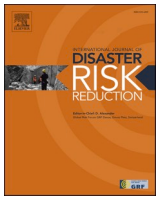
International Journal of Disaster Risk Reduction 49 (2020) 101660

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: http://www.elsevier.com/locate/ijdrr



Flood management in India: A focussed review on the current status and future challenges

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ARTICLE INFO

Keywords:
Flood management programme
Policy makers
Flood resilience
Socio-economic damages
Structural measures

ABSTRACT

Despite massive investments and continuous flood-control efforts in India, the socio-economic damages and death toll continue to remain high. Undoubtedly, the process of flood management in India is very complex due to the influence of several socio-hydroclimatological factors, such as climate change, sea level rise, and socio-economic dynamics. While these factors influence the intensity and frequency of flood events, factors explicitly related to the process of flood management, such as the improper execution of traditional structural measures, the lack of the proper implementation of schemes, lackadaisical execution of traditional structural measures and end-to-end management of the flood management programs/practices, ensure only partial protection. This review article identifies the region-specific flood problems in India and discusses the initiatives undertaken by major Indian flood management agencies, with an emphasis on the current ongoing flood management practices. The effectiveness of these practices in the long term is discussed, and specific gaps are identified. The recommendations provided in this article may be useful to guide stakeholders and policymakers in formulating and implementing sustainable flood management plans for improved flood resilience.

1. Introduction

Floods cause misery and fatalities worldwide. The recently published World Disaster Report by the International Federation of Red Cross and Red Crescent Societies 'IFRC' (http://media.ifrc.org/ifrc/wp-content/uploads/sites/5/2018/10/B-WDR-2018-EN-LR.pdf) reports that floods (41%) constituted the largest percentage of all known disasters between 2008 and 2017. This vast number has affected as many as 730 million people, which is over a third of the estimated 2 billion people affected by natural hazards. In terms of economic losses, floods have been more devastating than any other disaster. Among the flood-affected nations, India is known as one of the severely flood-affected countries in Asia (Fig. 1). With one-fifth of global flood deaths and 12% (40 million hectares) of geographical regions prone to various kinds of floods (https://ndma.gov.in/en/vulnerability-profile.html), the situation is alarming. CWC-2017 (http://cwc.gov.in/sites/default/files/statewiseflooddatadamagestatistics.pdf) reports that on average, 1650 people annually lost their lives between 1953 and 2016 due to floods. Ashraf et al. [1] reported that India has the highest number of flood-related deaths among Asian nations (Fig. 2). The statistics confirm the economic loss (7 billion USD), as reported by the Global Assessment Report by Ref. [2]. Floods are not new to India, as they occur with unfailing consistency and vary from region to region [3].

The leading causes of floods in India are incessant monsoon rainfall, reduced river channel carrying capacity for high flows, riverbank erosion and the siltation of channel beds, poor natural drainage in flood-prone areas, cloudbursts and several other meteorological factors [4–6]. Additionally, in recent decades, rapid urbanization and changes in the land use pattern have given rise to another type of 'disaster': urban floods [7,8]. There have been multiple devastating floods in different regions of India in past years, among which the Mumbai flood in 2005, Bihar floods in 2007 and 2008, Assam flood in 2012, Uttarakhand flood in 2013, Jammu & Kashmir floods in 2014, Chennai flood in 2015 and, most recently, the Kerala flood in 2018 are identified as the most severe ones.

The flood situation in India is not simple and thus makes flood management a tedious process. Since independence, the Government of India (GoI) has taken up numerous measures to reduce the chances of flood occurrence and limit their potential consequences. For instance,

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https://doi.org/10.1016/j.ijdrr.2020.101660
Received 18 July 2019; Received in revised form 6 March 2020; Accepted 10 May 2020
Available online 16 May 2020

List of abbreviations

CAG	Comptroller and Auditor General
CWC	Central Water Commission
DHARMA	Dam Health and Rehabilitation Monitoring Application
DPR	Detailed Project Reports
DRIP	Dam Rehabilitation and Improvement Project
DSO	Dam Safety Organization
EAP	Emergency Action Plans
FMP	Flood management programme
FRM	Flood Risk Management
GFCC	Ganga flood control commission
GoI	Government of India
GR	Ganga Rejuvenation
IMD	Indian Meteorology Department
MoEF	Ministry of Environment and Forests
MoWR	Ministry of Water Resources
MoWR, RD & GR	Ministry of Water Resources, River Development, and Ganga Rejuvenation
NCDS	National Committee on Dam Safety
NDMA	National Disaster Management Authority
NDMP	National Disaster Management Plan
NIDM	National institute of disaster management
NRLD	National Register of Large Dams
NRSC	National remote sensing centre
PWD	Public Works Department
RBA	Rashtriya Barh Aayog
RD	River Development

the GoI has set up various committees, task forces and working groups and formulated policies that have provided guiding recommendations for water resource management, including flood management. These strategies employed a normative approach by focusing on minimizing flood impacts by emphasizing various structural measures and emergency responses. The policies were formulated with short-term goals relying heavily on a handful of structural measures, which largely created a management system that is not adaptive enough to respond under changes and needs to be more rational by including stakeholder participation [1]. For instance, the Dam Safety Organization (DSO) was set up to develop a unified procedure of dam safety for all large dams in the country [9]. This would assist the state governments in identifying the causes of potential distress and recommend suitable remedial measures in the event of dam failure. As per the guidelines, a set of emergency action plans (EAPs) and operating manuals (OPs) [10] were to be prepared by every state that would help in maintaining a flood cushion and reduce damage during dam failure. However, only 349 (seven percent) EAPs and 231 (five percent) OPs for large dams out of 4862 large dams had been prepared as of March 2016. Out of 17 states/union territories (UTs), only two states had thoroughly carried out the pre- and post-monsoon inspections of the dams, while three states partially carried out the inspections, and the remaining 12 states could not initiate the inspections [11].

In another instance, Rashtriya Barh Aayogh (RBA) was constituted in 1976 to map flood-prone areas in various states. It submitted a report in March 1980 [12,13], after which the recommendations were forwarded in September 1981 to all the states/UTs/ministries in the form of guidelines and instructions for implementation. Assam and Uttar Pradesh were the only states to validate the RBA-assessed figures of flood-prone areas; the RBA recommendations could not be implemented in other states due to bureaucratic issues [11]. A detailed record of flood-prone areas could not be prepared in the form of a flood atlas, as neither the Central Water Commission nor the Ganga Flood Control Commission could carry out a test check in the areas marked on the RBA flood map. Passive flood management projects have also not succeeded in their proper execution. The possible reasons for this are: (1) limited financial resources, (2) challenges in the proper execution of projects, and (3) the absence of regular monitoring of their dam functioning and the evaluation of their benefits [14]. The current management system needs to recognize the importance of considering community participation and non-structural measures for creating flood-resilient communities and reducing the compounding risk. There are several socio-economic factors that have hindered an active build-up of community participation within a country such as India. On many occasions, it has been discovered that the social structure identified by diverse ethnic groups, religions, majorities, and minorities does not allow equal

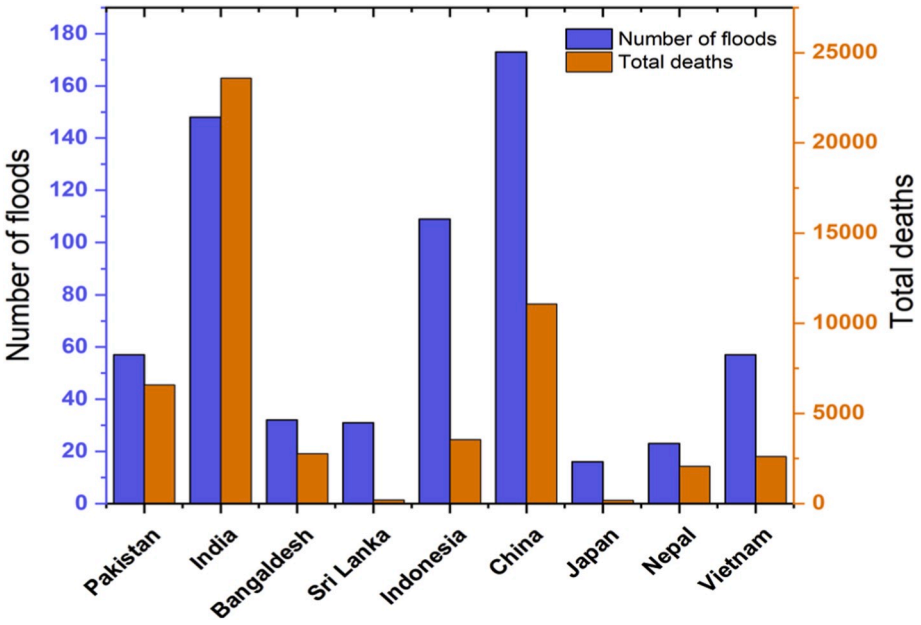

Fig. 1. Number of flood events and total deaths in selected Asian countries between 2000 and 2010 (data obtained from Ref. [1].

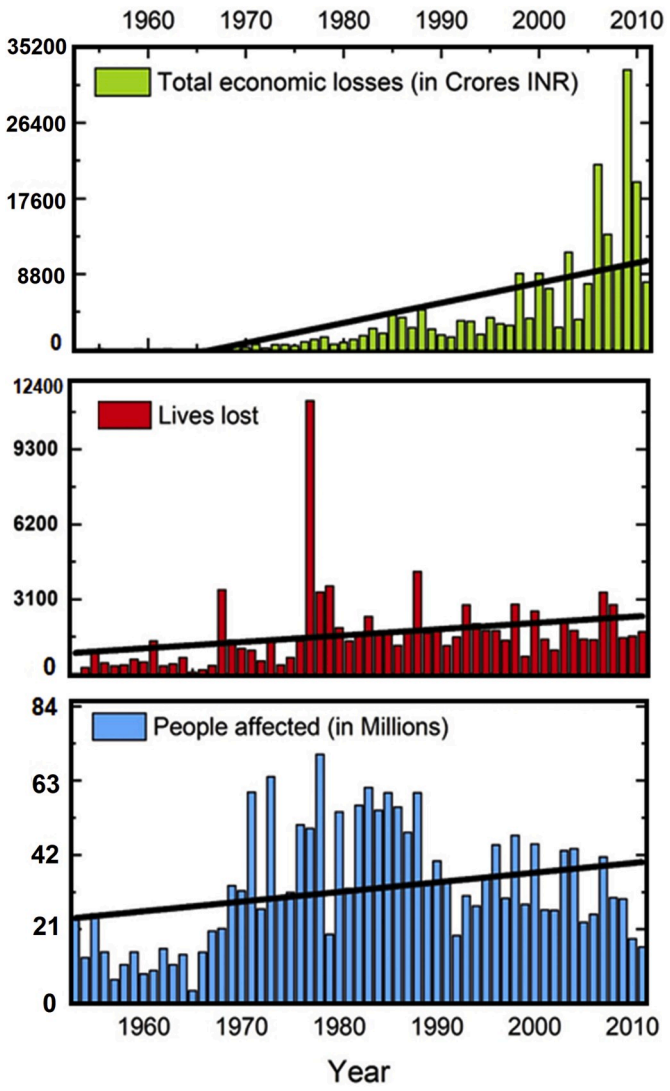

Fig. 2. Flood related data from the year 1953–2016 (data gathered from CWC report, 2017: http://cwc.gov.in/sites/default/files/statewiseflooddatadamagestatistics.pdf).

participation of everyone on a common platform [15]. It has also been noticed that individuals living in more racially fragmented areas participate less [16]. Similarly, there is strong evidence that rates of community participation are higher in societies with higher or similar income groups [17]. The gender disparity hinders the participation of women in flood management activities [18], thereby losing their potential in terms of additional human resources and knowledge. Though non-structural measures (such as regulations, land use planning, flood zoning, flood forecasting) find their mentions in flood-related policies and are practiced in a few regions of the country, they are yet to be enacted extensively by the States [19].

It is now certain that the situation of floods in India is multifaceted. To respond to such a heterogeneous distribution of flood risks along the length and breadth of the country, it was felt necessary to develop a hierarchy in which the centrally based organization functions at the core and provides direction to several other state-level organizations. Even though the central-level organizations have been provided the highest power, equal freedom is provided to the states to build and execute their plans as and when required. In this manner, the coherence between the two levels provides a dynamic feature to the hierarchy of the flood management system. Moreover, with the unprecedented growth of flood-prone regions with each passing year for various climatic and anthropogenic reasons, these organizations are continuously challenged in the execution of their plans and policies for keeping the human and economic losses to a minimum during and after disasters strike. Since independence, substantial progress has been achieved in flood disaster preparedness, recovery, and management activities. However, as the famous statement says, 'success is a success only when it is continuous' [20], there is an urgent need to review these activities and to strive to make them more useful for the future by considering scientific strategies.

This article presents a comprehensive and systematic review of the current flood management practices in India, identifies their shortcomings, and proposes possible future challenges that may be encountered. The purpose of the study is to (1) identify the region-specific flood problems in India; (2) understand the flood management system and organizations functioning at the central and state levels; (3) recognize the shortcomings that have hindered the successful implementation of various flood management plans; and (4) highlight future directions through practically feasible recommendations, which can possibly be incorporated within flood management action plans to reduce flood risk and damage. A comprehensive literature review is conducted by studying flood management information at different levels mentioned in past studies, technical documents, audit reports, and official websites of various water resources and disaster management organizations. The main contribution of the review is to agglomerate relevant statistics and data patterns that cannot be observed by looking at any individual study. In doing so, the study reports the suitability, efficiency, and performance of flood management plans and offers recommendations for flood risk management. This study can serve as a good foundation to gain an understanding of the existing management practices and identify areas for improvements in flood risk management that will lead to more significant advancements in the field. The flood-prone regions of India and their characteristics are discussed in the second section. The current flood management system and how it functions at various levels are elaborated in the third section. This section also highlights the success stories and limitations of the proposed flood management plans and various ongoing development measures. A set of recommendations is thereafter proposed for efficient flood management for the future in the fourth section. This section highlights the necessity to shift from a passive response (that relies mainly on only structural measures) to a progressive response that emphasizes non-structural measures and collaborative participation among government agencies and stakeholders along with the rationalized utilization of resources. The last section contains the summary and concluding remarks.

2. Flood prone regions in India

India is the seventh-largest country in the world. It lies on the Indian Plate that is the Northern part of the Indo-Australian Plate. On the South, it is bounded by the Indian Ocean, the Arabian Sea on the west, and the Bay of Bengal on the east, while the Himalayan mountain range borders the northern frontiers. The Tropic of Cancer passes through the middle of the country. These factors have given rise to varied topography, geomorphology, river systems, and precipitation patterns over the country, which in turn are the possible nature-induced reasons for different types of floods. Most of the floods are caused by the consistent rains and the torrential downpour during monsoon season (Fig. 3). Among all the river basins, the Ganga and Brahmaputra river basins experience the highest number of floods (Fig. 4). Based on the nature of floods experienced, India has four major regions [21] - Brahmaputra river region, North-west river region, Ganga river region, and the Central India and Deccan region. The Brahmaputra river region is confined to the North-Eastern parts of India. The frequent flooding is brought about by incessant rainfalls in these regions. A significant part of the region faces frequent earthquakes and landslides which disturbs the natural regime of river flow. Due to this phenomenon, regions that are expected to be flood-proof may not always be safe. As the name

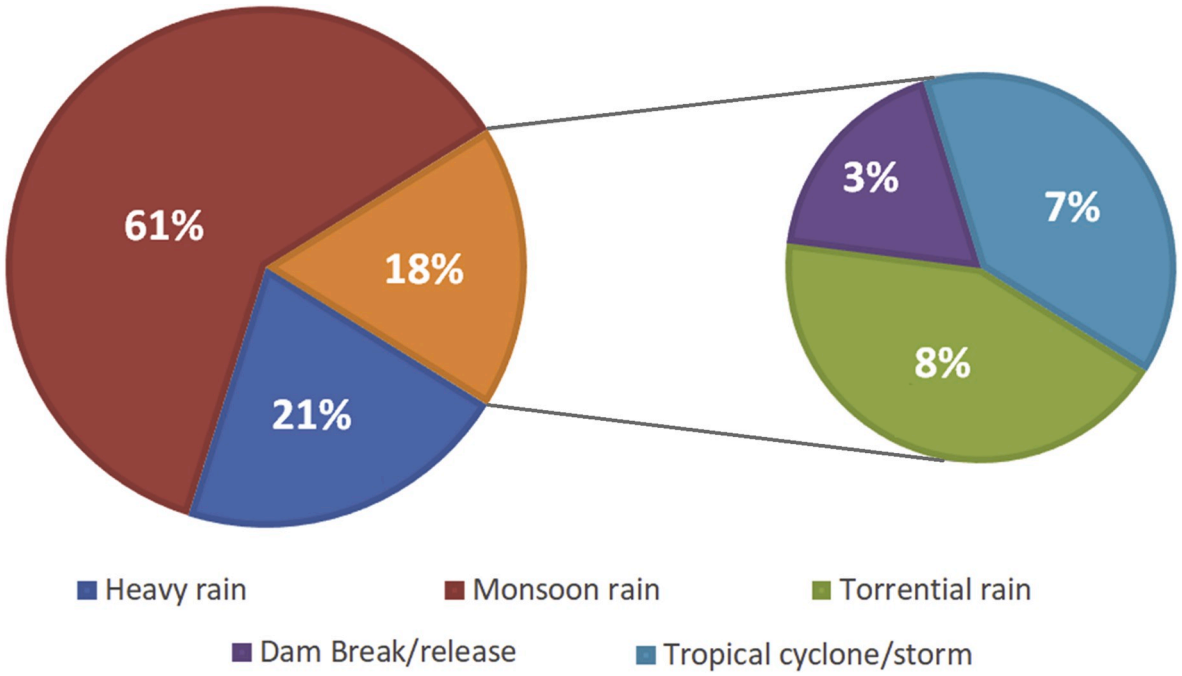

Fig. 3. Percentage distribution of flood causes for the flood events during 1985–2018 (based upon the data from the Dartmouth Flood Observatory Database).

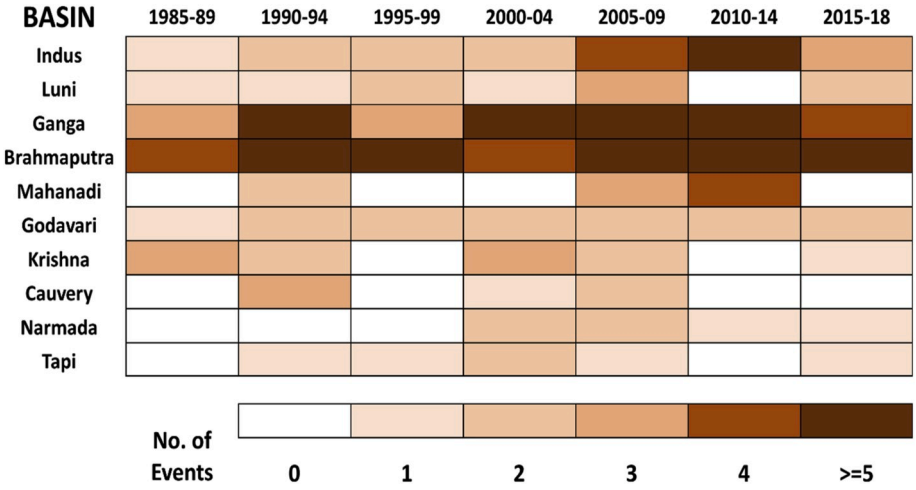

Fig. 4. Colour based representation of the number of flood events in various river basins in India from the year 1985–2018 (As per the data from Dartmouth Flood Observatory Database: http://www.dartmouth.edu/~floods/Archives/index.html). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

indicates, the North-west river region is located in the North-Western states of India. Although the flood risk in this region is relatively less, the major problem arises from inadequate surface drainage and water-logging. The Ganga river region covers a majority of North and a few states in Western India. However, it is the Northern part which is severely flood-affected. The drainage congestion due to heavy rainfall and river erosion due to massive sediment deposition are the two primary drivers to severe flood risk. The Central India and Deccan river region covers all the Southern states of India. The region is identified by a majority of coastal states, which are prone to tidal flooding during cyclonic disturbances. Most of the rivers in this region have adequate river water carrying capacity within the natural banks except in their lower reaches and in the delta area, where the average bed slope is very flat. This aggravates the flooding problem as the river water does not easily drain into the sea due to opposing tidal intrusion. A detailed discussion on the characteristics of these zones is presented in the following subsections.

2.1. *Brahmaputra river region*

The Brahmaputra River region comprises of the Brahmaputra (known as *Tsangpo* in Tibet) and Barak River basins and their tributaries. It extends over the north-eastern states of Assam, Arunachal Pradesh, Meghalaya, Mizoram, Manipur, Tripura, Nagaland, Sikkim, and few parts of northern West Bengal.

The streamflow in the Brahmaputra River is exceptionally high compared to any other river in the country. It is due to its location in the wettest place of India, recording an annual average rainfall of 248 cm in the Brahmaputra valley to 635 cm in north-eastern regions of Assam (https://www.tropmet.res.in/~lip/Publication/RR-pdf/RR-138.pdf), and heavy snow melts from the Himalayas [22,23].

The Brahmaputra River is the second-largest silt carrying river in the

world, which has substantially decreased the natural water carrying capacity with time. Heavy streamflow results in spilling of water from the river banks, inundating the adjoining floodplains. Moreover, this region is tectonically active and hence faces frequent landslides, which disturbs the natural river regime time and again. On 15 August 1980, a severe earthquake in the state of Assam was identified as the major cause behind a drastic change in the river's morphology due to a sudden rise in bed-levels of River Brahmaputra at many places [5]. The cloudbursts in this region often lead to flash floods, soil erosion, and bank erosion along the river channels. There are several incidences of embankment breaches that have resulted in major floods. More than 80% of the embankments have not been reinforced due to several issues between the contractor and administration. According to the Assam State Disaster Management Authority, 1846 villages were affected, and 1.6 million people were displaced during the 2014 floods in Assam alone. In 2016, the numbers rose to 2893 villages and 1.7 million people displaced. While natural causes remain, one of the major issues in the region to inadequate flood risk management is the lack of coordination between CWC and local administration. Although CWC disseminates flood forecasts every time, the local administration is not able to use it properly due to a lack of skilled personnel.

2.2. North-west river region

The North-west river region includes River Indus and its tributaries River Sutlej, River Beas, River Ravi, River Chenab, River Jhelum, and River Ghaggar. It covers the Northern and Western states of India namely, Jammu & Kashmir, Haryana, Punjab, Himachal Pradesh, and Rajasthan. Although severe floods are not a frequent occurrence in the states of Haryana and Punjab, a significant proportion of agriculturally dominated areas and inadequate drainage facilities result in flood inundation due to long hours of waterlogging [24]. Cloudbursts are the root cause of flash floods in the upper reaches of the region, such as Leh-Ladakh in Jammu and Kashmir. The water level in River Jhelum and River Indus seldom exceeds beyond the specified danger levels and submerges the nearby areas marginally. The rivers keep changing their natural course regime regularly and leave behind a dense mass of sand [25]. The arid regions of Rajasthan are also prone to flash floods, mainly due to soil behavior. This region has thin soil layers followed by impermeable layers of bedrock and hard calcium, which prevents the water infiltration and keeps the soil wet in case of any antecedent rainfall event before more torrential storms [26]. The monsoonal rainfall wrecked havoc in the state of Himachal Pradesh [27]. They often trigger landslides, mudslides which elevate the flood risk in the regions. Also, the failure of earthen embankments has resulted in stronger waves of floodwater, causing substantial damages in the region. Moreover, as Himachal Pradesh resides along the Indian Himalayan Region (IHR), the potential threat from glacial lake outbursts is significant, and it gets worse with time due to sensitive changes in climate [28]. For instance, the Satluj basin that drains from glaciated headwaters in Tibet into Himachal Pradesh experienced an increase in mean annual air temperature of 1.6 °C in the past century, which is infact far more than the mean global warming [29].

2.3. Ganga river region

The Ganga river region is the most populous river region in the world [30]. It is the longest river flowing in India and, together with its tributaries, forms the largest river system in the country. Spreading across the states of Uttrakhand, Uttar Pradesh, Bihar, South, and Central West Bengal, parts of Haryana, Himachal Pradesh, Rajasthan, Madhya Pradesh, and Delhi, Ganga and its tributaries are infamous for frequent flooding in the upper and middle regions of its course. Pluvial flooding is a major challenge since the basin receives an annual average rainfall between 60 and 190 cm, most of which is contributed from the southwest monsoon. The changing course of rivers due to tectonic movements [31–33] and uncontrolled sand mining [34,35] have aggravated the flood risk in this region.

River erosion is another major problem and is particularly severe in parts of Uttar Pradesh, Bihar, and West Bengal [36]. The rivers in this region usually spill across their banks since the erosion decreases the water carrying capacity of the channels due to massive silt deposits at several places. The Ganga and its tributaries in Uttarakhand pass through quite steep channels with high velocities and hence carry massive silt along with the flow. The silt mass is deposited in the lower regions where channel flow is comparatively tranquil [5]. The Chitale committee in 2016 recommended undertaking large-scale desilting by dredging to tackle the issue with silt deposition. The problem of drainage congestion is prominent in Northwest regions as well as in the West Bengal region. The high density of population with radical land-use changes [37], combined with pervasive poverty render flood management a unique global challenge in this river region.

2.4. Central India and deccan region

Central India and Deccan region consist of River Narmada, River Tapi, River Mahanadi, River Godavari, River Krishna, and River Cauvery in the states of Andra Pradesh, Telangana, Karnataka, Tamil Nadu, Kerala, Orissa, Maharashtra, and Gujarat. All these rivers carry high flood discharges generated by heavy rainfall. However, the coastal flood risk is most acute in this region. The coastal problems are severe in the deltaic stretches due to sea-level rise, cyclonic impacts, and tidal flooding. Most of the time, heavy rainfall in the upper catchments adds a substantial amount of water volume to these rivers. The river channel slope is higher in the upper reaches, which increases the velocity of flow but later spreads over the lower deltaic stretches where the terrain is relatively flat [38]. Several studies have reported the erosion problem in the coastal districts drained by Rivers Mahanadi, Krishna [39,40], Godavari [39,41], and Cauvery [42]. [43] identified that as high as 65% of the River Mahanadi coastline is facing erosion at present and the trend is expected to continue over the years. They also reported that by the end of 2050, the erosion scenario would worsen to the extent that it will pose a high risk for nearly one-third of coastal *mouzas* (small administrative blocks). The Bay of Bengal is also identified as the epicenter of post- and pre-monsoon tropical cyclones [5,44]. In the last decade, it has already faced a plethora of tropical cyclones such as Laila in 2010, Thane in 2011, Nilam in 2013, Hudhud in 2014, Kyant in 2016, Titli in 2017, Gaja in 2018, and Fani in 2019 that have resulted in considerable human and economic damages. Shallow bathymetry, flat terrain, and the existence of a high population density in these deltaic stretches increase the susceptibility to flood damages during the landfall of the cyclone. The intensity of floods can also be severe if the cyclone is accompanied by high tides.

Climate change is a significant factor that has added to the severity of large-scale floods in this region. It is reported that between 1901 and 2015, there has been a three-fold rise in widespread extreme rainfall events in this region [45], which is attributable to the increase in fluctuations of the monsoon westerly winds, due to increased warming in the Arabian Sea. This phenomenon results in heavy moisture transport from sea to landmass, resulting in torrential rainfall for 2–3 days. The Mahanadi River basin is known to be the worst sufferer of floods in the country with climate change [46]. Several reports have highlighted the fact that the intensity of flooding has increased in Mahanadi with concomitant climate change [47–52]. There are several reports which highlight the un-engineered operation of major dams that have resulted in flash floods. Many dam operations still follow the conventional 'Rule Book' rather than computer-based modeling. For instance,the operation of Hirakud Dam during heavy flows has been suspicious time and again. Though the dam was built to control floods, it has never been effective as expected. To support this fact, it was observed that the number of floods were three times as more between 1960 and 1980 than during the time Hirakud was even built [53].

2.5. Urban centers

Although urban floods were not native to India as the rest of the world, it has manifested into a serious problem over the years [54]. The rapid and unplanned urbanization has mostly contributed to the increased risk of urban flooding in many Indian cities [55,56]. The recurrent flood incidences in Mumbai, Bangalore, Surat, and Chennai are few of the many examples and a clear indication of the current state of Indian cities. Most of these cities are unplanned, have poor drainage infrastructure [7], which are highly susceptible to heavy rainfall event concentrated over a short period. Most often, it takes the form of flash floods and does not provide sufficient time for evacuation [57–59]. The encroachments of waterways and settlements [60], poor maintenance of usually blocked drainage system [61], highly dense urban agglomerations with impervious land [34,62], improper flood zoning [3] and ignorance of building codes [16,63] in flood-prone regions are key reasons behind increasing severity of urban flood occurrences. Urban floods require equal attention as that of riverine flooding since the economic and social impacts of floods in urban regions are quite higher because of the early onset and rapid development of flood event.

3. Flood management system in India

The flood management system has evolved over the years in the country. The seriousness of flood prevention and the need for an action plan to protect floodplain was acknowledged in 1954 after an unprecedented and devastating flood event in Bihar [8]. Since then, substantial efforts towards flood protection began with controlling riverine flooding, with massive investments put into the construction of structural measures such as embankments, detention reservoirs, and at the same time improving the drainage situation in river basins. In the long run, these measures have not been successful as was anticipated, since the number of flood-prone regions in the country has increased in the last five decades. The subject of 'water' and activities related to 'water resource management' are an essential part of the state-list of legislative powers, as mentioned in Schedule-7 of the Indian constitution [64]. It allows the states to plan, execute, and maintain all schemes related to water resources management as per their needs [65]. Since flood management is a subset of water resources management, the onus of implementation of work related to it, for instance construction and maintenance of flood control measures, lies with state government and state agencies [11]. The central government sets up various committees, task forces, and formulates policies [21] to guide the states to develop an efficient flood management system. The central government and its various agencies act as a catalyst for providing financial and technical assistance to the states through eligible schemes as per guidelines of various committees. Hence, the flood management institutional structure of India has twin hierarchies at (1) State government and (2) Central government levels. Each level has various active agencies responsible for carrying out specific tasks for managing floods. The institutional arrangement requires coordination and cooperation among various agencies at different levels. The subsequent sections provide a brief description of the institutional structure at each level.

3.1. National level organizations

It is the responsibility of the Central government to look after the process of disaster management in the country. The Central ministries implement measures of disaster prevention and mitigation by coordinating with other agencies. Flood management is a multi-disciplinary process and hence requires the cooperation and coordination of many agencies. The Ministry of Jal Shakti, Department of Water Resources, River Development, and Ganga Rejuvenation (MoWR; http://mowr.gov.in/) is the co-ordinator/supervising department at the central level. However, the Central government has established various other organizations and expert committees to monitor the flood problems more exhaustively. The various organizations and their roles in the context of flood management are described in the following sections.

3.1.1. Central Water Commission (CWC)

The nodal agency in the country for water resources management, CWC (http://cwc.gov.in/), has decades of expertise in planning, management, and design of water resources development. It was constituted to promote flood control practices as well as to act as a technical advisory body to the states and MoWR on policy-related issues. It is responsible for infrastructural development, maintenance, and development of a flood forecasting system, and its dissemination to various end-users. It also takes up the task of conducting and coordinating research on water-related issues and providing guidelines on various developmental projects concerned with the river basins, for instance, flood control strategies. CWC also undertakes morphological studies, dam safety studies, data collection, and management of major rivers and techno-economic appraisal of major multi-purpose projects. These are a few activities relevant to flood management among all the functions performed by CWC. To pay focussed attention to a couple of the major river basins of India, i.e., Ganga and Brahmaputra basins, MoWR constituted the Ganga Flood Control Commission (GFCC) and Brahmaputra Board, as statutory bodies to manage flood control activities in their respective basins.

- MoWR AGENCIES

3.1.2. Ganga Flood Control Commission (GFCC)

GFCC (http://mowr.gov.in/about-us/organisations/ganga-flood-control-commission-gfcc) is entrusted with effective flood management in the largest river basin of the country. Established in 1972, it is responsible for preparation and regular up-gradation of master plans for flood management in the Ganga basin and sub-basins [66]. Earlier, it prepared the comprehensive flood management plan for 23 sub-basins in the region [67]. GFCC coordinates programme of flood control works implementation. It is also responsible for formulating standards for the flood control works and ensures that the acting state agencies appropriately meet these. GFCC does the techno-economic appraisal of the projects proposed by the states as well.

3.1.3. Brahmaputra Board

To tackle the regional flood problems in Brahmaputra and Barak basin in North-east India, GoI set up the Brahmaputra Board (http://brahmaputraboard.gov.in/) in 1980. It functions in a similar way as GFCC. The board is responsible for formulating master plans for flood control in the region and scrutinizing its implementation. It also takes up the activities related to the construction and maintenance of multipurpose dams. The board prepares Detailed Project Reports (DPR) of all the projects related to flood control, bank erosion, and drainage improvement [68]. It enlists the standards for construction, operation, and maintenance of dams in the region. Till now, the board has prepared master plans for nearly 50 sub-basins in the region.

3.1.4. National disaster management authority (NDMA)

NDMA (https://ndma.gov.in/en/) is responsible for undertaking the actions for the development of a holistic and prompt response for floods or any other disaster. It lays down national policies and action plans for disaster management, provides guidelines and coordinates with states and other agencies to enforce the plans and takes necessary actions for disaster preparedness and capacity building. NDMA recognized the grave flood risk in this country and hence issued flood management guidelines in 2008. These guidelines aim at strengthening the existing flood preparedness capability and mitigation arrangements as well as improving post-flood response, relief, and rehabilitation practices.

3.1.5. Other organizations

While the above organizations have a direct involvement in flood

management, there are few institutions, such as India Meteorological Department (IMD; https://mausam.imd.gov.in/), National Remote Sensing Centre (NRSC; https://www.nrsc.gov.in/) and National Institute of Disaster Management (NIDM; https://nidm.gov.in/) which although are not subsidiary bodies for flood management, but their assistance is integral. For instance, the regular weather forecasts by IMD provides essential information related to flood forecasting. At the same time, the remote sensing capabilities of NRSC are significant for various kinds of observational studies, and flood mapping works. The research carried out by NIDM in the area of flood management is mostly related to policy formulation and capacity building by developing training modules.

3.2. State-level organizations

Since the subject of flood management lies in the purview of states, hence it is the responsibility of state agencies to plan, construct, maintain, and operate all flood control and mitigation work. For that matter, some of the states have set up a state flood control board that takes care of all the flood works. Nevertheless, in most cases, the Irrigation Department is the nodal agency responsible for water resources management and planning, whereas the Public Works Department (PWD) carries out the construction and maintenance of structures for flood control. In order to address the flood problem holistically and develop an integrated flood management system, a collaborative effort of various agencies is vital at the local scale. Hence, states have their disaster management authorities and disaster response teams responsible for post-flood relief and recovery operations. The states have been advised by MoWR to establish river basin authorities having practical managerial skills to overlook and complete tasks in a time-bound manner.

3.3. Major gaps in the existing flood management system

There are two basic approaches to provide flood protection namely, flood control and flood preparedness[69]. Flood control aims to reduce the tangible factors of flood risk i.e., hazard by preventing floodwaters from reaching the potential locations [70–73]. It is practiced through structural measures that are accomplished by constructing various flood control options such as embankments, reservoirs, check dams, etc. On the other hand, flood preparedness is more of a preventive option. The aim is to reduce the intangible factor 'vulnerability' [74–77] to floods. It is essentially a non-structural measure which tries to avoid or limit the adverse effects of flood [78]. Various options include flood forecasting, flood plain zoning, flood proofing, and disaster preparedness. India has majorly focused on structural measures of flood control and overlooked flood preparedness [79–81]. In the following sections, a review of major flood management initiatives taken by various bodies is provided. The focus here is to introduce the various flood management measures adopted and discuss their shortcomings.

3.3.1. Flood management programme (FMP)

The FMP (http://mowr.gov.in/sites/default/files/fmp-11th-plan5817362359.pdf) was approved in the XI five-year plan with an outlay of INR 8000 crores to financially assist the states in building structures for flood protection. FMP covers projects related to river management, flood control, river erosion, flood proofing, drainage development, and anti-sea erosion. The rehabilitation and restoration projects are also included under the FMP [82]. MoWR approves the project(s) proposed by the states if they fulfill the criteria as per FMP guidelines. The guidelines for FMP pertain to provisions of project approval, funds sharing between central and state agencies, and other aspects such as expenditure reimbursement and expenditure audit. The programme has been functional since the XI five-year plan with its budget increased to INR 10,000 crores in the XII five-year plan (http://mowr.gov.in/sites/default/files/FMP-XII-Plan.pdf) along with 517 projects sanctioned under it (till March 2014). While 420 projects were approved in the XI five-year plan, the number reduced significantly to 97 projects in XII five-year plan.

According to Ref. [11]; only 297 projects could be completed out of 517 in the last ten years, even though the guidelines clearly state that projects should be finished within 2–3 years of sanctioning of the budget. It also reports that the states were unable to provide their share of funds for the project. This resulted in a shortfall of funds and hence delays in the project completion. A few more suffered delays due to untimely or late submission of project proposals by the states, which delayed the release of funds from MoWR [11]. It is likely the states did not follow most of the guidelines of the FMP. As per the guidelines, states are required to disburse the funds received from central agencies to the executing agency within 15 days. Also, the states should not rush the expenditure towards the project near the end of the financial year. However, as reported in Ref. [11]; there were multiple instances of violations of these rules and guidelines.

On top of that, no penalty or fine was levied on states for the violations. There are multiple cases of funds diversion and fund parking, which indicates mismanagement in the process [11]. For the projects sanctioned under FMP, states did not submit audited project completion report as well as the utilization certificates on time. The project proposals submitted by states overlooked the recommendations of National Water Policy -2012 as well as the recommendations of earlier working groups. The project proposals and detailed project reports submitted by states were not formulated in an integrated and scientific manner. To add to this, the delays in project proposals sometimes rendered the submitted project reports outdated. Moreover, the cost to benefit ratio of the projects was not justified in several cases [11].

3.3.2. River management activities and works related to border areas (RMABA)

RMABA (http://mowr.gov.in/schemes-projects-programmes/schemes/river-management-activities-and-works-related-border-areas) is an ongoing central scheme initiated in the X^{th} five-year plan by integrating multiple small projects and schemes operated by MoWR to improve the then flood management plans. Under this scheme, numerous activities were carried out, such as field surveys, investigation & preparation of DPR for new large dam projects, maintenance works of projects on the river close to international borders, flood protection works near international borders, and flood forecasting operations in partnership with neighbouring countries. Only three river systems, namely Ganga, Brahmaputra, and Indus river systems, are covered under this scheme. A considerable capital investment was approved under this scheme in each five-year plan. However, the implementation was not free from shortcomings. There were huge delays in completing the preliminary works of the projects. The feasibility and preliminary studies of the projects were insufficient [11]. This was attributed to two reasons, namely law and order issues in the project area, and disagreements between the Indian and the counterpart country on terms and conditions of water-sharing. The law and order issue was serious on many occasions. For instance, during December 1991 a MoU was signed between India and Nepal to take up joint studies/investigations of the Saptakosi High Dam project and prepare a DPR. Later the joint project-Sapta Kosi Sun Kosi Investigation (JPO-SKSKI) was set up in August 2004, which was expected to complete the works by February 2007 [83]. However, the investigation works could not be completed in time due to law and order issues in the project area [11]. In another instance, the investigation of the Naumure Hydro-electric project (in Nepal) was initiated during the XI and XII Plans. CWC prepared an initial pre-feasibility report in March 2010. However, the Nepalese side expressed disappointment with the report as it did not cater to their irrigation demands for the Kapilvastu region [84]. As a result of which, the plans could not be executed further to date.

The delay in the investigation, finalization, and untimely implementation of the DPR increased the time of project completion by years. Also, the mechanism of awarding tenders and other financial matters did

not follow a smooth procedure, which was ultimately reflected in the flood protection measures. For instance, when the meandering River Kosi eroded its embankment, it was not repaired on time, resulting in a breach in August 2008. It is only after this that the funds were sanctioned under RMABA to repair the embankment but with a subsequent delay.

3.3.3. Dams and reservoirs

Currently, India has the third-largest count of large dams in the world [85]. The GoI identified potential risks associated with large dams and constituted the Dam Safety Organization in CWC in 1979. The organizational structure evolved in 1982 with the constitution of the National Committee on Dam Safety (NCDS; http://cwc.gov.in/damsafety/NCDS) which was appointed to oversee the dam safety practices in India. The NCDS formulated the guidelines for the development and implementation of Emergency Action Plans (EAP) in 2005. However, even after more than a decade of those prescribed guidelines, the EAPs are not available for most of the 5761 (till 2017) large dams, let alone the dam/embankment break studies or optimal operating procedure studies to reduce the sediment deposits. Till March 2016, out of 4862 large dams, only 231 dams had operation and maintenance manual, as reported by Ref. [11]. The preparedness for any unexpected event or flood-related disaster is inadequate. As per instructions of the NCDS, states need to carry out the pre and post-monsoon inspection of dams and provide a detailed report to the Dam Safety Organization (DSO; http://cwc.gov.in/damsafety/home). DSO monitors if the proposed activity is finished correctly. However, only a couple of states carry out the inspection fittingly, and only partial efforts are seen from other few states. Among the states who provided the inspection reports, none of them ensured the follow-up of remedial measures to correct the defects as suggested by the expert committee on dam safety, due to unavailability of sufficient funds [11]. State agencies find it easier to invest in post-flood mitigation measures rather than flood preparedness and damage protection.

MoWR launched the Dam Rehabilitation and Improvement Project (DRIP; https://www.damsafety.in/) in 2012 with the motive of providing technological advances, rehabilitation material, capacity building, and technical regulations to the dam operating authority. Under this project, 223 dams are expected to be rehabilitated by 2020 [86]. Although the scope and implementation of the project are both relevant and efficient, the pace of work should be speeded and expanded, considering the rise in the number of dams in the country. As per the plan, a timeline of 8 years is provided for complete rehabilitation and development of management system for 223 dams, whereas there are more than 5500 functional dams in the country, and the number is still increasing.

CWC provides the information related to large dams via the National Register of Large Dams (NRLD; http://cwc.gov.in/national-register-large-dams), which is maintained regularly. However, the information in NRLD is still incomplete and less reliable in some cases. The development of Dam Health and Rehabilitation Monitoring Application (DHARMA; https://damsafety.in/dharma/Home1/index.php) is taking place in parallel under DRIP. It is expected to effectively manage all dam safety-related data concerning large dams. Although the current scope of DHARMA is limited to dams under DRIP, but is expected to expand soon.

3.3.4. Committees for flood control

The state list mentions only structural measures such as drainage and embankment construction in the purview of flood management. This is the reason why we see a long history of extensive embankment construction for flood protection in many states. More than 35,000 km of embankments and almost 40,000 km of drainage channel has been constructed after independence till 2011 [67]. Although the states are responsible for carrying out flood protection works, GoI has constituted multiple agencies and committees to provide technical and management guidance to them, as well as assisting them financially. GoI constituted committees such as Rashtriya Barh Aayog (RBA) in 1976, the task force for flood control in 2004 & various other working groups in both XI and XII five-year plan. The National Water Policy of 1987, 2002 & 2012 provided the guiding principles for developing a sustainable flood management system. States were supposed to follow the recommendations and guidelines while carrying out their flood management activities. However, it was reported by the [11]; that most of the states did not comply with these suggestions and policy recommendations. For instance, RBA suggested that the states should identify the flood-prone areas in their region and carry out an assessment of the protectable area as well. It was suggested that this identification and assessment needs to be carried out every five years. But, none of the states acted proactively upon this and neither identification nor assessment was carried out [11]. Similarly, National Water Policy-2012 suggested morphological studies of the major rivers so that the planning and execution of construction of flood control structures can be carried out efficiently. Unfortunately, no studies were not carried out in any state [11]. Another important suggestion of National Water Policy-2012 includes preparation of frequency-based flood inundation maps for the flood-prone regions so that efficient strategies can be developed for coping with flood events. CWC provided the mathematical models for flood forecasting, which were to be further used for inundation mapping by states. But, states claimed that they could not obtain the necessary Digital Elevation Model (DEM) from NRSC due to a shortage of funds [11]. Hence, that recommendation was never fulfilled. The state agencies responsible for flood management need to recognize the importance of soft measures for flood protection. The focus of state agencies was and currently only on controlling floods and providing flood protection by structural measures, overlooking the efficiency of non-structural measures in the long-run [79].

3.3.5. Flood forecasting

Flood forecasting was launched in 1958 at a single CWC unit in the River Yamuna. Over time, the forecasting system has evolved and expanded significantly, and currently, there are 226 (as on May 2018) flood forecasting stations in India. These stations are responsible for providing information on water level and discharge forecasts to various local and reservoir operating agencies for flood mitigation related activities [87]. The current forecasting network is not very extensive as initially planned. Nevertheless, its necessity as a non-structural measure has been recognized time and again, and relevant plans for its expansion are formulated continuously [87]. Accurate forecasting requires real-time data acquisition from telemetry stations, which is transmitted to base stations where the forecast is generated, and information is disseminated accordingly [88]. However, the Indian agencies face multiple barriers in the execution of the proposed plan, mostly due to financial support and maintenance costs. As per the guidelines of the XI five-year plan (2007–2012), 222 new telemetry stations were proposed to be set-up, however only 56 could be established till August 2016 [11].

On top of that, only 41% of the already established telemetry stations are fully functional [5]. The incorrect set-up of water level gauges and malfunctioning equipment renders the current establishments incapable of providing reliable data for accurate forecasts. The instances of equipment theft are also common in areas that are not monitored regularly or are not secured [11]. The inadequate number of stations and malfunctioned system has already created several issues in the past. The delays in the establishment of new telemetry stations and the failure of already established stations explain the current poor condition of flood forecasting in India.

4. Recommendations

It is now known that floods are unpredictable and that providing complete protection against them and succeeding in controlling their incidences is not always possible. Unfortunately, the enormous recurrent damages in terms of disruption of regular lives and property

indicate that the current flood management system in India is not apt to provide the necessary protection measures. Hence, it is necessary to shift to a progressive management approach since the passive methods of flood control appear to be insufficient. From the comprehensive literature review, it is essential to highlight that the success rates of various flood management schemes still have a long way to go. On several occasions, they could not be adequately managed which resulted in substantial lags behind the proposed schedule. It is thus necessary to ascertain that allocated resources be utilized efficiently. Apart from timely execution of new projects, it is also important to pay adequate attention to the performance of earlier implemented projects.

We also realized that more focus had been laid on reducing flood damages by implementing the conventional structural measures. A limited focus has been granted to the equally vital non-structural measures, although they have been considered at some point of time, but could not be enforced adequately. A key component-People's and stakeholder's participation in flood control through community management of flood protection structures and training in emergency actions would go a long way in improving the preparedness to floods and reducing the damages. Hence, under such situations, it is necessary to shift from a passive response (that relies mainly on only structural measures) to a progressive response that emphasizes non-structural measures (e.g., flood forecasting, land-use planning, flood warning, and flood plain mapping) and participatory collaboration among government agencies and stakeholders (people, public, and private agencies in the affected areas) with timely vigilance of the utilization of resources. It is suggested to have a system that enhances the participatory collaboration between government agencies and the public [20]. The current global paradigm focuses on developing multi-target policies. Hence, it is suggested that flood management strategies can be aligned with flood risk, water resources management, development, and environment protection [89–91]. Based on the analysis of the existing flood management system in India, relevant recommendations are discussed in the following sections.

4.1. Accepting the residual risk

The flood control structures are designed for events of normal incidence, but there can always be a catastrophic flood, as there is no certainty about the severity of a future event. That is why it is necessary to accept that only a certain degree of protection can be assured from passive measures. Moreover, to guarantee a continuously high level of protection by flood control structures, huge investment is necessary for attempting both maintenance and expertise for their operation [92,93]. Some amount of residual risk can be accepted by structural measures to manage economic resources. This risk can be reduced by binding non-structural measures along with structural measures, as they will enable a higher degree of flood preparedness and prevention of exposure to flood water [94–96]. This step is crucial for the Brahmaputra and Ganga river regions, which are the most severe flood-affected regions, and a huge investment in structural measures has been done with little emphasis on the non-structural ones. A secure connection between structural and non-structural measures will ensure considerable risk reduction for the present scenario and also assure a flood-proof strategy for future flood events.

4.2. Implementation of multiple measures

The consideration of a wide range of management measures to reduce the flood probability and exposure is necessary for building a robust system. The works and activities that are implemented should be strictly based on proper scientific evaluation of that area, for instance, during dam operations and flood inundation mapping. Also, most of the activities carried out by states until now focused on flood fighting and control rather than overall flood risk management. Under such cases, integration of multiple measures is the key to building a robust system [97,98]. The following actions can be exercised for bringing an improvement in the flood management system.

- A scientific-based approach for preliminary and feasibility studies considering the strength and weaknesses of the proposed plan is necessary for successful implementation. The failure of RMABA preliminary and feasibility studies helped in understanding the complexity of implementing projects at sensitive regions. There is an urgent need to track the progress of these studies at the local level that can only ensure smooth implementation.
- In urban areas, along with the improvement in the drainage system, a real-time flood forecasting system is vital to address both flood control and preparedness aspects of flood management [99,100].
- Strict implementation of building codes and demarcation of flood zones in flood affected regions (as suggested by numerous Indian committees and policies) can regulate the development and minimize flood exposure [101,102]. It would benefit the communities, especially within the Brahmaputra and Ganga river regions, where unplanned settlements and encroachments near to the river over the years have significantly elevated the susceptibility to damages.

4.3. Improvement in governance

There had been multiple instances when the governance of flood management in India was not upto the mark [103,104]. Many experts associated with World Wild Fund for Nature, India; Centre for Energy, Environment & Resources, New Delhi, CWC, and voluntary non-profit organizations suggest, that the National Water Framework Law & River Basin Management Bill may lack efficient enforcement due to lack of coordination among state and centre. It is necessary to indulge the Central government proactively and provide legislation to the Centre in the works related to flood control. That is why the standing committee on water resources (2016-17) suggested the central government to reconsider the addition of 'water' to the concurrent list of legislative powers. It is integral to bridge the gap in governance and build a system that enables collaboration between states and the Centre with parallel responsibilities [20,105,106]. Several quick action forces, for example, the Chitale committee that was formed to monitor large scale desilting activity in the Ganga river region, have been set-up earlier to act as a catalyst in strengthening the connection between the Centre and State bodies with flood management control. There is a need to strive for such steps in the future for ensuring a transparent system between the two flood managerial levels.

4.4. Promote stakeholder's participation & reflect local context

The current flood management system is semi-transparent and lacks coordination among local communities [107,108]. As mentioned by Sayers et al. [20]; communities need to learn '*how to live*' with floods instead of '*how to fight*' them. The following actions can be undertaken to enhance stakeholder's participation in flood management strategies.

(i) Enhancing awareness, empowerment, and training of communities for effective flood preparedness [109,110].
(ii) Implementation of soft measures of flood risk management, e.g., land-use planning, to be identified as a social responsibility [111]. This would be particularly advantageous for communities residing within the Ganga and Brahmaputra river regions. A considerable dividend can be obtained within the urban regions as well, where the rate of urbanization is adding to flood susceptibility. In such regions, the newly identified concepts of sponge city [112,113], green roofs [114,115], rainwater harvesting [116], segregation of rainwater from sewer system, regular cleaning of sewer systems, and water infiltration and attenuation systems [117] can be initiated.

(iii) Elaborative dialogues with local agencies and people to develop a location-specific flood management strategy [118] may be initiated.

4.5. Uncertainty in the risk and its effective communication

The current forecasting system is limited to channel water level forecast, which does not convey the actual risk and cumbersome to be understood by the general public [119,120]. To enhance an effective communication, the following actions may be prioritized.

(i) Awareness of compounding risk to the general public to enhance the effectiveness of the warning system[121].
(ii) Development of easily understandable flood risk maps for frequently inundated areas to provide insights to people about the hazard they may face [96].
(iii) Conveying floodplain risk data to the general public will discourage development that exacerbates flood risk and impacts. It will also enhance the flood preparedness at the community level [122,123].

Several initiatives have already been identified in the country. For instance, a new Flood Management Information Systems Center has been set-up recently in Bihar (Ganga River region) to improve its capacity for flood forecasting and response [30]. In this connection, the neighbouring country Nepal, is also investing in crucial real-time information to strengthen forecasting and warning capacity. Real-time data from Nepal is routinely shared with CWC to issue flood warnings in downstream areas.

4.6. Efficient utilization of limited resources

The management strategies are employed to achieve a reduction in flood risks. However, it has been found that many of the projects related to FRM have not disclosed the number of resources utilized for their execution. The amount of risk reduction achieved was not enough as compared to the investment required for the same [124]. The effort should be on managing floods based on the nature of risk while maintaining high economic efficiency [125]. It can be achieved by studying various options available for FRM for a particular scenario or region and utilizing measures specific to the nature of risk [126]. The usage of universal or generalized measures in every region may not be the best approach to maximize protection. A rationalized system considering the strength and weaknesses of the proposed approach should be developed for achieving maximum efficiency.

4.7. Adaptability to future scenarios

There are high chances of an increase in monsoon onset variability along with an increase in extreme and frequently occurring extreme rainfall events in the future [127–130]. This combined with social changes, demographic changes and uncertain development scenarios, questions the coping capacity of existing and proposed plans of flood management, since the existing structures are regularly overwhelmed by the floods larger than their design capacity [131,132]. Planning for various low probability and high-intensity flooding scenarios should be the approach. Investing huge capital for infrastructure development may not serve its purpose in upcoming years due to limited resources. It is vital to learn from past disaster experiences as an opportunity for future preparedness. Although this step would be a boon for every flood-prone region, the communities facing the brisk impacts of climate change within the Central India and Deccan region will be hugely benefitted.

4.8. Guided implementation & regulated operation

The laxity in implementing policy recommendations or in operation and maintenance of flood protection works needs to be abolished [133]. The maintenance of flood protection works by authorized agencies nneds to be managed more effectively. In urban regions, timely checkup of the encroachments and drainage systems is required to ensure the protection is strong before a flood event happens. Few instances are found where the shortage of funds led to inadequate maintenance [134]. All the responsible agencies and organizations need to perform tasks assigned to them with utmost care [24]. The central government should make sure that the guiding principles are adopted and supervise the implementation of the same.

4.9. Creation of a central database

Flood related data such as historic flood levels & rainfall, topography, land use activities, drainage records, flood mitigation measures, and other related plans are required by managing agencies for planning and execution of works. In India, the data is scattered at multiple agencies as per their expertise [135,136]. Also, in some instances, the data is inconsistent, incomplete, or faulty [137–139]. The development of a central database with reliable data can be a better alternative to smoothen the process of data acquisition for the modelers. Researchers and experts in the flood management works will find it beneficial if the database is made public. A platform similar to BHUVAN (https://bhuvan.nrsc.gov.in/bhuvan_links.php) can be developed, including all aspects of flood management. This can boost research in the field of flood management in the country as well as improve transparency in the structure. A few initiatives at the regional level, such as the most recently developed 'integrated expert urban flood forecasting system for Chennai' [49,50]; have been taken to disseminate flood-related information.

4.10. Capacity building

In a vast country like India, where causes of flood vary in different regions, huge capacity building is vital for understanding the regional problem and planning mitigation measures based on the analysis [140,141]. To enhance capacity building, the following actions may be prioritized.

(i) Creation of a scientific database for flood management and recruitment of skilled human resource having strong R&D skills.
(ii) Encourage the operational use of hydraulic and hydrodynamic mathematical models [142]. Under data-scarce situations, availability of remotely sensed products should be made available to modelers.
(iii) Establishment of exclusive flood data centers at various local levels.

4.11. Developing resilient communities

Resilience is the product of the level of disaster preparation, relief, response, and reconstruction that promotes the city's sustainability [134]. Resilience should be a policy objective for the government in the future [16,110]. An optimum solution in the form of utilization of flood insurance for reducing the potential flood losses should be proposed. NDMP and various state disaster management plans should recognize the significance of micro-insurances for disaster recovery [143]. Government-sponsored relief funds or insurance programmes can assist people in recovery. It is necessary for developing a system that encompasses all aspects of the flood management system, i.e., preparedness, control, mitigation, and recovery after floods.

5. Summary and concluding remarks

After facing decades of numerous floods and employing many measures to reduce the flood risk, the vulnerability to disasters has not decreased to anticipated levels. State governments in association of local agencies execute FRM plans, and carry out disaster relief functions with support from the central government. However, there is a dire need to strengthen governance. Coordination among agencies and partnership with local communities should be enhanced. The flood policy guidelines are actively being developed in India but not adequately being implemented, thus leading to only partial success. Need of the hour is to develop a fool-proof mechanism that ensures successful enforcement of policy guidelines and recommendations. The funds available for flood risk management are limited in amount and are mostly depleted during the construction of large structures. Higher fund allocation and better bifurcation of these funds for the development of structural as well as nonstructural infrastructure will effectively boost flood risk management.

The research in the field of flood risk management is still in its early stages in India and needs to be promoted. A few steps by the government to push research in this area can greatly help policymakers and practitioners. The course of action for improving the flood management system should begin with correcting gaps in the existing system before investing in significant new developments. The gaps in the current system are mostly managerial and can be dealt with efficiently. The primary issue is the poor maintenance of flood-control structures. Communities should come forward and become involved in maintenance and operation after proper training. This approach will be beneficial in improving community participation and will enable timely maintenance.

Declaration of competing interest

None.

Acknowledgments

The authors would like to thank the Editor-in-Chief and the anonymous Reviewers for providing extremely insightful comments, which has improved the quality of manuscript. The work presented here is supported by ISRO-IIT (B)-Space Technology Cell (STC) through sponsored projects [RD/0114-ISROC00-013(14ISROC009) and RD/0119-ISROC00-001]. We thank Ms. Sheeba Sekharan for her contribution in shaping the manuscript.

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