Chapter 7
Flood Risk Estimation and Mapping: Present Status and Future Challenges

Mohit Prakash Mohanty and Subhankar Karmakar

Abstract Several regions of the globe are projected to experience elevated risks from flooding attributable to concomitant climate change and alterations in socio-economic dynamics. These impacts present major challenges to comprehensively quantify flood risk, which will facilitate building flood mitigation infrastructures, improve land use/urban planning, and assist the prioritization of emergency response strategies. Flood risk is built on two major components, namely, *hazard* and *vulnerability*. Most research conducted so far on vulnerability is limited to themes, such as physical, economic, and infrastructure vulnerabilities, and has frivolously excluded social vulnerability. Such works are solely based on a technocratic perspective rather than from a socio-technocrat's perspective. It is a fact that social vulnerability is less amenable to quantification because it is linked to the resilience of an individual, a community, or a society, which is acquired as a result of their perception, attitude, and coping capacity. The procedures for flood risk mapping are data-intensive, posing a difficulty in generating maps for middle- and low-income nations. Essentially, flood risk mapping is truly multidisciplinary in nature and requires inputs from engineers, social scientists, policymakers, and the general public.

Keywords Climate change · Flood risk · Hazard · Riverine flooding · Vulnerability

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7.1 Introduction

Floods continue to affect more nations than before and cause widespread human and economic damages with each passing year (Blaikie et al. 2014; Dottori et al. 2016; Vousdoukas et al. 2018). With the statistics documented in various global reports on natural disasters such as Centre for Research on the Epidemiology of Disasters (CRED) (https://www.cred.be/), International Federation of Red Cross and Red Crescent Societies (IFRC) (https://media.ifrc.org/ifrc/), The International Charter Space and Major disasters (https://disasterscharter.org/web/guest/home), The United Nations office for disaster risk reduction (UNDRR) (https://www.unisdr.org/), and The Global Flood detection system (http://www.gdacs.org/flooddetection/overview.aspx) and a plethora of notable research articles (Alfieri et al. 2015a, b; Berghuijs et al. 2017), it is now a well-established fact that the occurrence (frequency) and severity (socioeconomic losses and human death count) of floods have escalated in the recent decades.

Among other factors, the concomitant climate change and booming urbanization are identified as the root causes to the rising flood risk. The projected precipitation changes from regional and global climate models indicate a possible rise in the frequency of extreme precipitation. This is observed in the tropical regions and high latitudes and mid-latitudes of northern regions in winter (IPCC 2012). Pall et al. (2011) and Schiermeier (2011) reported that anthropogenic greenhouse gas emissions contribute to the increasing severity of flood risk. Also, rising sea levels and land subsidence due to climate change may influence future flood risk in coastal urban cities (Hallegatte et al. 2013; Jonkman 2013). The second root cause of increased flood risk is rising urbanization. Moreover, it is highlighted that if economic and infrastructural damages due to flood disasters can be recovered in the short term, social damages may be irreparable. Hence, economically poor countries with a low gross domestic product (GDP) may find it extremely difficult to cope with such disasters due to low resilience. Keeping these various things in mind, the present chapter highlights the practiced ways of flood risk estimation and mapping. The chapter also describes the major challenges associated with flood risk estimation while considering its two vital components, i.e., hazard and vulnerability, and the exigent need of considering a system that provides an equal weightage to them in the flood risk estimation (Bohle 2001). The importance of the new flood risk mapping approach is demonstrated on a severely flood-prone region residing inside a large river basin in India.

7.2 Flood Risk Management: A Risk-Based Approach to Managing Floods

Flood risk management is a complex decision-making process. Recent decades have diverted the conventional "flood management" to "flood risk management" approach in which flood risk analysis exists in the core (Schanze 2006). Under flood risk management, there are three major tasks: flood risk analysis, flood risk assessment, and flood risk reduction. These components are described in the subsequent subsections. The basic framework of flood risk management is given in Fig. 7.1.

7.2.1 Flood Risk Analysis

Flood risk analysis considers the past, current, and possible future risks associated with the community and environment (Apel et al. 2009). It is built on two major components: *flood hazard* and *vulnerability* (Apel et al. 2004; Kron 2005; Gotham et al. 2018). Narayan et al. (2011) proposed a Source-Pathway-Receptor-Consequence-Model (SPRC-Model) to demonstrate the flood risk system as illustrated in Fig. 7.2. The chain links physical processes, namely, "source," "pathway," and "receptor" with the societal values "consequence." Within the context of flood risk, "source" and "pathway" indicate the flood hazard. Here "source" is quantified as the probability (p) of an event to occur and several other features (m). To minimize the risk, early warning system (w) and the adaptive capacity (t) are considered vital. The "pathway" is defined by the inundation which can arise from

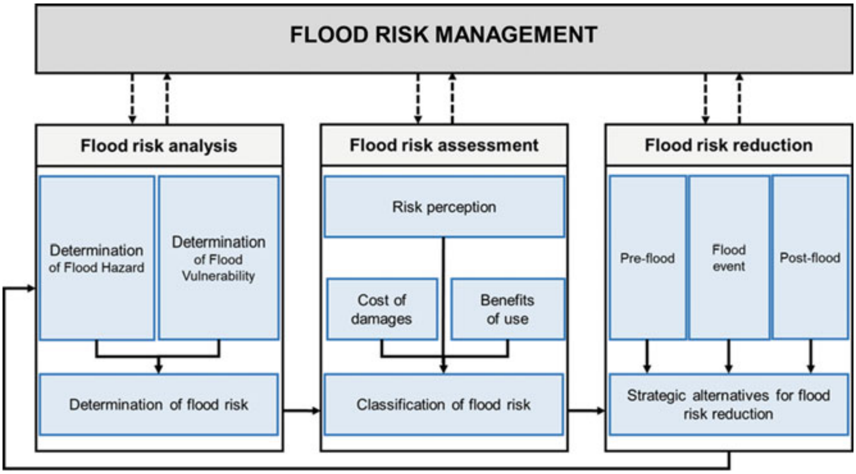

Fig. 7.1 Basic framework of flood risk management

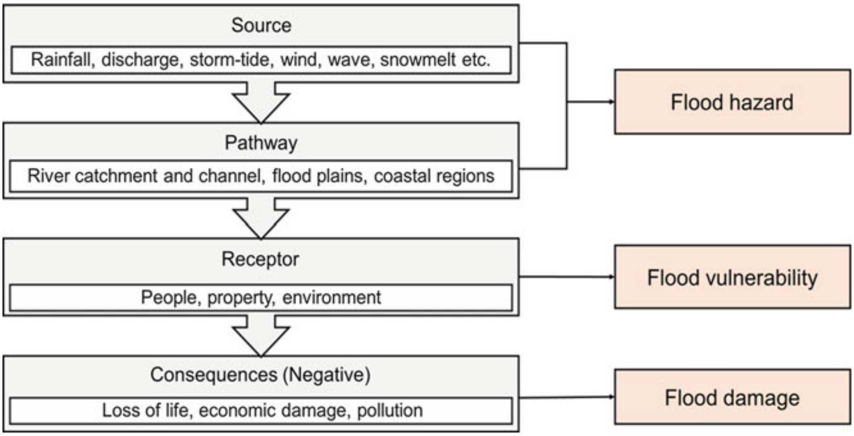

Fig. 7.2 Source-Pathway-Receptor-Consequence-Model (SPRC-Model). (Narayan et al. 2011)

various flood drivers such as discharge overflow, coastal impacts, and others (i), along with their attributes (a) and interventions available if any for flood control (c). Lastly, "receptor" is defined by the susceptibility (s) depending on the resistance and resilience (r) of the system. "Consequence" is nothing but the damage (v) with possible options to eliminate or reduce (d). Mathematically, flood risk can be expressed by the following equation:

$$\text{Flood risk} = f\left\{(p, m, w, t)_{\text{source}}, (i, a, c)_{\text{pathways}}, (s, r)_{\text{receptors}} (v, d)_{\text{consequences}}\right\} \quad (7.1)$$

7.2.2 *Flood Risk Assessment*

There are two relevant areas on which flood risk assessment is defined. They are *risk perception and risk weighing*. *Risk perception* is defined by the individual and collective backgrounds of the population facing the risk and those groups who are involved in flood risk management (Miceli et al. 2008; Ludy and Kondolf 2012; Cheikh Lounis et al. 2015).

For instance, a population who have the experience of facing the flood before are more likely to have a different perception of flood risks than those who have not faced it earlier (Grothmann and Reusswig 2006). A straightforward understanding of risk perception is complex, as it is multifaceted.

7.2.3 Flood Risk Reduction

Flood risk reduction is normally practiced through structural and nonstructural measures. In the timeline of risk reduction, they can be defined by *pre-flood, flood event, and post-flood* measures. *Pre-flood* is achieved by prevention, protection, and preparedness before any anticipated flood event by building retention ponds, flood plain zoning, and resilient building construction and creating awareness among people likely to face risk. *Flood event* measure consists of accurate flood forecasting and disseminating flood warning signals to provide information to people at risk. Lastly, *post-flood* measures consist of rebuilding and reconstruction of the damages that occurred after a flood event.

7.2.4 Flood Inundation and Hazard Mapping

Flood inundation is the result of the appearance of floodwater characterized by a specific areal extent, depth, and duration (Bates and De Roo 2000; Bates 2004). This inundation gives rise to flood hazard which is decided based on several factors. It is usually defined as the probability of occurrence of an event of a certain magnitude at a given time and space (Chakraborty et al. 2005). As per Peck et al. (2007) and Karmakar et al. (2010), flood hazard is identified as a probabilistic component, which calls for hydrological analyses and preparation of flood lines. As per Alcantara-Ayala (2002), a hazard is defined as those events capable of incurring damage to the physical and social structure through loss or injuries to human lives, damages to properties, or environmental degradation. A flood hazard map is an important component for appropriate landscape planning as it provides a piece of precise information on the areas prone to different degrees of flood impacts. Such maps can be prepared using various flood methods/models which can be (i) simplified, which can utilize the basin's geomorphology, or (ii) hydrodynamic, which is based on St. Venant's equations for deriving flood hazard areas.

7.2.4.1 Quantification of Flood Hazard

Flood hazard is defined as a function of both flood severity and probability. Flow depth "d" and velocity "f" are the two main attributes of flood severity, which can be obtained by performing flood inundation modeling. There are several standards that have defined the combination of floodwater depth and velocity into different hazard classes. Most well-known methods are the UK method, Australian method, Austrian method (Fiebiger 1997), the US Bureau of Reclamation method (USBR 1988), and the Swiss method (OFEE 1997). The widely accepted UK and Australian methods consider hazard as a combination of flood depth and velocity. On the contrary, the Austrian method considers the total energy defined as "$d + f^2/2g$," where d is the

Table 7.1 Classification of flood hazard based on the criteria of floodwater depth “d” and/or product of floodwater depth and velocity “$d \times f$” in different methods

Flood hazard						
Flood hazard rating	Hazard description	The UK method	Australian method	Austrian method	The US Bureau of Reclamation method	Swiss method
Very Low Hazard	Generally safe for people, vehicles, and buildings	0 to 0.3 m^2/s	0 to 0.3 m^2/s	0 to 3 m	0 to 3	0 to 0.5 m^2/s
Low Hazard	Unsafe for vehicles, children and the elderly	0.3 to 0.7 m^2/s	0.3 to 0.6 m^2/s			
Moderate Hazard	Unsafe for people and vehicles	0.7 to 1.2 m^2/s	0.6 to 1.0 m^2/s			0.5 to 2 m^2/s
High Hazard	Unsafe for vehicles and people. All buildings are vulnerable to structural damage. Some less robust building types vulnerable to failure.	1.2 to 1.6 m^2/s	1.0 to 4.0 m^2/s	>3 m	>3	>2 m^2/s
Very High Hazard	Unsafe for vehicles and people. All building types considered vulnerable to failure	>1.6 m^2/s	>4 m^2/s			

flood water depth, f is the velocity, and g is the gravitational acceleration. The USBR method considers hazard as a combination of depth and velocity. A description of hazard classes and their significance is provided in Table 7.1. Currently, there are very few works on riverine flood hazard mapping that apply both coupled flood modeling and hazard ranking. Figure 7.3 describes the representative past efforts on riverine flood inundation and flood hazard mapping.

7.2.4.2 Geomorphic Approaches

Although several models/software are available for quantifying inundation, their use may be restricted due to several reasons. The limitations are (i) scarcity of extensive data inputs required for precise flood modeling, (ii) fizzling performance of models in large and complex terrains, (iii) high computational cost and time, and (iv) inexpertise in handling model simulations by civic bodies. Recent studies have made use of linear binary classification techniques (Manfreda et al. 2014, 2015; Manfreda and Samela 2019) which are easy to use, computationally inexpensive, and easy compared to the hydrodynamic approach. These classifiers are used to

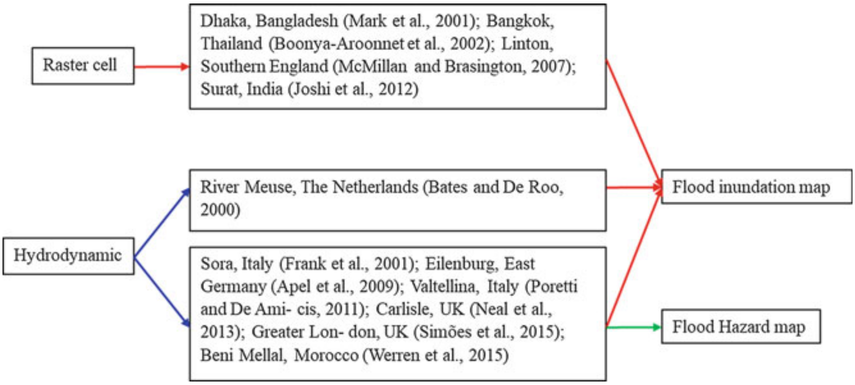

Fig. 7.3 Representative past efforts made on coupled 1D-2D flood inundation/hazard mapping

delineate flood hot-spots (flood-prone areas) based on the information contained in the study bathymetry. Table 7.2 enlists recent efforts made to map flood hazards through geomorphic classifiers.

7.2.5 *Flood Vulnerability Mapping*

The word “vulnerability” is derived from the Latin word *vulnus*, which means *to wound* (Turner et al. 2003). As per Adger (2006) and Füssel (2007), vulnerability may be expressed as a combination of three components: adaptive capacity, sensitivity, and exposure. Adaptive capacity is the ability of a system to fine-tune to actual or expected climate stresses. Sensitivity is the degree to which a system will respond to alterations, whereas exposure is the extent to which people and assets are exposed to hazards. Figure 7.4 portrays the various spheres of vulnerability theme as described by various researchers.

7.2.5.1 Various Approaches to Flood Vulnerability Assessment

Figure 7.5 illustrates a generic framework for the assessment of flood vulnerability. Once the geospatial data collection for the indicators is completed, statistical operations are performed to obtain an index of vulnerability through aggregation operations. These aggregation operations calculate, display, and validate the indicators of vulnerability, finally to obtain a composite vulnerability index.

Before aggregation, normalization of indicators (adjusting the values measured on different scales to a common scale) is performed. In the last step, suitable aggregation operations are performed using several methods based on the data availability and complexity of the problem statement. Different methods include averaging (Rygel et al. 2006; Karmakar et al. 2010), maximization, Analytic

Table 7.2 Recent efforts made to map flood hazards through geomorphic classifiers

Indicators considered	Case study	DEM considered	Remarks	References
Modified topographic index (TI_m) $\mathrm{TI}_m = \log \frac{a_d^n}{\tan(\beta)}$ a_d^n is drained area per unit contour length and $\tan(\beta)$ is local gradient	Arno River Basin, Italy ($8830\ \mathrm{km}^2$)	DEM obtained from Arno River Basin Authority (20 m) SRTM DEM (90 m) ASTER DEM (30 m) National elevation data (30 m)	The index is highly sensitive to DEM resolution; however, a resolution of ~100 m is satisfactory for good performance SRTM DEM showed good performance when compared with the other DEMs	Manfreda et al. (2011)
Surface curvature (H) Laplacian of the elevation (ΔH) Contributing area (A) Local slope (S)	Tanaro River Basin, Italy ($8000\ \mathrm{km}^2$)	SRTM: DEM–VOID (Void filled)and DEM–CON (Hydrologically conditioned) from HydroSHEDS	The classifiers could identify 93% of flood-prone areas, while validated with the flood inundation map	Degiorgis et al. (2012)
Single features Upslope contributing area, A_s (m^2) Surface curvature ($\nabla^2 H$) Local slope, S Distance from the nearest stream, D (m) Elevation to the nearest stream, H (m) *Composite indices* Modified topographic index (TI_m) Downslope index, (DW_i) Elevation (H) and ratio between the flow distance (D) $\ln[h_\mathrm{l}/H]$, where h_l is the variable water depth GFI (Geomorphic Flood Index): $\ln[h_r/H]$: hr. is computed as afunction of the contributing area A_r $[h_r{-}H]/\tan(\alpha_d)$ and $[h_r{-}H]/D$	Tiber River Basin, Italy ($17{,}375\ \mathrm{km}^2$)	-do-	Elevation to the nearest stream (H), downslope index (DW_i), and GF_i showed better performance	Manfreda et al. (2014)
			Among the single features, distance from the nearest stream (D) and elevation to the nearest stream (H) performed better, while among composite indices $\ln[h_l/H]$ and $\ln[h_r/H]$ performed better	
	Bradano River Basin, Italy ($2765\ \mathrm{km}^2$)	-do-	Composite indices were found to be less sensitive to the variations in DEM resolution	Manfreda et al. (2015)
	Bulbula river sub- catchment, Ethiopia	-do-	The composite index $\ln[\mathrm{h_r/H}]$ and elevation difference (H) showed the best performance	Samela et al. (2016)
	Ohio River Basin, USA, ($29{,}000\ \mathrm{km}^2$)	-do-	GFI was found to be the most suitable morphologic classifier, as it exhibited a higher accuracy than the other indices	Samela et al. (2017)

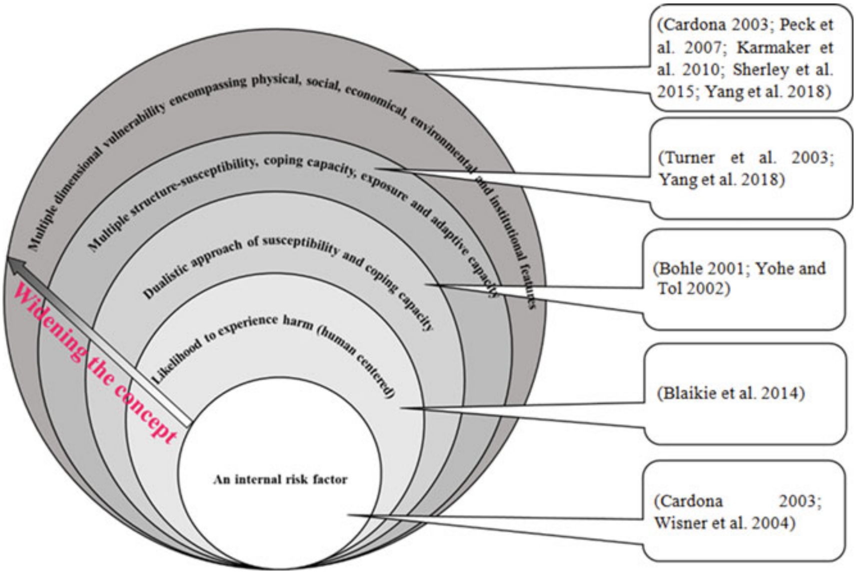

Fig. 7.4 Key spheres of vulnerability. (Birkmann 2005, 2006)

Hierarchy Process (AHP) (Wei et al. 2004), Data Envelopment Analysis (DEA) (Wei et al. 2004; Huang et al. 2011; Sherly et al. 2015b; Mohanty et al. 2020a).

7.2.6 Flood Risk Mapping

Flood risk constitutes flood hazard and vulnerability components (Koks et al. 2015). Assessing flood risk is not straightforward, keeping in mind the complex nature of flood caused due to the impounding precipitation affected by climate change impacts and river basin characteristics. At the same time, there exist numerous knowledge gaps in the conventional flood risk assessments, which most consider the damage to physical well-being in a population (Debortoli et al. 2017). During this approach, the socioeconomic vulnerability studies have produced valuable information, however unable to establish suitable linkages to flood risk. The need of the hour is to consider a compound and marginal assessment of flood hazard and vulnerability to derive the flood risk that directly provides necessary amendments to the flood risk management strategies. Figure 7.6 shows representative efforts on riverine flood risk estimation and mapping which have been addressed for the recent time scales and projected for the future time, considering climate change impacts as well.

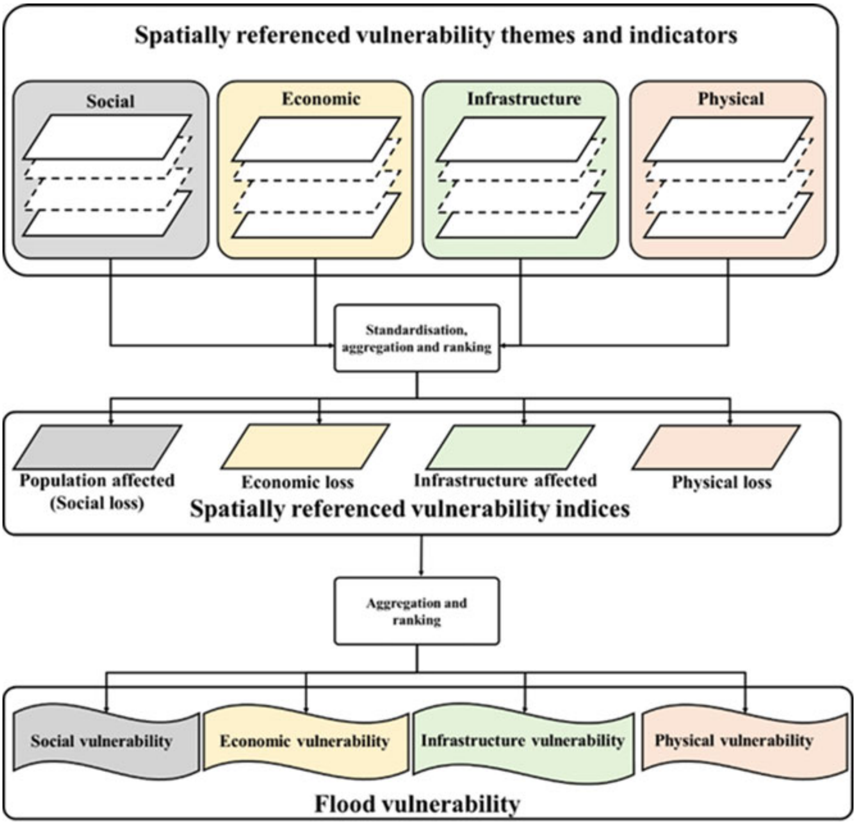

Fig. 7.5 A generic framework for assessment of flood vulnerability

7.2.7 *Flood Risk Reduction*

The most key aspect of flood risk management is the usage of preparedness measures for minimizing loss before the occurrence of a flood event. These measures are grouped into structural and nonstructural measures.

7.2.7.1 Structural Measures

In structural measures, two alternatives are practiced: (1) the construction of resilient hydraulic structures (defenses) to minimize hazard and (2) ensuring the adaptation of the exposed assets to provide resistance from floods. The crest levels of defenses are set according to design water levels, which are established through statistical analysis with little consideration of potential impacts. In most cases, design water levels just aim for individual flood defenses instead of considering the whole defense

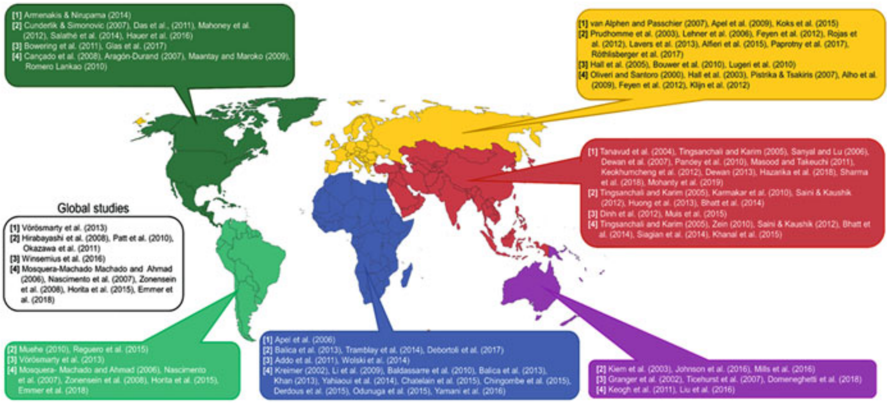

Fig. 7.6 Representative efforts on flood risk mapping across the globe. [**1**] Flood risk considering both hazard and vulnerability components. [**2**] Flood risk considering either hazard or vulnerability component. [**3**] Flood risk with climate change considering both hazard and vulnerability components. [**4**] Flood risk with climate change considering either hazard or vulnerability component

system (Boonya-Aroonnet et al. 2002). The major problem associated with structural measures is concerning the longevity and its associated cost. It usually takes a long time and high investment to build a flood control structure, and when it fails, it fails dramatically with less response time.

7.2.7.2 Nonstructural Measures

Nonstructural measures do not consider huge investments in infrastructures but rather rely on a precise understanding of the flood risk by considering the associated flood hazard and vulnerability components (Kundzewicz 2002; Kang et al. 2009; Bowering et al. 2014). Flood risk awareness forms the base of nonstructural measures. In the event of flooding, the lack of awareness results in communities failing to evacuate, thereby rendering them highly vulnerable. Awareness is high in areas of frequent floods but is often deficient in areas subject to low frequency but high impacts. This can be achieved by proper awareness campaigns and communication channels like posters, newspapers, brochures, televisions, radios, visual clues, training, and demonstrations.

Based on the extensive literature review, it is now well established that several regions in the globe are projected to experience an elevated risk from riverine flooding attributable to concomitant climate change and alterations in socioeconomic dynamics. Under such lines, their lies a major challenge to comprehensively quantify flood risk, which will facilitate in building flood mitigation infrastructures, improving land use/urban planning, and also prioritizing emergency response strategies. The quantification of flood risk is a complex process, not just because it is data-intensive but also involves several sensitive parameters in its formulation. The process becomes more challenging for data scarce regions as they suffer from considerable data unavailability, e.g., rainfall, discharge, high-resolution topography, etc. The research considers these research gaps and proposes a generic framework to quantify flood risk at the village level (finest administrative scale). The comprehensive framework is demonstrated over data-scarce Jagatsinghpur district in India.

7.3 Case Study of the Mahanadi River Basin in India

This section introduces the case study and demonstrates the proposed framework of flood risk estimation and mapping. The case study is situated in the severely flood-prone Mahanadi river basin in India.

7.3.1 Jagatsinghpur District: The Focal Point Witnessing Severe Flood Impacts in Odisha, India

Jagatsinghpur is located between 19° 58′ N to 20° 23′ N latitude and 86° 3′ E to 86° 45′ E longitude in the downstream of Mahanadi river basin, Odisha, India (Fig. 7.7). Among several other factors, the geographical location and demographic characteristics are considered the two most important reasons for high flood risk according to the District Emergency Operation Centre (DEOC 2016). Considering the fact that the case study is semi-urban, most of the rural villages suffer high risk. This is because a significant proportion of the population depends on agriculture and allied activities as their primary source of income, which is known to face highly vulnerability by floods. Moreover, many people live in their ancestral property for a long time and have left interest in shifting to safer places after a flood strikes (Mishra et al. 2010). The immediate need of the hour is to assemble information from various sources such as meteorological, hydrological, and social domains to quantify flood risks and provide answers to the current flood management situation.

7.3.2 Proposed Framework of Flood Risk Mapping

The flood risk in the case study is quantified for the latest census year 2011 by considering the hazard and socioeconomic vulnerability components. The proposed framework of flood risk mapping is illustrated in Fig. 7.8. This comprehensive framework consists of four building blocks. They are (i) estimation of regionalized design rainfall ($\mathcal{RDR}$), (ii) quantification of flood hazard ($\mathcal{H}$) through hydrodynamic modeling, (iii) analysis of socioeconomic vulnerability analysis ($\mathcal{V}$), and (iv) determination of flood risk through *risk classifier*. A brief description of these steps is outlined in the subsequent sections.

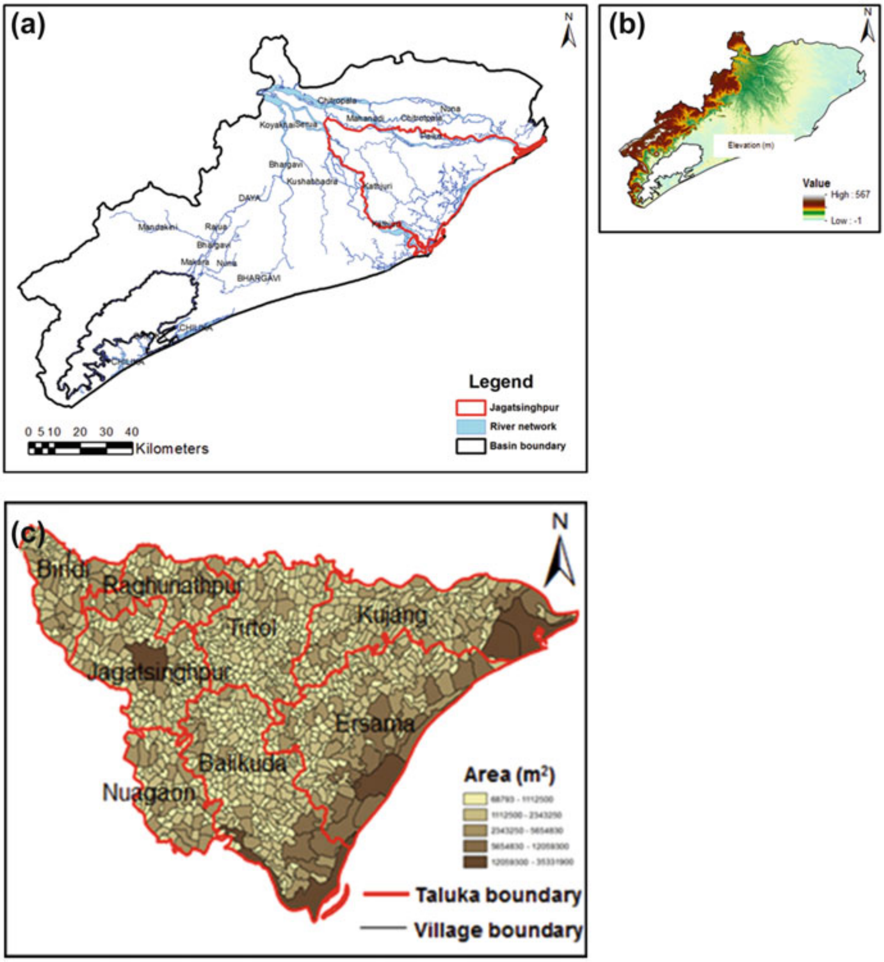

Fig. 7.7 Jagatsinghpur district in Odisha (India): (**a**) river network details; (**b**) description of elevation; (**c**) various administrative blocks and villages

7.3.2.1 Estimation of Regionalized Design Rainfall (*RDR*)

The only long-term hourly rainfall time series operated by the India Meteorological Department (IMD) from 1970 to 2011 located at *Bhubaneswar* (20.2961° N; 85.8245° E), *Paradeep* (20.3166° N, 86.6114° E), and *Puri* (19.8134° N; 85.8315° E) are utilized to form at-site design rainfall time series through a set of multivariate frequency and design temporal pattern analyses. To regionalize the at-site design rainfalls, two new nonlinear optimisation techniques, namely, complete optimisation and combined averaging optimisation, are introduced (Sherly et al. 2015a, b; Mohanty et al. 2018). These robust optimisation schemes are tailor-made to derive the regional bandwidth of the nonparametric kernel function, which has not been addressed in earlier studies.

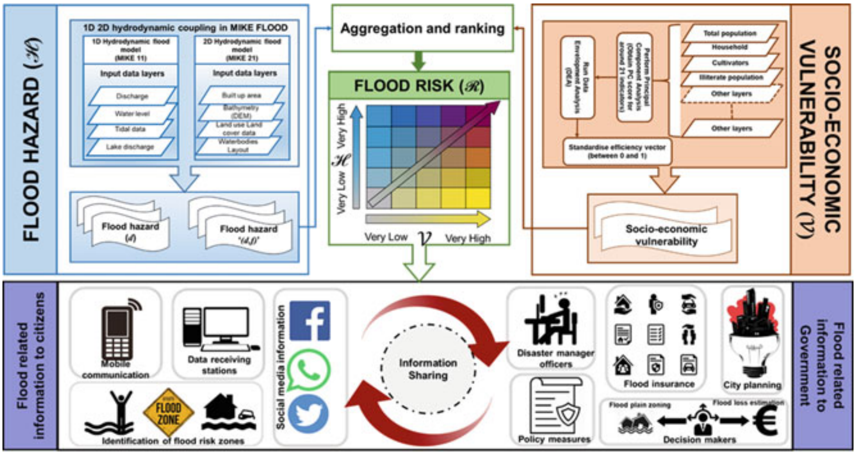

Fig. 7.8 A comprehensive framework for flood risk mapping using flood hazard and socioeconomic vulnerability. (Mohanty et al. 2020a)

7.3.2.2 Quantification of Flood Hazard (*H*) Through Hydrodynamic Modeling

The flood hazard is quantified with a 1D-2D-coupled MIKE FLOOD. The MIKE FLOOD interface houses MIKE 11 (one-dimensional) and MIKE 21 HD FM (two-dimensional) models, whose outputs are dynamically coupled by establishing appropriate hydraulic linkages (Frank et al. 2001). To represent the bathymetry in MIKE 21 HD FM, LiDAR DEM (horizontal resolution: 2 m × 2 m) is considered for the entire study area. A framework for flood risk mapping is given in Fig. 7.8.

An unstructured triangulated mesh of area <5000 m^2 is generated to account for the optimisation of computation time for the entire domain. The latest available land use and land cover classification map is utilized to represent the roughness values for each land use class. The MIKE 11 model set-up is developed by creating the river channel network and providing details of the channel cross-sections at close intervals of every 100 m along the river channel. The hydraulic inputs in the form of regionalized design rainfall for MIKE 21 HD FM and design discharge and storm tide (Mohanty et al. 2020b) for MIKE 11 are considered as the boundary conditions. The simulated outputs from these individual models are hydraulically combined in MIKE FLOOD by establishing lateral linkages between the river channel banks and adjoining flood plains (Mohanty et al. 2020c). The MIKE FLOOD model provides outputs in the form of flood inundation depth "*d*" and velocity "*f*" for each cell. The flood hazard is quantified in terms of "*d*" and tuple of "(*d,f*)." The severity of flood hazard is identified by discretizing it into five different classes (Mani et al. 2014) as outlined in Table 7.3.

Table 7.3 Discretization of "d" and "(d,f)" into various hazard categories

Severity of hazard	"d" [m]	"(d,f)" [m^2/s]
Very low	0–0.2	0–0.3
Low	0.2–0.6	0.3–0.7
Medium	0.6–1.5	0.7–1.2
High	1.5–3.5	1.2–1.6
Very high	> 3.5	> 1.6

7.3.2.3 Analysis of Socioeconomic Vulnerability Analysis (V)

A suite of 21 socioeconomic indicators is selected from the latest Census of India 2011 data (Census 2011). These indicators are classified into two categories: *cost type* (the larger the value, the larger the vulnerability) and *benefit type* (the larger the quantity, the lesser the vulnerability). The slack-based input-oriented BCC method (Banker et al. 1984) of data envelopment analysis (DEA) is considered for deriving the vulnerability values. Similar to hazard, the socioeconomic vulnerability values are grouped into five different classes.

7.3.2.4 Determination of Flood Risk Through Risk Classifier

This study introduces a bivariate approach for quantifying flood risk through a risk classifier. The classifier has the anatomy of a 5 × 5 choropleth as illustrated in Fig. 7.9. The new concept gives an idea of different levels of flood risk ($\mathcal{R}$) through the identification of the marginal and compound contributions from the hazard ($\mathcal{H}$) and vulnerability ($\mathcal{V}$) components.

7.3.3 Results and Discussion

A large portion of Jagatsinghpur was found to face high and very high $\mathcal{H}$ (Fig. 7.10a). In particular, the N-W and S-W flood plain stretch of Mahanadi and Devi rivers and coastal regions were seen to have several villages facing high and very high $\mathcal{H}$. The $\mathcal{V}$ was scattered, although several villages in the coastal regions were identified as high and very high $\mathcal{V}$ (Fig. 7.10b). The risk map was identified predominantly by $\mathcal{H}-$ and $\mathcal{V}-$ driven risk. The villages facing *very high risk* due to $\mathcal{H}$ or both $\mathcal{H}$ and $\mathcal{V}$ are situated in the N-W (Tirtol, Raghunathpur and Biridi) and the S-E (Ersama block) of Jagatsinghpur District (Fig. 7.10c).

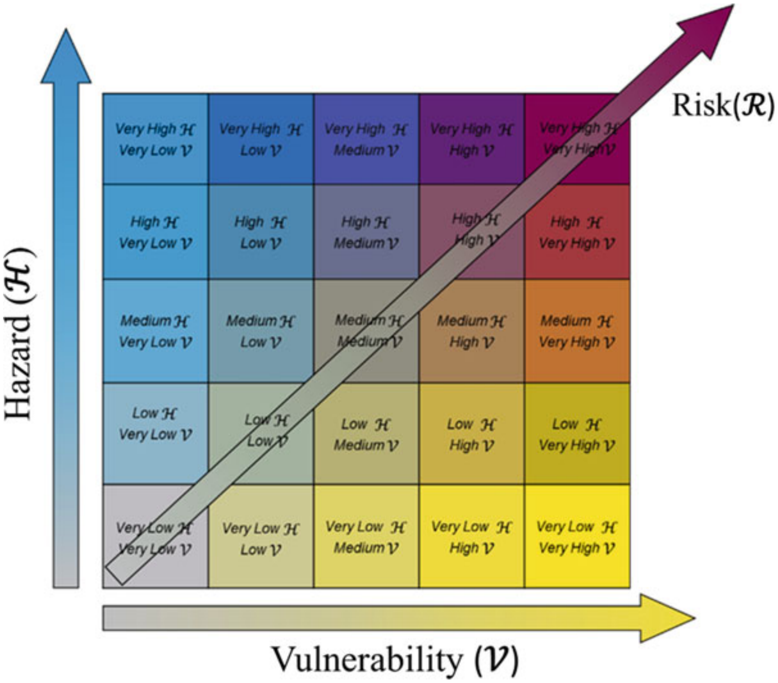

Fig. 7.9 A bivariate choropleth representation of flood risk ($\mathcal{R}$) aggregating flood hazard ($\mathcal{H}$) and socioeconomic vulnerability ($\mathcal{V}$). (Mohanty et al. 2020a)

7.4 Conclusion

Flood risk mapping is the opening step towards flood risk management for any flood-prone region. It paves the path to a comprehensive flood management strategy, as it divides a region into various zones of risk based on the values obtained in the flood risk analysis. Such a map acts as a tool to the public, professionals, and administration for decision-making purposes. This chapter reports the present status and future challenges of flood risk mapping through a comprehensive literature review. In the administration of the generic framework over a case study, the important components of flood hazard and vulnerability were treated keeping in the mind the technical commitments and needs of the society. The flood risk maps were developed using a bivariate concept, showing the gradual increase of both the components and the dependency of either one on risk. The proposed framework was applied in Jagatsinghpur district (Odisha), which has been identified as a severe flood-prone region. The identification of flood risk suggests possible areas of improvement in the current flood risk management plans. Those locations suffering from high risk due to vulnerability alone should be administered by enforcing stringent policies and schemes for the uplifting and spreading awareness on flood damage prevention. The disaster management bodies should focus on nonstructural

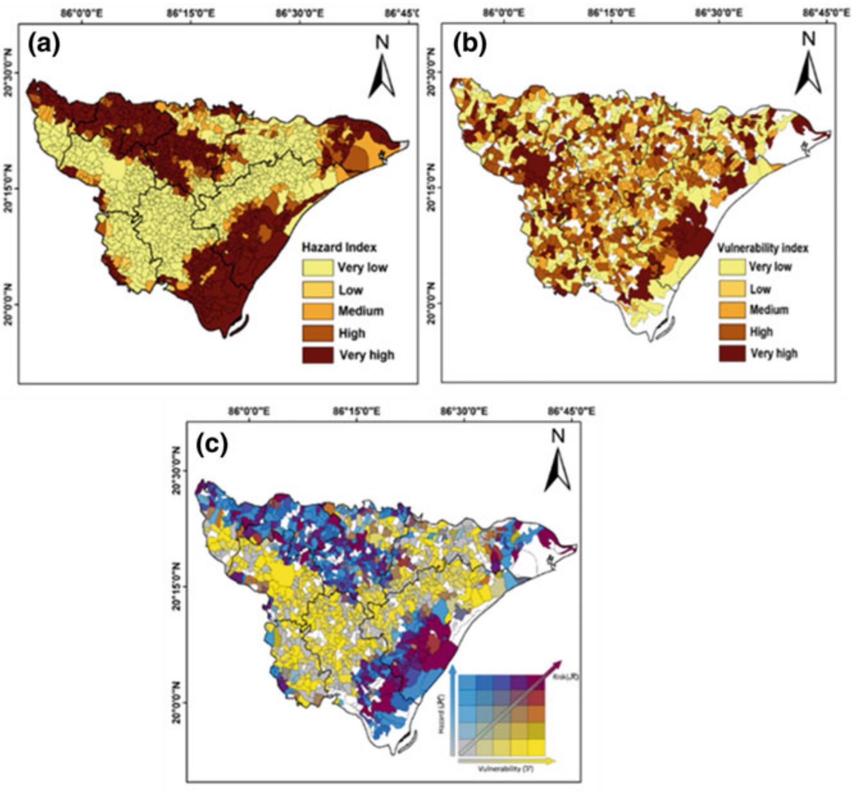

Fig. 7.10 (**a**) Flood hazard map; (**b**) socioeconomic vulnerability map; (**c**) bivariate flood risk map for 2011 for Jagatsinghpur district, Odisha. (Modified from Mohanty et al. 2020a)

measures and develop suitable tools to sensitize the population in combating any form of flood activity. For those regions facing risk from the hazard, improved structural measures and flood zoning practices should be implemented. The flood risk map demands easy access to the public and every end-user. It can be further developed as a cartographic product which can provide important guidelines for sustainable benefits by minimizing flood losses.

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