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Climate Change Adaptation in India in the context of Urban Flooding

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Prepared by

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About the Research Paper

This Research Paper is a part of our endeavor to improving accountability and inculcating professional excellence in the areas of environment and sustainable development. We have initiated from 2022 an Occasional Research Paper Series featuring different emerging areas of environment and sustainable development. This paper on **"Climate Change Adaptation in India in the context of Urban Flooding"** forms a part of this Occasional Research Paper Series from International Centre for Environment Audit Sustainable Development, Jaipur, under the Comptroller and Auditor General of India. It is the sixth such volume in the series which was launched in May-June 2022.

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Foreword

Climate change has become real and tangible, affecting people's lives worldwide. It is a major challenge for health, agriculture, food security and livelihoods. The impacts of climate change are global, but countries like India are more vulnerable in view of a sizeable component of the population depending on agriculture and a resultant high dependence on climactic parameters. Mitigation and adaptation strategies form a dual trajectory to address these issues. Mitigation strategies often receive more importance due to the involvement of more nations, evolving technology and transboundary impacts. In contrast, adaptation often received less importance as their benefits are regional. Mitigation and adaptation strategies are so closely entwined that if mitigation strategies are weak, adaptation costs due to climate impacts increase and vice versa. Experts suggest that even if concrete mitigation strategies are in place, climate change impacts are inevitable due to some anthropogenic and natural sources. Therefore, there is an urgent need to promote a paradigm shift towards climate-resilient development pathways by providing support to relevant sectors to adapt to the impacts of climate change.

The world is seeing an increase in the frequency of natural disaster occurrences. While there are different forms of climate change impacts, flooding is the most frequently occurring disaster globally, including in India. In 2021 alone, natural disasters were recorded much higher than the annual average of disasters between 2001 and 2020. The flood consequences are more critical for cities as they are the sites for major economic activity and thrive on often gigantic volumes of infrastructure and dense populations. Also, a cornucopia of climate change factors intensify the momentum of urban flooding events where in the flood peaks and volumes increase rampantly by making the impact sudden and with no time for adequate disaster management.

The need of the hour is to understand the significance of adaptation strategies related to urban flooding and mainstream them into a common policy framework. To make cities more resilient to such disastrous situations, efficient development and deployment of adaptation measures are crucial. Adaptation strategies should not just be an outlined list of activities but formulated with specific targets to be achieved in a given timeline with adequate provision of funds towards flood-resilient infrastructure.

Thus, considering the importance of this issue and as per the mandate of the International Centre for Environment Audit and Sustainable Development(iCED), Jaipur for improving accountability and governance in the area of environment and sustainable development, we planned to contribute a vital resource on this subject. This Research Paper on "Climate Change Adaptation in India in the context of Urban Flooding" is an outcome of our efforts. The document contains ample information about various flood events in India and the associated losses in terms of mortality and economy, climate change adaptation strategies and existing gaps in developing these strategies. The Paper outlines a macro-level framework that helps in building efficient adaptation strategies to urban flooding based on the latest available literature. It gives me immense pleasure to state that this Research Paper has been developed in time, and for this, I would like to congratulate the author Dr. Vajjarapu Harsha, former Research Associate, iCED. Incidentally, this is the sixth Research Paper of iCED in the initiative of an Occasional Research Paper Series undertaken since May-June 2022.

I hope that this Research Paper would be helpful for policymakers in reviewing the existing climate change adaptation strategies and would guide them in framing the best possible adaptation strategies to urban floods in Indian cities. iCED hopes to continue this area of research in upcoming efforts too; and thus we keenly look forward to any feedback/suggestions on this Research Paper.

30 January 2023

Jaipur

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Climate Change Adaptation in India in the context of Urban Flooding

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Abstract: Globally, the response to climate change has been through mitigation to reduce greenhouse gas emissions. But the inevitable climate change effects due to the constant feeding of emissions into the atmosphere lead to severe and extreme precipitation, causing flooding, which is considered as one of the climate change impacts. The combined impact of flooding and rapid urbanisation is a looming threat affecting developing economies disproportionately. India is one of the fastest developing economies and has been a frequent victim of urban floods in major cities. Therefore, there is an urgent need for Indian cities to adapt to these climate change effects to reduce human and economic losses. Adaptation is seen as the necessary tool to address this. This study presents a macro-level framework to be adopted in designing efficient climate change adaptation (CCA) strategies for urban floods in Indian cities. The impacts of floods in India are highlighted, and the Indian government's efforts in addressing these issues are briefly discussed. Some critical indicators that help to assess urban flood vulnerability are also presented.

Keywords: Climate Change, Mitigation, Adaptation, Cities, Urban Floods, India.

1. Introduction

The earth's climate is changing, and it has become one of the most complex issues at the global level. Carbon dioxide (CO_2) is the major pollutant that traps heat and lingers in the atmosphere for thousands of years, gradually warming the planet[3]. The two main approaches to address this issue are 'mitigation' and 'adaptation'.

- **Mitigation:** An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2001a)[4].
- **Adaptation:** Adjustment in natural or human systems in response to actual or expected

[3] https://climate.nasa.gov/solutions/adaptation-mitigation/

[4] IPCC, 2001a: *Climate Change 2001: Synthesis Report. A Contribution ofWorking Groups I, II, III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, R.T.Watson and the Core Team, Eds., CambridgeUniversity Press, Cambridge and New York, 398 pp.

climatic stimuli or their effects, which moderates harm or exploit beneficial opportunities (IPCC, 2001a)[4].

The initial efforts to combat climate change were mostly linked to mitigation measures. The progressive recognition of adapting to climate change's repercussions has led to connecting adaptation to sustainability[5]. Despite emissions mitigation measures being implemented globally, climate change consequences are inevitable due to some anthropogenic and natural sources. The risks associated with climate change cannot be nullified[6], making CCA crucial. However, without mitigation, a magnitude of climate change is likely to be reached that makes adaptation impossible for some natural systems. At the same time, it would involve very high social and economic costs for most human systems[7].

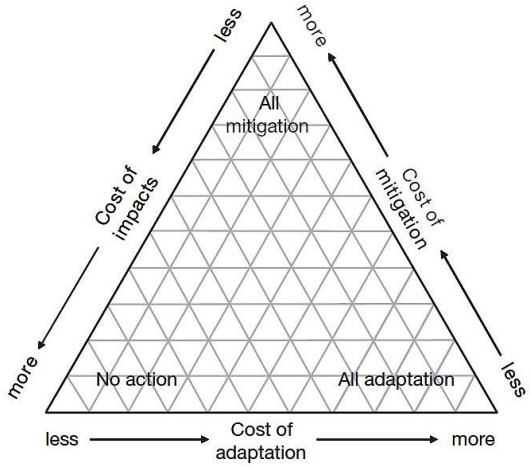

Fig. 1: A schematic overview of inter-relationships between[8,9]

As seen in figure 1, if the adaptation policies are weak and inefficient, the cost of mitigation policies will increase and vice-versa. Therefore, a strong balance between mitigation and adaptation policies is critical to reducing the economic costs in making cities more resilient. The main goal of adaptation is to develop an 'adequate adaptation response' to the 'global temperature goal', thereby enhancing adaptive capacity, strengthening resilience, and reducing vulnerability to climate change, ultimately contributing to sustainable development.

[5] S. Eriksen, K. Brown, Sustainable Adaptation to Climate Change, 2011.
[6] Hallegatte Stephane, Jun Rentschler, Julie Rozenberg. 2020. Adaptation Principles—A Guide for Designing Strategies for Climate Change Adaptation and Resilience. Washington, DC: World Bank.
[7] Klein, R.J.T., S. Huq, F. Denton, T.E. Downing, R.G. Richels, J.B. Robinson, F.L. Toth, 2007: Inter-relationships between adaptation and mitigation. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 745-777.
[8] Holdridge, L.R., 1947: Determination of world plant formations from simple climatic data. *Science*, **105**, 367 – 368.
[9] Holdridge, L. R., 1967: *Life Zone Ecology.* Tropical Science Centre, San Jose, Costa Rica.

The world is seeing an increase in the frequency of natural disaster occurrences[10,11]. While there are different forms of climate change impacts, flooding is the most frequently occurring disaster globally, as seen in figure 2. In 2021 alone, 432 natural disasters were recorded, higher than the annual average of disasters between 2001 to 2020, with floods occurring 51.6% of the time. These disasters accounted for 10,492 deaths, affected 101.8 million people and caused approximately 252.1 billion US$ of economic losses[12].

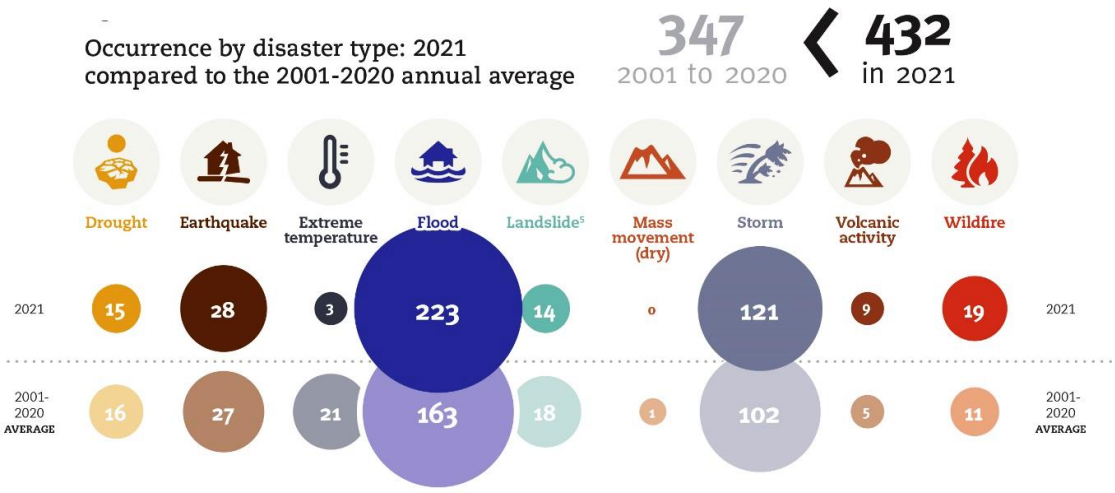

Fig. 2: Occurrence by disaster type in 2021 compared to the 2001-2020 annual average[12]

Despite climate change being a global phenomenon, the consequences are more critical for cities due to climate change interacting with the city infrastructure, rising population and economic activities. Urban flooding is significantly different from rural flooding as urbanisation leads to developed catchments, increasing the flood peaks from 1.8 to 8 times and flood volumes by up to 6 times[13]. Consequently, flooding occurs very quickly due to faster flow times, sometimes in a matter of minutes. These events are expected to be exacerbated by climate change[13]. Since cities are the breeding places for economic growth, and most of the world's inhabitants live in cities, even a minimal natural disaster leads to severe losses. This urges the necessity for executing adequate adaptation measures if the cities are to be more resilient towards climate change effects[14]. Based on the discussion presented thus far, this

[10]M. Fayazi, I.A. Bisson, E. Nicholas, Barriers to climate change adaptation in indigenous communities: a case study on the mohawk community of Kanesatake, Canada, International Journal of Disaster Risk Reduction 49 (2020) 101750.
[11]A.S. Sam, S.S. Padmaja, H. K¨achele, R. Kumar, K. Müller, Climate change, drought and rural communities: understanding people's perceptions and adaptations in rural eastern India, International Journal of Disaster Risk Reduction 44 (2020) 101436.
[12] CRED. 2021 Disasters in numbers. Brussels: CRED; 2022. This document is available at: https://cred.be/sites/default/files/2021_EMDAT_report.pdf
[13] Avashia, V., & Garg, A. (2020). Implications of land use transitions and climate change on local flooding in urban areas: An assessment of 42 Indian cities. Land use policy, 95, 104571.
[14] D.R. Nelson, Adaptation and resilience: responding to a changing climate, Wiley Interdisciplinary Reviews: Climate Change 2 (1) (2011) 113–120.

report highlights the significance of climate change adaptation in cities specific to urban flooding events.

2. Differences between Mitigation and Adaptation

While mitigation addresses the degradation rate of climate change, adaptation deals with weakening the adverse impacts of climate change[15]. Although they share a common ultimate objective, namely, the sustainable development of human society, there are significant differences between mitigation & adaptation (M & A) in practice, including the scales of the departments and the research involved. Based on the previous studies, the key differences and similarities between the mitigation and adaptation strategies are highlighted in table 1.

Table 1: Key differences and similarities between mitigation and adaptation[16, 17, 18, 19]

		Mitigation	**Adaptation**
Concept		Reducing GHG emissions and increasing carbon sinks	Regulating strategies under actual or expected climatic stimulation
Differences	Causal association	From causes	From results
	Spatial scale	Global	District and region
	Departments	Energy, transportation, architecture, industry	Urban planning, water, agriculture, human health, coastal zone
	Time scales	Long-term	Current and short-term
	Beneficiaries	Altruistic	Self-interest
	Incentive	Need motivation	Spontaneous
	Level of urgency	Low	High
Similarities	Objective	Aims to reduce climate change risk and associated losses	
	Benefits	Climate-related and associated benefits	
	Driven by	New science and technology	

a. **Differs across sectors:** The mitigation actions primarily focus on the energy sector and

[15] Laukkonen, J., P. K. Blanco, J. Lenhart, M. Keiner, B. Cavric, and C. Kinuthia-Njenga. 2009. "Combining Climate Change Adaptation and Mitigation Measures at the Local Level." Habitat International 33 (3): 287–292. doi:10.1016/j.habitatint.2008.10.003.

[16] Duguma, L. A., P. A. Minang, and M. van Noordwijk. 2014b. "Climate Change Mitigation and Adaptation in the Land Use Sector: From Complementarity to 92 C. ZHAO ET AL. Synergy." Environmental Management 54 (3): 420–432. doi:10.1007/s00267-014-0331-x.

[17] Duguma, L. A., S. W. Wambugu, P. A. Minang, and M. van Noordwijk. 2014a. "A Systematic Analysis of Enabling Conditions for Synergy between Climate Change Mitigation and Adaptation Measures in Developing Countries." Environment Sciences Policy 42: 138–148. doi:10.1016/j.envsci.2014.06.003.

[18] Swart, R., and F. Raes. 2007. "Making Integration of Adaptation and Mitigation Work: Mainstreaming into Sustainable Development Policies?." Climate Policy 7 (4): 288–303. doi:10.1080/14693062.2007.9685657.

[19] Chunli Zhao, Yan Yan, Chenxing Wang, Mingfang Tang, Gang Wu, Ding Ding & Yang Song (2018) Adaptation and mitigation for combating climate change – from single to joint, Ecosystem Health and Sustainability, 4:4, 85-94, DOI: 10.1080/20964129.2018.1466632

carbon emissions reduction. At the same time, the passive stress response of adaptation exists in areas and departments directed against climate change risk (Table 2).

Table 2: Activity fields for climate change mitigation and adaptation[19]

Mitigation action	Adaptation action
Adjustment of industrial structures	Urban-rural construction
Optimisation of energy structures	Infrastructure
Energy conservation	Water resources
Increasing carbon stocks	Sensitive industries
Industry Architecture, transportation, Agriculture, commerce, waste, Low-carbon living	Coastal regions, Ecologically fragile areas, Human health, Disaster prevention & Mitigation

b. Size and scale of benefits: Different countries and regions deal with climate change issues differently. The developed economies with a better resilient infrastructure focus primarily on mitigation actions. In contrast, developing economies which have minimal scope for emissions reduction and poor resilience require strong adaptation measures[20,21].

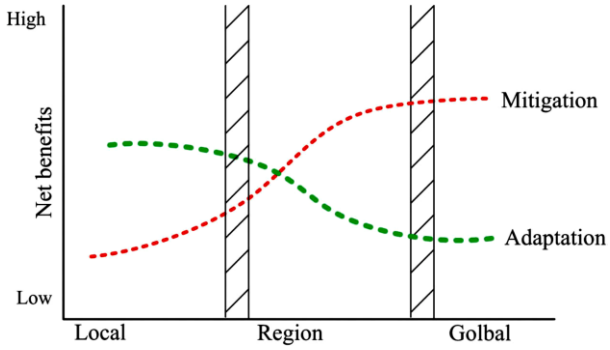

Fig. 3: Comparing the net benefits of mitigation and adaptation in different scales[19,21]

Mitigation actions are mainly undertaken at a country and regional scale (Figure 3), and net benefits are larger on global than regional scales. Also, these benefits take time to reflect in reality. The costs and benefits of adaptation actions are multi-scaled, but the net benefits at regional scales are more significant than those worldwide. Therefore, the adaptation action is more attractive to address climate change issues at a tiny scale[21,22]. Adaptation has immediate effects, and on a regional scale, adaptation actions have higher

[20] Ayers, J. M., and S. Huq. 2009. "The Value of Linking Mitigation and Adaptation: A Case Study of Bangladesh." Environmental Management 43 (5): 753– 764. doi:10.1007/s00267-008-9223-2.
[21] Wilbanks, T. J., P. Leiby, R. Perlack, J. T. Ensminger, and S. B. Wright. 2007. "Toward an Integrated Analysis of Mitigation and Adaptation: Some Preliminary Findings." Mitigation and Adaptation Strategies for Global Change 12 (5): 713–725. doi:10.1007/s11027-007-9095-4.
[22] van Vuuren, D. P., M. Isaac, Z. W. Kundzewicz, N. Arnell, T. Barker, P. Criqui, and A. Kitous. 2011. "The Use of Scenarios as the Basis for Combined Assessment of Climate Change Mitigation and Adaptation." Global Environmental Change 21 (2): 575–591. doi:10.1016/j.gloenvcha.2010.11.003.

incentives and urgency than mitigation.

3. Climate Change Adaptation Strategies for Urban flooding in India

3.1. Methodological framework

As discussed in the previous sections, there is a growing climate risk to the sustainable development of communities and countries. Under such circumstances, to develop effective adaptation strategies, it is critical to have a climate risk assessment and management framework to avert, minimise and address losses and damages, considering the uncertainty in extreme weather events. A robust macro framework to create evidence-based solid CCA strategies for urban flooding is shown in figure 4.

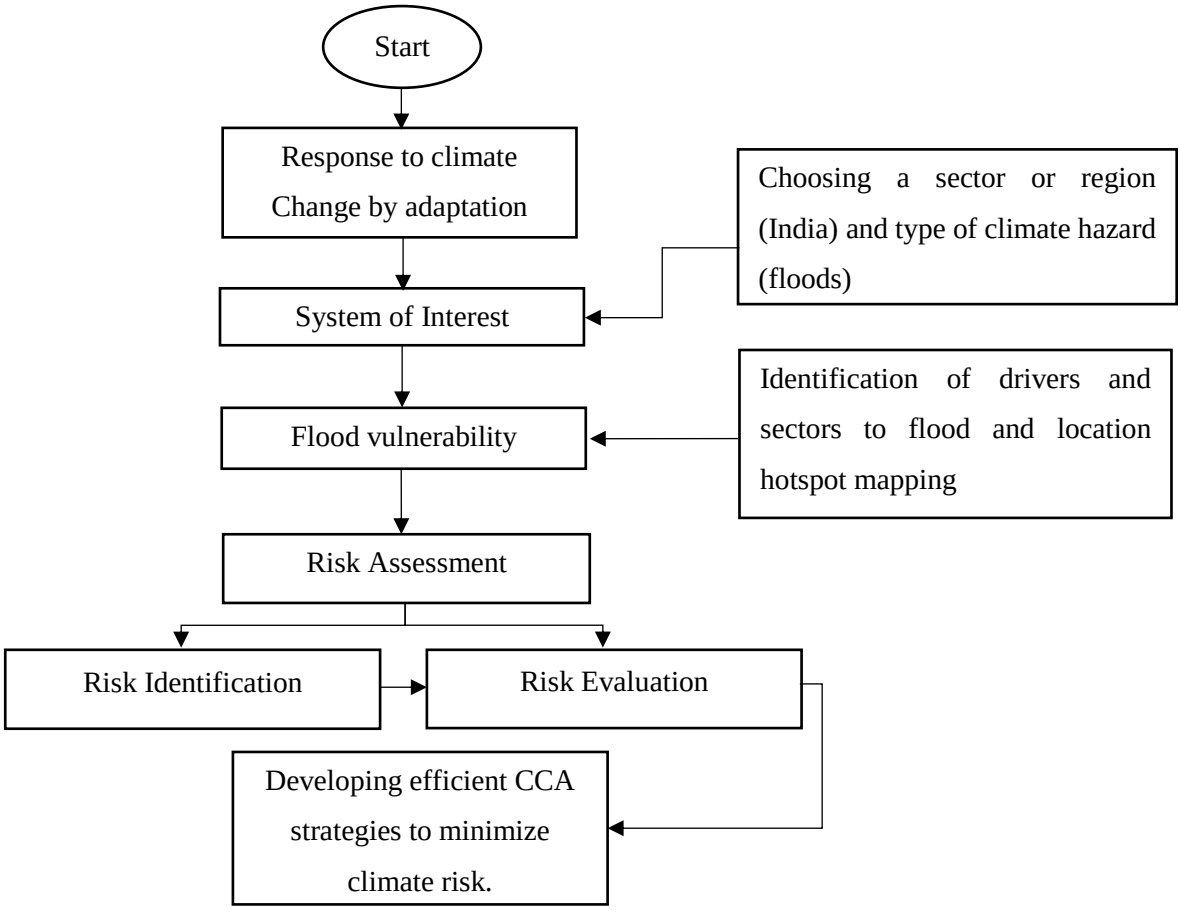

Fig. 4: A macro framework to design robust CCA strategies for urban floods in India

Source: Developed by the author

3.2. Vulnerability Assessment

Extreme weather events like cyclones, floods, sea-level rise and shifts in precipitations affect India and may have an increased threat to human health and an essential food supply[23]. Over

the past 50 years, escalations in the frequency and intensity of rains have been observed. The forecasted trends suggest that in the coming decades' extreme rainfall over India has enhanced risk associated with it[23]. To develop efficient adaptation strategies, assessing the vulnerabilities due to extreme weather events is critical. Vulnerability quantifies the associated risks within the context of environmental and socio-economic capacity to adapt to extreme weather events, in this case, urban floods[24]. Exposure, sensitivity and resilience are the key factors of vulnerability. ***Exposure*** refers to the alteration of the operational system, operating out of its regular operation[25]. ***Susceptibility*** is the potential or the likelihood of a hazard impacting the system[26]. ***Sensitivity*** refers to the degree to which a system is adversely or beneficially affected by a given exposure[27]. Exposure and vulnerability factors are directly proportional to flood vulnerability, whereas resilience is inversely proportional.

3.2.1. Flood vulnerability

The enormous population growth and people migrating to cities searching for opportunities have made the cities more vulnerable because of the increased socio-economic impacts of extreme weather events[29]. Evidence shows that although there has not been an increase in the annual mean rainfall received in India, the number of flooding events is constantly rising[30]. Every year, India faces extreme weather events in the form of primary floods, which take lives, destroy homes and agricultural yields, and result in substantial revenue losses. A report by the Council on Energy, Environment and Water (CEEW)[31] mapped India's decadal flood hot spots from 1970 to 2019. The evidence indicates the rising incidences of floods, as shown in figure 5. Some recent flood events over the past few years are tabulated in Table 3. These two pieces of evidence show India's increasing vulnerability due to the impacts of flooding which can be attributed to climate change.

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[23] A. Leiserowitz, J. Thaker, Climate Change in the Indian Mind. Yale Project on Climate Change Communication in Collaboration with GlobeScan Incorporated, 2012, p. 220 (environment.yale.edu/climate-communication-OFF/files/Climate-Change-Indian-Mind.pdf).

[24] Munyai RB, Musyoki A, Nethengwe NS. An assessment of flood vulnerability and adaptation: A case study of Hamutsha-Muungamunwe village, Makhado municipality. Jamba. 2019 Jun 24;11(2):692. doi: 10.4102/jamba.v11i2.692. PMID: 31308887; PMCID: PMC6620490.

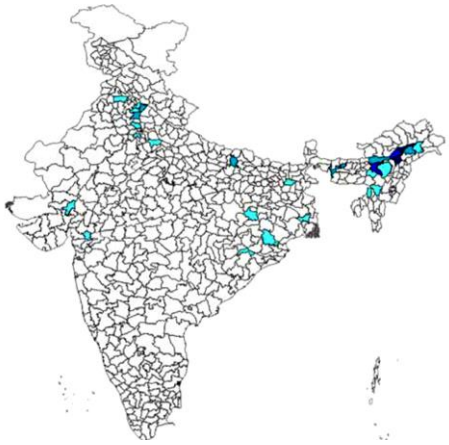
[25] Judy W.L., Tegg S., Reisinger A. & Quade D, 2011, *Vulnerability and adaptation to increased flood risk with climate change*, Hutt Valley report 02, The New Zealand Climate Change Research Institute, Victoria University, Wellington.

[26] Samuels P., Gouldby B., Klijn F., Messner F., van Os A., Sayers P. et al., 2009, *Language of risk – Project definitions*, Floodsite project report T32-04-01, 2nd edn, viewed n.d., from www.foodsite.net/html/partner_area/project_docs/T32_04_01_FLOODsite_Language_of_Risk_D32_2_v5_2_P1.pdf.

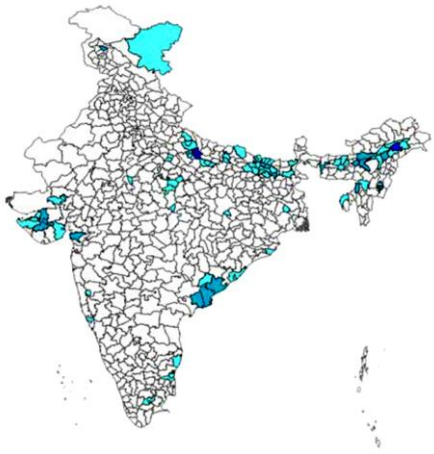
[27] Intergovernmental Panel on Climate Change (IPCC) , 2007, *Climate change: Impacts, adaptation and vulnerability*, Cambridge University Press, Cambridge.

[29] U.S. De, R.K. Dube, G.S.P. Rao, Extreme weather events over India in the last 100 years, J. Indian Geophys. Union 9 (3) (2005) 173–187.

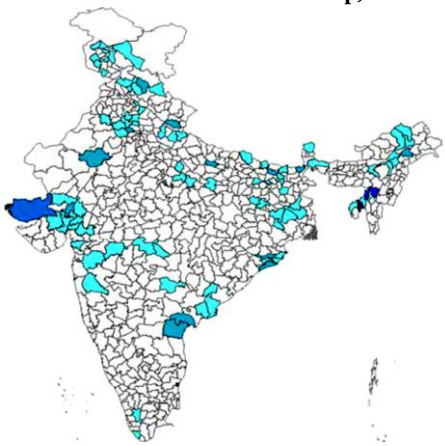
[30] Xavier, A.; Manoj, M.G.; Mohankumar, K. On the dynamics of an extreme rainfall event in northern India in 2013. J. Earth Syst.Sci. **2018**, 127, 1–13.



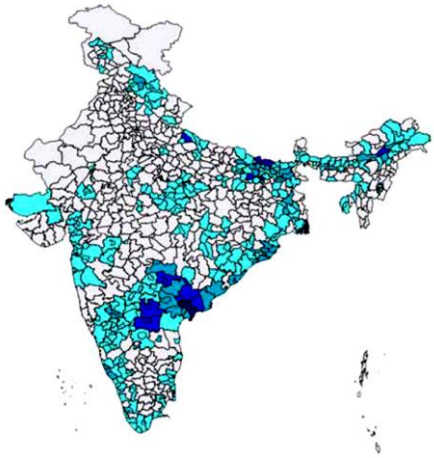
Decadal district affected flood map, 1970–79



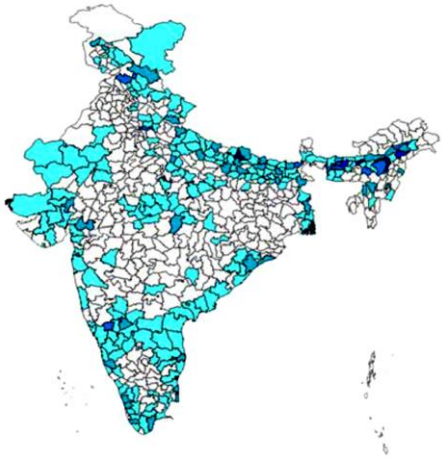
Decadal district affected flood map, 1980–89



Decadal district affected flood map, 1990-99



Decadal district affected flood map, 2000-09



Decadal district affected flood map, 2010–19

Fig. 5: Decadal flood hotspot districts[31]

[31] Mohanty, Abinash. 2020. *Preparing India for Extreme Climate Events: Mapping Hotspots and Response Mechanisms.* New Delhi: Council on Energy, Environment and Water.

Table 3: Notable flood events in India between 2000-2021

Flood location	Notable Incident	Losses		
		Deaths	**Economic losses (in INR)**	**Other damages**
Maharashtra floods (2005)[32]	994 mm rainfall in 24 hours	5000	4982 crores	20 million affected; 437 primary health centers destroyed; 97 school buildings collapsed; 71 towns and villages affected;
Ladakh Floods (2010)[33]	250 mm of a single storm rain	249	200 crores	No info
Uttarakhand flash floods (2013)[34]	Highest rainfall in last 80 years of about 385.1 mm	7000	32500 crores	1.6 million people affected; 4120 missing; 19590 business establishments devastated
Kashmir floods (2014)[35]	Rainfall on 6 September alone was 106mm	300	100,000 crores	2000 homes devastated; Srinagar city submerged in water; 2600 villages affected; Huge loss to paddy & fruit crops
Chennai floods (2015)[36]	246 mm rainfall between Nov 15-16; 490 mm 24 hrs rainfall on 1 December	500	100,000 crores	1.8 million people displaced
Kerala (2018)[37]	2346.6 mm of rainfall (from 1 June 2018 to 19 August 2018)	433	36000 crores	Floods and landslides affected 5.4 million people, displaced 1.4 million people,
Kerala (2019): Malappuram and Wayanad districts	400% over the normal average rainfall	81	No info	>39 houses and a walkover bridge completely washed away
Assam (2020)[38]	Rainfall of 1,164mm as compared to normal rainfall of 894mm during the period, an excess of nearly 30%.	149	10000 crores	5 million people were affected
Bihar (2021)[39]	Unusually high rainfall— an excess of 111 per cent over the normal, during the monsoon season	351	3764 crores	5 lakhs in 359 panchayats across 73 blocks of 13 districts

Note: The values presented in table 3 approximate the actual numbers and may vary slightly based on sources. The main intention is to highlight the scale of damage due to floods in India and the urgency to address the same.

[32] https://en.wikipedia.org/wiki/Maharashtra_floods_of_2005#Financial_effect
[33] https://en.wikipedia.org/wiki/2010_Ladakh_floods#cite_note-DisasterPlan-1
[34] https://www.worldbank.org/en/results/2014/07/29/rapidly-assessing-flood-damage-uttarakhand-india
[35] Gulzar S. 2014. Preliminary guidelines for repair, retrofitting, rebuilding and restoration of flood affected areas of Jammu & Kashmir, (October), National Institute of Tecnology Srinagar, pp. 02-03. Available at: goo.gl/jE87kf
[36] South Indian floods (2015), Wikipedia - The free encyclopedia. Available at: https://en.wikipedia.org/wiki/2015_South_Indian_floods.
[37] Post Disaster Needs Assessment, 2018, Government of Kerala, available at: https://www.ilo.org/newdelhi/whatwedo/publications/WCMS_660139/lang--en/index.htm
[38] https://www.hindustantimes.com/india-news/assam-flood-loss-may-be-around-10-000-crore-asmda-101657650824302.html
[39] https://www.hindustantimes.com/cities/patna-news/bihar-pegs-flood-related-losses-at-rs-3-764-cr-central-team-visits-state-101631021275085.html

The flood events listed in table 3 are some of the major flood events with severe damage. Many flood events occur at a lesser scale annually. In some incidents, some sections of vast cities, such as Mumbai, Hyderabad, Chennai, and Bengaluru, flooded due to heavy rains, eventually paralysing them for many days. Flooding-related loss and damage are rising as more people and properties are exposed to these hazards because of poor planning and lack of access to flood-resilient infrastructure and other resources. In the last six decades, the economic loss due to floods in India accounted for Rs. 4.6 lakh crores[40]. In the first half of 2022, India ranks first among the top ten deaths from natural disasters, with 1354 deaths due to floods, as shown in figure 6.

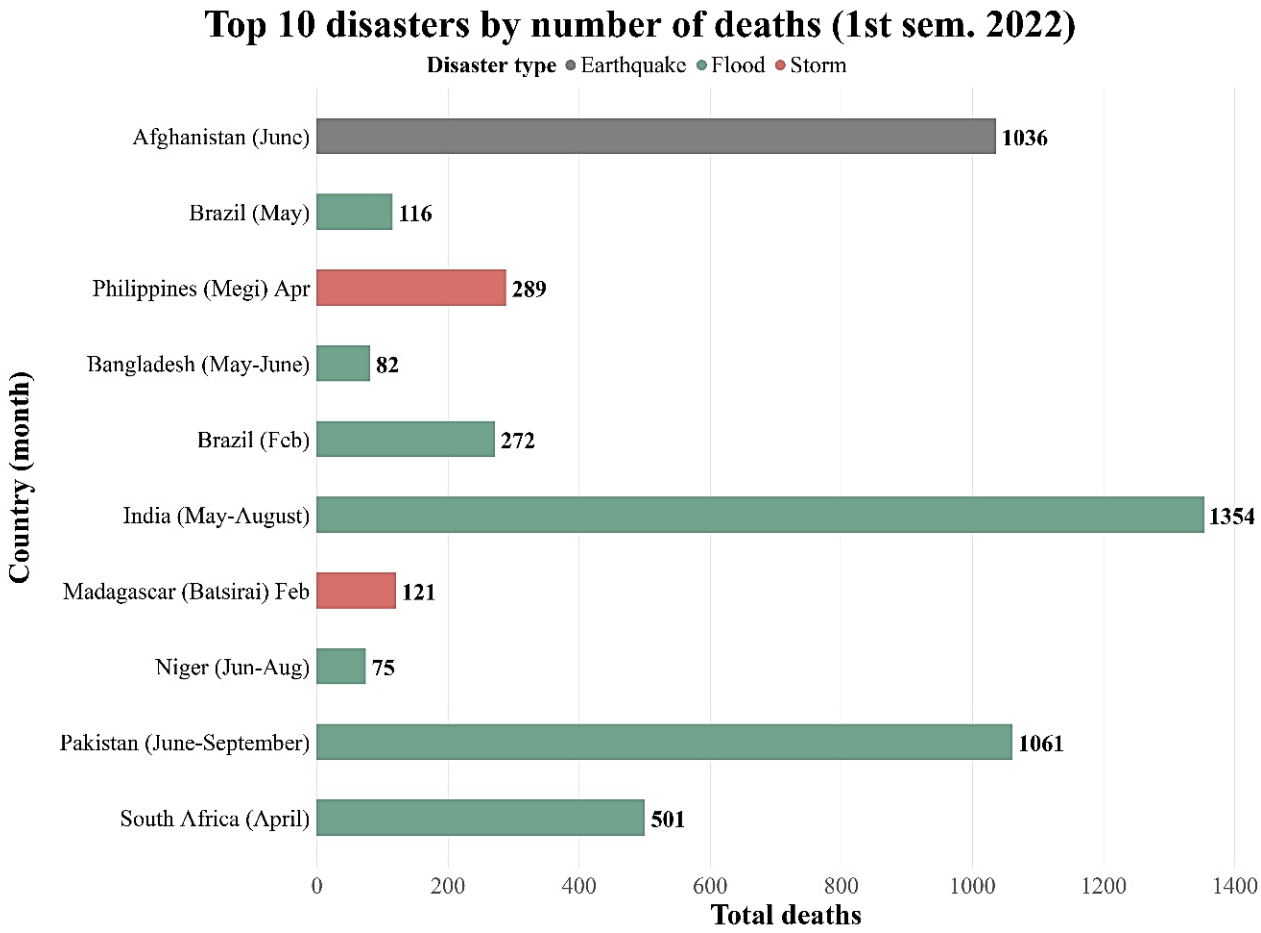


Fig. 6: Top 10 disasters by number of deaths (1st sem. 2022)[41]

[40] https://www.downtoearth.org.in/blog/climate-change/floods-cost-india-rs-4-7-lakh-crore-in-last-6-decades-72401
[41] Cred crunch, issue no. 68, september 2022: natural hazards and disasters - an overview of the first half of 2022

3.2.2. Key development indicators to assess CCA

India is one of the world's most vulnerable countries to climate change[42,43,44]. India's vulnerability to climate variability and change is shaped by a mix of non-climatic drivers, including those related to its economy, social development, governance, and environmental sustainability. Poverty and inequality are two of the critical underlying socio-economic drivers that increase the vulnerability of a given society, such as India's, to climate risks[45]. Some of the key development indicators of the country are presented in Table 4 to provide a snapshot of various socio-economic and political factors essential to understanding the vulnerability context of the country.

Table 4: List of India's development tracking indicators and their relationship to flood vulnerability[48]

Category	Indicator	Impact on vulnerability	
		If the rank/ indicator value is	Vulnerability will be
Human Development	Rank in Human Development Index (rank out of all countries)	high	high
	Population in multi-dimensional poverty (%)	high	high
	Under-five mortality rate (per 1,000 live births)	high	high
	Adult literacy rate (15 years of age and above)	high	low
	Improved water source, rural (% of population with access)	high	low
	Access to electricity (% of population)	high	low
	Gender Inequality Index (value/ranked out of all countries)	high	high
Demographics	Total population (in millions)	high	high
	Average annual population growth rate	high	high
	Population, urban (% of population)	high	high
Economic development	GDP (at current price)	high	low
	GDP growth (annual %)	high	low
	Agricultural land (% of land area)	high	low

[42] Intergovernmental Panel on Climate Change (IPCC), in: C.B. Field, V.R. Barros, D. J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y. O. Estrada, R.C. Genova, et al. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK; New York, NY, USA, 2014.

[43] D. Eckstein, V. Kunzel, L. Sch€afer, Global Climate Risk Index 2018, 2017, p. 36. Bonn, Germanwatch e. V., Germany, http://germanwatch.org/sites/germanwatch. org/files/publication/20432.pdf.

[44] NAPCC, National Action Plan on Climate Change, 2008. www.mma.gob.cl/1304 /w3-article-49744.html.

[45] Rao, N.D., Riahi K., & Grubler, A. (2014). Climate impacts of poverty eradication. *Nature Climate Change.* 4, 749–751 doi:10.1038/nclimate2340

Governance	Corruption Perceptions Index (Rank)	high	high
	Fragile States Index (score out of 120 points)	high	high
	Expenditure on health (% of GDP)	high	low
	Expenditure on education, public (% of GDP)	high	low
Environment	Population living on degraded land (%)	high	high
	Change in forest area	increased	reduced
Note: Indicators are taken from the sources mentioned above whereas the impact on vulnerability is assessed by the author.			

The indicators provided in table 4 help to monitor the trajectory of the country's development and its vulnerability to floods. For instance, if the percentage of agricultural land is high, the flood vulnerability reduces because a significant share of the Indian economy comes from agriculture. However, in recent years, the Indian economy has witnessed a substantial shift from being predominantly rural and agriculture-based to more focused on service and manufacturing. The share of India's GDP from agriculture and allied sectors consistently declined from 51.9% in 1950–1951 to 13.7% in 2012–2013 and increased to 20.2 % in 2020-21[46]. During this period, the industry and services sector contributing to India's GDP increased[47], causing a reduction in agricultural employment and increased employment in non-agricultural sectors. The shift has also partly fuelled a large-scale rural-urban migration making the urban areas denser. Due to increased urbanisation, economic activity and population density, the damages from city floods increased significantly.

In contrast, it can also be argued that since agricultural land incurs heavy losses during floods, a reduction in agricultural land should reduce the vulnerability. This statement holds if the indicator is evaluated in isolation. However, to validate the claims, the other indicators, such as poverty, human development index, GDP etc., should be considered together to understand the overall impact. Therefore, evaluating the development indicators as a package is always better than in isolation.

3.2.3. Key sectors of flood vulnerability and indicators

Climate change impacts are likely to be most pronounced, with far-reaching consequences in some of India's key sectors, such as water, agriculture, forests and other land ecosystems,

[46] https://www.pib.gov.in/PressReleasePage.aspx?PRID=1741942
[47]https://tinyurl.com/qekphz.

coastal and marine resources, human health, and energy. Table 5 presents a brief overview of the flood vulnerabilities of some of the sectors in India.

Table 5: Key flood-vulnerable sectors in India[48]

Water resources	• Increased rainfall will result in high water yield for all the river systems, but changes in precipitation are highly variable across river basins. • Changes in annual stream discharge are likely to increase the risk of floods in basins. • Temperature changes will melt snow and glacier retreat in many parts of the Himalayas and might cause floods downstream.
Agriculture	• Sudden and excess rainfall leads to flooding, thereby damaging crops
Fisheries	• Fisheries, both inland and coastal, are likely to suffer huge losses because of declines in fish catch due to changes in sea temperature and hydrological changes in major river systems.
Health	• Water-borne diseases are likely to become widespread because of water stress-related issues such as lack of clean water or outbreaks of diarrhoea after floods. • The incidence of vector-borne diseases such as malaria and dengue will increase. • Seasonal transmission and distribution patterns of many disease-transmitting vectors, such as mosquitoes and ticks, will be altered. • Climate change–induced natural disasters pose severe threats to infrastructure development and investments. The risks could be physical, technological, supply chain–related, or regulatory in nature.
Infrastructure systems	• Natural resource-based infrastructure, such as hydro-power projects in the Himalayas, is at greater risk of cloudbursts, flooding, and landslides. • Critical infrastructure in coastal regions, including power transmission, telecommunications, roads and railways, and health care facilities, is at higher risk of cyclones and sea level–related changes.

While table 5 showcases some rural sectors, such as agriculture and fisheries, which are impacted by floods, the critical sectors to get affected in cities are water resources, health and infrastructure systems. Commonly, the vulnerability of urban floods is usually evaluated across

[48] Patra, J. 2016. Review of Current and Planned Adaptation Action in India. CARIAA Working Paper no. 10. International Development Research Centre, Ottawa, Canada and UK Aid, London, United Kingdom.

the social, economic, and hydrogeological/environmental dimensions, and political-administration dimensions are also considered for a more comprehensive vulnerability assessment. Some of the widely used indicators to assess flood vulnerability across various sectors are shown in table 6.

Table 6: Indicators to assess urban flood vulnerability[49,50,51,52].

Dimension	Indicator	If the indicator value is	Vulnerability will be
Social	Population density	high	high
	Population under poverty	high	high
	Under and elderly population	high	high
	Population with special needs	high	high
	Access to medical facilities	high	low
	Access to transportation and other communication means	high	low
Economic	Homeownership	high	low
	Unemployment rate	high	high
	Female labour force	high	low
	Commercial infrastructure in flood hot spots	high	high
	Industrial infrastructure in flood hot spots	high	high
Hydrogeological/ Environmental	Urbanisation	high	high
	Urban green spaces	high	low
	Water bodies	high	low
	Storm water drains	high	low
	Drainage length and connectivity	high	Low
Note: Indicators are taken from the sources mentioned above whereas the impact on vulnerability is assessed by the author.			

[49] Vajjarapu, H., & Verma, A. (2021). Composite adaptability index to evaluate climate change adaptation policies for urban transport. *International Journal of Disaster Risk Reduction*, *58*, 102205.
[50] Salazar-Briones, C., Ruiz-Gibert, J. M., Lomelí-Banda, M. A., & Mungaray-Moctezuma, A. (2020). An integrated urban flood vulnerability index for sustainable planning in arid zones of developing countries. *Water*, *12*(2), 608.
[51] Balica, S. F., Wright, N. G., & Van der Meulen, F. (2012). A flood vulnerability index for coastal cities and its use in assessing climate change impacts. *Natural hazards*, *64*(1), 73-105.
[52] Moghadas, M., Asadzadeh, A., Vafeidis, A., Fekete, A., & Kötter, T. (2019). A multi-criteria approach for assessing urban flood resilience in Tehran, Iran. *International journal of disaster risk reduction*, *35*, 101069.

3.3. Risk Assessment

3.3.1. Climate Risk Management

A Climate Risk Management (CRM) framework highlights various risk management actions to respond to climate-related risk considering any perceived or actual constraints and limits to adaptation. It includes risk assessment and risk evaluation. This framework can be utilised at a national level to inform the risk management and adaptation discourses to assess and develop various national and state measures when dealing with large-scale climate risks and residual risks that could contribute to potential loss and damage. In this regard, the National Institute of Disaster Management (NIDM) 2019 developed a CRM framework for India addressing loss and damage[53], as shown in figure 7. This six-step approach CRM process builds on several best-practice criteria identified in the literature.

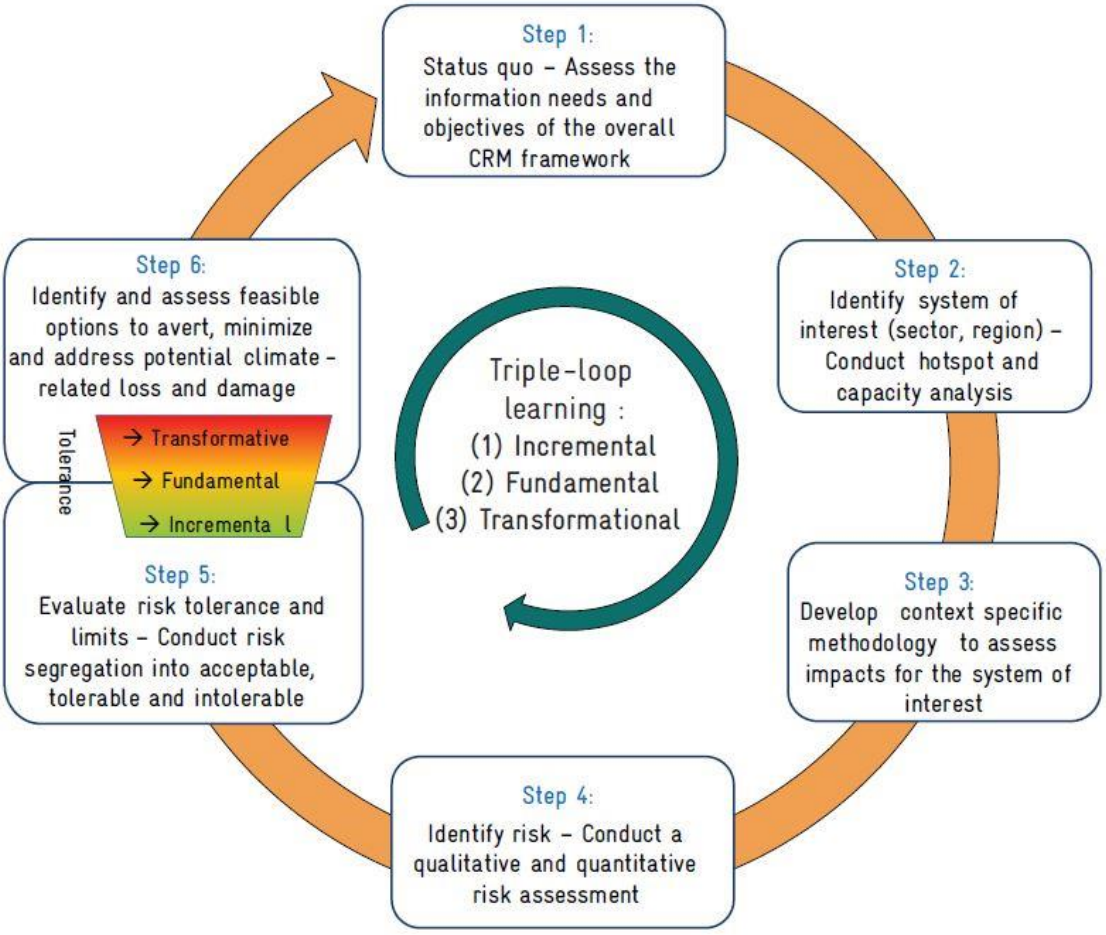


Fig. 7: Six-Step CRM Framework[51]

[53] Mechler, R., Schinko, T., Awasthi, K., Bhatt, S., Chaturvedi, A., Toast, J., ... & Sahany, S. (2019). Climate Risk Management [CRM] Framework for India: Addressing Loss and Damage (L&D).

One of the widely used techniques to incorporate interventions to mitigate climate risk is loop learning. It is a framework that integrates different learning theories, such as experiential learning, adaptive management, and transformative learning. Each loop, or theory of learning, targets a specific CRM situation characterised by differences in the level of uncertainty decision-making processes are confronted with. A typical example of loop learning related to flood management is shown in figure 8.

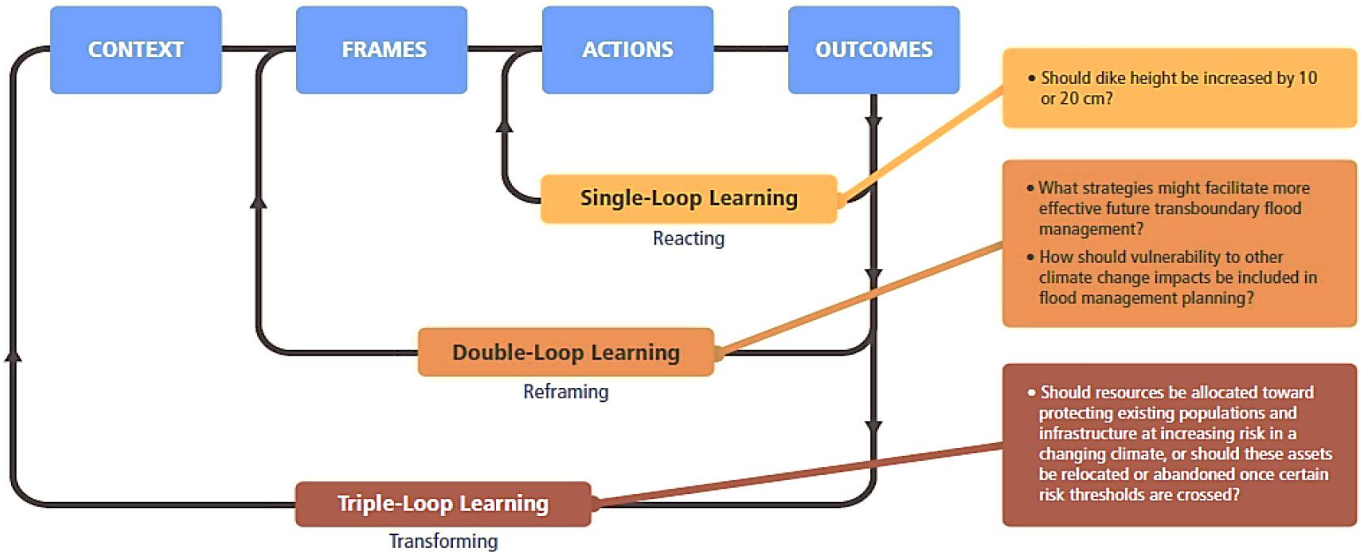


Fig. 8: Learning loops: pathways, outcomes, and dynamics of single-, double-, and triple-loop learning and applications to flood management[54]

3.4. Building efficient CCA strategies

The CRM framework shown in figure 7 runs on triple-loop learning, which embeds the adjustments/interventions into incremental, fundamental and transformative options based on the type of risk-mitigating solution.

- **Incremental Interventions:** Standard Disaster Risk Reduction (DRR) and CCA interventions directly address specific risks, e.g., raising dikes
- **Fundamental Interventions:** Non-standard interventions in the system of interest, e.g., opening floodplains instead of a dike.
- **Transformative Interventions:** Interventions that change fundamental attributes of the system, i.e., doing things differently, either voluntarily to work towards improved

[54]Lavell, A., M. Oppenheimer, C. Diop, J. Hess, R. Lempert, J. Li, R. Muir-Wood, and S. Myeong, 2012: Climate change: new dimensions in disaster risk, exposure, vulnerability, and resilience. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK,

outcomes, such as options and action focussed on broadly building resilience. For example, migration from floodplains to cities to provide alternative livelihood opportunities via access to new labour and other markets, or options are taken by force, such as forced displacement.

Considering the increasing impacts of climate change, the CRM framework needs to focus on fundamental and transformative actions beyond the traditional DRR and CCA measures, in addition to fostering transformative capacities of communities which are particularly at risk. To strengthen the CCA policies, to confront climate change, the World Bank developed a guide for designing strategies for Climate Change Adaptation and Resilience, as presented in table 7.

Table 7: Priority areas and concrete actions for climate change adaptation and resilience policy: an overview[6]

Priority Areas	**Lead Ministry**	**Action points**	
Foundations: Rapid, robust, and inclusive development is the first priority	Finance/Economy	1	Increase economic productivity and growth, while keeping buffers for shocks
		2	Ensure that economic growth is inclusive
Priority Area 1: Facilitate the adaptation of people and firms	Economy	1.1	Assess disaster and climate risks, and make the information available
		1.2	Clarify responsibilities and align incentives with resilience and adaptation objectives.
		1.3	Facilitate access to technologies through trade policies and investments in research and development
		1.4	Ensure financing is available to all, and provide support to the poorest and most vulnerable people
		1.5	Facilitate structural change in the economic system
Priority Area 2: Adapt land use plans and protect critical public assets and services	Economy, planning, investment, or infrastructure	2.1	Identify critical public services and assets
		2.2	Design and implement a government-wide strategy to increase the resilience of infrastructure and public assets
		2.3	Revise land use and urban plans to make them risk informed
Priority Area 3: Help firms and	Interior or environment	3.1	Save lives (and money) with hydromet, early warning, and emergency management systems

people manage residual risks and natural disasters		3.2	Provide all firms and households with risk management instruments
		3.3	Develop the insurance sector, building on public private partnerships
		3.4	Build a social protection system and make it responsive to shocks
		3.5	Help firms develop business continuity plans and financial preparedness
		3.6	Be prepared to build back better after disasters with contingency plans and financing
Priority Area 4: Manage financial and macro fiscal issues	Finance	4.1	Include contingent liabilities from natural disasters and environmental shocks in the planning and budgeting process
		4.2	Develop a financial strategy to manage contingent liabilities, combining multiple instruments
		4.3	Anticipate and plan for long-term macro-economic impacts
		4.4	Communicate and mitigate the disaster and climate risk exposure of the financial sector and pension systems
Application: Prioritisation, implementation, and monitoring progress	Finance/economy and agency in charge of climate change	A.1	Create a strong institutional and legal framework, with appropriate stakeholder involvement
		A.2	Design an adaptation and resilience strategy with prioritised actions
		A.3	Set concrete sector-level targets to guide implementation by line ministries
		A.4	Screen all public policies and expenditures for disaster and climate risks, and align them with adaptation targets
		A.5	Allocate appropriate funding to the adaptation and resilience strategy
		A.6	Track progress over time, and review and revise the strategy

The action points in table 7 help ministries who oversee the broader economic and environmental system approach adaptation challenges. It does not go into detailed sector-level adaptation strategies but focuses on concrete macroeconomic-level actions.

4. India's efforts towards climate change adaptation

Until recently, policies in India aimed at mitigating the floods, droughts and cyclones that are recurring natural hazards in many parts of India focused on investments in physical

infrastructure and other financial measures such as post-disaster compensation and relief. With emerging knowledge of human-environment interactions, and more specifically around human-induced climatic changes and their influence on various natural hazards, greater policy attention to climate change issues has been triggered in the country. Over time, the adaptation planning context in India has grown from a purely environmental and stand-alone sectoral initiative into a more integrated and multisectoral development planning process[48].

- In response to the imminent catastrophe triggered by climate change, the government of India established a comprehensive institutional structure addressing this issue. At the apex of this structure is the Prime Minister's Council on Climate Change, a high-level advisory panel with India's Prime Minister as its chairperson. It was initially established in 2007 and reconstituted in November 2014, when its objectives were revised to the following:
    - Coordinate a national action plan for assessing, adapting, and mitigating climate change.
    - Advise the government on proactive measures India can take to deal with climate change.
    - Facilitate inter-ministerial coordination and guide policy in relevant areas.

- In advancing efforts to tackle climate change, the GOI developed the National Action Plan on Climate Change (NAPCC) in 2008[55]. It is a watershed in India's efforts to design, plan, and implement climate change adaptation and mitigation actions across sectors and regions. The NAPCC outlines eight national missions: National Solar Mission (NSM), National Mission for Enhanced Energy Efficiency (NMEEE), National Mission on Sustainable Habitat (NMSH), National Water Mission (NWM), National Mission for Sustaining the Himalayan Ecosystem (NMSHE), National Mission for a Green India or Green India Mission (GIM), National Mission for Sustainable Agriculture (NMSA), National Mission on Strategic Knowledge for Climate Change (NMSKCC). Amongst these missions, NMSH, NWM and NMSHE focus on the flood aspect, while NMSH specifically focuses on urban flooding. Further, to make climate change planning more inclusive and needs-based, in 2009, the GOI requested that states develop their respective State Action Plans on Climate Change (SAPCC). The SAPCCs are created with the objectives in line with the NAPCC.

[55] National Action Plan on Climate Change (NAPCC), 2021. Frequently Asked Questions (FAQs), Ministry of Environment, Forest and Climate Change, Press Information Bureau, Ministry of Information and Broadcasting, GOI. Available at: https://static.pib.gov.in/WriteReadData/specificdocs/documents/2021/dec/doc202112101.pdf

- India's five-year plan and the NAPCC provide a framework for guiding adaptation action in different sectors. A concern was expressed that these frameworks have not been clear and consistent in their approach to facilitating relevant and required changes in sectoral policies and planning[56]. However, many of India's significant sectoral policies recognise climate change as a potential risk and have identified adaptation measures of various kinds. The progress India has made in integrating climate change concerns into these and other sectoral policies provides the basic institutional framework required to refine further and improve the strategies for more effective mainstreaming of climate change adaptation measures. Although these sectoral policies incorporated climate change into their framework, no specific adaptation targets are mentioned.
- Stormwater drainage congestion (pluvial in nature) is one of the primary reasons for flooding in towns/cities during extreme weather events[57]. The devastation caused due to floods in the past has drawn the attention of the country's planners towards comprehensive flood management plans, policies and implementation thereof. In this regard, the National Disaster Management Authority (NDMA), in 2010, brought out detailed guidelines for managing urban floods[58] to boost the efforts for urban flood disaster management and strengthen the national vision of moving towards a more proactive pre-disaster preparedness and mitigation-centric approach. These guidelines contain all the details required by planners and implementers and help Central Ministries/ Departments and the States/ UTs prepare the plans.
- The Climate Change Action Program (CCAP) is a central sector scheme initially launched in 2014, with an outlay of INR 290 crores for five years[59]. The scheme has now been extended up to 2025-26. It consists of eight broad sub-components, including the National Action Plan on Climate Change (NAPCC) coordination, State Action Plan on Climate Change (SAPCC), National Institute on Climate Change Studies & Actions, National Carbonaceous Aerosols Programme (NCAP), Long Term Ecological Observations (LTEO), International negotiations and capacity building. India's climate actions, especially the adaptation efforts, are financed mainly domestically.

[56] Dubash, N.K., Raghunandan, D., Sant, G., & Sreenivas, A. (2013). Indian climate change policy exploring a co-benefits based approach. *Economic & Political Weekly*, *48*(22), 47–61.
[57] NITI Aayog (2021) "Report of the Committee constituted for formulation of strategy for Flood Management Works in entire country and River Management Activities and works related to Border Areas (2021– 26)"
[58] National Disaster Management Guidelines: Management of Urban Flooding. A publication of the National Disaster Management Authority, Government of India. ISBN: 978-93-80440-09-5, September 2010, New Delhi.

- The National Adaptation Fund on Climate Change (NAFCC) was launched in 2015, and 30 projects with a total allocation of INR 847.5 crores have been sanctioned from 2015-19[59]. The projects focus on climate-sensitive sectors such as agriculture, water, forestry, and coastal and Himalayan ecosystems. They are being implemented to enhance the adaptive capacity of the most vulnerable sections of our population and ecosystems.

5. Gaps in India's adaptation strategies concerning urban floods

The first decade of the 21st century was a period of great churning in terms of the political and economic discussions around climate change. Despite no institutional pressure, developed countries constantly pushed developing countries to reduce their emissions. In 2007, China released its national plan to address climate change issues, leaving India as the only big developing country without such an instrument[60]. As a result, the government wanted a policy instrument before the G8 Summit in Tokyo in 2008 and the Conference of Parties in Copenhagen in 2009[60]. Therefore, the Indian government formed NAPCC in 2008 ahead of the crucial Copenhagen Summit, which served as a tool to showcase India's seriousness in tackling climate change.

5.1. Policy level

Evaluating NAPCC shows the inadequate inter-ministerial coordination and lack of clarity on climate change co-benefits as some of the implementation challenges that various missions and responsible ministries faced[48]. Even though NAPCC has existed for close to a decade, research shows that for most missions, it has only been three to four years since they came into effect. It is also clear that most missions' progress has been almost uncertain. Currently, the approach to climate change, as seen in the NAPCC, is too broad and lacks specificities. While the solar, energy efficiency and forestry missions include mitigation components in the form of quantified targets, missions on sustainable agriculture, water, and sustainable Himalayas, which focus on flooding, are purely adaptive, and no specific targets are mentioned. The National Mission on Strategic Knowledge for Climate Change is unlikely to attract most of its

[59] Tripathi. S. (2022). Climate Finance Critical to Successful Climate Action: Economic Survey Acction (2021-2022). Outlook Planet. Retrieved from: https://planet.outlookindia.com/news/climate-finance-critical-to-successful-climate-action-economic-survey-2021-22--news-414698

[60] Rattani, V., Shreeshan , V., Pandey, K., Jitendra, Kukreti, I., Avikal, S., & Akshit . (2018, October 31). India's National Action Plan on Climate Change needs desperate repair. Retrieved from Down to earth: https://www.downtoearth.org.in/news/climate-change/india-s-national-action-plan-on-climate-change-needs-desperate-repair-61884

funding unless green technology and research development are mainstreamed into the central plans of scientific departments and research institutes.

Missions dealing with subjects such as sustainable habitat, water, agriculture, and forestry are multisectoral, overlapping, and multi-departmental in nature. They are advisory and holistic and have been slow-moving. Several ongoing activities are, in principle, aligned with the objectives of the sustainable habitat and agriculture missions, but there has been no official announcement of their integration with the missions. For instance, the AMRUT mission has elements similar to those of the NMSH; the significant difference is AMRUT's more sectoral approach[62]. The climate impacts vary across sectors, and the fact that the missions have been placed in 'eight separate bins'[55] has led to viewing the problems and solutions with sector-specific lenses. However, considering both crucial, there is no mention of an integrated and unifying policy framework combining mitigation and adaptation strategies.

Additionally, a tremendous variation between the different State Action Plans on Climate Change (SAPCCs) due to differences in ascribing priority to climate change, institutional heterogeneity, developmental circumstances, and resource availability[61]. The SAPCCs have been noted to be inadequate in many respects, particularly in capacity and well-designed institutional mechanisms at the implementation and monitoring stage[6263]. The missions' accomplishments must be done at the ground level, which requires functional and efficient decentralised structures and institutions at the state, district and village levels. States and sub-state structures also need methodological guidance to prepare action plans and create implementing structures and agencies, as well as monetary and technological support. Another challenge for the missions is their monitoring systems, which are either ineffective or absent.

The Ministries are also required to report progress and have regular meetings with the PM's Council on Climate Change, but the Council has met only once since its reconstitution. Apart from putting out the mission's progress in quantitative and qualitative terms, progress reports should highlight their impact on the ground in terms of supporting communities and making them more climate resilient. Unfortunately, no such approach has been adopted.

[61] Kumar, P., & Naik, A. (2019, February 14). Engage: India's Domestic Climate Policy is Fragmented and Lacks Clarity. Retrieved from Economic & Political Weekly (EPW): https://www.epw.in/engage/article/indias-domestic-climate-policy-fragmented-lacks-clarity.

[62] Kumar, Vineet (2018): "Coping with Climate Change: An Analysis of India's National Action Plan on Climate Change, Vol II," 20 February, New Delhi: Centre for Science and Environment, https://www.cseindia.org/volume-ii-coping-with-climate-change-8489.

[63] *Vasudha Foundation* (2018): "Unpacking the Paris Agreement: Implications and State of Preparedness–India," 20 February, http://www.vasudha-foundation.org/unpacking-paris-agreement-implications-state-preparedness-india/.

5.2. Lack of Climate-Resilient Infrastructure in cities

The primary reasons for urban flooding and its reoccurrence are poor urban planning and lack of flood-resilient infrastructure. The uncontrolled expansion of cities led to floodplain encroachments, reducing the previous area and increasing runoff[64]. Until recently, India's stormwater drains were designed per the Central Public Health and Environmental Engineering Organisation (CPHEEO) guidelines. They are designed for rainfall intensities of once in one year to once in two years return periods. If rainfall records are unavailable, rainfall intensity is usually adopted in the range of 12 mm/hr – 20 mm/hr. In the revised CPHEEO guidelines, 2019[65], the design parameters were changed to two to five years of return periods or a maximum of 25 mm/hr, still significantly lower than significant rainfall intensities in the recent past[66].

The lack of data or maps of underground drains is another issue faced in Indian cities. Municipal bodies are often unaware of the underground and overground stormwater drain network since no regular mapping exercise takes place. In many cities like Mumbai and Kolkata, underground pipes are over 100 years old[66]. All urban local bodies need to do contour mapping of cities and drain mapping along with that, which will tell them the existing situation of drains along with the new ones that need to be laid according to land contours to determine the natural flow of water[66]. This information also helps connect stormwater drainages to create a continuous network and disconnect regular drainages from stormwater drains. The informal areas and encroached settlements in cities are not connected through the stormwater drain networks. The rainwater often gets mixed up with sewage and garbage, causing considerable bottlenecks in the existing system. A consistent effort must be carried out to prevent such areas from mushrooming or create networks connecting them.

5.3. Funding

Globally, the financial investment in mitigation is much higher than in adaptation. Although adaptation is now being taken more seriously, it still suffers from insufficient financial investment and institutional research[19,20]. For example, 96% of the global funds for combating

[64] Singh (2022). Causes, impacts, risk and mitigation of Urban Flood Management in India – Compendium report. International Centre for Environment Audit and Sustainable Development (iCED). Available at: http://iced.cag.gov.in/wp-content/uploads/Urban%20Flood%20Management%20in%20India.pdf.
[65] CPHEEO, 2019. Manual on Storm water drainage systems, Volume I, Part A: Engineering Design, Ministry of Housing and Urban Affairs (MoHUA).
[66] Mankikar, S. (2020, August 13). Urban Futures: Inadequate storm water infrastructure biggest hurdle in urban flood resilience. Retrieved from Observer Research Foundation (ORF) Online: https://www.orfonline.org/expert-speak/inadequate-storm-water-infrastructure-biggest-hurdle-in-urban-flood-resilience/

climate change in 2010 and 2011 were for mitigation measures[67]. However, as of 2020, the climate finance allocations stand at 64% mitigation, 25% adaptation and 11% for cross-cutting measures[68]. Although funding for adaptation projects increased over time, this is still not a balanced allocation.As mentioned in section 3.4, in India, the projects related to adaptation in sectors such as agriculture, animal husbandry, water, forestry, tourism etc., are eligible for funding under NAFCC. National Bank for Agriculture and Rural Development (NABARD) is the National Implementing Entity (NIE). As of February 2022, NAFCC is implemented in project mode, and 30 projects are sanctioned in 27 States and UTs[69]. However, fresh data show that the central government grants released under the National Adaptation Fund on Climate Change (NAFCC) have declined steadily for the last five years. Grants released under NAFCC fell from Rs 115.36 crore in 2017-18 to Rs 42.94 crore in 2020-21 and Rs 27.76 crore (till December 2021)[70]. To add, no new adaptation projects have been implemented since 2018-19. Amongst the implementation, the amount catered to flood-resilient infrastructure is significantly less. Therefore, very little money is available for the upgradation of stormwater drains since most of the expenses are diverted towards operation and maintenance. While funds are allocated for this through the AMRUT scheme, which must be used, the MOHUA has encouraged cities to explore tapping private funds through public-private partnerships (PPP) for this purpose[66].

6. Summary and Conclusions

As discussed in the previous sections, India is one of the most vulnerable countries to climate hazards worldwide. The literature has shown that the frequency and intensity of these extreme weather events will continue to rise in future. The cities are expanding by reducing the natural vegetation and encroaching on the natural water bodies. Under such dire circumstances, extreme rainfall events lead to increased runoff and cities get inundated. Although mitigation efforts from the Indian government receive greater attention, extreme weather events are inevitable. Therefore, the cities should have strong climate change adaptation strategies to

[67] Li, Y. 2010. "Study on Environmental Effects of Emission Reduction in West-to-East Electricity Transmission."China Population, Resources and Environment, 20 (9): 36–41.
[68] United Nations Climate Change (2021, November 2). The Climate Finance Question. Retrieved from United Nations Framework Convention on Climate Change: https://unfccc.int/blog/the-climate-finance-question.
[69] National Adaptation Fund on Climate Change (NAFCC). (2018). Ministry of Environment, Forest and Climate Change. Press Information Bureau. Government of India. Retrieved from: https://pib.gov.in/newsite/PrintRelease.aspx?relid=176178.
[70] Verma, S. (2022, February 10). Explained: Despite govt's climate focus, why grants to a key adaptation fund are sliding. Retrieved from Indian Express: https://indianexpress.com/article/explained/budget-climate-government-grants-7764151/.

overcome these issues.

This paper presented a broad methodological framework that Indian cities can adopt in developing robust CCA strategies to overcome urban flooding. Some extreme flooding events across various states in India are highlighted with economic and human losses. Further, the flood-vulnerable district hotspots are presented, and the crucial indicators to evaluate the flood vulnerability are compiled. A six-step CRM framework to assess and manage the risks associated with urban flooding and the guidelines proposed by the World Bank to combat climate risks are briefly discussed.

This study has shown that mitigation and adaptation are two pillars in the fight against climate change. Although there are significant differences in their functionality and impact, they act together against climate change, and their benefits/consequences are deeply interlocked. The Indian government has made efforts to develop climate change adaptation strategies such as NAPCC, SAPCC and NAFCC etc. However, cities succumb to urban flooding, highlighting that much more action is needed. Some major loopholes include a lack of a robust policy framework, insufficient climate-resilient infrastructure and lack of funding.

Eight missions under the NAPCC are spread across eight sectors and multiple players delineating responsibilities. However, the multi-dimensionality of climate impacts makes it vital that India adopts an interdisciplinary approach, breaks traditional ministerial boundaries, and learns rapidly from the ongoing warming effects and our successes and failures in dealing with it them. Efforts should be made to mainstream adaptation strategies into sustainable planning processes to increase the effectiveness of reducing climate change impacts.