The Extremes of the Extremes: Extraordinary Floods (Proceedings of a symposium held at Reykjavik, Iceland, July 2000). IAHS Publ. no. 271, 2002.

Highest floods in India

P. R. RAKHECHA*
Indian Institute of Tropical Meteorology, Pune, India
e-mail: p_rakhecha@hotmail.com

Abstract This paper provides information on the highest recorded floods at some sites in India's major river basins. The data available for the last 100 years or so indicate that the highest floods recorded on rivers in India had peak discharges ranging from 1170 $m^3 s^{-1}$ for a 133 km^2 area to 72 900 $m^3 s^{-1}$ for a 935 000 km^2 area. The flood comparison studies showed that the highest recorded floods in India are remarkably comparable with the highest floods reported from other parts of the world for drainage areas larger than 1000 km^2. Two powerful floods recorded in India—the flood of 6 September 1970 on the Narmada River and the flood of 11 August 1979 on the Machhu River were found to be record-breaking events in the world.

Key words highest floods; summer monsoon; cyclonic storm; heavy rainfall; spillways; Indian rivers; envelope curve

INTRODUCTION

India is situated in the monsoon climate zone of south Asia. Due to the monsoon circulation, almost 80–90% of the annual rain over most parts of the country falls during the summer monsoon season from June to September. During this period cyclonic disturbances from the Bay of Bengal and the Arabian Sea produce widespread and heavy rainfall which often causes severe floods in Indian rivers.

According to the records, about 210 severe floods with serious consequences have occurred in India during the 30 years from 1966 to 1995—almost seven floods every year. Of these, some large floods overflowed the banks of the rivers and inundated a lot of land and human habitat. Some extreme floods have damaged the levee systems and destroyed dams causing considerable loss of life and property. An example is an extreme flood of August 1979 on the Machhu River, which totally destroyed the Machhu-2 dam in the state of Gujarat. The flood disaster killed as many as 1500 people and caused damage worth millions of US dollars. Such high magnitude floods are extremely useful not only for examining the safety of existing dams, but also for investigating estimates of probable maximum floods (PMF) for spillways of any new dams built especially in the case of inadequate flood information at the design site. The purpose of this paper is to provide information on the highest recorded floods at some sites on Indian rivers and compare their values with the highest floods from around the world.

MAJOR RIVER BASINS OF INDIA

India has 14 major river basins (Fig. 1). These river basins are the principal sources of water for more than 990 million people in India. The Indus River, the Ganga River and

* *Present address:* 940, Flat above Jagdamba Sweets, Pimpri Waghere, Pune-411017, India

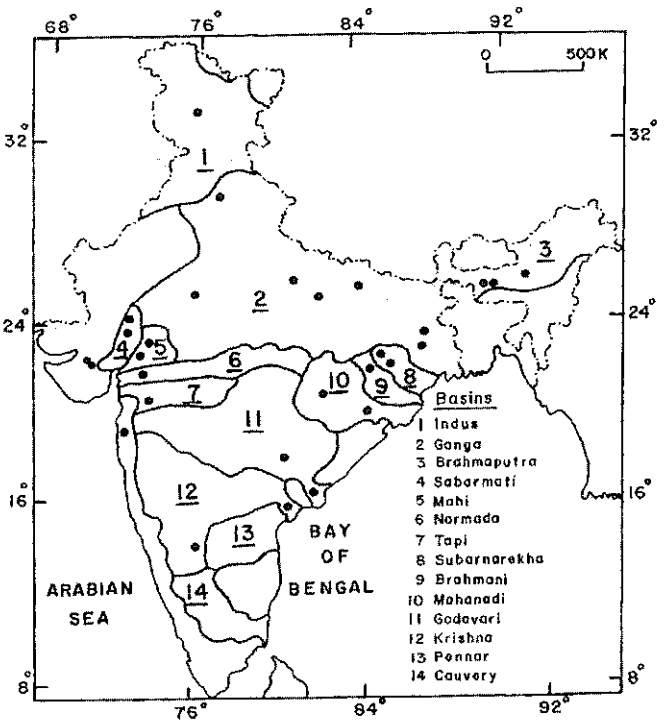

Fig. 1 Major river basins of India and locations of the highest floods in India.

the Brahamaputra River are the important Himalayan rivers in the northern part of India. These rivers are both snowfed and rainfed and therefore have continuous flow throughout the year. The Ganga River and its tributaries spread out like a fan on the plain of India forming the largest river basin with an area one quarter of the total area of India. The highest water levels and strongest flows in these rivers occur in the summer monsoon season.

The main rivers in central and southern India are the Mahanadi, the Subarnarekha, the Tapi, the Narmada, the Godavari, the Krishna, the Mahi, the Sabarmati, the Cauvery and the Pennar. These rivers are entirely rainfed with the result that many of them shrink into rivulets during the hot season.

Floods are caused by extraordinary meteorological situations that produce heavy to very heavy rainfall on a drainage area. In view of this, the meteorological causes of heavy rainfall over different river basins in India are briefly discussed.

METEOROLOGICAL CAUSES OF HEAVY RAINFALL

The principal causes of heavy to very heavy rainfall in India are:

- formation and movement of cyclonic disturbances across the country,
- breaks in the monsoon,
- thunderstorms.

Cyclonic disturbances are known to generate widespread and heavy rainfalls. During the summer monsoon season, cyclonic disturbances (mainly depressions) from the Bay of Bengal and the Arabian Sea move across the country and bring heavy rainfall. The rainfall area may be 400 km wide and 1000 km long, and point rainfall may range from 40 to 80 cm day^{-1} (Pisharoty & Asnani, 1957; Rakhecha & Pisharoty, 1996). Disturbances from the Arabian Sea move in a northerly or northeasterly direction and produce heavy rainfall over the Mahi River and the Sabarmati River basins. When a depression from the head of the Bay of Bengal moves, a belt of heavy rainfall spreads to the eastern part of the Ganga River basin and lower Brahamaputra River basin. With the further movement of the depression, the area receiving rain extends to the Mahanadi River and adjoining basins. By the time the depression moves over central India, it is weakened due to depletion of the moisture supply. Sometimes, the depressions after reaching central India intensify due to the fresh feed of moisture from the Arabian Sea. This causes another spell of heavy rains over the central and peninsular river basins. Towards the end of the monsoon, i.e. in September, some depressions after reaching central India curve northwards causing heavy rains and serious flooding both in the Indus River and upper reaches of the Ganga River basins.

Rainfall during the monsoon period is not continuous, but it alternates with active and break monsoon conditions. During a break, the monsoon trough shifts northwards from its normal position, and heavy rainfall occurs over the foothills of the Himalayas resulting in severe floods in the Himalayan rivers.

During the post monsoon months (October–December) more severe cyclonic storms form in the south Bay of Bengal in the latitude belt of 10°–15°N. These storms move inland and produce heavy rainfall over the Cauvery River and Pennar River basins.

Thunderstorms frequently occur in eastern India in the months of April and May. They are capable of releasing considerable amounts of rainfall although their areal extent is small. In some years due to excessive thunderstorm activity in the eastern region, the Brahamaputra River becomes flooded even in late May or early June.

HIGHEST FLOODS IN INDIA

The magnitude of a flood is measured by either its stage or its discharge rate. The stage is important in defining the extent of the area inundated and the minimum elevation of any structure built on the flood plain, as is the peak discharge in the design of spillways of dams. Systematic stages and discharges on several rivers at different sites in India are available since about 1950 as most of the gauging stations were established after Indian independence in 1947. Numerous scientific papers and reports contain information for different gauging sites about the highest floods, such as their date of occurrence, stage height, rate of flood discharge, etc. The highest flood discharges at sites on India's major rivers obtained from various publications and reports are listed in Table 1. The locations of these floods are shown in Fig. 1. Table 1 shows that the 12 major rivers in India have records at about 32 sites, with peak discharges ranging from about 1170 $m^3 s^{-1}$ for a 133 km^2 area to about 72 900 $m^3 s^{-1}$ for a 935 000 km^2 area. The highest-ever flood of 72 900 $m^3 s^{-1}$ was recorded on the mighty Ganga River in 1954. According to Kale (1999), the 1968 flood on the Tapi River at Ukai was the highest

Table 1 Highest floods in the major river basins of India.

No.	River basin	Stream	Site	Area (km^2)	Flood ($m^3 s^{-1}$)	Year
1.	Brahamaputra	Gish	-	133	1 170	July 1968
2.	Mahi	Kharm	Patadungri	212	1 177	–
3.	Subarnarekha	Ramiala	Ramiala	328	3 108	Sept. 1983
4.	Kutch	Moj	Moj	440	3 981	–
5.	Kutch	Brahmani	Brahmani	699	5 450	-
6.	Kutch	Machhu	Machhu-1	735	9 340	August 1979
7.	Kutch	Damanganga	Damanganga	1 813	12 900	–
8.	Kutch	Machhu	Machhu-2	1 930	16 307	August 1979
9.	Godavari	Kadam	Kadam	2 590	13 450	August 1958
10.	Sabarmati	Banas	Dantiwada	2 862	11 950	August 1973
11.	Mahi	Mahi	Chandangarh	4 320	8 160	June 1977
12.	Sabarmati	Sabarmati	Dharoi	5 540	14 150	August 1973
13.	Indus	Ravi	Madhopur	6 087	26 052	Sept. 1988
14.	Ganga	Yamuna	Tajewala	11 059	15 947	Sept. 1947
15.	Ganga	Tons	Meja Rd	17 400	10 800	July 1971
16	Brahmani	Brahmani	Bolani	18 070	13 570	August 1974
17	Mahanadi	Mahanadi	Kantamel	19 600	15 400	Sept. 1977
18	Ganga	Damodar	Rhondia	19 900	18 100	August 1935
19	Ganga	Ganga	Rishikesh	21 800	16 000	August 1924
20	Ganga	Chambal	Jhalawar	22 584	37 000	August 1969
21	Mahi	Mahi	Kadana	25 491	33 000	-
22.	Godavari	Indravati	Barthagudem	40 000	24 860	August 1976
23.	Ganga	Betwa	Sahijna	43 870	43 800	July 1971
24.	Ganga	Kosi	Barakshetra	59 052	23 085	August 1924
25.	Tapi	Tapi	Ukai	62 225	42 475	August 1968
26.	Ganga	Sone	Kolewar	67 878	36 800	July 1971
27.	Narmada	Narmada	Garudeshwar	88 000	69 400	Sept. 1970
28.	Mahanadi	Mahanadi	Naraj	127 000	44 827	August 1982
29.	Krishna	Krishna	Vijayawada	257 000	39 000	July 1903
30.	Godavari	Godavari	Dowlaishwaram	309 000	78 800	Sept. 1959
31.	Brahamaputra	Brahamaputra	Pandu	404 000	72 700	August 1962
32.	Ganga	Ganga	Farrakka	935 000	72 900	August 1954

since 1849, the 1970 flood on the Narmada River was the highest for the last 107 years, and the 1982 flood on the Mahanadi River was the highest since 1834. It is remarkable to find that the highest floods of 9340 $m^3 s^{-1}$ for a 735 km^2 area and 16 307 $m^3 s^{-1}$ for a 1930 km^2 area occurred in the arid region of the state of Gujarat. Figure 1 shows that most of the extreme floods have occurred in the northern and the central river basins, the areas most frequently impacted by the monsoon depressions from the Bay of Bengal.

The highest 32 flood values were plotted against their drainage areas in Fig. 2 and an envelope curve was drawn. Figure 2 shows that the remarkable floods at many sites fall far below the envelope line indicating that a much greater flood than has been experienced could occur on most rivers. As such, the envelope curve could be considered as an indicator of the reasonable limits for estimating maximum floods.

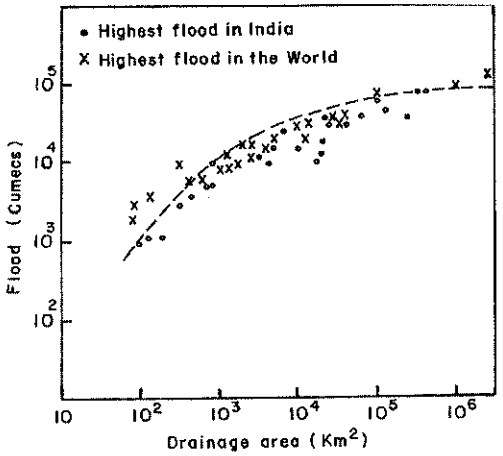

Fig. 2 Envelope curve of the highest floods in India compared with the highest floods in the world.

COMPARISON OF THE HIGHEST FLOODS IN INDIA WITH WORLD'S HIGHEST FLOODS

It is of interest to compare the highest floods recorded in India with those recorded in other parts of the world. Rodier & Roche (1984) have given the data for the 40 highest floods from different countries of the world. These data are given in Table 2. The available world flood data indicate that the highest floods with peak discharges ranging from 250 $m^3 s^{-1}$ for a 3.2 km^2 area to 370 000 $m^3 s^{-1}$ for a 4 640 000 km^2 area have been observed in the different rivers of the world. For comparison, the world's highest floods are plotted along with the highest Indian floods in Fig. 2. The figure shows that the flood discharges of the Indian rivers are remarkably comparable with the highest flood discharges recorded in the world for drainage areas larger than about 1000 km^2. However, for areas less than 1000 km^2, India's highest floods are considerably lower in magnitude. The records given in Tables 1 and 2 indicate that two floods recorded in India were record breaking floods in the world as they far exceeded any other flood for the same drainage size. The first flood was on the Machhu River on 11 August 1979, which destroyed the Machhu-2 dam. This flood peak of 16 307 $m^3 s^{-1}$ from 1930 km^2 was caused as a result of exceptionally heavy rainfall in the Machhu River basin. During the period 10–12 August 1979, the Machhu River basin received nearly four times the mean basin rainfall for August (Rakhecha & Mandal, 1983). The second flood was on the Narmada River on 6 September 1970. This flood peak of 69 400 $m^3 s^{-1}$ from 88 000 km^2 was caused by a depression during which several stations recorded rainfalls exceeding 20 cm in 24 h. The Narmada River is a west flowing river. For west flowing rivers like the Narmada River, the magnitude of the floods frequently gets amplified because the depressions move parallel to and in concert with the river flow.

Acknowledgement I express my sincere thanks to the symposium organizing committee for providing the financial support which enabled me to attend.

Table 2 Highest floods in the world.

No.	River	Country	Area (km^2)	Flood ($m^3 s^{-1}$)
1.	San Rafael	USA	3.2	250
2.	L. San Gorgonio	USA	4.5	311
3.	Halawa	USA	12	762
4.	SF Wailua	USA	58	2 470
5.	Bucy	Cuba	73	2 060
6.	Papenoo	France	78	2 200
7.	San Bartolo	Mexico	81	3 000
8.	Quinne	France	143	4 000
9.	Quaieme	France	330	10 400
10.	Yate	France	435	5 700
11.	Little Nemaha	USA	549	6 370
12.	Haast	New Zealand	1 020	7 690
13.	Midfork	USA	1 360	8 780
14.	Cithuatlan	Mexico	1 370	13 500
15.	Pioneer	Australia	1 490	9 840
16.	Hualien	Taiwan (China)	1 500	11 900
17.	Nyoda	Japan	1 560	13 510
18.	Kiso	Japan	1 680	11 150
19.	West Nueces	USA	1 800	15 600
20.	Machhu	India	1 930	16 307
21.	Tamshui	Taiwan (China)	2 110	16 700
22.	Shingu	Japan	2 350	19 025
23.	Pedernales	USA	2 450	12 500
24.	Daeryong Gang	North Korea	3 020	13 500
25.	Yoshino	Japan	3 750	14 470
26.	Cagayan	Philippines	4 244	17 550
27.	Tone	Japan	5 110	16 900
28.	Nueces	USA	5 504	17 400
29.	Ecl	USA	8 060	21 300
30.	Pecos	USA	9 100	26 800
31.	Betsiboka	Madagascar	11 800	22 000
32.	Toedong Gang	North Korea	12 175	29 000
33.	Han	South Korea	23 880	37 000
34.	Jhelum	Pakistan	29 000	31 100
35.	Hanjiang	China	41 400	40 000
36.	Mangoky	Madagascar	50 000	38 000
37.	Narmada	India	88 000	69 400
38.	Changjiang	China	1 010 000	110 000
39.	Lena	USSR	2 430 000	189 000
40.	Amazonas	Brazil	4 640 000	370 000

REFERENCES

Kale, V. S. (1999) Long period fluctuations in monsoon floods in the Deccan peninsula, India. *J. Geol. Soc. India* **53**, 5–15.

Pisharoty, P. R. & Asnani, G. C. (1957) Rainfall around monsoon depressions over India. *J. Met. Geophys.* **8**, 1–6.

Rakhecha, P. R. & Mandal, B. N. (1983) Estimation of peak flood at Machhu-2 dam on the day of disaster of 11 August 1979. *Vayu Mandal* **13**, 71–73.

Rakhecha, P. R. & Pisharoty, P. R. (1996) Heavy rainfall during monsoon season: point and spatial distribution. *Current Sci.* **71**, 177–186.

Rodier, J. A. & Roche, M. (1984) *World Catalogue of Maximum Observed Floods*. IAHS Publ. no. 143.