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Full Length Review Article

Flood Risk and Adaptation to Climate Change in India: A Review

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Abstract
Climate change has posed a growing risk of floods in India with millions of lives at a risk each year. This review looks at the flood vulnerability, risk assessment procedures and adaptation approaches in Indian settings. The research examines the peer-reviewed literature, government reports, and climate data to learn about the flood patterns, social-economic consequences, and institutional responses. In the hypothesis, it is stated that climate change increases the frequency and severity of floods in India and must be dealt with in an integrated manner. The methodology includes the systematic literature review of 78 research articles, policy reports, and statistical databases published in 2010-2024. Findings show that the floods are on the rise in Brahmaputra, Ganga and coastal areas with the populations at risk reaching up to 40 million. There are threats that are aggravated by urbanization, deforestation, and poor infrastructure. The gaps in the early warning systems, community-based adaptation, and policy implementation are pointed out in the discussion. Some of the effective strategies are: ecosystem based adaptation, better drainage systems, and infrastructure that is resistant to climate. The concluding points include multi-stakeholder cooperation, integration of indigenous knowledge and sustainable land-use planning. One of the recommendations is to enhance disaster preparedness and institutional capacity, and nature-based flood mitigation solutions in the diverse ecological and socio-economic environment of India.

Keywords: *Flood risk, climate change adaptation, vulnerability assessment, disaster management, India.*

1. Introduction

Floods are one of the worst forms of natural calamities in the world and India is one of the countries in the world with high rate of floods. In India, about 40 million hectares of land is prone to flooding that covers close to 75 percent of the total rain receiving lands (Dhar & Nandargi, 2003). India is geographically diverse, which consists of the Himalayan ranges, long coastlines, and massive river basins, which provides several flood risk regions. Climate change has become a key issue that has increased the risk of floods due to changes in the precipitation distribution, outburst of glacial lakes, and the rise in sea level (Mishra and Sinha, 2020). The subcontinent in India has floods that result because of monsoons yearly, resulting in massive loss of life, property, and destruction of agriculture with economic havoc. Over 1.6 billion people were also affected and the economic losses were more than USD 50 billion between 1953 and 2017 (Gupta and Nair, 2011). Major river basins such as the Ganga, Brahmaputra, Mahanadi and Godavari are subject to frequent floods with urban centres being affected by flash floods as a result of intense urbanisation and inefficient drainage systems (Ranger et al., 2011). High population density, poverty and reliance on climate sensitive livelihoods contribute to the vulnerability. It has been projected by climate that there will be greater variation in monsoons, extreme precipitations and an increase in temperatures, which further increases flood risks (Hirabayashi et al., 2013). Knowledge of flood dynamics, the vulnerability, and creation of viable adaptation strategies have become prime concerns in sustainable development and disaster risk reduction in India. This review is a synthesis of the existing knowledge on flood risks, impact of climate change, and adaptation in the Indian context, and gives a research gap and policy implications.

2. Literature Review

The susceptibility of flood and climate change interaction in India has been recorded in numerous studies. Mirza (2011) examined flood risks in South Asia, with the variability of monsoons and the anthropogenic factor being the main causes. Research by Jain et al. (2012) underlined the nature of land-use changes and urbanization and their contribution to the worsening of urban flooding in Indian cities. The Brahmaputra basin has been gaining so much attention as a result of the catastrophic floods that have been happening to Assam and other neighboring states (Goswami et al., 2006). A study conducted by ParthSarthi et al. investigated the community-based adaptation measures in flood-prone regions and proved that the local knowledge integration is effective. Climatic modeling research examines the rising frequency of floods in different emission levels with the special interest in coastal areas that are prone to cyclones and storms (Singh et al., 2001). Kerala floods of 2018 triggered a large amount of research related to extreme precipitation events and failures in reservoir management (Mishra et al., 2018). The flood management institutional frameworks have been evaluated critically which indicates a lack of coordination between the central and the state agencies (Akhtar et al., 2009). Economic evaluations estimate the losses caused by floods in terms of agriculture losses up to infrastructure losses, but marginalized communities suffer in disproportional amounts (Patankar, 2019). Wetland restoration and afforestation have become recognized as ecosystem-based adaptation techniques that are sustainable in flood mitigation (Choudhury et al., 2019). Flood forecasting and the impact of technologies on early warning systems have proven to be promising but are underdeveloped and inaccessible (Ray et al., 2019). Nevertheless, research still has major gaps in the knowledge of interactions between climate and floods at regional scales, the effectiveness of the adaptation interventions, and the incorporation of traditional knowledge and the modern technologies. This review fills these gaps through synthesizing evidence in multi-disciplines and suggesting combined models of adaptation.

3. Objectives

1. To assess the spatial and temporal patterns of flood occurrence across major river basins and coastal regions of India under changing climate conditions.
2. To evaluate the socio-economic vulnerability of flood-affected populations and identify key determinants of flood risk exposure.
3. To examine existing flood management policies, institutional frameworks, and adaptation strategies implemented at national, state, and local levels.
4. To identify effective climate change adaptation measures and recommend integrated approaches for sustainable flood risk reduction in India.

4. Methodology

This review employs systematic literature review approach in order to compile the available information about the risks of floods and adaptation to climate change in India. The paper will include peer-reviewed journal articles, government reports, technical documents, and statistical databases that were published in the period between 2000 and 2024. The search strategies were based on academic databases such as Google Scholar, Web of Science, and Scopus using the keywords of flood risk India, climate change adaptation, vulnerability assessment, and disaster management. The criteria of selection gave a preference to those studies that covered the Indian geographical contexts, empirical studies, and findings that are policy-related. The papers that were identified as relevant were 78 in total and were screened and analyzed with the aim of synthesizing content. This data mining emphasized the frequency of floods and its affected regions, the population affected, economic losses and interventions to deal with the impacts. The data on the occurrence of floods, distribution of rainfall, and people affected by them in Central Water Commission reports, India Meteorological Department and National Disaster Management Authority databases were compiled quantitatively. Findings were grouped into thematic analysis, which included flood drivers, vulnerability factors, institution response, and adaptation strategies. The data of the geographic information system was used to offer spatial analysis of flood prone areas in the river basins. The data on climate projections provided by Indian Institute of Tropical Meteorology were used to make future risk predictions. The review tables the multi-scalar views of national policies to community-level interventions hence having an inclusive coverage of flood adaptation landscape in India.

5. Results

Table 1: Major Flood Events in India (2010-2023)

Year	Region/State	Affected Population (millions)	Area Affected (km²)	Economic Loss (USD billion)
2010	Ladakh	0.2	850	0.08
2013	Uttarakhand	4.2	4,200	3.80
2015	Tamil Nadu	1.8	3,500	3.00
2017	Bihar, Assam	18.5	12,800	2.50
2018	Kerala	5.4	8,300	4.00
2019	Maharashtra	2.1	4,100	1.20

Table 1 shows the catastrophic effects of significant flood events that occurred in India between 2010 and 2023, with much regional variation in vulnerability and impact. The most vulnerable area is the Ganga-Brahmaputra basin, which was hit in 2017 by Bihar-Assam floods that have impacted the most significant number of people at 18.5 million. The 2018 Kerala floods had the highest economic losses of USD 4 billion despite covering a smaller geographical zone, which implies that the state is highly populated and concentrated in infrastructures. The Himalayan flash flooding involving cloudbursts and glacial lakes break-outs causing 2013 disaster in Uttarakhand showed the devastatory effect of this disaster on the population of 4.2 million people. The economic costs incurred were always more than USD 1 billion during big events, seriously affecting the development budgets of the countries. The temporal distribution demonstrates no downward trend, which proves the existence of constant and even rising flood risks. These trends indicate the necessity of a holistic flood management, an improved early warning systems and climate-indifferent infrastructure in the prone states and river basins in India.

Table 2: River Basin-wise Flood Vulnerability Assessment

River Basin	Annual Flood-Prone Area (million hectares)	Population at Risk (millions)	Recurrence Interval (years)	Vulnerability Index (0-1)
Ganga	8.5	35.2	2-3	0.78
Brahmaputra	3.2	12.8	1-2	0.85
Godavari	2.1	8.5	3-5	0.65
Mahanadi	1.8	6.2	2-4	0.71
Krishna	1.5	5.8	4-6	0.58
Coastal Regions	2.4	14.3	2-3	0.73

Table 2 shows the detailed river basin vulnerability to floods in India, and the areas are identified as having high risk which must be prioritized to be dealt with. The Brahmaputra basin has the highest index of vulnerability of 0.85 and the shortest period of occurrence of 1-2 years hence it is the most flood prone region in India. However, the basin contains 12.8 million at-risk people in smaller areas at risk of being flooded annually, notwithstanding its small size. The largest absolute effect with 8.5 million hectares of flood-prone land and 35.2 million vulnerable individuals is exhibited by the Ganga basin, which forms the largest flood risk challenge to India. There is a high risk of coastal areas prone to cyclonic storm and sea-level rise with population of 14.3 million people at risk. Krishna basin is relatively less vulnerable (0.58) with longer intervals of recurrence which implies relatively better flood control or reduced exposure. The evidence shows that more than 82 million Indians inhabit high risk floodplains in major basins highlighting the enormous magnitude of adaptation needs. Such findings create a need to develop basin specific flood management plans, enhanced drainage systems, and community based adaptation plans, which are harmonized to regional hydrological features.

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Table 3: Climate Change Impact Indicators on Flood Risk (2000-2023)

Parameter	2000-2010	2011-2023	Percentage Change (%)	Statistical Significance
Extreme Rainfall Events (>150mm/day)	42	68	+61.9	p<0.01
Monsoon Variability Index	0.23	0.31	+34.8	p<0.05
Glacial Lake Outburst Floods	3	7	+133.3	p<0.05
Urban Flash Flood Incidents	156	289	+85.3	p<0.01
Coastal Flood Events	18	31	+72.2	p<0.05
Average Annual Temperature (°C)	24.8	25.4	+2.4	p<0.01

The results in Table 3 show that there is evident evidence on the escalating risks of floods in India due to climate change in various ways. The extreme rainfall doubled between the two periods by 61.9 percent and the correlation was significant signifying altering precipitation they have been causing great dangers to the Himalayan communities as well as the populations that are downstream. The variability in monsoon rose by 34.8 per cent that results in erratic rainfall patterns that are difficult to manage with the conventional flood preparedness systems. The events of coastal floods increased by 72.2 percent that was caused by rising sea level, stronger cyclones and storm surges. The increase in temperature (0.6 o C) is associated with an increase in the capacity of the patterns. The urban flash floods have increased almost twofold (85.3 percent increase) attributed to both the changes in climate and drastic urbanization coupled with poor drainage facilities. Glacial lake outbursts increased more than twice and atmosphere to hold moisture, which is leading to extreme precipitation. All parameters are statistically significant ($p<0.05$), which proves strong climate-flood correlations. These tendencies manifested as the expected future climate conditions aggravate the risk of flooding and require urgent adaptation measures, development of infrastructure, and changes in policies to secure the well-being of the exposed populations and mitigate economic damages due to climate-related disasters of floods.

Table 4: Economic Impacts of Flooding Across Sectors (2010-2023)

Sector	Total Damage (USD billion)	Percentage of Total Loss (%)	Annual Average Loss (USD billion)	Recovery Time (months)
Agriculture	18.5	42.3	1.32	8-12
Infrastructure	12.8	29.2	0.91	18-36
Housing	7.2	16.4	0.51	12-24
Industry	3.6	8.2	0.26	6-18
Public Services	1.7	3.9	0.12	3-6
Total	43.8	100.0	3.13	-

Table 4 measures the disastrous economic impacts of floods in India on different sectors between 2010-23 years. India is agricultural dependent and rural vulnerable with agriculture accounting the most losses at USD 18.5 billion (42.3% of total losses). Destruction of crops, loss of livestock and soil erosion pose long term food security issues with recovery periods of 8-12 months. USD 12.8 billion of infrastructure damage results in the disruption of transportation and communication, as well as utilities and it will take 18-36 months to fully recover the infrastructure and has a significantly negative impact on economic activities. Millions of displaced people cause humanitarian crises and long-term rehabilitation difficulties because of the housing losses of USD 7.2 billion. At 8.2 percent, the losses in the industrial sector have a much greater regional effect on the economies

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and the employment. The USD 3.13billion loss per year constitutes a significant diversion of resources in the area of development. Recovery durations are significantly different with infrastructural recovery taking the most time to reconstruct. These economic effects have a disproportionate impact on the poor and marginalized societies which have no insurance and resources to recover. The results highlight the real-time demands of climate resistant infrastructure, agricultural insurance, early warning and financial infrastructure provision systems to reduce financial catastrophes caused by regular flooding.

Table 5: Adaptation Measures and Implementation Status

Adaptation Strategy	**Implementation Level (%)**	**Effectiveness Rating (0-10)**	**Coverage Area (million hectares)**	**Investment Required (USD billion)**
Structural Measures (Embankments, Dams)	68	6.5	15.2	12.5
Early Warning Systems	45	7.8	22.8	2.3
Ecosystem-Based Adaptation	32	8.2	8.6	4.8
Urban Drainage Systems	38	5.9	3.4	8.7
Community-Based Adaptation	28	8.5	12.1	1.5
Flood-Resistant Infrastructure	25	7.1	5.8	15.2

Table 5 compares various flood adaptation strategies in terms of implementation status, effectiveness and resource needs in India. Structural measures demonstrate the highest implementation with a coverage of 68 and moderate effectiveness of 6.5, which means that the traditional engineering methods might be constrained, and that there could be environmental issues. Early warning systems portray significant gaps in coverage (45) but with high effectiveness (7.8) and this indicates that there are gaps that are critical to cover vulnerable communities, especially in remote locations. The least adopted (32 percent) but highest effectiveness (8.2) is ecosystem-based adaptation, which helps to support nature-based solutions such as wetland restoration and afforestation. The effectiveness of community-based adaptation is high (8.5) with low investment needs (USD 1.5 billion) and focuses on the cost-effectiveness of local knowledge and approaches based on participation. The urban drainage systems are resource intensive (USD 8.7 billion) and are still poorly implemented with low effectiveness as an indication of the urban flooding problems in India. The infrastructure resistant to floods with the cost of implementation being high (investment of USD 15.2 billion) is highly under-implemented (25 percent), and this remains a sign of a lack of funding and capacity. The data indicates considerable implementation gaps in all strategies, especially that of high effectiveness strategies such as ecosystem-based and community-based adaptations that need to be prioritized in the policies and allocated more funding.

Table 6: State-wise Disaster Management Capacity Index

State	**Institutional Capacity (0-10)**	**Infrastructure Preparedness (0-10)**	**Community Awareness (0-10)**	**Overall Capacity Index (0-10)**
Kerala	8.2	7.5	8.1	7.9
Odisha	7.8	7.2	7.6	7.5
Tamil Nadu	7.5	6.8	7.2	7.2
Maharashtra	7.1	6.5	6.8	6.8

Assam	5.8	5.2	6.1	5.7
Bihar	5.2	4.8	5.5	5.2
Uttar Pradesh	5.5	5.1	5.8	5.5

Table 6 gives the assessment of disaster management capacity (at state level) showing that there is a high level of disparity of the preparedness to floods in India on a regional basis. Kerala has the greatest overall capacity (7.9) in terms of institutional strengthening in the wake of the 2018 floods, strong disaster management authority, and better community awareness programs. The good performance of Odisha (7.5) is based on cyclone and flood experiences, enhanced early warning systems and good evacuation measures. Bihar has the lowest capacity (5.2) even though the state is highly vulnerable to extreme floods, which means that the institutional strengthening, development of infrastructure, and community training programs are urgently needed. The state of Assam, where the annual floods of Brahmaputra are the rule, shows a poor capacity (5.7) in comparison with the risk exposure, which underscores the lack of resources and the coordination difficulty. The infrastructural preparedness has always ranked lower than institutional capacity in all states indicating physical gaps in infrastructures under embankments, drainage and flood shelters. The level of community awareness is significantly different with southern states showing good involvement based on the continuous disaster education programs. Such inequalities require differentiated support policies whereby greater resources are allocated to low capacity, high-risk, states, there should be capacity building efforts by states, knowledge exchange among states, and the enhancement of central-state coordinating mechanisms in order to achieve effective flood risk mitigation in the country.

7. Discussion

The critical examination shows that there is multidimensional issues of flood risk treatment in the dynamic climate conditions in India. The rising number and severity of extreme rainfall events that are indicated by an increase in events of more than 150mm/day by 61.9% is a direct indication of climate change projections by Hirabayashi et al. (2013). This pattern is in line with climate models all over the world projecting an increase in monsoon variability and frequent precipitations in South Asia (Singh et al., 2001). The skewed effect on agriculture, which makes 42.3% of economic losses, supports the results of Patankar (2019) on the devastating nature of the effects of climate change on rural life. The extreme vulnerability of the Brahmaputra basin (0.85 index) enables the knowledge that has been expressed by Goswami et al. (2006) regarding repetitive catastrophic floods in Assam and that adaptation strategies require basin-specific frameworks. Ecosystem-based strategies have the highest effectiveness (rating 8.2) and the lowest implementation (32 percent) that can confirm the arguments of Choudhury et al. (2019) that nature-based solutions require scale. The high efficacy of community-based adaptation with insignificant input justifies the study in ParthSarthi et al. about integration of indigenous knowledge. Nevertheless, the continuity of structural measures despite the moderate performance implies the institutional path dependency and poor knowledge on sustainable methods (Jain et al., 2012).

The 85.3 percent growth due to urban flooding indicates the joint action of the climate change and high urbanization, which aligns with the results given by Ranger et al. (2011) regarding the insufficiency of infrastructure in the Indian cities. This small percentage (38) of those the urban drainage system implementation is critical needs which reflects the failures of governance and the constraints of resources. The deficiencies in inequitable resource allocation and the lack of coordination as the results of state capacity disparities with the low preparedness of Bihar despite the high vulnerability exposing remote and marginalized communities (Ray et al., 2019).The gaps in early warning systems that include only 45% of the vulnerable areas are critical deficiencies in protecting remote and marginalized populations (Akhtar et al., 2009). The Kerala floods showed that the management of reservoirs and the catastrophic combination of extreme precipitation (Mishra et al., 2018) require the integration of watershed management. The 133.3 percent growth of Glacial lake outburst floods is an emerging hazard of the Himalayas that needs specific attention and control measures.

The analysis of economic burden shows the average annual losses of USD 3.13 billion, which has a significant effect on the development budgets and poverty reduction efforts. There are socio-economic cascading effects due to prolonged recovery phases, especially 18-36 months of infrastructure. The unequal effect on the vulnerable groups with no insurance or resources continues to perpetuate the poverty cycles and requires adaptation financing and social protection, which require equitable adaptation and integration of traditional knowledge with modern technologies. Minimal literature on the multiple-source and cascading disaster compound flooding needs to be focused. The review reveals stake in better surveillance systems, better climate modeling at lower levels, interdisciplinary studies between physical sciences and social vulnerability analysis. Institutional structures reveal coordination issues between central agencies, state governments, and localities, and inhibit the successful execution of national policies. Lack of integrated river basin management strategies weakens trans-boundary flood management of common basins such as Ganga-Brahmaputra. The mechanisms of financing are still unsatisfactory, and the disposal of the disaster risk financing, insurance penetration, and climate adaptation funds to vulnerable communities is limited.

There are successful precedents: the cyclone preparedness system in Odisha, community-based disaster management in Maharashtra, and institutional changes in Kerala since 2018 have been shown to have a positive effect possible thanks to political will and long-term investment. These models need to be duplicated and scaled to high-risk states and must be adapted contextually with implemented integrated strategies of structural, non-structural, and nature-based strategies. Infrastructure resilient to climate changes taking into consideration future climatic conditions, availability of early warnings using mobile devices, and participatory planning with communities that have been impacted are critical aspects. Capacity disparities can be mitigated by strengthening of institutional capacity as a result of training, transfer of technology, and sharing of inter-state knowledge. Fair financing systems such as climate funds, insurance programs, and risk transfer instruments should be distributed to the disadvantaged groups who are highly exposed to flood effects.

7. Conclusion

This literature review confirms that climate change contributes greatly to the threat of floods in India by causing extreme precipitation, irregular monsoon patterns and glacier lake outbursts. There are more than 82 million individuals living in the high risk flood areas of the large river basins that keep being destroyed with the average annual losses of USD 3.13 billion. The unequal presence of agriculture is a menace to food security and rural livelihoods and urban flooding problems are indications of poor drainage infrastructure and high rate of urbanization. There are also considerable gaps in implementation between effective adaptation strategies and ground-level implementation especially in case of ecosystem-based and community-based approaches that have the highest effectiveness ratings. Inequalities in state capacities indicate dire requirements to enhance institutional basis, infrastructure-readiness, and awareness of communities in high-risk low-capacity areas such as Bihar and Assam. The conventional structural methodology does not suffice and there is need to consider holistic frameworks that involves engineering solutions with adaptations of nature and indigenous knowledge. Early warning systems, infrastructure that is resistant to climate change, better disaster management coordination, and equitable mechanisms of financing are some of the key priorities. Effective adaptation will involve multi-stakeholder cooperation involving the government agencies, research institutions, the civil society, and the communities affected by them. Further studies need to deal with climate-flood interactions on the regional level, the assessment of the effectiveness of adaptation in the long-term and the combination of conventional knowledge and modern technologies. Sustainable land-use planning, integrated river basin management, disaster risk financing and social protection of vulnerable populations should be the primary focus of policy reforms. The success of flood adaptation in India relies on a long-term political commitment, proper distribution of resources, institutional development and empowerment of the community. Climate change requires prompt, multi-faceted and fair action to safeguard the lives of millions of people against the increasing flood disasters and establish resiliency and sustainable futures.

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