Conceptual Approach for Flood Risk Assessment

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Abstract

Flood control infrastructural measures like levees, dikes and dams have been developed to protect socio-ecological system from the consequences of flood events. These measures aim to reduce systems' risk from exposure to flood water. The traditional measures involved in minimizing the flood risk is to keep water away from land. These flood control infrastructural measures are huge capital intensive but damages caused by flood increases manifold on failure of these structures. This led to the birth of another notion of flood protection i.e. managing flood water rather than controlling it. It involves non-structural measures with or without the combination of flood control to create a flood resilient region. The foremost step in non-structural measures for flood protection is the assessment of risk associated with flood. Flood risk assessment provides necessary information for decision making in flood risk management. The paper reviews the conceptual approach of flood risk and its application in flood protection. The paper structured into three section. The first section briefly discusses the concepts of flood risk. The second section analyses the components involved in flood risk and its empirical derivation. In last section paper discusses the conclusion and gives recommendation for flood risk management.

Keywords: *Exposure, Flood Risk, Flood Control Infrastructure, Hazard, Vulnerability.*

1. Introduction

Flood is a natural phenomenon caused due to overflow of water when the water level in the main channel reaches beyond its carrying capacity. It occurs in rivers when the flow rates exceed the capacity of the river channel, generally at bends or meanders in its

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course (Gangwar, 2013). Flood plains are defined as the land adjacent to river channels that are subjected to recurring inundation (Di Baldassarre, Viglione, *et al.*, 2013). The earlier civilizations throughout world have settled in floodplains of various rivers such as Chinese civilization (Huang He river), Indus civilization (Indus river), Egyptian civilization (Nile river), Mesopotamia (Tigris and Euphrates rivers) (Macklin and Lewin, 2015). These civilizations flourished in floodplains as they offer favorable conditions for trade, agriculture, and economic development (Di Baldassarre, Kooy, *et al.*, 2013). It is estimated that almost one billion people currently live in floodplains. Mazzoleni et al., (2021) analyzed that in low-income countries, there is increase in the population along floodplain after a period of high flood fatalities and in high-income countries, there is positive growth in built-up areas. The increased urbanization pressure leads to encroachment of flood plains close to river for human activities. The boundary of a floodplain cannot be defined as the magnitude of a flood is limitless. As the distance to the river decreases, the hazard increases, because areas closer to the river network are prone to flood hazard (Patrikaki et al., 2018). Areas near the river network (less than 200m) are high flood hazard zone, and the impact of flood water decrease with increasing distance more than 2000 m (Kazakis, Kougias and Patsialis, 2015; Adlyansah, Husain and Pachri, 2019). These encroachments and unchecked developments on flood plains translate the flood from a natural phenomenon to man-made disasters and put human lives and environment at risk. The risk of flooding has increased exponentially due to extreme rainfalls, sea-level rises, higher river discharge, etc. This led the change in discourse of current infrastructure measures in dealing with flood management (Molenveld and van Buuren, 2019).

The flood management system in India has evolved over the years. The 1954 flood event in Bihar coerced the government to acknowledge the flood risk and prepare an action plan to protect flood plains (Shrestha et al., 2010). This led to huge investment in construction of structural measures such as embankments, dams, reservoirs, etc. As per National Register of Large Dams (NRLD), in India, there are 5334 completed large dams and 411 under-construction large dams (PIB, 2021). Dam Rehabilitation and Improvement Project (DRIP) has envisaged comprehensive rehabilitation plan for 736 dams across 19 states. This plan has financial implication of approximately Rupees 102110 million. Despite such huge investment, these infrastructure measures do not provide protection as anticipated. The following section discussed the definition of flood risk and key components involved in flood risk management.

2. Conceptual Approaches of Flood Risk

Flood risk is the probability of harmful consequences or expected losses in terms of deaths, population affected, property damaged, livelihoods impacted, economic activity disrupted or the environmental damages (Westen and Jetten, 2015). The curtailment of flood risk leads to development of flood control approach. The flood control approach involves the infrastructural measures like constructions of dams and embankments. These infrastructural measures control the river and the flood water. The research shows that these engineered solutions are huge capital intensive and failure of these structures quadruples the flood damages (Mishra, 1997; Liao, 2014). The approach to mitigate the flood losses shifted from controlling the flood to managing the flood. This give birth to the notion of Flood Risk Management (FRM). FRM aims in minimizing the losses and damages caused by flood by preventing the exposure of people and property to flooding (Klijn et al., 2009). FRM approach is the combination of structural and non-structural measures for managing the flood waters. The structural measures aim in lowering the flood probability whereas non-structural measures aim in reducing the vulnerability of society by managing the exposure of vulnerable people and property. The structural measures include the flood defense mechanism against flooding to reduce possible impact of hazards. It involves application of engineering techniques and technologies to achieve resistance to flood. Non-structural measures uses knowledge and practice to mitigate flood risk through policies and laws, public awareness, training, and education (UNISDR, 2009). The three phase of flood i.e. pre-flood, in time of flood, and post-flood, have different non-structural measures. The measures such as public awareness, training, education, land use planning, building codes in flood prone areas, flood forecasting (early warning system), research and assessment, information resources are some of the pre-flood non-structural measures (JICA, 2016). The response-recovery plan to reduce vulnerability and strengthen the system of emergency assistance in flood prone areas are activated during flood. The post-flood measures include insurance, financial aid, capacity to compensate losses not covered by insurance, and relocation of affected population (Kundzewicz, 2002). The combination of structural and non-structural measures reduces the risk of flood. The understanding of flood and its impact helps in managing the flood risk efficiently.

Flood risk is defined in two alternative ways i.e. product of hazard, its exposure and vulnerability of exposed region, and product of flood probability and consequences

(Ernst et al., 2008; Klijn et al., 2009). The first definition uses three elements of flood risk i.e. hazard due to flood, exposure of flood and vulnerable society or area. The characteristics of floods are flood depth, flood velocity, and retaining time. The exposure to a certain depth is necessary for a society to be harmed by occurrence of a flood (Klijn et al., 2009). It is to be noted that without exposure to certain flooding characteristics (for ex. flood depth), the risk of even high vulnerable area or society is terminated (Klijn et al., 2009). In the second definition, flood risk depends upon the probability of hazard, chance or likelihood. Probability in this definition refers to the probability of flood (hazard), and probability of consequences. The inclusion of probability is a quintessential element in defining the risk and in assessing flood risk.

Flood hazard is the combination of flood probability and its level of intensity that expressed in terms of its characteristics. Flood hazard assesses the intensity of flood occurrences over an extended period of time (Wright, 2016). Probability is the likelihood of flood event i.e. return period (in years).

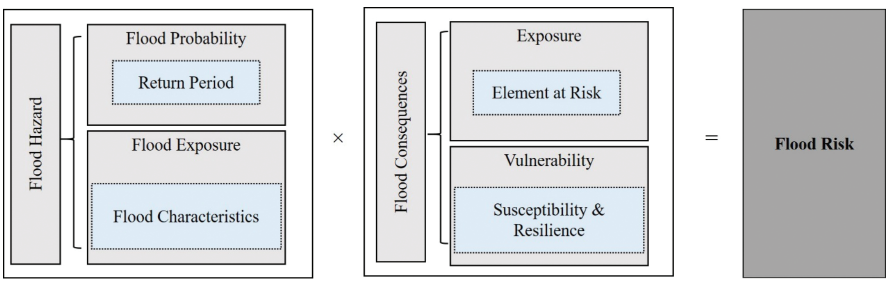

Figure 1: Conceptual Approach of Flood Risk Management

(Source: Adapted from Pieterse et al. (2015); Wright (2016)

3. Components of Flood Risk

Flood probability relates to the probability that a region will be flooded, either in case of unprotected areas by high water levels in a river or in the case of protected areas. The probability of occurrence is dependent upon flood's magnitude gauged by the status of risk (Pieterse et al., 2015). Stream gage helps us to record the level of water when it is in above the danger mark. The technique uses to define probability of flood or to predict the return period of certain flow value is flood frequency analysis. The flood frequency analysis uses statistical information such as mean, standard deviation, and skewness to calculate frequency distribution graphs. The statistical method used in analyzing distribution are Gumbel, Normal, Log-normal, Exponential, Weibull, Pearson and Log-Pearson. Samantaray and Sahoo (2020) discussed the four common used methods for calculating flood frequency for Mahanada river basin from four stations on Mahanadi River, in Eastern Central India. The statistical methods employed in the study for different time period to forecast stream flow are, Normal, Gumbel max, Log-Pearson III (LP III), and Gen. extreme value method. Flood frequency plays a vital role in providing probability of flood occurrence that can be use in planning the regions.

Flood Exposure: It is defined as the intensity of flood based on its physical characteristics. Flood duration, river discharge, flow velocity, and flood water depth are some of the physical characteristics of flood used for measurement of hazard intensity of flood (Balica, Douben and Wright, 2009). Pieterse et al., (2015) classified the flood water depth in three categories and this can be used as a parameter to classify hazard:

1. Depth less than 0.5m – walkable limit to evacuate the area.
2. Depth between 0.5 - 2 m – Rooftop of second floor of building
3. Depth greater than 2 m – immediate evacuation should take place.

The classification of physical characteristics of flood with the probability of flooding in a particular area help in developing detailed hazard map which helps in assessing risk associated with corresponding flood.

Flood Consequences: The second component of flood risk management framework is the consequences of flood. Flood consequence is the impact of certain magnitude of flood on the region affecting social, economic, and ecological aspects (Pieterse et al., 2015). Ernst et al., (2008) discussed three parameters to assess flood consequences i.e. exposure, elements at risk, and vulnerability. Ernst et al., (2008) and Pieterse et al., 2015 defined exposure as the characteristics of flood. Klijn et al., (2009) referred to exposure as impact of flood on people and infrastructure. Balica, Douben and Wright, (2009) used social, economic, and ecological components to define exposure and its impact due to flood. Indicators like population density, population in flooded area, closeness to inundation area, percentage of rural population, land-use, proximity to river, etc are used to assess exposure. Exposure is the value of areas which face the flood regularly (Beevers, Walker and Strathie, 2016). Thus exposure and elements at risk can be grouped under one umbrella for analysing flood consequences and physical characteristics of flood exposure need to be studied under flood hazard.

Vulnerability: According to the International Panel of Climate Change (IPCC), the magnitude and character of disasters are defined as the exposure of people, assets at risk and susceptibility to harm i.e. vulnerability of human and natural systems (IPCC, 2014). IPCC (2012) outlines the vulnerability as the magnitude and consequences of hazards. UNISDR (2009, p.30) adds the dimension of characteristics, circumstances, and susceptibility dimensions while defining vulnerability. Hyogo Framework for Action (HFA) 2005-15 specified vulnerability with gender perspective, cultural diversities, age, etc. and its integration ed with disaster risk management policies and plans related to sustainable development (UNISDR 2005). The HFA provides a framework for action focusing on disaster response, which includes rescue and providing post-disaster assistance. However, it does not elaborately address the hazards, risk and vulnerabilities. Its progress is the weakest in the area of social vulnerabilities (UNISDR 2015a). The successor of HFA, the Sendai Framework for Disaster Risk Reduction 2015-30, apprehends the importance of vulnerability to improve disaster risk management. The first two goals of this framework are substantial reduction of the mortality rate and the number of affected people by 2030. HFA aimed to lower the average global figure per 100,000 in the decade 2020-30 as compared to 2005-15 (UNISDR 2015b). This could be achieved by understanding the vulnerability of the populace. Vulnerability is the function of three variables i.e. exposure, sensitivity and adaptive capacity (Marshall et al., 2010; Yates, 2010). Beevers, Walker and Strathie, (2016) quantified the vulnerability as three-dimensional unit by assessing exposure, susceptibility, and resilience as three different axes. The exposure and sensitivity are directly proportional to the vulnerability whereas adaptive capacity is inversely proportional to it (Nguyen, Nguyen and Man 2016). The vulnerability to floods is dependent on various factors. The social, economic, and cultural factors influence the vulnerability of the population. The factors such as wealth and its distribution across society, demographics, migration, access to technology, employment pattern, education, societal values, and governance structures play an important role in addressing the vulnerability of society (IPCC 2014).

There exist numerous definitions of vulnerability by various authors (Marshall et al., 2010; Yates, 2010; Morgan, 2011; Beevers, Walker and Strathie, 2016; Nguyen, Nguyen and Man, 2016). All these definitions are formed by combining components vulnerability. The conceptual expression of vulnerability incorporating concepts of exposure, susceptibility and adaptive capacity is given in figure 2.

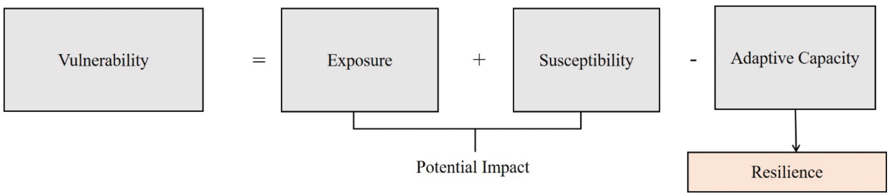

Figure 2: Conceptual expression of Vulnerability

(Source: Balica, Douben and Wright, (2009); Morgan, (2011); Beevers, Walker and Strathie, (2016)

The assessment of vulnerability is an important step for risk analysis. Nasiri et al., (2019) Flood vulnerability index is a method to assess flood vulnerability at various spatial scale (river basin, sub-catchment, district, block or village level) (Nasiri, Mohd Yusof and Mohammad Ali, 2016; Marzi, Mysiak and Santato, 2018; Nasiri et al., 2019). It is done by categorizing social, economic, environmental and physical components of flood prone areas based on numerous indicators. Kim and Gim, (2020) assessed the social vulnerability to floods at the municipality level on Java, Indonesia by developing two indices; the socioeconomic vulnerability index (SEVI) and the built environment vulnerability index (BEVI).

Susceptibility: It relates to system characteristics that influence the probabilities of flood consequences. The characteristics of social, economic and environmental aspects of system that triggers the impact of hazard are considered under vulnerability assessment. Balica, Douben and Wright, (2009) used literacy rate, past experience, child mortality rate, population access to water supply, unemployment, Regional GDP, rainfall, evaporation, etc. as the indicators for analysing susceptibility. Morgan (2011) used sensitivity of the elements at risk as the potential impact due to flood. The term 'exposure or elements at risk' includes all elements of the human system, the built environment and the natural environment that are exposed to flooding. Morgan (2011) interprets adaptive capacity as the resilience of a system to bear disturbances induced by floods while managing its efficiency level. In order to assess flood susceptibility, many researchers have used different models such as fuzzy logic simulation method (Oladokun, Proverbs and Lamond, 2017), HOWAD/GRUWAD model (Schinke et al., 2016), logistic regression (LR) model (Song, Huang and Li, 2017), evidential belief function (EBF), random forest (RF), and boosted regression trees (BRT) models (Rahmati and Pourghasemi, 2017).

Table 1: Components Involved in Risk calculation

Term	Definition
Flood Hazard	• event causing losses, disruptions, and damages to both personnel and built resources. • depends upon flood probability and its physical characteristics.
Element at Risk	• social, physical, economic, environmental or any other assets exposed.
Vulnerability	• impact of conditions and factors on susceptibility of resources.
Consequence	• expected losses in an area
Resilience	• specific set of elements at risk
Total Risk	• calculated by integrating the consequences of a hazard.

(Source: Adapted from Westn and Jetten (2015)

4. Empirical Derivation of Flood Risk

Flood risk is defined by the sum of the product of hazard by consequences. Risk can be presented empirically with the following framework as indicated in equation 1:

Risk = Hazard * Consequences(1)

Risk = (Probability + Exposure) * (Elements at Risk + Susceptibility – Resilience)

This equation focuses on the analysis of social, economic, environmental and physical losses, using vulnerability data. It studies the impacts and consequences and compares the results to determine the acceptable level of risk in a region. The equation gives the possible scale of analysis for different scale of vulnerability and the possible approaches. It discusses the qualitative approaches and quantitative approaches to calculate the risk. The equation can be integrated in flood modelling such as hydrodynamic model (MODCEL) formulating Flood Resilience Index as proposed by Miguez and Veról, (2017).

5. Conclusions and Recommendations

The flood control measures are limited to structural measures to control flood water to inundate the settlements. It does not guarantee an absolute safety from flood, as there is always a possibility of having a greater flood than the safety of designed structures. The design solution of these flood control infrastructures may withstand with 100-year flood or 500-year flood but it will turn out ineffective for 1000-year flood. It is necessary to understand and live with the possibility of flood and to accommodate them, rather than in controlling flood. The effective flood protection system is the combination of structural and non-structural measures in the spirit of sustainable development. The flood risk management approach deals with non-structural measures to live with flood. The non-structural measures such as response-recovery plan, land-use planning, bye-laws, insurance system, evacuation plan etc. have shown better results in managing the flood consequences. The understanding of flood and its impact helps in managing the flood risk efficiently.

The flood risk is interpreted as an interaction of hazard and its consequences. Hazard is the combination of flood probability and flood characteristics. The accepted definition of flood hazard is product of flood probability and flood exposure. It forms a basis for risk informed decision upon probability of occurrence of hazard. The probability of flood is a quintessential element in assessing flood risk. It is the likelihood of flood event. Flood exposure in the intensity of flood based on physical characteristics. The another component of flood risk is its consequences. Flood consequences is the impact of flood on social, economic, and environmental aspect of region. Flooding is the exposure of systems and its environments. It is assessed through analyzing ‘elements-at risk’ which in turn defines the vulnerability of the region. Vulnerability is the function of susceptibility and adaptive capacity of region.

The paper recommends that the integration of flood control approach and flood risk management approach is required for developing a flood resilient region. Flood needs to be assessed empirically to recognized the change within flooding system. A definite set of indicators for all components of flood risk need to be identified for varied spatial scales. The paper demonstrated the flood risk equation based on existing approach that fitted in coherent framework. In India, flood risk management is at nascent stage and needs to be propagated. The flood risk management should consider the gaps present in analyzing its components. It should begin with correcting gaps in existing components and its related definitions.

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