7

Flood Hazards in India and Management Strategies

Dhrubajyoti Sen

1. INTRODUCTION

India suffers from a large variability of precipitation both spatially and temporally. It is generally known that though the average rainfall for the country is about 1160 mm, the highest anywhere in the world of a comparable size (Kumar et al., 2005), the spatial variability ranges from an average of 2800 mm for most of the north-eastern states, Andaman and Nicobar Islands and northern areas of West Bengal to about 300 mm in the western part of Rajasthan (http://www.rainwaterharvesting.org/urban/Rainfall.htm). Again, except for the States of Assam, Jammu and Kashmir and the southern peninsula, more than 75% of India's annual rainfall is received during the southwest monsoon season, i.e., June through September (Jagannathan and Bhalme, 1973). An effect of this skewed distribution of rainfall is excess water for a region received during a short interval of time, leading to flooding of the surroundings, if not drained off suitably. The region may be small as an urban space, like cities or towns, for which an intense rainfall of even half a day may cause flooding, or larger areas like the over bank and floodplain areas of a river where the state of flooding may extend for several days due to continuous rainfall of a couple of days in the upper catchment. Examples of the former include flooding events in the cities of Kolkata and Mumbai, which occasionally get flooded due to drainage congestion aggravated primarily because of insufficient slopes of drainage channels and tidal influences at the outfalls. Examples of floodplain inundation are common for the rivers of the eastern and north-eastern states of the country, though a few others from the other parts of the country are in the news sometimes. In addition, rivers flowing through the hills often suffer from flash floods due to occasional cloud bursts and the coastal regions, especially in the eastern part of the country, is prone to flooding due to cyclonic storms either by the associated intense rainfall or the impact of storm surge waves, or both. One other aspect that is being investigated lately by many researchers is the probable impact of global warming or a climate change scenario on the risk associated with flooding. There are quite a few reports, though not all agreeing to a common conclusion, wherein it is generally believed that the variability in extreme rainfall is likely to increase in the future which in turn may lead to larger incidents of flash floods (Pal and Al-Tabbaa, 2009).

It may be emphasized that flooding as such would not be a concern unless associated with consequential socio-economic losses. In India, the flooding of the rural areas within the inundated floodplains of rivers result mainly in the losses of agricultural produces with occasional loss of human lives and livestock, whereas those of the cities and towns result in the losses of infrastructure and domestic assets. Similar situation exists for other densely populated countries as well, like those in Europe namely United Kingdom, Germany, Spain, Austria, Italy, etc. and some other places around the world (Christensen and Christensen, 2003; Zbigniew et al., 2005). In fact, there are several institutions and organizations in these countries working on monitoring and providing information on floods, and assessing and managing their risks. Some of these are: Flood Hazard Research Centre (http://www.fhrc.mdx.ac.uk/), Integrated Flood Risk Analysis and Management Methodologies (http://www.floodsite.net/), Water Information System for Europe (http://ec.europa.eu/environment/water/flood_risk/), European Commission-Joint

Research Centre (http://natural-hazards.jrc.ec.europa.eu/activities_flood_riskmapping.html), etc. There has also been an increasing awareness in flood management and monitoring programs in India over the past few decades. Newer tools and policies are being implemented for reducing the risks associated with flooding in the country. A paradigm shift in flood management from the rehabilitation of a post-flood scenario to building up resilience as a pre-flood measure is gradually being introduced across the country (MHA, 2004).

This chapter reviews the hazards associated with different types of floods affecting India, in particular the broad areas of river and coastal flooding as well as the measures to mitigate consequential damages. The specific regions prone to each type of floods, the mechanisms of flood generation and the intensity of flooding for the areas are discussed. Thereafter, the long-term management measures adopted for regulating the developmental activities taking place in and around the flood-prone areas and the possible damages expected for the existing developments are discussed. The current methods of early warning system for flood and the emergency preparedness initiatives adopted for different flooding scenarios have also been described in this chapter.

2. FLOOD HAZARD IN INDIA: AN OVERVIEW

Of the different natural hazards affecting India, the threat due to floods appears to be the most recurring, widespread and disastrous (Kale, 2003, 2004). In recent times, the number of people affected by flooding in India by hydrological disasters overwhelmingly exceeds that by meteorological, climatological and geophysical disasters (Scheuren et al., 2008) as available in the OFDA/CRED International Disaster Database (www.em-dat.net), one of the comprehensive disaster databases currently available. However, it must be remembered that the consequences of flooding is experienced within a much smaller time span, requiring more emergency mitigation measures than the calamity of drought. Moreover, apart from the immediate loss of life and property due to the action of flood water (e.g., drowning and fatal injuries), the post-flood health hazard (by the contamination of drinking water and sanitation) continues to inflict a lingering loss to the affected populace long after the recession of the flood peak (Ahern and Kovats, 2006). As indicated by Ray et al. (1999), the average annual loss of human lives from meteorological disasters in India for the period 1975 to 1996 was maximum due to floods triggered by heavy rains (1441) followed by cyclonic storms (348) and those due to other reasons like cold and heat waves being much lower. The maximum economic loss in India from natural hazards, according to EM-DAT (www.em-dat.net), during the past couple of decades is also due to flooding. According to BMTPC (1998a), an analysis of damage figures since 1953 shows that on an average every year about 7.5 million hectare area is affected by floods, which involve damages of the order of Rs. 9800 million including damages to 11,68,000 houses with a loss of Rs. 1350 million and damage to public utilities costing about Rs. 3750 million. In addition, about 1500 human lives and about 97,000 cattle heads are lost each year due to floods. Table 1 presents the losses incurred in India due to the combined actions of natural hazards, including flooding, at the end of last century (MHA, 2004). Thus, it can be inferred that the hazard due to floods is an important issue for the Indian society and comprehensive and dedicated studies focusing on the causes of floods and the risks involved can enable one to seek the solution for the mitigation of consequential damages.

3. CAUSES AND TYPES OF FLOODING

Although the term ‘flooding’ is used in common parlance in India to refer to the overtopping of the banks by river water, the broad causes of flooding could be due to either river or coastal submergences. Of

Table 1. Annual damages due to heavy rains, landslides and floods in India from 1999 to 2001 (MHA, 2004)

Year	*Districts affected*	*Villages affected*	*Population affected (million)*	*Crop area affected (Mha)*	*Houses damaged*	*Loss of lives*		*Estimated value of losses (million Rupees)*	
						Humans	*Cattle*	*Private houses*	*Public properties*
1999	202	33,158	32.81	0.85	884,823	1,375	3,861	7.2	-
2000	200	29,964	41.62	3.48	2,736,355	3,048	102,121	6312.5	3897.2
2001	122	32,363	21.07	187.2	346,878	834	21,269	1955.7	6760.5

course, the coastal regions of India in the vicinity of river estuaries often get submerged due to flooding from heavy local precipitation resulting from cyclonic storms as well as over-bank spill of rivers caused by the high flows being conveyed from the upper catchment and it is often difficult to distinguish specifically between the two. An example is the inundation of the coastal region of the State of Orissa where many significant rivers discharge into the Bay of Bengal and also where the probability of the cyclonic influence is very high. Figure 1 shows an inundated area in the coastal area of Orissa (http://orissafloods.wordpress.com/). Closer to the coastline, the direct impact of the high cyclonic storm surges may additionally have an effect on the habitation and infrastructure in the vicinity. Additionally, the force of the high winds of the cyclones may cause damages or destruction.

Fig. 1 An inundated region of Orissa in eastern India under the impact of 2008 floods (*Source:* http://orissafloods.wordpress.com/).

Flooding of rivers, that is, overflowing of its banks due to sudden bursts of high discharges which exceeds the river's conveying capacity may occur due to the following reasons (Smith, 2004):

(1) Atmospheric: Flood is caused by heavy rainfall, snowmelt or ice jam,
(2) Tectonic: Flood is caused by landslides, and
(3) Technological: Flood is caused due to the incidents like failure of dams or intentional breaching of river embankments.

The first of the above causes is by far the most common cause of occurrences of flooding of rivers in India and is almost invariably due to heavy rainfall within the catchment and the inadequate capacity of rivers to contain within their banks the high flows brought down. Kale (2003), however, differentiates between the *rainfall floods* and *rainstorm floods* as two basic types of meteorological flooding phenomena. The former is stated to be most predominant of the causes of river flooding that result from heavy or intense precipitation in association with active to vigorous monsoon conditions for a number of days. The *rainstorm floods* are defined as those generated by excessively heavy rainfall associated with lows, depressions and cyclonic storms originating over the Bay of Bengal or the adjoining coastal belt. Again, the temporal characteristics of the flood event may lead it to be classified as: *flash floods, single-peak floods, multiple-peak floods* and *synchronized floods* (Dhar and Nandargi, 1998). *Flash floods* are characterized by very fast rise and recession of flow of relatively small volume but very fast flowing discharge, which causes high damages because of its suddenness. Usually, this sort of river flooding is noticed in the hilly and not too hilly regions and sloping lands where heavy rainfall and thunderstorms are common. *Single-peak floods* are characterized by a rising and falling limb of the discharge hydrograph in contrast to the *multiple-peak floods* which have multiple rises and falls. *Synchronization of floods* in more than one tributary of a main river may cause severe impact on the downstream flows by their combined impact. Though meteorological factors are the primary driving force behind river flooding in India, other reasons like riverbed aggradation due to siltation and back-water flooding caused by higher downstream water levels, often due to high sea levels for the estuarine rivers are equally responsible for the increase in the extent of devastation. Construction of flood embankments or levees, as has been practiced for major Indian rivers over the second half of the last century, has also induced rise of riverbeds thus increasing the risk of flooding for rivers carrying large amount of silt from its upper catchments.

The incidence of rivers flooding due to snowmelt and ice jam is rather unheard of in India, except perhaps for some regions of extreme north, in the Himalayas. There have been however, albeit rare, occurrences of flooding caused by landslide as the Alaknanda tragedy (Bhandari, 2003) when a dam was created in the river by the landslide and caused devastation in the valley downstream when it ultimately breached. Other instances of the formation of such natural dams and devastations caused by their failures have been listed by Kale (2003). As for the flooding of rivers by the failure of man-made dams, the extent of damage depends upon the degree of dam collapse, the head of water behind the dam at the time of the disaster and the distance of the point of damage assessment from the location of the dam. There have been quite a few incidences of dam failures in India and brief overviews are presented by Thandaveswara and Mahesh Kumar (1993) and Kale (2003), among others.

On the other hand, coastal flooding may be generated by the effects of the following two prime reasons (Smith, 2004):

(1) Atmospheric: Floods occur due to surges in ocean produced by cyclonic storms, and
(2) Tectonic: Floods occur due to tsunami wave produced by high intensity underwater earthquakes.

Though the losses due to the tsunami wave flooding of the coastal tracts of South India by an undersea earthquake-triggered landslide in the Indian Ocean in December 2004 was enormous (Sheth et al., 2006), such events are extremely rare for the Indian coastline. In fact, flooding of Indian coasts by storm surges is relatively more frequent (Murty and Flather, 1994). This type of flooding is caused by the tropical cyclone, usually originating somewhere in the Bay of Bengal and heading north-westwards, pushing the surface of water on its track. As the eye of the cyclone nears the coast, there is generally a pile-up of water against the coast aided by the shallow ocean bottom nearer coast, which ultimately breaks upon the coastal shoreline at the time of the cyclone's landfall. The resulting wave running up the beach is similar to that caused by the tsunami wave and the extent of run-up depends upon the energy of the wave, represented by the wave height and speed. According to NDMA (2008b), the degree of disaster potential depends on the storm surge amplitude associated with the cyclone at the time of landfall, characteristics of the coast, phases of the tides and vulnerability of the area and community. The world's highest recorded storm tide has been about 12.5 m (about 41 ft) associated with the Backergunj cyclone in 1876 near the Meghna estuary in present-day Bangladesh. A storm tide of closer magnitude (12.1 m) has been estimated to have been observed in West Bengal at the mouth of the River Hooghly in association with a severe cyclone in October 1737. In recent times, the super cyclone of October 1999 generated an estimated wind speed of 252 km/h with an ensuing surge of 7 to 9 m close to Paradip in Orissa (eastern India) which caused unprecedented inland inundation up to 35 km from the coast. It is worth mentioning that, at times, persistent standing water was identified in the satellite images even 11 days after the cyclone landfall, as it happened in the Krishna delta (in the State of Andhra Pradesh, southern India) in May 1990 and in several other instances. The cyclone of 1977 which hit the same delta area, particularly at Divi Seema, also generated winds exceeding 250 km per hour.

It is worth mentioning that since cyclones rotate counter-clock wise in the northern hemisphere of the earth, on approaching the coast the right forward sector of the cyclone experiences wind from ocean to land (*on-shore wind*) which pushes the seawater towards the coast and finally appears as storm surge. The direction of the wind on the left forward sector of the cyclone is from land to ocean (*off-shore wind*) which pushes the water from the coast towards the ocean producing even negative surge.

4. AREAS PRONE TO FLOODING

Maps of flood-prone areas in India have been brought out by various expert committees, like the Building Materials & Technology Promotion Council (BMTPC), Ministry of Housing & Urban Poverty Alleviation, Government of India and the National Disaster Management Authority (NDMA), under the Chairmanship of the Prime Minister of India, and made available via their respective websites, viz., BMTPC: http://www.bmtpc.org/ and NDMA: http://ndma.gov.in/. Figures 2 and 3, adapted from these references, indicate the flood-prone regions of India due to river flooding as well as coastal flooding, respectively.

In comparison to the flooding due to tectonic actions or technological disasters, which are rather unpredictable, those due to meteorological factors follow a definite pattern both spatially and temporally. The geographical extent of the country which suffers from riverine flood hazards may be broadly divided into the following four regions (Mohapatra and Singh, 2003; NDMA, 2008a): (i) Brahmaputra River Region, (ii) Ganga River Region, (iii) North-West Rivers Region, and (iv) Central India and Deccan Region, which are briefly described in the subsequent sections.

4.1 Brahmaputra River Region

Consisting of the rivers Brahmaputra and Barak and their tributaries, this region covers the States of Arunachal Pradesh, Meghalaya, Mizoram, Manipur, Tripura, Nagaland, Sikkim and the northern parts of West Bengal. The catchments of these rivers receive very heavy rainfall ranging from 1100 mm to 6350

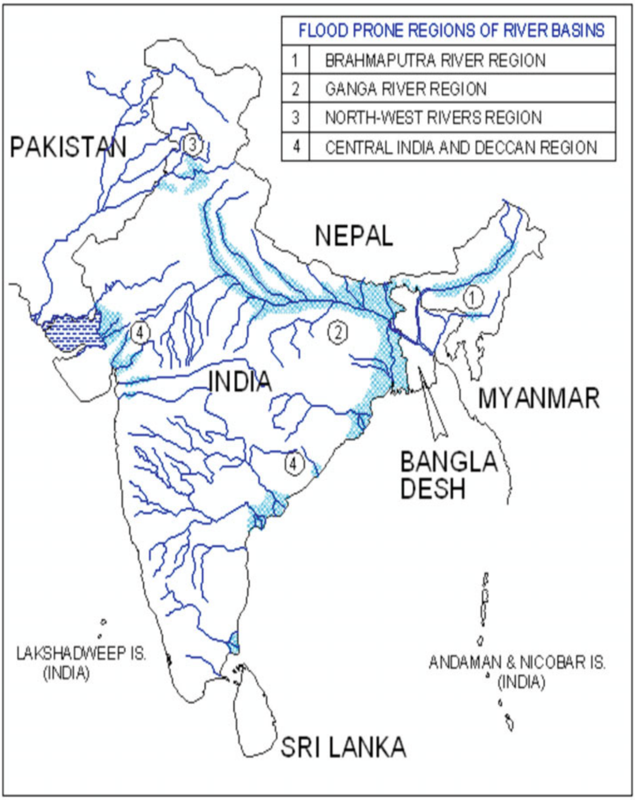

Fig. 2 Areas prone to river flooding in India (adapted from NDMA, 2008a).

mm a year which occurs mostly during the months of May-June to September. As a result, floods in this region are severe and quite frequent. Further, the hills where the rivers originate are fragile and susceptible to erosion and thereby contribute exceptionally high silt discharge to the river flow. The predominant problems in this region are cloud bursts followed by flash floods, soil erosion in the watershed and bank erosion along the rivers, the flooding caused by spilling of rivers over their banks, drainage congestion, and the tendency of some rivers to change their courses. The plain areas of the region suffer from the inundation caused by the spilling of the rivers Brahmaputra and Barak (in the Kachhar region of Assam).

4.2 Ganga River Region

The river Ganga has many tributaries, the important ones being Yamuna, Sone, Ghagra, Rapti, Gandak, Bagmati, Kamla Balan, Adhwara group of rivers, Kosi and the Mahananda. This region covers the States of Uttarakhand, Uttar Pradesh, Jharkhand, Bihar, south and central parts of West Bengal, Punjab and

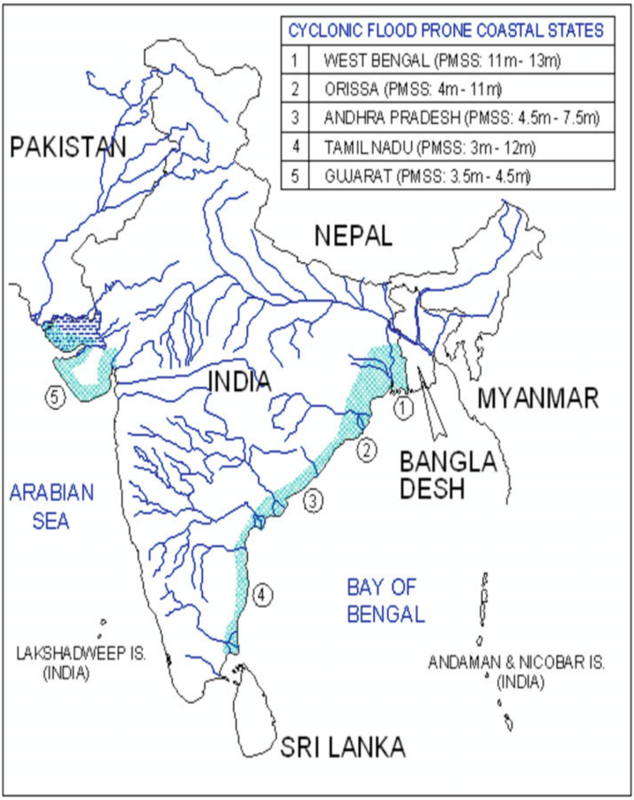

Fig. 3 Coastal areas of India prone to severe flooding due to cyclones. The table inside the figure indicates the States with maximum hazard and corresponding Probable Maximum Storm Surge (PMSS) heights (adapted from NDMA, 2008b).

parts of Haryana, Himachal Pradesh, Rajasthan, Madhya Pradesh and Delhi. The normal annual rainfall in this region varies from about 600 mm to 1900 mm of which more than 80% occurs during the southwest monsoon. The rainfall increases from west to east and from south to north. Most of the damage is caused by the northern tributaries of the Ganga, which spill over banks and frequently change courses. Even though the peak flood of river Ganga may be high, in the order of 57,000 to 85,000 m^3/s, the inundation and erosion problems are confined to relatively few places. In general, the flood problem increases from the west to the east and from south to north. In the north-western parts of the region, the problem of drainage congestion prevails in some places. The drainage problem also exists in the southern parts of West Bengal, where the outflowing discharges from smaller tributaries of the river Hooghly (which itself is a distributary of river Ganga) are sometimes prevented from flowing out by the tidal influences on the Hooghly river.

4.3 North-West Rivers Region

The important rivers in this region, Sutlej, Beas, Ravi, Chenab and Jhelum, are the tributaries of the river Indus and carry quite substantial discharges during the monsoon season and also large volumes of sediment. In the plains, these rivers change their courses frequently and leave behind vast tracts of sandy waste. This region covers the States of Jammu and Kashmir, Punjab and parts of Himachal Pradesh, Haryana and Rajasthan. Compared to the Ganga and the Brahmaputra river regions, the flood problem is relatively less in this region. The major problem is that of inadequate surface drainage which causes inundation and waterlogging over vast areas.

4.4 Central India and Deccan Region

Rivers of importance in this region are the Narmada, Tapi, Mahanadi, Godavari, Krishna and Cauvery, which mostly have well defined and stable courses. In general, these rivers have adequate capacities within the natural banks to carry the flood discharge except in the delta area. The lower reaches of the important rivers on the east coast have been embanked, thus largely eliminating the flood problem. This region covers the States of Andhra Pradesh, Karnataka, Tamil Nadu, Kerala, Orissa, Maharashtra, Gujarat and parts of Madhya Pradesh. The region does not have serious flood problem except for some of the rivers in the State of Orissa namely Mahanadi, Brahmini, Baitarni, and Subarnarekha and in the stretches closer to the sea. The problem of flooding and drainage congestion gets accentuated when the floods synchronize with high tide. Rivers Tapi and Narmada occasionally affect the areas in lower reaches in Gujarat during periods of high floods.

In addition to the above regions of mainland India, the flooding and drainage characteristics of the islands of the Andaman and Nicobar archipelago and Lakshadweep suffer from drainage congestion due to very flat slopes.

The long coastal shoreline of the country, measuring about 5700 km on the mainland (about 7500 km including the islands), is prone to flooding by cyclonic storm surges. According to NDMA (2008b), though the frequency of tropical cyclones in the North Indian Ocean covering the Bay of Bengal and the Arabian Sea is the least in the world (about 7% of the global total), their impact on the east coast of India and the adjoining Bangladesh coast is relatively more devastating. This is evident from the fact that in the last 270 years, 21 of the 23 major cyclones (with a loss of about 10,000 lives or more) worldwide occurred over the area surrounding the Indian subcontinent (India and Bangladesh). This is primarily due to the serious storm-tide effect in the area.

It may be observed that the above mentioned flood-prone regions may be classified under one of the following geographical environments (Smith, 2004):

(1) Low-lying areas of major floodplains
(2) Low-lying coasts and deltas
(3) Small basins and valleys affected by flash floods
(4) Areas below unsafe or inadequate dams
(5) Low-lying inland shorelines
(6) Alluvial fans

However, the vulnerability to river flooding has increased over the years due to anthropological reasons like increase in population resulting in the occupancy of areas previously uninhabited. Plate (2002) reports that earlier human settlements that grew up near rivers were, in general, located at safer places determined by the years of accumulated societal wisdom. Houses near rivers prone to regular flooding were either provided with high plinth or, as in some parts of Assam and Bengal, on raised bamboo platform on stilts (bamboo columns) so as to remain above the dominant flood water levels. This harmonious attitude of "living with floods" has been greatly reduced in the last century with the rapid increase in population of cities through migration from rural areas and construction of flood embankments along rivers, providing a false security for the bank-side environment and encouraging new floodplain development. Smith (2004) calls this the "Levee Effect" and is a global phenomenon.

The phenomenon of riverbank erosion, though not a case of widespread land inundation by water, is often associated with river flooding because of its almost simultaneous occurrence during high floods of rivers (Mohapatra and Singh, 2003). This aspect of river floods also causes enormous losses by damaging the land and property of inhabited areas.

4.5 Urban Flooding

Another aspect highlighted by Mohapatra and Singh (2003) is the rising flooding events of urban spaces in the country, which may once again be attributed to the encroachment of the flood plain areas, presence of several structures of permanent nature within the rightful way of the river floodway and absence of proper regulations for maintenance of the drainage arteries.

4.6 Coastal Flooding

The extensive coastal belt of India is very vulnerable to the deadly storms known as *tropical cyclones*. About 4 to 6 such storms originate in the Bay of Bengal and the Arabian Sea every year. Tropical cyclones, which are characterized by torrential rain, gales and storm surges cause heavy loss of human lives and destruction of property. The States that are most prone to coastal flooding are: West Bengal, Orissa, Andhra Pradesh, Tamil Nadu and Gujarat.

As for the assessment of vulnerability of coastal tracts, an analysis combining storm risk and poverty suggests that the State of Orissa in eastern India is the most vulnerable due to its low coping capacity determined by the per capita income of about Rs. 6,767 and high likelihood cyclonic storms (NDMA, 2008b). Tamil Nadu and Andhra Pradesh in south India as well as West Bengal in eastern India are also vulnerable because they are situated in the high cyclone hazard zones and also have low per capita incomes. Maharashtra and Goa are the two States which are also affected by cyclones, but they are less vulnerable as the cyclones are less frequent and people living there have better coping capacity because of higher incomes (per capita income is more than Rs. 18,365).

5. MANAGEMENT MEASURES FOR RIVER FLOODS

The globally accepted flood management measures for river floods include the following broad strategies (Smith, 2004; NDMA 2008a), which are explained in detail in the subsequent sections:

(1) Prevention or protection from floods by abatement, control or proofing of floods;
(2) Adaptation to existing flood situations like preparedness, forecasting and warning and proper land-use planning; and
(3) Mitigation of flood related losses by disaster aids or insurance coverage.

According to some experts (e.g., Mohapatra and Singh, 2003) the above-mentioned flood management strategies may also be classified as: (a) *structural* (involving structural constructions), and (b) *non-structural*. The former refers to the structural constructions that are installed across the river or in its vicinity with an aim to, primarily, reduce the peak of the flood discharge. On the other hand, the non-structural measures include the strategies adopted other than any structural constructions for reducing flood damage such as forecasting of flood and dissemination of flood warnings, floodplain zoning and regulation of land use within the floodplains, implementation of flood proofing measures, modifying upstream land management practices, etc. The following sections elaborate the above-mentioned flood management strategies in the Indian context.

5.1 Prevention from Floods

The prevention of large-scale flooding may be reduced by truncating the flood peak through construction of large reservoir dams or utilization of low-lying depressions and tanks for accommodating part of the flood discharge. The Hirakud Dam on River Mahanadi in Orissa or the series of dams on the Damodar River system (Maithon, Panchet, Tilayia and Tenughat) in Jharkhand (eastern India) had been primarily constructed for this purpose. In fact, most of the high dams in India are multi-purpose and serve the cause of flood abatement quite efficiently. However, as the capacity of these reservoirs gets reduced with time by siltation and the "live storage" of the reservoir is affected, the utility of these dams in carrying out flood moderation starts reducing.

Other means of surviving from the impact of flooding is by protecting a segment of river floodplains by the construction of flood embankment or levees. According to NDMA (2008a), divergent views have however emerged on the utility of embankments as a means for flood protection. While some NGOs have voiced serious criticisms of existing embankments and advocated their removal, others favor construction of additional lengths of embankments as the only practical medium-/short-term solution for the flood problem. Positive benefits provided by embankments include, apart from flood protection, roads that provide useful communication link in the area. They also provide shelter to the villagers during floods, though as a result they often get damaged by the actions of the villagers themselves. On the negative side, breaches in embankments have often resulted in large-scale flooding in the protected areas. Poor drainage in the protected area also leads to drainage congestion. The worst impact of the embankments is the deposition of silt and rise in riverbed levels, thereby decreasing the carrying capacity of the river and aggravating drainage congestion. This situation exists for many Indian rivers, for example, River Ganga near Patna and Teesta near Jalpaiguri. Also, the prevalent designs of flood protection embankments presently adopted by the different states of India appear to be rather weak to withstand erosion (e.g., Ghosh, 1997). For example, the flood embankments of the Ajoy River in West Bengal, whose bed level has also risen over the past decades due to embanking, regularly breach during floods with consequent high river water levels. As such, the alignments of the embankments are generally arbitrarily decided and often very close to the rivers, disregarding the need to consider an appropriate floodway corresponding to a certain return period of flood discharge as determined by the accepted societal risk.

A recent example of embankment breaching is the devastating failure of the eastern flood embankment of the Kosi River at about 12 km upstream of the Kosi Barrage in Nepal on 18 August 2008, which resulted in widespread inundation of many districts of Bihar, eastern India. After the 18 August breach of the Kosi embankment, the Kosi River has taken a new course almost similar to that of the 1930s and hence, the 18 August 2008 flood caused huge damages to the agricultural land, houses and other properties as well as loss of several lives, besides rendering a large number of people homeless and devoid of resources to sustain their livelihoods. Figure 4, adapted from the images available on the website of the Disaster Management Department, Government of Bihar (http://disastermgmt.bih.nic.in/), shows the extent of flooding due to the breach and the new course of River Kosi. The extent of damage caused by this incident may be gauged from the statistics presented in Table 2 (http://disastermgmt.bih.nic.in/).

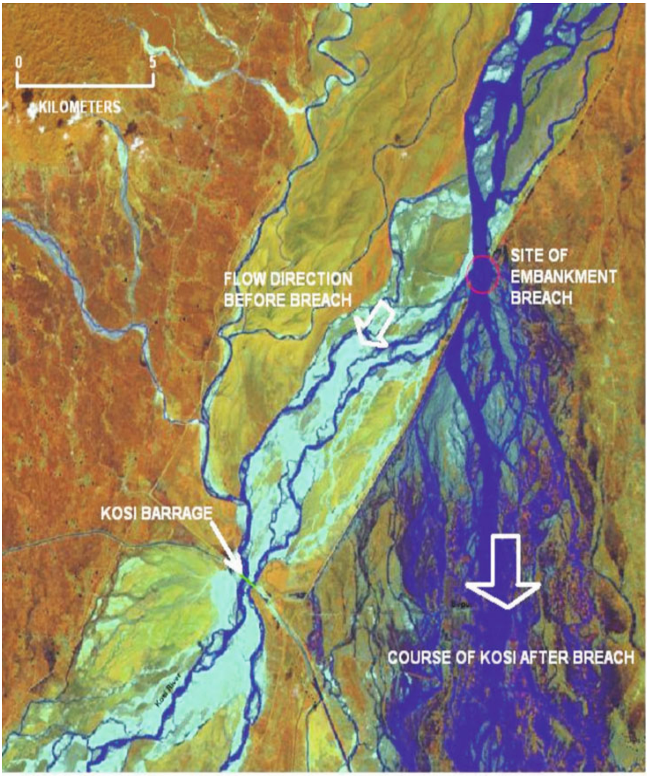

Fig. 4 New course of Kosi River charted out after breach of the left embankment upstream of Kosi Barrage on 18 August, 2008 (http://disastermgmt.bih.nic.in/).

Table 2. Status of 18 August 2008 Kosi flood impact (as on 24 February 2009)

Impact	*Districts affected*					*Total*
	Supaul	*Madhepura*	*Araria*	*Saharsa*	*Purnea*	
Blocks affected	5	11	4	6	9	35
Panchayats affected	65	140	71	59	77	412
Villages affected	178	370	141	169	140	993
Population affected	670709	1419856	626062	448796	164000	3329423
Livestock affected	417704	303640	80000	161000	35000	997344
Area affected (ha)	75000	157000	45000	44000	47000	368000
Human deaths	211	272	2	41	1	527
Livestock deaths	8585	10725	0	13	0	19323

Desilting and dredging of rivers to increase conveyance capacity remains the only viable option when the other (structural) methods for protection against floods are found unsuitable. The difficulty in this case lies in the excavation of the huge quantity of material and its disposal. In fact, this method is rather expensive, but it has been attempted for some rivers as the River Ichhamati in West Bengal-Bangladesh border.

Flood proofing is a means of either designing or retrofitting buildings and their contents to make them more resistant to flood losses (Smith, 2004). The methods normally applied are: (a) Raising of habitable parts of property above flood level; (b) Making uninhabited parts of property resistant to flood damage and allowing water to enter these parts; (c) Sealing the property to prevent flood water from entering; and (d) Relocating properties. According to Mohapatra and Singh (2003), however, the flood proofing measures taken in the past in India consisted of raising of a few flood-prone villages above a pre-determined flood level and connecting them to nearby roads or high lands. Under this program, several villages in West Bengal, Uttar Pradesh and Assam were raised. This method was subsequently discontinued, as it was observed that it could not protect the nearby agricultural areas.

Moreover, for the prevention of riverbank erosion during high floods, the properly designed riverbank protection techniques using synthetic geo-textile, geo-jute fabric or the low-cost alternative of "*darma-mat*" was adopted with equally enduring and sustainable effect. In fact, the latter has been successfully tested in the lower reaches of the River Ganga at Farakka (Sen, 2008). The "*darma-mat*", made of inter-woven bamboo splicings, has to be manually fabricated and is thus labor intensive and employment generative.

Rising river waters normally do not make a forced impact on buildings and structures. However, the inundation may remain for days at some places and if the structures are not strong enough to resist this inundation, for example, the rural mud houses, then the walls may collapse leading to the losses of life and property. Hence, for the flood-prone areas, BMTPC (1998b) recommends certain modifications in material and building construction technology that may help to increase the life of the structures. Apart from such structural modifications of the existing housing technology, recommendations have been provided like raising plinth level above the recurrent flood inundation level of the region. However, a scientific evaluation of the plausible inundation levels for floods of different intensities has to be decided by floodplain zoning studies, as discussed in the following sections.

5.2 Adaptation to Flooding

For societies in human habitations accepting the hazards of flooding, the need to be prepared in the eventuality of any flooding becomes a part of standard adaptive practice. This requires preparedness for food, shelter, rescue and medical aid, and needs to be activated on the basis of an efficient flood forecasting and warning system. The preparedness processes and warning schemes are generally looked after by the local civic administration, though some NGOs also come forward to help according to their capabilities. The key step, however, lies in accurately predicting the arrival time of the flood (i.e., rise, peak and fall) and the expected water level rise. It is on this basis that the social administration offices need to deploy its strength in reducing possible losses in the event of flood hazard. However, since the methods for predicting floods are highly technical, the prediction of flood is mostly entrusted to specialized technical organizations like Central Water Commission or the Water Management organizations of the states (for example, the Department of Irrigation of the Government of Andhra Pradesh, the Department of Irrigation and Waterways of the Government of West Bengal, the Irrigation and Flood Control Department of the Government of Delhi, etc.).

The Central Water Commission under the Ministry of Water Resources, Government of India (http://cwc.nic.in/), has a specialized River Management Wing that is responsible for the collection, compilation, storage and retrieval of hydrological and hydro-meteorological data, formulation and issue of early warnings on flood forecast on all major flood-prone rivers and inflow forecasts for selected important reservoirs. The Central Water Commission is currently maintaining 175 flood-forecasting stations (NDMA, 2008a) of which 147 stations are for river stage forecast and the rest for inflow forecast. These forecast stations, located on various river basins, communicate advises to the respective State Administrations on the expected level of floods. The prevalent technique of issuing flood forecast by the Central Water Commission is the gauge-to-gauge and rainfall-runoff correlation techniques. The gauge to gauge correlation is based upon many years of recorded stage (i.e., water level) data of a river at a number of locations on the upstream of the forecasting station. The forecast is issued based upon this correlation and the current water level at an upstream station is transmitted to the forecasting station through a network of wireless radio system (CWC, 1989). At present, there are over 500 VHF/HF wireless stations of the Central Water Commission spread throughout the country that transmit the rainfall and gauge data on a real-time basis. However, steps are being taken to improve the lead time for forecast by attempting to predict using real-time data of rainfall recorded through automatic rainfall recorders with the data relayed down using satellite communication and internet. This kind of setup has been installed recently in the catchments of Mahanadi and Damodar Rivers, among others. Further improvement in the lead time is possible, if atmospheric models are developed and adapted for the respective regions which can then serve to forecast the amount of rainfall ahead of the actual rainfall data collected by the automatic recorders.

Though a society may be well adapted to the threats of flood hazards, it is prudent to understand and appreciate the risks of development in the flood-prone areas vis-à-vis their proximity to the river itself. This brings about the issue of land use planning for the region taking into account the zoning of floodplains classified according to a given risk. Though this demarcation of river adjacent areas is essential for future development and planning as well as for flood preparedness, the response of the State Governments towards the enactment of floodplain zoning bill has not been encouraging (Mohapatra and Singh, 2003). Though some of the states (e.g., Manipur and Rajasthan) have enacted the floodplain zoning legislation, major flood affected states such as Assam, Goa, Himachal Pradesh, West Bengal and Sikkim have not considered such legislation.

According to NDMA (2008a), one of the main requirements for the implementation of floodplain zoning measure is the availability of high accuracy survey maps. The Central Water Commission had initiated in 1978 a program for surveying areas prone to floods under the central sector through the Survey of India as a pilot scheme. However, of the 106,000 km^2 of area identified in the country as prone to frequent floods, about half (around 55,000 km^2) had been surveyed in the states of Bihar, Assam, Uttar Pradesh, West Bengal, Punjab, Haryana and Jammu and Kashmir. These maps, on the scale of 1:15,000 with a contour interval of 0.3 m or 0.5 m, have been made available to the respective states but no progress has been made so far by any of the states to produce floodplain zoning maps.

It may be noted that though high precision survey maps are required to generate floodplain zoning maps, the validation if these maps may be possible only with accurate mapping of actual flood inundation extent areas for certain given flood events. Also, the manual survey of inundation extents may be extremely difficult and time consuming, if not inaccurate, and satellite pictures using remote sensing technology can provide great help (Bhanumurthy, 1999). Though remotely sensed flood image usually connotes recording of the extent of flooding using satellite imagery, more precise information may be collected using the airborne Synthetic Aperture Radar (SAR) surveys as carried out by the National Remote Sensing Centre, Hyderabad. These surveys, carried out using special airplanes flying at low altitudes, help in gathering finer details which may not be possible to be captured using satellite-borne sensors. In fact, the manual survey of floodplains, as mentioned earlier, may also be substantially improved by employing the airborne Laser Terrain Mapping (LIDAR) survey, which is carried out by the National Remote Sensing Centre.

5.3 Mitigation of Flood Disaster Losses

In the event of the failure of preventing or managing floods from inflicting losses, the society has to rely upon the rescue measures for the minimization of losses. Though the response to such disasters in India have been the duty of the respective State administration, rescue operations during devastating floods, like the recent breaching of the flood embankments of the Kosi River (eastern India), have been carried out with the help of the military and para-military forces. Alleviation of flood losses would be effective if the response system is fast and efficient. This requires proper institutionalization of the system as well as the formulation of a sound evacuation plan. Apart from the official setup, the NDMA (2008a) also stresses the needs of having community-level local search and rescue teams because having such groups would help to act faster, at least as a first aid, than the official team which might have a delayed response time.

Another way of minimizing the losses from flood inundation is by having compensation from flood insurances. However, according to Mohapatra and Singh (2003), though flood risk has been included in the list of items covered by the general insurance companies in India, it has so far been popular in the urban areas only, as seen from the vehicle loss claims after the floods of Mumbai in 2005 and of Surat (Gujarat) in 2006. The insurance companies have also not been able to arrive at different rates of insurance premiums for different areas.

6. MANAGEMENT MEASURES FOR COASTAL FLOODS

Management practices for coastal flooding are similar to those for river floods as mentioned in the previous sections and may be grouped in similar order as discussed below.

6.1 Protection from Floods

For the protection of flood-prone areas of the coastal tracts from the impact of waves and inundation by flooding resulting from tropical cyclonic activities, the recommended measures can be classified as either *structural* or *non-structural*. The principal structural recommendations are those for cyclone shelters and local buildings since the loss of life due to cyclones has been observed to be largely due to the lack of an adequate number of safe shelters which can withstand the fury of cyclones, including wind and storm surge (BMTPC, 1998c). The provisions in the guidelines consider the strength of a building to be adequate in resisting the impact of storm surge waves and also remain stable against high cyclonic winds.

Compared to normal buildings constructed away from the shore, additional requirements for the design of these structures have been recommended. For example, wind, a primary force in destabilizing a building by producing negative lift pressures, is recommended to be taken as 1.3 times the value adopted for a normal structure. The design of the building is also recommended for being able to withstand seismic forces in the regions vulnerable to earthquake hazard. The minimum reinforced concrete grade is recommended to be M30. Though the material specifications are considered important, the planning and design of cyclone shelters have been advised to include special provisions like being located preferably at least 1.5 km away from the coast. The plinth height on stilts is suggested to be of 1.5 m with the height varying from 2.5 m to 4.5 m if the storm surge level is in the range of 1.5 m to 4.5 m. In all the cases, the floor level of a shelter is recommended to be at least 0.5 m above the possible maximum surge level. Additionally, the foundation depths of the shelters are required to be extended to depths equal to that of the surge level to avoid scouring, with a minimum value of 1.5 m.

It has been noticed that during inundation of coastal areas by cyclonic flooding, the communication between neighboring human habitations get snapped. This is because many of the coastal villages do not have all-weather approach roads. Hence, properly designed roads with appropriate base and raised at an elevation higher than the expected inundation level are required for connecting the villages. The road crossing of coastal drainage system should also to be provided with suitably designed bridges or culverts as found appropriate.

Among the non-structural measures, the protection provided by the coastal environment has been highly commended by the experts to play a major role in reducing the impact of storm surge waves. After the tsunami disaster of 26 December 2004 along the Indian coast, it was observed that shorelines endowed with mangroves, forests, sand dunes or coastal cliffs provided the best natural barriers against the tsunami waves. In contrast, heavy damage was reported in the areas where sand dunes had been heavily mined (for example, at Nagapattinam and Kolachal in the State of Tamil Nadu) and where the coastal vegetation was less. Thus, the stretches of mangrove vegetation act as natural bio-shield against the fury of cyclones, coastal storms, tidal waves and tsunamis. The present management principles in mitigating the impact of cyclones, therefore, encourage the regeneration of mangrove vegetation or at least prevent degradation of the already existing stock. Among the coastal states of the country, the State of West Bengal has been found to contain the largest and densest mangrove cover (about 48% of the country's total), especially in and around the Sunderban delta region (MoEF, 2005). Though the other coastal states of the country are not equally gifted with this bio-wealth for cyclone protection, steps for the conservation of mangrove forests have been undertaken to various degrees.

Those coastal belts not suitable for mangrove growth (mangroves normally thrive in sheltered shores enriched with abundant silt brought down by the estuarine rivers) have been encouraging the growth of other non-mangrove bio-shields popularly known as *shelterbelts*. Raising coastal shelterbelts to mitigate the adverse impact of cyclonic winds has been identified as one of the short-term objectives of the National Afforestation Program through Community Participation scheme of the National Afforestation and Eco-Development Board. Based on the Coastal Regulation Zone Notification of 1991 of the Ministry of Environment and Forests, which recognizes the mangrove areas as ecologically sensitive and categorizes them as CRZ-I areas implying the highest order of protection for such areas and from the best land use practices, steps are being taken by the various states of the country to plan for conservation and restoration of mangroves and raise tree shelterbelts extensively in all potential coastal zones.

Coastal shorelines may also be affected by the impact of cyclonic storms and consequential surge waves. Several solutions exist and those similar to the suggestions for riverbank erosion protection have been employed with a varying degree of success. A major difference between the riverbank erosion and coastal shoreline erosion is that the former is subject to toe undercutting by river currents, whereas the latter is predominantly forced with a direct impact of the ocean waves.

6.2 Adaptation to Flooding

Strategies quite similar to those provided for coping with river flooding is adopted for coastal flooding as well. It is natural that habitations may not be completely protected from the vagaries of cyclonic winds and resulting storm surges. In fact, the structural recommendations discussed in the previous section can only be effective in resisting the impact of cyclones up to a given degree. Nature, however, may induce forces that may exceed the design values which are decided on accepted risks and economic constraints. Hence, it is normally thought prudent to be prepared in case of disastrous eventualities. Such preparedness is somewhat similar to those adopted for river flooding. However, the forecasting strategies of an impending coastal disaster differ considerably from river related disasters, as described below.

Tropical cyclonic storms brew up in the Bay of Bengal and the northern part of Indian Ocean, which ultimately approach the east coast of the country. Similarly, those originating in the Arabian Sea move towards the west coast. As tropical cyclones originate over the ocean from a given combination of meteorological factors the origin of which is generally difficult to predict, a constant watch is kept on the Arabian Sea and the Bay of Bengal by the India Meteorological Department (IMD) for its likely genesis with the help of satellite imagery, particularly those from the Indian geostationary satellite, INSAT. The data from ships and ocean buoys are also analyzed.

As a particular cyclonic system develops and gathers strength and moves towards the coast, it becomes necessary to both track it as well as forecast its probable course and the likely place on the coast where it is going to strike, often called the landfall point. The tracking of the path of a cyclone is mostly done from satellite imagery. However, these images are not continuous and are snapshots taken from the satellites (non-geostationary) when they pass above the specific region encompassing the main body of the storm. At present, the prediction of cyclone tracks is done by the IMD using a quasi-Lagrangian dynamic model along with other synoptic, climatological and empirical techniques. The forecast advisories received from different international agencies such as the Joint Typhoon Warning Centre, USA; United Kingdom Meteorological Office; European Centre for Medium Range Weather Forecasting; and the National Centre for Medium-Range Weather Forecasting, Government of India are also considered while finalizing the forecast.

As a cyclonic system closes on to the Indian coastline, its subsequent development and movement is monitored by a chain of Cyclone Detection Radars set up by IMD to cover the entire coastal belt. The latest S-band Doppler weather radars or the somewhat older storm detention X-band radars are used to provide the necessary data. This information is used to prepare and disseminate warning messages from the Area Cyclone Warning Centres at Kolkata, Chennai and Mumbai and Cyclone Warning Centres at Vishakhapatnam, Bhubaneshwar and Ahmedabad.

These early warnings are issued in four stages, viz., (i) Pre-cyclone watch indicating the potential development of a cyclonic system; (ii) Cyclone alert, issued 48 hours prior to the expected time of commencement of adverse weather over a specific coastal area; (iii) Cyclone warning provided 24 hours in advance of a cyclone's landfall; and (iv) Post landfall outlook, issued 12 hours before the landfall indicating the effect the system is likely to cause once it strikes the land. Though the final warnings predicting, normally, the storm intensity and velocity is important, the probable height of storm surge as the cyclone makes a landfall is equally significant in predicting the extent of coastal area that is likely to get submerged. For the prediction of storm surge, IMD uses both nomograms developed from past records and a dynamical storm surge model developed by the Indian Institute of Technology, Delhi. Very recently, IMD has also implemented the dynamical storm surge model of National Institute of Ocean Technology, Chennai for the east coast of India on an experimental mode.

Although the real-time availability of cyclone warnings is helpful for bracing up against an impending disaster, a long-term planning like coastal belt flood inundation zoning, similar to the river floodplain zoning, is helpful for the developments taking place in the coastal region and the likely risks associated thereof. Satellite images showing past inundation extents corresponding to various levels of storm surges combined with high resolution terrain elevation data are being used to demarcate the probable inundation extent areas. The procedure involves mathematical techniques quite similar to those used for demarcating probable flood inundation zones for rivers, except that the possible impact of a dynamic surge wave has to be additionally taken into account.

6.3 Mitigation of Flood Disaster Losses

This is the emergency response part which is activated once a cyclonic disaster has struck. Since the most affected parts of the country by cyclones are the states of Tamil Nadu, Andhra Pradesh, Orissa and West Bengal and the Union Teritorry of Puducherry (previously Pondicherry) on the east coast and the State of Gujarat, the emergency preparedness plans for coastal disasters are generally stronger in these states than in others. Of these, Andhra Pradesh having faced quite a few disastrous cyclones in the recent past has set up a separate Disaster Management Unit to implement the World Bank-funded Andhra Pradesh Hazard Mitigation and Emergency Cyclone Recovery Project, and is currently functioning as the Andhra Pradesh State Disaster Mitigation Society. In Orissa too, the Orissa State Disaster Mitigation Authority, as a Government owned autonomous body, was constituted after the October 1999 super cyclone in order to have a systematic and planned approach for disaster management in the state. This organization coordinates various activities of disaster mitigation in the state, including the capacity building of the community and disaster managers, strengthening of infrastructure, improvement in communication system, etc.

7. DISASTER PREPAREDNESS AND MITIGATION

The Ministry of Home Affairs, Government of India, in its publication on the status of disaster management in the country (MHA, 2004), have very elaborately discussed the strategies adopted by the Central and State Governments of the country in the context of preparedness against a probable disaster and its mitigation. The guidelines prepared by the National Disaster Management Authority for the steps that need to be taken by various states of the country for safeguarding against the hazards of floods due to heavy rainfall in rivers and intense cyclonic precipitation and storm surges are also in place (NDMA, 2008a, b). Although many of the states are yet to formulate a comprehensive disaster management plan, including that of floods, some actions have already been taken in this regard. The following sections discuss some of these measures in the context of disaster preparedness and mitigation of flood hazards in India.

7.1 National Policy on Disaster Management

Disaster management is a multidisciplinary activity involving a number of departments and agencies spanning across all the sectors of development. Where a number of departments and/or agencies are involved, it is essential to have a policy in place, as it serves as a framework for action by all the relevant departments and agencies. According to MHA (2004), a National Policy on Disaster Management has been drafted, and is in the process of finalization. In line with the changed focus, the policy proposes to integrate disaster mitigation into development planning. The National Disaster Management Guidelines for preparing State Disaster Management Plans (NDMA, 2007) has outlined the steps to be followed by the states while preparing the plans. This is in accordance with the Disaster Management (DM) Act 2005 passed by the Government of India on 23 December 2005. The highlights of this Act include a shift from a response and relief-centric approach to a proactive and comprehensive mindset towards disaster management covering all aspects from prevention, mitigation and preparedness to rehabilitation, reconstruction and recovery. It also provides for the following:

- The creation of a policy, legal and institutional framework backed by effective statutory and financial support.
- The mainstreaming of multi-sectoral disaster management concerns into the developmental process and mitigation measures through projects.
- A continuous and integrated process of planning, organizing, coordinating and implementing policies and plans in a holistic, community-based, participatory and sustainable manner.

The DM Act mandates the National Disaster Management Authority (NDMA) to lay down policies and guidelines for the statutory authorities to draw their plans. In essence, the NDMA will concentrate on the prevention, mitigation, preparedness, rehabilitation and reconstruction and will also formulate appropriate policies and guidelines for effective and synergized national disaster response and relief. It will coordinate the enforcement and implementation of policies and plans.

7.2 Mitigation and Preparedness Plans/Measures

In order to respond effectively to floods, the Ministry of Home Affairs (MHA) has initiated National Disaster Risk Management Program in all the flood-prone states. Assistance is being provided to the states to draw up disaster management plans at the State, District, Block/Taluka and Village levels. Awareness generation campaigns are being organized to sensitize the stakeholders on the need for flood preparedness and mitigation measures. Elected representatives and officials are being trained in flood disaster management under this program. Bihar, Orissa, West Bengal, Assam and Uttar Pradesh are among the 17 multi-hazard-prone States where this program is being implemented with assistance from international organizations, viz., United Nations Development Program, United States Agency for International Development and European Commission (MHA, 2004). It is also reported that the Central Government is now in the process of training and equipping eight battalions of Central Para-Military Force (CPMF) as specialist response teams. Each team consists of 45 personnel including doctors, paramedics, structural engineers, etc. and thus there will be 144 Specialist Search and Rescue Teams in the earmarked eight battalions. The process of training and equipping of the 144 specialist search and rescue teams has been initiated and so far 18 teams have been trained. These teams are being trained in collapsed structure search and rescue, medical first response, rescue and evacuation in flood and cyclone situations, underwater rescue, etc. In effect, they will have the capability to operate in all types of terrain in all contingencies/disasters. It is proposed to group together the eight battalions of CPMFs earmarked for specialized emergency response as "*National Emergency Response Force*". These specialist response teams are being provided modern equipments and also dog squads for search and rescue. They will be provided with special uniforms made of fire retardant materials with enhanced visibility in low light and having equipment carrying capacity.

The use of Information Technology (IT) in disaster management is reflected by the fact that there are plans to set up a Geographical Information System (GIS) database for emergency responders to access information in terms of crucial parameters for the disaster affected areas. The crucial parameters include location of the public facilities, communication links and transportation network at national, state and district levels. The GIS database already available with different agencies of the Government is being upgraded and the gaps are proposed to be bridged. The database will provide multi-layered maps on a district-wise basis. These maps taken in conjunction with the satellite images available for a particular area will enable the district administration as well as State Governments to carry out hazard zonation and vulnerability assessment and coordinate response after a disaster.

8. CONCLUSIONS

According to the estimates of the National Commission on Floods (RBA, 1980), the area prone to floods in India is around 40 million hectares, which is about one-eighth of the country's geographical area. Though the area affected by floods each year is of the order of about 7.4 million hectares (Kale, 2004), most of this falls in the States of Uttar Pradesh, Bihar, Punjab, Himachal Pradesh, Assam, West Bengal, Haryana, Orissa, Andhra Pradesh and Gujarat, in decreasing order of distribution. With rising population and enhanced migration to the cities, there has been a recent spate of urban flooding for many of the Indian cities and towns. Hence, coping with flood disasters is an important priority for the administration of the Central or State Governments and a lot of investment is made each year in this context. Also, a number of initiatives have been taken to institutionalize the actions of flood prevention and loss minimization, flood occurrence prediction, warning dissemination and emergency response. However, given the economic constraints, not all the measures, as would have been ideally desirable, have so far been implemented. For example, a lot remains to be done in terms of implementing satellite data for on-line river flood monitoring or its accurate prediction using numerical simulation models. Further, though the real-time data collection and transmission of hydro-meteorological data using satellite communication has been initiated by the Central Water Commission for a few river basins, the program has faced some operational difficulties and is yet to be made completely functional. Ideally, such monitoring and surveillance of rainfall and occurrence of floods should be provided for every major river basin that can be coupled with real-time flood propagation and inundation spread prediction models. Furthermore for the coastal flooding hazard, establishment of a denser network of S-band radars for better capturing of approaching cyclones and application of numerical models to predict flood inundation due to storm surges and heavy rainfall in the coastal regions need to be implemented. Also, over the past couple of years, there has been a new approach to the disaster management paradigm, as emphasized by MHA (2004), which proceeds from the conviction that development cannot be sustainable unless disaster mitigation is built into the development process. Another corner-stone of the approach is that mitigation has to be multi-disciplinary spanning across all the sectors of development. The new policy also emanates from the belief that the investments in mitigation are much more cost effective than expenditure on relief and rehabilitation. It is hoped that with the initiatives taken by the Building Materials & Technology Promotion Council, the National Disaster Management Authority, and the National Institute of Disaster Management, the security against flood hazards in India can be increased in near future.

REFERENCES

Ahern, M. and Kovats, S. (2006). The Health Impacts of Floods. *In:* R. Few and F. Matthies (editors), Flood Hazards and Health: Responding to Present and Future Risks. Earthscan Publications Ltd., London, U.K., pp. 28-53.

Bhandari, R.K. (2003). Two great landslides of India. *In:* H.K. Gupta (editor), Disaster Management. Orient Longman, New Delhi, pp. 110-127.

Bhanumurthy, V. (1999). Remote sensing for flood management. In: K.M.B. Rahim (editor), Natural Disasters: Some Issues and Concerns. Natural Disasters Management Cell, Visva Bharati, Santiniketan, West Bengal, India, pp. 104-115.

BMTPC (1998a). Major Natural Disasters in India. *In:* Report of Expert Group on Natural Disaster Prevention, Preparedness and Mitigation having bearing on Housing and Related Infrastructure; Part I: Techno-Legal Aspects of Earthquake, Windstorm and Flood Hazards and Land Use Zoning, Building Material and Technology Promotion Council (BMTPC), Ministry of Urban Affairs and Employment, Government of India, New Delhi.

BMTPC (1998b). Improving Flood Resistance of Housing – Guidelines. *In:* Report of Expert Group on Natural Disaster Prevention, Preparedness and Mitigation having bearing on Housing and Related Infrastructure; Part III: Guidelines for Improving Hazard Resistant Construction of Buildings and Land Use Zoning (for Earthquake, Windstorm and Flood Hazards). Building Material and Technology Promotion Council (BMTPC), Ministry of Urban Affairs and Employment, Government of India, New Delhi.

BMTPC (1998c). Improving Wind/Cyclone Resistance of Housing – Guidelines. *In:* Report of Expert Group on Natural Disaster Prevention, Preparedness and Mitigation having bearing on Housing and Related Infrastructure; Part III: Guidelines for Improving Hazard Resistant Construction of Buildings and Land Use Zoning (for Earthquake, Windstorm and Flood Hazards). Building Material and Technology Promotion Council (BMTPC), Ministry of Urban Affairs and Employment, Government of India, New Delhi.

Christensen, J.H. and Christensen, O.B. (2003). Severe summertime flooding in Europe. *Nature,* **421:** 805-806.

CWC (1989). Manual on Flood Forecasting. River Management Wing, Central Water Commission (CWC), Ministry of Water Resources, Government of India, New Delhi.

Das, P.K. (1981). Storm surges in the Bay of Bengal. Proceedings of the Indian Academy of Science (Engineering Science Section), September 1981, Vol. 4, Part 3, pp. 269-276.

Dhar, O.N. and Nandargi, S.S. (1998). Floods in Indian rivers and their meteorological aspects. *In:* V.S. Kale (editor), Flood Studies in India. Memoir 41, Geological Society of India, Bangalore, India, pp. 53-76.

Ghosh, S.N. (1997). Flood Control and Drainage Engineering. Second Edition. Oxford and IBH Publishing, New Delhi.

Jagannathan, P. and Bhalme, H.N. (1973). Changes in the pattern of distribution of southwest monsoon rainfall over India associated with sunspots. *Monthly Weather Review*, **101(9):** 691-700.

Kale, V.S. (2003). The spatio-temporal aspects of monsoon floods in India: Implications for flood hazard management. *In:* H.K. Gupta (editor), Disaster Management. Orient Longman, New Delhi, pp. 22-47.

Kale, V.S. (2004). Floods in India: Their frequency and pattern. *In:* K.S. Valdiya (editor), Coping with Natural Hazards: Indian Context. Orient Longman, New Delhi, pp. 91-103.

MHA (2004). Disaster Management in India — A Status Report. Ministry of Home Affairs, National Disaster Management Division, Government of India, New Delhi.

MoEF (2005). State of Forest Report. Forest Survey of India, Ministry of Environment & Forests, Government of India, Dehradun, Uttarakhand.

Mohapatra, P.K. and Singh, R.D. (2003). Flood management in India. *Natural Hazards*, **28:** 131-143.

Murty, T.S. and Flather, R.A. (1994). Impact of Storm Surges in the Bay of Bengal. *In:* C.W. Finkl Jr. (editor), Coastal Hazards: Perception, Susceptibility and Mitigation. *Journal of Coastal Research*, Special Issue No. **12**, pp. 149-161.

NDMA (2007). National Disaster Management Guidelines: Preparation of State Disaster Management Plans. National Disaster Management Authority, Ministry of Home Affairs, Government of India.

NDMA (2008a). National Disaster Management Guidelines: Management of Floods. National Disaster Management Authority, Ministry of Home Affairs, Government of India, New Delhi.

NDMA (2008b). National Disaster Management Guidelines: Management of Cyclones, National Disaster Management Authority, Ministry of Home Affairs, Government of India, New Delhi.

Pal, I. and Al-Tabbaa, A. (2009). Trends in seasonal precipitation extremes: An indicator of climate change in Kerala, India. *Journal of Hydrology*, **367:** 62-69.

Plate, E.J. (2002). Flood risk and flood management. *Journal of Hydrology*, **267:** 2-11.

Ray, K.C., Mukhopadhyay, R.K. and De, U.S. (1999). Meteorological Disasters during Last Twenty Two Years. *In:* K.M.B. Rahim (editor), Natural Disasters: Some Issues and Concerns. Natural Disasters Management Cell, Visva Bharati, Santiniketan, West Bengal, pp. 10-23.

RBA (1980). Report of the Rashtriya Barh Ayog (National Commission on Floods). Volume 1, Ministry of Energy and Irrigation, Government of India, New Delhi.

Scheuren, J-M., le Polain de Waroux, O., Below, R., Guha-Sapir, D. and Ponserre, S. (2008). Annual Disaster Statistical Review: The Numbers and Trends 2007. Center for Research on the Epidemiology of Disasters, Université Catholique de Louvain, Brussels, Belgium.

Sen, P. (2008). Riverbank erosion and protection in Gangetic Delta. *In:* K.M.B. Rahim, M. Mukhopadhyay and D. Sarkar (editors), Riverbank Erosion. Natural Disasters Management Cell, Visva Bharati, Santiniketan, West Bengal, India, pp. 1-31.

Sheth, A., Sanyal, S., Jaiswal, A. and Prathibha Gandhi, P. (2006). Effects of the December 2004 Indian Ocean Tsunami on the Indian Mainland. Earthquake Spectra, Earthquake Engineering Research Institute, Oakland, California, U.S.A., Volume 22, No. S3, pp. S435-S473.

Smith, K. (2004). Environmental Hazards: Assessing Risk and Reducing Disaster. Fourth Edition, Routledge, USA.

Thandaveswara, B.S. and Mahesh Kumar, D.V. (1993). Dam break analysis using MacCormack Scheme for Kali River. Proceedings of the International Conference on Dam Engineering, Jahore Behru, Malaysia, pp. 12-13.

Zbigniew, W.K., Ulbrich, U., Brucher, T., Graczyk, D., Kruger, A., Leckebusch, G.C., Menzel, L., Pinskwar, I., Radziejewski, M. and Szwedl, M. (2005). Summer Floods in Central Europe – Climate Change Track? *Natural Hazards*, **36:** 165-189.