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Flood Dynamics and Hazards in the Brahmaputra Valley of India

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Abstract

In the vast and dynamic river system of the Brahmaputra, the natural processes alone are adequate to cause severe floods. The frequent landslides, steep slopes, high erodibility of rocks and high seismicity of the Himalayan domain coupled with heavy monsoonal rain constitute the major natural causes of floods in the Brahmaputra valley. Besides, a host of recently emerging human-induced causes have also significantly contributed to an increase in flood size and damages. The Brahmaputra floods during 1955-2000 with their mean annual magnitude of 47,660 m^3s^{-1} having a recurrence interval of 2.31 years are usually characterised by large magnitudes, high frequencies and extensive devastations. The large floods have their major geomorphic impact on floodplain morphology and channel configuration resulting in severe bank erosion and frequent thalweg shifting. The recurring floods of characteristically high magnitudes assume devastating dimension heavily affecting the agrarian economy of the valley. The extent and volume of flood damages have recently risen with concomitant changes in the nature of flooding in terms of frequency and spread of inundation to new areas. A package of appropriate flood management activities is regarded as the key factor of socio-economic development of the valley.

Key words: *Recurrence interval (of floods), channel configuration, geomorphic impact, thalweg shifting, flood management.*

Introduction

The Brahmaputra valley located in the north-eastern region of India is one of the major physiographic units of the country. It is a narrow valley with an approximate east-west extension of about 720 km and average width of 75 km (Fig. 1). The valley is girdled on three sides by the Eastern Himalayas on the north and east, and the Naga hills, Karbi and Meghalaya (Shillong) plateaus on the south. It is open only to the west merging with the plains of the West Bengal (India) and Bangladesh. The valley as a whole gently slopes from north-east to south-west with an average gradient of 0.15 m/km. In fact, it is a valley developed over the foredeep in between the Indian

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Peninsular mass and the Tethyan Geosyncline. The foredeep received deposits during all the periods of Tertiary and Quaternary Ages and was thus built by the deposition of alluvium upto about 1500 m thick (Wadia, 1968).

The Brahmaputra is one of the largest rivers of the world. The river traverses a total distance of 2,906 km from its source through the Tibetan Plateau, Himalayan mountains and hills and alluvial plains of India and Bangladesh until reaching the Bay of Bengal. Its extensive drainage system covers about 580,000 km^2 area of China, India, Nepal, Bhutan and Bangladesh. Over the Indian territory the river drains a area of 194,413 km^2 and it rolls down the 720 km long east-west trending narrow valley. The river in the valley receives innumerable tributaries with 18 major north-bank and 10 major south-bank rivers flowing down the northern, eastern and southern hill ranges. In Indian territory the upper part of the river is named Dihang while the lower part is called Brahmaputra. Being a land of rivers, the Brahmaputra valley is thus prone to frequent inundation during summer (monsoon) months.

Historical floods in the valley

Floods in the Brahmaputra valley of India have been a recurring feature since early times. Though systematic historical records of the Brahmaputra floods are non-existent,

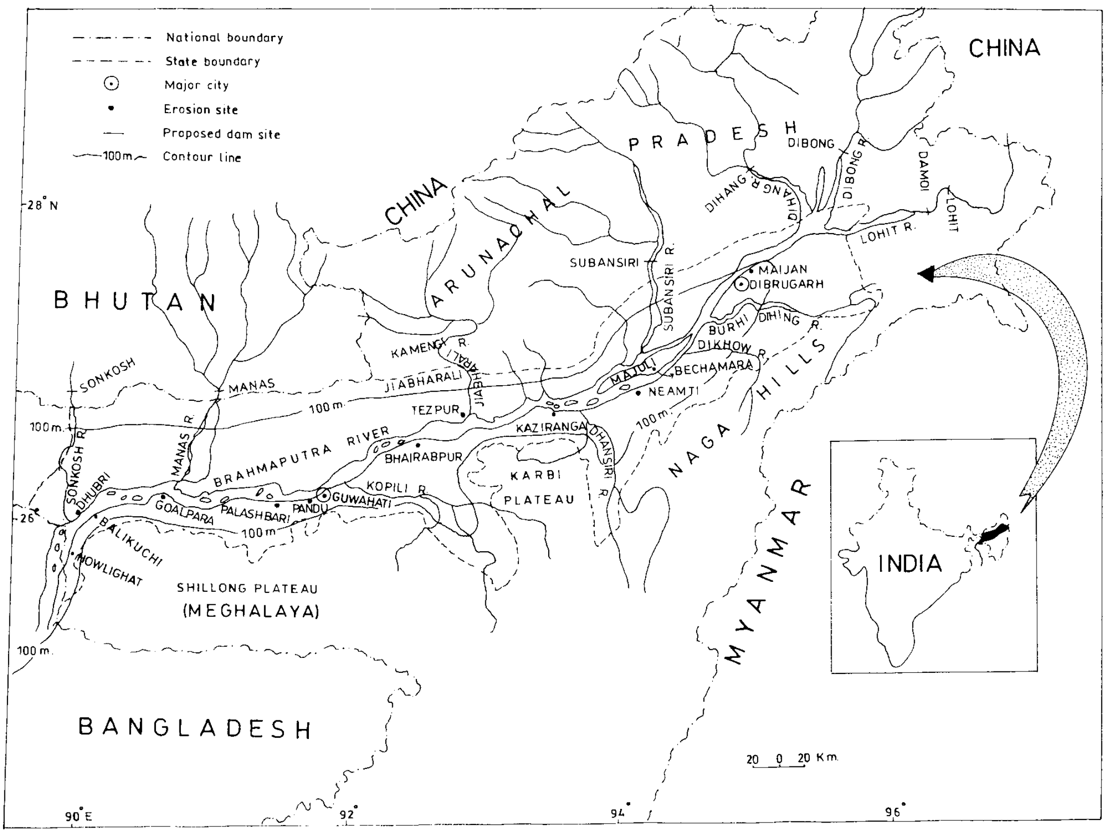

Fig. 1. The Brahmaputra River system and the Brahmaputra Valley in India

there are some scattered information about past floods of the river. However, the first written account of a flood reveals that there was a flood in 1241 in the upper part of the valley which caused the *Ahoms* (a community) to leave Majuli island and settle down in the area between the Burhi-Dihing and Dikhow rivers (Bhuyan, 1962). There is also a written record that during the reign of *Ahom* king Sukapha a great flood occurred causing large scale crop damage that led to a famine in 1570. In 1642 a heavy flood occurred and many cattles were washed away and drowned (Gait, 1984). The historical notes in the *Tungkhungia Buranji* (a historical account of *Ahom* kings who ruled the Brahmaputra valley from 1228 to 1826) on flood damage in the years 1691, 1696 and 1735 suggest the occurrence of devastating floods in the Brahmaputra valley (Barbarua, 1966). There is a record of channel shifting in the upper Barhmaputra valley that was caused by the flood on the Dibong river in 1735 (Gait, 1984).

The earthquake of 1897 (8.7 magnitude on the Richter scale) with its epicentre in the Shillong Pleateau was the most severe quake in the historical record of the Brahmaputra valley. The quake, so-called great earthquake of 1897 caused tremendous changes in the fluvial regime of the Brahmaputra resulting in devastating floods in the valley during 1898, 1905, 1907, 1916 and 1921. There are also records of high floods in 1931, 1935 and 1949 in the valley that caused serious damage to crops and cattles (Flood Control Department of Assam, 1989). Another great earthquake in 1950 (8.6 magnitude on Richter scale), the so-called Assam earthquake with its epicentre in the north-eastern part of Arunachal Pradesh resulted in extensive silting in the Brahmaputra and its tributaries and consequently, the frequency of flooding has increased since 1950. The floods of 1954, 1955, 1956 and 1958 are the examples of the occurrence of floods just after this earthquake.

Natural determinants and human dimensions of flooding

Natural factors

The Brahmaputra river with its well-knit network of tributaries forms a vast and complex drainage system. The Brahmaputra river system is so vast, and geophysically and hydrologically so dynamic that its natural processes and factors alone are adequate to cause devastating floods in its valley. Being characterised by a set of favourable natural situations, occurrence of flood is, in fact, inherent in the Brahmaputra channel confined to the narrow valley. Besides the frequent landslides, steep slopes, high seismicity and high erodibility of rocks of the Tertiary Himalayan domain, the hydrometeorological factors like the strong effects of monsoonal rhythm are primarily responsible for severe floods (Bhattacharyya and Bora, 1997; Bora, 2001a). The runoff pattern of the Brahmaputra catchment in the Himalayas, which is, to a large extent, responsible for floods in the plains, is primarily governed by the quantity and natural distribution of precipitation in the area.

Although precipitation is highly variable in the catchment, three basic characters relevant to the cause of floods must be noted. Firstly, precipitation is mainly in the form of rain in the south of the central Himalayas and in the form of snow in the trans-Himalayas. Secondly, heavy monsoonal rains occur along the foothills of the Himalayan ranges bordering the Brahmaputra valley. Thirdly, rain is heavily concentrated in the order of about 70-80 per cent of the annual total during the summer monsoon months from June to September. The three characteristics of precipitation distribution explain why floods are common during the summer monsoon period. The average annual rainfall in the Brahmaputra catchment is 2650 mm. The upper and lower Brahmaputra valleys and the Himalayan foothill zone respectively receive average annual rainfalls in the order of 3000 mm, 2500 mm and more than 5000 mm (Fig. 2). Of the total annual rainfall nearly 70 per cent, i.e. the flood-causing major portion occurs during June-September. But, although small in amount, the rainfall during the premonsoon season (March to May), accounting for 20 per cent of the annual total is quite important in favouring necessary conditions for monsoon floods. The premonsoonal rains cause early saturation of soil and reduce the flood modifying capacity of the soil layers, thereby providing potentials for early monsoon floods. As a result, occasional rainfall associated with depression in the month of June itself becomes sufficient to cause major floods in the Brahmaputra. The heavy summer monsoons produce the strongest effects on the

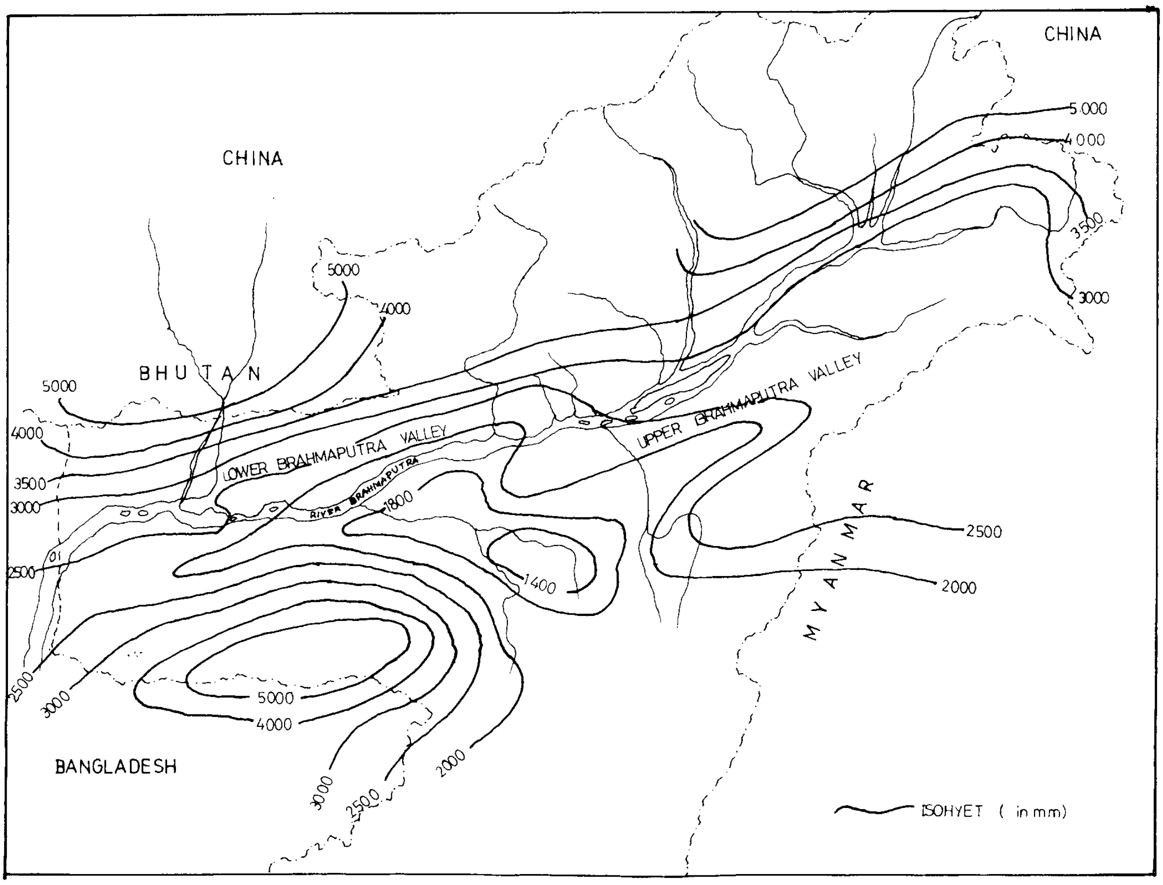

Fig. 2. Rainfall distribution pattern in the Brahmaputra Valley

Brahmaputra and its tributaries. High intensities of rainfall along the foothills boardering the valley lead to peak the flow of the tributaries at their confluences within a very short time, which eventually gives rise to high flood level of the Brahmaputra.

Seismic and tectonic situation of the Brahmaputra valley also constitutes one of the major natural factors of floods. The earthquakes of 1897 and 1950 measuring 8.7 and 8.6 magnitudes on the Richter scale respectively caused extensive subsidence and fissuring in the valley and brought about considerable changes in the fluvial regime of the Brahmaputra river system of India (Oldham, 1899; Poddar, 1952). Changes in river courses and accompanying erosion in the mountains have together accelerated the silt deposition on the river beds. The bed of the Brahmaputra got silted upto 2.5 to 3 metres near Dibrugarh in the upper Brahmaputra valley due to the effect of 1950 earthquake which, in turn, caused the river bed as well as water level of the river to rise abruptly (Fig. 3). Besides, heavy landslides triggered by the 1950 earthquake blocked the tributaries like Subansiri and Dibong and also the mainstream Brahmaputra, and consequently devastating floods occurred downstream when the dams burst (Bandyopadhyay and Gyawali, 1994). The impact of 1950 earthquake in raising the Brahmaputra river bed in Bangladesh was also observed by Timm (1989).

Human factors

Alike natural factors, human-induced factors are also highly responsible for aggravating flood situation in the valley. Observations made in the field suggest a host of human activity generated causes of floods like (i) deforestation due to unwise tree felling and practice of shifting cultivation in the hilly catchment, (ii) large scale human encroachment upon the floodplain, (iii) degradation and degeneration of wetlands and (iv)

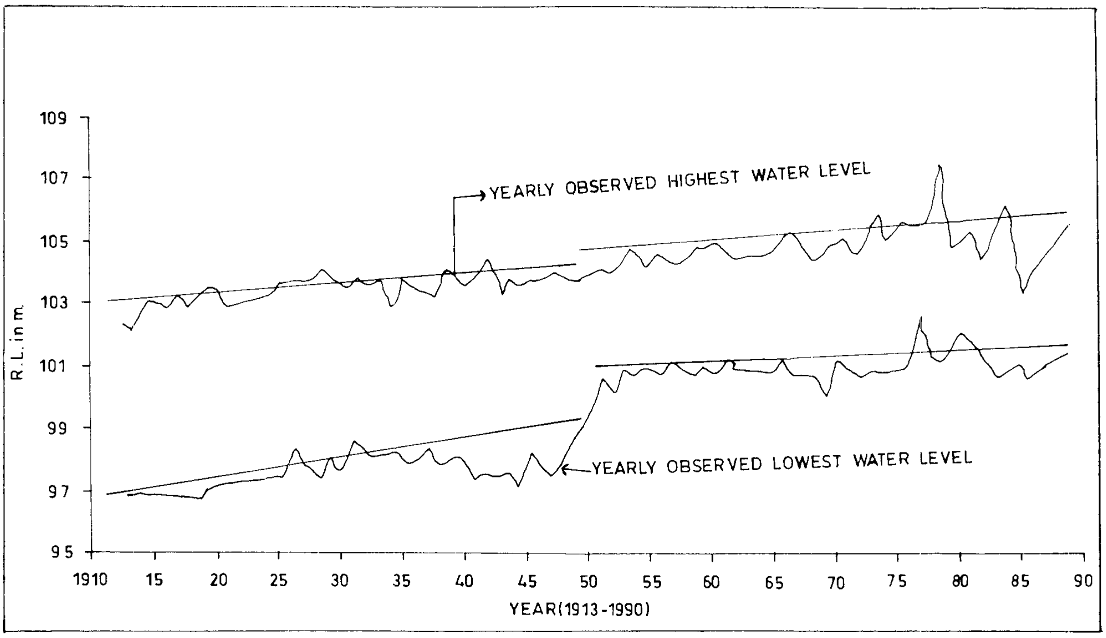

Fig. 3. Rise of water levels of Brahmaputra at Dibrugarh after the 1950 earthquake

the poorly managed ad hoc structural flood control measures.

(i) Deforestation and unwise tree felling coupled with the practice of shifting cultivation in the hilly catchment lead to accelerated sedimentation and increase in flood potential downstream. The forest cover in the valley records substantial decrease from 31.5 per cent in 1972-73 to 19.6 per cent in 1999-2000 (Table 1). It is also estimated that average firewood consumption in the rural areas of the valley is at the rate of 2.5 kg/day per capita. The rate of firewood consumption exceeds the annual natural increment in biomass in the local forests, thereby leading to depletion of capital biomass. The forests of the valley are thus under considerable pressure to meet the growing demand for firewood, fodder, timber and other forest products. A case study aimed at estimating soil loss resulting from shifting cultivation widely practised in the hilly catchment of the Jia Bharali river (Fig. 1) reveals annual soil loss rates ranging from 84.6 to 137.3 tons/ha (Bora, 1990) with an average rate of 106.7 tons/ha per year. Such a high amount of soil loss coupled with an alarming basin sediment yield rate of 4721 tons/km^2 per year, which is the highest among that of all the tributary basins of the Brahmaputra system in India, may be very much responsible for channel aggradation and frequent flooding downstream in the Jia Bharali river (Bora 1990). It may be an evidence to believe that deforestation of any form in the Brahmaputra valley has considerable bearing on river channel sedimentation and resultant increase in flood potential downstream.

(ii) In recent years, increasing encroachment on the floodplain and low-lying areas for habitation and cultivation has significantly aggravated the flood problem. A field survey conducted in 20 semi-permanent and permanent river islands (*chars*) located within the 6-8 km wide channel of the Brahmaputra in the lower part of its valley reveals high population growth at the rate of 137.36 per cent during 1991-2000. As of the year 2000, the area under field survey has as many as 17,257 persons in total representing a population density in the order of 285 persons per km^2.

(iii) The destruction and degradation of wetlands, swamps etc. due to various forms of human interference has also added an adverse dimension to the flood problem. In the

Table 1. Forest cover status in the Brahmaputra Valley

Period	Percentage of forest area to total valley area	Percentage of dense forest area
1972-73	31.5	22.8
1982-83	26.3	17.5
1992-93**	23.8	13.3
1999-2000**	19.6	11.4

* Data source: Flood Control Department of Assam (1989)
** Data source: Bora (1995, 2001b)

Brahmaputra valley there are as many as 3007 wetlands having areal size equal to or more than 2.5 hectares each which mainly belong to wetland types like pond, ox-bow lakes or meander cut-off, seasonal waterlogged tracts, swamps or marshes. All these wetlands besides being the economic resource base and rich in biodiversity help in reducing flood height, and thus flood damage by containing flood waters as they act as buffer zones for rivers and other water ways during the period of heavy monsoonal rains (Bora, 2001a). But due to large scale human encroachment upon the floodplain as mentioned earlier, the wetlands of the valley suffer from the problems of degeneration and ecodegradation.

(iv) The structural measures of flood control, especially the poorly managed embankments also often cause sudden floods. The flood water coming across the embankments through overtopping or breaching eventually remains stagnant in a locality for days together and causes gross damage.

Flood hydrology and dynamics

The Brahmaputra river of India represents the most dynamic and unique water and sediment transport patterns. Being a vast river system and charged with strong effects of monsoonal rhythm, the Brahmaputra happens to be the fourth largest river in the world in terms of average discharge at the mouth, i.e. its confluence with the Ganges, carrying a flow of 19,830 m^3s^{-1} (Goswami, 1982, 1985). Flow during the rainy season (May through October) accounts for 82 per cent of the annual flow at Pandu in the lower Brahmaputra valley (Bora, 2001a). As regards sediment transport, the river is also one of the leading sediment carrying rivers of the world. It is the second river only to the Yellow river of China in the amount of sediment transported per unit of drainage area (Goswami, 1985). As measured at Pandu the river carries an average annual suspended load of 402 million metric tonnes. During the rainy season more than 95 per cent of the annual suspended load is transported at Pandu at an average daily rate of 2.12 million metric tonnes. The river with such high volumes of water discharge and sediment load has become one of the highly braided rivers of the world (Fig. 4). Coleman (1969) and Goswami (1985) observed intense braiding along the Bangladesh and Indian section of the river respectively. In fact, the high variability of flow marked by its fifteen fold variation between the flood and lean seasons, coupled with its high sediment load and highly erodible bank materials seem to provide favourable situation for braiding. The bank materials of the Brahmaputra are mostly composed of dominant proportions of fine sand and silt with only occasional presence of clay being less than 5 per cent, which largely contribute to the progress of braiding process in the channel. Besides, aggradation of its channel plays an important role in inducing development of braided channel pattern. The river section of the valley has in general an aggrading type of bed which is found to undergo a secular trend of aggradation. A suspended load budget indicates that at least 70 per cent of the incoming load is trapped in the river, resulting in an overall aggradation of the channel by about 16 cm (Goswami, 1985). The ongoing channel aggradation and braiding processes have together led to formation of a large number of mid-channel bars (Fig. 4). The wide alluvial channel of the river with an average width of 6-8 km is thus dotted with more than 600 small and large sandbars locally called *chars*. Some sandbars with fertile alluvial top soil support a good number of permanent, semi-permanent and temporary settlements which are susceptible to frequent inundation. Notably, a small fraction of the total number of *chars* are more or less permanent in existence. During summer monsoon season most of the *chars* are submerged by flood water and they change their sizes, morphology and locations. Changes in terms of locations and physical parameters of the *chars* may be well attributed to the processes of channel shifting and bank instability. The rate of rise and fall of the stage, the number and positions of major channels active during flood, the formation and movement of large bedforms, variability in composition of bank materials

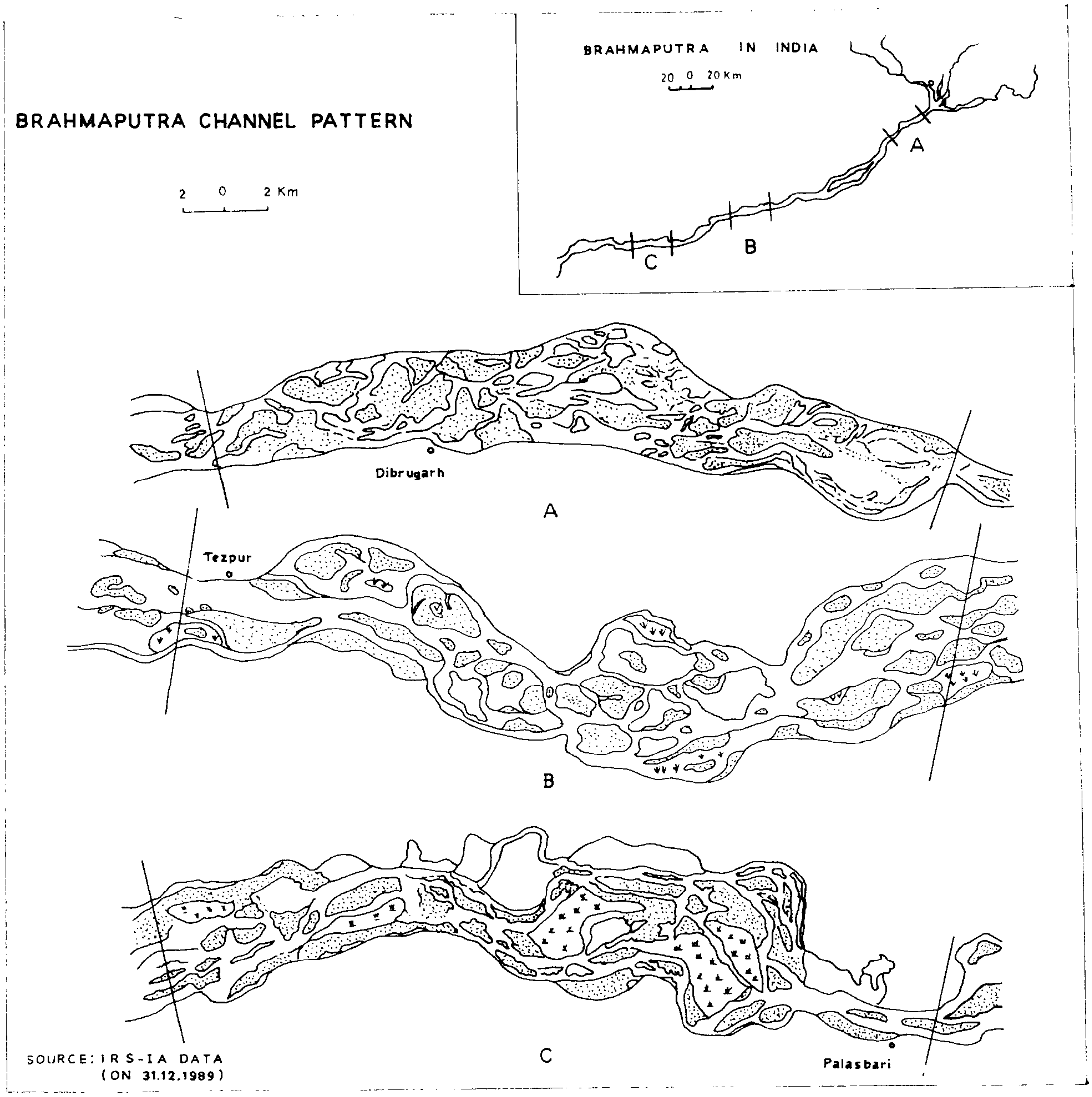

Fig. 4. Channel patterns of the Brahmaputra along selected sections in the upper (A), middle(B) and lower(C) Brahmaputra Valley of India

and intensity of bank slumping are the important factors responsible for channel shifting and bank instability. Bankline changes are very noticeably associated with the rise and fall of stage during a flood cycle. Thalweg movement is generally high during rising stage of flood in May-June, relatively less during the peak of flood in July-August and most irregular during the falling stage in September-October. The most significant bankline modifications take place during the falling stage of flood, when excess sediment is deposited as bars within the channel, causing a change in local flow direction and migration of the thalweg. Moreover, subaqueous bank failure is common when hydraulic pore pressure on the bank wall gets decreased during the falling stage of flood. With all these characteristics, the dynamic fluvial regime of the Brahmaputra along with its swinging braided channels and the *chars* presents a peculiar geomorphic make-up quite distinct from the other physiographic units of the valley, which assumes much significance from fluvio-geomorphic point of view.

Available flow data suggest high fluctuations in the daily discharge of the river. High variability in discharge is mainly caused by seasonal rhythm of the monsoon and freeze-thaw cycle of the Himalayan snow (Bhattacharyya and Bora, 1997). The mean annual maximum and minimum flows in the river are 47,660 m^3s^{-1} and 3253 m^3s^{-1} respectively at Pandu. On the average, therefore the maximum flow is about fifteen times the minimum flow. The flow in the river is less than or equal to the mean annual flow about 52 per cent of the time.

High-magnitude floods regularly occur in the valley. Floods in the valley are truly monsoon dependent, responding to the intraseasonal rhythm of the monsoon and they commonly come in 3–4 waves in a year. During the last 46 years covering the period 1955–2000, floods ranging between 72,748 m^3s^{-1} and 31,638 m^3s^{-1} have been recorded (Fig. 5). A flood frequency analysis of the river taking the 46-year flood series for the period 1955–2000 is illustrated in Fig. 6 using Log Pearson Type III method. On this curve, the mean annual flood of 47,660 m^3s^{-1} has a recurrence interval of 2.31 years. The 100-year flood is found to be about 1.5 times that of 2.33-year flood. During the last 46 years of observation at Pandu the highest flood occurred in 1962 measuring 72,748 m^3s^{-1} with corresponding water level of 49.35 m. But, the flood of 1988, although of lesser magnitude (47,737 m^3s^{-1}) than that of 1962 maintained the highest water level of 49.76m so far observed at Pandu. It is interesting to note that not only at Pandu, but also throughout the Brahmaputra valley from Bechamara to Dhubri, the water level of the river also remained highest on the record from August 26 to 29 during the 1988 flood (Table 2). This fact thus well explains why the flood of 1988 assumed the most devastating dimension causing extensive inundation in the valley.

The north-bank and south-bank tributaries of the Brahmaputra also contribute significantly towards aggravating the overall flood situation of the Brahmaputra valley. Some major tributaries, viz. Dibong, Dihang (mainstream), Subansiri, Jia Bharali, Manas and Sonkosh of north bank and Burhi Dihing and Dhansiri of south bank (Fig. 1) are the most flood-causing rivers creating havocs along their plain courses. However, the northern and southern tributaries bear varying degree of flood petentiality. The wide variations in geology, geomorphology, physiography, relief and precipitation pattern of the northern and southern regions of the Brahmaputra valley bring about marked differences among the two groups of tributaries in terms of their fluvio-geomorphic characteristics (Bora, 2001a). In general, the northern Himalayan tributaries characterised by steep channel gradient over the hilly terrain, short courses on the plains, high basin rainfall, and enormous amount of sediment load and discharge, have more flash floods as compared to the southern tributaries.

There is a common problem of drainage congestion especially near the outfalls of the Brahmaputra tributaries during their high stages. The tributaries, especially in their lower reaches upto their confluences with the Brahmaputra are generally hydraulically less efficient due to low channel gradient to drain rain water as well as spills from the sub-tributaries. The situation further worsens when the Brahmaputra itself is in high floods and its water level remains higher than that of the tributaries. The Brahmaputra flood water then backs up into the tributaries causing back water effect which eventually

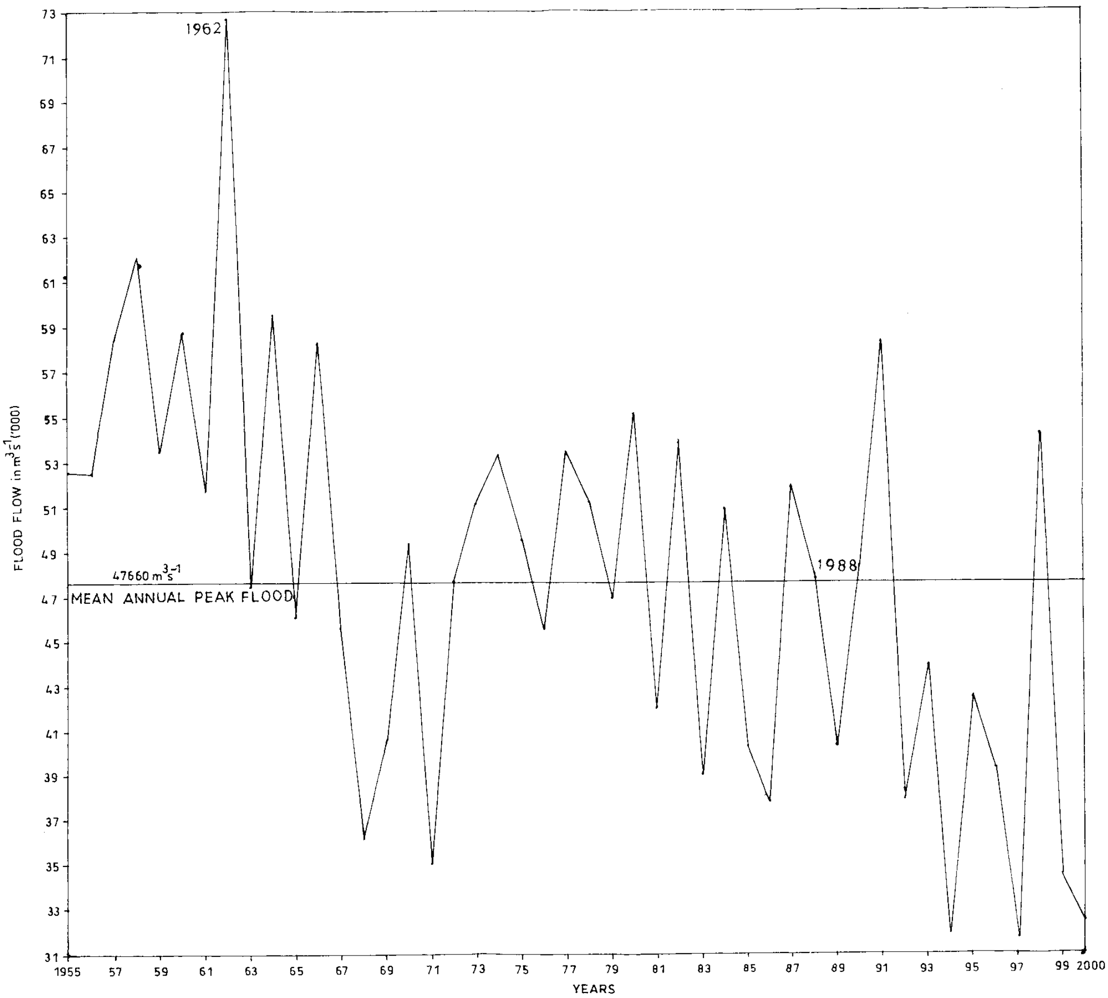

Fig. 5. Annual peak floods of the Brahmaputra at Pandu, 1955-2000

leads to floods in their lower reaches and confluence zones. The chronically flood-prone areas along with the areas affected by combined inundation of the Brahmaputra and its tributaries are shown in Fig. 7. As many as eight areas which are chronically affected by combined inundation of the Brahmaputra and some of its tributaries have been identified. These include the areas, viz. Lower Dibong and Lohit area, Noa Dihing-Kakopathar area, Dhemaji-Jia Dhal area, Pani Dihing-Disangmukh-Dikhowmukh area and Gelabil-Dhansirimukh-Kaziranga area of the upper Brahmaputra valley, Lower Kopili-Morigaon area of the middle Brahmaputra valley and Lower Puthimari-Pagladia-Beki and Lower Kulsi areas of the lower Brahmaputra valley. Interestingly, these areas are found to be solely inundated by the combined effects of the Brahmaputra and its tributaries. Besides, an elongated tract lying adjacent to both the north and south banks of the Brahmaputra falls prey to chronical floods (Fig. 7). As evident from the figure the chronical floodplain is irregular showing discontinuity in its extension along the Brahmaputra. The continuity of the chronical floodplain is broken by the presence of some isolated hillocks of Archaean origin and incipient levees on both the banks of the river. The isolated hillocks are the remnants of the northerly outcrops of the Archaean Meghalaya (Shillong) and Karbi Plateaus of the south (Bora, 2001b). In the lower Brahmaputra valley the chronical floodplain along the south bank is, therefore generally narrow due to jutting out of the two plateaus. But in certain parts along the south bank in the middle and upper Brahmaputra valley, the floodplain appears to be somewhat extensive following the

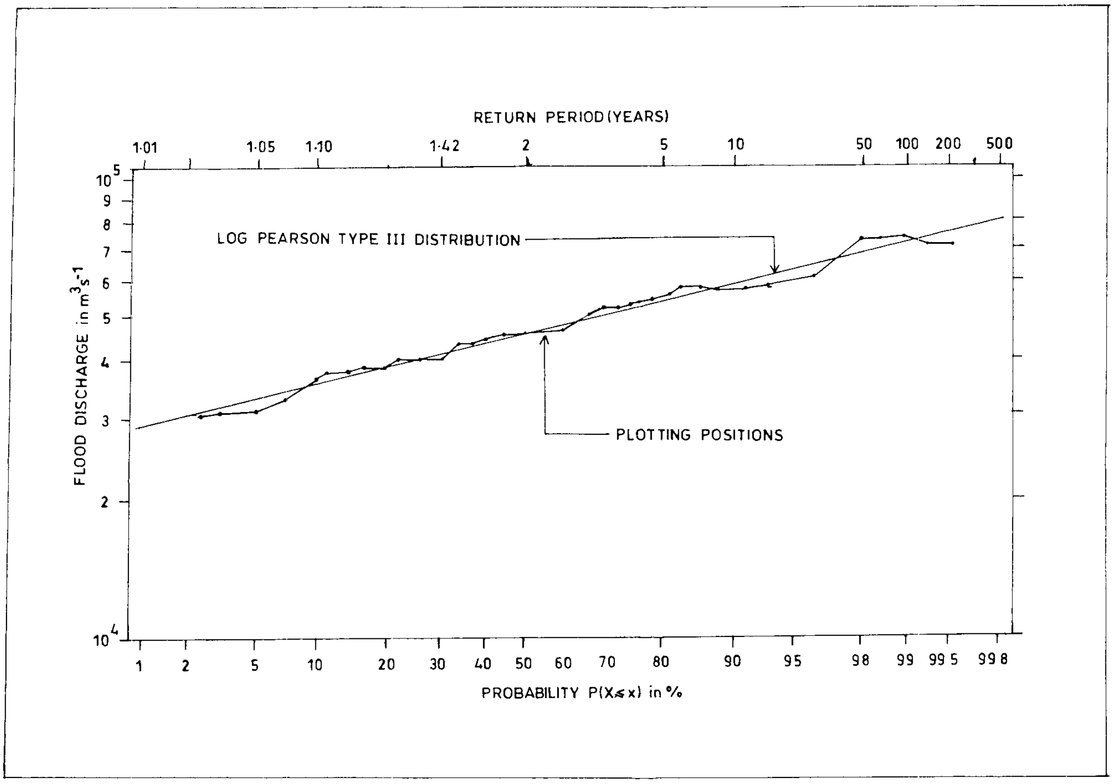

Fig. 6. Flood frequency analysis of the Brahmaputra floods at Pandu, 1955–2000

Table 2. Maximum water level of the Brahmaputra

Site	Date	Maximum Water Level (m)	Danger Level (m)
Dibrugarh	20.7.82	107.95	104.24
Bechamara	26.8.88	88.23	85.32
Neamati	14.8.87	87.79	85.04
Tezpur	27.8.88	66.59	65.23
DC's Court (near Guwahati)	29.8.88	51.37	49.75
Pandu	29.8.88	49.76	48.77
Goalpara	29.8.88	37.29	36.27
Dhubri	29.8.88	30.36	28.65

Each location (site) is shown in Fig. 1

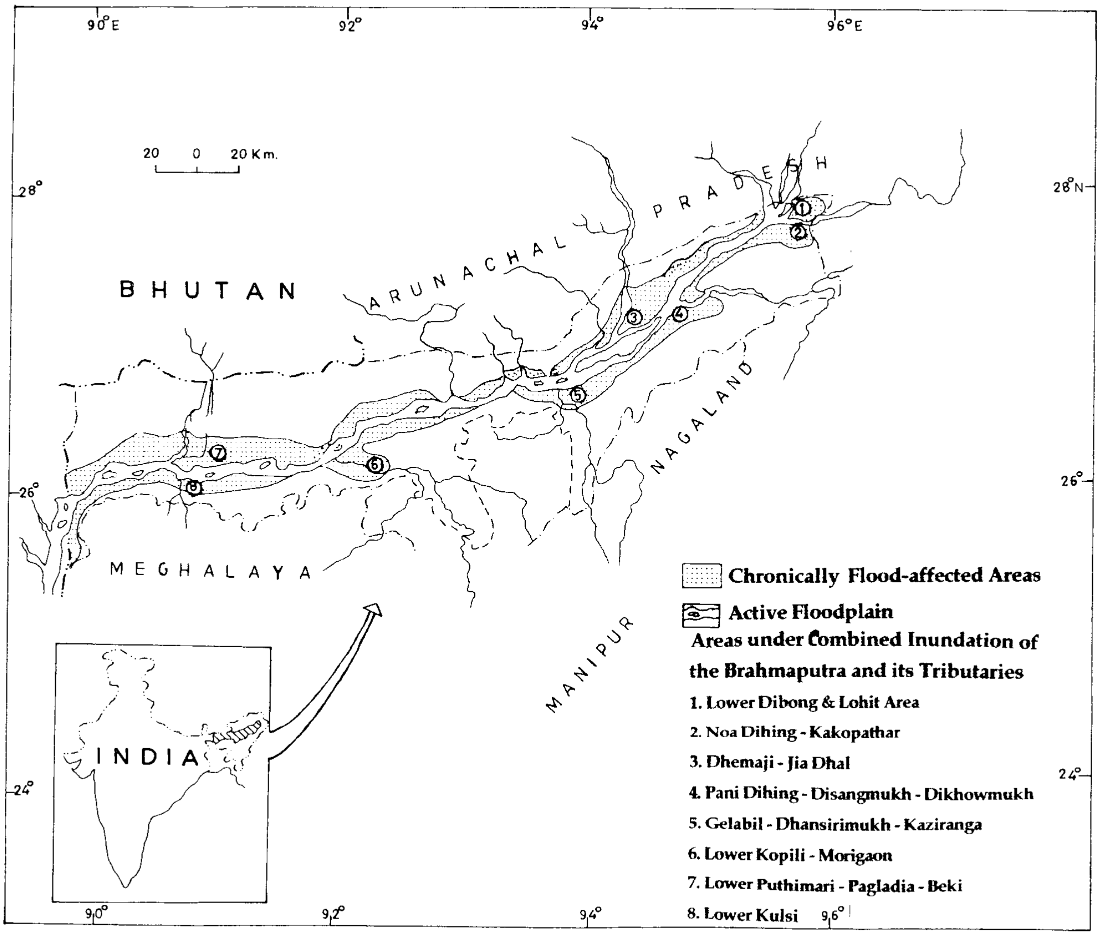

Fig. 7. Flood-prone areas of the Brahmaputra Valley

plains expanded by some tributaries. However, the same along the entire north bank of the Brahmaputra is relatively wider except at certain locations, where it discontinues due to occurrence of occasional hillocks and levee deposits. On the north bank, comparatively more areas receive the fury of chronical floods primarily because of heavy drainage congestion in the lower reaches of the tributaries and back water effects of the Brahmaputra, relatively narrow north-bank plain especially of the upper Brahmaputra valley traversed by turbulent Himalayan tributaries having their short plain-courses and charged with heavy rainfall occurring in the Himalayan foothills (Fig. 2 and Fig. 7). The highly flood-prone areas, on the other hand including numerous *char* lands and large riverine Majuli island confined to the dynamic fluvial regime of the Brahmaputra form the active floodplain zone of the valley. The *char* lands of the Brahmaputra getting gradually humanised in recent years account for substantial quantum of flood damage following perennial attacks of monsoon dominated deluging floods.

Flood hazards and impact

Floods form the core of geomorphic hazards in the riverine environment of the Brahmaputra valley. Floods in the valley are characterised by their large magnitudes, high frequency and extensive devastations. The frequency and time of flood occurrence are very relevant to the understanding of the patterns and dimensions of flood hazards. The valley commonly receives severe floods of different orders occurring at least 3-4 times in the monsoon period of a year. Normally about 40 per cent area of the valley is affected by flood. The valley presently accounts for about 95 per cent of the total flood-prone area in the North-Eastern Region of India and 8.5 per cent of India's total. Flood damage data relating to the major floods of the valley during 1950-2000 (Table 3) indicate that the cropped area damaged and number of affected people are gradually increasing over the years. It is mainly due to increasing severity of floods, large scale dwelling upon summer cultivation and growing human encroachment into the floodpains. The most dominant impact of floods is on the agricultural sector of the valley, which happens to be the mainstay of its economy. As much as 70 per cent of the flood loss in the valley is accounted for by crop damage. The high intensity of flood hazard is well demonstrated by the fact that in one of the worst floods that occurred in the year 1988, as much as 3.82 million hectares of area were affected, damaging 1.12 million hectares of croplands (Table 3). The devastating nature of the 1988 flood can well be attributed to the corresponding highest water levels on records at different gauge sites on the Brahmaputra (Table 2), which led to extensive inundation accounting for 62 per cent of the area of the valley including the flood-prone areas shown in Fig. 7.

A substantial amount of flood damage, i.e. 36 per cent of the total annual damage comes from frequent inundation of the sandbars and islands under human use, located within the river. As the flow begins to rise with the onset of the monsoon in May, most of the bars start getting submerged. During high floods, the river flows in a more or less straight channel and only a few bars remain visible. The core area of the bars with permanent settlements and cultivation is relatively high, and thus least affected by floods. Away from the core upto the fringe areas, the settlements and agricultural lands become increasingly susceptible to erosion and frequent inundation.

Erosion hazard posed by the Brahmaputra also constitutes a serious dimension of its flood problem. The river with dynamic fluvial regime is characterised by intense braiding, rapid bed aggradation and drastic bankline migration. With the progress of the flood cycle, sediment transport in the Brahmaputra increases,the thalweg starts to change positions, and the geometry and locations of bars change (Goswami, 1985). The changes in channel configuration during flood season result in frequent thalweg shifting,

Table 3. Flood damage during major floods in Brahmaputra Valley (1950-2000)

Year of major floods	Number of flood waves	Area affected (million hectare)	Cropped area damaged (million hectare)	Population affected (million)
1954	4	2.90	0.30	1.30
1955	3	1.35	0.07	0.18
1958	2	1.23	0.06	0.40
1959	2	1.01	0.17	0.66
1962	2	1.59	0.36	3.91
1966	4	1.51	0.06	3.62
1969	3	1.06	0.07	0.89
1972	3	1.01	0.36	2.95
1973	3	2.31	0.17	1.84
1974	2	1.07	0.24	2.31
1977	3	1.02	0.21	4.54
1980	3	1.14	0.26	3.35
1984	4	1.49	0.14	5.61
1987	3	1.62	0.43	3.27
1988	4	3.82	1.12	8.31
1993	3	1.25	0.22	5.30
1996	4	1.33	0.28	5.12
1998	3	0.97	0.29	4.69
2000	3	0.98	0.24	3.88

Source: Compiled by the author on the basis of data collected from various departments of the Government of Assam (India) which eventually induces heavy bank erosion. The banks of the river particularly near Nagajuli-Maijan, Majuli, Kaziranga, Bhairabpur, Palashbari, Balikuchi and Howlighat areas (Fig. 1) experience the threat of severe erosion during floods. A striking example of unabated erosion hazard of the Brahmaputra is the Majuli island. The island emerges to be the world's largest riverine island situated within the Brahmaputra in its upper valley (Fig. 8). But, in recent years, especially after the great earthquake of 1950, recurring floods and severe bank erosion are causing havoc to the island inundating and eroding large areas. The island occupied an area of 1245 km^2 in 1915 and its area was reduced to 925 km^2 and 752 km^2 in 1971 and 1984 respectively. The area of the island was further reduced to 645 km^2 in 1995, thereby maintaining an average rate of erosion in the order of 7.4 km^2/year (Bora, 2001b).

Flood hazards management

In view of growing extent of inundation and increasing quantum of flood damage,

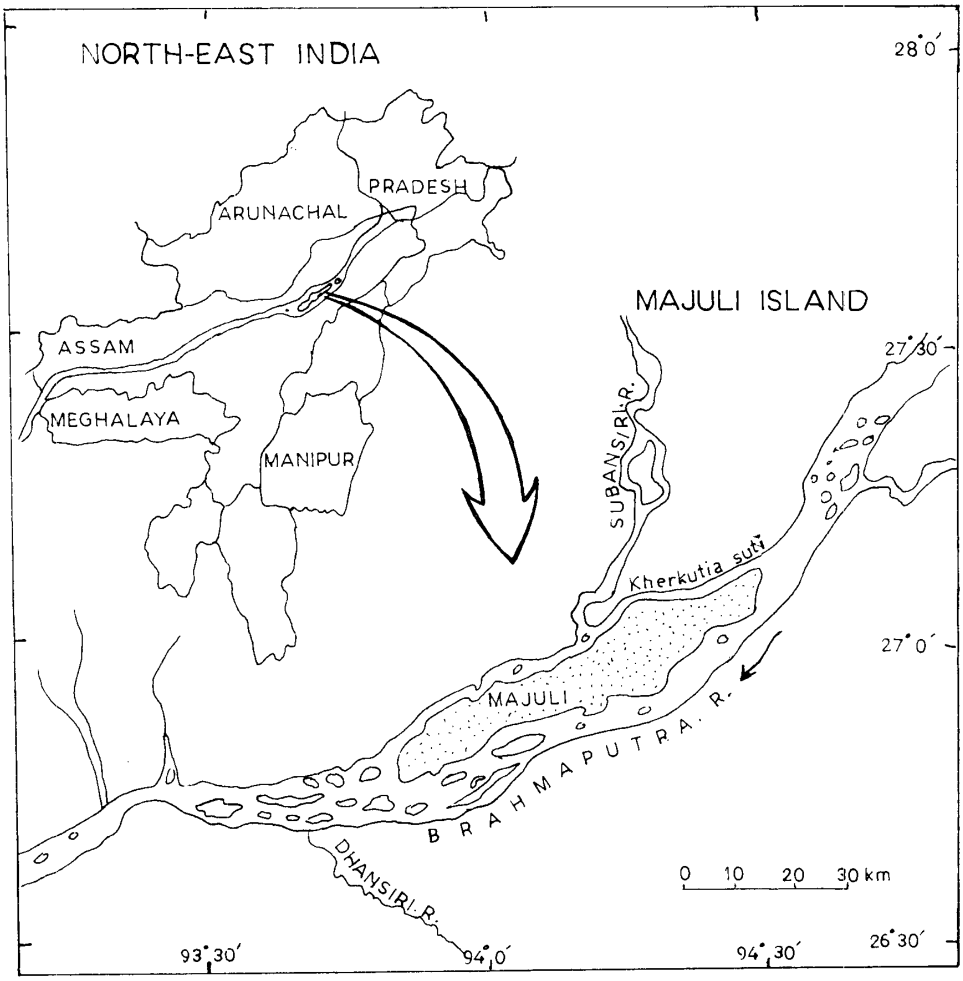

Fig. 8. Majuli Island within the Brahmaputra Channel

there arises an overriding need to take up some effective flood management approaches for achieving prosperous development in all fronts of the Brahmaputra valley's economy. A package of flood management activities comprising (i) water resources development, (ii) floodplain zoning and management, and (iii) pursuance of the approach of 'living with floods' is considered most appropriate for proper management of floods in the valley.

By virtue of some favourable natural factors, especially the relief and slope, physiography and heavy monsoonal rains, the Brahmaputra and its tributaries bear abundant water resources. This river system in india represents hydropower potential of 31,857 MW (at 60 per cent load factor) accounting for 38 per cent of the India's total potential. But, only a nominal fraction of 600 MW, i.e. only 1.88 per cent is so far harnessed. The utilization level of the Brahmaputra runoff represents a more dismal picture in the context of the other Indian rivers. Out of the total runoff of 1853.5 cubic km. for Indian rivers, the Brahmaputra carries an average annual runoff of 627.87 cubic km, i.e. 33.87 per cent of India's total. But, only 0.07 per cent of the Brahmaputra runoff is utilised so far, as water storage for hydro electric power generation is concerned. However, some hydropower projects on certain tributaries of the Brahmaputra have been proposed (Table 4). If the dam projects like Dihang (mainstream) and Subansiri are implemented, the flood level of the Brahmaputra is expected to go down by 1 to 2 m and 0.25 to 0.6 m respectively. In the case of other dam projects similar lowering of flood level may also be anticipated. Moreover, there is also tremendous prospect to utilise the Brahmaputra's water resources to irrigate the fertile croplands of the valley, where only 15.06 per cent of its gross cropped area is brought under irrigation. It is thus clear that the Brahmaputra provides ample prospect for its water resources development which in turn, may be a key factor in the control and management of flood.

In view of the increasing trend in flood damages in the valley, it can be realised that the existing flood control measures including embankments measuring a total length of 3551 km along the Brahmaputra and its tributaries, 600 km long drainage channel, 421 anti-erosion schemes and 56 major sluices are totally incapable of combating the chronic flood problem of the valley. It is notable that the earthen embankments have been mainly used so far as the sole answer to the flood problem of the valley. The overdependence on this particular measure can be realised from the fact that out of India's total length of embankment of 13,500 km, the Brahmaputra valley alone has 3551 km, which is about 26 per cent of the country's total. The undesirable consequences of embankments especially in aiding channel aggradation and overbank flooding are well evident in the valley. Considering the ill effects of the existing embankment system, the expert committee constituted in 1989 to examine the causes of flooding in the valley suggested no further construction of embankments along the Brahmaputra and its tributaries and recommended for strengthening the existing ones (Flood Control Department of Assam, 1989). However, experiences gained from other parts of the world suggest that floodplain zoning and management is the most effective way of moderating floods and reducing hazards. It is thought to be even more effective in the Brahmaputra valley, where large scale human encroachment of the floodplain and other low-lying areas for habitation and cultivation has already given rise to an acute flood problem.

The plain and floodplain of the valley assume great human significance mainly for their fertile alluvial formations. Interestingly, even the active floodplain zone has also come recently under large scale human occupance for habitation and cultivation. The active floodplain confined to the braided channel of the Brahmaputra contains innumerable *chars* numbering more than 600 with their varying sizes and degree of permanency. It is to be noted that majority of the *chars* are temporary and semi-permanent in existence. Till recently, the *chars* continued to be the sites of nature and human visit to them was extremely casual. But, by the beginning of the 20th century men, especially those who immigrated from erstwhile East Pakistan (now Bangladesh) gradually started peeping into these hitherto uninhabitated *chars*. The Brahmaputra riverine ecology having great resemblance to that in Bangladesh could easily attract the land-hungry peasants of Bangladesh and thus the *chars* used to be gradually humanised. Side by side, the immigrants from Nepal as well as some indigenous peasants also stepped into the *chars* for seasonal grazing and cropping. Presently, the *chars* support a large number of permanent, semi-permanent and quite temporary human settlements. The core areas of the *chars*, being relatively high are least affected by floods and, therefore support permanent settlements. Away from the cores with the decrease in elevation, the effect of flood gets increased thereby rendering the settlements a semi-permanent character. On the other hand, the fringes of the *chars* are highly susceptible to erosion and frequent inundation and consequently less attractive for settlements. Only the rootless immigrants quite temporarily settle in such *char* fringes. During flood the

Table 4. Proposed dam projects and hydro power potential in theBrahmaputra Vallay

Dam Projects		Potential Hydro Power (MW)
1.	Dihang	20,000 (F.L. down to 1-2m)
2.	Manas	5,000
3.	Subansiri	4,800 (F.L. down to 0.25-0.6m)
4.	Lohit	3,000
5.	Damoi	1,000
6.	Dibong	2,500
7.	Jia Bharali	2,000
8.	Kameng	600
9.	Sonkosh	1,500

Proposed dam sites are shown in Fig. 1

char dwellers generally take shelter on rafts made up of banana tree, small country boats and embankments and also in some relief camps arranged by the government and non-government agencies.

The floodplain of the Brahmaputra has thus become the site for large scale human encroachment leading to manifold increase in the quantum of flood damage. Obviously, the increasing pressure of population on the *char* areas has put concomitant pressure on the Brahmaputra valley. It may be mentioned that the valley recorded a total population of 12.45 million in 1971 with population density of 222 persons per km^2. Its population then increased to 19.1 million in 1991 representing a population density of 338 persons per km^2. The valley further received a total population of 22.65 million in 2001 with high population density of 403 persons per km^2. The increase of population in the Brahmaputra valley, especially due to immigration has led to large scale encroachment upon the floodplain. The use of the floodplain can, however, be regulated by identifying the risk zones and appropriate flood management programmes can be carried out in these zones. Floodplain zoning based on remote sensing as well as conventional data using modern techniques like the GIS can surely be an effective tool for management of the Brahmaputra floods. Realising the growing dimensionality of Brahmaputra flood problem, the Government of India had set up the Brahmaputra Board in 1981. The Board with is responsibilities for preparing the master plan for the control of floods, bank erosion and drainage improvement of the Brahmaputra has recently completed only the first part of the plan. This part of the master plan also suggests that effective floodplain zoning is the only way to minimise the flood damages of the Brahmaputra. But, the present scenario of flood management and control in the Brahmaputra valley is indeed a dismal one, as no floodplain management programme including floodplain zoning has so far been implemented.

Historically, the people of the valley are well acquainted with floods and spontaneously they have acquired the art of living with floods to a considerable extent. But, in the recent years, the Brahmaputra floods with their high frequency and magnitudes have appeared to be greatly hazardous to the floodplain dwellers. The people living in the floodplain suffer severely from recurring floods, and particularly the poor peasants find no alternative but to cultivate the land and accept the risk and the loss. The present mode of human adjustment in the valley is, therefore of 'accepting the risk' type, which needs to be shifted to the mode of 'risk management and exposer reduction'. However, majority of the experts now agree that complete control of floods of the valley is not at all feasible in view of the flood-generating hydrometeorological and geophysical situations of the valley. Under such circumstances, the approach of 'living with floods' is thought to be much more effective in averting the risk of flood damages in the valley. As a part of the approach of living with floods and also as an alternative adjustment to flood besides the structural measures, a change in the existing crop calendar and cropping pattern may be a viable way of avoiding the crop damage due to flood. Generally, the extent of damage caused by floods depends on the time of their occurrence. Unfortunately, the main cropping season of the valley, i.e. the summer cultivation season or paddy season during June-August well coincides with the season of intense monsoonal activity and resultant floods. Such coincidence obviously leads to most devastating impact on agriculture, which happens to be the mainstay of the people of the Brahmaputra valley. The present cropping system in the valley (Fig. 9), therefore, has to be scientifically adapted to the rhythm of regular flooding. To this effect, a suitable and appropriate crop calendar is suggested (Fig. 10), so as to reduce crop damage. The suggested crop calendar, however, gives emphasis on the change in the period of cultivation for *sali* rice, the only largely practised summer paddy of the valley,

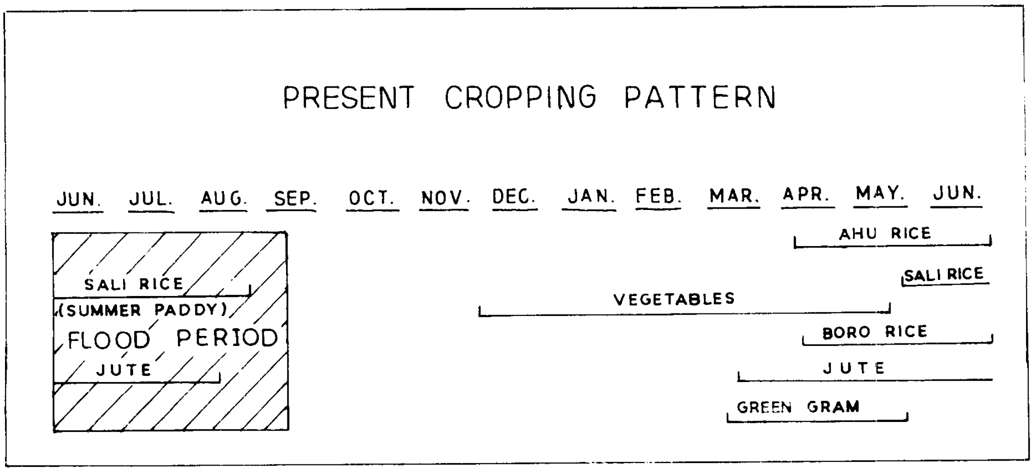

Fig. 9. Present cropping pattern of the Brahmaputra Valley

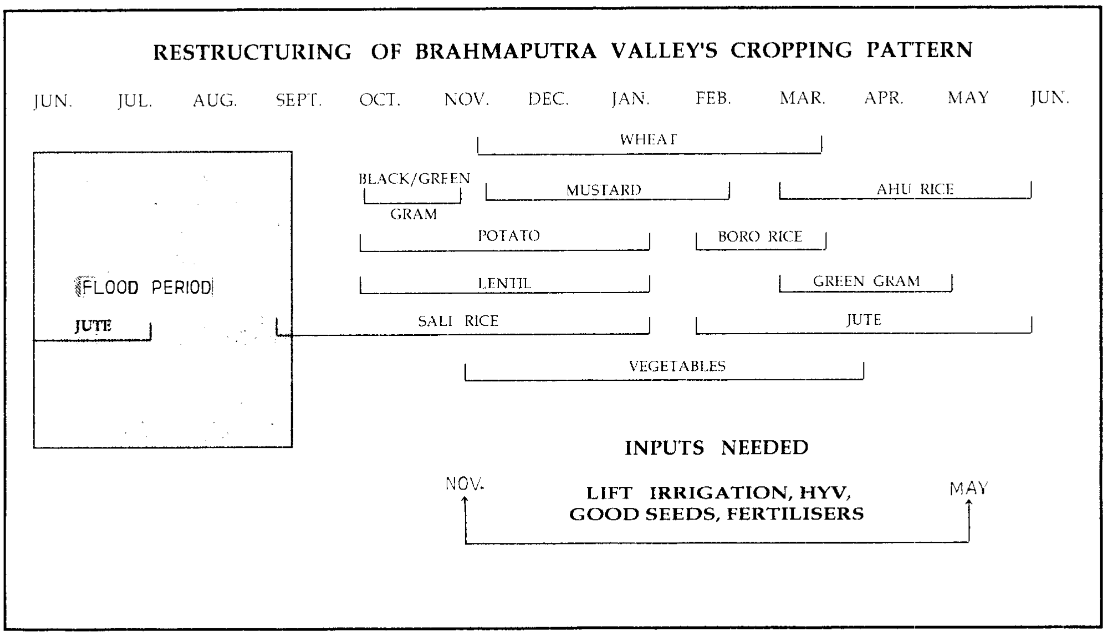

Fig. 10. Suggested crop calendar for the Brahmaputra Valley

and also the large scale practice of few more crops like wheat and mustard for more economic benefits, provided adequate irrigation facilities are extended. Indeed, the present cropping pattern of the valley has been restructured mainly with the view to avoiding the impact of flood and ensuring sustained productivity especially in respect of *sali* rice. In the chronically flood affected areas of the valley (Fig. 7) summer cropping should, therefore, be substituted by large scale winter cropping by providing good irrigation and other necessary inputs like high yielding variety (HYV), good quality seeds and fertilizers. Moreover, the flood resistance variety that can be successfully raised during low and moderate floods and the flood escaping high yielding variety of short duration may also be introduced.

Conclusions

The Brahmaputra river system is so vast and dynamic that natural processes alone are capable of creating deluging floods in its narrow and elongated intermontane valley. In recent years, a host of human-induced factors have also considerably aggravated the flood situation of the valley. The flood hazards created by the river cause havoc in the valley leading to huge loss, especially in the agrarian sector of its economy. The flood control measures hitherto being used have not yielded gainful results and they are in most cases, inadequate, ineffective and wasteful. Alternative adjustments to floods, besides the structural measures need to be taken up seriously with immediate effect. Development and management of the vast water resources of the Brahmaputra, zoning of floodplain and its management and pursuance of the approach of 'living with floods' are considered appropriate in arresting the ever expanding and still unresolved flood problem of the valley. Change in the existing crop calendar and cropping system of the valley is a viable alternative to avoid agricultural loss resulting from the coincidence of flood timing with the season of widely practised summer cultivation in the valley.

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インド・ブラマプトラ川における洪水と災害

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要　　旨

ブラマプトラの巨大でダイナミックな河川システムにおいては，河川の自然のプロセスのみでも深刻な洪水を引き起こすのに充分である．頻発する地すべり，急な斜面，侵食されやすい岩石やヒマラヤ地区の地震の起きやすさなどは，モンスーンの多量の降水と結合してブラマプトラ川の洪水を引き起こす主要な自然の原因となる．その上，最近顕在化した人間が引き起こす原因が洪水の規模や洪水損害を増大させるのに貢献している．1955年から2000年におけるブラマプトラ川の洪水（年平均47,660 $m^3 s^{-1}$）は2.31年の再現周期をもっており，大きな流量，高い頻度と壊滅的破壊という特徴をもっている．大きな洪水は氾濫源の地形や流路形状に大きな地形学的インパクトを与え，結果として深刻な河岸の侵食や頻繁な河谷位置の遷移をもたらす．大きな規模の洪水が繰り返して起こると壊滅的な打撃となり川沿いの農業経済に影響を与える．新しい地域への氾濫の広がりという洪水特性の変化にともない，洪水による損害の広がりや規模は最近増大している．適切な洪水調整の活動（河川管理）は川沿いの社会—経済発展の重要な要因である．

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