is very poor. This is now in need of rehabilitation, build new embankments, and construct roads. Also a variety of fruit trees should be planted along the embankments and roads which will prevent their erosion.

(v) Proper preparedness program can be made less harmful before and after cyclone. Building more public cyclone centers, availability of volunteers for disseminating of warnings and evacuating residents are suitable preparation before cyclone. After cyclone necessary to remain availability of relief goods, first aid, rehabilitation to affected people.

12 Conclusion

Bangladesh is one of the most disaster-prone areas in the world. In this study, we have reviewed the cyclonic storm AILA which furiously hits south western region of Bangladesh. This study identifies some reasons for the economic cost and sufferings for the coastal people. The study suggests that research and development activities centering on cyclone mitigation including short and long term measures like a proper warning system based on an accurate forecasting model, afforestation, embankment establishment should receive priority attention of academic community in developing societies. This article recommends improvements to the cyclone warning systems, establishment of more public cyclone shelters, preparedness, institutional arrangement, policy formulation and implementation of an education campaign in coastal areas to increase the utilization of public shelters for future cyclone events.

Acknowledgment

This research is partially supported by a grant from Dean of the faculty of science of the University of Rajshahi, 776 Bangladesh with No. 673−5/52/UGC Project/Science−8/2014. The first authors acknowledge this support. The second author was an MS student who would like to thank Professor Md. Mizanur Rahman for his helpful discussion when the manuscript was being prepared.

Fig. 9 Bangladeshi villagers wade through flood water as they go to collect water on the outskirts of Khulna on 1st June 2009. (Source: Monir Uz Zaman/AFP).

TABLE 3
Recorded wind speed in different observatories of BMD during the passage of cyclone AILA.

Station	Date	Time (UTC)	Wind Speed ($km\,h^{-1}$)	Direction
Khepupara	25-05-09	0425	92	SE'ly
Khulna	25-05-09	0730-0930	74	E'ly
Kutubdia	25-05-09	1110	46-56	SE'ly
Barisal	25-05-09	0730	60	E'ly
Patuakhali	25-05-09	0600-0900	46-56	
Chittagong	25-05-09	1015	62	S/SE'ly
Cox's Bazar	26-05-09	2045	43	S/SE'ly
Hatiya	25-05-09	1300-1330	59	S/SE'ly
M. Court	25-05-09	0900	37	E'ly
Rangpur	25-05-09		65	E/SE'ly
Sayedpur	25-05-09	1710-1718	65	

Fig. 10 Bangladeshi villagers work to rebuild embankment at Protap Nagar in Shatkhira on 31 May 2009. (Source: Monir Uz Zaman/AFP).

References

[1] Paul G. C. Ismail A. I. M. (2013). Contribution of offshore islands in the prediction of water levels due to tide–surge interaction for the coastal region of Bangladesh. Nat. Hazards, 65:13–25.

[2] Murty T. S., Neralla V. R. (1992). On the recurvature of tropical cyclones and the storm surge problem in Bangladesh. Nat. Hazards, 6:275–9.

[3] Paul G. C., Murshed M. M., Haque M. R., Rahman M. M., Hoque A. (2017). Development of a cylindrical polar coordinates shallow water storm surge model for the coastof Bangladesh. J. Coast. Conserv., 21:951–966.

[4] Rahman M. M., Paul G. C., Hoque A. (2011). A shallow water model for the coast of Bangladesh and applied to estimate water levels for 'AILA'. J. App. Sci., 11:3821-3829.

[5] Roy K., Kumar U., Mehedi H., Sultana T., Ershad D. M. (2009). Initial damage assessment report of cyclone AILA with focus on Khulna district. Unnoyan Onneshan-Humanity Watch-Nijera Kori, Khulna, Bangladesh.

[6] IFRC (2010). Bangladesh: Cyclone Aila.

[7] Abedin M. A., Habiba U., Shaw R. (2012). In Envi ronment Disaster Linkages, ed. R. Shaw and T. Phong, Emerald Publishers, UK, vol. 9, pp. 165–19.

[8] Jahan I. (2012). Cyclone Aila and the Southwestern Coastal Zone of Bangladesh: In the Context of Vul nerability. Master's Thesis, Lund University, Centre for East and South-East Asian Studies.

[9] Debsarma S. K. (2009). Simulations of Storm Surges in the Bay of Bengal. Mar. Geod., 32:178–198.

[10] Rambabu S., Gayatri V. D., Ramakrishna S. S. V. S., Rama G. V., Appa Rao B. V. (2013). Sensitivity of movement and intensity of severe cyclone AILA to the physical processes. J. Earth Syst. Sci., 122:979-990.

[11] https://en.wikipedia.org/wiki/Cyclone_Aila.

[12] Khalil G. M. (1993). The catastrophic cyclone of April 1991: Its impact on the economy of Bangladesh. Nat. Hazards, 8:263–281.

[13] Roy C., Sarkar S. K., Aberg J., Kovordanyi R. (2015). The current cyclone early warning system in Bangladesh: providers' and receivers' views. Int. J. Disaster Risk Manage, 12:285–299.

[14] Roy C., Kovordanyi R. (2012). Tropical cyclone track forecasting techniques - a review. Atmos. Res., 104– 105:40–69.

[15] Miyan M. A. (2005). Cyclone disaster mitigation in Bang ladesh. South Asian disaster management center (SADMC). Available (December 2008). www.researchsea.com/html/article.php/aid/141/cid/6?PHPSESSID=36f90mj40it9tvbao1otg8ljj7.

[16] Hossain M. Z., Islam M.T., Sakai T., Ishida M. (2008). Impact of tropical cyclones on rural infrastructures in Bangladesh. Agric. Eng. Int., 10(2):1–13.

[17] White G. F., Haas J. E. (1975). Assessment of research on natural hazards. MIT Press, Cambridge.

[18] Paul G. C., Ismail A. I. M. (2012a). Numerical modeling of storm surges with air bubble effects along the coast of Bangladesh. Ocean Eng., 42:188–194.

[19] Paul G. C., Ismail A. I. M., Rahman A., Karim M. F. Hoque A. (2016). Development of tide–surge in teraction model for the coastal region of Bangladesh. Estuar. Coasts, 39:1582–1599.

[20] Paul G. C., Senthilkumar S., Pria R. (2018). An efficient aproach to forecast water levels owing to the interaction of tide and surge associated with a storm along the coast of Bangladesh. Ocean Eng., 148:516-529.

[21] Paul G. C., Ismail A. I. M. (2012b). Tide-surge interacttion model including air bubble effects for the coast of Bangla desh. J. Frankl. Inst., 349:2530–2546.

[22] Murshed M. M., Paul G. C., Haque M. R. (2016). On the approximation of complex geometric domain to be compatible for the implementation of finite difference method. IJSER, 7:495-501.

TABLE 4
LOSS OF PROPERTY DUE TO CYCLONE AILA OCCURRED IN BANGLADESH. (SOURCE: RELIEF CONTROL CELL, MINISTRY OF FOOD AND DISASTER MANAGEMENT, MAY 2009).

Name of Districts	No. of affected upazila	No. of affected people	No. of death	No. of injured people	Damage Full	Crops (acre) Partial
Barishal	10	267105	7	121	0	15592
Bhola	7	413709	17	226	-------	22023
Pirojpur	7	248470	1	--------	7960	55107
Patuakhali	7	615785	8	610	14262	83736
Borguna	5	284079	---------	--------	36620	52660
Jhalokathhi	4	396877	---------	--------	11644	11621
Khulna	5	494900	35	73	1854	3980
Bagerhat	5	234237	2	--------	1537	1106
Satkhira	7	595122	43	5407	454	183
Chittagong	3	13530	1	10	235	234
Cox'sBazer	8	29445	2	--------	-------	---------
Laxmipur	4	12371	7	6	350	4671
Feni	1	40000	--------	--------	-------	496
Noakhali	3	49244	24	255	127	1373
Chandpur	2	14460	--------	--------	81	127553
Total	**76**	**3709334**	**147**	**6708**	**75124**	**265535**