Assessment of flood events in the data-sparse Brahmaputra Basin in northeast India

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Abstract A preliminary quadratic relationship was developed to predict the flood events in the Brahmaputra Basin. A rainfall of 70 mm or more in a day, followed by spells of 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 slope of the catchment, amount of rainfall, vegetation cover, soil moisture and clay content of the soil were used to predict the runoff generation since rainfall and subsequent runoff generation impact the flood events. The observed and predicted values of runoff showed highly significant correlation *(*R = 0.8716), with a predictability of 75.9%.

Key words assessment of flood events; Brahmaputra Basin, northeast India

INTRODUCTION

Floods are natural hazards capable of triggering disasters of great significance and affecting the socio-economic fabric of a society. These are difficult to avoid but the damage can be minimized by appropriate and timely warning, and structural and non-structural approaches. The escalation of severe disaster events is among the most prevailing obstacles to sustainable socio-economic development and poverty reduction initiatives. The impact can be quantified in terms of economic losses due to infrastructural damage, loss of property and human lives. The methods of estimation of flood magnitude are sensitive to the requirements of the decision making process. The use of regional information to estimate flood magnitude at sites with little or no observed data has become important as many projects are located in areas where the actual observed flood data are inadequate. In the Brahmaputra Basin, the combined effects of prolonged and intense rainfall, steep slopes, well-developed drainage networks and the fragile geology of the mountains make flooding an annual event. The frequent flood events result not only from the climatological factors such as heavy rainfall, but also due to human interference, deforestation because of shifting cultivation and short-term economic gains. The basin is predominantly hilly and mismanagement of rainwater causes heavy loss of soil in the hills and silting of river beds and floods in the plains (Sharma & Prasad, 1995; Sharma 1998). Though the rainfall is an important indicator to flood processes in the basin, the characteristics of the catchment also play a major role. The prevalence of shifting cultivation over 2119 km^2 of the basin also results in heavy soil erosion, deforestation and water resources degradation (Sharma & Sharma, 2004). Rapid population growth, urbanization, uncontrolled development works, encroachment and land-use changes have significantly contributed to flood events and risk enhancement. An attempt has been made to devise simple mathematical hydro-meteorological models to predict runoff generation, rainfall and flood events. The knowledge of flood generation processes is crucial for evaluating the vulnerability of a basin to floods.

STUDY SITE AND METHODOLOGY

The Brahmaputra River Basin extends over four northeastern states of India: Arunachal Pradesh, Assam, Meghalaya and Nagaland, with an area of 1.94×10^5 km^2 (Fig. 1). The Brahmaputra River has more than 100 tributaries, of which 15 in the north and 10 in the south are fairly large. The average annual runoff in the Brahmaputra River is 537.2 km^3, at a rate varying from 3200 $m^3\ s^{-1}$ to 19 200 $m^3\ s^{-1}$during the dry and monsoon seasons, respectively. About 43.6% of the basin lies at

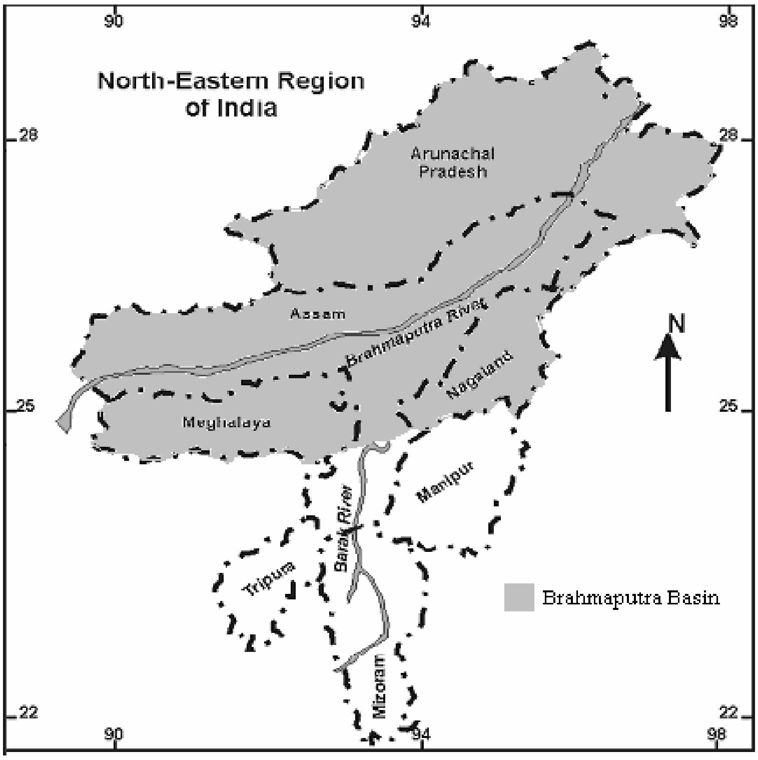

Fig. 1 Brahmaputra Basin in the northeastern region of India.

elevations below 300 m a.m.s.l., 10.2% at 30–600 m and 46.1% above 600 m. More than 80% of the total rainfall is received from May to October, the period during which floods occur. A preliminary quadratic relationship was developed for predicting when flood events occur:

$$FE \text{ (rainfall in mm per day causing flood event)} = a + bx + cx^2 \quad (1)$$

where x is the month of the rainy season (1 for May, 6 for October). As the amount of rainfall affects the runoff generation process, a multiple regression equation was developed to quantify the runoff. The runoff (RO) prediction model involves a partial regression equation of the form:

$$RO = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 \quad (2)$$

where RO is the runoff (% rainfall) and b_1, b_2, b_3, b_4 and b_5 are the partial regression coefficients for slope (x_1) in %, annual rainfall (x_2) in cm, vegetation cover (x_3) on a 1 to 5 scale, soil moisture content (x_4) in % and soil clay content (x_5) in %, respectively. The equation was developed using the Dolittle method as described by Goulden (1960), which gave a reasonably high degree of accuracy in prediction or estimation of soil erosion (Sharma & Sharma, 2003) and runoff. The equation can be solved by direct application of elementary methods involving successive elimination of the unknowns. The vegetation is the only independent variable for which the values (1 to 5) have to be based on visual estimates. For uniformity, the classification used for the vegetation values is given in Table 1.

More available data for calculating the values of the coefficients may result in an increase in the accuracy of the model in predicting runoff. In principle, the model can be used for predicting runoff under a wide range of climatic and physical conditions. Monitoring of runoff generation in watersheds by installing gauges at different locations in the basin is not feasible due to inaccessibility, the manpower required, costs involved, etc. The developed model can be used for predicting runoff magnitude reliably. There is a need to improve and refine the model by including observed data from recent studies, as well as by additional systematic studies of the factors that control runoff. The rainfall variability index (RVI) was calculated as:

$$RVI = (\textit{Actual rainfall during the year} - \textit{Average rainfall of the location}) \,/\, \textit{standard deviation} \quad (3)$$

Table 1 Vegetation classification.

Vegetation value	Extent of vegetation
1	Bare ploughed soil
2	Scrubs or effective covered area <25%
3	Cropped soil surface or effective covered area of 25–50%
4	Open forest vegetation or effective covered area of 50–75%
5	Dense forest cover with trees, bushes and grasses or effective covered area above 75%

RESULTS AND DISCUSSION

Floods are an almost annual feature in the Brahmaputra Basin with variable magnitudes and frequencies (Borthakur, 1992). Problems related to high stream flows are complex and are affected by natural (e.g. climatic, hydro-geology), and anthropogenic (urbanization, irrigation, water works, socio-economic) factors and human interference (through deforestation and land-use change). Shifting cultivation, prevalent across 2119 km^2 of the basin, and affecting an area five times greater, is a major factor responsible for flood events in the basin. The runoff water goes untapped from the denuded hill slopes instead of infiltrating into the soil to recharge aquifers (Sharma, 2003). Three types of processes causing flood events in the Brahmaputra Basin are: (i) long rain floods, where long duration rainfall saturates the catchment resulting in high flows causing floods, (ii) short rain floods, where high-intensity rainfall occurs for short duration, and (iii) flash floods, when short but high-intensity rains cause floods even when the catchment is dry. The plains of the Brahmaputra Basin are being ravaged by the floods recurring almost every year, causing substantial damage to the economy and bringing in a sea of miseries to the inhabitants. Although the total area annually affected by floods in the basin is 3609 km^2, the total flood-prone area is 31 740 km^2 (Table 2). About 10.1% of the cultivated area is flooded every year. The ecosystem has been seriously disrupted by rapid population growth and uncontrolled development, resulting in increased flood risk. Two types of factor mainly trigger floods in the Brahmaputra Basin.

Table 2 Approximate flood-affected area in Brahmaputra Basin states.

State	Area prone to floods (km^2)	Annual flood affected area (km^2)	Flood prone area as % geographical area	Annual flood affected area as % cultivated area
Arunachal Pradesh	145	7	0.17	0.46
Assam	31 450	3 597	40.09	13.29
Meghalaya	75	3	0.33	0.14
Nagaland	70	2	0.42	0.11
Total basin	31 740	3 609	16.30	10.10

Natural factors

The climate of the Brahmaputra Basin is undoubtedly by far the single major factor causing the precipitation and floods. The region receives about 2450 mm of rainfall, annually, more than 80% of which is received from May to October. The high frequency of severe hourly rainfall often causes flash floods in the basin. The huge runoff from high-gradient hillslopes carries a very high sediment load which results in siltation of river beds, thereby reducing its intake capacity year after year. The plains in the Brahmaputra Basin are alluvial, formed by the flooding of the river. These plains are vulnerable to floods and yet are the most populated, thereby increasing the flood risk and its resultant impact on population. These plains belong to the Warm-Humid Tectonic Zone. The combined effect of prolonged and high-intensity rainfall, steep slopes and fragile geology of the surrounding mountains make flooding a frequent event. Besides rainfall, the consequences of increased temperature can be observed through higher evaporation, depletion of soil moisture, increase in water use by crops, requiring water resource planning and management. The flood events in the Brahmaputra Basin are also affected by terrain, physiographic features and the water holding capacity of the catchment. The rainfall variability index (*RVI*), calculated on the basis of 25 years of data, varied between –1.77 and +1.85, as shown in Fig. 2. The negative values of the *RVI* indicate rainfall deficit years and positive values, high rainfall years. When correlated with flood incidences in the basin, the positive *RVI* values were significantly correlated with flood years (see Fig. 2), indicating the significance of precipitation in flood events.

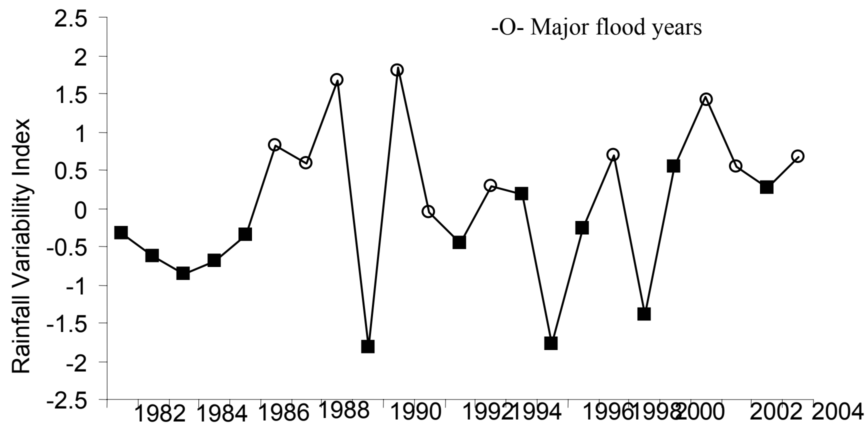

Fig. 2 Rainfall variability index (*RVI*) and flood events in Brahmaputra Basin.

Anthropogenic factors

Of the anthropogenic factors, land use is the most important in the Brahmaputra Basin. The practice of shifting cultivation was economic about five decades ago when the demographic pressure was low and the land available was sufficient to sustain the pressure. The return period used to be 25 to 30 years and the land had enough time for rejuvenation. But with the fast increase in population (2.67% annual compound growth rate, ACGR) from 1951 to 2001, the shifting cycle or return period has reduced to 2 to 7 years. With the decline in the soil fertility due to soil erosion by runoff, the productivity in shifting cultivation has reduced, rendering it an uneconomic practice. Erosion of as much as 13 000 t km^{-2} of soil has been reported in shifting cultivation on a hill having a slope of 70% (Singh & Singh, 1978). The practice is not only unproductive but induces floods in the long run. Intensification of agriculture has a potentially harmful impact on the already fragile hydrological system. The other major flood-inducing factor is the prevailing land tenure system in the basin. The land mostly either belongs to the village chief, who allots it to the cultivators for cultivation for one or more years, and takes it back as per his will. Rapidly urbanized and densely populated areas have a high potential of flood damage. The population of the northeastern region of India increased from 10.5 million in 1951 to 39.3 million in 2001 (ACGR of 2.67%) and is expected to reach 60.9 million by the 2021 (Fig. 3). In order to produce sufficient quantity of food grains, there has been tremendous pressure on the ecosystem, resulting in natural resources degradation, soil erosion in the hills and silting of river beds and flood events in the plains.

Model validation

To understand effective eco-system management, there is a need to use interactive models to simulate the hydrological processes, together with the meteorological and climatic variables and also the ecological behaviour of the system. From the standpoint of hydrological applications and water resources management, it is necessary to determine the spatial and temporal distribution of

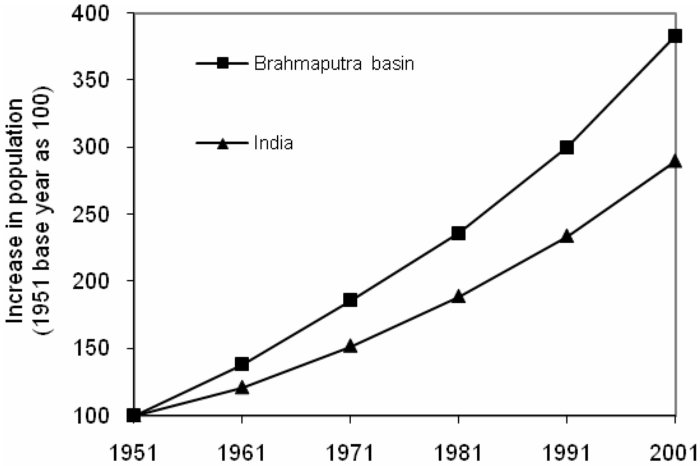

Fig. 3 Population growth in the Brahmaputra Basin with respect to the whole of India.

rainfall to understand the relationship between rainfall and floods so that the occurrence of floods can be predicted well before the event happens and appropriate measures taken. Changes in the flood regime can be expressed in two ways: (a) for a fixed return period, by changes in the magnitude, and (b) for a fixed magnitude, by changes in the return period. In the regression, equation (1), to determine the amount of rainfall mm d^{-1} necessary to induce flood, the values of a, b and c were calculated as 86.24, 11.22 and 0.538. 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 flood during subsequent periods as the catchments become saturated.

In the Brahmaputra Basin, slope, amount and intensity of rainfall, vegetation cover, initial soil moisture content and soil texture are the most important factors determining the runoff generation leading to the flood events. These parameters were used to determine the amount of runoff based on observed data from various experiments conducted in the basin. In the second regression equation (2), the values of a, b_1, b_2, b_3, b_4 and b_5 were 9.293, 0.147, 0.048, 3.469, 0.054 and 0.125, respectively. The model was validated by comparing the predicted values with the observed values from different land use systems and these agreed relatively well as given in Table 3.

Table 3 Observed and predicted values of runoff in different land-use systems.

Parameters	Grasses	Forestry	Agriculture	Horticulture	Shifting cultivation
Slope (%)	32	33	32	53	46
Rainfall (cm)	245	245	245	245	245
Vegetation (1–5 scale)	4	4	4	3	1
Soil moisture (%)	14	13	14	12	11
Clay (%)	18	17	18	16	17
Predicted runoff (mm)	254	259	254	418	557
Observed runoff (mm)	210	253	213	466	517

CONCLUSIONS

The prevalence of shifting cultivation and high rainfall in the Brahmaputra Basin has resulted in resource degradation, loss of soil and soil fertility, deforestation and environmental degradation. The heavy runoff generation from the hilly catchments results in floods almost every year. More *in-situ* retention of rainwater and harvesting of runoff water is necessary to check soil erosion and land degradation, as well as the incidence of flood events. Although it is difficult to avoid floods, their effects can be mitigated with proper and timely warning to the people and concerned agencies to take appropriate measures. The proposed models can be used for predicting flood events and amount of runoff generation resulting from rainfall. The amount of rainwater received during the monsoon period (May–October) is important since this is the period of maximum rainfall.

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