Trends in hydro-meteorological variables in the Brahmaputra basin in India and their impact on flood events

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Abstract The Brahmaputra River basin in India has an area of 1.94×10^5 km^2. Floods are almost an annual feature in the basin, with variable magnitudes and frequencies. The annual rainfall variability index (RVI), monthly evaporation variability index and monthly maximum temperature variability index range from –1.77 to +1.85, –0.892 to +2.11 and –0.185 to +0.115, respectively. A negative relationship was found between the difference of monthly mean maximum and minimum temperature and rainfall, with gradient of up to –54.52 mm per °C. To study hydro-meteorological variables, a long-term- multidisciplinary study has been in progress since 1983. Evaporation was relatively less during high rainfall months, resulting in higher runoff generation inducing floods.

Key words hydro-meteorological variables; Brahmaputra basin, India; flood events

INTRODUCTION

Floods are natural hazards capable of triggering disasters of great human significance in terms of socio-economic impact. Floods are difficult to avoid but the damage can be reduced by appropriate and timely warning, and structural and non-structural approaches. Between 1973 and 1997, an average of 66 million people a year suffered flood damage in the world, making flooding the most damaging of all natural disasters (Cosgrove & Rijsberman, 2000). Many studies have shown a significant effect of rainfall on runoff from catchments (Mahe *et al.*, 2001, Sharma, 2003, Sharma & Sharma, 2009). The escalation of severe disaster events are obstacles for sustainable socio-economic development and poverty reduction initiatives. The Brahmaputra basin receives heavy rainfall at an average of about 2450 mm annually (Anon., 2000). The basin is predominantly hilly and mismanagement of rain water causes heavy loss of soil in the hills, and silting of river beds and floods in the plains (Sharma & Prasad, 1995). Though the rainfall is an important driver to flood processes in the basin, other hydro-meteorological variables and the characteristics of the catchment also play a major role. The prevalence of shifting cultivation in the Brahmaputra basin and unabated deforestation have resulted in severe soil erosion and degradation of water resources (Sharma & Sharma, 2004). There is a need to promote sustainable use of resources, which allows long-term economic growth and enhancement of production capacity, along with being equitable. The aim of this study was to evaluate hydro-meteorological variability and its impact on flood events in the Brahmaputra basin in northeast India.

STUDY SITE AND METHODOLOGY

The Brahmaputra basin lies in the northeastern region of India, covering an area of 1.95×10^5 km^2 (Fig. 1). The average annual flow in the River Brahmaputra is 537.2 km^3, varying from 3200 m^3 s^{-1} in the low flow period to 19 200 m^3 s^{-1} during monsoon. A maximum discharge of 72 748 m^3 s^{-1} was recorded in 1963, and minimum of 3280 m^3 s^{-1} in 1960. The basin has a very steep gradient in the north and eastern parts, but an extremely gentle gradient in the south, falling at the rate of 13 cm km^{-1}. The river and its tributaries produce enormous quantities of sediment load when they flow through geologically young and unstable terrain, with the river banks being extremely unstable and prone to subsidence. The basin receives about 450 km^3 of water annually, as rainfall at an annual average of 2450 mm. Misuse and mismanagement of rainwater results in the loss of about 438×10^6 tonnes of soil annually, through runoff from the hills, resulting in silting of the river bed and floods in the valley and plain areas.

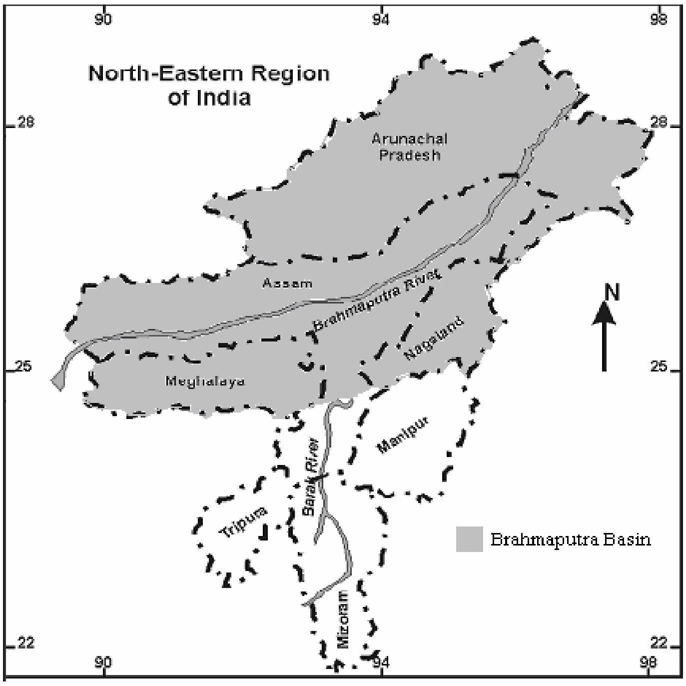

Fig. 1 Brahmaputra basin in the northeastern region of India.

The RVI (rainfall variability index) was calculated as:

$$\text{RVI} = \frac{\text{(actual rainfall during the year – average rainfall of the location)}}{\text{standard deviation in rainfall during the period}}$$

Monthly evaporation and maximum temperature indices were calculated similarly. A multi-disciplinary long-term study was undertaken with seven land-use systems, viz. livestock-based (fodders and grasses), forestry, agro-forestry, agriculture, agri-horti-silvi-pastoral, horticulture and traditional practice of shifting cultivation. Soil and water conservation measures such as bench terracing, trenching, contour bunding and grassed water-ways, were followed in all the land uses except shifting cultivation.

RESULTS AND DISCUSSION

Hydro-meteorological variability

The data on the average month-wise annual rainfall, mean temperature, evaporation and relative humidity in the Brahmaputra basin are given in Table 1. The annual rainfall variability index (RVI), monthly evaporation variability index and maximum temperature variability index in the Brahmaputra basin varied from –1.77 to +1.85, –0.892 to +2.201, and –0.185 to +0.115, respectively, in the basin between 1981 and 2005. More variability was observed in annual rainfall compared to evaporation and maximum temperature, indicating that rainfall events are more unpredictable in the basin. A highly significant positive relationship was found between rainfall and flood events (r = 0.8715), followed by maximum temperature (r = 0.3288) and a non-significant negative relationship with evaporation (r = –0.3612). The relationship between flood events and rainfall variability index in the basin is presented in Fig. 3. A preliminary quadratic relationship was developed for the flood event occurrence as: FE (rainfall in mm per day causing flood event) = $86.24 - 11.22x + 0.538x^2$, where x is the nth month of the rainy season (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 become saturated. A negative relationship was found between the difference of monthly mean maximum and minimum temperature and rainfall, with a 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 (Sharma & Sharma, 2005).

Table 1 Monthly rainfall, temperature, evaporation and relative humidity (mean of 6 years).

Month	Mean rainfall (mm)	Mean air temperature (°C)	Mean pan evaporation (mm)	Mean relative humidity (%)
January	14	11.4	66	80
February	9	13.2	92	70
March	39	19.7	179	61
April	155	22.7	194	67
May	285	21.8	109	72
June	376	24.1	114	78
July	493	23.5	79	82
August	366	24.6	94	83
September	368	22.8	83	81
October	232	21.0	77	78
November	61	15.5	72	73
December	27	13.3	76	82

HYDRO-METEOROLOGICAL VARIABLES AND FLOODS

The region receives about 2450 mm of rainfall annually, more than 75% of which is received from June to September (Fig. 2). The quantification and understanding of hydrological variability is of considerable importance for the estimation of floods. Figure 2 clearly shows that from May until October the rainwater received in the basin exceeds the potential evaporation, rendering the rainwater surplus. It takes about one month for saturation of the catchment, based on the soil physical condition, and the flood generation process starts from late May, depending on the amount and intensity of rainfall. The climate of the Brahmaputra basin undoubtedly plays a major role in causing the floods, and precipitation is by far the single major factor, which is clearly evident from Fig. 3. The years during which rainfall was high, the probability of occurrence of flood was greater. Because of this complexity, analysing and estimation of flood probabilities is usually based on fitting a statistical distribution to a sample of observed flood peaks or regionalized flood information (Merz & Bloschl, 2003).

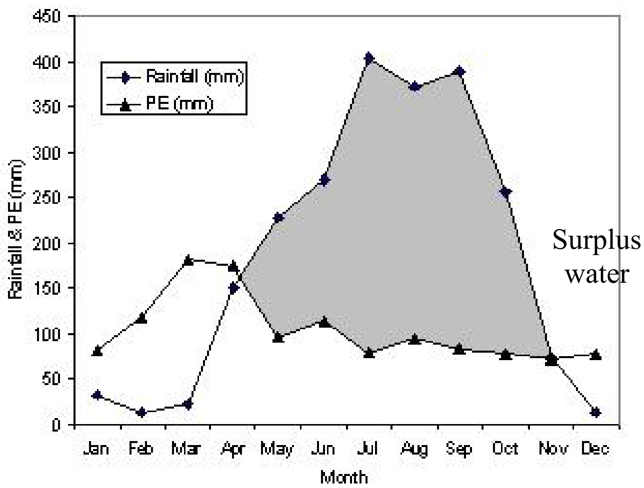

Fig. 2 Mean monthly rainfall and potential evaporation in the northeastern region.

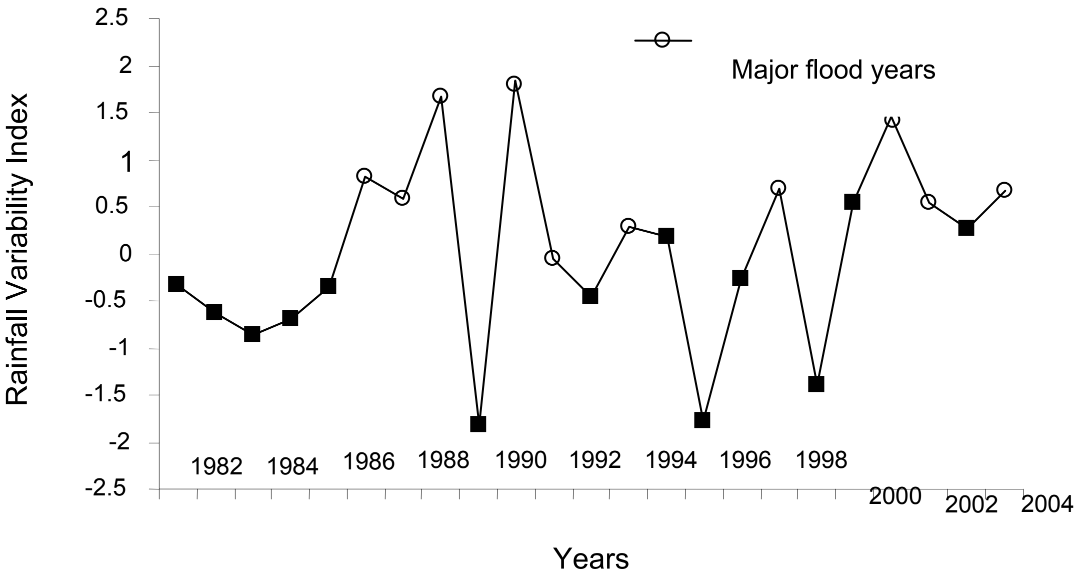

Fig. 3 Rainfall variability index (RVI) and floods in the Brahmaputra basin.

Table 2 Soil and nutrient loss through erosion from states of the Brahmaputra basin.

State	Soil loss (10^6 tonnes)	Nutrient loss (10^3 tonnes): Nitrogen	Phosphorus	Potassium	Micronutrients
Arunachal Pradesh	177.7	217	36.6	153	47.4
Assam	178.4	201	34.4	155	48.3
Meghalaya	57.7	62	7.0	48	9.7
Nagaland	24.9	26	3.2	20	4.8
Total	438.7	506	81.2	376	110.2

It has been estimated that total annual loss of soil and nutrients through erosion from the basin is 438.7×10^6 and 1073.4×10^3 tonnes, respectively (Table 2). The annual rate of individual annual contribution towards soil loss from shifting cultivation, cultivated and non-cultivated areas is estimated to be 60.2, 25.5 and 20.2 t ha^{-2}, respectively (Sharma & Prasad, 1995). Shifting cultivation is prevalent in 2119 km^2 of the area annually, while about five times as much area has been affected by the practice. The crop production from the shifting cultivation areas was sufficient to feed the limited population about five decades ago (Sharma, 2003). But with the population increasing at a very fast rate, the shifting cycle has come down to 2 to 5 years. Since shifting cultivation has been responsible for inducing flood events due to large-scale soil erosion, an effective change in land use is imperative under the situation prevailing in the Brahmaputra basin as a non-structural measure for flood control (Sharma & Sharma, 2004).

The flow of the Brahmaputra River is highly seasonal, and heavily influenced by monsoon rainfall. As a result, the river swells to fill its banks and often overflows during the monsoon months. The results corroborate the findings of Chowdhury & Ward (2004) who have quantified how the streamflows of the river are highly correlated with the rainfall in the upper catchments. The hydro-meteorological variables, such as rainfall, evaporation, temperature and humidity, play a significant role in inducing floods in the Brahmaputra. The data generated from the multi-disciplinary study, revealed that the total water yield or runoff was 835.3 mm from shifting cultivation compared to a rate varying from 14.0 mm to 319.5 mm in new land use systems (Table 3). This shows the high amount of runoff generation and sediment load from shifting

Table 3 Effect of land use on the soil loss and water yield from different watersheds.

Parameters	Livestock based	Forestry	Agro-forestry	Agri-culture	Agri-horti-silvi-pastoral	Horti-culture	Shifting cultivation
Base flow(mm)	2.9	365.3	202.2	0.5	8.5	106.8	275.3
Surface flow (mm)	11.1	68.0	35.4	20.4	69.1	212.7	560.0
Total water yield (mm)	14.0	433.3	237.6	20.9	77.6	319.5	835.3
% rainfall	0.6	17.7	9.6	0.9	3.1	13.0	34.1
In situ rainwater retention (%)	99.4	82.3	90.4	99.1	96.9	87.0	65.9
Soil loss (t ha^{-1})	0.2	2.0	1.9	0.1	1.8	8.3	42.4
Benefit/cost ratio	2.1	1.2	1.5	1.8	1.9	1.7	0.6

causing floods. *In situ* rainwater retention and soil loss varied from 87.0 to 99.4% and 0.2 to 8.3 t ha^{-1} in new land uses as against 65.9 % and 42.4 t ha^{-1} in shifting cultivation. It is evident from Table 4 that, during six years of study, percentage runoff was influenced by the amount of rainfall received during the year. It varied from 3.5% of rainfall when the annual rainfall was 1992 mm, to 16.6% of rainfall when the total amount of rainfall during the year was 2770 mm. When correlated with flood incidences in the basin, the positive RVI values correlated significantly well with flood years, indicating the significance of precipitation in flood events.

Table 4 Effect of precipitation on runoff (mm).

Parameter	Annual rainfall (mm):						
	2195	2705	2770	2599	2288	1992	Mean
Base flow	91	198	200	171	116	16	132
Surface flow	77	182	206	181	122	54	136
Total runoff	168	380	406	352	238	70	269
% of rainfall	7.6	14.0	14.6	13.5	10.4	3.5	10.7

CONCLUSIONS

The Brahmaputra basin has plenty of water resources, but their misuse has resulted in large-scale erosion of soil and associated elements. Transport of soil and sediment-associated nutrients in the runoff and its deposition in various sinks, including the river bed, results in floods of various frequencies and magnitudes in the basin. More variability was observed in annual rainfall compared to evaporation and maximum temperature, indicating that rainfall events are more unpredictable in the basin. 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 floods during subsequent periods as the catchments get saturated. The data generated from the multidisciplinary study, revealed that the total water yield or runoff was 835.3 mm from shifting cultivation compared to varying from 14.0 to 319.5 mm in new land use systems. This shows the high amount of runoff generation and sediment load from shifting cultivation, causing floods. There is a need to introduce new eco-friendly and sustainable land use systems to replace shifting cultivation, to discourage deforestation, and to improve *in situ* retention of rainwater and consequent flood events. It is necessary to record and study time series of hydro-meteorological data to understand the pattern of occurrence of floods in the basin and take corrective measures accordingly. Judicious management of rainwater is necessary so that maximum quantities of rainwater can be retained *in situ* in order to reduce runoff and associated sediment loss. In the light of these observations, it is necessary to review flood prone areas using modern technologies like remote sensing, satellite data and air-borne laser terrain mapping.

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