Chapter 6
Flood Hazard of the Brahmaputra River in Assam: Current Mitigation Approaches, Challenges and Sustainable Solution Options

Lalit Saikia

INTRODUCTION

The Brahmaputra is a trans-boundary river originating from the Angsi glacier near Manasarovar lake in southern Tibet; flowing through China, India and Bangladesh into Bay of Bengal. The Brahmaputra basin in India is shared by six states: Arunachal Pradesh (41.9%), Assam (36.3%), Nagaland (5.5%), Meghalaya (6.1%), Sikkim (3.7%) and West Bengal (6.5%) (Ojha and Singh, 2004). The basin is enclosed by the Himalayas on the north, the Patkai range of hills on the east, the Mikir hills and Shillong plateau on the south and the ridge separating it from Ganga basin on the west. The Brahmaputra valley is 80 km in width, where the river itself occupies about 1.5 to 25 km during its course in Assam. Spatial variability in morphodynamics of the river is strongly linked to central uplift, the slopes, and depressions (Lahiri and Sinha, 2012).

About 26 tributaries on the north bank and 13 on the south bank join the river in Assam (Fig. 1). The main river Brahmaputra along with the well-knit network of its tributaries controls the geomorphic regime of Brahmaputra valley. The river is unique due to its peculiar drainage pattern, diverse geological setting, high sediment load and critical bank erosion problem (Mahanta and Saikia, 2015). The ferocity or devastation capacity of the Brahmaputra is unparalleled. The Brahmaputra and its tributaries and sub-tributaries cause major problems during the monsoon months every year by flood and bank erosion.

Amongst all flood impacted states of India, the recurrence of flood continues to be the burning problem for Assam state. Flood prone areas of the country as a whole stands at about 10.2% of the total area of the country, but flood prone area of Assam is 39.58% of the area which implies that the flood prone area of Assam is four times

L. Saikia (✉)
Department of Earth Science, University of Science and Technology, Meghalaya, Ri-Bhoi, India

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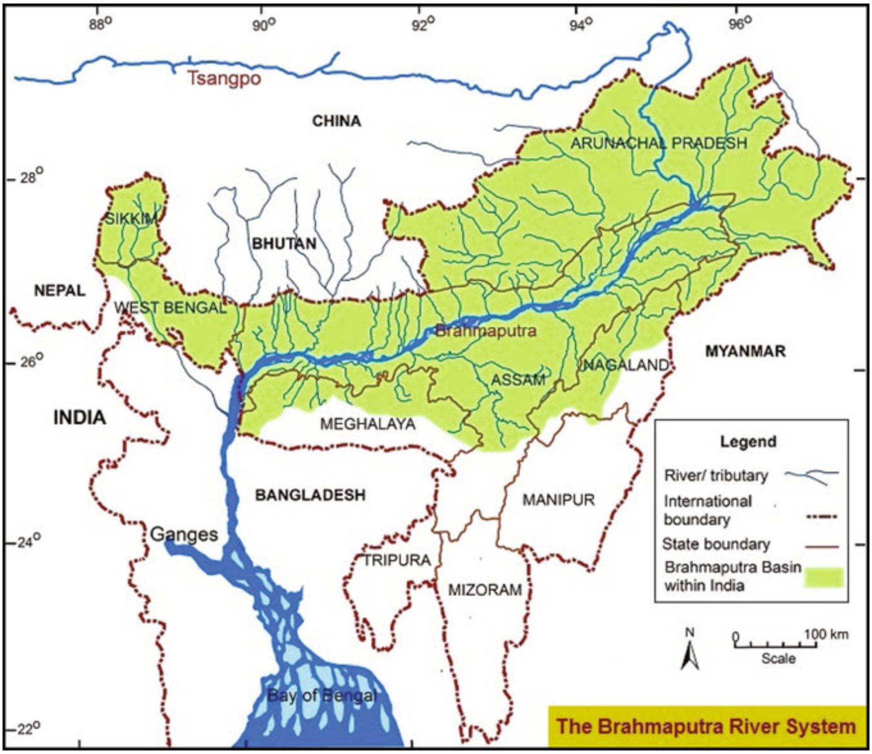

Figure 1. Brahmaputra river system within India.

Table 1. Flood affected areas of Assam and India during high flood years

Year of high flood in Assam	*Total area affected in India (Mha)*	*Area affected in Assam (Mha)*	*% share of Assam in India (flood affected area)*
1954	7.49	3.15	42
1959	5.77	1.04	18
1962	6.12	1.62	26
1966	4.74	1.78	38
1972	4.10	1.10	26.8
1987	8.89	1.53	17.2
1988	16.29	3.82	23.5
1993	4.63	1.25	36.9

Source: NEC, 1993

the national mark of the flood prone area. Records show that average annual area affected by flood in Assam is 9.31 lakh hectares. The Brahmaputra valley, surrounded by hilly terrain, is worst affected due to floods. Damage in Assam during high flood years were much higher in comparison to the fraction of total area affected in India (Table 1).

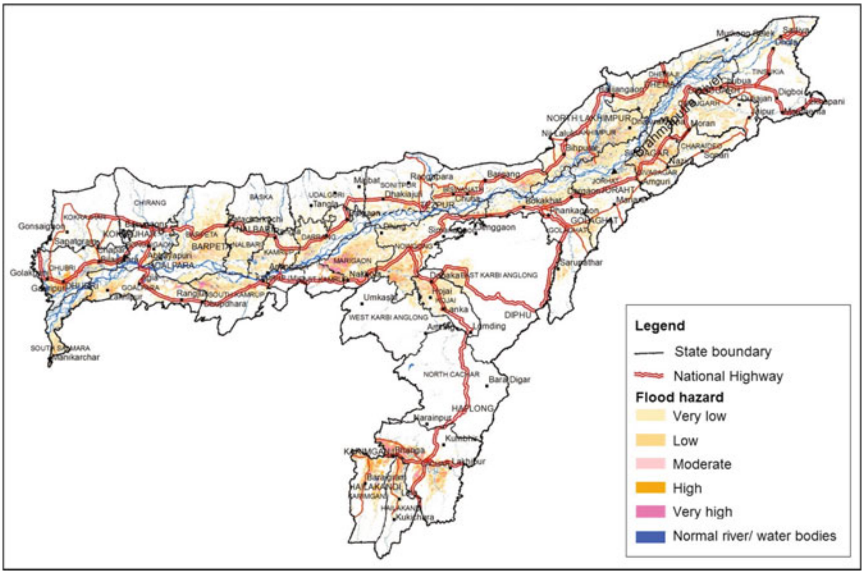

Figure 2. Flood hazard zones of Assam.

Table 2. Flood hazard classification (ASDMA, 2019)

Flood hazard classification	*Number of times/year (area subjected to flood inundation during 1998-2007)*
Very Low	1-2 times
Low	3-4 times
Moderate	5-6 times
High	7-8 times
Very High	9-10 times (almost every year)

Flood hazard map (created by NRSC-Hyderabad, collected and modified from ASDMA 2019) for 10 years (1998-2007) showed flood hazard zones of Assam with five classifications, viz. very low, low, moderate, high and very high (Fig. 2, Table 2).

Being an agrarian state, economy of Assam basically emerges from agriculture. Around 75% population of the state depends directly or indirectly on agricultural activities. But three or four devastating floods annually wipes out major chunk of the fruit of people's labour. Thus, flood has virtually destroyed the economy, more particularly the agro-economy of the state. Average annual loss due to flood in Assam is about Rs 200 crore but in 1998, the loss suffered was about Rs 500 crore and during the year 2004 it was about Rs 771 crore. Statement of tangible losses by flood in Assam during 2015-2017 are given in Table 3.

Floods cause havoc to wildlife also. Kaziranga National Park located in flood plains of Brahmaputra River is an example where flood annually submerges

Table 3. Losses by flood in Assam during 2015-2017

Year	*No. of Villages/ Localities affected*	*Crop area affected (Hect)*	*Population affected*	*Human lives lost*	*Big animal/ cattle loss*	*Houses damaged fully*	*Houses damaged partially*
2015	4763	329303	4203609	64	212	1519	82095
2016	4471	282060	4008602	64	5580	5953	27652
2017	6151	397910	5602090	160	111	3991	74354

Source: Office of the Chief Engineer, Water Resources Department, Govt. of Assam, Chandmari, Guwahati

Table 4. Number of days inundated by flood in Kaziranga National Park in a few years

Year	*Days of flood*
1998	91
2002	42
2003	17
2004	63
2007	14
2008	4

Source: Office of Director, Kaziranga National Park, Bokakhat.

maximum area affecting large number of wild animals including famous one-horned rhino. Total 2479 number of rhinos died during 1986-2015 and 26% deaths were in monsoon season. Large number of rhinos died in monsoon months of 1988, 1991, 1998, 2012 and those years witnessed high flood. Plight of different wild animals in flood situation due to loss of habitat and scarcity of food is easily understood from number of days inundated in Kaziranga in flood years (Table 4).

CAUSES OF FLOODS IN BRAHMAPUTRA

Main factors for extensive floods in Brahmaputra are adverse physiography of the region, heavy rainfall, landslides, excessive sedimentation in valley, frequent earthquakes, reduction of forest cover and human encroachment in the riverine area.

The Brahmaputra is flowing through a tectonically complex and seismically active zone (V). Long-range interactions of mega tectonic units like north-south convergence of the Indian-Eurasian plate along the Himalayas and east-west convergence in the Indo-Burma mountain and under thrusting of the Indian plate below the Eurasian plate (Tiwari et al., 2004) make the region seismically active.

Slope of Brahmaputra river is very steep when it crosses the Himalayas (Fig. 3). Average gradient of the Brahmaputra river is 1.52 m/km. In the course of the river, ~100 km reach known as *Tsangpo* gorge where the river abruptly bends southward is a locus of extremely rapid and focused erosion (Finlayson et al., 2002; Finnegan et al., 2008; Stewart et al., 2008; Larsen and Montgomery, 2012). The geologically

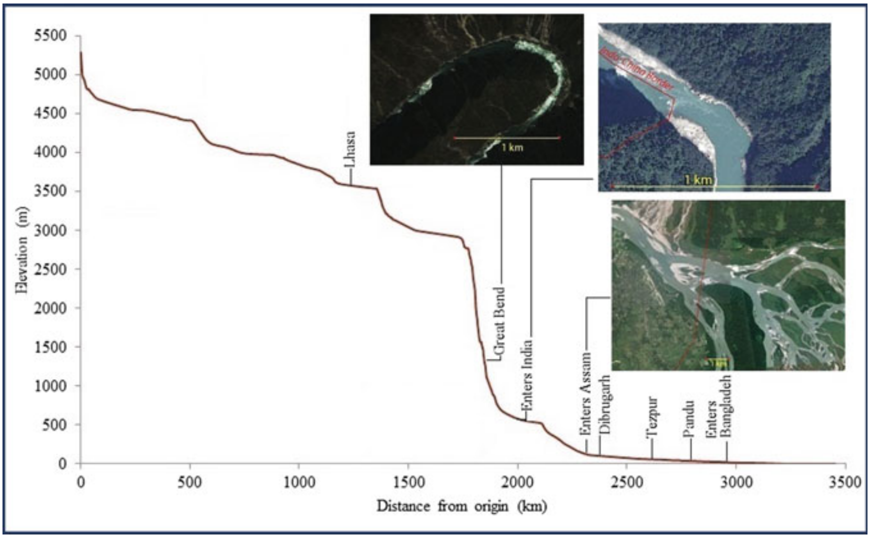

Figure 3. Slope of Brahmaputra River (Saikia, 2017; Mahanta and Saikia, 2017).

youngest lithology of the Himalayas under the influence of intense rainfall and seismicity, load the main river and tributaries with large amount of sediment. The north bank tributaries like *Subansiri, Ranganadi, Jia Bharali, Noa Nadi, Moridhal, Jiadhal* and *Pagladiya* have very steep slopes and shallow braided channels for a considerable distance from the foot hills and in some cases right upto the outfall. Steep slopes of the Brahmaputra and tributaries in the mountainous reaches led to high amount of sediment generation and transportation. The sediment transporting capacity of a flow is highly sensitive to the velocity. Theoretical considerations have shown that the rate of sediment transport is proportional to the fourth to sixth power of velocity. The 10% decrease in flow velocity would result in the reduction of 30 to 40% of its original transport capacity. Sudden decrease in slope of Brahmaputra results in a large amount of sediment deposition developing a prominent braided pattern near *Pasighat* in Arunachal Pradesh, where slope is abruptly decreased. The slope is further decreased during course of river in Assam plains.

Excessive riverbed aggradation due to siltation is considered one of the main short term causes of flood of the Brahmaputra. Due to 1950 earthquake (epicenter in China at about 50 km from north-east border of India, magnitude 8.6 in the Richter scale) and resulting extensive landslides, the river beds of Brahmaputra and most of the tributaries have been raised considerably by heavy deposit of silts, leaving very little scope for sufficient drainage during the peak monsoon period. The Brahmaputra silted up by about 3 m at Dibrugarh within 10 years, whereas the annual average silting rate at Dibrugarh was only 3 cm prior to 1950 (WRD, 2004). Abrupt change in water levels (yearly observed lowest water levels) of Brahmaputra at Dibrugarh after 1950 is discernible (Fig. 4). Since then, floods have been occurring regularly in Brahmaputra as a periodic and anticipated phenomenon.

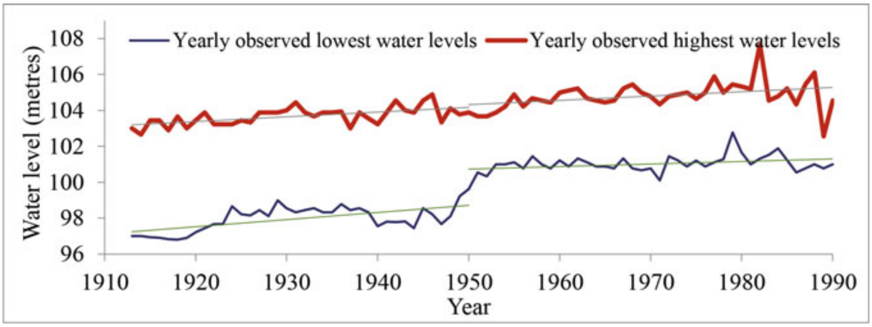

Figure 4. Water levels of Brahmaputra at Dibrugarh during 1913-1990.

Heavy rainstorms occur over Brahmaputra basin due to meteorological situations like shifting of the eastern end of seasonal monsoon trough to the foot-hills of Himalayas, 'break' monsoon and active monsoon conditions prevailing over the region. Prolonged and heavy rainfall ranging from 2,480 mm in the valley to 6,350 mm or more in hilly areas is largely concentrated during monsoon months. Synchronization of heavy rainfall over a smaller time window across a large part of watershed covering both river and tributaries is major reason of high floods in the region. Breaking of artificial lake upstream of river dams and further release of excess water from the reservoir flowing over dams are the immediate causes of a few devastating floods in recent times.

The width of Brahmaputra valley between the foot hills is very narrow, i.e., only 80-90 km where the river itself is 6-10 km. Forest covers a width of only few kilometers, mostly along foot hills, the tea gardens in some districts occupy much of the higher areas. The remaining portion of land in the narrow valley is occupied by villages for settlement, cultivation etc. Population of the state has been increasing faster and this narrow strip of land has to sustain a heavy pressure of increasing population. Large scale deforestation and loss of forest cover in north-east India are already reported due to shifting cultivation in hilly areas (FSI, 2015). Total area under shifting cultivation in the region is about 8,500 sq. km (MoSPI, 2014). Deforestation in the upstream region, soil erosion due to tilling and faulty land use practice are significant long term factors of flood problem. Severity of flood hazard in the state has been further aggravated by the acuteness of bank erosion with permanent loss of land on both banks of river Brahmaputra and its tributaries.

The Brahmaputra valley has been facing a heavy instability of landmass due to river bank erosion, believed to be accelerated after the 1950 earthquake. The stretch falling within Assam (India), has already lost about 7.4% of its total land due to bank erosion and channel migration (Baruah and Goswami, 2013). From a study using remote sensing and GIS tools, total area of erosion in Brahmaputra river was found to be 1557 km^2 during 1973-2014 (Saikia et al., 2019).

EXISTING FLOOD MANAGEMENT PRACTICES

Flood management measures started in Assam after the declaration of National Policy in 1954. Accordingly, a huge network of flood embankments along Brahmaputra and its tributaries was erected across the state. Extensive riverbank protection or anti-erosion measures were initiated only when the existing embankments became more and more vulnerable to breaches from erosion. Different protection works/ technologies taken up in different erosion affected reaches of Brahmaputra since 1970 are construction of:

- Boulder revetment with launching apron
- Deflector/bull head along with up-stream and down-stream protection work.
- Spurs/land spurs.

RCC porcupines have been used as pro-siltation devices. Sediment inducing devices perform satisfactorily in river Brahmaputra by inducing siltation in the channels. High sediment load and comparatively lower velocity of the river provides favourable conditions for the sediment inducing devices. Originally, porcupines were made of timber or bamboo, but these have a limited lifespan. It has been observed that the porcupine performs very satisfactorily as silt inducing device in rivers having the silt factor from 0.7 to 1.50 (grain size 0.158 mm to 0.725 mm). The silt factor of Brahmaputra ranges from 0.9 to 1.0, and the silt inducing performance of porcupines is excellent.

Flood control works executed by the Water Resources Department (WRD), Government of Assam upto December 2018 are as follows:

1. Total length of embankment	4486.44 km
2. Brahmaputra embankment	1031.807 km
3. Brahmaputra tributaries embankment	2697.657 km
4. Barak embankment	251.08 km
5. Barak tributaries embankment	505.896 km
6. Drainage channels	881.966 km
7. Major sluices	100 Nos
8. Minor sluices	545 Nos
9. Town protection works	983 Nos

Courtesy: Office of the Chief Engineer, WRD, Government of Assam, Chandmari, Guwahati, Assam

Implementation of the above structures have afforded reasonable benefit to about 16.173 lakh hectares of land. WRD has adopted use of geo-synthetics materials, imported Amphibian Mini Dredger and hydraulic driving method for bank protection, dredging of river bed and bamboo palisading works. WRD has started use of geo-textile technology in the form of geo-bags and geo-tubular mattress in selected areas. Advantages of geo-textiles are:

- Usage of sand filled geo-textiles in different forms, size, shape is found as perfect replacement for boulder.
- Tubular mattress filled with sand serve dual purposes of preventing bank erosion and bank sloughing due to seepage of water as the seepage water is filtered out by the sand filled mattress.
- Can be manufactured at factories according to site requirements.
- Geo-tubular mattress coupled with bio-engineering techniques provides solution for erosion control.
- Sand for filling and installing the geo-textile bags/mattresses/tubes, is abundantly available at site. Unskilled labours required for filling are also locally available.

CHALLENGES

It has been observed that flood management measures implemented so far could provide reasonable protection to the area from low and medium floods but during high floods there have been large-scale breaches. Structural measures executed so far have remained inadequate to provide satisfactory solution as in most cases these have treated the problem section of a particular portion in isolation without looking into the environmental consequences or downstream impacts. Most of the embankments in Assam were constructed during the first five year plan (1951-1956) and second five year plan (1956-61). The embankments were apparently constructed and planned on inadequate hydrological and hydro-meteorological data, sub-surface information and were designed on specifications short of what is actually required (WRD, 2005). Again, as these rivers were being confined to relatively narrow channels, the water rises quicker and higher and flows with increasing speed and force. In case of a breach, the flood water submerges the surroundings often with devastating impact. Table 5 gives number of breach/cut in embankments of Brahmaputra and its tributaries during 2009-2018.

Table 5. Number of breach/cut during 2009-2018

Year	*Number of breach/cut in entire Assam*	*Number of breach/cut in Brahmaputra basin*	*Number of breach/cut in Brahmaputra river*
2009	41	41	1
2010	60	48	3
2011	22	15	1
2012	74	73	6
2013	45	41	1
2014	28	17	2
2015	27	26	0
2016	37	23	4
2017	26	22	6
2018	32	07	0

Maximum breaches occurred in the tributaries and the causes were overtopping of flood water with a few cases of public cut. On the contrary, embankment breaches in the main Brahmaputra are due to heavy thrust of water, slumping of slope and bank erosion. Irrespective of debate on effectiveness and apparently flawed execution, damages in embankments almost every year since 1962, indicated that the embankment system with the present condition cannot provide assured protection from medium and high flood. Hence, examination, continuous maintenance and improvement of embankments at right time (i.e. not during flood time but after flood in post- or pre-monsoon months) is need of the hour to protect embankments from damage as well as to ensure secured flood protection. High cost and the situation at failure of the Geo-tubes are still putting a question mark on feasibility of geo-textile technique, as long as it is executed and demonstrated as a fool-proof technology for Brahmaputra. Fate of damaged RCC porcupines and the environmental consequences in river ecosystem are other concerns.

In 2016, Government of Assam decided to start dredging of Brahmaputra with objectives of erosion control, sediment management, flood control and water transport development (NDTV, 2016). Although, dredging is practiced in different rivers of the world for navigation, remediation and flood protection; there are evidences of negative impacts from dredging, e.g., increasing risk downstream, ecological risks affecting habitat, disrupting riverine ecosystem and reduced connectivity with the floodplain (Barbe et al., 2000; Gob et al., 2005; Freedman and Stauffer, 2013). Alluvial channels which have been artificially deepened by dredging silt-up more frequently as they tend to return to their pre-dredged state (Environment Agency, 2013). Regular repetitions of dredging is needed and hence, dredging cannot be considered as a sustainable option for large alluvial river Brahmaputra.

Brahmaputra valley is located at transitional zones between different climatic regions and different distinct geomorphologies, e.g., cold dry climate of the Tibetan plateau, warm tropical humid climate of Assam-Bangladesh plains. The valley is vulnerable to climate change impacts due to its location in the eastern Himalayan periphery, fragile geo-environmental setting and economic underdevelopment, in spite of abundant natural resources. Eastern Himalayas are experiencing warming of 0.1 to 0.4°C/decade; the highest rates of warming are in winter (ICIMOD, 2009). Simulation model indicates widespread warming of NE India by 1.8 to 2.1°C during 2030s. Rainfall of higher intensity is likely to occur during monsoon (INNCA, 2010). Thus, climate change is adding additional risk to the flood hazard in Assam. There is a great challenge before the scientists regarding the correct assessment of the causes of disastrous floods and their possible solutions adding climate change dimension as an additional layer of risk assessment and management.

WAY FORWARD

It has been realized that floods in Brahmaputra valley can only be managed, they cannot be controlled. Due to financial and geographic constraints, no structural measure can be adopted for total (or absolute) protection against all conceivable magnitudes of floods. No method can be termed as the best and any method can be adopted according to the circumstances. A combination of various measures is possibly the best way of flood management; for instance, the construction of embankments along with the reservoir or a combination of structural and nonstructural measures (Fig. 5).

Structural measures provide protection to areas hit by direct impact of flood, where public safety is the greatest concern. Increased emphasis should be given, however, on non-structural measures as well, which provide protection while reducing adverse environmental impacts to sensitive areas. Many new technologies are holding some promises, but they should be administered properly with sufficient research and development, and pre-planning.

Embankments can be strengthened to super levee as developed in Japan (Takahasi and Uitto, 2004). Super levee is a high standard river embankment with a broad width (Stalenberg and Kikumori, 2008) having mild slope of 1:30 (Arakawa-Karyu River Office and MLIT, 2006) and is resistant to overflow and seepage. The mild slope of the super levee prevents sliding of the top layer. The great width of the super levee reduces seepage (Arakawa-Karyu River Office and MLIT, 2006). Super levee concept will overcome the drawbacks of existing embankment system in Assam.

Afforestation and conservation of water bodies like ponds, wetlands can help in flood minimization. There are more than 3,500 wetlands covering an area of around 1,01,232 ha in Brahmaputra floodplains. Wetlands can soak up flood water like sponges and have potential in flood cushioning. Grass vegetation and porous concrete surface are highly encouraged in urban areas to improve infiltration along with provision for natural drainage to reduce flash floods.

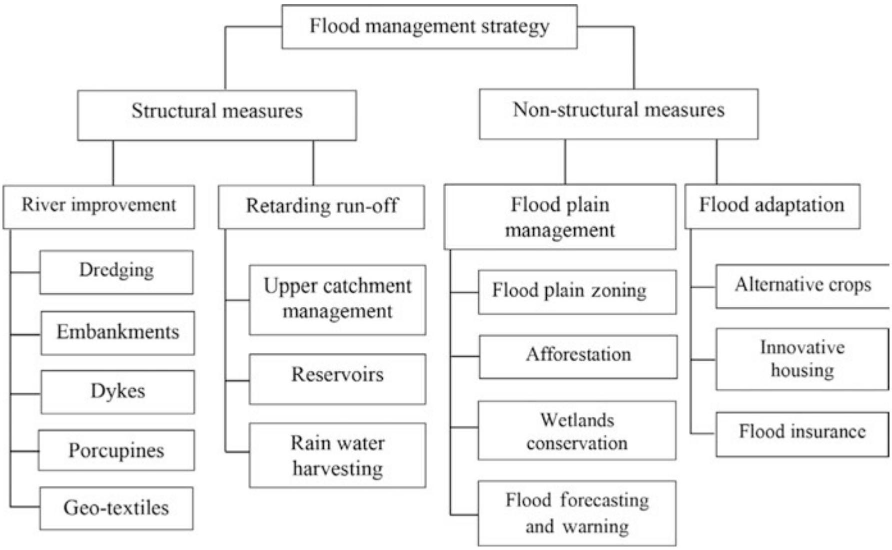

Figure 5. Flood management strategy for Brahmaputra River.

Thousands of farmers in Assam live and cultivate in vulnerable areas in the flood plains. Capacity building should be an integral component of flood management to empower people to live within the dictate of their ecological situations. Flood plain zoning aims at identification of locations and determination of damage from floods of different magnitudes/frequencies and development of those areas to reduce the damage to minimum. Flood proofing measures are essentially a combination of structural change and emergency action which can help greatly in the mitigation of distress and provide immediate relief in the flood inundated areas. Flood forecasting provides advance warning about when the river is going to rise and to what extent.

Private adaptation by individual farmers encompasses steps like switching on to crops and production methods that are best suited for the climate they live in. To compensate crop damage in flood, cultivation of some flood resistant varieties should be recommended with necessary technological intervention. Advancement of sowing season to March-April and direct seeding can ensure early crop establishment escaping floods and higher plant population. Agronomic practices like basal fertilizer application to tolerate submergence are to be developed and popularized. Transplanting two months old seedlings of suitable variety after flood water recedes in the first week of September is a promising alternative (Bhowmick et al., 2000). The rejuvenation of fertility of flood plains by the flood derived sediments can be best utilized by knowing the renewed nutrient status of different croplands and thereby opting for crops which are best suited for a particular land.

Social changes in terms of innovative dwelling house, suitable occupation and raised platforms are also need of the present. Some tribes of flood prone areas are traditionally using ‘chang ghor’ (a typical house on stilt practiced by the *Mishing* tribe) and boat. These can be encouraged with more innovative ideas to live with the floods. Flood insurance facility, drinking water and sanitation support, provision of other basic amenities including medical facilities during and after flood events need attention. More shelters in high lands of protected areas are to be constructed to reduce death of wild animals in floods.

Due to unique topography and abundant surface water resources, north-east India is endowed with a hydropower potential of 66,000 megawatts, which represents about 40% of the national potential (World Bank, 2007). Hydropower sector emerges as one of the best opportunities for development in the region provided that the projects are developed in a manner appropriate for the region’s geographical, social and environmental contexts including their potential for flood cushioning. The dams can reduce flood dimension in Assam if storage facilities with proper engineering structure to withstand in earthquakes were an integral part of the hydropower projects in Arunachal Pradesh.

It is essential to study the whole river to identify effected and erosion prone areas based on severity of river bank erosion problem and probability of occurrence. Site specific protection measures considering causes and mechanisms of erosion and impact assessment studies for protection of other vulnerable reaches can be suggested for erosion prevention.

In northeast India, climate change issue is still at a backstage with no clear responsibilities assigned to any of the departments. Policy interventions and institutional mechanism with participatory processes, capacity building, inter-state and international cooperation are essential to cope with climate change impacts on vast water resources and agriculture sector of Brahmaputra floodplains. Finally, a holistic approach for the entire region and honesty in real sense while addressing flood issue is utmost important.

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