Impact of natural variability and anthropogenic factors on the flood events in northeastern India

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Abstract The northeastern region of India has two major rivers viz. the Brahmaputra and the Barak, with annual flows of 537.2 km^3 and 59.8 km^3, respectively. The region receives about 510 km^3 of water as rainfall. Indiscriminate use and mismanagement of rainwater have resulted in frequent floods in the Brahmaputra and Barak river basins. The climate, with prolonged rains of high intensity, causes rivers to overflow their banks. Anthropogenic factors including the prevalence of shifting cultivation, land use, deforestation and free range grazing have made the hills prone to soil erosion, causing silting of river beds and floods in the region. However, the impact of meteorological conditions on flood events is greater than man-induced changes. A preliminary quadratic relationship between the rainfall per day was developed as: FE (rainfall in mm per day causing flood event) = $86.24 - 11.22x + 0.538x^2$, where x is the nth month (1 for May and 6 for October). A rainfall of 70 mm or more in a day, followed by spells of even lower intensity during the following days can result in floods at the initial stages of the monsoon, while rains of even low intensity can cause flooding during subsequent periods as the catchments get saturated and are unable to absorb more water. A statistically significant negative relationship was found between the difference of monthly mean maximum and minimum temperature and rainfall with gradient up to –54.52 mm per °C. The relationship is: rainfall (mm) =$724.2 - 54.52x$, where x is the difference in monthly mean maximum and minimum temperature.

Key words anthropogenic factors; flood events; natural climatic variability; northeastern India

INTRODUCTION

The northeastern region of India, having an area of 255 090 km^2, lies between latitudes 21°57′ and 29°28′N and longitudes 89°40′ and 97°25′E. The region is drained by two major rivers, viz. the Brahmaputra and the Barak with an average annual runoff of 537.2 km^3 and 59.8 km^3 and draining 194.4×10^3 and 78.2×10^3 km^2 area, respectively (Table 1). The region receives about 510 km^3 of water as rainfall, which shows temporal and spatial variations. The physiography and location of the two river basins, high gradient in the hills, prevalence of shifting cultivation, heavy runoff along with soil during the rainy season (May–October), deforestation, cropping patterns, free range grazing, urbanization, etc., are the major factors responsible for frequent floods in the region. Gross human interference has rendered the hills vulnerable to soil erosion which results in silting of river beds, thus reducing their water intake capacity. Floods in the region, particularly during 1954, 1962, 1966, 1972, 1977, 1985, 1986 and

Table 1 Water availability in major rivers of the northeastern region.

River basin	Drainage area (km^2)	Average annual runoff (km^3)	Average runoff per km^2 (m^3)
Brahmaputra	194 400	537.2	276 300
Barak	78 100	59.8	765 600

Table 2 Area affected by floods in northeastern region of India (km^2).

Sub-region	Area prone to floods	Annual flood affected area	Flood affected area as % of cultivated area
Brahmaputra basin	31450	3597	49.69
Barak & Manipur basins	4390	163	2.28
Total	35840	3760	14.05

1987 are a reminder of the consequences of extreme climate events on the people and the society (Borthakur, 1992). Floods in the plains of the Brahmaputra and Barak basins are primarily due to the climatic variability and precipitation is the major causal factor. The influence of rainfall is aggravated by the anthropogenic factors prevailing in the region such as shifting cultivation, unabated deforestation, free range grazing and urbanization (Sharma, 2000a). About 35 840 km^2 area in the region is prone to floods while 3760 km^2 area experience floods every year, on average (Barthakur *et al.*, 1991) (Table 2). Combined, the flood plains of the Brahmaputra, Barak and Manipur rivers, have an area of about 71 000 km^2 (Sharma, 2000b).

In regional or national programmes for protection from floods, a main component is a real-time flood forecast and warning system. The system must be able to predict the flood event, with a lead time long enough for taking counter measures. Eagleson (1972) derived flood frequency distributions from the statistical characteristics of rainfall and the development of his analytical method and its application to derive peak frequencies of rainfall and snowmelt. This has been further described by Carlson & Fox (1976) and Diaz-Granadoz *et al.* (1984). The predicted value is represented by a random variable whose distribution must be known in order to make proper decisions. The present study was, therefore, undertaken to develop a relationship between rainfall and flood events in the northeastern region of India, based on a large body of weather data (precipitation) and occurrence of floods. The aim of the study was to contribute to a better understanding of the temporal and spatial variability of rainfall and flood events in the region vis-à-vis the anthropogenic impact on runoff.

AREA OF STUDY

The study pertains to the northeastern region (Fig. 1), more specifically focusing on the Brahmaputra and Barak basins which experience floods almost every year. The meteorological component is an extremely important part of the flood forecasting in northeastern region of India where floods are caused generally by rainfall with little or no snowmelt contribution. Major floods are the result of the monsoon depressions which have a long track stretching from the Bay of Bengal to the catchment areas of the rivers. Various meteorological situations regarding the rainfall trends need to be monitored to predict the amount and timing of the flood producing rains.

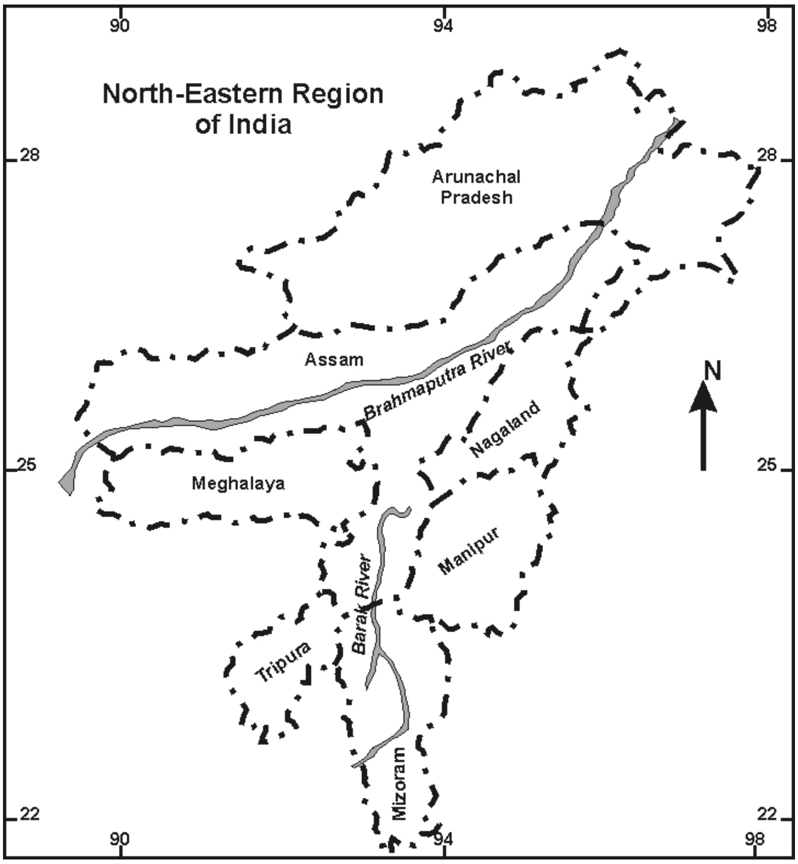

Fig. 1: Northeastern region of India.

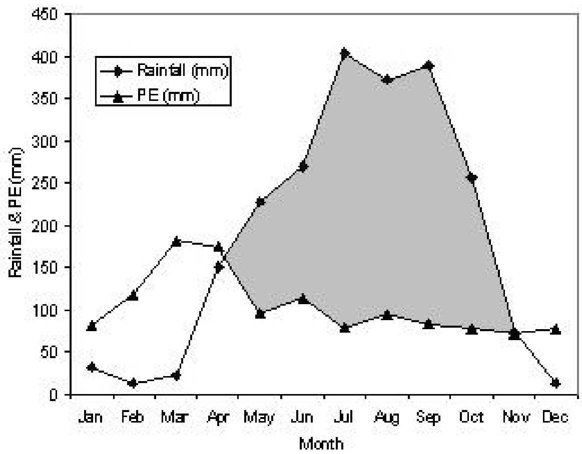

Fig. 2 Mean monthly rainfall and potential evaporation in the northeastern region.

The northeastern region of India receives heavy rainfall, particularly from May to October, with more than 750 mm in a month during some years (Fig. 2). Cherrapunji, a place in the region receives 11 000 mm of rainfall, on an average, in a year. The region has about 72% hilly area where heavy rain causes huge amounts of runoff due to steep gradients, crystallizing into floods in the plains of the Brahmaputra and Barak basins. Rainfall regimes were considered to understand the links between rainfall and flood events and the possible modifications of rainfall regimes due to anthropogenic factors. The uncertainty of the occurrence of floods in the region can be understood only through linking of the amount and intensity of rainfall with possible flood events for advance warning and sustainable development of water resources.

DISCUSSION

Natural climatic variability

Rainfall Extreme flood events in the northeastern region are the product of precipitation and snowmelt as well as spatially and temporally variable basin properties including those influenced by anthropogenic factors. First-hand information on flood generation processes and the infrastructure within a basin is necessary for understanding and evaluating the vulnerability of a basin as a whole. The physical processes giving rise to floods of a given probability of occurrence in the region are controlled largely by the longer duration high intensity rainfall events between May and October (Fig. 2) and the state of the catchment. The surplus rainwater (shaded portion) during the period is that which requires efficient management through harvesting, introducing efficient cropping systems which may encourage maximum *in situ* retention of rainwater for groundwater recharge and judicious management of runoff by constructing dams and reservoirs. This would reduce the incidence of floods which have devastated the whole ecology of the region, caused huge economic losses, and rendered many people homeless.

The floods in the region can be classified into three categories, viz. long-rain floods, short high-intensity rain floods, and high-intensity rains for short duration or flash floods. Because of the complexity, analysing and estimating flood probabilities is usually based on fitting a statistical distribution to a sample of observed flood peaks or regionalized flood information (Merz & Bloschl, 2003). Data on the parameters causing floods in the regions are inadequate for accurate prediction of flood events. However, the rainfall trend gives a good picture of the periods of peak flow occurrences, crystallizing into floods. A rainfall of 70 mm or more in a day, followed by rains of even low intensity can cause floods at the initial stages of onset of monsoon, i.e. May; while rains of even lower intensities may cause floods in subsequent months because the catchments get saturated and are unable to absorb more water. Temporary water storages in the region are full of rainwater and serve as mini-lakes, inducing flood events. Based on the available data on rainfall and flood events in the region, a preliminary quadratic relationship on the time series scale was developed between rainfall per day and occurrence of floods. The relationship holds good from May to October, the peak period of rains. It is:

$$FE \text{ (rainfall in mm per day causing flood event)} = 86.24 - 11.22x + 0.538x^2$$

where x is the nth month (1 for May, 6 for October). The severity and magnitude of flood would increase with increase in rain intensity and its duration.

Temperature Analysis of the data sets on temperature showed that the difference between monthly mean of maximum and minimum temperatures had a tremendous

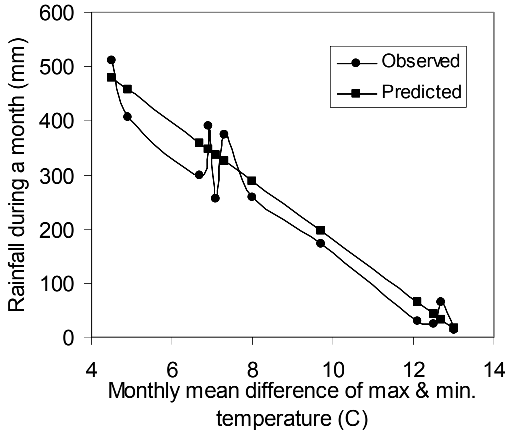

Fig. 3 Relationship between differences of monthly mean maximum and minimum temperature and monthly rainfall.

effect on the occurrence and intensity of rainfall. A statistically significant negative relationship between the difference of monthly mean maximum and minimum temperatures and rainfall has been observed and the gradient was up to –54.52 mm per °C (according to the best linear fit). The relationship developed is:

rainfall (mm) = 724.2 – 54.524x

where x is the difference between monthly mean maximum and minimum temperatures. The coefficient of correlation was $r = -0.906$, with a predictability of 82.1%. The lower the difference between the monthly mean maximum and minimum temperatures, the higher the probability of rain during the month (Fig. 3). Figure 3 only gives the relationship between the difference of the monthly mean maximum and minimum temperature and the occurrence of rain, a prelude to floods. Mean monthly maximum or minimum temperature were not as significantly correlated to the rainfall as the difference between them and so the latter was considered to highlight the rainfall events which ultimately crystallize into flood. A warning needs to be issued to the people of the region to remain vigilant during the days when the difference between maximum and minimum temperatures begins to decrease, particularly below 5°C.

Anthropogenic factors

The anthropogenic factors are very significant in affecting flood events in the northeastern region. The prevalence of shifting cultivation, unabated deforestation, urbanization, rapid increase in demographic pressure, eco unfriendly cropping patterns, conflicting demands for water and misuse and mismanagement of rainwater have created conditions encouraging floods in the region. Flood disasters, in turn, cause immense loss of property, infrastructure and human life, and affect the very people whose activities help in inducing flood events, so, all activities, natural and anthropogenic, are interrelated (Fig. 4). The disasters result not only from the climatological conditions but also from human development. The population growth in northeastern region increased at an annual compound growth rate of 2.43 % during 1991–2001 as

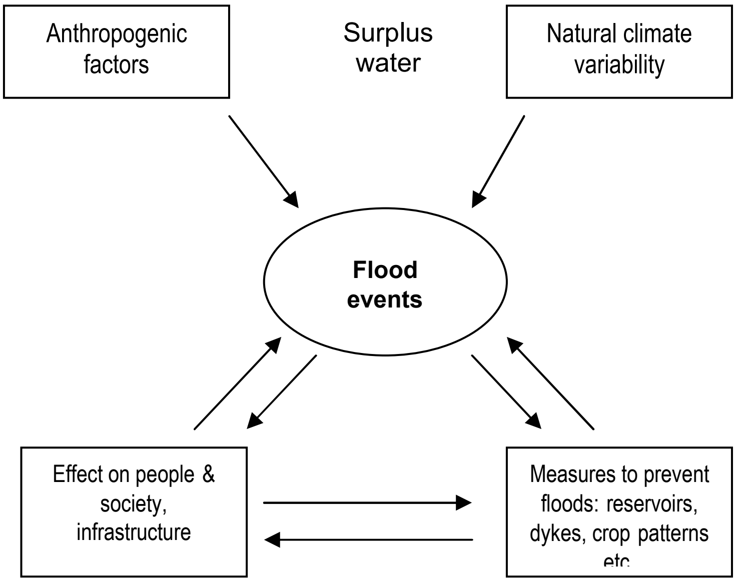

Fig. 4 Inter-relationship between climate variability, flood events and socio-economic implications.

Table 3 Population growth in northeastern region of India.

Year	Population (millions)		Annual compound growth rate (%)	
	NE region	India	NE region	India
1951	10.5	361.1	–	–
1961	14.5	439.2	3.28	1.97
1971	19.6	548.1	3.06	2.24
1981	24.7	683.3	2.34	2.23
1991	31.5	846.3	2.46	2.16
2001	40.2	1001.1	2.43	1.69

against 1.69% in the country as a whole (Table 3). Increase in the demographic pressure at a faster rate than elsewhere and uncontrolled urbanization have changed the whole ecology and severely disrupted the ecosystem of the region. The flood events have a direct impact on the socio-economic activities in the river basins of the region as human activities are often hampered. The human interference may be quantified in terms of economic losses to the infrastructure, crops and property. The estimates of flood magnitude have significant economic implication for the region, besides being required for civil engineering works. Due to this link, the methods used to estimate flood magnitudes are sensitive to the requirements of the decision-making process.

Shifting cultivation, a transitional stage between nomadic hunting and gathering and secondary agriculture, is thought to have started in the region about 9000 years ago. This practice is prevalent in all the states of the region, annually covering an area of 3869 km^2 and affecting an area of 14 660 km^2 at one time or the other (Table 4). The tribal people of the region are socio-culturally associated with the practice and it has become difficult to wean away the cultivators from this age-old practice. It implies the whole nexus of people's belief, cultural activities, and tribal identity. The shifting cultivation was acceptable when the shifting cycle used to be 25–30 years and land

Table 4 Area under shifting cultivation in the northeastern region.

States	Number of families involved	Total affected area (km^2)	Annual area (km^2)	Annual area as % of area cultivated
States having more than 75% hilly area	342 300	12 153	2950	39.54
States having less than 25% hilly area	101 000	2 507	919	3.08
Total	443 300	14 660	3869	10.39

used to get enough time for vegetation rejuvenation, but, with increase in population, this cycle has come down to 2–10 years. Due to cutting of forests with access to new forest areas, the whole ecology of the region is in peril. About 601×10^6 t of soil along with more than 1.0×10^6 t of nutrients are lost every year due to erosion with runoff. This results in silting of river beds causing floods with rains in the catchments.

The prevailing land use in the region has contributed to the amount of runoff. The land use changes over time, coupled with their effect on the water holding capacity of soil under a range of land uses, has a tremendous influence on the runoff. Sharma (1997) reported that with suitable land use, more than 90% of rainwater can be retained in the soil, which also helps in groundwater recharge. The runoff can be minimized with suitable vegetation cover which could intercept more rainwater.

CONCLUSIONS

Various flood events, which have devastated parts of the northeastern region, are a reminder of the dramatic consequences of extreme climatic events on people and society. There is now a growing concern regarding these events. Despite the uncertainties of meteorological factors, it is necessary to investigate the possible impacts of the climate, due to both natural and anthropogenic variability, to face the future consequences. Judicious management of water resources, particularly rainwater, will not only reduce the heavy loss of soil and nutrients in runoff but also reduce the flood incidence in plains and valley areas in the region. There is a strong need for doing away with the practice of shifting cultivation by introducing new sustainable and eco-friendly cropping patterns as well as through awareness programmes. Deforestation has increased flood risk in the region, so suitable legislation is required to forbid cutting of forest vegetation. This is important from the point of view of integrated river basin management to reduce flood risk. The measures adopted to mitigate the risk of floods and sustainable upgrading of the ecosystem should take into account social, economic and ecological consequences. The understanding and quantification of hydrological variability is of considerable importance for the estimation of flood risk.

REFERENCES

Barthakur, H. P., Bora, C. K., Phukan, U., Bhattacharya, B. K., Bhowmic, B. C. & Khound, H. P. (1991) *Agro-climatic Regional Planning, Eastern Himalayan Region: Profile and Strategy*. Assam Agricultural University, Jorhat India.

Borthakur, D. N. (1992) *Agriculture in the Northeastern Region.* Bee Cee Publishers, Guwahati, Assam, India.

Carlson, R. F. & Fox, P (1976) A northern snowmelt-flood frequency model. *Water Resour. Res*. **12**, 786–794.

Diaz-Granados, M. A., Valdes, J. B. & Bras, R. L. (1984) A physically based flood frequency distribution. *Water Resour. Res*. **20**, 995–1002.

Eagleson, P. S. (1972) Dynamics of flood frequency. *Water Resour. Res*.**6**, 878–898.

Merz, R. & Blöschl, G. (2003) Regional flood risk: what are the driving processes. In: *Water Resources Systems - Hydrological Risk, Management and Development* (ed. by G. Blöschl, S. Franks, M. Kumagai, K. Musiake & D. Rosbjerg), 49–58. IAHS Publ. 281. IAHS Press, Wallingford, UK.

Sharma, U. C. (1997) Water resources of northeastern region and their sustainable development for increasing agricultural productivity and resources conservation. In: *Civil Engineering for Sustainable Development* (Proc. Roorkee Conf., February 1997), 183–191. Jain Printing Press, Roorkee, India.

Sharma, U. C. (2002a) Managing the fragile hydrological ecosystem of the northeast hilly region of India for resources conservation and improved productivity. In: *Regional Hydrology: Bridging the Gap between Research and Practice* (ed. by H. A. Van Lanen & S. Demuth), 357–364. IAHS Publ. 274. IAHS Press, Wallingford, UK.

Sharma, U. C. (2002b) Land use options for the flood plains of northeastern region of India. In: *The Structure, Function and Management Implications of Fluvial Sedimentary Systems* (ed. by F. J. Dyer, M. C. Thomas & J. M. Olley), 239–244. IAHS Publ. 276. IAHS Press, Wallingford, UK.