Parametric Evaluation for Flood Management: A Review

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Abstract

Flood is a disastrous event causing loss, damage and destruction to life, property and environment. Due to population growth and resulting industrial, commercial and agricultural activities the devastations due to flood are making more severe impact on mankind. Thus, in view of assessing, mitigating and managing the floods, the present paper reviews different flood management techniques. Different components associated with flood management have been studied. These different components involves the salient parameters associated with management of flood like rainfall, discharge, water level, land cover, topography and population density, were critically studied. The parameters were utilized for flood hazard assessment and management of the flood affected areas. The flood affected areas could be managed using non-structural or structural measures at province level and nearby stream level. Various techniques for management of flood were critically reviewed and a generalized composite Hybrid Flood Management System (HFMS) and Flood Management Index (FMI) for parametric evaluation are suggested as the outcome of the study.

Keywords: Devastation, Flood Management Index (FMI), Hybrid Flood Management System (HFMS), Mitigating, Mapping, parameters.

1 Introduction

Occurrence of flood is a natural phenomenon and it may also be influenced by manmade activities. Flooding is the most common disaster of nature among all disasters leading to economic losses and deaths [1] and can be defined as a mass of water, which produces runoff on land with high flow, which overburdens the natural channel. Flood is a major cause for loss of lives, crops and properties. Flood occurs frequently and causes enormous risk to human life and property [2]. Flood damage has been provoked by rapid economic progress [3]. Major causes of floods are intense precipitation, inadequate capacity within river banks to contain high flows, silting of river beds, landslides leading to obstruction of flow, change in the river course, retardation of flow due to tidal and backwater effects, poor natural drainage, cyclone, heavy rain storms, snowmelt, glacial outbursts and dam break failures. Many parameters affect the extent of damages arising from a flood. The damages depend upon depth of flooding, velocity of floodwaters, duration of flooding, sediment load and warning time. Some historical damage assessment procedures have focused on depth of flooding [4-5].

The severity of the floods by excessive rainfall depends on the nature and extent of rainfall and characteristics of watershed. Hence occurrence and pattern of flooding could be different in different regions. The problem of flooding is increasing day by day.

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Thus, in view of assessing, mitigating and managing the floods, the present paper reviews different management techniques. Different components associated with flood management have been studied. These different components involves the salient parameters associated with management of flood like rainfall, discharge, water level, land cover, topography, population density etc. Parametric evaluation was carried out after identifying the associated parameters. Identified flood affected areas were managed using non-structural or structural measures at province level and nearby stream level. The present paper includes different flood assessment, management and mitigating techniques applied as below:

- Flood inundation mapping for identification of areas under potential flood threat.
- Flood forecasting, early warning and evacuation system for preparedness and planning.
- Mandatory insurance policies for preparedness, planning and recovery.
- Strategies based on technical and non technical stakeholders' views
- Flood damage estimation to identify the feasibility of water resources project.
- Structural measures as a flood protecting structure for flood management.

2 Flood Management Techniques

2.1. Flood Inundation Mapping

Identification of area under potential flood threat can be achieved after identifying the associated parameters for flood inundation mapping or flood plain zoning The flood affected areas in the Kosi river basin, India were demarcated [6] using a multicriteria decision technique, Analytical Hierarchy Process (AHP) [7], to systematically evaluate conflicting and qualitative parameters. The population density was considered as an important parameter for flood hazard mapping [8]. A framework for flood modeling and mapping was developed in which rainfall, spatial data and hydrological data were integrated [9]. River terrain models were created for hydrodynamic modeling and flood inundation mapping [10]. The techniques presented were mapping and analyzing river channel data, interpolation of river cross-sections and integration with surrounding topography. The extent of flooding, soil loss due to erosion and sediment load in basin were mapped and soil erosion was estimated using the universal soil loss equation and revised universal soil loss equation was used to identify the damaged areas [11]. Flood was affected by several parameters like poor agricultural practices, uncontrolled developments in floodplains, clear cutting of vegetative cover and narrow waterways. Study helped in identification of areas that needed conservation, extent of soil loss and flooding in different parts of the watershed. Flood inundation mapping was carried out using computational model by integrating maps with hydraulic data to obtain flood plain mapping [12].

2.2. Flood Forecasting, Early Warning and Evacuation System

Flood forecasting and early warning system would be helpful for management of flood prone areas and helps in preparedness and mitigation. After having mapped the affected areas, it should be protected through flood forecasting, early warning and evacuation system. Flood forecasting and early warning system would be helpful for management of flood prone areas and helps in preparedness and mitigation. Flood was forecasted using artificial neural networks [13]. Artificial neural network was used to complete information processing of the network through interaction of neural cells for flood forecasting from historical data. A real time flood forecasting system was developed which was made from five modules; real-time rainfall data conversion, hydrologic forecasting, model calibration, precipitation forecasting and analysis [14]. This model was used for flood forecasting using real-time data. A model for early warning system for flood prevention and disaster management was designed which monitors sensor network installed in flood protecting structure, detects sensor signal, calculates probability of dike failure and simulates dike breaching and flood propagation [15]. Tropical storm disaster was examined using ground elevation at each building and building floor heights [16]. Storm surge risk was examined by incrementally increasing the inundation level and assessing the resulting flooding pattern. Spatial dataset were developed for road network for evacuation planning and digital elevation model was developed for flood risk assessment.

2.3. Mandatory Insurance Policies

Mandatory insurance policies help in preparedness, planning and recovery of the damaged utilities and properties. A technology for disaster prevention, early warning and mitigation of flood losses was presented and focused on property value and insurance strategies for a developing region [17]. The parameters incorporated in this decision model helps in estimating value of property lost, compensation to be provided and requirement of funds for flood disaster. The insurance policies for short-term and long-term damages were suggested and a model was generated for insurance related flood risk index, flood hazard index, long-term flood impact on sustainability index and sustainable development index [18]. Indices were integrated to classify study area into different zones for providing suitable flood risk policies.

2.4. Strategies based on technical and non technical stakeholders' views

Consideration of stakeholders' views helps for making an acceptable decision on any specific problem or issue. Some strategies for technical and non technical Stakeholders' could be applied for response and fighting. It involves response of the stakeholders' collectively for fighting against flood. On the basis of stakeholders' decisions, watersheds, catchments, drainage basins and agricultural farms would be utilized for preparedness and response against flood threat. A tool by considering views of large number of technical and non-technical stakeholders was developed using questionnaire for flood management [19]. Flood risk management was carried out by storing runoff water on farmland by incorporating views of stakeholders [20]. A flood and agriculture risk matrix tool was designed for investigating and managing the affected areas. Good farming practices were suggested for conserving soils, maintaining infiltration capacity, pollution control and protection of wildlife and landscapes. Open-book watershed model was developed for flood monitoring. The rainfall information of upstream region was gauged and rainfall-runoff variation, infiltration, overland flow and river flow of downstream region were estimated [21]. Stream flow was forecasted by connecting a forecasting algorithm to the stream flow output. It was a satellite based flood monitoring system for lowermost region using global precipitation measurement mission with no restriction of district or state boundaries. Watersheds or reservoirs were identified as sustainable flood retention basin which help in flood defense and pollution control. Drinking water reservoirs available in the specific area were kept full and their spillways were continuously operated for flood management and control [22]. According to them, this simple operation would create capacity to enhance water storage in the upper reaches of the catchments, which reduces the chances of flooding at down-stream reaches.

2.5. Flood Damage Estimation

Flood damage estimation is useful for identifying the losses and compensation to be paid to the stakeholders. It is necessary to identify the feasibility and planning of a water resources project. Flood damage information was useful for comparison of losses with project cost to obtain a better benefit-cost ratio [23]. Damage during a flood was directly proportional to flood depth, hence damages corresponding to depths were investigated and a depth-damage relationship was developed from interview surveys. Two categories of damages were involved namely, structural and content damages. Structural damages were the damages that cannot be carried during evacuation and content damages were the damages that can be carried while evacuation. Total 287 interviews were conducted to develop data inventory. Damages were estimated with warning and without warning, for long duration floods and for different household characteristics. A flood model using stream discharge and topographic data was developed to determine frequency of floods over the floodplains which estimate the damages and losses to various types of buildings and infrastructure, vehicles, agricultural crops and population [24]. Damage to crops depends on the timing and duration of flooding. Indirect economic loss methodology estimated indirect agricultural losses. Based on damages incurred, the model also estimated the need for shelter. A decision support system for assessment of flood damage using remote sensing image layers and other feature layers like zoning layer, survey database and census block boundaries were used for calculation of flood damage and loss of life [25]. The model illustrated stage-damage curves and estimated flood damages and loss of lives. A model for estimating flood affected areas and damages was developed using the sources which lead to flood like stream, river and elevation below water level [26]. The flood damage was presented in raster format by overlaying flooded area with thematic maps which helps in estimating flood area and damage, for flood fighting and control. Extensive damage evaluation involves parameters such as the depth and frequency of flooding, velocity of runoff, erosion potential of inundated land and socioeconomic values of flooded areas. Damages during a dam-break flood are sudden and harmful and cause loss of lives, properties and environment. An equation was derived for maximum dam-break discharge using a common formula and compared the discharges with other formulae [27]. The stability of dam was assessed using an evaluation model which incorporates loss of life, economic losses, environmental impact and established dam risk assessment software based on risk assessment index methods [28]. The Indian Ocean tsunami in 2004 and the East Japan tsunami in 2011 caused devastating damage to coastal areas [29]. Tsunami fluid force acting on a bridge deck and its wave load was evaluated by considering effects of the breaker bores and the variation of horizontal waves by hydraulic experiments [30].

2.5. Structural measures for flood protection

Structural measures are the historical methods for managing the floods. It was difficult to control the water if it left the river [31]. Hence, structural measures were required to protect the existing regions. Levees were an important alternative due to their relatively low construction costs, general effectiveness in protecting low-lying areas and are politically expedient. However construction of levees may change the hydrological conditions of the downstream areas [32-34]. Association of State Floodplain Managers (ASFPM) has recommended 500-year level of protection for any federal investments on structural measures [35]. Impact of flooding on property values should also be considered as properties get devalued immediately after a flood event [36-37]. However, the depression in property values remains for many years and also impacts surrounding non flooded areas in the similar way [38]. Failure mechanism and performance of levee was modeled and identified. It focuses on each component of the levee system to determine its failure modes. Various failures considered were failure of water-side protective facing by vegetation, burrowing animals, floating objects, river geomorphology, burrows and erosion. Failure due to composition of levee, pipes through levee, seepage in body of levee and internal erosion were also considered. All the visible information

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and disorders like disorder position on levee, disorder characteristics i.e. burrows, vegetation, slope erosion, photograph of the disorder and comments related to the disorders were entered in the software using digital forms for further decision making and analyzing performance of levee [39].

3 Discussion

Different assessment and management techniques like flood inundation mapping, flood forecasting, early warning, evacuation system, mandatory insurance policies, strategies based on views of technical and non technical stakeholders', flood damage estimation and structural measures for flood protection have been included in the present paper. Each technique focuses on certain specific issues related to mitigation and management of flood.

These assessment, management and mitigating techniques are integrated together to derive a Hybrid Flood Management System (HFMS). Various components of HFMS are shown in Fig. 1. Different parameters related to occurrence of flood are responsible for making a correct decision for analysis and mapping of the flood. These parameters could be integrated in a multicriteria decision making technique to obtain an index called as Flood Management Index (FMI) [40] as given in equation 1.

$$\text{Flood Management Index (FMI)} = \Sigma\, W_1 * W_2 * W_3 \quad (1)$$

In above equation, W_1, W_2 and W_3 are the weights of first, second and third level parameters, respectively. The vulnerability can be assed based on different parameters. These parameters can be classified and used to estimate the FMI. The classification of parameters has been shown in Fig. 2. The different parameters considered at level 2 are hydrological parameters, hydraulic parameters, land use or land

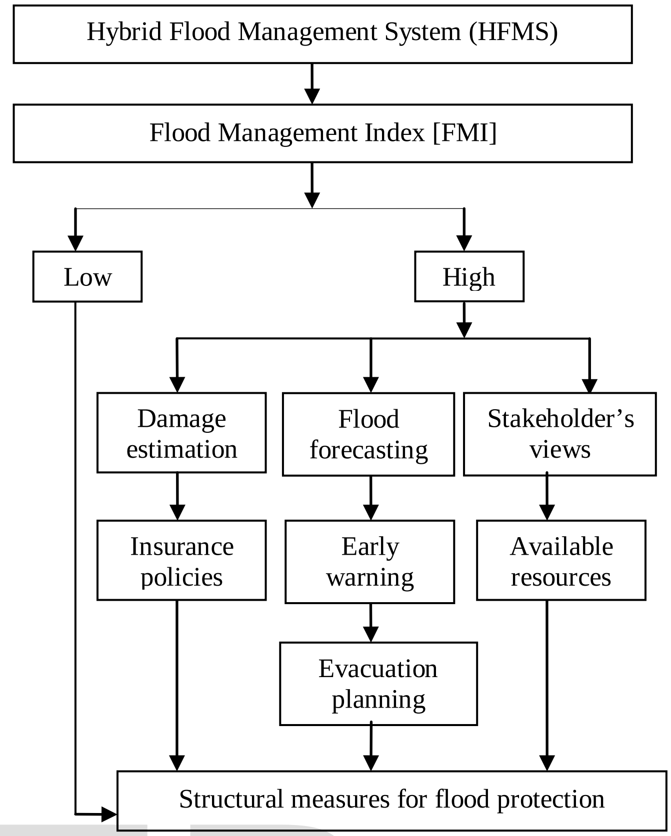

Fig.1: Components of Hybrid Flood Management System (HFMS)

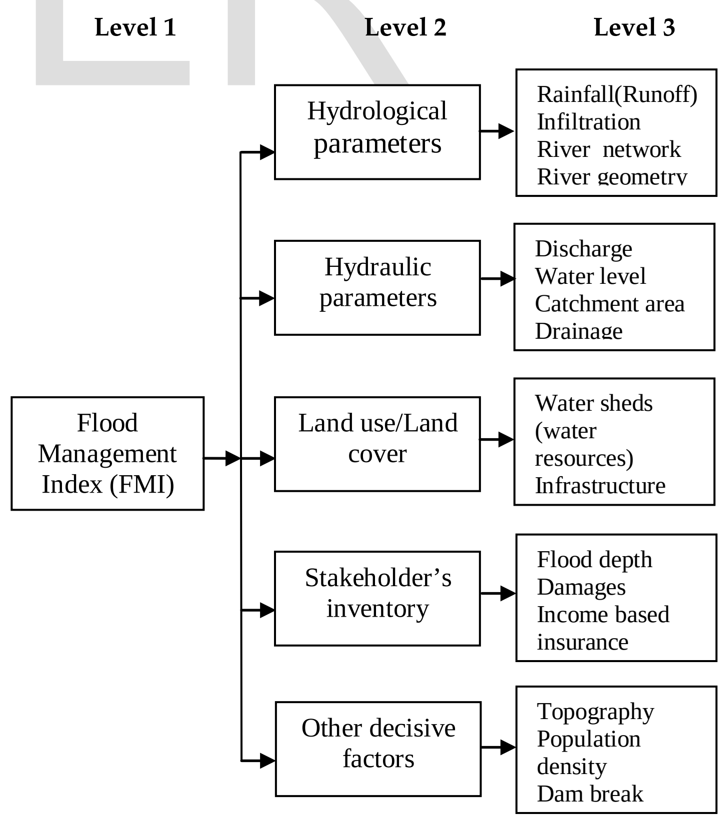

Fig. 2: Flood Management Index (FMI)

Table 1 Parameters for flood management

Parameters at stream level	
Rainfall	[9], [11], [13], [14], [15], [18], [19], [20], [21], [22], [26], [40]
Discharge	[9], [11], [13], [14], [15], [16], [21], [22], [24], [26], [40]
Water level	[9], [13], [14], [15], [16], [26], [40]
River geometry	[9], [10], [11]
River network	[18]
Infiltration	[20], [21]
Water resources	[21], [22]
Catchment area	[25]
Parameters at province level	
Topography	[6], [9], [10], [11], [12], [14], [15], [16], [18], [20], [21], [22], [24], [25], [26], [40]
Land cover	[6], [9], [11], [12], [14], [15], [16], [18], [20], [21], [22], [25], [26], [40]
Population density	[6], [11], [16], [17], [18], [40]
Damages	[17], [23]
Income/ Insurance	[17]
Drainage	[18], [22]
Stakeholders views	[19], [20]
Flood depth	[23]

cover, stakeholder's inventories and other decisive important parameters. The different parameters considered at level 3 are rainfall, discharge, water level, river geometry, river network, topography, land cover etc. These parameters have been used by different researchers and are shown in **Table 1**. The index represents the vulnerability of the flood affected area. If FMI is high, then losses and damages and related insurance policies should be worked out. The flood forecasting of areas with high FMI should be carried out and necessary early warning and evacuation planning should be made. The views of stakeholders' residing in the areas with high FMI is extremely important and on the basis of their views, certain available resources or watersheds can be utilized for management of flood. After a detailed analysis of all the management techniques, if required, structural measures should be designed.

4 Conclusions

Different flood management techniques have been critically reviewed. Identification of flood affected areas depends on a large number of parameters and their data inventory varies from region to region. If the parameters represented in **Fig. 2** are used with a proper range of values and correct weightage, Flood Management Index (FMI) would give an accurate representation of vulnerability and management to be provided. It can be widely applied for any region by considering the relevant parameters of that region. Researchers had worked independently on different management techniques. All the techniques require planning well in advance. Thus, data inventory of the flood affected area plays an important role. Flood causes high impact on infrastructures, environment and society; hence to achieve a competent model, non-structural and structural measures should be clubbed together. Hybrid Flood Management System (HFMS) could be a generalized composite tool which would give an enhanced flood management system. The study would help various resource persons involved in disaster management for an initiative in developing a flood management tool which would include both non-structural and structural measures.

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