Trans. Inst. Indian Geographers
Vol. 31, No. 1, 2009

Tropical cyclones in Bangladesh

M. Shamsul Alam, Rafique Ahmed

Abstract

Bangladesh is one of the most cyclone-prone countries in the world. Tropical cyclones that hit the coastal areas of Bangladesh from 1960 through 2004 have been statistically analyzed and presented in this paper. During this 45-year period, 22 cyclones hit Bangladesh, with a frequency of one every two years. Of these 22 cyclones, 6 were category 1 cyclones (27.3%), 9 were category 2 (41%), 3 were category 3 (13.6%), 3 were category 4 (13.6%), and 1 was a category 5 cyclone (4.5%). Of the 22 cyclones, 9 (41%) occurred during the pre-monsoon season (April-May), and 13 (59%) during the post-monsoon season (end of September to mid-December), and none during the summer monsoon season (June-September). The coastal zone from the Feni River to Teknaf (the southeast corner of the country) is the most cyclone-prone region in the country, which accounts for 68% of the cyclone occurrences (15 out of 22).

Keywords: *Cyclones, cyclone categories, cyclone frequency, cyclone zones, Bangladesh.*

Introduction

The Bay of Bengal is one of the most cyclone-prone regions in the world. Of the average of 80 or so severe tropical cyclones (hurricanes) that occur around the globe annually, 3-5 may form in the Bay of Bengal (Barry and Chorley 2003, Fink and Speth 1998, Lal 2001). Some of these cyclones move toward the eastern coast of India, and some move toward the coastal areas of Bangladesh or adjoining Myanmar (Subrahmanyam, *et al.* 1998, Alam, *et al.* 2003, Chowdhury 2003). Tropical cyclones that hit the coastal areas of Bangladesh cause immense loss of human life and livestock, extensive damage to property and roads, and serious shipping hazards in the coastal areas of the country due to strong winds, rough seas, flooding from heavy rainfall, and storm surge in the coastal areas.

The devastation in the coastal areas of Bangladesh is aggravated by the funnel-shaped configuration of the coastline, the low, flat terrain of the coastal areas and off-shore islands, the region's poorly built houses, and – most importantly – the high density of population in these areas which ranges from 380 to over 1,300 people per square kilometer (Haque 1997, Chadwick 2002, Karim, 2002, Chowdhury 2003, BBS 2003). Cyclones can be extremely deadly under these circumstances -- more than

200,000 people were killed by the cyclone of 12 November, 1970. Some measures have been taken to minimize cyclone-related deaths in the country (Haque 1995, Haque 1997, Chadwick 2002). These measures include: early cyclone warnings (through radio, TV, volunteers, government officials, and community leaders), construction of coastal embankments, construction of cyclone shelters, tree planting in coastal areas, and an improved road network in the coastal areas and on off-shore islands.

In the coastal area of Bangladesh, there are 14 administrative units, called zilaas. Names of these zillas, their areas, populations and population densities are shown in Table 1, and their locations are shown in Fig. 1. These 14 coastal zillasl cover an area of 39,331 square kilometers, with a total population of about 29 million.

Table 1: Area and Population in the Coastal Districts, 2001 (From W-E)

Districts	Area (sq. km.)	Population	Density
Satkhira	3858	1,845,120	478
Khulna	4995	2,357,940	472
Bagerhat	3999	1,516,820	379
Pirojpur	1308	1,099,780	840
Barguna	1832	845,060	461
Jhalokathi	759	692,680	913
Barishal	2791	2,348,440	841
Patuakhali	3221	1,404,800	436
Bhola	3408	1,703,200	500
Laksmipur	1455	1,486,540	1021
Noakhali	3001	2,570,640	857
Feni	928	1,205,980	1300
Chittagong	5283	6,543,800	1239
Cox's Bazar	2492	3,249,460	1304
Total	39331	28,870,260	734

Population densities in these zilas range from 380 people per square mile to 1,300 people per square mile (Fig. 2). Nearly one-fourth of the population living in the coastal zilas of Bangladesh live in the high-risk zones, within a few kilometers of the coastline or on off-shore islands. There are about 1,700 cyclone shelters in the highly risky and risky coastal areas of Bangladesh, which can accommodate nearly 1.3 million people (LGED: www.lged.org/sre). The highly risky areas are subjected to damages caused by both winds and storm surges that accompany the tropical cyclones. These include the areas within a few kilometers of the coastline and off-shore islands. The risky areas are subjected only to wind damages caused by the tropical cyclones, but not to the storm surges that accompanying them. These areas lie next to the highly risky areas, 25-50 km inland from the Bay of Bengal coast. One study estimated that the growing population in the high-risk and risky costal areas would reach 12.5 million by the year 2021, requiring an extremely large number of cyclone shelters to be built in those areas (Karim 2002).

Although Bangladesh is known for the occurrences of tropical cyclones and their devastating effects, little is known about their generalized statistical characteristics, and their geographic distribution in the coastal areas of the country. Specifically, no work has been done on the frequency and percentage of cyclones in various intensity categories, magnitudes of their accompanying storm surges, seasonality of cyclone occurrences, and their geographic distribution in different coastal zones of the country. Tropical cyclones that made

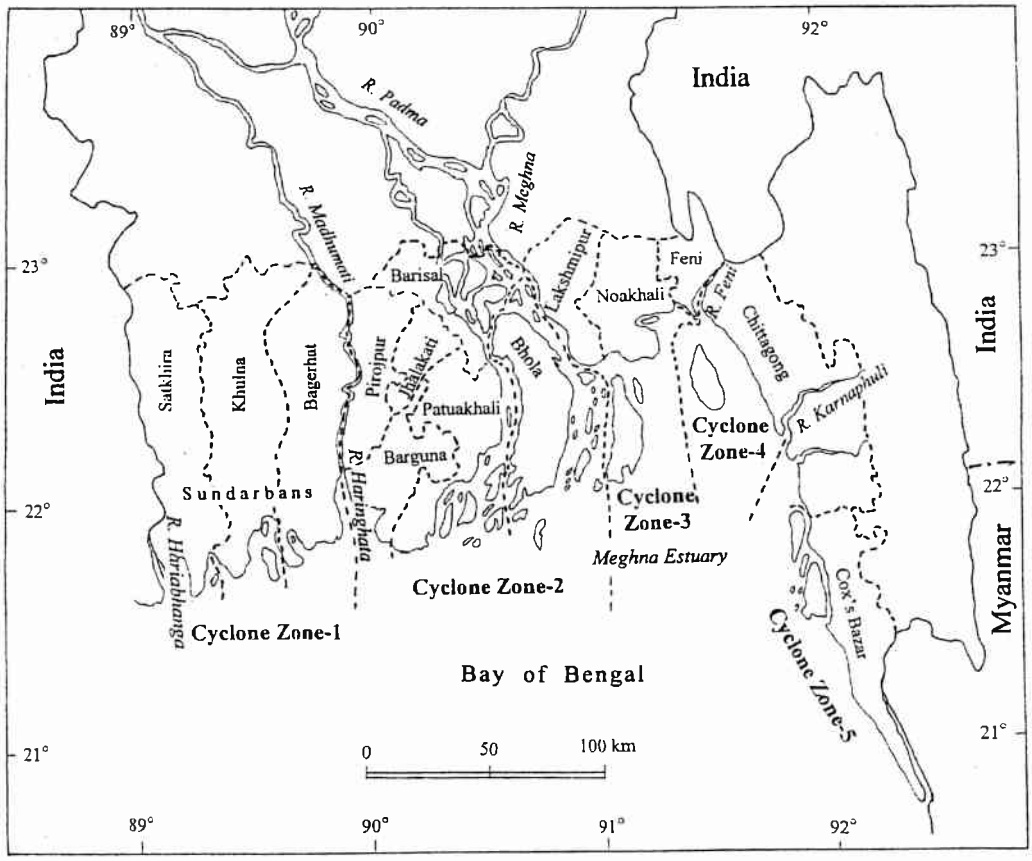

Fig. 1: Administrative units, called zillas (e.g., Satkhira), and cyclone zones in the coastal areas of Bangladesh.

landfall in the coastal areas of Bangladesh during the 45-year period from 1960 through 2004 have been statistically analyzed to address these research objectives, and are presented in this paper. These include the determination of the frequency and percentage of cyclones in different intensity categories, their occurrences by month and week to determine their seasonal patterns, and their frequency and percentage of occurrence in different coastal zones of the country.

General Characteristics of the Bay of Bengal Cyclones

Tropical cyclone is the generic term for the convergent wind circulation in the low-pressure systems over tropical waters (counter-clockwise circulation in the northern hemisphere and clockwise

in southern hemisphere). If the sustained wind speed exceeds 33 m/s (119 km/hr), the system is called a hurricane in the Atlantic and East Pacific, a typhoon in the western North Pacific, and a severe tropical cyclone in the remaining tropical ocean basins including the North Indian Ocean and the Bay of Bengal (Fink and Speth 1998, Alam, *et al.* 2003).

Tropical cyclones (hurricanes) are classified into five different intensity categories by the Saffir–Simpson Hurricane scale (Saffir and Simpson 1974), which is based on wind speed, storm surge and damage potential (Table 2).

A typical tropical cyclone may have a diameter of 300 - 650 km, the central pressure may drop below 980 hPa (mb), with a sustained wind speed of 33 m/s (119 – 154 km/hr) for a minimum category 1 cyclone (Barry and Chorley 2003, Oliver and Hidore 2002). Formation, development, and maintenance of tropical cyclones depend on the moisture supply from a warm sea surface with temperatures of at least 26.5°C. The energy that drives these disturbances is derived from huge amount of latent heat of condensation, which is released by 100-200 cumulonimbus clouds

Table 2: Saffir-Simpson Hurricane (Tropical Cyclone) Intensity Scale

Cyclone Category	Wind m/sec	Speed Km/hr.	Storm Surge (m)	Damage
1	33-42	119-154	1-2	Minimal
2	46-49	155-178	2-3	Moderate
3	50-58	179-210	3-4	Extensive
4	59-69	211-250	4-6	Extreme
5	> 69	> 250	> 6	Catastrophic

associated with a typical tropical cyclone (Barry and Chorley 2003, Oliver and Hidore 2002). As a result, tropical cyclones are warm-core cyclones, which are warmer than surrounding air in the upper levels, with compensating outflow in the upper air (Barry and Chorley 2003, Fink and Speth 1998, Ramage 1971). The outflow in the upper air maintains the ascent, with consequent inflow in the lower level of the atmosphere. This provides a continuous generation of potential energy (from latent heat) and transformation of the potential energy into kinetic energy.

Another essential element of a tropical cyclone is that the central region of a cyclone (eye) remains cloud free because of the adiabatic warming of the descending air in this region. Air descends in the central region in response to the unusually low pressure in this region. Without the sinking air in the eye, the pressure at the center could not fall below 1000 mb (Barry and Chorley 2003, Ramage 1971).

The most destructive component of a tropical cyclone is its accompanying storm surge. A storm surge is characterized by abnormal rise of seawater along a coast, which is primarily brought about by the strong winds that accompany a tropical cyclone. Such storm surges in Bangladesh can be 2-7 meters high, and can run up streams up to 200 km (SoE 2001).

There are two distinct cyclone seasons in the Bay of Bengal, one before the summer monsoon season and one after the summer monsoon season. No cyclones form in the Bay of Bengal during the summer monsoon season. There are two reasons for this. First, with the monsoon trough and

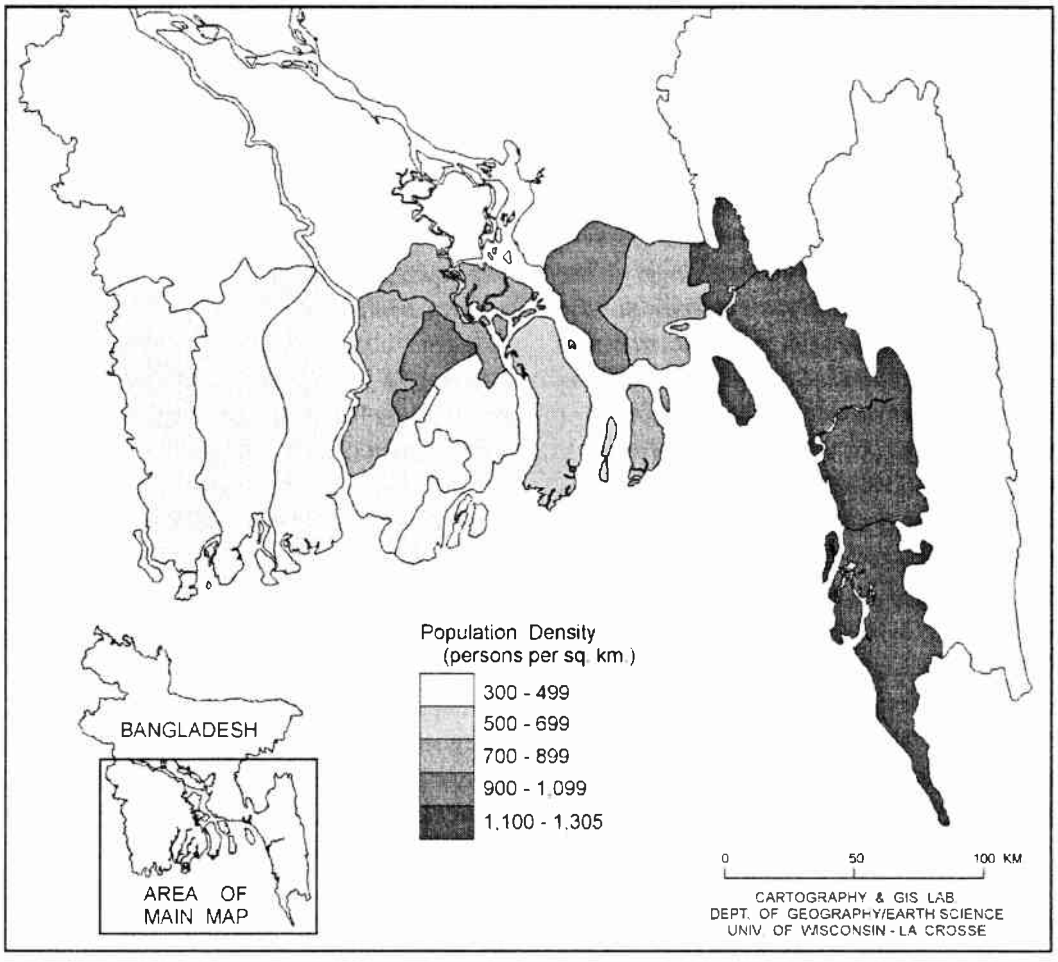

Fig. 2: Density of population in the coastal administrative units (zilas) of Bangladesh.

clouds confined to the head of the Bay of Bengal, the sea surface temperature (SST) cannot rise enough to supply the massive amount of latent energy essential to a tropical cyclone. Secondly, the presence of strong vertical wind shear during the summer monsoon season (approx. 15 m/s between 850 mb and 200 mb levels) deters the formation a cyclone. Conversely, the wind shear in the central Bay of Bengal in April and November are 7 m/s and 4 m/s, respectively. These weaker wind shears favor the formation of tropical cyclones (Fink and Speth 1998, Ramage 1971, Alam, *et al* 2003).

There are different opinions about the origins of the Bay of Bengal cyclones. Some studies suggest that the severe cyclones of the Bay of Bengal have their origins in the western Pacific Ocean. These

are the remnants of the weakened Pacific typhoons which cross the Malay peninsula and rejuvenate over the warm water of the Bay of Bengal (Johnson 1981, Johnson 1982). On the other hand, a more recent study suggests that the severe cyclones during the pre-monsoon season originate in the central and southern Bay of Bengal, but the post-monsoon severe cyclones are the remnants of the weakened Pacific typhoons (Subhramanyam, *et al* 2005). After crossing the Malay peninsula, they rejuvenate over the warm water of the Bay of Bengal. Four or five tropical storms typically form in the Bay of Bengal annually, of which 2 may reach severe tropical cyclone status (Fink and Speth 1998). After reaching the minimum category 1 status, a tropical cyclone may take 2-3 days to make landfall.

Data

Tropical cyclones belonging to categories 1–5 that made landfall in the coastal areas of Bangladesh from 1960 through 2004 are considered in this study. Archived meteorological data for these cyclones for the above period were collected from the Bangladesh Meteorological Department. In addition, data on the area and population of the coastal zilas and death tolls were obtained from the Statistical Yearbook of Bangladesh-2003 published by the Bangladesh Bureau of Statistics (BBS 2003).

Methodology

First, we divided the coastal area of Bangladesh into 5 zones to observe the variation of cyclone occurrence in different coastal zones (**Fig. 3**). Important rivers that empty into the Bay of Bengal were taken as the boundaries between the zones. Coastal Zone 1 extends from the Hariabhanga River, at the western border, to the Haringhata River. Sundarbans, the only mangrove forest in the country, is located in this zone. Moreover, Haringhata River marks the eastern limit of the moribund delta of the Ganges (the active delta lies to the east of Haringhata River). Zone 2 extends from the Haringhata River to the Meghna Estuary, Zone 3 from the Meghna River Estuary to the Feni River, Zone 4 from the Feni River to the Karnaphuli River, and Zone 5 extends from the Karnaphuli River to Teknaf, the extreme southeast corner of the country.

We analyzed data to determine the frequency and percentage of the occurrence of tropical cyclones in different intensity categories;occurrence of tropical cyclones by month and week, and frequency and percentage of cyclones in different coastal zones of Bangladesh during the 45-year period.

Results and Discussion

Chronological occurrences of tropical cyclones that made landfall in. A total of 22 tropical cyclones made landfall in Bangladesh during the 45-year period (1960-2004) considered in this study. It may be noted that, there were years with no cyclone occurrences (e.g., 1967-1969, 1975-80, 2000-2004), there were years with a single occurrence (e.g., 1963 and 1966), and there were years with multiple occurrences of cyclones in the country (e.g., 2 in 1960 and 3 in 1965).

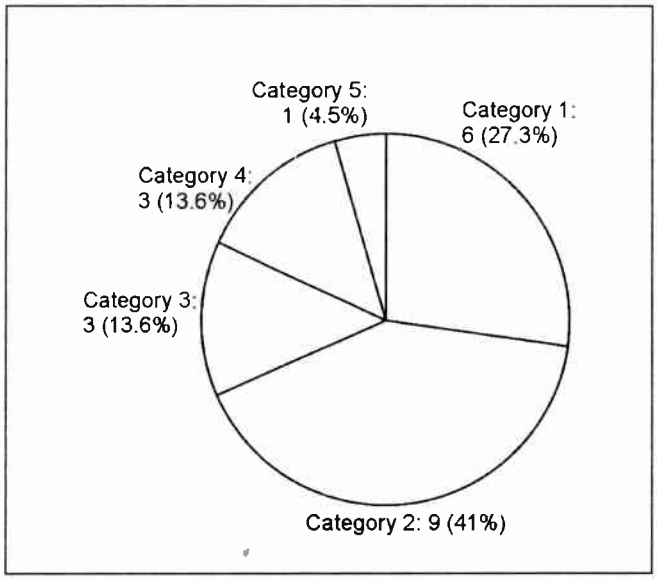

Fig. 3: Frequency and percentage of different categories of cyclones in Bangladesh during the period from 1960 to 2004.

Frequency and percentage of cyclones that made landfall in Bangladesh in different intensity categories are shown in Fig. 3. Of the 22 cyclones, 6 (27.3%) were category-1, 9 (41%) were category-2, 3 (13.6%) were category-3, 3 (13.6%) were category-4, and 1 (4.5%) was a category-5 cyclone. It is clear that more than two thirds (68.3%) of the cyclones belong to categories 1-2.

As stated earlier, there are two distinct cyclone seasons in Bangladesh, one before the summer monsoon season and the other after the summer monsoon season. Grouping the cyclone occurrences by week show the pattern of their seasonal distribution (Fig. 4). The pre- monsoon cyclone season lasts from the final week of April to the final week of May accounting for 41% of the cyclones that hit the coastal areas of Bangladesh. Then, from June to the end of September, which is the summer monsoon season, no cyclones at all have occurred (Fig. 4). The post-monsoon cyclone season lasts from the final week of September to the third week of December, when 59% of the cyclones occur. It is apparent from Fig. 4 that the pre-monsoon cyclones are generally stronger (category 3-5) than those of the post monsoon cyclone season (mostly in category 1-3). The Bay of Bengal is slightly warmer in the pre-monsoon season than the beginning period of the post-monsoon season, 29-30°C and 28-29°C, respectively (Sengupta and Ravichandran 2001). This accounts for the occurrence of relatively stronger tropical cyclones in

Table 3: Some of the Deadliest Cyclopnes in Bangladesh during the period 1960-2004 (Deaths in escess of 1000)

Date	Cyclone Category	Storm Surge (m)	Landfall Zone	Deaths (Estd.)
Oct. 11, 1960	2	3.00	3	3,000
Oct. 03, 1960	3	6.00	3	8,000
May 09, 1961	2	2.75	2	11,500
May 28, 1963	3	3.05	5	11,500
Dec. 15, 1965	3	2.75	5	17,300
Nov. 01, 1966	1	6.40	4	1,000
Nov. 12, 1970	4	6.56	5	2,00,000
May 24, 1985	1	4.58	4	11,000
Nov. 29, 1988	2	2.70	1	12,000
Apr. 29, 1991	4	5.15	5	1,39,000

the pre-monsoon season than in the post-monsoon season.

Occurrences of cyclones in different coastal zones of Bangladesh are shown in Fig. 5. Of the total 22 cyclones that hit the coastal areas of Bangladesh in the 45-year period from 1960 to 2004, 2 (9%) made landfall in coastal Zone 1, 2 (9%) in coastal Zone-2, 3 (14%) in coastal Zone 3, 8 (36%) in coastal Zone 4, and 7 (32%) in coastal Zone-5. It appears that the coastal area that extends from the Feni River to the extreme southeast corner of the country (Zones 4 and 5) is most vulnerable to tropical cyclones which accounts for 68% of the cyclone occurrences. Besides these two zones, Zone 3 is also very vulnerable to tropical cyclones, which accounts for 14% of the cyclone occurrences. In general, the trajectory of the tropical cyclones in the northern Bay of Bengal is from southwest to northeast. So, the coastline of Zones 4 and 5, having a north-south rientation, lie in the direct path of the tropical cyclones. This accounts for a much greater vulnerability of these two zones than other coastal zones.

Cyclone-related fatalities are variable, and may range from a few hundred to 200,000. Some of the deadliest cyclones are listed in Table 4. Of the 10 most of devastating cyclones listed in Table 4, 6 made landfall in coastal Zones 4 and 5, 2 in Zone 3, and 1 each in Zones 1 and 2. It may be noted that Zones 3 - 5 have a very high population density (1100 – 1300 people per square km). The two most devastating cyclones to hit the coastal areas of Bangladesh were the cyclones of 12 November, 1970 and 29 April, 1991, which caused human death tolls of 200,000 and 139,000, respectively. Both these cyclones were of category 4, with high storm surges (6.5 m and 5.15 m, respectively), and made landfall in coastal zone 5 where population density is very high, causing large numbers of human deaths.

Conclusions

Although Bangladesh has been known for the tropical cyclones and their devastating effects, little has been known about their generalized statistical characteristics, and their geographic distribution in the coastal areas of the country. This study presents the results of a statistical analysis of the tropical cyclones that made landfall in the

coastal areas of Bangladesh during the 45-year period from 1960 through 2004. The findings of the study are summarized below: In the 45-year period (1960-2004), 22 cyclones hit the coastal areas of Bangladesh, with an average frequency of one cyclone every two years. In some years 2-3 cyclones may hit the coastal areas of Bangladesh, while at other times, there may be multiple years in a row without any cyclones.

Occurrences of cyclones by week show that there are two cyclone seasons in Bangladesh. One is the pre-monsoon cyclone season (last week April to last week of May) when 41% of the cyclones occur, and the other is the post-monsoon cyclone season (last week of September to the third week of December) when 59% of the cyclones occur. No cyclones occur during the summer monsoon season (June – September).

In general, the pre-monsoon cyclones are stronger (category 3-5) than those of the post-monsoon cyclone season (category 1-3). This may be attributed to the higher sea surface temperatures in the pre-monsoon season than in the pos-monsoon season.

Of the 22 cyclones that hit the coastal areas of Bangladesh during the 45-year period (1960-2004), 6 (27.3%) were category-1, 9 (41%) were Category-2, 3 (13.6%) were category-3, 3 (13.6%) were category-4, and 1 (4.5%) was a category-5 cyclone.

There is spatial variation in the distribution of cyclones in the coastal areas of Bangladesh. Of the 22 cyclones during the 45-year study period (1960 to 2004), 2 (9%) made landfall in coastal Zone 1,

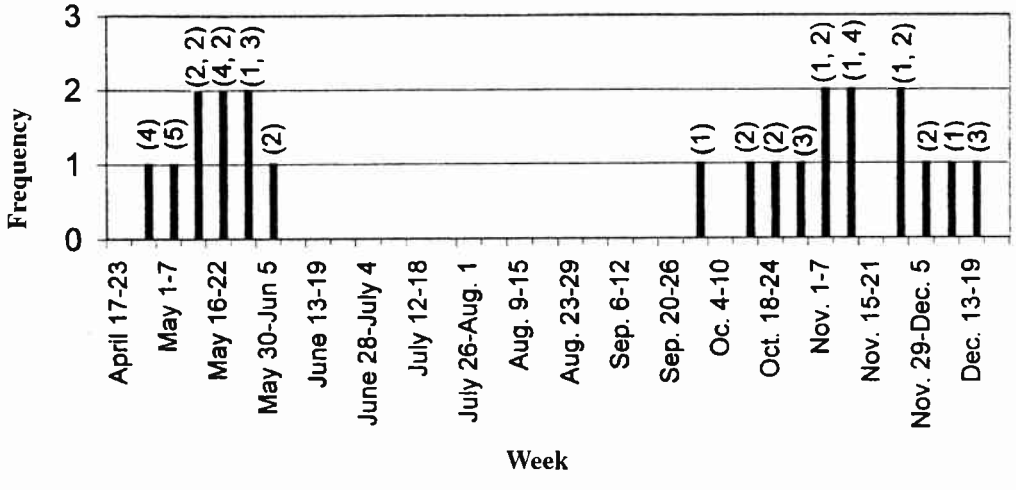

Fig. 4: Frequency of tropical cyclones in Bangladesh, by week (1960- 2004). Numbers in parenthesis above each bar represent the intensity category of cyclones

2 (9%) in coastal Zone 2, 3 (14%) in coastal Zone 3, 8 (36.4%) in coastal Zone 4; and 7 (32%) in coastal Zone 5. It appears that the coastal area from the Feni River to the extreme southeast corner of the country (Zones 4 and 5) is most vulnerable to cyclones, which accounts for 68% of the cyclone occurrences.

It is hoped that this study will contribute to a better understanding of cyclone occurrences in Bangladesh. It is also hoped that the results of this study will be useful for the allocation and utilization of resources for cyclone preparedness, post-cyclone activities and land management in the costal areas of the country. One of the ways to minimize the cyclone damage potentials is to increase cyclone preparedness and coastal land management. Cyclone preparedness includes increasing the resources cyclone warning system, construction of more cyclone shelters, increasing the road network, and improvement in evacuation plans. The coastal management includes coastal embankment, tree planting and sustainable development in the coastal areas. Post-cyclone activities include relief operations, recovery and reconstruction in the affected areas. All these activities would involve undertaking of actions at various levels of governmental institutions and non-governmental organizations – ranging from local to zila and national levels. The long-term development policies for the coastal areas have to be integrated into its national concerns and policies. Results of this study will be useful for the allocation of resources in the coastal areas of the country in proportions to the relative vulnerability of its various coastal zones for cyclone preparedness, post-cyclone relief operations, and various coastal land management projects.

Acknowledgments

The authors express their thanks to: (a) US Council of International Exchange of Scholars (CIES) for offering a Fulbright Scholarship to Dr. M. Shamsul Alam, Professor, Geography and Environmental Studies, University of Rajshahi, Rajshahi, Bangladesh, to conduct this joint research project, and (b) the University of Wisconsin-La Crosse for providing the material and resource support in the Department of Geography and Earth Science to work on the research project.

References

Alam, M.M., Hossain, M.A., and Shafee, S. 2003. Frequency of Bay of Bengal Cyclonic Storms and Depressions Crossing Different Coastal Zones, *International Journal of Climatology*, 23: 1119-1125.

Barry, R.G. and Chorley, R. J. 2003. *Atmosphere, Weather and Climate* (8th Ed.). London/ New York: Routledge.

BBS, 2003. *Yearbook of Bangladesh*, Bangladesh Bureau of Statistics (BBS). Dhaka: Government of the Peoples Republic of Bangladesh.

Chadwick, M. 2002. Integrated Coastal Zone Management in Bangladesh – Improving Policy-LivelihoodRelationships in South Asia: Policy Review Paper-6. London: The UK Department for International Development (DFID).

Chowdhury, M.H. 2003. Cyclones (in Bangladesh). In Islam, S. (ed.) Banglapedia – National Encyclopedia of Bangladesh, Dhaka, Asiatic Society of Bangladesh, 45-58.

Fein, J. S. and Stephen, P.L. 1987. *Monsoons*, New York: J. Wiley & Sons.

Fink, A.H, and Speth, P. 1998. Tropical Cyclones. *Naturwissenschaften,* 85: 482-493

Haque, C.E. 1995. Climatic Hazards Warning Process in Bangladesh: Experience of, and lessons from the 1991 April cyclone. *Environmental Management*, 19 (5): 719-734.

Haque, C.E. 1997. Atmospheric Hazard Preparedness in Bangladesh: A study of warning, adjustments, and recovery from the April 1991 Cyclone, *Natural Hazards*, 16: 181-202.

Johnson, B.L.C, 1981. *South Asia* (2nd Ed.), Heinemann Educational Books, London.

Johnson, B.L.C, 1982. *Bangladesh* (2nd Ed.), Heinemann Educational Books, London.

Karim, N. 2002. Options for Cyclone Protection: Bangladesh Context, paper presented at the First International Conference on Post-natural Disaster Reconstruction in Developing Countries, Univ. of Montreal, Montreal, Canada, May 23-25, 2002.

Lal, M. 2001. Tropical Cyclones in a Warmer World, *Current Science*, 80: 103-1104.

LGED. Local Government Engineering, Department, Government of Bangladesh, Dhaka, Bangladesh. Website: www.lged.org/sre

Oliver, J. E. and Hidore, J. H. 2002. *Climatology: An Atmospheric Science* (2nd Ed.). Upper Saddle River, New Jersey: Prentice-Hall.

Ramage, C.S., 1971. *Monsoon Meteorology*, New York: Academic Press.

Saffir, H.S. and Simpson, R.H. 1974. *Saffir-Simpson Hurricane Intensity Scale*. United States National Weather Service, Camp Springs, Maryland.

Sengupta, D. and Ravichandran, M. 2001. Oscillations of Bay of Bengal Sea Surface Temperature During the 1998 Summer Monsoon, *Geophysical Research Letters*, 28 (10), 2033-2036.

SoE (State of Environment) Study Team, 2001. *State of Environment, Bangladesh 2001*, United Nations Environment Programme (UNEP), Regional Resource Center for Asia and Pacific (RRC.AP), pp. 99.

Subrahmanyam, B. Murty, V.S.N, Sharp, R.J., and O'Brien, J.J. 2005. Air-sea Coupling During the Tropical Cyclones in the Indian Ocean: A Case Study Using Satellite Observations, *Pure and Applied Geophysics*, 162: 1643-1672.

M. Shamsul Alam
Professor, Geography and
Environmental Studies
University of Rajshahi
Rajshahi 6205
Bangladesh
alam_ges@ru.ac.bd

Rafique Ahmed
Professor, Geography and Earth Science
University of Wisconsin-La Crosse
La Crosse, Wisconsin 54601
USA
ahmed.rafi@uwlax.edu