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Kolkata and Mumbai: Climate Disaster Mitigation in Coastal Megacities of India

Shatabdi Das

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Introduction

The United Nations outlines rising temperatures, environmental degradation and climate change along with its effects triggering natural disasters, weather extremes, food and water insecurity, economic disruption and conflict as a crisis in today's time.[1] The United Nations High Commissioner for Refugees (UNHCR) states that climate change and the emergency demand for climate action has caused disaster displacements above millions in number in India.[2]

The Heads and Representatives of States and Governments at the UN Summit in New York on 25 September 2015, adopted the global 'Sustainable Development Goals (SDGs) Agenda 2030' that underscored the importance of data requirement, and its assessment for fulfilment of the targets and assurance 'No One Is left Behind.'[3] The goals call for actions for changing the world, by way of strengthening finance, enhancement of technology and capacity building, at national and regional level including global level. The National Indicator Framework monitors the SDGs in India and strives to build resilient infrastructure; promote inclusive and sustainable industrialisation and foster innovation; make cities and human settlements inclusive, safe, resilient and sustainable; take urgent action to combat climate change and its impacts, among others.[4]

The United Nations International Strategy for Disaster Reduction (UNISDR) defines disaster mitigation as "lessening or limitation of the adverse impacts of hazards and related disasters. Mitigation measures encompass engineering techniques and hazard-resistant construction as well as improved environmental policies and public awareness."[5] In the context of climate change policies, mitigation also incorporates the reduction of greenhouse gas emissions as one of the sources triggering climate change. The adverse impacts of hazards often cannot be prevented fully, but the severity or scale of damage can be considerably reduced through the implementation of a number of strategies and actions.

India has the highest number of internal displacements in the world, majorly triggered by disasters every year. Flooding as a result of rainfall is controlled by the amount of precipitation a site receives, though the magnitude of floods is to a large extent impacted by drainage network and preparedness of cities in terms of architecture, settlement morphology, and civic planning for storm water drainage. The frequency of climate hazards, large population size and socio-economic

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vulnerability increases the intensity of damage due to disasters. India in a number of ways has been working towards environmental stewardship, climate action and decarbonisation, with focus on the reduction of damaging and polluting resource consumption practices.[6] Closing the gaps and regional disparities, and distinguishing the areas that require improvement for climate resilience, demands inclusive, grassroot and participatory planning. In this approach, analyses of interconnected causes of displacements manifested by extreme weather conditions, environmental degradation and climate stresses, coupled with other drivers of disasters are significant.

The Internal Displacement Monitoring Centre (IDMC) states that around 14 million people in India have been displaced due to climate related changes. Migrants receive support in terms of immediate relief and rehabilitation; however, long term institutional support is negligible, especially in areas hit by cyclones, storm surges and floods, and such deteriorating environments are growing in Sundarbans, Chilika lagoon of Odisha, Kochi backwaters of Kerala. In the hilly districts of Uttarakhand erratic rainfall pattern and receding water table are forcing people to abandon farmlands and migrate to the plains, whereas back in the plains of Bihar, the strike of incessant rain is causing floods.[7] Breakdown of traditional livelihood opportunities and amenities in disarray due to climate change, are pushing people out of their habitats and supporting ecosystems. Policies or initiatives looking into the issues of climate induced migration are necessary in India.

According to the Census of India (2011), urban agglomerations or cities in India with more than 10 million population are considered as megacities (namely Mumbai, Delhi, Kolkata).[8] The Intergovernmental Panel on Climate Change (IPCC) in its Sixth Assessment Report (2022) warns of the risks of flooding in coastal Indian cities such as Mumbai, Chennai, Kolkata, that necessitate infrastructural interventions with growing number of storm surges, cyclones and the rising sea surface temperatures.[9] The report also resounds with alarm, the limitations of resilience and challenges of combating climate crises for the coastal cities of India.

Study Area

The research delves into the effects of environmental hazards and approaches to climate disaster mitigation in coastal megacities of India, with Kolkata and Mumbai as two cases.

The location of Kolkata in coastal Bengal, enclosed by estuary and the fragile ecosystem of the Ganga delta, is vulnerable to environmental degradation, heightened risk of rapid sea level rise, periods of intense rainfall, damages of cyclones and storm surges. Limited funds for infrastructure and inadequacy in terms of capacity-building both physical (structural) and societal, and the urgency of building 'climate resilient cities' become crucial issues in urban management and planning. Destructive winds and thundershowers accompanying cyclones raise serious concern of safeguarding the growing, dense population in the coastal metropolitan region of Bengal. With an intensification of cyclonic occurrences and spiralling damages on landfall along the Bengal coast in the last two decades, the patterns of urban expansion, livelihood and consumption and emission trends together with the ensuing bearings on migration, and at times displacements, require appraisal.

Mumbai is prone to flooding due to the low-lying topography along the Arabian Sea coast, accompanied by high tides and heavy rains. The history of planning in Mumbai, indicates that the waterways were meant for draining out excess accumulated rain water, but have been replaced by houses and industries; the reclamation of the seven islands instead served to accommodate the growing population. The location of a city in relation to its natural surroundings, physical configuration of land and city morphology, plays important role in the approaches of urban planning and disaster management. While the expansion of built-up space in Mumbai encroaches upon natural

land cover, the challenges arise in formulation of development policies, delineation of hazard prone zones, and hazard adaptive measures for mitigation and infrastructure projects inclusive of sustainability and conservation, more so in the present time when climate resilient cities call for attention.

The study is limited in scope as it only looks into the mechanisms of climate disaster management in Mumbai and Kolkata, and does not include Chennai. Also a coastal city, Chennai with a population above 4.6 million,[10] has not been enumerated as a megacity (megacities have population above 10 million) as per 2011 Census.[11] The Census of India (2011) enumerates 3 megacities in India i.e., Mumbai, Delhi and Kolkata; and owing to their coastal location, this paper aims to study Mumbai and Kolkata with population sizes above 18.4 million and 14.1 million respectively.[12] This paper analyses the interrelation between urban development and the impacts of climate disasters. The research looks into the role of community-based organisations, urban local bodies, and environment management and conservation in mitigating climate disasters in coastal urban scape. The study also attempts to outline how flood risk management approaches and ecological conservation in the megacities help to strengthen disaster mitigation.

Advancements in alternative options such as low carbon emitting transport usage and mobility systems, and shift to the use of electric vehicle, directed towards green transition, environmental and social sustainability, infrastructure for walking, cycling, and access to public transit, add up to efforts towards reduction of vehicular emission volume and the resultant air pollution.[13]

For cities to adapt to everyday episodes of heavy or prolonged hours of rain, the infrastructure, civic amenities and urban land-use and land cover needs to be planned in a manner that the settlement is able to function and recover from the repercussions of climate disasters. Distinction between man-made and natural disasters is critical to urban governance and prevention of mismanagement. The methods, approaches and plans that urban settlements can adopt for living with extreme weather events and natural disasters, and at the same time prepare and control anthropogenic activities to reduce damaging impacts of hazards are crucial.

Section 1: The Case of Kolkata

The IPCC Working Group II Sixth Assessment Report (2022) underlined Kolkata's vulnerability to multiple climate risks and referred to the lack of resilience of the city. Kolkata is enlisted among the seven megacities in Asia most vulnerable to disaster-related mortality (the others being Tokyo, Osaka, Karachi, Manila, Tianjin, and Jakarta) and Kolkata is also threatened by subsidence due to sea level rise.[14]

1.1. Vulnerability to Climate Disasters

Warming of Bay of Bengal augments high intensity cyclones in Bengal coast with the potential to affect Kolkata. Rising sea level in the Sundarbans, around 100 kms away from the megacity, threaten Kolkata with subsidence and extended floods.[15] Kolkata Metropolitan Area (KMA) holds a population of 15 million and above (Census of India 2011), with a population density of 8,500 persons per sq. km.;[16] with more than 14.1 million people residing in the Kolkata city,[17] escalating climate change impact heightens the risks of disaster for a large population. The major causes of concern for flood in the city come from the century old drainage and sewer network in Kolkata. The drainage network today falls short of the carrying capacity of surface runoff, both due to larger

discharge from the sprawling city and decrease of exposed surface for ground infiltration as a result of expanding concrete and urban built-up environment.

Kolkata receives maximum rain from the South-West Monsoon.[18] Records of rainfall show that both the total annual rainfall and monthly rainfall during the monsoon months have increased recently.[19] Kolkata had received exceptionally high amount of rainfall of 236 mm within a span of a day (24 hours) in 2020, when Cyclone Amphan hit West Bengal; whereas the stormwater pumping stations in the city can accommodate a maximum of 150 mm per day or 6 mm per hour.[20] The sudden onset of monsoon rain in June, as well as mounting downpour worsens situation for flood control due to inhibited drainage capacity; the drainage channels fail to cope and carry the storm water runoff within a given time when there is excessive rain over short duration.

The annual mean land surface temperature in Kolkata has increased by 4.72 °C in the last three decades. The loss of vegetation cover and increase of built-up space enhances the heat island effect in the city.[21] High rainfall within a short period of time adds to surface runoff losses rather than underground recharge, and this high volume of runoff causes flash floods. The addition of heat raises the temperature of ambient air over land. This variability of temperature and heat between land and sea intensifies energy for cyclone formation over the Bay of Bengal. Recently, the changing trend of sea surface temperatures, has given rise to pre-monsoon cyclones.[22] The Office of Climate Research and Services of the India Meteorological Department (IMD) Pune, demarcates Gangetic Bengal as an area with cyclonic storm return period of four to six years.[23]

There has been an increase in the number of cyclones traversing West Bengal in the last 20 years that have caused intensive damage, namely cyclones BOB 03 (2002), Aila (2009), Bulbul (2019), Amphan (2020), Yaas (2021). The advancement of forecasting systems and monitoring in recent times helps to reduce the number of deaths through evacuation, warning and storm shelters, relief and disaster management authorities operating at ground level, but property damage and interruption of basic services ravage people's lives. The recurrence of cyclones every year burdens resources, and delays recovery and rehabilitation. Cyclone Bulbul in 2019 had destroyed crops in 198,000 hectares of land, while Amphan in 2020 took lives and destroyed property, with 4.45 million people affected in both rural and urban areas of Bengal;[24] consequently, agricultural fields in low-lying areas inundated by storm water leave farmers without work amidst the ruins of homes.

In September 2021, the cyclonic storm 'Gulab' left Kolkata and the southern districts of the state of West Bengal waterlogged for days.[25] Devastation and property damage by recent cyclones such as Amphan in May 2020, depicted the post-disaster phase inadequacy of urban infrastructure in Kolkata.[26] Understanding the role of ecological stakeholders who may work in coordination with civic bodies in the phases of preparation and mitigation to reduce risks, losses and the burdens of relief and rehabilitation, is indispensable for protection against disasters. Lack of outlets for rain runoff and clogged mouth of sewage pipes due to littering are common scenes in many localities across the city. Unless sweeping drives at the onset of monsoon stir clear of the waste fragments obstructing pathways meant for rainwater passage, submergence, spread of water borne diseases, and damage to property will remain impending threats.

Kolkata is located near the river mouth and bound by distributaries of river Ganga. The city requires investment and flood vulnerability monitoring because the natural drainage network in most parts of the metropolitan area has been reduced to a system of effluent channel, further encroached by squatters, slums, and transport development projects. The city needs to look for new ways of contending the shocks of climate disasters through protection, rejuvenation and conservation of the lakes and distributary channels draining the East Kolkata Wetlands (EKW) and bounding several parts of the urban agglomeration. The urban forest cover in Kolkata is insignificant compared to the

area of the city; comparatively Mumbai has about 25% of the city's area under forest cover, which is higher than the national average of total forest and tree cover (Table 1). This indicates the need for afforestation and urban forestry schemes in Kolkata, due to very low green cover, not only compared to its geographical area, but also the national average of total forest and tree cover in the country (24.62%).[27]

Table 1: Forest Cover in Megacities (ISFR 2021)

Megacity	Area	Very Dense	Moderately Dense	Open Forest	Total	Area under Forest (%)	National Average for Total Forest and Tree Cover, 2021 (%)
	(Area in sq. km.)						
Kolkata	186.55	0	0.10	1.67	1.77	**0.95%**	**24.62%**
Mumbai	435.91	0	51.13	59.65	110.77	**25.41%**	

Data Source: Government of India, "India State of Forest Report 2021," *Ministry of Environment, Forest and Climate Change,* January 20, 2022, https://static.pib.gov.in/WriteReadData/specificdocs/documents/2022/jan/doc20221207001.pdf; Government of India, "India State of Forest Report 2021," *Ministry of Environment, Forest and Climate Change, Press Information Bureau,* January 13, 2022, https://pib.gov.in/PressReleasePage.aspx?PRID=1789635.

Localities within the municipal boundary of Kolkata are vulnerable to hazards. Low lying areas situated along the bank of river Ganges (closer to open water) such as Garden Reach, Khidderpore, Tollygunge are prone to tidal surges; exposed areas near the riverfront in Central, West, and South West Kolkata and the southern suburbs are more vulnerable to the lashes of cyclones. Neighbourhoods of North and North-Central Kolkata with dense residential and commercial land-use are paralysed by more frequent incidences of urban storm or heavy rain related flash floods and waterlogging.[28] The Kolkata Municipal Corporation (KMC) action plan for mitigation of flood, cyclone and waterlogging (2021) enlists the major waterlogging pockets in Kolkata in sixteen boroughs of the municipal corporation. Out of the 144 municipal wards in the city, 101 wards have waterlogging pockets.[29] The river strand with higher density of buildings [also in many ways serving as the Central Business District (CBD)], is prone to flash floods and waterlogging.

1.2. Flood Management in the City

A number of ponds, and waterbodies have disappeared in the east and south Kolkata, along with the shrinkage of canals and tidal inlets into dry, narrow channels, as a result of recent phases of metro railway extension project. Waterbodies and tidal channels in the southern and eastern part of the city play an ecological role in sustaining drainage and balancing homeostasis as part of a larger network of the EKW. The EKW was included in the Ramsar list of 'Wetlands of International Importance', on August 19, 2002.[30] Located adjacent to the Dhapa waste disposal ground, the EKW in the eastern fringe of Kolkata is not only a productive ecosystem, but also serves functions such as water purification, aquifer recharge, flood mitigation and microclimate regulation, to mention a few. These wetlands interweave a number of facilities for urban ecological services, thereby making sustainable ecological protection and management practices for conservation of the wetlands vital with the

involvement of local communities.[31] Encroachment into the wetland fringes affects this multifunctional niche, and makes it essential for environmental education institutes, departments of urban local bodies as well as residents and stakeholders in the city to plan initiatives and awareness programmes for dissemination of information regarding the ecological role played by the wetlands in Kolkata.

The intercepting canals in the fringes of the East Kolkata Wetlands remain clogged, especially with the metro rail track extension project in progress – with this, blockage of canal discharge and encroachment of drainage channels remain a common problem. The blocked paths of drainage channels ensue heightened risks of flash floods in the city. The localities near the East Kolkata Wetlands in the eastern part of the city are affected by real estate and transport development and have recorded disappearance of several waterbodies. Lack of dredging of canals before monsoon looms large with threat of flash floods during incessant rains, making the eastern stretch of Kolkata particularly vulnerable.

Floods in large parts of South Kolkata and localities adjacent to the Eastern Metropolitan Bypass (road) that flanks the eastern fringe of the Kolkata Municipal Corporation are connected to outfall canals for flushing out rainwater from the city.[32] Among the common problems are the intercepting canals in the fringes of EKW remaining clogged (especially with the metro rail track extension and construction work in progress), consequent blocking of canal discharge and encroachment of drainage channels. Field observation show that since December 2022, there have been phased (quarterly) dredging and cleaning of the intercepting canals in East and North-East Kolkata, such as the Kestopur canal in March and June 2023. Despite the cleaning drive, the canals had been flowing to the brim, with rising water level during heavy monsoon rainfall between July to September 2023, with remnants of the South-West Monsoon wreaking havoc in Kolkata even in the first week of October 2023.[33] Plastic pollution and non-biodegradable waste too clog parts of canals and add to the risk of overflowing sewage channels aggravating the possibilities of flash floods.[34]

Convectional currents heating up ambient air and the subsequent untimely thundershowers, intermittent torrential rain and flash floods in the city, can be managed to an extent with rejuvenation of water bodies acting as sponge for excess flood water retention. It is critical that urban forestry and waterway restoration with the inclusion of dependent, local stakeholders are taken up, alongside planning of investments and environmental and social impact assessments for infrastructure, real-estate and commercial projects.

1.3. Migration and Displacement due to Climate Disasters

Pummelling cyclones leave behind ravaged islands in Sundarbans while people struggle to rebuild homes from wreckages. There is pollution of water due to salt water (left behind by storm surges within the enclosures of embankments). Slow and sudden onset of climate stress causes socio-economic vulnerability, and push people to migrate from one island to another. Some of the islands have reduced in size due to erosion like Ghoramara Island, resulting into displacement of thousands to the nearby Sagar Island; and islands such as Lohachara, Suparibhanga, Bedford, have been submerged in the sea. Compaction of soil and deltaic subsidence add to the vulnerability due to a rise in sea level of about 3 mm to 8 mm every year;[35] this ecologically fragile zone has been transformed into a hotspot of displacement, owing to its natural environment.

In Sundarbans, the storm water breaks through embankments built around islands during cyclones and fill paddy fields with sea water; land turns saline and affects subsistence agriculture. After Cyclone Aila struck in 2009, land was left uncultivable for three to four years and inhabitants

were forced to migrate out of Sundarbans[36] in search of work, leaving families behind with lean sources of remittances; but in case of Amphan in 2020, at a time when people were already struggling to survive through the medical crisis of the Covid19 pandemic, Sundarbans witnessed an influx of return migrants.[37] News dailies[38] reported the aids and reliefs of the central and state governments but the complexity in this situation lies in the fact that short-term relief barely helps to reverse the long-term changes in environment and difficulties of adaptation that cyclones leave behind in the fragile ecosystem of the delta (due to its geomorphological characteristics and socio-economic attributes).

The escalating impacts of frequent storms and cyclones induce a domino-effect. Ravaged by cyclones, people with no means of livelihood, often migrate from the peri-urban areas lacking in infrastructure and amenities to recover from disasters. There may be seasonal migration to the neighbouring districts or to the metropolitan region of Kolkata, due to accessibility; or else long-term migration to cities in distant states like Kerala, Karnataka, Tamil Nadu, Gujarat, Maharashtra in hopes of finding opportunities of income generation.[39] However, they struggle to find affordable housing facilities and end up in slums or dwell in shanties, pavements, or are often tagged as encroachers of public or open spaces. Although it is difficult to identify climate migrants among slum dwellers—the slums still remain the most prone areas to city floods.

Ecosystem-based adaptation strategies are effective while working on climate action plans. Kolkata receives the protection of the Sundarbans mangrove delta as an estuarine ecosystem, that intercept storms and cyclones during landfall, due to its location across the trajectory of storms and cyclones crossing over from the Bay of Bengal towards Bangladesh, and further east and north-east. Sundarbans, the largest continuous mangrove forest and delta straddling the international boundary shared by both India and Bangladesh, is also a United Nations Educational, Scientific and Cultural Organisation (UNESCO) world heritage site (since 1987) and a Ramsar site (since 2019). It is evident from a number of studies that mangroves act as bio-shield for coastal population and other resources, and are potential protectors from coastal disasters, depending on the density of forest, diameter of stem and roots, forest floor, characteristics of the incident waves, and the tidal stage at which the wave enters the forest.[40] Compared to the mangrove coverage assessment in India State Forest Report of 2017, mangrove cover in West Bengal had reduced slightly from 2017 to 2019, but increased in 2021.[41] The Sundarbans has recently witnessed a two sq. km. change (increase) of mangrove coverage, from 2,112 sq. km to 2,114 sq. km. area from 2019 to 2021 respectively (Table 2).[42] Increasing mangrove forest cover would further facilitate protection from floods; this calls for bringing larger land area under afforestation schemes for mangroves.

Table 2: Mangrove Cover Assessment 2019 & 2021 (in sq.km.)

State	Year	Very Dense	Moderately Dense	Open Forest	Total	Change (with respect to 2019 Report)
West Bengal	2019	996	692	424	2112	-
	2021	994	692	428	2114	2
Maharashtra	2019	0	88	232	320	-
	2021	0	90	234	324	4

Data Source: Government of India, "India State of Forest Report 2021," *Ministry of Environment, Forest and Climate Change,* January 20, 2022, https://static.pib.gov.in/WriteReadData/specificdocs/documents/2022/jan/doc20221207001.pdf; Government of India, *India State of Forest Report 2019* (Dehradun: Forest Survey of India, 2019), 55, https://static.pib.gov.in/WriteReadData/userfiles/ISFR2019%20Vol-I.pdf.

1.4. Scope of Disaster Risk Management

Disaster risk management holds is important in the purview of urban development. Kolkata has been the first in India to be planned with underground sewer system at the city scale back in 1863, at that time covering about 19 sq.km. Much of the city's infrastructure today has exceeded the carrying capacity of the drainage channels with a large informal population size living without access to basic amenities, and more than a third of the total population of the city residing in slums.[43] The mosaic of informal economy and informal use of land amplifies risk for population in the event of climate disaster, specifically in low-lying areas of the city. Slums aggravate vulnerability combined with weak adaptation and lack of means of recovery; emergency exits and access to rescue operations are hindered by narrow lanes in slum settlements, with a large distance to water points and gaps in use of land and economic productivity.[44] Around 1.4 million slum dwellers are at risk, and may face the impacts of flood in the city.[45] Rapid transitions in economic structure and infrastructural projects in Kolkata also require placing the transitions of 'risk governance' as one of the focal points in urban development and protection from climate change.

Kolkata has scope for enabling local community-based risk management and individual responsibility for resilience building, while integration, information exchange, coordination and joint effort of departments for housing, water and environment planning and management are equally important; in addition to bridging the gaps between administration and people, in terms of participatory management. Surveys reveal that local residents identify the significance of conservation of water bodies and green spaces as part of disaster risk management.[46] City dwellers also opine that the city does not exhibit a wide scope for investment from international organisations and private businesses for climate disaster mitigation and risk management.[47] The role of civil society groups and community-based organisations in raising social and ecological issues has also not taken up the front stage. Thus, residents in many cases are not aware of the risks and lack of resilience they are faced with. Accessibility to information plays foremost role in supporting local resilience building, and explaining the needs and requirements in policy frameworks.

Vulnerability mapping (in 2020) by the Building Materials and Technology Promotion Council (BMTPC) of the Ministry of Housing and Urban Affairs, Government of India, indicates that Kolkata and surrounding districts may be categorised in the 'Very High Damage Risk Zone' due to wind and cyclone (in addition to earthquakes), susceptible to being hit by wind speed of 180 kmph and above.[48] The Kolkata Municipal Corporation (KMC) in its action plan for the mitigation of flood, cyclone and waterlogging (2021) outlines the necessary implementation measures such as prevention, mitigation or risk reduction, capacity building, preparedness to deal with disasters, prompt response, assessment of severity or magnitude of effects of disaster, evacuation, rescue, relief, rehabilitation and reconstruction.[49]

One shortfall in case of Kolkata comes from the lack of coordination and collaboration with joint management and vested interests between city stakeholders. The distance between policy makers and those on the ground bearing the consequences of policies and worst hit by climate disasters, has been growing in the absence of evidence-based planning. The opportunities and

advancements in adaptation pathways and effective governance for disaster risk reduction as part of projects and schemes like Smart Cities, Atal Mission for Rejuvenation and Urban Transformation (AMRUT) in the context of city transition, call for further analysis and adds to the scope of the research.

Manual cleaning and de-clogging of the non-Irrigation and Waterways Department (I&WD) canals and monitoring to ensure that waste materials are not dumped into drains, canals or waterbodies, including inventory details, has been expedited in Kolkata this year, through the activities of West Bengal Disaster Management and Civil Defence Department, and Urban Development and Municipal Affairs Department of the Government of West Bengal.[50] The Kolkata Municipal Corporation (KMC) is focused on the development of flood mitigation plan including renovation of drainage system, prevention of waterlogging, dredging of outfall canals, restoration of ponds, lakes and waterbodies, installation of rain-gauge meters at drainage pumping stations calibrated to operate in synchronisation with flood monitoring control room located at the KMC headquarters. Construction of drainage pumping station and lock-gate at the confluence of river Hugli and Tolly Nalah in Khidderpore area has been projected with the possibility of saving people residing in 31 wards of the municipal corporation sprawling across the western part of the city, along the river front.[51]

Awareness generation is at times limited to school curriculum, and demands extension to higher levels of education and research. Researchers have drawn attention to the approaches that disaster management plans in Kolkata may take up–preserving current environmental status by checking and controlling further degradation that trigger hazards,[52] and planning for Kolkata keeping in mind the damages that may come about to natural ecosystems. Further research on the role of social capital, and implementation of strict rules (especially in case of slums) would help to strengthen protection mechanism for disaster management. The Disaster Management wing of the Kolkata Municipal Corporation has planned the engagement of trained personnels with knowledge of the city and could help with relief and restoration work.[53] Despite initiatives Kolkata is witnessing fragmented development in terms of informal settlements that enhances vulnerability, and the task of reducing disaster risks caused by extreme climate events give rise to demands of effective plans for disaster risk reduction. Mumbai comparatively remains at a more advantageous position than Kolkata, in terms of fostering social cohesion[54] by advancing and depending on the networks of community-based organisations and community participation.

Section 2: The Case of Mumbai

Urban floods cause damages to life and property and result into diseases and disturbances. The havocs and massive disruptions bring life to a standstill for prolonged phases till rescue and recovery operations are effective. The location of a city in relation to its natural surroundings, physical configuration of land and city morphology plays important role in the approaches of urban planning and disaster management. While the expansion of built-up space in a city encroaches upon natural land cover, the challenges arise in formulation of development policies, delineation of hazard prone zones, hazard adaptive measures for mitigation[55] and infrastructure projects that are inclusive of sustainability and conservation, there is need to draw attention to the phased development of climate resilient cities.

2.1. Location and Climate Disaster Vulnerability

The city of Mumbai is prone to flooding due to the low-lying topography along the Arabian Sea coast, accompanied by high tides and heavy rain. The Intergovernmental Panel on Climate Change (IPCC), Sixth Assessment Report in 2022,[56] warns of the dangers of imminent sea-level rise in Mumbai. Rainfall above 240 mm is a normal occurrence in Mumbai at the onset of monsoon, however, the rains doubled with the development of low-pressure belts over the sea, trigger high tides, that in turn draw-in prolonged rain shower. History of the city's planning points out that the waterways were meant for draining out excess accumulated rain water, but have now been replaced by construction of houses and growth of industries, with the seven islands reclaimed to accommodate the increasing population instead. The slums and other constructions that have developed on reclaimed land and the complex terrain made up of creeks, channels, rivers, drains, ponds, encroach upon the storm water drains, and in turn affect natural drainage in the city.[57]

Studies on the drainage system of Mumbai and the measures taken by the city to mitigate future floods, bring to light the impacts of floods on public transport in the city. A large size of the city population resides in the suburbs in the north and commute to the CBD located in the south. The rail network constitutes the lifeline of the city and more than 6 million people are transported daily in Mumbai's suburban railways alone – close to 50% of the total number of passengers travelling daily by train in India.[58] This reflects the large number of people at risk during floods, who commute to various parts of the city. Thus, any disruption due to flooding results in economic and social disruptions also, leading to livelihood losses for individuals and loss of business to commerce and industry. Research shows that improvement of storm water drains would minimise water logging, especially in case of rivers Dahisar, Poisar and Mithi.[59] It is essential to stress on the sources of flooding in the municipal area and layout of urban environment, role played by structural and non-structural measures and land-use zonation in case of Mumbai.[60]

The IPCC Sixth Assessment Report (2022) projects coastal zone regulation as an effective adaptation option in Mumbai. However, it is obligatory to also assess that infrastructural interventions are not maladaptive over a long period of time. For instance, the Mumbai Coastal Road (MCR) project which was initially aimed at reducing flood risk and protecting against sea level rise may possibly damage intertidal fauna and flora, further affecting fishing livelihoods.[61]

Flood risk depends upon the variety of sources of flooding and layout of civic infrastructure within urban morphology; thereby, source control measures should be prioritised instead of transferring flood to downstream reaches. Urban flood mitigation and management strategies in Mumbai take into consideration[62] the following:

a) land-use planning for urban areas,
b) drainage network management,
c) solid waste collection and disposal system,
d)building design and materials, including non-structural measures (legislation, financing, environmental impact assessments, reconstruction, rehabilitation, etc.).

Structural measures on the other hand entail—improvement and maintenance of drainage efficiency, use of bulk water-resistant material in construction of buildings, channelising pathways for water infiltration, restoration of urban wetlands and other natural water storage sites, promotion of structures for rainwater harvesting.[63]

One major cause of severe flood in Mumbai during intense rainfall is the tide cycle. Water usually recedes during low tide, but if rainfall persists for seven to ten hours and the next high tide sets-in, then it becomes difficult for the excess rainwater to recede and drain out and compounds the

flooding. Most detention ponds have been lost to urban development and it is estimated that urbanisation has contributed to increased surface runoff by two-three times.[64] The monsoon and seasonal shift of winds that bring pouring rains to Mumbai, adds uncertainty to projecting how much flooding will accompany the gradual sea rise for climate threats to the city.

2.2. Areas Prone to Flooding

One major reason of flooding in Mumbai may be attributed to the history of engineering when the British had laid the foundation of the city in 1661, connecting a collection of coastal islands, metamorphosed into a contiguous landmass by filling in land gaps to connect the islands, even in the wet season.[65]

Squatters in Mumbai are vulnerable to sudden climate events due to their location in low-lying areas. Therefore, drainage network management in coastal zone is important for prevention of disaster.[66] A large proportion of the squatter population are migrants and others are often evicted from their land for resource accession. The newer communities dislodged from their location often relocate in the low-lying area squatters of the city, adding to their vulnerability.

Changes in landcover in Kalyan-Dombivli region, has given rise to the risk of water stagnation during tidal surges. Flood risk mapping in Kalyan-Dombivli region, in addition to the analysis of water regime in the Mithi river, sewers, land-use and land cover changes are crucial for reducing disaster risk.[67]

Mumbai is prone to flooding during Monsoon season, especially the municipal neighbourhoods of Mumbai that have higher density of slums and squatter settlements.[68] Field-based study reveals that Mira Road (in the northern suburbs), Vikhroli and Mulund-Thane (in east and north-east respectively), Andheri-Jogeshwari-Milan, Kalina and Bandra-Kurla Complex, the slums of Asalpha and Ghatkopar, Dharavi, the localities near Dadar market and rail station (in south-central Mumbai), and Sion, Chembur (in the south-eastern suburbs), are areas that face waterlogging for a day or two during prolonged periods of monsoon rain.[69] In monsoon, many a times sewage contaminated effluent gurgles out of the city's obsolete and often-clogged drainage system, and backs up into rivers and creeks, then gradually overflows into homes, shops and buildings.[70]

Squatter communities and slum dwellers in Mumbai are threatened by larger magnitude of flooding owing to a large bulk of debris and refuse obstructing storm sewers, in addition to heavy monsoon triggering landslides. Lakhani and Andharia (2020) evaluate in their study that selected municipal wards in Mumbai that have 70% and above of slum population, such as Khar Danda in H West ward, Sathe Nagar (upper and lower) in M/E ward, are more susceptible to disasters owing to 'proximity to sea coast' and 'low-lying area' respectively;[71] the topographical characteristics, lack of amenities, and dense clustering of population in these areas serve as 'risk enhancers' for climate-induced disasters.

2.3. Community Participation in Disaster Management

The Brihanmumbai Municipal Corporation (BMC) is the first to prepare a climate action plan for an Indian city. The Mumbai Climate Action Plan (MCAP) 2022 aims at intensifying focus of the municipal corporation on tackling climate change and increasing climate resilience. The climate action plan identifies urban flooding, coastal risks, urban heat, landslides, and air pollution as the major vulnerabilities faced by Mumbai.[72] Mobilisation of resources and strategic projects are also cited as central objectives of the action plan. It lays emphasis on the institutional mechanism of a

'Climate Cell' to coordinate the implementation and monitoring of activities related to climate change.

Mumbai has always worked with community involvement as one of its mechanisms to recover from disaster damages. Community based disaster management gives focus on identification, assessment, evaluation and management of disaster risks at local level, with special focus on vulnerable communities. During the 2005 Maharashtra floods that majorly impacted the state capital, health camps were set-up in flood-affected areas of Mumbai. Hospitals in different parts of the municipal corporation area of Mumbai worked on their plan of actions for relief and treatment of flood-related diseases. Teams of doctors, public health department and community participation, in the flood affected municipal wards came together while working on information, education, communication, and flood related diseases.[73]

The community-based organisations (CBOs) act as an intermediary link between government and civil society organisations and facilitate social capital among flood affected communities of Mumbai. During floods, Mumbai experience continuous functioning of social capital through the networks that CBOs routinely maintain. The substitutability of social capital is seen when CBOs lacking financial resources utilise networks for acquiring relief for the affected families. The appropriability of social capital was seen in the form of extension of CBO services in disasters; information and response during disasters are defined by pre-disaster preparedness.[74] Field study sheds light on the essence of teamwork and cooperation among disaster affected persons and community-based organisations in Mumbai and relief aids as the main reason for successful functioning of disaster mitigation system during and after disasters.

The work of Bombay Environmental Action Group (BEAG) on recommendations for coastal zone management and conservation of greenery to protect sea shores and reclaimed land, draws attention to the efforts of development and port authorities in Maharashtra,[75] and paves the path to inquire the role of coastal conservation in combating climate hazards. The article 'Beyond the Margins of Land and Water',[76] harps at the significance of wetland conservation and urban flooding and water resource management in supporting the natural protection mechanism against climate disasters such as cyclones.

2.4. Role of Ecological Conservation in Environmental Protection

The waters off Worli along the western coast of Mumbai, present an interesting contrast of murky water providing good catch of marine fishes while the clear, blue waters inhibit fish catch[77]—this further entails the scope of studying urban planning in the coastal environment, keeping in mind the complex spheres created by land reclamation, built-up environment, plastic pollution and adaptability of livelihood to the changing climate regimes in different seasons of a year; reforms in urban renewal and sustenance of civic amenities in both slums and neighbourhoods with high-rises and multi-storied housing societies also play significant role. The mangrove cover along the coast at Bandra surrounding the Mahim Bay holds the coastal soil in place, thereby, helping in prevention of coastal erosion and also plays a significant role in acting as a barrier during high tides and storm surges from overflowing into the nearby densely populated residential localities. As the coastal city of Mumbai grows sea-ward, there is growing dependence on the marine waters and this comes at the cost of deteriorating implications on the local climate regime.

Table 3: Area (Sq. Km.) of Mangrove Forest Density in Maharashtra, 2009

District	Very Dense	Moderately Dense	Open Forest	Total
Thane	23.09	19.93	8.74	51.76
Mumbai Suburban	30.03	20.91	6.08	57.01

Data Source: Government of India, *Monitoring the Health of Mangroves of Maharashtra State Using Near Real Time Satellite Remote Sensing Data,* Annual Report (Thiruvananthapuram: Indian Institute of Space Science and Technology, 2019), https://mangroves.maharashtra.gov.in/Site/SiteInfo/Pdf/IIST.pdf.

The Thane creek is home to migratory birds and marine species—the nature and biodiversity study centre hosting the flamingo sanctuary in Thane is the city's refuge to natural landcover. The Bhandup pumping station in the Godrej mangrove area along the Thane creek exemplifies how the mangrove forested creeks act as the green filters in the city, to not only absorb pollution but also provide support to the filtration and natural drainage network of the city. This creek with dense mangrove forest lining on both banks is used for releasing treated sewage for waste management, and calls for protection of greenery in the city, amidst the imminent threats of growing sky-scrappers, land conversion, and encroachment in its vicinity.

Table 4: Area (Sq. Km.) of Mangrove Forest Density in Maharashtra, 2014

District	Very Dense	Moderately Dense	Open Forest	Total
Thane	29.15	15.2	6.84	51.19
Mumbai Suburban	36.67	17.93	5.58	60.18

Data Source: Government of India, *Monitoring the Health of Mangroves of Maharashtra State Using Near Real Time Satellite Remote Sensing Data,* Annual Report (Thiruvananthapuram: Indian Institute of Space Science and Technology, 2019), https://mangroves.maharashtra.gov.in/Site/SiteInfo/Pdf/IIST.pdf.

Table 5: Area (Sq. Km.) of Mangrove Forest Density in Maharashtra, 2017

District	Very Dense	Moderately Dense	Open Forest	Total
Thane	24.46	19.36	11.64	55.46
Mumbai Suburban	37.63	16.84	9.86	64.33

Data Source: Government of India, *Monitoring the Health of Mangroves of Maharashtra State Using Near Real Time Satellite Remote Sensing Data,* Annual Report (Thiruvananthapuram: Indian Institute of Space Science and Technology, 2019), https://mangroves.maharashtra.gov.in/Site/SiteInfo/Pdf/IIST.pdf.

Mangrove coverage assessment shows that there has been slight increase in the areal cover of very dense mangrove in Mumbai from 2009 to 2017; whereas moderately dense mangrove cover has increased in Thane from 2014 to 2017 (Tables 3-5). Mangroves act as buffer against cyclones and storm surges, and also act as a major reserve for carbon sequestration, thereby, protecting their dense cover is essential. Open mangrove cover has slightly increased owing to plantations during afforestation schemes,[78] and strategies for mangrove management—promotion, participatory and regulatory,[79] though very dense mangrove cover has declined slightly from 2019 to 2021 (Table 2). It is indispensable to develop awareness among people living in neighbourhoods along the mangrove stretches to preserve the trees to keep the carbon emission levels low. Replication of such mangrove management strategies is also required for regeneration and planned activities with plantation.

The Mumbai experience makes an insightful case for other metropolitan cities, to work with panned response strategies in coping with similar disasters in future. Investment in ecosystem protection and conservation are effective ways towards reducing underlying risk factors that may trigger disasters. According to tide gauge data, Mumbai's coastal water level has increased at least nine centimetres during the twentieth century, and today, seawater regularly spills over the promenade of the Marine Drive in the southern part of Mumbai during high tide.[80] Preparation of maps and flood zonation plans demarcating the areas prone to flooding and making them publicly available is one of the requisites of flood management, along with restoration of coastal land with mangrove trees.

Concluding Observations

Resilience in terms of climate change and disaster risk bring with it instances of individuals, households, communities, economic sectors and city economies. In the context of climate change and cities, resilience generally encapsulates the capacity of a city to absorb climate change-related disturbances or shocks, while depending upon and utilising its structure and functional morphology, in such a way that the settlement is able to resist and recover from the shocks of climatic disruptions, and is also able to reduce damages that may occur in future.[81] Inter-relating risk and vulnerability with resilience may help pave the path for socio-economic policy decisions and infrastructural planning, including quality of housing, amenities like piped water, sewer networks, and roads; keeping under consideration the health effects or diseases caused by floods and the benefits that public spaces and conservation of waterbodies in cities provide in flood management. Relationship of citizens with city resilience is an important aspect that integrates citizens' role in promoting innovations and investments for disaster risk reductions. Monitoring, tools for reporting and strategising action plans are efficient ways of working with priorities for disaster risk reduction and strengthening infrastructure, as the 'Making Cities Resilient' campaign of the United Nations Office for Disaster Risk Reduction (UNDDR) indicates (with the objective of hastening the enactment of the Sendai Framework for Disaster Risk Reduction [2015-2030] at local level).[82]

Inclusive, consultative and collaborative programmes that focus on goals, targets, indicators and measurements of the progress for disaster risk reduction and resilience are required in today's context of growing deviations of climatic patterns. Development of economy and visualisation of the fundamental principles of sustainable development are vital for the recognition of issues that

contribute to the challenges faced due to climate disasters along with focused action for building resilience and reducing levels of risk. City's resilience can also be assessed on the degree of risk of vulnerable groups who are worst affected by climate disasters and have least capacity to recover or dearth of coping mechanism. Interaction of components in the disaster mitigation systems may be expected to act as 'accumulated resilience'[83] in terms of adaptations to climate change events.

River catchment and estuarine zone management, and sustainable solutions for urban drainage become relevant in case of Kolkata. The struggles with economic growth, decarbonisation, environmental protection and health infrastructure bring in more complicated challenges. Slums and squatters in Kolkata are more vulnerable to the effects of climate disasters because they have dearth of adequate infrastructure required for reduction of the magnitude of damage posed by climate hazards. Crowded residential areas with higher density of population raise vulnerability for a larger population size in the city.[84] Kolkata, similar to many other megacities of India, has a long way to go in the adoption of alternative sources of energy and strengthening green energy use. One essential requirement is analysis of cost incurrences and impacts of basic services in cities (like housing, transport, infrastructure), on the urban life, planning for green space management, and vegetation conservation within the city, in addition to demands of investments and blue prints.[85] Capacity-building and preparedness measures are drawn-up by the departments of KMC and government agencies—the action plans in the different stages pre-waterlogging and post-waterlogging are important.[86] The Kolkata Environmental Improvement Investment Programme (KEIIP) with the financial assistance of the Asian Development Bank (ADB) together with the Government of India and Government of West Bengal, took up renovation, upgradation and construction of new drainage and sewerage pumping station (underway) in the core area of the city,[87] with the objective of reduction of waterlogging and improvement of environmental condition.

Urban growth, pollution of air and water, groundwater extraction, ineffective waste management, deteriorating wetland, unusual climate events, may be listed as some of the major factors that induce higher vulnerability to disasters in Kolkata.[88] Effective disaster mitigation information system in Kolkata functions in conjunction with quick-response teams at waterlogging areas, temporary pumping systems along with pumping stations, in addition to communication between various departments of the Kolkata Municipal Corporation, West Bengal Disaster Management and Civil Defence Department, and the regional IMD office (in Kolkata). A 'Kolkata Dialogue' by the C20 India 2023 Working Group on 'Climate Change, Health and Disasters' organised in May 2023, with the objective of working on sustainable and resilient communities and climate, environment and net zero targets, deliberated on themes, such as preparation for health impacts of climate change and disaster risk resilience in times of climate change. Such dialogues aim at creating platform for bringing together experiences from multiple backgrounds that can support the development of policy recommendations for persistent climate challenges.[89] The Kolkata Municipal Corporation has begun work on Kolkata's Climate Action Plan (KCAP) since June 2023, in collaboration with experts, environmental organisations and climate action networks, research institutes and industrial forums, with focus on securing plan for climate impacts (cyclones and intense rainfall), along with sustainable development measures for waste management, biodiversity, flooding, water conservation, energy efficiency, air quality, reduced emission levels, sustainable mobility.[90]

Coastal reclamation in Mumbai, with dearth of concern for fragile ecosystem along the shoreline and the livelihoods of artisanal fishermen are major challenges in terms of disaster risk governance and reinforcing resilience in case of Mumbai.[91] The 'Mumbai Climate Action Plan 2022' indicates that Ward M East (M/E) stretching across the neighbourhoods of Deonar, Govandi, are

characterised by low-lying topography, and ranks among the lowest in terms of socio-economic conditions, infrastructure and access to amenities. This part of the city with high number of informal workers and migrant dwellings, is also hit by urban heat island effect (as a result of compact clumping of built-up structures) and has high vulnerability to flooding.[92] It shows that the assessment of intensity of climate risks and disaster vulnerability for different sections of population, residential and commercial clusters in Mumbai requires planned urban development keeping in sync with the terrain attributes and accessibility to resources.

In addition to atmospheric factors that influence and control microclimates, the growth of urban structures and dense population concentration in hazard-prone locations are also important drivers of damages during disasters. Approaches for determining, controlling and reducing the impacts of ecological issues in Mumbai focus on technology and alternatives to the reduction of fuel use, restoration of local streams, and waterbodies, and landscaping open and green spaces.[93] Such factors necessitate in-depth analysis of cost and benefit of building technologies, the use of building materials and building location—also requisites for low-lying coastal stretches that are susceptible to inundation and flooding. Commissioning plans for raised bases for construction, access to waste collection (to prevent pollution and littering of sewers or open ground), and emergency health services to reduce the scale of damage caused by sudden, extreme climate events, are indispensable. Specifications and provisions in the sectors enlisted below may help with more efficient management of climate disasters, in case of Kolkata and Mumbai.

- Slum pockets housing the urban poor are the most vulnerable to climate disasters due to the lack of infrastructure, access to rescue, recovery, sanitary facilities and healthcare provisions and protective support mechanism (physical, social and economic) for resettlement and rehabilitation.
- In the aftermath of climate disasters, many a times people dwelling in slums are ousted or displaced from their habitat. Therefore, workshops in slums would play significant role for increasing awareness on disaster mitigation during rescue and recovery stages and in phases of preparedness through drills.
- Emphasis on budget allocation is decisive for further strengthening social capital in Mumbai and Kolkata with the purpose of modelling disaster resilient coastal megacities.
- Construction of safe shelters in areas vulnerable to floods following forecasts of heavy rainfall or severe storms.

The precondition in capacity-building comes as the practice of including community-based knowledge and understanding of the urban issues faced by local stakeholders. Climate data monitoring, data sharing, and disseminating climate-related experiences through institutional support is decisive for capacity-building of stakeholders.

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