CLIMATE OF BANGLADESH

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1. Introduction

The climate is important to man in everything he does. The climate pervades all aspects of human lives. The food he eats, the house he lives in and the clothes he puts on depend upon the climate regime. Even in to-day's technological advanced world, food supplies are vulnerable to the effects of the climate. Spells of bad weather can disrupt transport and harvesting and prolonged bad weather can lead to shortages and high prices. Drought and flood can result in people starving and famine can occur unless Govt. intervenes.

Bangladesh is known as the land of six seasons which appears in our literature. Each season consists of two mounts and they are summer, rainy season, autumn, dry season, winter and spring. However, in reality the most of the six seasons are overlapped with each other. For example rainy season lasts for more than two months and with the exception of nearly three months winter, the summer lasts rest of the year. We have the hottest weather during the so called spring season. Thus from meteorological view point Bangladesh climate is divided into the following seasons. Winter: December, January and February. Pre monsoon: March, April and May. Monsoon: June, July, August and September. Post Monsoon: October and November. It may mentioned that in this classification the seasons are not of equal length Monsoon which is actually summer monsoon is of four month's duration and lasts almost to the middle of October. The winter monsoon is short lived in Bangladesh and is of three months duration from December to February though it becomes quite warm beginning from the middle of February. Pre-monsoon is actually hottest season of the year and during this period there is some rainfall accompanied by Norwester and hailstorm and often with recurrence of tornadoes. The mean temperature during summer months remains within 23 to 30^0C. April and May are the hottest months. The highest temperature ranging from 44 to 45^0C is attained in the northern and northwestern districts. Over rest of the country, it ranges from 41 to 43^0C. The post monsoon months of October and November are transition months from summer to winter and it is quite hot in October.

Rainfall over the country during winter is very scanty and does not exceed 5% of the yearly total. The driest month of the season is December when the northern and the western districts get hardly 3-10 mm of rainfall; the coastal districts of Barisal, Noakhali, Chittagong and Chittagong Hill Tracts get 15-30 mm of rain. With the progress of the season, the rainfall increases over the whole of the country. The rainfall during the pre-monsoon is about 15% though it varies from region to region. The rainfall during the summer monsoon is about 75% of the yearly total. The rainfall during post monsoon period is about 5% though it may be more if there is a depression or cyclone.

The monsoon phenomenon must have been known to the inhabitants of the south Asian sub-continent since the ancient times. It has been mentioned in the holy Ramayana and Mahabharata and other Vedic books. In the book Artho-Sastra (Science of Economics) written during the reign of Chandragupta Maurya (321-296 B.C) by his minister Kautilaya, there is mention about the amount of rain at different places indicating that they had knowledge about rainfall measurements. With the conquest of western India by Alexander the Great, the knowledge of monsoon must have reached the Greeks. It may be

mentioned that the first book on Meteorology named Meteorologica' was written by Aristotle in 350 B.C.

Astronomer Varahamihira (505-587 A.D.) used to predict rain. Astronomers Arya Bhatta and Brahmagupta also studied monsoon. The famous Sanskrit poet Kalidas composed poems out of monsoon clouds as depicted in his Meghdoot (Cloud Messenger) and Ritusamahara (Cycle of Seasons). However, the real credit of the meteorological and the agrometeorological predictions during the ancient times goes to a lady named Khona. Even to-this day her verses are remembered by the farmers of Bangladesh and northeastern India. This could be the envy of any scientist at any time.

The Arabs used the knowledge of the changing pattern of monsoon winds with season very profitably for trade with India. The name monsoon is derived from the Arabic word `Mausam' meaning season of winds. This was in reference to the seasonally shifting winds in the Indian Ocean and the surrounding regions. These winds blow from northeast during winter and southwest during summer. As the northeast wind blows from the continental areas, it carries little moisture and as a result, we have very little rain during winter. On the other hand, as the southwest wind blows from the sea, it carries lot of moisture and as a result, we have plenty of rain in summer. An Arab geographer named Al-Masudi wrote a book with the title of Meadows of Gold and Mines of Gems in the tenth century. The book, as the name suggests does not deal with meadows of gold or the mines of gems but deals with the seasonal reversal of ocean currents over the north Indian Ocean which facilitates the Arabs in their trade. One Arab geographer helped Vasco-da-Gamma to find his way to India.

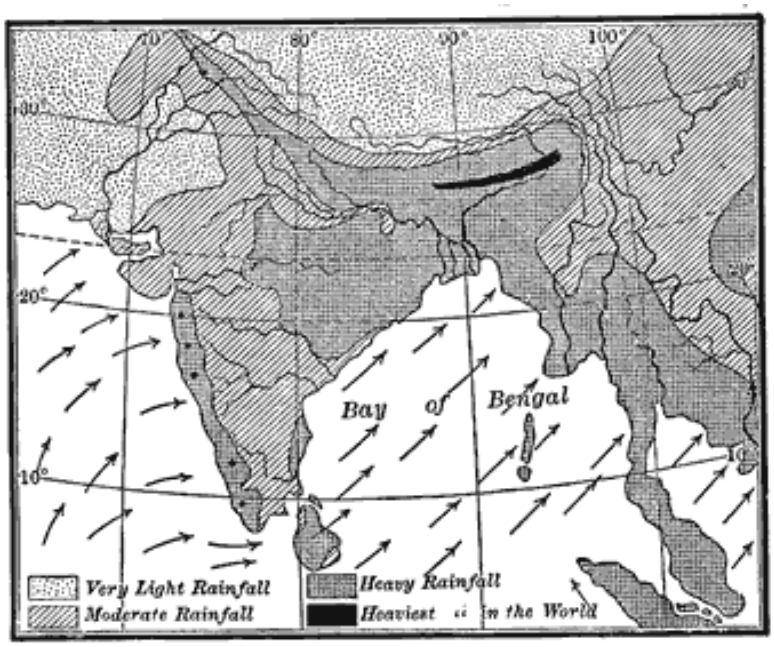
If we are to understand the fluctuation of monsoon rain, we have to understand the causes of the monsoon phenomenon.

2. Causes of the Monsoon

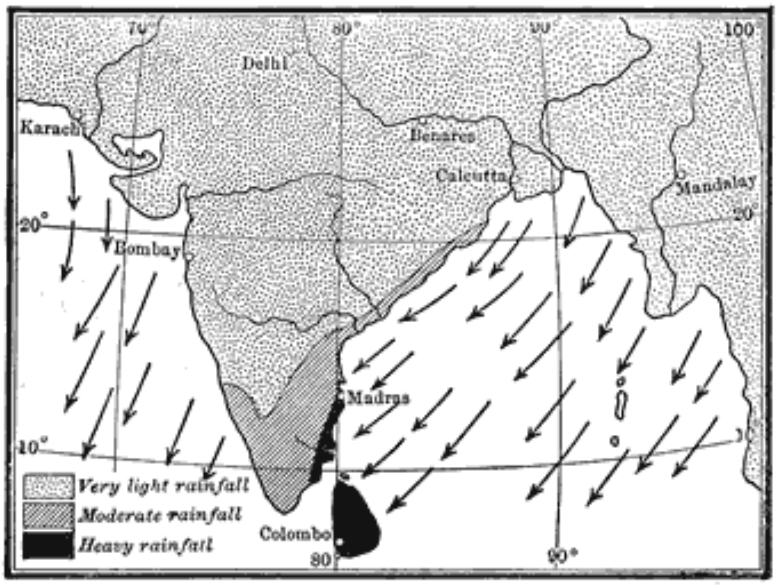
Though the monsoon phenomenon is regional in character, it is affected by the global movement of air known as the general circulation and it also affects the latter. In the north-eastern hemisphere of the globe where monsoon is predominant, land area is about 60% whereas in the rest of the world, this is about 20%. The monsoon or the seasonal changes of wind are primarily the result of differences in the quantity of heat received from the sun by the earth's surface. There is a striking contrast between the response of the land and water areas to seasonal changes in solar radiation. We know that the sun stays in the northern hemisphere during summer and in the southern hemisphere during winter. Solar radiation does not penetrate the earth's surface beyond only a shallow layer and hence most of the solar radiation received by the land areas is used up in heating the air rather than the soil. On the other hand, solar radiation penetrates to much greater depths in the ocean, because there can be up and down movement in water. Hence in the ocean, large part of the solar radiation is used up by water and air is heated less there. The result is that in summer, the land areas where the solar radiation falls perpendicularly are heated more than the ocean areas and the temperature difference could be as large as 10^{O}C. In winter, the sun stays in the southern hemisphere where the solar radiation falls perpendicularly and which is largely ocean. Because of the greater heat storage capacity of water, the ocean is heated more than the land in winter. This differential heating is broadly speaking is the reason for reversal of wind with season in our region. The vast Eurasian land mass dominated by the Himalays and the Tibetan Plateau

and surrounded by the Indian and Pacific oceans contribute largely to Monsoons. The dramatic change of the wind system with season is shown in Fig.1.

This explanation of the monsoon phenomenon fell to Edmund Halley (1686) of Comet Halley fame, sponsor of Newton's Principia and secretary of the Royal Society. Subsequently George Hadley (1735), a London lawyer and a Fellow of the Royal Society improved upon Halley's idea by introducing the effect of the Coriolis Force arising out of earth's rotation. Even to this day Halley and Hadley's ideas remain valid. The summer monsoon starts first in Myanmar during the last fortnight of May. Then it approaches gradually westwards. In Bangladesh and southern India, the monsoon sets in around the 1st week of June. By the end of July, it reaches almost the entire sub-continent. It starts withdrawing from the western part of the sub-continent in early September and from Bangladesh in mid October.



SUMMER MONSOON WINDS



WINTER MONSOON WINDS

Fig-1

3. Rainfall Variation in Bangladesh

Analysis has shown that rainfall over Bangladesh shows periodicities of 2-3 years, 6 years and 11 years. The year to year variation of the monsoon rainfall is perhaps related to the natural response mechanism of the ocean-atmospheric system to the changes of various physical parameters. This also could be related to climatic changes that can arise due to natural or man-made factors.

4. The El-Nino

As climate involves the motion of the entire ocean-atmospheric system of the earth, it is expected that a climatic event in one part of the globe may have its impact in some form in another part. But nothing is more striking than the ENSO phenomenon in this respect. It has been observed for quite sometime that positive anomalies in the sea surface temperature (SST) of the southeastern Pacific Ocean have worldwide climatic repercussions both in the tropics as well as in extra tropics. This warming of the ocean occurs with an irregular period of 2-10 years and as it starts appearing immediately after Christmas, it was called El-Nino meaning Child Jesus in the Spanish language. The temperature of the southeastern Pacific is colder in normal times and is one of the most productive regions of the world oceans. The prevailing southeasterly trade wind drives the surface water off the shore and causes upwelling of deep cold water that is rich in inorganic plant nutrients such as nitrate, phosphate and silicate. The continuous injection of nutrients into the surface layers in a region of abundant sunlight sustains the high rate of production. However, during El-Nino condition the southeastern Pacific Ocean warms up, southeasterly trade wind stops with the consequent cessation of upwelling and as a result the inflow of nutrients and the fish industry specially the Peruvian anchovy suffers drastic reduction. Deprived of the fish to eat, birds also die and disappear.

It is not only the South American coast which is affected during am El-Nino event but also the islands in the central tropical dry zone, equatorial eastern Africa are the places which get excessive rainfall, the places where deficit rainfall occurs are Indonesia, Australia, Philippines, South Asian subcontinent, southwestern Africa, Ethiopia and northeast Brazil.

5. Southern Oscillation and El Nino

This periodic warming and cooling of the southeastern Pacific Ocean is actually related to a phenomenon known as Southern Oscillation. Walker and Bliss described the phenomenon like this: "When pressure is high in the Pacific Ocean it tends to be low in the Indian Ocean from Africa to Australia; these conditions are associated with low temperatures in both these areas and rainfall varies in the opposite direction to pressure. Conditions are related differently in winter and summer and it is therefore necessary to examine separately the season of December through February and June through August". Southern Oscillation is a seesaw of pressure oscillation in the tropics between the Indian and the west Pacific Oceans on the one hand and the southeast Pacific Ocean on the other. This is an atmospheric phenomenon whereas El Nino is an oceanic phenomenon. The connection between the Southern Oscillation and the sea surface temperature variations in the southeastern Pacific was

discovered by Bjerknes though perhaps there is no one to one correspondence. They are now jointly named ENSO and this represents an excellent example of ocean-atmospheric coupling. It is usual to take the Tahiti minus Darwin surface pressure anomaly difference as an index of ENSO though other measures are also used. When this index is positive, it reflects cold phase of sea surface temperature in the southeastern Pacific Ocean. During an El-Nino event (warm phase) this index is negative.

6. Bangladesh Flood, Drought and ENSO

Bangladesh is perhaps the unique country in the world where casualties due to a cyclone could rise upto hundreds of thousands. Floods can devastate more than half of the country causing damages to billions of dollars. Could ENSO phenomenon throw some light on the floods and cyclones in Bangladesh? A Study on Bangladesh monsoon rainfall has shown that in general there is decrease in rainfall in El-Nino years in all the seasons-the pre-monsoon, the monsoon and the post monsoon. It is remarkable that the great Bengal famine year of 1770 when millions of people in Bengal died was wiped out was an El-Nino year. Another great famine occurred in Bengal in 1943 which was also an El Nino year. The years 1940-41 were also El-Nino years. Perhaps the combined effect of these consecutive bad monsoon years depleted the crop stock to a great extent and the war procurement accelerated this famine of 1943 in undivided Bengal. Another famine occurred in modern Bangladesh in 1974. The years 1972-73 were El-Nino years which continued in 1974 when again there was the recurrence of a great flood. Perhaps a combination of all these depleted the food stock and the famine of 1974 occurred. In recent years, of course, large scale irrigation has been introduced and because of better food policy, shortfall of crops is averted.

Some interesting features have come out with regard to a connection between ENSO and floods in Bangladesh. The most catastrophic floods in recent years in Bangladesh occurred in 1954, 1955, 1974, 1987, 1988, 1998 and 2004. The years 1954, 1955 and 1988 are years with highly positive ENSO index whereas 1974 and 1987 are years of continuing El-Nino years, the main El Nino occurred in the previous years and in these years negative anomaly were not that strong. Let us note the major El Nino years in this period. These are 1951, 1957, 1972, 1976, 1982, 1986 and 2006. In these years, there was no catastrophic flooding in Bangladesh. Thus we can conclude that during major El Nino years at least during the first year of El Nino, Bangladesh can be spared from catastrophic floods. The years 1963, 1965 and 1969 were moderate or weak El Nino years and in those years there were moderate floods in Bangladesh. Thus we conclude that during highly positive or weak ENSO (positive and negative) years, Bangladesh can be a victim of flood. The year when SOI index is usually highly positive during monsoon months, floods can be severe whereas when SOI index is strongly negative there can be scarcity of rainfall and even drought. A schematic diagram of the ENSO circulation is shown in Fig-2.

The following tables show the climatic parameters of Bangladesh mainly rainfall, temperature, relative humidity, atmospheric pressure and wind for six divisions of Bangladesh.

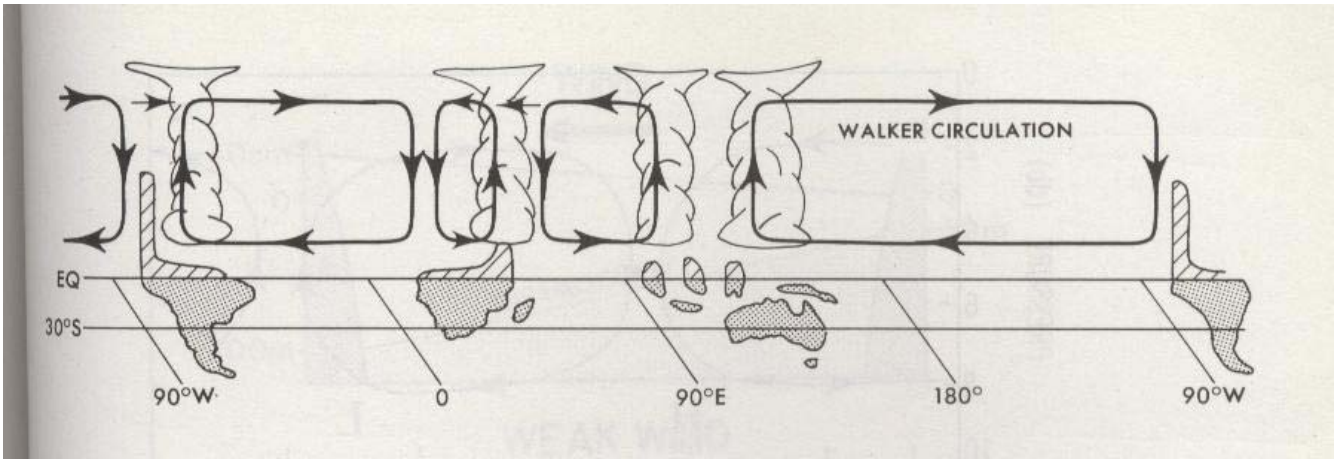


Fig-2: Schematic diagram of the normal Walker circulation along the equator during LANINA condition. Rising are and heavy rains tend to occur over Indonesia and the western Pacific and extends upto Bangladesh. During an El-Nino condition, the Walker circulation is weakened and rainfall over our region diminishes.

7. CLIMATIC PARAMETERS OF DIFFERENT DIVISIONS OF BANGLADESH (NORMAL)

Dhaka

Month	**Rainfall** (mm)	**Temperature** (Max.) (Deg.C)	(Min.) (Deg.C)	(Normal) (Deg.C)	**Relative Humidity**	**Pressure** (MBS)	**Wind** (in N.M)
Jan.	12	25.1	9.6	18.7	69	1014.7	4.6
Feb.	20	29.0	14.3	21.2	63	1012.5	4.1
Mar.	69	34.8	18.2	26.3	61	1009.8	5.0
Apr.	120	35.3	25.7	29.0	70	1006.5	8.4
May	258	32.5	24.0	28.9	79	1003.3	5.3
Jun.	397	31.2	25.9	28.6	86	1000.4	5.8
July.	386	31.7	26.7	28.6	86	1000.4	6.4
Aug.	326	30.8	26.1	28.6	86	1001.5	5.2
Sep.	264	31.7	25.8	28.7	85	1004.6	7.6
Oct.	158	30.4	23.1	27.2	81	1009.4	2.3
Nov.	26	28.5	16.7	23.4	75	1012.7	2.6
Dec.	8	25.7	12.4	19.7	71	1014.6	3.7
Annual	2044	30.6	20.6	25.8	76	1007.6	

CLIMATIC PARAMETERS OF DIFFERENT DIVISIONS OF BANGLADESH (NORMAL)
Chittagong

Month	**Rainfall** (mm)	**Temperature** (Max.) (Deg.C)	(Min.) (Deg.C)	(Normal) (Deg.C)	**Relative Humidity**	**Pressure** (MBS)	**Wind** (in N.M)
Jan.	5	25.1	12.4	20.2	73	1014.8	4.4
Feb.	12	28.3	16.2	22.2	71	1013.0	5.6
Mar.	59	31.6	20.1	25.7	75	1011.0	6.5
Apr.	86	32.0	24.3	27.9	78	1008.6	14.8
May	240	32.5	25.0	28.7	80	1005.2	8.0
Jun.	589	30.4	25.3	28.2	86	1002.1	9.0
July.	687	31.3	25.7	27.9	87	1002.3	8.4
Aug.	538	30.6	25.2	27.9	87	1002.8	7.7
Sep.	285	32.1	25.6	28.2	85	1005.7	8.1
Oct.	246	30.8	24.0	27.5	83	1009.7	4.1
Nov.	55	28.8	18.6	24.6	78	1012.7	2.6
Dec.	8	26.5	14.7	21.0	75	1014.8	2.8
Annual	2810	30.1	21.5	25.9	80	1008.6	

CLIMATIC PARAMETERS OF DIFFERENT DIVISIONS OF BANGLADESH (NORMAL)
SYLHET

Month	**Rainfall** (mm)	**Temperature** (Max.) (Deg.C)	(Min.)	(Normal) (Deg.C)	**Relative Humidity**	**Pressure** (MBS)	**Wind** (in N.M)
Jan.	15	**	**	17.5	72	1014.6	**
Feb.	49	**	**	20.2	66	1012.7	**
Mar.	82	**	**	24.3	63	1010.3	**
Apr.	278	31.8	22.4	26.6	73	1007.6	4.1
May	580	31.8	23.4	26.8	82	1004.4	4.5
Jun.	826	30.6	24.7	27.4	88	1001.5	4.3
July.	719	25.0	25.6	28.1	88	1001.2	3.5
Aug.	596	31.6	25.4	28.2	87	1002.2	3.5
Sep.	453	31.7	24.9	27.9	86	1005.2	4.1
Oct.	254	30.4	23.2	26.3	84	1009.6	3.2
Nov.	21	28.2	17.2	23.2	77	1013.0	4.5
Dec.	4	25.5	12.1	20.2	75	1014.6	4.8
Annual	3877	**	**	24.8	78	1008.1	

CLIMATIC PARAMETERS OF DIFFERENT DIVISIONS OF BANGLADESH (NORMAL)
RAJSHAHI

Month	**Rainfall** (mm)	**Temperature** (Max.) (Deg.C)	(Min.) (Deg.C)	(Normal) (Deg.C)	**Relative Humidity**	**Pressure** (MBS)	**Wind** (in N.M)
Jan.	12	24.7	10.9	18.5	71	1015.5	2.1
Feb.	12	28.7	13.9	20.9	64	1013.2	2.0
Mar.	29	35.1	18.5	25.9	55	1009.8	2.1
Apr.	49	35.9	23.5	29.8	59	1005.8	2.5
May	120	34.1	24.3	30.3	69	1002.7	3.0
Jun.	298	34.0	26.6	29.6	81	999.4	3.0
July.	350	31.1	25.9	29.1	86	999.8	2.9
Aug.	276	31.8	26.6	29.1	85	1000.8	3.3
Sep.	256	31.8	25.9	29.1	84	1004.8	2.4
Oct.	116	30.7	24.5	27.3	79	1010.1	4.2
Nov.	17	28.7	18.2	23.8	75	1013.3	2.7
Dec.	5	26.2	13.6	19.4	73	1014.5	2.9
Annual	1540	31.1	21.1	26.1	73	1007.5	

CLIMATIC PARAMETERS OF DIFFERENT DIVISIONS OF BANGLADESH (NORMAL)
BARISAL

Month	**Rainfall** (mm)	**Temperature** (Max.) (Deg.C)	(Min.) (Deg.C)	(Normal) (Deg.C)	**Relative Humidity**	**Pressure** (MBS)	**Wind** (in N.M)
Jan.	10	26.0	14.7	19.2	75	1014.9	2.7
Feb.	14	25.4	14.9	21.8	73	1013.0	2.5
Mar.	45	32.2	22.9	26.5	71	1010.5	4.2
Apr.	82	34.6	24.9	29.2	77	1007.6	2.9
May	187	33.7	25.6	29.4	79	1001.1	2.4
Jun.	419	31.7	25.8	28.7	87	1000.8	1.7
July.	429	31.3	26.3	28.3	88	1000.8	2.5
Aug.	389	31.2	26.1	28.5	88	1001.5	2.5
Sep.	326	31.1	26.1	28.7	87	1004.8	3.2
Oct.	203	31.7	24.8	27.7	85	1009.4	1.6
Nov.	24	28.9	19.2	24.0	79	1013.1	1.5
Dec.	5	25.0	12.7	20.3	75	1014.9	2.2
Annual	2139	30.3	22.0	26.1	80	1008.0	

CLIMATIC PARAMETERS OF DIFFERENT DIVISIONS OF BANGLADESH (NORMAL)
KHULNA

Month	**Rainfall** (mm)	**Temperature** (Max.) (Deg.C)	(Min.) (Deg.C)	(Normal) (Deg.C)	**Relative Humidity**	**Pressure** (MBS)	**Wind** (in N.M)
Jan.	8	26.2	14.8	20.4	72	1015.6	2.8
Feb.	8	26.5	15.4	23.2	69	1013.3	3.6
Mar.	33	33.2	23.4	27.6	68	1010.4	5.7
Apr.	66	35.2	25.8	29.7	74	1007.5	3.5
May	171	33.7	25.6	30.3	77	1004.0	3.8
Jun.	371	31.2	26.9	29.4	86	1000.3	3.4
July.	385	31.0	26.4	28.8	89	1000.3	3.8
Aug.	270	31.1	25.5	29.0	89	1001.1	3.6
Sep.	232	30.9	25.9	29.2	87	1004.5	3.4
Oct.	156	27.1	16.4	27.9	83	1009.7	3.0
Nov.	13	28.5	19.3	24.9	76	1013.4	0.0
Dec.	3	25.2	12.2	21.1	74	1015.3	3.7
Annual	1716	30.0	21.6	26.8	79	1008.0	

8. NATURAL CATASTROPHES

Bangladesh currently ranks as one of the world's foremost disaster-prone country. The situation is aggravated, all the more by its being the most densely populated country in the world. Environmental disasters like tropical cyclones, storm surges, floods, norwesters, tornadoes and droughts ravage the country almost every year. During the period 1960-2000, the country was devastated by forty severe cyclones of varying intensities. One of the severe ones in recent times was that of 29 April 1991, when material damage was to the tune of about 2.4 billion US dollars and human casualty of about 1,40,000 lives. On a previous occasion of a similar catastrophe in 1970, about half a million lives were lost. The Bangladesh flood of 1988 caused economic loss to the extent of about one billion dollar. The loss due to the 1998 flood of Bangladesh has exceeded that due to any previous flood and may be around two billion dollars. The flood of 2004 was also similar to 1998 flood though its duration was less. And flooding in Bangladesh is a perennial problem. Every year Bangladesh is also affected by norwesters and tornadoes causing loss of lives and immense damage to property. Though Bangladesh is affected by floods frequently, it is not spared from drought which occurs in Bangladesh occasionally causing extensive damage to crops. Bangladesh also lies in the seismic zone and hence comes under the risk of earthquakes.

8.1 Tropical Cyclones

The tropics can be regarded as the region of the earth lying between 30^{O}N latitude and 30^{O}S latitude. All the tropical seas of the earth with the exception of the south Atlantic and east south Pacific give birth to deadly atmospheric phenomena known as tropical cyclones. On the average, 80 tropical cyclones are formed every year all over the globe. Bangladesh is a part of humid tropics, with the Himalayas in the north and the funnel shaped coast touching the Bay of Bengal in the south. This peculiar geography of Bangladesh causes not only the life giving monsoons but also catastrophic ravages of cyclones, norwesters, tornadoes and floods. The Bay of Bengal is an ideal breeding ground for tropical cyclones. A tropical storm does not form if the sea temperature is less than 27^{0}C, a condition which is satisfied in the Bay of Bengal most of the time. In Bangladesh, tropical cyclones occur during pre and post monsoon season.

8.2 Floods

The primary cause of flood in Bangladesh is rainfall in the catchments areas of the rivers of Bangladesh. Situated in the monsoon belt with the Himalayas in the north, Bangladesh falls in the region of very heavy rainfall. About 80 percent of the rainfall occurs during the 5-month period from May to September. The annual rainfall varies from about 60 inches in the western part of the country to about 200 inches in the north eastern part. At Cherapunjee in Assam very near our Sylhet border the average annual rainfall is about 500 inches which is the highest in the world. But the average rainfall in Bangladesh generates annually only 100 million acre feet of water whereas 1100 million acre feet of water comes from outside Bangladesh. Thus about 90 percent of the water carried by our river system, the Brahmaputra, the Ganges, the Meghna and other smaller rivers is brought from outside the country.

These rivers carry water from an area of about 600,000 sq. miles of which only 7.5 percent lies in Bangladesh. Water enters in Bangladesh through three major channels but the discharge takes place through one major channel. The river system has evolved to carry the normal flow of water generated in the catchment area. Whenever the inflow of water is greater than the carrying capacity of the rivers (and this happens very often) flood results. The magnitude of the flood depends on the magnitude of excess water that is generated.

8.3 Norwesters and Tornadoes

Though cyclones are the most devastating storms affecting Bangladesh, there are other kinds of storms which affect Bangladesh. Of these, mention may be made of Norwesters and Tornadoes which cause lot of destruction of lives and property.

Norwesters come mainly from the north westerly direction (and hence the name) and are land based. They are a very common phenomenon in Bangladesh during late Chaitra and Baishak months and are known in Bengali as Kalbaishaki.

Another kind of storm very similar to a tropical cyclone but is of much smaller dimensions and very destructive is known as a Tornado. A tornado is also a low pressure region where strong winds blow around a centre in an anticlockwise direction in the northern hemisphere and clockwise direction in the southern hemisphere. But unlike a cyclone, a tornado develops on land. A cyclone lasts for days whereas a tornado lasts for a very short duration.

A tornado is formed because of the interaction of two air masses, one moist and warm air and the other dry and cold air resulting in extreme form of instability. Tornadoes often form a series and travel in almost parallel paths. The whole tornado moves at a speed of 25-30 miles an hour, whereas the maximum wind in a tornado could be 300 miles/hr.

Since the horizontal diameter of a tornado is so small and it forms so suddenly that it is difficult to recognize a tornado either in the surface weather map or in the satellite picture and hence forecasting of a tornado well ahead of occurrence becomes very difficult.

8.4 Drought

Though Bangladesh is a land of abundant rainfall, drought is very familiar to us. It is difficult to define the term drought precisely and hence any definition is rather subjective. It simply means lack of water and may be defined as lack of sufficient water to meet requirements. Thus, drought can be of various kinds according to various requirements. Some of the droughts in Bangladesh seem to be related to El-Nino phenomenon.

8.5 Earthquakes

There is ample evidence from various geological studies that the earth's crust is in motion both horizontally and vertically. The modern theory of this aspect of the earth's surface is called plate tectonics.

Earthquakes occur in regions of the earth's crust which are undergoing deformation. As the region is deformed, energy is stored in the rock in the form of elastic strain. This continues until at some point the accumulated strain exceeds the strength of the rock. Then fracture or faulting occurs. Of the theories of earthquakes, perhaps the elastic rebound theory is the most successful one. This states that opposite sides of the fault rebound to a position of equilibrium and the energy is released in the form of heat, in the crushing of rock and in the vibration of elastic waves. The waves or vibrations which are generated at the moment of fracture produce the shaking which is experienced in earthquake.

The major earthquakes that have affected Bangladesh since the middle of the last century are the Cachar Earthquake of January 10, 1869, the Bengal Earthquake of July 14, 1885, the Great Earthquake of July 12, 1897, the Srimangal Earthquake of 8th July, 1918, the Dhubri Earthquake of July 3, 1930, the Bihar-Nepal Earthquake of January 15, 1934 and the Assam Earthquake of August 15, 1950. Of these, only the Bengal Earthquake of 1885 and the Srimangal Earthquake of 1918 had their epicentres in Bangladesh.

The damages caused by these shallow focus earthquakes however were restricted to narrow zones surrounding the epicentres. The greatest damage was caused by the 1897 earthquake. The tremors were felt all over the country and severe damages were caused in the northern parts of Sylhet and Mymensingh districts and in the eastern part of Rangpur district. The 1950 earthquake was also felt all over the country though no damage was reported. Thus we see that Bangladesh is not entirely free from the menace of earthquakes. Specially the northern belt of greater Sylhet, Mymensingh and the eastern part of Rangpur Districts could be vulnerable. Bangladesh should develop adequate facilities for detection and study of earthquakes.

Small magnitudes earthquakes occur every year in Bangladesh many times without much damage. But occurrence of a high magnitude earthquake cannot be ruled out in Bangladesh. Recently we witness the great Tsunami which occurred as a result of Sumattara earthquake in December, 26, 2004 which caused widespread destruction and two persons died in Bangladesh coast because of this. Thus Bangladesh cannot be spared from Tsunami either.

9. GLOBAL CLIMATE CHANGE AND BANGLADESH

During the last 100 years human population soared from little more than one to six billion and economic activity increased nearly 10-fold between 1950 and 2000. The world’s population is more tightly connected than ever before via globalization of economies and information flows. Half of Earth’s land surface has been domesticated for direct human use.

It is now known that the accelerating pace of human activities (both agricultural and industrial) has caused, among other things, an increasing accumulation of polyatomic molecules such as carbon dioxide (CO_2), various chloroflucarbons ($CFCs$), methane (CH_4), nitrous oxides and other which absorb the infrared radiation emitted by the Earth's surface. They add to the "greenhouse effect" of atmospheric water vapour and natural CO_2, causing an augmentation of long wave infra-red radiation emitted downwards by the atmosphere and absorbed by the Earth's surface. This is largely responsible for what is now referred to as global warming. The evidence that these changes are affecting the basic functioning of the Earth System particularly the climate grows stronger every year.

Global warming is the observed increase in the average temperature of the Earth's atmosphere and oceans in recent decades. The Earth's average near-surface atmospheric temperature rose 0.6 ± 0.2^0 Celsius (1.1 ± 0.4^0 Fahrenheit) in the 20^{th} century. The prevailing scientific opinion on climate change is that "most of the warming observed over the last 50 years is attributable to human activities. The increased amounts of carbon dioxide (CO_2) and other green house gases ($GHGs$) are the primary causes of the human-induced component of warming. They are released by the burning of fossil fuels, clearing, agriculture, and lead to an increase in the greenhouse effect. The term 'global warming is a specific case of the more general term 'climate change'.

Based on estimates by NASA's Goddard Institute for Space Studies, 2005 was the warmest year since reliable, widespread instrumental measurements became available in the late $1800s$, exceeding the previous record set in 1998 by a few hundredths of a degree Celsius. The enclosed diagram (Fig-3) shows that the global temperature has recently moved well outside the range of natural variability exhibited over at least the last half million years. Its magnitude and rate of change is unprecedented in human history and perhaps in the history of the earth.

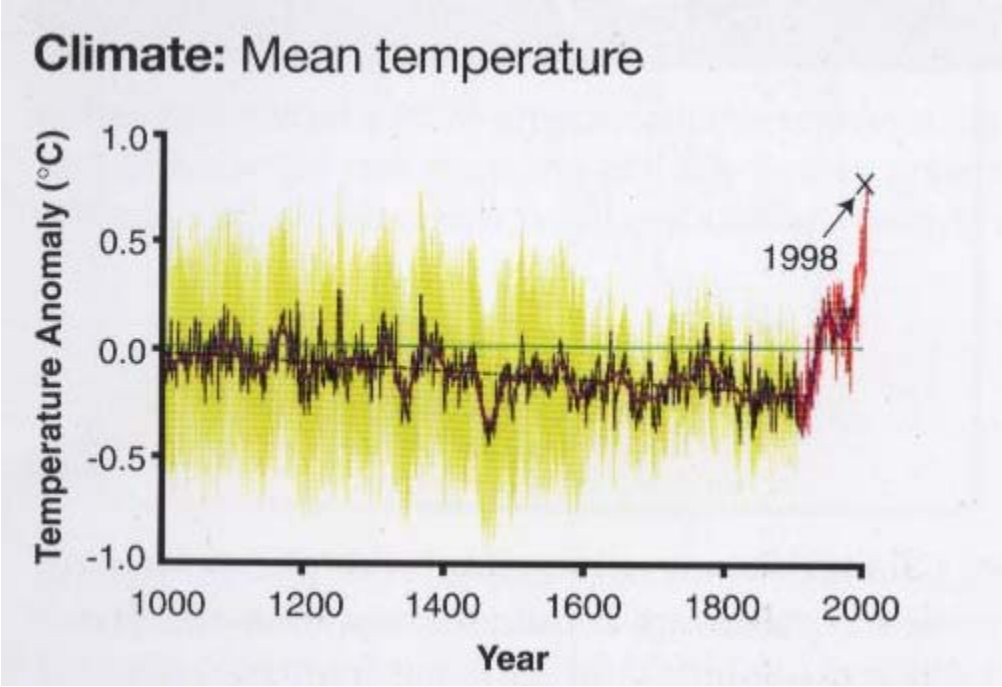


Fig-3

The global sea level has risen by between 10 and 20 cm over the past 100 years and much of the rise may be related to the increase in global mean temperature. From around 1850 onward, most of the world's glaciers including those of the Alpine regions, Mt. Kilimanjaro in Africa and Mt. Chacaltaya in Bolivia, have been retreating. The retreats of glaciers in the mountainous regions of the world are striking indicators of climate changes. The Arctic ice is thinning. The ice is about 40 per cent thinner than what it was at the beginning of the last century. Its spread has also noticeably declined. The WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) has predicted that the globally averaged surface temperature is projected to increase by 1.4-5.8 ^{0}C between 1990 and 2100. It is very likely that nearly all land areas will warm more rapidly than the global average. Global mean sea level is projected to rise by 9-88 cm between 1990 and 2100. The prospect of rising sea level is one of the most widely recognized potential impacts of climate change. Sea level rise as well as climate and weather extremes cause problems associated with beach erosion, siltating of waterways and flood risk in coastal communities.

Bangladesh would be one of the most severely affected countries in this regard. Under the present estimate of about one meter rise of sea level by the year 2100, a substantial area of the country will go under water. One-meter rise of sea level will inundate approximately 17% of the total area of Bangladesh. This will affect 7% of GDP of Bangladesh. Thus, it has far-reaching consequences for Bangladesh if the estimate comes true. This rise of ocean water will force more population to be congested into smaller areas and will force migration, inundate wetlands and lowlands, accelerate coastal erosion, and increase salt water intrusion into rivers, agricultural and coastal forest lands and into groundwater. This will in turn create multiple problems in coastal urban areas, cause damage to port facilities and coastal embankments/structures, destroy agricultural land, dislodge mangroves and fisheries, and affect cyclone and storm surge protective measures in coastal areas. The poverty

alleviation programme will be seriously hampered and there will be serious damage to bio-diversity. UNEPJ reported that loss of original habitat in Bangladesh is already 94%. A theoretical model of tropical storms suggests that maximum possible intensity would increase by 40% in its destructive power for an increase of 3^0C of SST*s*. The enhanced evaporation over the Bay of Bengal during the monsoon season as predicted in the model simulation, leading to increased moisture convergence and latent heat release may increase the number and duration of tropical cyclones in a warmer atmosphere.

9.1 Cyclone

The number of severe cyclonic storms that affected Bangladesh over a ten year period from 1780-1998 shows that in the past, in some ten, twenty or thirty year period Bangladesh was not affected by any tropical cyclone. But this has changed in recent years. Since 1960 onwards, there is no ten year period when tropical cyclone was absent. During the period 1960-1970, there occurred ten severe cyclones in Bangladesh averaging one cyclone every year. The human casualties were also tremendous. During the 12 Nov. 1970 cyclone alone, five lakh people died. Though the frequency has decreased recently than during 1960-70, it still has a significant value. During 29 April, 1991 another cyclone of very severe intensity hit Bangladesh, where human casualty was one lakh thirty eight thousand. In the last few years, human casualties have declined because of taking protective measures. 1997 Cyclone of Bangladesh was almost of the same intensity as in 1970 or 1991 but the casualty has been much less. In the coastal areas, some 2500-cyclone shelters have been built. Thus we find that during the forty year period 1960 to 1999, tropical cyclones hitting Bangladesh far exceeds those in any corresponding period of recorded history. The catastrophic cyclone which used to occur after hundred year interval now occurs at some ten year interval.

9.2 Flood

The flood-affected area of Bangladesh has also undergone significant increase. There is no adequate record of past flood data. However, from 1954 onwards, flood record exists. Significant peak flooding occurred in 1955, 1974, 1987, 1988, 1998 and 2004. It is significant that in each succeeding peak year, the area affected exceeds that in the previous peak. In 1998, nearly two third of the country was affected by flood which lasted for more than two months which is rather very unusual. The catastrophic flood which used to occur at 50 year interval occurs now at some ten years interval.

9.3 Rainfall trend

A regression analysis of rainfall for various stations in Bangladesh was carried out for the years 1960-1992. The analysis shows an increasing trend in rainfall between 150-350 mm in most of the places at 95% confidence level. This gives an annual increase of 8mm/year of rainfall in Bangladesh. The rainfall decreased somewhat during last few years. But it may start increasing again.

9.4 Sea Level Rise

Sea level rise of 4mm - 7.8mm / year at different points of Bangladesh coast has been reported by SAARC Meteorological Centre, located at Dhaka. Part of this rise is due to subsidence and part due to global warming.