

Flood risk assessment of River Indus of Pakistan

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Abstract Annual flood peak discharges is widely used in risk assessment. Major sources of flooding in Pakistan are River Jhelum, River Chenab, River Kabul, and upper and lower parts of River Indus. These rivers are major tributaries of the River Indus System which is one of the most important systems of the world and the greatest system of Pakistan. River Indus is the longest river of Pakistan containing seven gauge stations and several barrages, and it plays a vital role in the irrigation system and power generation for the country. This paper estimates the risk of flood in River Indus using historical data of maximum peak discharges. On the basis of our analysis, we find out which dam/barrage reservoir need to be updated in capacity, and whether there are more dams/barrages needed.

Keywords Annual flood peak discharges · Risk assessment · River Indus

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Introduction

Life loss and capital damages are of major concerns in human societies. One of the major causes to such phenomena is floods which occur in almost all the South Asian countries. Especially, over the past 25 or 30 years, the frequency and magnitude of disastrous floods is increased due to the impacts of climate changes. Now, risk assessment is defined as scientific quantification of hazard from data to understand the procedures involved in (Coburn and Spence 1994). Incompatibility between hazard and vulnerability is the main cause of risk (Ologunorisa and Abawua 2005). In the context of risk, some closely related terms are also used, viz., hazard and vulnerability. However, according to the United Nation Commission for Human Settlements (UNCHS-HABITAT 1981), there are clear distinctions among the meanings of these terms. They define that risk can be directly related to the perception of disaster, given that it incorporates total losses and harm that can undergo after a natural hazard. Risk involves a future potential condition, a function of the magnitude of natural hazard and the vulnerability of all exposed elements in a determined moment, whereas, hazard is defined as the probability that, in a given period and a given area, a catastrophic damaging natural phenomenon occurs.

Flood risk is measured in terms of probability of occurrence of events and the related consequences (Smith 1996). This means that risk and improbability in water resources take place from the natural inconsistency of geophysical progressions and alterations in difficult socio-economic features. As a result, risk analysis is performed on the measurement of the probabilities of occurrence of flood and their likely consequences (Kaczmarek 2003). There are various techniques for assessment of flood risk, such as assessing meteorological parameters, hydrological

parameters, socioeconomic factors, and combination of hydrometeorological and socioeconomic factors along with assessment based on geographical information system as explained in (Ologunorisa and Abawua 2005). The authors state that meteorological parameters have been widely used in most countries, such as Malaysia, Korea, USA, Australia, Ethiopia, and Israel including Pakistan. Risk is also assessed via annual flood peak discharge (Kattlemann 1997), the technique is now termed as assessment of flood through hydrological parameters, and the key factor is rainfall on snow-covered catchments during warm storms. He also notices that rivers of Sierra Nevada, California, experience most destructive floods all through warm storms when rain waters falls in snow-covered catchments of the river. Oriola (1994) noticed that many of the Nigerian urban surroundings flooding are caused by the violation of the river canal. The author attributes illiteracy, ununiformity, deprived ecological culture and supervision, inefficient municipality laws, and community unawareness as major socioeconomic factors contributing in flood risk. He furthers the insights in flood risk by showing that flood risk in Nigeria acts as a function of not only the above characteristics but the amount and duration of precipitation, slope of river basin, and some other parameters of river basin. Combination of hydrometeorological and socioeconomic factors is explained (Hogue et al. 1997). They identify the hazard risk in Chittagong by predicting the probability of occurrence of the storm flooding of different extents and depths. They divide the city into five major sectors whereas the residents and the economic importance of that sector are considered as the importance indices while the sectors are trading or industrial sector, deliberated housing sector, business or commercial sector, ingenuous housing sector, and combined or mixed sectors. Laughlin and Kalma (1990) built up a technique for flood risk mapping based on regional weather data and local territory. This study demonstrates the regional weather and the territory's effect with 3D block diagram. Hayden (1988) noticed that the existing literature based on flood risk assessment does not make a general nature of flooding; therefore, author delineates the climate regions on global scale by using the basis of meteorological parameters. McEwen (1989) compares the rain fall pattern with the published study of other long-standing rainfall proceedings to assess the local deviation in the nature of severe rainfall. It is further discussed that flood risk can also be assessed by the probability of embankment or dam failure (Van et al. 2005). The Indian Meteorological Department (1971) classifies the seasonal rainfall as the flood of less intensity if it lies in 0–26% of normal, the moderate flood if it is between 26% and 50% of normal, and the flood of high intensity if the flood is above 50% of the normal.

Geographical Information system (GIS) is another very successful tool to assess the flood risk in the flood-prone areas. Recently, GIS technique is shown to be able to unite all the known procedures and factors for predicting flood risk (Ologunorisa and Abawua 2005). In this study, it is observed that GIS technique is more powerful technique to assess the flood risk. As for Pakistan, this technique is used to assess flood risk in flood-prone areas near River Indus (Khan 2007). The author uses remote sensing, geographical information system, and digital image processing to assess the flood risk in River Indus. The study integrates the remote-sensing techniques with geographic information system using satellite data and gives a solution to reduce flood risk by constructing some new dams on the river. Tahirkaili and Nawaz (2003) and Nawaz and Shafique (2003) also use the same methodology to assess the flood risk in the river Jhelum, Pakistan.

This study examines flood risk of river Indus in Pakistan. We use flood peak discharge data from 1942 to 2008 of the River Indus to assess risk. The data set, obtained from Federal Flood Commission, Islamabad, comprise less than 30 recorded values at seven gauge stations. In “[Estimation of probable maximum flood](#)” section, we describe our calculations regarding modeling of the data using normal, log-normal, and Weibull distribution on both the observed and simulated data models. Here, we also compute return period (T) and exceedence probability (P) of the flood of different intensities for the period from 1992 to 2008. The “[Flood risk assessment of River Indus](#)” section is used to describe our results obtained after applying log-Pearson type III (LP3) analysis in order to forecast flood peak discharge values with specified T for the same period. “[Summary and discussion](#)” section is opens with discussion and summarizes the conclusion based on our findings.

Estimation of probable maximum flood

Pakistan faces large amounts of frequent river flooding every year due mainly to monsoon rains and melting snow which push the rivers of Pakistan over their banks. The major rivers which cause flooding in the country are the River Jhelum and the River Chenab in Punjab province and lower part of River Indus in Sindh province, see Fig. 1). Besides, hill torrents also take some part in flooding Sindh. This sort of flooding also affects the hilly areas of North-West Frontier Province (NWFP), Baluchistan, and northern areas of Pakistan. Districts of Charsadda, Noshera, and Peshawar in NWFP are exposed to risks from flooding in River Kabul. Large cities of Pakistan like Karachi, Lahore, and Rawalpindi have experienced flooding due to the failure of sewerage system to cope up with intense



Fig. 1 Location map of the River Indus in Pakistan

precipitation. In the present work, assessment of flood risk on the river Indus is attempted. This river, i.e., the River Indus is a great trans-Himalayan river and one of the longest rivers in the world. It is the longest river in Pakistan containing seven dams/barrages and having a length of 1,800 miles. It has a total drainage area of about 450,000 square miles of which 175,000 square miles lie in mountains and foothills and the rest lie in the semiarid plains of Pakistan. The annual rainfall in the Indus region varies between 125 to 500 mm and excluding the mountainous regions of the country, the Indus valley lies in the driest part of the subcontinent (Britannica). River has seven gauge stations to monitor its flow continuously throughout the year. Likewise, it has seven dams/barrages

namely Tarbela Dam, Kalabagh or Jinnah Barrage, Chashma Barrage, Taunsa Barrage, Guddu Barrage, Sukkur Barrage, and Kotri Barrage, respectively.

We obtain uneven data of annual peak discharge of River Indus from 1942 to 1992 and evenly distributed yearly data from 1992 to 2008. According to Federal Flood Commission, Islamabad, classification of flood in Pakistan is defined 250,000–300,000 cusecs per cubic feet per second (cfs) as low flood, 300,000–450,000 cfs as medium flood, 450,000–650,000 cfs as high flood, 650,000–800,000 cfs as very high flood, and 800,000 cfs to onward as extremely very high flood (Annual Flood Report 2006). First, we compute probable maximum flood (PMF) from observed values. The values of PMF are shown in Table 1 for normal,

Table 1 Estimation of PMF using normal, log-normal, and Weibull distributions on observed data of flood peak discharge from 1942 to 2008 (significance level used is $\alpha=0.05$)

Gauge stations	Normal		Log-normal		Weibull	
	PMF (cfs)	AD statistic	PMF (cfs)	AD statistic	PMF (cfs)	AD statistic
Tarbela	369	0.216	368	0.258	369	0.250
Jinnah	–	–	517	0.255	514	0.665
Chashma	485	0.223	489	0.544	485	0.209
Taunsa	478	0.520	–	–	479	0.522
Guddu	630	0.508	657	0.520	632	0.456
Sukkur	648	0.628	–	–	645	0.810
Kotri	473	0.531	–	–	470	0.435

×1,000 except for AD test results

log-normal, and Weibull distributions. The Anderson–Darling (AD) test results show that Jinnah Barrage cannot be modeled by normal distribution. Similarly, Taunsa, Sukkur, and Kotri Barrages do not follow log-normal distribution. However, it is quite clear that data of all dams/barrages follows Weibull distribution.

We next perform simulation on observed data by employing normal, log-normal, and Weibull distributions and generate samples of sizes 100 for each of the seven dams/barrages of the river Indus (viz., Tarbela Dam, Kalabagh or Jinnah Barrage, Chashma Barrage, Taunsa Barrage, Guddu Barrage, Sukkur Barrage, and Kotri Barrage, respectively). Each of these samples is used to compute PMF of hundred years for each dam. The results are summarized in Table 2. The AD test results for this also show that Jinnah Barrage cannot be modeled by normal distribution whereas Taunsa, Sukkur, and Kotri Barrage do not follow log-normal distribution. Similarly, Weibull distribution again is found to fit in all the cases considered in the present study.

The use of simulation proves to be very useful as it gives us estimate of PMF for hundred years. This means that classification among various gauge stations of the River Indus can now be performed by finding where the values of

PMF (Table 2) lie in the ranges as defined by Federal Flood Commission, Islamabad as mentioned above. For instance, one can easily see that Tarbela Dam and Kalabagh are on the risk of medium flood, Chashma and Taunsa Barrage are on the risk of high flood, Guddu and Kotri Barrage are on the risk of high to very high flood, and Sukkur Barrage is on the risk of very high flood.

Let us now compute the return period using the following Weibull formula:

$$T = (n + 1)/m \quad (1)$$

where T denotes the return period or recurrence interval, and P stands for exceedence probability,

$$P = 1/T \quad (2)$$

of low, moderate, high, very high, and extremely very high flood, where n is the number of annual flood peak discharge, m shows the rank of flood; the highest peak has $m=1$, second highest peak has $m=2$, and so on (Kiely 1998). We summarize our calculation in Table 3 which manifests this procedure for Tarbela Dam; flood of 1992 has return period of 18 years with 5% exceedence probability, flood of 1995 has return period of 9 years with 10% exceedence probability, flood of 1997 has return

Table 2 Estimation of PMF of simulated data of flood peak discharge from 1942 to 2008 (significance level used is $\alpha=0.05$)

Gauge station	Normal		Log-normal		Weibull	
	PMF (cfs)	AD statistic	PMF (cfs)	AD statistic	PMF (cfs)	AD statistic
Tarbela	360	0.729	362	0.273	362	0.219
Jinnah	–	–	518	0.235	524	0.375
Chashma	478	0.6	458	0.431	470	0.213
Taunsa	476	0.263	–	–	471	0.288
Guddu	588	0.302	703	0.159	671	0.396
Sukkur	663	0.563	–	–	650	0.266
Kotri	480	0.280	–	–	471	0.144

×1,000 except for AD test

Table 3 Annual MPD data in cusecs from 1992 to 2008 versus return period T and exceedence probability P for Tarbela Dam

Year	MPD (cfs)	Log peak discharge X	m	T	P
1992	500,000	5.69897	1	18	0.05
1995	480,000	5.681241	2	9	0.1
1997	450,000	5.653213	3	6	0.166
1994	420,000	5.623249	4	4.5	0.2
1996	402,000	5.604226	5	3.6	0.27
2005	372,900	5.571592	6	3	0.33
1999	372,000	5.570543	7	2.5	0.4
2006	371,800	5.570309	8	2.25	0.44
1993	370,000	5.568202	9	2	0.5
2003	350,000	5.544068	10	1.8	0.55
1998	347,700	5.541205	11	1.6	0.625
2007	292,600	5.466274	12	1.5	0.666
2002	290,900	5.463744	13	1.38	0.72
2004	269,900	5.431203	14	1.28	0.78
2000	243,600	5.386677	15	1.2	0.83
2008	237,000	5.374748	16	1.125	0.88
2001	229,900	5.361539	17	1.0588	0.94

period of 6 years with 16.6% exceedence probability, and finally, we see that flood of 2001 has return period of 1 year with 94% exceedence probability, which shows that flood of larger intensities have low probability of occurrence and longer recurrence interval whereas flood of smaller intensities occurs more frequently with short return period. We find similar results for other gauge sites of River Indus.

Flood risk assessment of River Indus

This section applies log-Pearson type III analysis for flood risk assessment. For this analysis, the annual flood events from 1992 to 2008 are presumed to be random variables observing log-Pearson type III probability distribution. The analysis is performed in conjunction with the historic record adjustments (Flynn et al. 2006). If X shows the ordinary logarithm of the peak discharge data, S is the standard deviation of X , \bar{X} is the mean of X , K_N is the 10%

significance level critical value for outlier test statistic for samples of size N from normal distribution, then

$$X_H = \bar{X} + K_N S \tag{3}$$

is the logarithmic higher outlier test threshold, and

$$X_L = \bar{X} - K_N S \tag{4}$$

is the logarithmic low outlier test threshold. The historic record adjustment is applied by computing

$$W = (H - N_{HP} - N_{HO}) / (N_s - N_{HO}) \tag{5}$$

to mitigate the historic peaks and high outliers, where W is the weight applied to below threshold systematic peak, N_s is the number of systematic peaks (peaks below high outlier threshold and above base peaks), N_{HP} is the number of historic maximum peaks, N_{HO} is the number of high outliers, and H shows the time period. The number of peaks above the flood base is $N = H - W \times N_{BB}$ with N_{BB} being the number of peaks lower than the flood base

Table 4 Parameters for log-Pearson type III analysis by using peak flow data from 1992 to 2008

#	Gauge site	\bar{X}	X_H	X_L	S	\bar{S}	N_s	N_{HO}	\bar{M}	G
1	Tarbela	5.54	5.67	5.40	0.11	0.12	15	01	5.54	–
2	Kalabagh	5.64	5.81	5.47	0.13	0.03	15	01	5.64	–
3	Taunsa ^a	5.60	–	5.38	0.17	–	–	–	–	–0.1
4	Chashma	5.64	5.82	5.46	0.14	0.07	16	00	5.64	–
5	Guddu	5.64	5.99	5.28	0.28	0.27	15	01	5.64	–
6	Sukkur	5.56	6.01	5.11	0.35	0.16	16	00	5.6	–
7	Kotri ^a	5.37	–	4.64	0.38	–	–	–	–	–0.4

The values of $K_N=1.28$, $N_{HP}=01$, $N_{BB}=0$, $H=N=17$, $P_0=1$, $\bar{G} = 0$, $W=1$

^aNo observations could be obtained via historic record adjustment

Table 5 Flood risk calculation in Tarbela Dam and Taunsa Barrage by using peak flow data from 1992 to 2008

Number	(T)	Tarbela Dam		Taunsa Barrage	
		(K)	\bar{Q} (cfs)	(K)	Q (cfs)
1	2	0.000	343,510	0.017	4,044,867
2	5	0.842	433,491	0.846	561,680
3	10	1.282	489,531	1.27	664,056
4	25	1.751	557,263	1.716	791,943
5	50	2.054	605,927	2.000	885,931
6	100	2.326	653,221	2.252	978,628.8
7	200	2.576	699,939	2.482	1,071,674.7

including any peak flow of zero magnitude or low outlier. Few sites possess annual peak flow of magnitude zero or a peak of very low magnitude called gauge base. The probability of flood exceeding the flood base is

$$P_0 = \frac{N}{H} \tag{6}$$

The weighted mean, \bar{M} , weighted standard deviation, \bar{S} , and weighted skew coefficient, \bar{G} , of systematic peaks are given, respectively, by

$$\bar{M} = \left(W \sum X' + \sum X'' \right) / N, \tag{7}$$

$$\bar{S} = \sqrt{\frac{W \sum (X' - \bar{M})^2 + \sum (X'' - \bar{M})^2}{N - 1}} \tag{8}$$

and

$$\bar{G} = \sqrt{\frac{N \times \left(W \sum (X' - \bar{M})^3 + \sum (X'' - \bar{M})^3 \right)}{(N - 1)(N - 2)\bar{S}^3}} \tag{9}$$

where X' and X'' both are ordinary logarithm of systematic peaks and historic maximum peaks plus high outliers, respectively. The risk of flood, \bar{Q} in cfs, is described here as under:

$$\log \bar{Q} = \bar{M} + \bar{S}K, \tag{10}$$

where K is the frequency factor (see frequency factors K for gamma and LP3 distributions (Haan 1977)). If there are no peaks above the high outlier threshold, i.e., any historic peak and high outlier (see Taunsa and Kotri in Table 4), then LP3 Analysis without historic record adjustment is used (Hydraulic Design Manual 2004) in which peaks below the lower outer threshold is excluded such that

$$\log Q = \bar{X} + SK \tag{11}$$

where Q is the risk of flood in cfs, \bar{X} is the mean of logarithmic annual peaks, and S is the standard deviation of logarithmic annual peak discharges.

Now, by using Eq. 6, we calculate probability of flood exceeding flood base (P_0) which equals to 1 because the annual flood peak discharge record of River Indus is concern, no zero or low magnitude peak is obtained in last 17 years, likewise weighted mean (\bar{M}) by using Eq. 7, standard deviation (\bar{S}) by using Eq. 8, and weighted skewness (\bar{G}) by using Eq. 9 of systematic peaks for Tarbela Dam, Kalabagh, Chashma Barrage, Sukkur Barrage, and Guddu Barrage along with logarithmic high outlier threshold (X_H) and logarithmic low outlier threshold (X_L ; see Table 4). Later than using Eq. 10, we calculate the risk of flooding in the aforesaid dams/barrages where as Eq. 11 is used to calculate flood risk in Taunsa and Kotri. Table 5 shows these calculations for the gauge sites Tarbela and Taunsa by using the parameters of Table 4 with specified return period while the remaining gauge stations of River Indus also experience the same procedure for calculating the flood risk.

Table 6 Design/spillway capacity of reservoirs are shown with maximum peak discharge data according to Federal Flood Commission, Islamabad classification with return periods

Gauge sites	Design/spillway capacity of reservoir (cfs)	Extremely very high flood		Very high flood		High flood	
		MPD	T	MPD	T	MPD	T
Tarbela	1,500,000	–	–	–	–	500,000	18
Jinnah	950,000	849,245	18	654,200	9	551,553	6
Taunsa	950,000	–	–	655,079	18	612,300	9
Chashma	1,100,000	–	–	668,336	18	635,400	9
Guddu	1,200,000	1,086,919	18	790,163	4.5	626,410	3
Sukkur	1,500,000	1,068,072	18	757,390	4.5	572,500	3
Kotri	850,000	826,369	18	799,440	9	–	–

Summary and discussion

The values of PMF as obtained through observed and simulated data shows similar results, as discussed in “[Estimation of probable maximum flood](#)” section. This also means that our results of simulation are found to be consistent with those obtained by using observed data. Also, the use of simulation proves to be very useful as it gives us estimate of PMF for hundred years. This means that classification among various gauge stations of the River Indus can now be performed by finding where the values of PMF (Table 2) lie in the ranges as defined by Federal Flood Commission, Islamabad and mentioned in “[Estimation of probable maximum flood](#)” section. For instance, one can easily see that Tarbela Dam and Kalabagh are on the risk of medium flood, Chashma and Taunsa Barrage are on the risk of high flood, Guddu and Kotri Barrage are on the risk of high to very high flood, and Sukkur Barrage is on the risk of very high flood. To the best of our knowledge, such a classification is done the first time on the River Indus, using probabilistic approach. However, Khan (2007) performs similar analysis through GIS technique. Also, the results of Weibull formula show that the small floods are more likely to occur than large floods. These results are also confirmed by LP3 analysis (see Table 4) which is also used here to forecast flood risk. Moreover, our analysis suggests (see Table 6) that, except Tarbela Dam, there is an urgent need to construct new dams/barrages on the River Indus and to increase the spillway capacity of reservoir because the differences in the design capacities of reservoirs and corresponding maximum peak discharges (MPDs) are very little. The construction of dam in the vicinity of Jinnah Barrage is also of great importance provided all political issues are sorted out. The return period, corresponding to each value of risk, is found to be helpful in assessing what precautionary measures should be taken in case of flood according to risk value. For example, the flood risk at Tarbela Dam is 343,510 and 433,491 cfs against 2-and 4-year return period, respectively. Although both of these values lie in the range of medium flood, however, the difference in the values should reduce the amount of investment required in dealing with the expected flood.

List of acronyms

Terms	Acronyms
Federal Flood Commission Islamabad	FFC
Annual flood peak discharge	APD
Probable maximum flood	PMF
Maximum peak discharge	MPD
Standard deviation of simulated flood data	σ

Coefficient of variation	CV
Anderson–Darling (goodness of fit) Test	AD Test
Significance Level (at $\alpha=0.05$, the critical value is 2.5018, and if the value of test statistic is smaller than the critical value, we cannot reject the null hypothesis, which according to this study states that data does follow the normal, log-normal, and Weibull distributions.)	α
Cusecs	cfs
Return period	T
Probability of exceedence	P
Number of annual flood peak discharge	n
Rank of the flood	m
Log peak discharge data	X
Standard deviation	S
Sample size	N
Mean of X	\bar{X}
10% significance level critical value for outlier test statistic	K_N
Log higher outlier test threshold	X_H
Log lower outlier test threshold	X_L
Weight applied to below threshold systematic peaks	W
Number of systematic peaks	N_s
Number of historic maximum peaks	N_{HP}
Number of high outliers	N_{HO}
The time period	H
Number of peaks lower than flood base	N_{BB}
Probability of flood exceeding the flood base	P_0
Ordinary logarithm of systematic peaks and historic maximum peaks	X'
High outliers	X''
Risk of flood with historic peak adjustment	\bar{Q}
Risk of flood without historic peak adjustment	Q
Frequency Factor	K
Weighted mean	\bar{M}
Weighted standard deviation	\bar{S}
Weighted skewness	\bar{G}
Log-Pearson type III	LP3

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References

Annual Flood Report (2006) Federal Flood Commission, Ministry of Water & Power, Islamabad
 Coburn AW, Spence RJS (1994) Vulnerability and risk assessment, disaster management training program, 2nd edn. UNDP
 Flynn KM, Kirby WH, Hummel PR (2006) User’s manual for program PeakFQ annual flood frequency analysis using Bulletin 17B Guidelines: U.S. Geological Survey, Techniques and Methods
 Haan CT (1977) Statistical methods in hydrology. The Iowa University Press, Iowa

- Hayden BP (1988) Flood climates. In: Baker et al (eds) Flood geomorphology. Wiley, New York
- Hogue MM et al (1997) Storm surge flooding in Chittagong City and associated risks. IAHS Publications 239:115–122
- Hydraulic Design Manual (2004) Texas Department of Transportation, Design Division (DES)
- Kaczmarek Z (2003) The impact of climate variability on flood risk in Poland. Risk Anal 23(3)
- Kattlemann R (1997) Flooding from rain-on snow events in the Sierra Nevada. IAHS Publications 239:59–95
- Khan G (2007) Flood hazard assessment and mitigation along River Indus from Chashman Barrage to Sukkur Barrage using satellite image. M.Phil thesis, Institute of Space and Planetary Astrophysics, University of Karachi
- Kiely G (1998) Environmental engineering. McGraw-Hill, Singapore
- Laughlin GP, Kalma JD (1990) Flood risk mapping for landscape planning: a methodology. International Journal of Theoretical and Applied Climatology 42:41–51
- McEwen LT (1989) Extreme rainfall and its implication for flood frequency: a case study of the Middle River Tweed basin, Scotland. Trans Inst Br Geogr 14(3):287–298
- Nawaz F, Shafique M (2003) Data integration for flood risk analysis by using GIS/RS as tools. In proceedings of MAP Asia, Second Annual Asian Conference and Exhibition in the field of GIS, GPS, Aerial Photography and Remote Sensing
- Ologunorisa TE, Abawua MJ (2005) Flood risk assessment: a review. App Sci Environ Mgt J 9(1):57–63
- Oriola O (1994) Strategies for combating urban flooding in developing countries: a case study from Ondo. The Environmental 14 (1):57–62
- Indian Meteorological Department (1971). Rainfall and Drought in India, Report of the Drought Research Unit, Poona
- Smith K (1996) Environmental hazards. Rutledge, London
- Tahir-kaili T, Nawaz F (2003) Role of GIS and RS for flood hazard management in Pakistan: a case study of Jhelum, Pakistan. MAP Asia 2003. <http://www.gisdevelopment.net/proceedings/mapasia/2003/disaster/index.htm>
- UNCHS (1981) Settlement planning for disasters, Nairobi, World Meteorological Organization
- Van E et al (2005) Quantitative flood risk assessment for polders. Reliab Eng Syst Saf 90:229–237