J. Ind. Geophys. Union (April 2013)
Vol.17, No.2, pp. 153-165

Urban flooding in recent decades in four mega cities of India

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ABSTRACT
Floods, extreme weather events, have occurred with frequent regularity over last two decades causing severe urban flood related inundations. In the present scenario, rapidly expanding mega cities (due to migration of people from rural India) are facing many problems. The four mega cities: Delhi, Kolkata, Mumbai and Chennai are the most populated cities of India. Uncontrolled growth of mega cities has increased their vulnerability to flooding. For a better understanding of the problem, extreme rainfall events have been analysed for the period 1970-2006 for two stations each in the four Mega Cities. Their spatial variation, frequency and trends have been computed and discussed.

In this study, analysis has been made about the casualties due to floods in these cities from the period 1988 to 2007. Data from Disastrous Weather Events published by India Meteorological Department have been used. The study brings out the impact of urban flooding, leading to human deaths, for each city taking in to context the different geographical and climatic aspects. Some measures are suggested to minimize the losses from such natural hazards.

INTRODUCTION

Floods are the natural hazards caused directly by weather events like heavy rains over inland area and cyclones in the coastal belt. They often become disastrous, due to human activities that interfere with natural ecology.

During the last two decades there has been a major shift of population in urban areas, especially in major metro cities of India. By 2025, the population of tropical Asia is projected to rise to 2.4 billion. Significant number of the world's most populated cities are located in Asia viz., Tokyo, Mumbai, Shanghai, Kolkata, Jakarta, Delhi, Seoul, Manila and Dhaka. Three of these are located in India. This demographic explosion enhances further the vulnerability of these urban conglomerations to floods and flash floods. Since the ecological intervention is minimal due to lesser population in United States, which is a developed nation (even though floods cause about $ 6 billion worth of damage) the human loss is limited to about 100-150 people every year. In contrast in China's yellow river valley (a densely populated region), where some of the world's worst floods have occurred, millions of people have perished in floods during the last century. During the past 25 years, there have been over three million deaths, of which 90 percent were in developing countries (Bedritsky, 1999).

Several authors have studied increase in frequency of very heavy rainfall and impact of urbanization on meteorological variables (Guhathakurta et al, 2011, Ghosh et al, 2009, Goswami et al 2006, De and Rao, 2004, Khole and De 2001, De et al 2005, Rao et al, 2004, Sinha Ray et al, 1999). Some of the growing urban mega cities such as Delhi, Mumbai, Kolkata and Chennai are likely to undergo severe resource stress in coming decades due to rising population. Residents of flooded cities face another type of disaster where unavailability of clean water and improper sanitization facilities after and during flood lead to outbreaks of deadly waterborne diseases like typhoid, hepatitis A and cholera. Rapid industrialization and urbanization has led to concentration of the population around the expanding fringes of the mega cities. Due to improper planning of growing mega cities there is a very low capacity of such societies to absorb climatic shocks. The present

study analyses the last twenty years data pertaining to major floods in four metro cities of India, which have a population exceeding 5 million.

DATA AND METHODOLOGY

The first census of India during the 20th century showed that only one city had a population more than one million. In 1991 census, 14 cities with population more than one million existed while the census of 2001 shows, 22 such cities. The four mega cities, which are under study, are located in the four quadrants of India, North - Delhi, East - Kolkata, West - Mumbai, and South - Chennai. Their population and population growth are taken as reported in Govt. of India census of 1991 and 2001 (Table- 1). The major disasters caused due to floods in the four mega cities as reported in Disastrous Weather Events (DWE), (India Meteorological Department) are used in this study. In order to study urban flooding daily rainfall data for two observatories in each of the mega cities are used (1970-2006). For each mega city one observatory in the city and one in the airport are taken so that its spatial distribution of rainfall can be better analyzed. The stations are Colaba and Santacruz Airport in Mumbai, Nungambakkam and Minambakkam Airport in Chennai, Alipur and Dumdum Airport in Kolkata and Safdarjung and Palam Airport in Delhi. Daily rainfall data for the period 1970-2006 have been utilized to study very heavy rainfall (≥125 mm) and phenomenal rainfall (≥150 mm) and their trends.

FLOODS/HEAVY RAINS

Floods occur in almost all the river basins of the country. A flood is an overflow of an expanse of water that submerges land. Every year floods affect nearly 400 million hectares of land in India (Sinha Ray et al, 1999). Seasonal peak in mortality occurs during rainy season in the tropical belt. Specific cases of floods in the four metros of India are discussed in the next section.

Urban Floods

India is primarily an agricultural country. In the past, rural infra structure was adequate to sustain population of country. Migration of population towards mega cities has resulted in random expansion of urban sector. Such migrations are due to industrial growth. Presently some of the urban agglomerations accommodate more than 10 million people. According to a recent estimate, by 2015 India will have 34 cities in the population range of 1.5 million and above. Four mega Cities selected for the present study would have crossed 10 million mark, in which Mumbai would have the largest population density of more than 27 million. Majority of the poor live in informal settlements. In future these settlements would grow in a random way due to inadequacy of space and resources. Thousands of illegal colonies have emerged in the mega cities resulting in constriction of natural drainage causing urban floods. Urban areas get flooding by different types of floods like river floods, flash floods, coastal floods, release of excess water from reservoir or failure of dam on the upstream side etc. Heavy rainfall is the main cause of urban flood. Due to intense and periodic rain, huge quantity of water flows, beyond the capacity of old drainage systems of the mega cities. Drainage system gets blocked due to silting, dumping of waste material at the inlets of drainage, encroachment over natural drainage and water bodies.

Significant Urban Floods in India in recent years

The Year 2005 was recorded as the hottest year of the century. Incidentally, in the same year the worst urban flooding was reported in Mumbai on 26/27 July, with the historical rainfall of 944 mm. In this year 10 severe urban floodings, were also reported, in which

Table 1. Population of four mega cities in India (MILLIONS)

Megacities	Census 1991(million)	Census 2001 (million)	Estimate growth(%)
Mumbai	12.6	17.7	4.05%
Kolkata	11.0	14.7	3.36%
Delhi	8.4	13.8	6.43%
Chennai	5.4	8.2	5.18%

Chennai flooding was remarkable. It affected more than 5, 00,000 people. Three fourths of Chennai was inundated. Next year i.e. 2006, number of urban floodings were reported in 22 cities. The increasing trend of flooding was carried into 2007 also, where number of affected cities rose to 35 in which Kolkata was the worst affected. In the year 2008, severe urban floodings were reported, Mumbai was the worst affected. In the year 2010, Mumbai (Colaba) received 130 mm and 210 mm rainfall on 19th and 25th June. On 4th July, it received 149 mm rainfall. Santacruz received 158 mm and 138 mm rainfall on 17th and 30th August. A summary of casualties due to floods /heavy rains is shown in Table - 2.

It is observed from the table that maximum number of deaths have occurred in Mumbai. Amongst all the four cities Delhi reported lowest deaths. In Delhi (capital of the country), an inland city, proper planning and preventive measures have been taken, resulting in minimum number of causalities.

Impact of flooding on mega cities

The direct and secondary effects of major floods in these selected 4 mega cities are briefly described below:

Delhi

Delhi, capital of the country with an area of 1483 km^2 has an estimated population of 13.8 million. The average annual rainfall of Delhi is 670 mm, most of which falls during SW monsoon, in July and August. The flood season observed by Delhi govt. is

Table 2. Number of Deaths/Injured in four mega cities

Year	Delhi		Kolkata		Mumbai		Chennai	
	Deaths	Injured	Deaths	Injured	Deaths	Injured	Deaths	Injured
1988	-	-	2	2	26	19	3	4
1989	-	-	-	-		-	-	-
1990	3	5	1	19	79	66	15	-
1991	5	-	-	2	78	100	21	6
1992	1	-	-	15	19	2	-	-
1993	3	3	14	15	40	61	-	-
1994	-	-	-	-	27	46	3	2
1995	2	-	6	22	7	-	12	-
1996	10	-	3	5	27	14		-
1997	2	1	-	-	25	59		-
1998	-	-		-	8	-	-	-
1999	-	-		-	24	6	-	-
2000	-	-		-	87	65	6	-
2001	-	-	-	-	18	-	-	-
2002	2	-	-	-	10	-	-	-
2003	7	6	-	-	6	2	-	-
2004	-	-	35	4	36	51	2	-
2005	-	-	16	4	1000	3	13	-
2006	-	-	-	-	182	18	47	-
2007	-	-	34	-	57	3	8	-

from July to October. In recent times this city has attracted millions of people from neighboring states like Haryana, Punjab, Uttar Pradesh, Rajasthan and Bihar. Delhi can be divided into three major geographical regions: the Yamuna flood plain, the ridge, and the Gangetic plains. The average elevation of Delhi from mean sea level is 233 m, where as from ridge area to Yamuna flood plain, it varies from 305 m to 213 m. Heavy rains in the past, over Delhi high land ridge area have not affected the city due to natural drainage system for rain water to flow to the Yamuna river. Most populated parts of Delhi are inside the Yamuna flood plains. In the recent past thousands of illegal colonies have emerged in this part as well as in Delhi. Many unauthorized colonies have been developed on agricultural land by local colonizers without considering city plans, drainage, and sewerage etc. Number of surface water bodies has been reduced from 800 to 600 due to encroachment. Capital has suffered floods in 1924, 1947, 1967, 1971, 1975, 1976, 1978, 1980, 1993, 1995 and 1998. In Delhi 5 persons were killed and normal life was completely paralyzed due to heavy rains on 25-26 August 1991. During floods in 1993, 206 localities were inundated and traffic was disturbed in 130 stretches. Flooding resulted in the damage of roads and collapsing of bridges, causing traffic congestion. In the month of September (24-26), 2010 a flash flood in Uttarakhand has raised the water level in Yamuna above danger mark, which did not recede for several days. The ground water table in the low lying areas rose so high that one of the buildings collapsed leading to death of 70 people. In many colonies water was in the basement of the buildings. This indicates that such collapsing of buildings may happen in future also. In 1995-1996, 21300 people developed jaundice after drinking contaminated water, De and Ray (2000). There was outbreak of malaria, dengue, and other diseases after every flood.

Kolkata

As per 2001 census Kolkata metropolitan area is 1851.41km^2 with a population of 14.72 million. It is one of the most densely populated cities of India. Kolkata Municipal Corporation (KMC) is even more densely populated as its population density is 24,429 persons per km^2. Floating population is about 60,00,000 in KMC. Much of the city was originally a vast wet land, reclaimed over decades to accommodate the city population. Its elevation from mean sea level is from 1.5 m to 9 m. Average annual rainfall is 1500 mm. Floods in Kolkata are due to heavy rains in monsoon or because of tropical cyclones. In summer many of the depressions, which form in the head Bay of Bengal and move along monsoon trough, yield maximum rainfall in and around Kolkata region. Because of very flat flood plains of south Bengal delta, floods are a major concern for these areas. There are many non-permanent housing structures in Kolkata, which are subjected to heavy damage during floods. Slum dwellers constitute approximately 40 per cent of the population. On 4th may 2005, heavy rains killed 11 people in Kolkata and in the same year, on 21st October, 7 lakh people were affected due to heavy rains. In September (2nd and 3rd week) 2004, 17 persons died and 2700 houses were damaged. Kolkata was affected by severe floods during 22-26 Sept. 1999. On 27 May 2009, Cyclone Aila has crossed the West Bengal coast. At least 18 of the 45 fatalities in West Bengal were in Kolkata.

Mumbai

Mumbai is the financial capital of India. Its area is about 600 km^2 with a population of 17.7 million (2001). City is built by merging of 7 islands and hilly areas. Most parts of the city are developed with massive reclamation. Because of limited land area the population density of the city is growing rapidly. Mumbai is not only the most populated city in India, but also the sixth most populated city in the world. It is among the few port cities of the world where influx of work force for major industrial and economic activities has resulted in increase of total population from 12.6 million in 1991 to 17.7 million in 2001. Over 60 per cent of population resides in poorly built temporary settlements. South West monsoon lashes the city with rains between June to September. Some of the semi permanent synoptic systems like the "Off shore trough", "Off shore vortex", "Mid tropospheric cyclone" are responsible for heavy to very heavy rain fall in this city. Normal annual rainfall of Mumbai is 2422 mm. Floods in Mumbai are a common feature during the monsoon season. The existing storm drainage system in Mumbai was put in place in early 20th century. Only 3 outfalls to the sea have flood gates and rest of the 102 outfalls open directly into the sea. During high tide the sea water rushes into the drainage system causing more flooding.

A heavy rain in Mumbai leads to street flooding, disruption of traffic and telecommunication lines. City is paralyzed and thousands of working hours are lost causing economic loss, when railway tracks are submerged under water. Slums and hutments on the slopes of hills in suburban Mumbai face landslides, causing heavy causalities. Many people are killed when old buildings collapse in heavy rains. The unprecedented rains of 26-27 July, 2005 have drawn global attention.

This city has witnessed the historic rainfall of 944 mm in 24 hours, which is one of the eight heaviest rainfalls ever recorded (De et al, 2006). For the first time domestic and international airports were shut down for 30 hours during the period due to heavy flooding and poor visibility. Again on 31th July more than 700 flights were cancelled or delayed with the increase of water logging of runways. Rail links were disrupted and long distance trains were cancelled till 6th of August. Nearly 1000 human deaths were reported and estimated loss in terms of industry and commerce was about US $ 10 million. During 5-7 August, 2005, 8 persons died and many got injured due to landslide in Kurla. On 8th July 2000, 5 people died in building collapse and on 21st July, 65 people died and 50 got injured due to landslide in Ghatkopar area. Heavy rains on 7-10 June 1991 in Mumbai and Thane have taken 74 lives and injured100 people. A study by Tongdi Jamir et al, (2008) over west coast reveals that meteorological conditions and physiography of the study area make them vulnerable to floods during the summer monsoon season. In Mumbai, every year epidemics are reported during SW Monsoon season, where flooding mixes the sewerage with fresh water supply causing waterborne diseases like jaundice, cholera, hepatitis A etc. Thousands of cases of water borne diseases are reported every year.

Chennai

Chennai is located on the southern part of eastern coast of India. It is state capital of Tamilnadu with a population of 8.2 million. It is the fourth most populated city of India. Chennai is in northeastern part of Tamilnadu on a flat coastal plain with an average elevation of around 6.7 meters. Two rivers meander through the city, the Cooum River and Adyar River. Several lakes of varying sizes are located on the western fringes of the city. Chennai's economy has a broad industrial base in car, computer, technology, hardware manufacturing and health care. The city accounts for 60 per cent of country's automotive exports. The infrastructure and population of Chennai has developed many folds in recent years. The average annual rainfall of Chennai is 1300 mm. The city gets most of its seasonal rainfall during northeast monsoon season from mid October to mid December. Cyclones in Bay of Bengal hit the Tamil Nadu coast. On October (4th week) 2006, flash floods in many of the districts of Tamil Nadu including Chennai resulted in the death of 47 persons. 5500 people were evacuated to safer places. On 3-4 December 2005, 5,00, 000 people were affected by floods in Chennai and its suburbs after rain fed rivers and lakes inundated almost 75% of the city. 6 persons died due to electrocution and 5 persons were drowned in small ponds. In 1990, 15 persons died in Chennai due to floods. Silting of the rivers, lakes and houses in flood plains is the main cause for flooding in Chennai.

Analysis of extreme rainfall in four mega cities

The events and frequency of heavy rainfall (≥125 mm in 24 hrs) and phenomenal rainfall (≥150 mm in 24 hrs) during 1970 to 2006 have been analyzed for four mega cities.

In Mumbai heavy rainfall events during 1970-2006 for Colaba were 96 whereas Santacruz recorded 105 such events. The overall year wise rainfall trend for Colaba has shown a decease but Santacruz Airport shows an increasing trend (Fig.1a, 1b). In case of phenomenal rainfall both stations have same number of events i.e. 62 and show similar trends (Fig. 2a, 2b) for heavy rainfall. In Chennai for Nungambakkam 46 heavy rainfall events have occured as compared to 33 for Minambakkam Airport. Both stations show increasing trends (Fig.1c and 1d). There is a sharp difference in phenomenal rainfall events between Nungambakkam 27 and Minambakkam Airport 14 and both the stations show deceasing trend (Fig. 2c, 2d). Kolkata (Alipur) recorded 21 heavy rainfall events whereas 22 events were recorded in Dumdum Airport, showing deceasing trend (Fig.1e, 1f) for both the stations. But phenomenal rainfall events were more in Dumdum with similar deceasing trend (Fig.2e, 2f). Among the four mega cities Delhi has minimum number of such rainfall events. Heavy rainfall events recorded in Safdarjung were 14 and

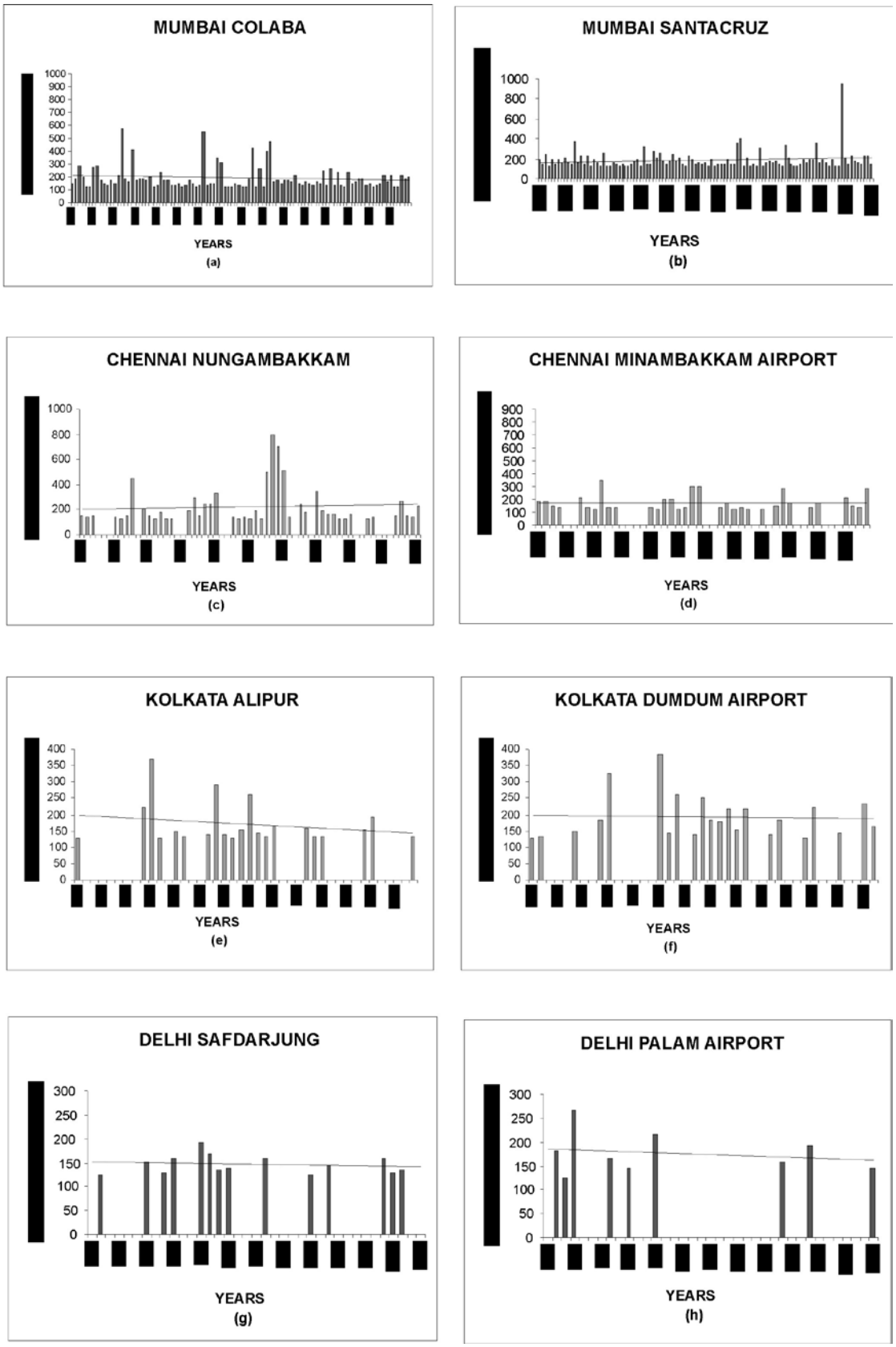

Figure 1(a-h). Year wise distribution of very Heavy Rainfall (≥125 mm and above) and their trends for Mega cities.

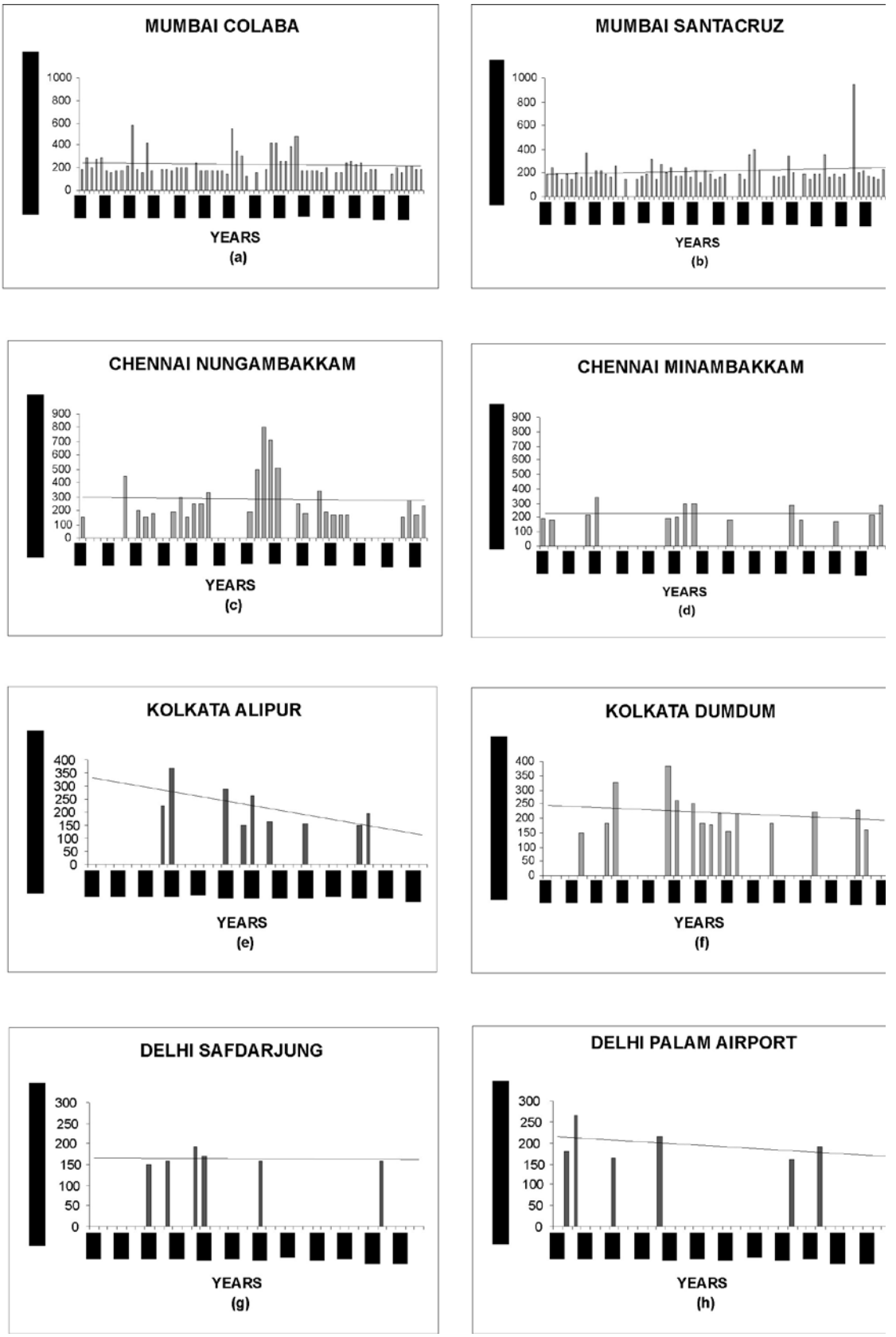

Figure 2(a-h). Year wise distribution of Phenomenal Rainfall (≥ 150 mm) and their trends for Mega Cities.

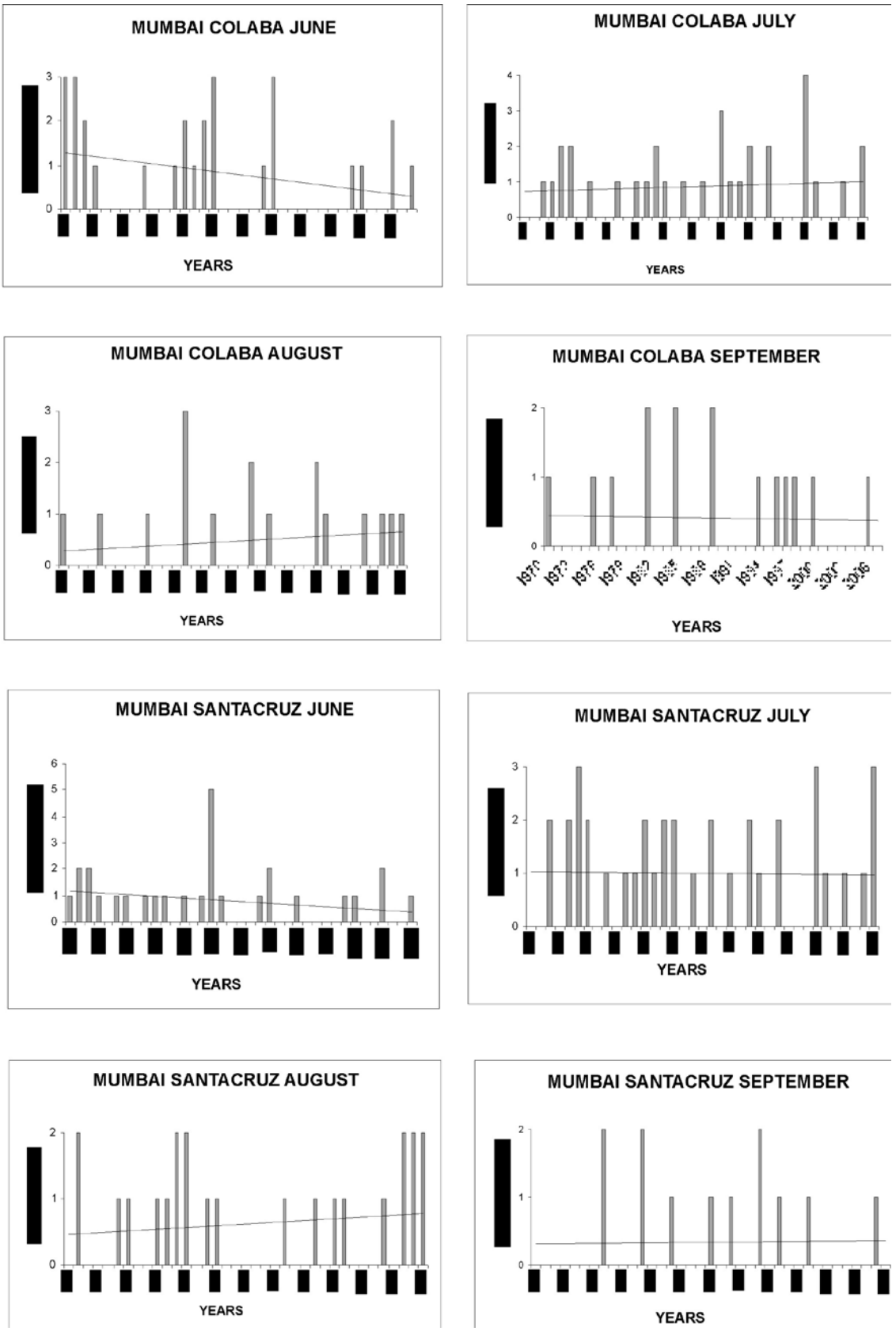

Figure 3. Month wise frequency analysis of very Heavy rainfall event during SW Monsoon for Mumbai

9 in Palam Airport. Phenomenal rainfall events recorded were 6 for both the stations. Delhi also shows deceasing trends (Fig.1(g&h) and Fig.2(g&h)), for both categories of rainfall like Kolkata.

From Fig. 3, it is observed that in Mumbai, there is decreasing trend for the months of June and September. Increasing trend is noticed for July and August for Colaba. Santacruz Airport shows deceasing trend in June and July and increasing trend in the months of August and September. Monthly frequency of heavy rainfall for Santacruz is more in July and August and less in September. This is same for the month of June, as compared to Colaba. In Chennai, heavy rainfall frequency is more during NE monsoon. Nungambakkam has more number of occurrences compared to Minambakkam for the months of October, November and December. However, Nungambakkam shows an increasing trend (Fig. 4) for October and December and deceasing trend for November. Whereas, Minambakkam shows a decreasing trend for all the months. In Kolkata there is no significant difference of monthly frequency

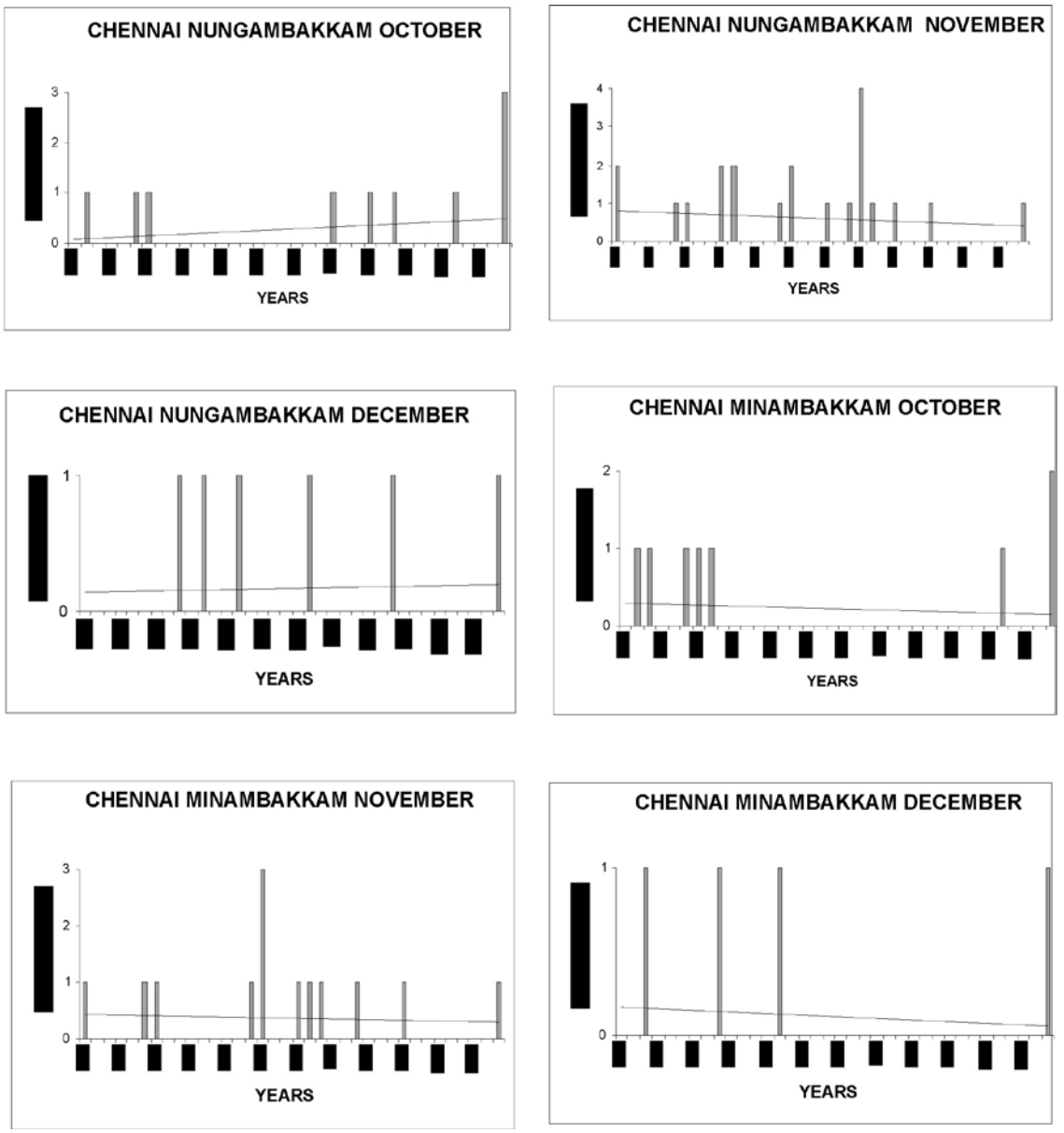

Figure 4. Month wise frequency analysis of very Heavy rainfall event during NE Monsoon for Chennai.

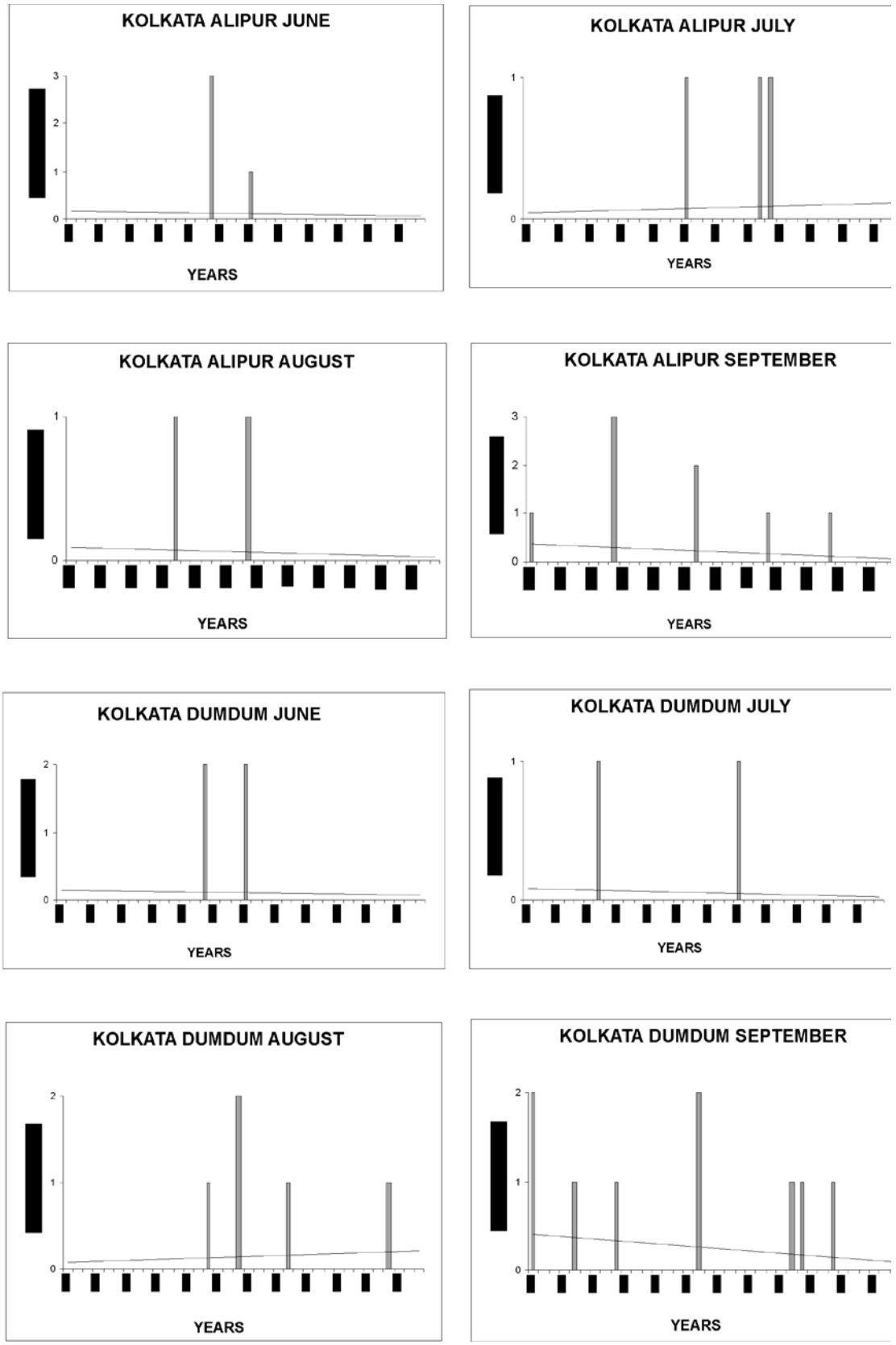

Figure 5. Month wise frequency analysis of very Heavy rainfall event during SW Monsoon for Kolkata.

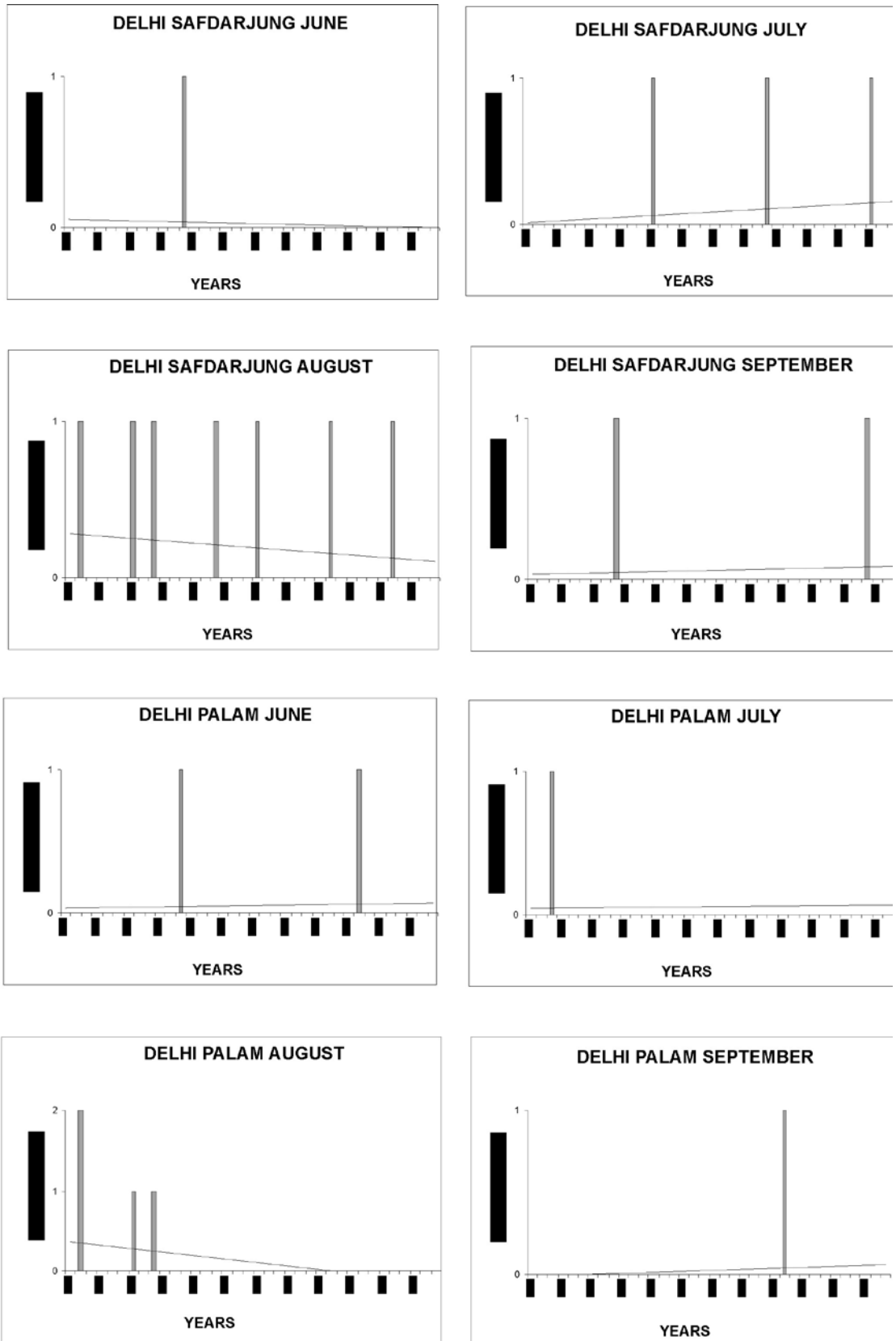

Figure 6. Month wise frequency analysis of very Heavy rainfall event during SW Monsoon for Delhi.

between two stations. However, there is an increasing trend (Fig. 5) in the months of July at Alipur and August for Dumdum. In Delhi, Safdarjung shows more number of events in August compared to Palam. Safdarjung shows an increasing trend in July and September and a decreasing trend in June and August. Whereas, Palam shows an Increasing trend (Fig. 6) for June, July and September and a decreasing trend in August.

Preventive and active measures:

Urban flood management in developing countries requires an evaluation of socio-economic issues related to land use and urban development in context to the frequent urban flooding (Tucci, 2004). Deaths due to natural hazards associated with floods are inevitable. However, impacts can be reduced by various measures, some of which are given below.

a. Better forecasting of heavy rain over mega cities with the help of Doppler radars.
b. Identification of vulnerable zones in and around the mega cities against risk of floods and improved disaster management procedures.
c. Improvement of old drainage systems, re-enforcement of weak and old buildings and introduction of area specific building codes.
d. Implementation of health and sanitation measures to prevent spreading of diseases.
e. Preparation of a long term plan aimed at diversification of industries and employment opportunities to prevent large scale migration of population and overcrowding of the mega cities.
f. Greater awareness among the public for the weather warning and forecasts.
g. Pollution control measures with planning of green cities, including urban reforestation.

CONCLUSIONS

Mechanism of urban flooding is very complex and location specific. In the recent years due to global warming flash flood frequencies have increased creating havoc in urban cities.

There are substantial spatial variations in extreme rainfall within and around Mega cities.

In the period (1970-2006) it is observed that there is an increasing trend of very heavy rainfall ($\geq$125mm) in Santacruz and over Colaba in Mumbai, Safdarjung and Palam airport in Delhi, Nungumbakkam and Minambakkam airport in Chennai, as all these observatories (Santacruz, Safdarjung, Nungambakkam) are located inside the city. There is, however, no significant trend for Alipur and Dumdum airports of Kolkata.

The number of deaths due to floods is minimum in Delhi as it is an inland station, as compared to other three Mega cities. The casualties are maximum in Mumbai. Landslides also cause increase in deaths and damage in Mumbai. Kolkata is very close to sea and is inside Ganges Delta plains. So, it is prone to flooding not only due to heavy rains but also due to tropical cyclones.

ACKNOWLEDGEMENTS

The authors are thankful to Dr. Jagadish Singh, Former Deputy Director General of Meteorology (Hydrology Division) and Deputy Director General of Meteorology (Training) for useful discussions.

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Manuscript received : June, 2012; accepted: Dec, 2012

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