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Flood events, fatalities and damages in India from 1978 to 2006

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Abstract High temporal and spatial variability of rainfall qualifies India to be highly vulnerable to floods. Recurring floods of various magnitudes play havoc with the lives and property of the people, leading to unplanned development and unchecked environmental degradation, thwarting and retarding the overall development of the country. Therefore, the purpose of the present study is to analyze the types and trends in terms of flood events, frequency, number of people killed, injured, missing and economic damage both in space and time on the basis of a nationwide database published by India Meteorological Department, Pune, from 1978 to 2006. Analysis of these long-term data has revealed that 2,443 flood events claimed about 44,991 lives with the average of 1,551 lives each year. In terms of population size, these figures translate into a loss of 1.5 human lives per million of the population. A majority (56 %) of flood fatalities were caused during severe flood events. However, the frequency of these events was just 19 % in comparison with heavy rainfall events (65 %). In spatial context, flood-related fatalities are distributed all over the country with highest fatalities in Uttar Pradesh (17 %), Maharashtra (13 %), and Bihar and Gujarat (10 % each). Most fatalities occurred during the summer season monsoon months of August (30 %) followed by July (29 %) and September (20 %). The country suffered a cumulative flood-related economic loss of about 16 billion US$ between 1978 and 2006 and a maximum economic loss of 1.6 billion US$ in the year 2000 alone. The study further suggests that both flood events and fatalities have increased in India over a period of time.

Keywords Flood · Event · Fatality · Damage · India

1 Introduction

Floods are probably the most common, frequent, hazardous and widespread natural event on the surface of the earth, causing serious loss of life and economic damage

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(Wang et al. 2011; Sharma et al. 2011; Sharifi et al. 2012). Since the dawn of human civilization, floods have always been a major cause of concern because settlements located in river valleys and plains have been jeopardized (Kundzewicz 2002). The data maintained by the Centre for Research on the Epidemiology of Disasters (CRED) demonstrated an occurrence of about 2,156 floods in the last three decades of the twentieth century, resulting in 206,303 deaths, affected more than 2.6 billion lives and caused an economic loss of nearly US $ 386 billion (Guha-Spair et al. 2004). More than one-third of the world's land area in 90 countries is exposed to catastrophic flooding representing about 82 % of the world's population (UNDP 2004; Dilley et al. 2005; Adhikari et al. 2010). Flooding, on an average, claims more than 23,000 lives per year over the globe and adversely affects 140 million people each year (WDR 2003, 2004). In addition, the frequency and magnitude of disastrous floods has increased on account of the global warming and impacts of economic development over the past 25 or 30 years (Knox 2000; Milly et al. 2002; Emanuel 2005; Jonkman and Kelman 2005; Macklin and Rumsby 2007; Zhang et al. 2008; Dankers and Feyen 2008; Allamano et al. 2009; Tschakert et al. 2010; Pall et al. 2011; Syvitski and Brakenridge 2013). Heavy rains, monsoonal rains and tropical cyclones are the most common causes of floods, which together account for 91 % of all the floods and 99 % of all displaced people (Few 2003; Tschakert et al. 2010). Destructive floods are very common in lower latitude regions, particularly in Asia (Kundzewicz et al. 2009; Sharma 2012).

Furthermore, floods are one of the most common hazards in India and about 40 million hectares of land, roughly one-eighth of the country's geographical area, are prone to floods (Gupta et al. 2003; Mohapatra and Singh 2003; Roy et al. 2008). Flood-prone area in India has increased substantially with time at the rate of 0.014 million hectare per year. The annual average area affected by floods for the period 1953–2007 is 7.51 million hectare with variability ranging from 0.5 million hectare in 2006 to 17.5 million hectare in 1978 (Kumar 2013; Singh and Kumar 2013). The area susceptible to floods has been shown in Fig. 1. The chronic flood-prone basins are Ganga and Brahmaputra covering northern and north-eastern parts of the country. Also, the severity and intensity of flood disasters in various parts of the country have increased especially during the past few years due to climate change (Das et al. 2009; Singh and Singh 2011). Floods mostly occur due to the extreme spatial and temporal variations in the rainfall pattern over the short monsoon period of 3–4 months, resulting in a very heavy discharge from rivers during this period (Kumar et al. 2005) In addition, inadequate capacity within river banks to contain high flows, silting of riverbeds, change in river course, poor natural drainage in the flood-prone area, dam break, and glacial outbursts are other factors leading to the occurrence of floods. Flood causes more damages in terms of loss of life, property and economic activity than any other natural disasters in the country (FEMA 2000; NDMA 2008). Floods also leave in their wake epidemiological threats, breakdown of social order, migration (temporary and permanent) and a constant obstacle to the local development programs. Roughly, 30 million people in the country are affected by floods and more than 1,500 lives are lost each year, which accounts for about one-fifth of the global death count due to floods (Gupta et al. 2003). Despite such a huge number of flood fatalities annually, no single study has presented a comprehensive spatial and temporal analysis of flood fatalities and injuries for the country over a long period of time. However, the loss of life associated with flooding has been studied both from a nationwide and global perspective (Berz et al. 2001; Mitchell and Thomas 2001; Thomas and Mitchell 2001; Jonkman 2005; Jonkman and Kelman 2005; Bryant 2005; Ashley and

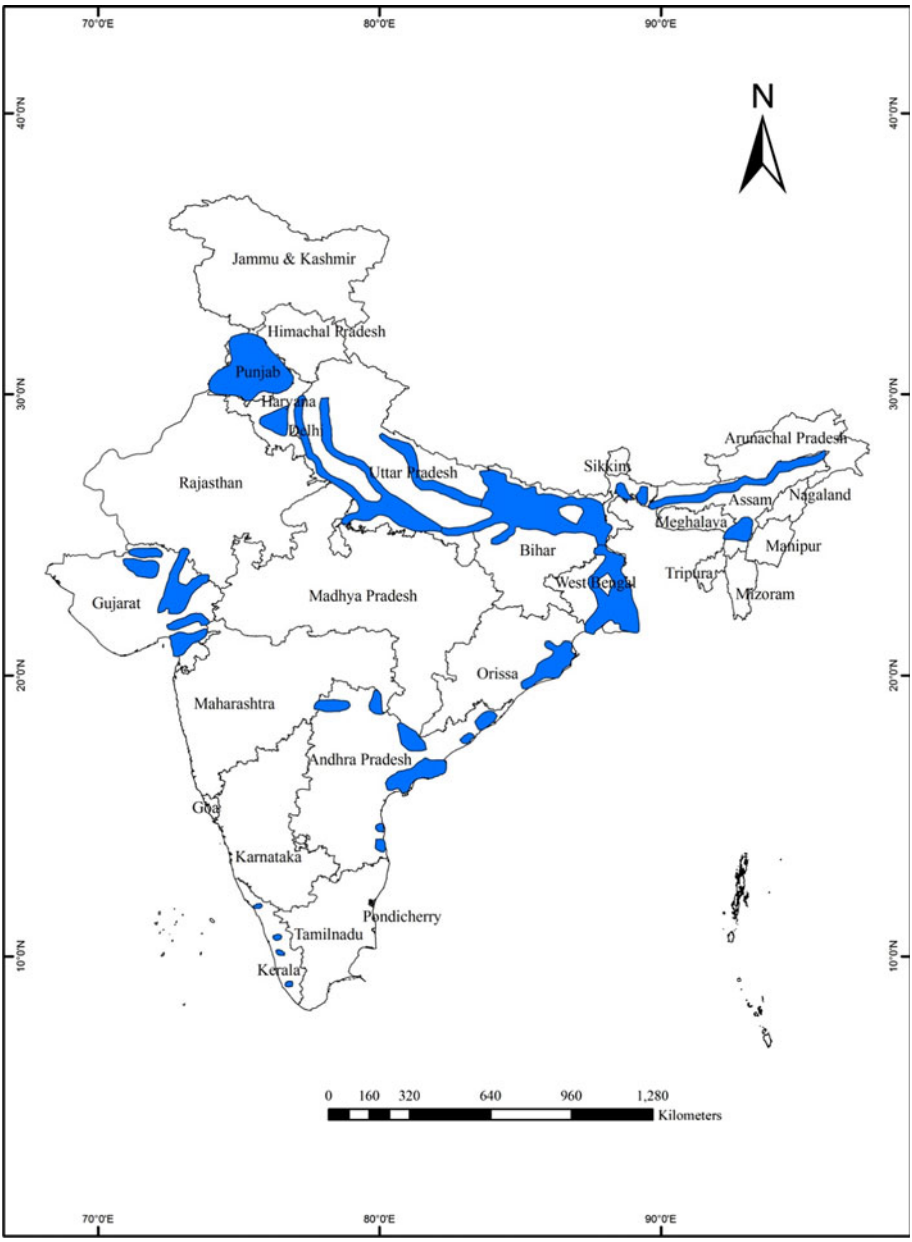

Fig. 1 Flood-prone area in India (Mohapatra and Singh 2003)

Ashley 2008; Di Baldassarre et al. 2010; Diakakis et al. 2012). The present study, therefore, to fill the research gap has been aimed to examine both flood events and fatalities resulting from various flood types occurring in India over a specific period of time between 1978 and 2006.

2 Data and methodology

The present study is pursued and accomplished by compiling the data pertaining to the flood events and fatalities from published reports on Disastrous Weather Events of India Meteorological Department (IMD), Pune, covering the period from 1978 to 2006. Moreover, minimum prerequisite for a flood event to be included in the database was the availability of the detailed account of the destruction of buildings, agricultural crops, casualties and seriously injured persons. In recent years, studies that use qualitative information to reconstruct natural disaster history are being conducted more frequently, especially in those cases where scientific data and descriptions are not available (Diakakis et al. 2012). The database in these reports provides an account of each fatal flood event that occurred in the country along with its location, duration, type of flood, intensity, severity, casualties, injuries, population affected and the magnitude of economic loss. The causes and circumstances of flood disaster deaths have not been spelt out in this database. However, the publication on 'flood/heavy rain' is unique and is the data set of its only kind available in India and thus has been used for this type of analysis. The accuracy of the data in terms of location, timing and casualties could be considered satisfactory. The flood fatality data pertaining to this study include all those deaths that are attributable directly to the flood event such as death. However, cyclone-triggered floods and associated casualties have been excluded from the scope of the present study.

For quantitative analysis, simple numerical calculations such as frequencies, percentages and sums were applied on the above compiled database. Subsequently, derived calculations were summarized in the form of simple tables, graphs and maps using Geographical Information System (GIS). Following this procedure, several conclusions in relation to spatial and temporal distribution of flood events and casualties were drawn. Further, the compiled information was analyzed for:

- The spatial distribution of flood events and the associated fatalities during the period 1978–2006
- The temporal distribution of events and fatalities caused by floods in the same period
- The seasonality of flooding in India as a whole and possible difference in seasonality among different regions
- The possible presence of any trend or pattern in the occurrence of flood events in time and space that can be useful to further understand flooding and protect lives and properties.

Furthermore, the state fatalities (standardized by population) were mapped separately on the basis of event type such as heavy rainfall, moderate flood, severe flood, flash flood and cloudburst. These five flood event types have been duly recorded in the IMD publication on 'Disastrous Weather Events' from 1978 to 2006. From these maps, the geography of flood-related fatalities can be delineated, and any region whether suffering from high or low number of fatalities can be pinpointed while interpreting the locational flood distribution character of different physiographic and climatic zones. However, certain limitations in data analyses and interpretations were encountered due to inadequacy of data. Flood events and fatality analyses for several new states such as Uttarakhand, Jharkhand and Chattisgarh could not be undertaken as these states were carved out in Indian Union after 1999. Therefore, analyses and interpretations on flood events and human fatalities in space and time (decadal) in the present context could not be reproduced in its entirety, giving rise to certain questions in the minds of the readers.

3 Results and discussion

3.1 Flood events and fatalities

Statistical processing of the flood data concerning India revealed 44,991 fatalities resulting from 2,443 flood events in total during the period 1978–2006, whereas 9,085 of them (20 %) occurred in just 10 events. The most destructive event in terms of human fatalities was undoubtedly the 1979 incident in Gujarat that caused at least 1,485 fatalities. A dam failure in Rajkot district of Gujarat triggered flash flood inundating the entire Saurashtra region, which resulted into the total destruction of about 8,000 houses. Interestingly, the human fatalities in the wake of top 10 deadliest floods in India are well in agreement with top 10 deadliest flood fatalities in Australia and United States (Coates 1999; Ashley and Ashley 2008). On an average, approximately 1,551 human fatalities occurred annually in India during the study period. Conversely, the annual average number of human fatalities in the United States is reported to be 100 for a period of 28 years and 98 for a period of 47 years (Jonkman 2005; Ashley and Ashley 2008). This discrepancy in reported results is due to the records of different periods having been examined. Ranking of Indian states in terms of human fatalities reveals that Uttar Pradesh has the highest number of fatalities followed by Maharashtra and Bihar (Table 1). Despite low ranking in flood occurrences, Gujarat's ranking in terms of human fatalities is not far behind, being at the fourth rank. High ranking of human fatalities in the state can primarily be attributed to disastrous flash flood events. About 75 and 55 % of areas of Punjab and Haryana states, respectively, are flood prone; however, these states rank 17th and 18th, respectively, in terms of human fatalities. Less number of human fatalities, in spite of there being more flood-prone area that sounds anomalous on the face of it, could have been possible thanks to a large number of flood management programs undertaken by these states. When ranking of human fatalities per flood event type was performed, it was observed that severe floods (55 per event) and flash floods (mostly from dam failures, 21 per event) had ostensibly much higher ranking than those of other flood types.

3.2 Flood events and fatalities yearwise

Both flood events and human fatalities progressively increased in India during the period 1978–2006 (Fig. 2). These results are in agreement with various other studies carried out in India (Shrestha 2008; Sreekesh 2009), and the main causes for this deteriorating situation are growing deforestation and overgrazing which subsequently is denuding of the earth from the green cover. This trend is not peculiar to India alone; rather, this kind of trend is a global phenomenon. (Hoyois and Guha 2003; Jonkman 2005; Shrestha 2008). This increase in flood disasters has been attributed to improved information communication technology (ICT), leading to increase in reporting activities (Shrestha 2008). It could also be attributed to the increased socioeconomic vulnerability and development processes leading to increased number of disasters. The adverse effects of rapidly rising population, economic growth, rapid urbanization, environmental degradation and climate change also accelerate the trend of the vicious natural disaster erupting in the form of floods (Shrestha 2008).

The number of flood fatalities per year in the country is seen to be highly variable, from a low of 562 in 1985 to a high of 2,561 in 1998 (Fig. 2). Of the six astoundingly high human fatalities due to floods in India, three in the years 1998, 2005 and 2000 were characterized by heavy rainfall events. Heavy rainfall events during these years killed

Table 1 Number of flood fatalities, injuries, missing persons, casualties and flood events with their ranks for India during the period 1978–2006

States	Flood events		Fatalities		Injuries		Missing		Casualties	
	No.	Rank	No.	Rank	No.	Rank	No.	Rank	No.	Rank
Andhra Pradesh	70	16	2,622	6	4	26	30	11	2,656	7
Arunachal Pradesh	51	18	195	19	33	20	2,042	1	2,270	9
Assam	175	5	2,055	8	208	5	0	16	2,263	10
Bihar	89	10	4,238	3	56	17	10	15	4,304	5
Gujarat	85	11	4,172	4	118	8	16	14	4,306	4
Haryana	55	17	380	17	37	19	0	16	417	18
Himachal Pradesh	147	7	1,475	11	138	7	100	6	1,713	13
Jammu and Kashmir	76	13	1,365	13	99	12	0	16	1,464	15
Karnataka	211	2	1,437	12	327	3	326	5	2,090	11
Kerala	203	4	1,166	15	488	2	46	10	1,700	14
Madhya Pradesh	118	8	1,213	14	144	6	26	12	1,383	16
Maharashtra	290	1	5,667	2	2,092	1	353	4	8,112	1
Orissa	80	12	2,220	7	14	23	83	7	2,317	8
Punjab	74	15	768	16	89	13	0	16	857	17
Rajasthan	111	9	1,979	9	71	15	1,231	2	3,281	6
Tamil Nadu	75	14	1,762	10	116	9	75	8	1,953	12
Tripura	32	19	193	20	100	10	20	13	313	20
Uttar Pradesh	149	6	7,448	1	109	14	53	9	7,610	2
West Bengal	207	3	3,915	5	291	4	502	3	4,708	3
Chandigarh	23	21	23	24	15	22	0	16	38	24
Goa	14	25	13	26	11	24	0	16	24	25
Manipur	12	26	19	25	5	25	0	16	24	25
Meghalaya	22	22	82	23	100	11	0	16	182	22
Mizoram	17	24	174	21	16	21	0	16	190	21
Nagaland	6	27	1	28	0	27	0	16	1	27
Sikkim	19	23	315	18	69	16	0	16	384	19
Delhi	30	20	91	22	52	18	0	16	143	23
Pondicherry	2	28	3	27	0	27	0	16	3	26

3,087 persons, of which 1,828 persons happened to be killed in 2005 alone. Dwelling upon it further, the worst human fatality event during 2005 occurred in Maharashtra, with 1,187 deaths due to heavy rainfall events. The other 3 years with heavy human fatality reports were 1979, 1980 and 1983. During 1979, four events of flash floods killed 1,534 persons, the largest being a dam failure in Gujarat (1,485 persons). However, during 1980 and 1983, severe floods devoured a large number of human lives. There were as many as 1,313 deaths due to severe floods in Uttar Pradesh alone during 1980. The frequency of flood events was exceptionally high in the country during 2005 and 1995 when 138 and 134 incidents were recorded. The spatial spread of these events was extensive and floods engulfed about 22 states and union territories of India. The major cause of the floods during 1995 and 2005 was incessant heavy rains, and the worst hit states were Kerala, Karnataka and West Bengal. Interestingly, 75 % of flood events in the country occurred after 1990, whereas the flood events were found to be lowest during 1987, 1979 and 1980 when only 39 and 51

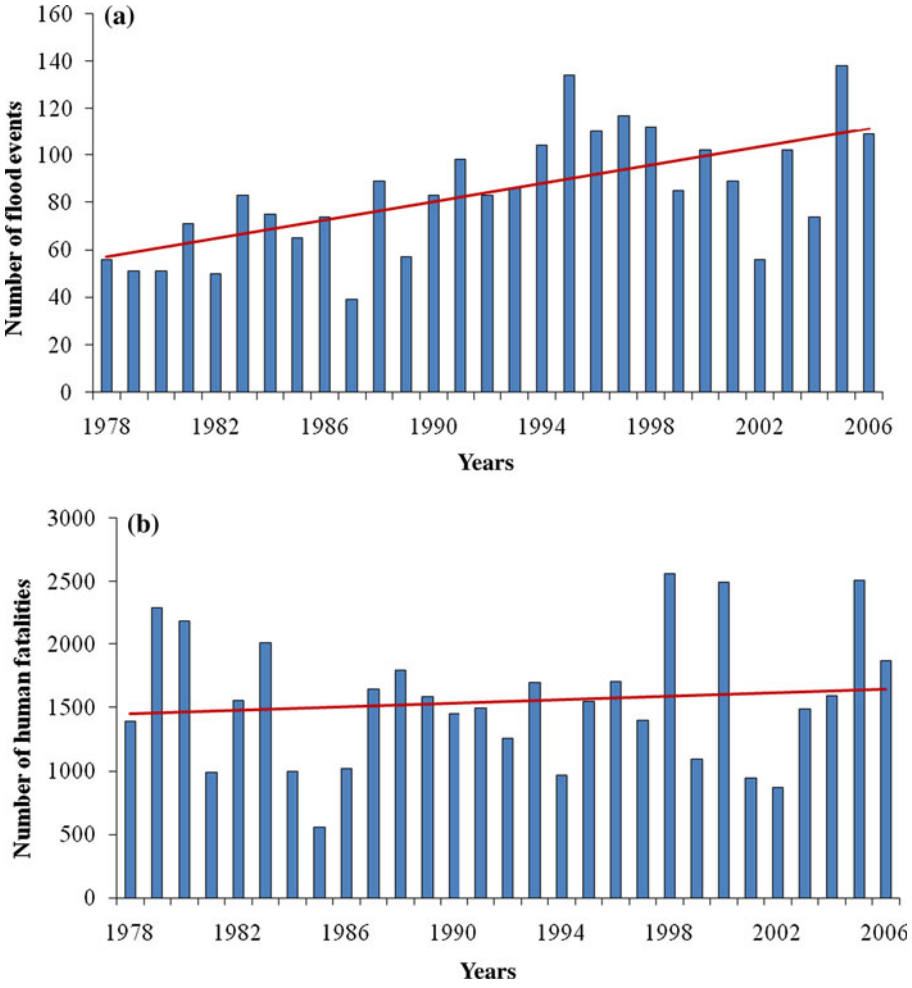

Fig. 2 **a**, **b** Total number of flood events and human fatalities in India during the period 1978–2006. **a** Flood events and **b** human fatalities

flood incidents were observed and their spatial spread were restricted to only 14 states and union territories.

The further analysis of the data reveals that maximum flood events during 1978–2006 were recorded in Maharashtra (12 %) followed by Karnataka (9 %) and West Bengal (8 %), whereas more vulnerable states in terms of human fatalities were found to be Uttar Pradesh (17 %) followed by Maharashtra (13 %) and Bihar and Gujarat (10 % each; Table 2). To examine the temporal distribution of flooding in India, events and fatalities were grouped in 10-year periods between 1978 and 2006, in order to examine their decadal occurrence variations and to note the shifts, if any, in the vulnerability across time and space. From the analysis, it emerges that there is an increase in flood events, whereas human fatalities remain roughly at the same level, and no appreciable increase is observable (Fig. 3). Further, in respect of death rates per million of population (representing the more stable measure), however (Table 3), the mountain states like Sikkim, Himachal

Pradesh, Mizoram, Arunachal Pradesh and Jammu and Kashmir turn out to be more vulnerable states over the entire period, with a death rate of 582.4, 242.7, 195.8, 177.6 and 134.5, respectively. The introduction of population figures dramatically changes the perception of the vulnerable state (Coates 1999). While following the standardization of population figures, we should take note of the fact that mountainous states being very sparsely populated, any flood fatality is bound to have a considerable impact on the death rate. Conversely, Uttar Pradesh, for example, being a heavily populated state, even a huge number of flood fatalities translate into relatively a low death rate. Certainly, Maharashtra, Bihar and West Bengal are the worst hit states in terms of flood fatalities.

3.3 Flood events and fatalities vis-à-vis by seasons and months

Flooding occurs seasonally, depending on the weather pattern, monsoon activities and local climate. Analysis of the IMD database highlights that most of the flood events and human fatalities occurred during monsoon season in India followed by post-monsoon season. Monsoon season represents about 80 % of flood events and 90 % of flood-related human fatalities. Moreover, severe floods caused 23,162 deaths followed by heavy rains 10,132 and flash floods 4,413 during the season. The high number of flood frequency and fatalities can be explained by the widespread outbreak of monsoon rainfall across the country. Moreover, 75 % of the total rainfall in India occurs during the period. As a result, the rivers witness rise in water level speedily, leading to widespread floods in the country.

As far as monthly distribution is concerned, the analysis makes it amply clear that flood events start increasing during May and reach a peak in July and August. In India, July is the month fraught with highest flood events. However, the monthly distribution of flood fatalities does not bear any correspondence with the number of flood events. It is important to note that a reasonable difference is seen in the fatalities/event ratio in the July and August months, the months with the largest flood events. August records 582 events and 13,620 fatalities (approximately 23.4 death per event), whereas July records 658 events and 12,893 fatalities (approximately 19.6 fatalities per event). The large incidence of fatalities in July and August months can preeminently be ascribed to the onset of the Asian monsoon. These 2 months alone account for about 60 % of the human fatalities due to floods. Finally, there is a moderate incidence of flood events and fatalities during October and November, which is due to retreating monsoons in southern states of India. Moreover, heavy rains and flash flood events in northern states due to western disturbances were responsible for 70 % of human fatalities during January, February and March.

Regionally, an analysis of flood events and fatalities was also carried out to illustrate the temporal differences in their occurrence. The analysis reveals variations in the occurrence of flood events and fatalities under different geographical regions of the country. In the northern, north-eastern, western and southern parts of the country, maximum frequency of floods occurred in July, whereas in eastern and central parts of India, maximum flood frequency occurred in August. In addition, flood fatality pattern in northern, central, eastern and western regions of India follows approximately the same pattern as that of flood events. However, flood fatalities in north-eastern and southern parts of the country do not follow the maximum flood frequency pattern. The north-eastern region peaked in fatalities during June, while southern region reached a peak in fatalities during October. The extremely high occurrence of flood fatalities in June in the north-eastern region is due to early onset of monsoons. Maximum flood fatalities in October month in the southern India could be attributed to the high propensity of retreating monsoons especially in Tamil

Table 2 Total and percentage of flood events and fatalities in India by states and union territories, 1978–2006; and at decadal intervals

Decades/states	1978–1987		1988–1997		1998–2006		Total (1978–2006)	
	Flood events	Fatalities	Flood events	Fatalities	Flood events	Fatalities	Flood events	Fatalities
Andhra Pradesh	23 (3.7)	561 (3.8)	27 (2.8)	1283 (8.6)	20 (2.3)	778 (5.0)	70 (2.9)	2,622 (5.8)
Arunachal Pradesh	8 (1.3)	6 (0.1)	30 (3.1)	104 (0.7)	13 (1.5)	85 (0.6)	51 (2.1)	195 (0.4)
Assam	41 (6.7)	254 (1.7)	57 (5.9)	702 (4.7)	77 (8.9)	1,099 (7.1)	175 (7.2)	2,055 (4.6)
Bihar	34 (5.5)	1,574 (10.7)	29 (3.0)	540 (3.6)	26 (3.0)	2,124 (13.8)	89 (3.6)	4,238 (9.4)
Gujarat	29 (4.7)	2,360 (16.1)	25 (2.6)	925 (6.2)	31 (3.6)	887 (5.7)	85 (3.5)	4,172 (9.3)
Haryana	9 (1.5)	45 (0.3)	24 (2.5)	297 (2.0)	22 (2.5)	38 (0.2)	55 (2.3)	380 (0.8)
Himachal	20 (3.3)	64 (0.4)	58 (6.0)	782 (5.2)	69 (7.9)	629 (4.1)	147 (6.0)	1,475 (3.3)
Jammu and Kashmir	40 (6.5)	209 (1.4)	31 (3.2)	1,124 (7.5)	5 (0.6)	32 (0.2)	76 (3.1)	1,365 (3.0)
Karnataka	44 (7.2)	173 (1.2)	61 (6.3)	606 (4.1)	106 (12.2)	658 (4.3)	211 (8.6)	1,437 (3.2)
Kerala	39 (6.3)	268 (1.8)	84 (8.7)	380 (2.5)	80 (9.2)	518 (3.4)	203 (8.3)	1,166 (2.6)
Madhya Pradesh	41 (6.7)	516 (3.5)	32 (3.3)	176 (1.2)	45 (5.1)	521 (3.4)	118 (4.8)	1,213 (2.7)
Maharashtra	81 (13.2)	888 (6.1)	119 (12.4)	2,421 (16.2)	90 (10.4)	2,358 (15.3)	290 (11.9)	5,667 (12.6)
Orissa	23 (3.7)	1,280 (8.7)	43 (4.5)	613 (4.1)	14 (1.6)	327 (2.1)	80 (3.3)	2,220 (4.9)
Punjab	24 (3.9)	160 (1.1)	31 (3.2)	562 (3.8)	19 (2.2)	46 (0.3)	74 (3.0)	768 (1.7)
Rajasthan	13 (2.1)	861 (5.9)	54 (5.6)	447 (3.0)	44 (5.1)	671 (4.3)	111 (4.5)	1,979 (4.4)
Tamil Nadu	23 (3.7)	588 (4.0)	23 (2.4)	644 (4.3)	29 (3.3)	530 (3.4)	75 (3.1)	1,762 (3.9)
Tripura	10 (1.6)	108 (0.7)	14 (1.5)	58 (0.4)	8 (0.9)	27 (0.2)	32 (1.3)	193 (0.4)
Uttar Pradesh	44 (7.2)	3,700 (25.3)	43 (4.5)	1,981 (13.3)	62 (7.2)	1,767 (11.5)	149 (6.1)	7,448 (16.6)
West Bengal	28 (4.6)	820 (5.6)	112 (11.7)	882 (5.9)	67 (7.7)	2,213 (14.3)	207 (8.5)	3,915 (8.7)
Chandigarh	6 (1.0)	6 (0.1)	10 (1.0)	8 (0.1)	7 (0.8)	9 (0.1)	23 (0.9)	23 (0.1)
Goa	8 (1.3)	3 (0.1)	2 (0.2)	0 (0.0)	4 (0.5)	10 (0.1)	14 (0.6)	13 (0.1)
Manipur	3 (0.5)	0 (0.0)	6 (0.2)	4 (0.1)	3 (0.3)	15 (0.1)	12 (0.5)	19 (0.1)
Meghalaya	2 (0.3)	34 (0.2)	10 (1.0)	35 (0.2)	10 (1.2)	13 (0.1)	22 (0.9)	82 (0.2)
Mizoram	0 (0.0)	0 (0.0)	11 (1.1)	160 (1.2)	6 (0.7)	14 (0.1)	17 (0.7)	174 (0.2)

Table 2 continued

Decades/states	1978–1987		1988–1997		1998–2006		Total (1978–2006)	
	Flood events	Fatalities	Flood events	Fatalities	Flood events	Fatalities	Flood events	Fatalities
Nagaland	1 (0.2)	0 (0.0)	2 (0.2)	1 (0.0)	3 (0.3)	0 (0.0)	6 (0.2)	1 (0.0)
Sikkim	3 (0.5)	115 (0.8)	11 (1.1)	150 (1.0)	5 (0.6)	50 (0.3)	19 (0.8)	315 (0.7)
Delhi	16 (2.6)	56 (0.4)	12 (1.2)	27 (0.2)	2 (0.2)	8 (0.1)	30 (1.2)	91 (0.2)
Pondicherry	2 (0.3)	3 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.1)	3 (0.0)
Total	615	14,652	961	14,912	867	15,427	2,443	44,991
%	25.2	32.6	39.3	33.14	35.5	34.3	100	100

Figures in the parenthesis indicate % flood events and fatalities

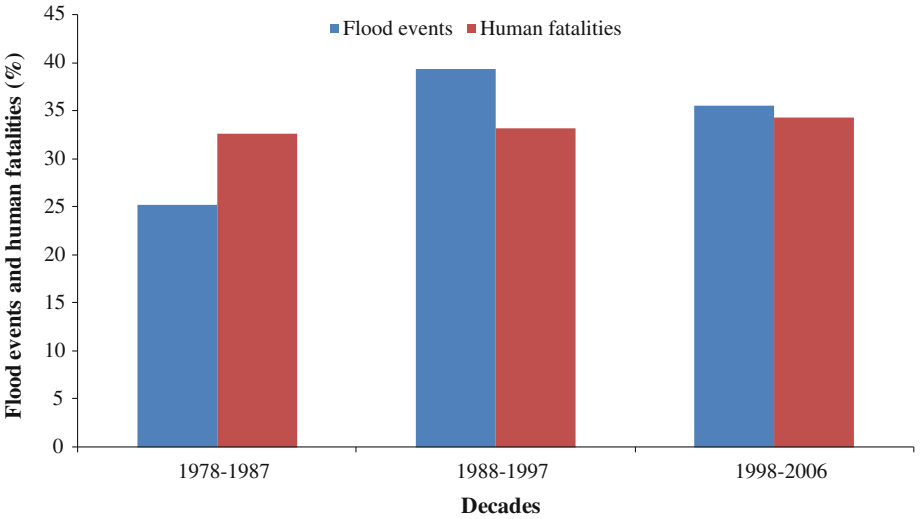

Fig. 3 Decadal distribution of flood events and fatalities in India during the period 1978–2006

Nadu. Further, flood event and fatality pattern of north-eastern and southern regions are temporally extended as compared to other geographical regions of the country.

3.4 Flood events and fatalities versus flood type

The occurrence of heavy rainfall events exceeded those of other categories in India. Heavy rainfall events occurred 1,578 times and claimed 13,019 lives (29 %), averaging about 8 fatalities per event, whereas the frequency of these events was observed to be remarkably high (65 %). Interestingly, severe floods were responsible for more than 50 % of all the human fatalities with 54 deaths per event. In addition, there were a total of 225 flash flood events with 4,756 human fatalities, averaging about 21 fatalities per event. The major flash floods observed in this study were from dam failures in different parts of the country, which were primarily caused by incessantly heavy rainfall over a short period of time. One such example of dam failure in Gujarat state of the country has already been discussed.

3.5 Spatial variation of flood events and fatalities

While examining the flood frequency per year by state, Maharashtra, Karnataka, West Bengal, Kerala and Assam are the worst hit accounting for about 45 % of the total flood events in the country. This dismal situation in these states could be mainly attributed to the incidence of early onset of monsoons in these states. State-wise flood events mapped by flood types reveal high incidence of heavy rain events per year in Maharashtra, Karnataka and Kerala, whereas the incidence of moderate, severe and flash flood events per year was found to be prominently high in Assam. In addition, cloudbursts demonstrated highest frequencies per year in north-western Himalayan region (80 %) and especially in the state of Himachal Pradesh (50 %). But the severest cloudburst event in the country claimed 84 lives in the eastern Uttar Pradesh during the year 2004. A cloudburst is a sudden downpour with an intensity of rainfall over 100 mm per hour. It usually lasts no longer than a few minutes but is quite capable of flooding the area of occurrence profusely.

Table 3 Flood death rates per million of population in India by states and union territories, 1978–2006; and at decadal intervals

States/decades	1978–1987	1988–1997	1998–2006	Total (1978–2006)
Andhra Pradesh	10.4	19.3	10.2	34.4
Arunachal	9.5	120.3	77.4	177.6
Assam	14.1	31.3	41.2	77.1
Bihar	30.1	6.3	19.3	38.5
Gujarat	69.2	22.4	17.5	82.3
Haryana	3.5	18.0	1.8	17.9
Himachal	14.9	151.2	103.5	242.7
Jammu Kashmir	34.9	145.6	3.15	134.6
Karnataka	4.6	13.5	12.4	27.2
Kerala	10.5	13.1	16.3	36.6
Madhya Pradesh	13.5	2.7	6.4	14.9
Maharashtra	14.1	30.7	24.3	58.5
Orissa	48.5	19.4	8.9	60.3
Punjab	9.5	27.7	1.9	31.5
Rajasthan	25.1	10.1	11.8	35.0
Tamil Nadu	12.1	11.5	8.5	28.2
Tripura	52.6	21.0	8.4	60.3
Uttar Pradesh	35.2	14.2	10.1	42.6
West Bengal	15.0	12.9	27.6	48.8
Chandigarh	13.2	12.46	9.9	25.5
Goa	2.97	0	7.4	9.6
Manipur	0	2.17	6.9	8.8
Meghalaya	25.4	19.7	5.6	35.4
Mizoram	0	231.9	15.7	195.8
Nagaland	0	0.8	0	0.5
Sikkim	363.9	369.0	92.4	582.4
Delhi	9.0	2.9	0.6	6.6
Pondicherry	4.9	0	0	3.1
Total	22.7	17.6	15.0	43.7

Moreover, while examining total human fatalities state wise, we see that Uttar Pradesh (7,355), Maharashtra (5,667), Bihar (4,223), Gujarat (4,172) and West Bengal (3,915) fall among the states with highest fatalities. Nagaland, Manipur and Goa states pertain to the category of low human fatality states, fewer than 50 fatalities during the recorded period of 29 years. When human fatalities in India were standardized in terms of population, the states possessing highest ranking were observed to be Sikkim, Himachal Pradesh, Mizoram, Arunachal Pradesh, Jammu and Kashmir, Gujarat, Assam, Orissa, Tripura, Maharashtra and Bihar in the stated respective order. These states represented more than 50 human fatalities per million of population during the period 1978–2006.

State-wise human fatalities mapped by different flood types show high number of heavy rainfall fatalities (standardized by population) in the states along the Himalayas such as Sikkim, Mizoram, Himachal Pradesh and Arunachal Pradesh. However, heavy rainfall fatalities demonstrated a clear-cut east–west divide of human fatalities per million of

population. Further, high numbers of moderate flood fatalities (standardized by population) are found predominantly in Arunachal Pradesh. Severe flood-related very high human fatalities (standardized by population) were quite noticeable in Sikkim, Jammu and Kashmir, Himachal Pradesh, Assam and Orissa, whereas high number of flash flood-related human fatalities (standardized by population) was evident in Arunachal Pradesh. As expected, states with high number of cloudbursts fatalities (standardized by population) were found predominantly in north-western Himalayan region, particularly in the states of Himachal Pradesh and Jammu and Kashmir.

Figure 4 shows the rank of flood-related events (Fig. 4a) and fatalities (Fig. 4b) by step of 7 in rank. In regard to flood-related fatalities, the top 7 states are Uttar Pradesh, Maharashtra, Bihar, Gujarat, West Bengal, Orissa and Andhra Pradesh, all of which are in the western and eastern parts and almost all have higher flood events than other states. Moreover, the rate and rank of flood-related events and fatalities of each state (standardized by population) have been shown in Table 4. With regard to flood fatality rate, the top two states are Sikkim and Himachal Pradesh, while they have 23rd and 7th rank in respect of the number of flood events (Table 1). When population was taken into account, there was maximum shift from eastern and western states (Fig. 4b) toward less populated states such as Jammu and Kashmir, Himachal Pradesh, Sikkim and Arunachal Pradesh (Fig. 5a). The flood events and fatality analysis by taking population into account reveal the maximum shift from high-population states to lowly populated mountainous states. Similar results of fatality rate per million of population in the United States and China were observed for lightening-related fatalities (Curran et al. 2000; Zhang et al. 2011). The ranks of flood fatality rate in central and southern states were found to be low (Fig. 5b). The flood fatality rate of 1.5 persons per million per year in India is much higher than the 0.004 rate in Australia for 1788–1996 (Coates 1999).

3.6 Comparison of flood events and fatalities versus various regions

Table 5 provides a comparative overview of flood events and flood-related human fatalities region wise. Results of the table reinforce the fact that countries or continents with tardy

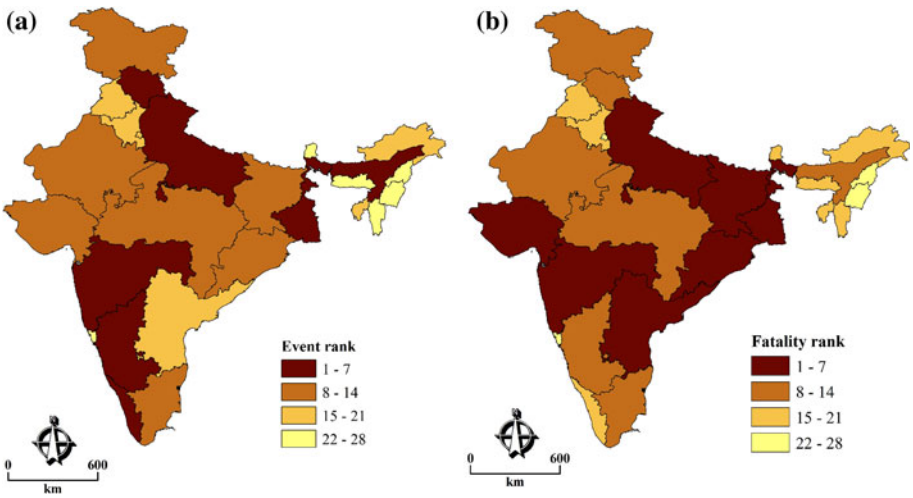

Fig. 4 Rank of each state in number of flood-related **a** events and **b** fatalities in India from 1978 to 2006

Table 4 Rate per million people per year of flood fatalities and flood events and their ranks for India from 1978 to 2006

States	Population (millions)	Flood events rate		Fatalities rate	
		Rate	Rank	Rate	Rank
Andhra Pradesh	76.2	0.03	20	1.18	17
Arunachal Pradesh	1.1	1.60	1	6.12	4
Assam	26.7	0.22	10	2.65	7
Bihar	109.9	0.03	20	1.32	13
Gujarat	50.7	0.05	18	2.8	6
Haryana	21.1	0.09	15	0.61	22
Himachal Pradesh	6.1	0.83	4	8.36	2
Jammu and Kashmir	10.1	0.25	9	4.64	5
Karnataka	52.9	0.13	13	0.93	20
Kerala	31.8	0.21	11	1.26	14
Madhya Pradesh	81.2	0.05	17	0.51	23
Maharashtra	96.9	0.10	14	2.01	10
Orissa	36.8	0.07	16	2.07	9
Punjab	24.3	0.10	14	1.08	18
Rajasthan	56.5	0.06	17	1.20	16
Tamil Nadu	62.4	0.04	19	0.97	19
Tripura	3.2	0.34	7	2.08	8
Uttar Pradesh	174.6	0.03	20	1.47	12
West Bengal	80.17	0.09	15	1.68	11
Chandigarh	0.9	0.9	3	0.9	21
Goa	1.3	0.35	6	0.33	24
Manipur	2.1	0.19	12	0.33	24
Meghalaya	2.3	0.32	8	1.21	15
Mizoram	0.9	0.65	5	6.75	3
Nagaland	1.9	0.10	14	0.01	27
Sikkim	0.5	1.2	2	20.08	1
Delhi	13.9	0.07	16	0.22	25
Pondicherry	0.9	0.07	16	0.11	26
Total	1,028.6	0.08		1.5	

economic development are more exposed to flooding events and flood fatalities per year. Also, there was a relatively high fatality per event in these regions. This calls for the establishment of flood prediction system and disaster mitigation efforts to minimize the impact of flood hazards in the affected countries. Further, analyzing the flood fatalities, it was found that Asia, South Asia and India are highly prone to flood fatalities. Interestingly, about 41 % of flood disasters occurred in Asia that accounted for about 65 % of the human fatalities. Such huge human fatalities in this part of the world could be attributed to limited resources and tardy economic development. Moreover, strong linkages have been identified between poverty, high social vulnerability and low capacity to cope with flooding events.

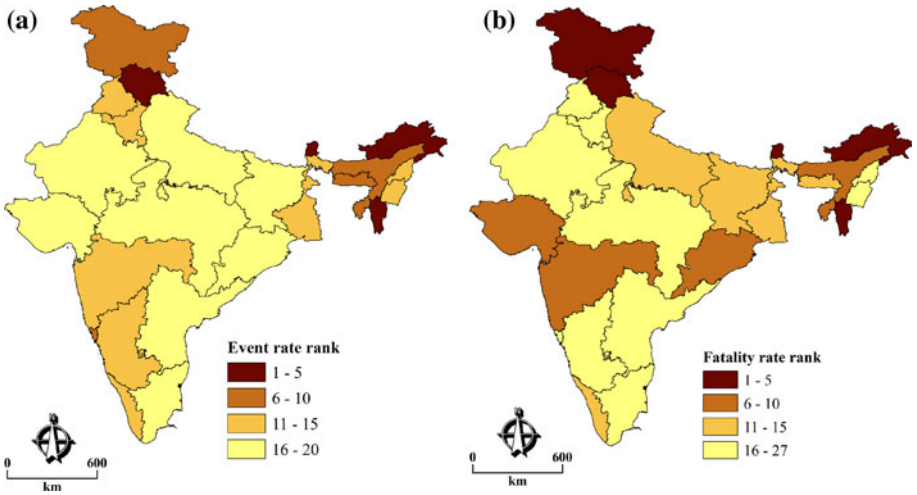

Fig. 5 Rank of each state in the rate of flood-related **a** events and **b** fatalities in India from 1978 to 2006

Table 5 Number of flood events and human fatalities by floods in India as compared to others parts of the world

Regions	No. of flood events	Flood fatalities	Flood fatalities per event	Flood fatalities per year	Periods	Source
Africa	438	13,825	32	460	1976–2005	Shrestha (2008)
America	605	48,506	80	1,617	1976–2005	Shrestha (2008)
USA	–	4,586	–	98	1959–2005	Ashley and Ashley (2008)
Europe	292	1,975	7	66	1976–2005	Shrestha (2008)
Greece	545	686	1	5	1880–2010	Diakakis et al. (2012)
Oceania	86	219	3	7	1976–2005	Shrestha (2008)
Australia	155	2,213	14	11	1788–1996	Coates (1999)
Asia	994	122,521	123	4,084	1976–2005	Shrestha (2008)
South Asia	332	64,658	195	2,155	1976–2005	Shrestha (2008)
India	2,443	44,991	18	1,551	1978–2006	Present study
World	2,415	187,046	78	6,234	1976–2005	Shrestha (2008)

3.7 People affected and economic losses due to floods

Flooding causes loss of property worth millions of dollars every year in India. The number of people affected and the reported economic losses due to floods in country have been shown in Fig. 6. The total number of affected people by floods in India during the period 1978–2006 is about 6.5 billion, accounting to be 25 million people on an average per year. Moreover, 1998 floods in different parts of the country affected more than 50 million people. Also, an increasing trend in the number of affected people was observed (Fig. 6a). The increasing trend in the flood-affected population in India is in agreement with those reported in the World Water Development reports and the findings of the impacts of the

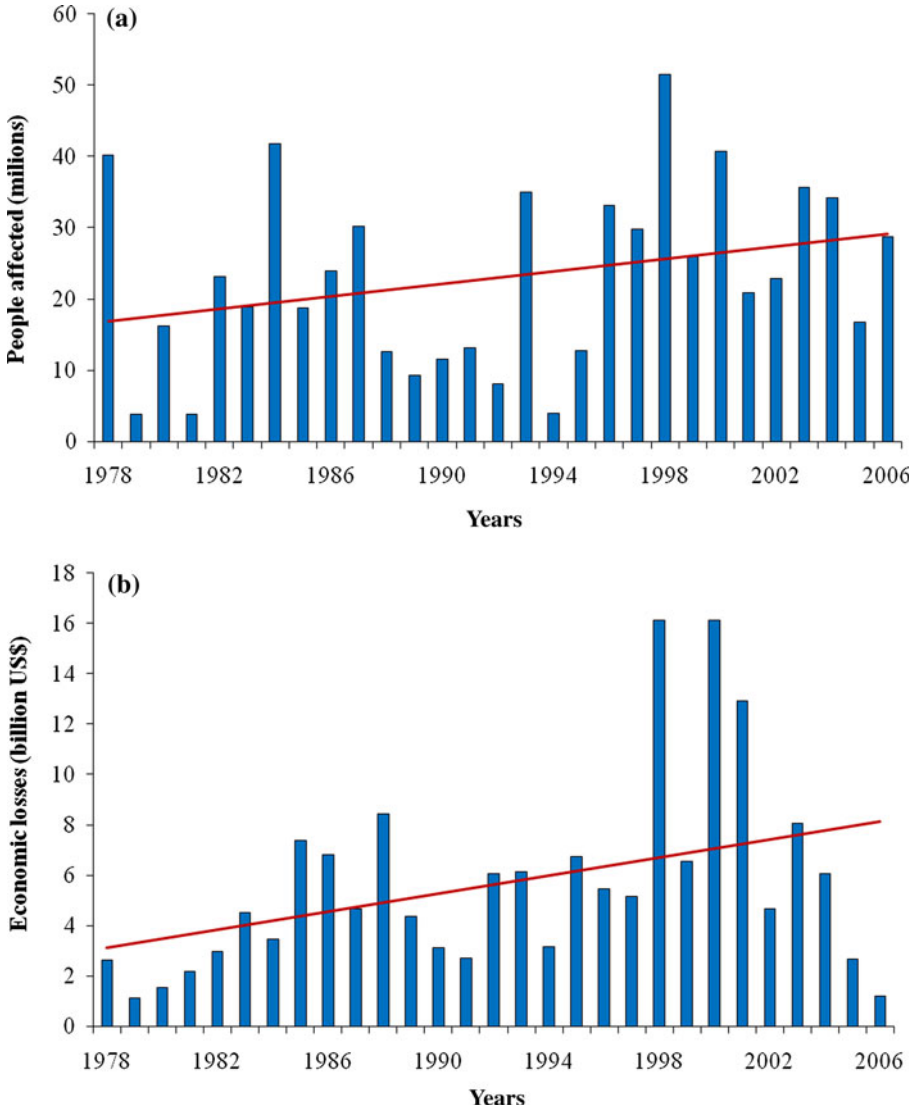

Fig. 6 Total number of people affected and economic losses due to floods in India during the period 1978–2006. **a** People affected and **b** economic losses

global flood disasters reported by Jonkman (2005). Bihar has the highest number of flood-affected people in India followed by Uttar Pradesh and West Bengal. Higher number of affected people in these states can be attributed to greater flood plain occupancy, high density of population and greater channel alterations by human structures (Rao 1975; Chaphekar and Mhatre 1985; Ives 1988; Hofer 1994). Failures of man-made dams and other structures across rivers have also been responsible for some unusual floods, thus aggravating the flood problem (Kale 1997, 1998). The reported economic loss due to floods in the IMD database for the period 1978–2006 was found to be about 16 billion US$. The maximum economic losses due to floods in the country were observed in the year 1998 and

2000, and these damages are almost in agreement with the affected population during these years (Fig. 6a, b). Moreover, the occurrence of flooding events corroborates the phenomenon well (Fig. 2a). The huge losses in India can be attributed to poor structural measures undertaken in the floodplains of India.

4 Conclusions

India is the most flood-prone country in the world after Bangladesh. In this study, flood-related fatalities for India were summarized for a period of 29 years from the IMD publication *Disastrous Weather Events.* Records covering 1978–2006 indicate that at least 44,991 fatalities occurred as a result of 2,443 flooding events in India. Moreover, the numbers of flood events and human fatalities have increased over the years in the country. An increase in flood events and flood-related human fatalities is attributable to population increase, expansion of urbanization, enhancement in the means of reporting and recording disasters through information communication technology, increased social and media interest and increased human interference in the hydrological processes through the expansion of public works, road network, etc. (Shrestha 2008; Diakakis et al. 2012). Further, these findings also suggest that flood management plans in both structural (embankments, flood walls, channel improvement, diversion of floodwaters) and non-structural (flood proofing, forecasting, warning systems, rescue services) measures have not been executed efficiently in the country (Mohapatra and Singh 2003; Gupta et al. 2003). Also, decadal increase has been observed in flood events, whereas no perceptible changes were noticed in human fatalities. Furthermore, an increase in flood events will have greater devastating impact on India, and therefore, a relatively high susceptibility and vulnerability of population will ensue. Susceptibility of population to floods will undermine and wreck the social and economic fabric, delivering a stupendous blow to culture and means of livelihood (Shrestha 2008). Moreover, the number of fatalities varies from year to year, with high flood event years coinciding with high human fatalities. An interesting result that emerged enormously from the study reveals that the occurrence of heavy rainfall events was more, whereas human fatalities occurred more due to severe flood events.

Fatal floods have occurred in India during every month of the year, peaking in July and August. However, it is noteworthy that there is a considerable difference in the fatalities per event between July and August. This considerable difference can be attributed to storm characteristics (intensity and duration). Furthermore, analysis also demonstrates a difference in seasonality between the different regions of the country, indicating a possible change in storm development. Monthly distribution of flood events and human fatalities depicts a primary indication of seasonality of flooding in the country. Such information can provide a preliminary guidance toward some proactive preparedness for flood management programs and mitigation measures that will subsequently be useful in reducing both the flood events and human fatalities. Similar suggestions have been advocated by Cutter and Emrich (2005) in order to reduce flood-related fatalities in the United States.

Flood-related human fatalities in India were found to be more dominant in the flood plains of Uttar Pradesh, Bihar, Orissa and West Bengal. It is assumed that there will be more human fatalities in the flood plains of these states because this region reels under a very high incidence of severe floods, high-population density, limited resources and tardy economic development. In addition, this region suffers from the high velocity surging water streams originating from the Himalayas. However, when standardized population

data were incorporated, mountainous states were found to be more vulnerable in terms of flood fatalities. It is worth noting that the low size of population in the hill states contributes significantly to raising death rate among the inhabitants. Conversely, Uttar Pradesh, for example, has a relatively large population, and so even high numbers of flood fatalities translate into relatively low death rates. Moreover, the number of people affected and the reported economic losses in India have also demonstrated immensity of the problem of flood events and flood fatalities with the categorical signs of its rising trend. It can be primarily attributed to poor structural measures undertaken in the floodplains of India.

To conclude, the results of this study reveal that the Indian population is largely unaware of the life-threatening powers of floodwater. The study establishes that a close examination of historical flooding events and resultant human fatalities through a reliable data set like IMD publication on *Disastrous Weather Events* could be a useful tool in understanding the occurrence of floods in India, in terms of seasonality, temporal trends and spatial distribution. Moreover, the data analyzed under this study could help us a lot to reset our priorities in relation to flood-prone areas to cope with the perils unleashed by the various types of flood events.

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