Flood Hazard Modeling and Flood Risk Zoning for a River Basin

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Abstract In recent years the number and scale of water related disasters, flood in particular has been increasing. The losses from floods often offset years of hard-won social and economic development. The problem is further expected to be aggravated with the phenomena of climate change. Therefore, mitigation and managing of flood hazards has become a priority for alleviating poverty, ensuring socio economic progress, preserving our eco-systems and ensuring the gains of development. The paper presents procedure for flood hazard modeling and flood risk zoning for a river basin. Floods of various return periods have been estimated using the L-moments approach. Rating curves have been developed employing the Artificial Neural Network and the least squares techniques. Depth of flooding, inundation for various return periods and risk associated with the flooding have been simulated using the HEC-RAS package. The flood inundation simulated by the HEC-RAS has been compared with the flood inundation mapped using the satellite data.

Key Words Flood hazard, Hydrologic Modeling, L-moments, Flood risk zoning.

INTRODUCTION

Flood is the most frequent natural disaster claiming loss of life and property compared to any other natural disaster. About one-third of all losses due to nature's fury are attributed to floods. On an average floods claim a loss of more than 50 billion US dollars per year and 40000 victims per year in the last decades of the twentieth century in the world (Berga, 2000). In India also, floods are the most frequently faced natural disasters. As reported by Central Water Commission (CWC) under Ministry of Water Resources, Government of India, the annual average area affected by floods is 7.563 million ha. This observation is based on the data for the period 1953 to 2000 published in Indian Water Resources Society (IWRS, 2001) with variability ranging from 1.26 million ha in 1965 to 17.5 million ha in 1978. On an average floods have affected about 33 million persons during 1953 to 2000 and average annual damage due to floods is about IRs. 46 billion. There is every possibility that this figure may increase in future due to rapid growth of population and increased encroachments of the flood plains for habitation, cultivation and other activities (Kumar et al., 2005).

Some of the important policies on flood management have been described by Kumar et al. (2005). Various types of structural as well as non-structural measures have been envisaged to reduce the damages in the flood plains in India. Construction of embankments, levees, spurs, etc. have been implemented in some of the states. The total length of constructed embankments is 16800 km and drainage channels are of 32500 km. A total of 1040 towns and 4760 villages are currently protected against flood. Barring occasional breaches in embankments, these have provided reasonable protection to an area of about 15.07 M ha. A large number of reservoirs have been constructed and these reservoirs have resulted in reduction of intensity of floods. The non-structural measures such as flood forecasting and warning are also being adopted. The flood forecasting and flood warning in India commenced in 1958, for the Yamuna river in Delhi. It has evolved to cover most of the flood prone interstate river basins in India. The Central Water Commission has established a flood forecasting network for 70 rivers basins covering 18 States/Union Territories. The forecasts are issued at about 175 stations. Out of these 145 stations are for river stage forecasts and 28 for inflow forecasts to the reservoirs. A Working Group of National Natural Resources Management System (NNRMS, 2002) standing committee on water resources for flood risk zoning of major flood prone rivers considering remote sensing input was constituted by the Ministry of Water Resources in 1999. The working group recommended flood risk zoning using satellite based remote sensing with a view to give thrust towards implementation of flood plain zoning measures. There is a need for taking more effective structural and non-structural measures of flood management and flood damage reduction based on long term reliable data, advance analyses and modelling procedures and antecedent rainfall forecasting using information based on radar, satellite based instrumentation and high resolution Numerical Weather Prediction (NWP) models. It also necessitates capacity building for implementation of these measures and bridging the gaps between the developed advance and robust procedures and their field applications.

Definitions of Terms

The definitions of terms (i) flood inundation map, (ii) flood hazard map, (iii) flood risk zone map and (iv) flood plain zoning map used in the study are described below.

Flood inundation map

A flood inundation map provides information about the areal extent of inundation for a reach of a river during a flood event when the flood water in the river overtops its banks and leads to the flooding of adjoining areas or flood plains. The flood inundation map for a reach of river may be prepared by demarcation with physical inputs i.e. by demarcating the various locations of the flood plains which get inundated during a particular flood, by hydraulic/hydrologic modelling and using the satellite data.

Flood hazard map

A flood hazard map provides information about the return period associated with the areal extent of inundation for a reach of a river. The flood hazard maps are prepared delineating areas subjected to inundation by floods of various magnitudes and frequencies. These maps may serve as important tools in proper flood plain management. It is necessary that the area flooded by a particular flood is shown by suitable colour scheme or designs on the map. In addition, explanatory notes, tables and graphs may also be provided with flood hazard maps to facilitate their use.

Flood risk zone map

A flood risk zone map provides information about the risk associated with the damages caused or losses resulting from a flood event in a particular area or flood risk zone. Preparation of flood risk zone map incorporates the financial aspects and provides the actuarial inputs for flood insurance plans and for other purposes.

Flood plain zoning map

A flood plain zoning map categorizes various zones based on administrative legislations for planning and development of the flood plains for various purposes such as agricultural activities, play fields, industrial areas and residential areas etc. Preparation of flood plain zoning maps takes into consideration the inputs from flood inundation, flood hazard and flood risk zone maps.

Methodology

The methodology for flood hazard modeling and flood risk zoning for a reach of a river basin is briefly described as follows. The objective of the study are: (i) to develop L-moments based flood frequency relationships using the annual maximum peak flood series and the partial duration series for the gauging sites of the river reach, (ii) to develop rating curves for the gauging sites of the river reach, (iii) to prepare flood inundation maps for the river reach, (iv) to prepare flood hazard maps for the river reach, (v) to prepare flood risk zone maps for the river reach and (vi) to predict flood inundation and flood hazard areas for various stages of river flow.

In the study, risk is defined as the probability of occurrence of a flood at least once during successive years of design life. The return period for which a structure should be designed is computed based on the risk acceptable. Risk acceptable depends upon economic and policy considerations. If for a time invariant hydrologic system the probability of occurrence of an event, x, greater than the design event, x_o, during a period of n years is P, then the probability of non-occurrence, Q is 1-P. The probability that x will occur at least once in the n years i.e. the risk of failure, R is: $R = 1-(1-1/T)^n$; where, R is the risk, T is the return period for which the structure should be designed, and n is the design life of the structure (Robson & Read, 1999). Using the above formula, the return period T can be determined for a given R (acceptable risk) during a period of time in years (n). The flood corresponding to this T is estimated and routed through the river reach for estimation of the water surface profile and inundation mapping. The expression of risk mentioned above may be extended to incorporate other variables related to losses due to floods, which can be defined as functions of return period (T). The flow chart illustrating the general terminology of flood inundation mapping, flood hazard mapping, flood risk zone mapping and flood plain zoning is shown in Fig. 1.

Analysis and results

In the study, flood frequency analysis has been carried out using the L-moments approach (Hosking & Wallis, 1997; Kumar & Chatterjee, 2005; Kumar et al., 2003). For identifying the robust frequency distribution for the respective gauging sites, L-moment ratio diagram and Z^{dist} statistic criteria have been adopted. Table 1 gives the Z^{dist} statistic values for seven sites of the study area. The values of the parameters of the robust identified distributions for the stream flow gauging sites are given in Table 2. Floods of various return periods viz. 2, 10, 20, 25, 50, 100, 200, 500 and 1000 return periods have been estimated for the seven stream flow gauging sites of study area, using the robust identified frequency distribution for each of the stream flow gauging sites. The Digital Elevation Model (DEM) of the study area has been prepared employing the GIS package Arc View 3.2 (Fig. 2). Rating curves have been developed using the least squares approach and the Artificial Neural (ANN) technique (Kumar et al., 2004). The mosaic of satellite data for the study area covered in three satellite scenes of IRS 1C and 1D has been prepared and flooding for some of the previous years simulated by the hydraulic modelling have been compared with the spread of flooding over the flood plain estimated from the analyses of the remote sensing data using the GIS package ERDAS. Hydraulic modeling of the river reach has been carried out using the HEC-GeoRas 3.1 and HEC-RAS 3.1.2 (Hydraulic Engineering Centre-River Analysis System) packages developed by the U.S. Army Corps of Engineers. Fig 3 shows flood plain area inundated and depth of flooding for 1000 year return period flood for the study area. Fig 4 illustrates flood plain area inundated for various return periods for the study area. Flood risk zone maps have been prepared for various risk levels and for different durations of flooding. Fig 5 shows flood risk zone map for a risk (R) of 25% over a period (n) of 25 years.

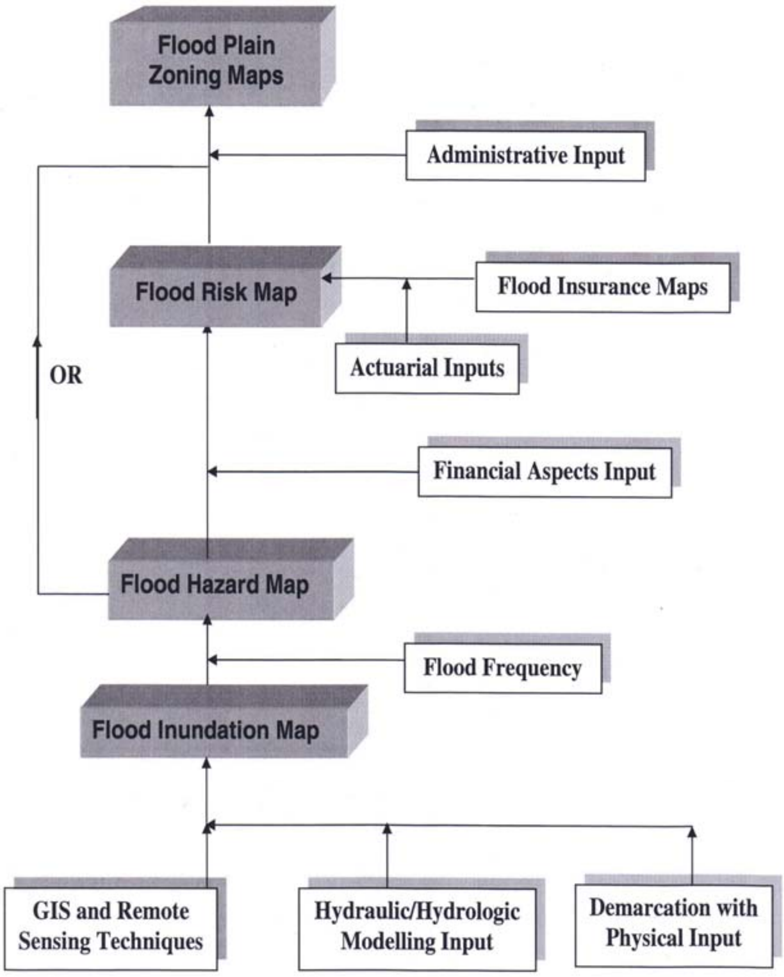

Fig. 1 Flow chart illustrating the general terminology of flood inundation mapping flood hazard mapping, flood risk zone mapping and flood plain zoning

Table 1 Z_i^{dist} -statistic for various frequency distributions

Sl. No.	Distribution	Site-1	Site-2	Site-3	Site-4	Site-5	Site-6	Site-7
1	GLO	-0.04	0.37	0.35	1.91	0.72	0.10	1.03
2	GEV	--0.66	-0.01	-0.62	1.51	-0.26	-0.12	0.42
3	GNO	-0.50	-0.08	-0.26	1.38	0.03	-0.33	0.36
4	PE(3)	-0.50	-0.24	-0.33	1.12	0.02	-0.69	0.17
5	GPA	--1.77	-0.88	-2.19	0.57	-1.97	-0.76	0.90

Table 2 Values of parameters for various distributions for seven gauging sites

Site	Distribution	Parameters of the Distribution		
Site-1	GEV	$\xi = 0.856$	$\alpha = 0.238$	k = -0.025
Site-2	GLO	$\xi = 0.999$	$\alpha = 0.174$	k = -0.002
Site-3	GNO	$\xi = 1.022$	$\alpha = 0.210$	k= 0.208
Site-4	GPA	$\xi = 0.230$	$\alpha = 0.978$	k = 0.269
Site-5	GLO	$\xi = 0.905$	$\alpha = 0.162$	k = -0.316
Site-6	PE-III	$\mu = 1.000$	$\sigma = 0.339$	$\gamma = -0.166$
Site-7	PE-III	$\mu = 1.000$	$\sigma = 0.433$	$\gamma = 1.010$

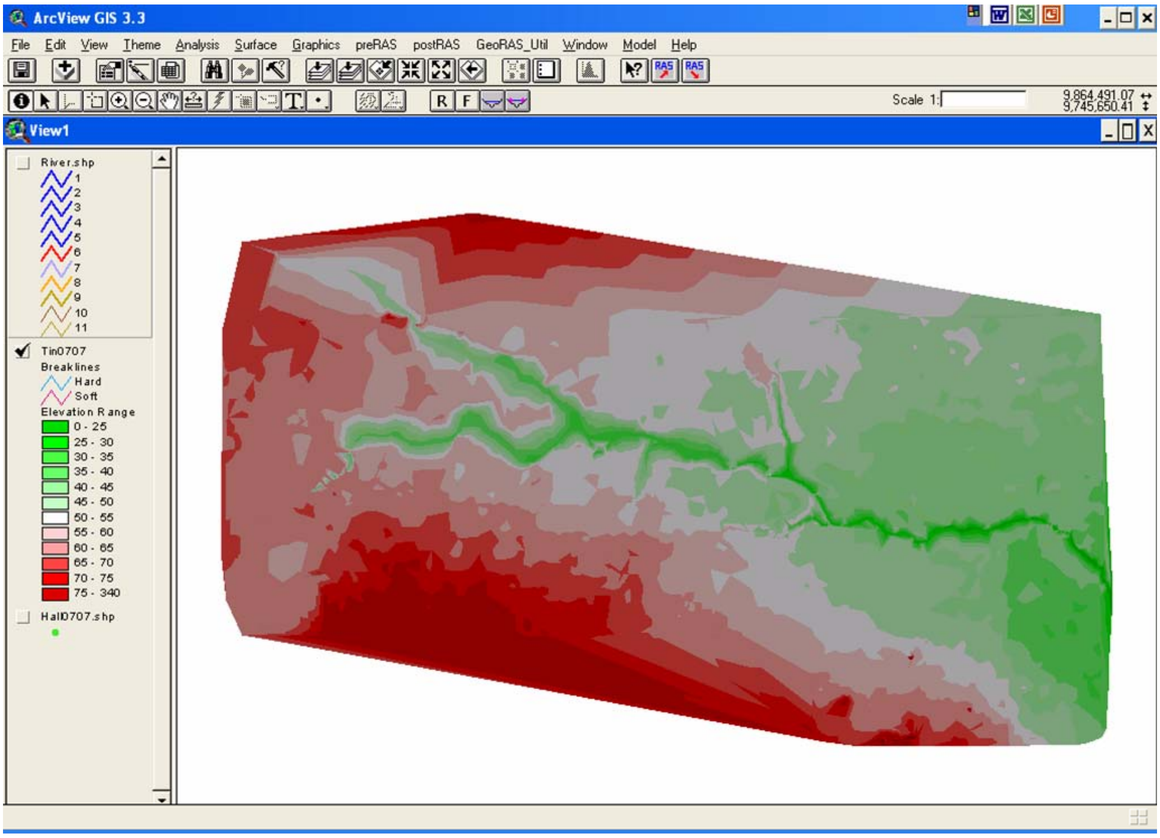

Fig. 2 Digital Elevation Model (DEM) of the Study Area

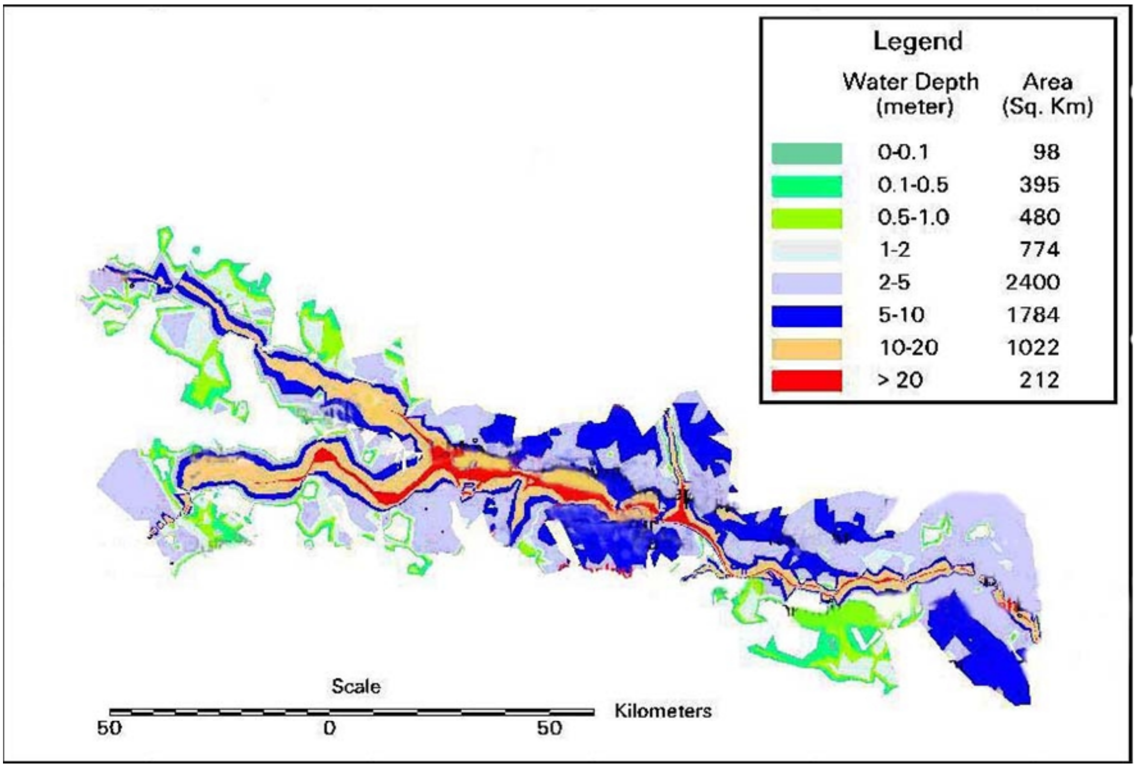

Fig. 3 Flood plain area inundated and depth of flooding for 1000 year return period flood for the study area

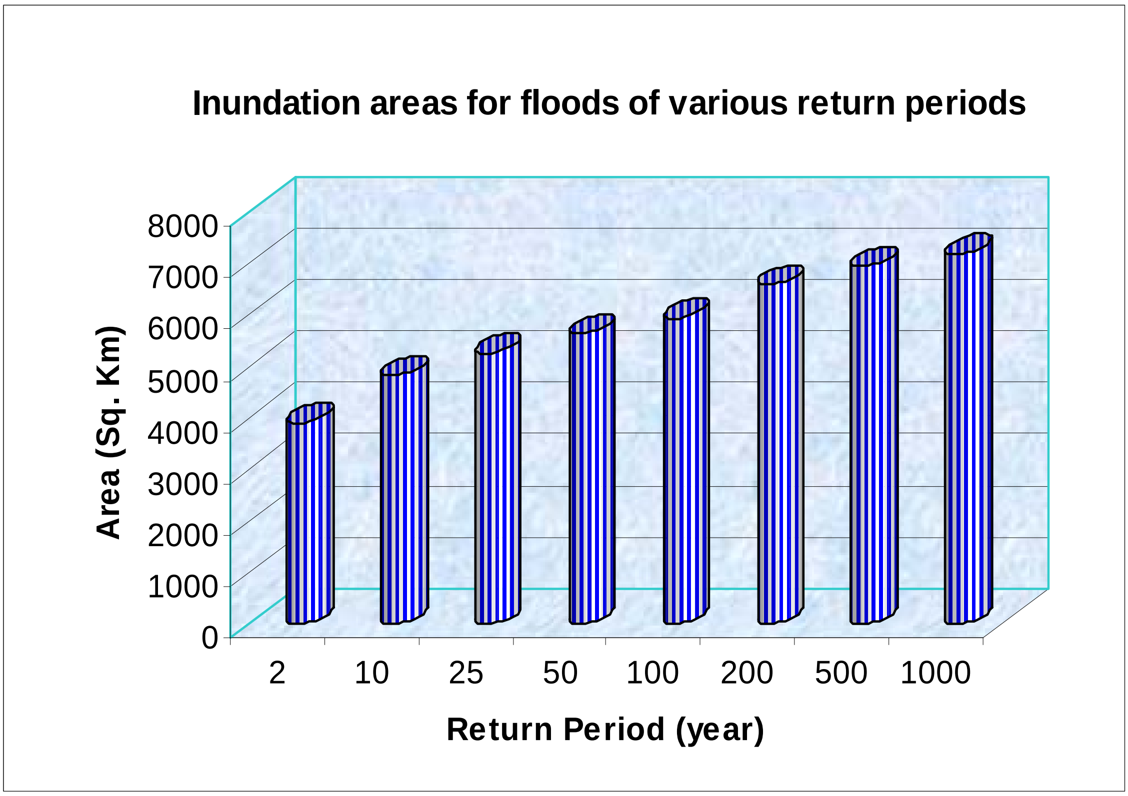

Fig. 4 Flood plain area inundated for various return periods for the study area

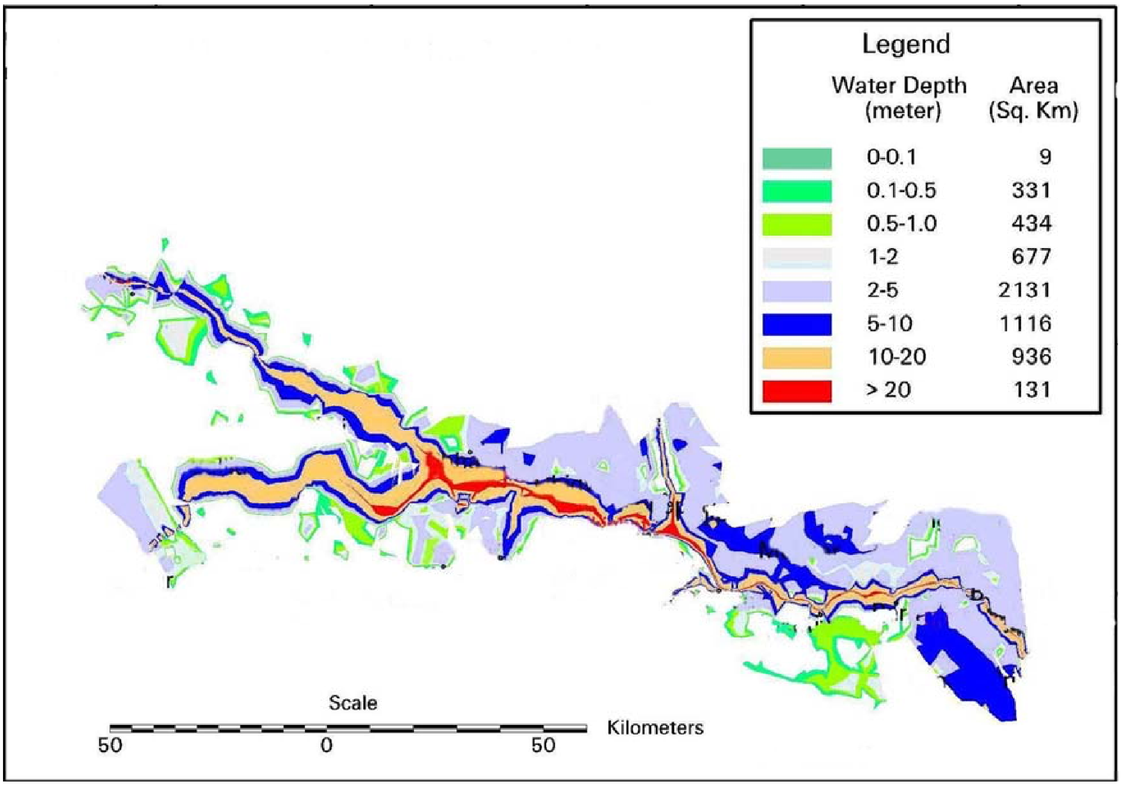

Fig. 5 Flood risk zone map for a risk (R) of 25% over a period (n) of 25 years

CONCLUSIONS

In this study flood inundation maps, flood hazard maps and flood risk zone maps have been developed for a river reach of a basin. The flooded areas for some of the years for the study area simulated by the HEC-RAS package have been compared with the flooding mapped using the satellite data employing the GIS package ERDAS. These maps may be used for land use planning, flood insurance purposes and flood damage reduction. The calibrated and validated hydrologic model, as described in the study may be coupled with a distributed rainfall-runoff model using the antecedent rainfall forecasts based on radar, satellite based instrumentation and high resolution Numerical Weather Prediction (NWP) models and may be used for simulation of flood inundation, depth of flooding and risk associated with the flooding in real time for flood mitigation and management. Presently, there are many uncertainties in forecasting heavy rainfall and the uncertainty should be minimised, quantified and presented as an integral part of the forecast. It would help in providing improved flood hazard warning and lead to better flood management and flood damage reduction.

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