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Research Note

Urban Flooding: Status of Sediment Management Strategies in Tropical Regions

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Abstract: *Urban flooding is a recurrent issue in Indian cities, exacerbated during the monsoon seasons. The recent impact of cyclone Michaung in Chennai, which led to approximately 400 mm of rainfall in two days, acts reminiscent of the 2015 floods, which killed more than 300 people. The influx of people from rural areas, unplanned urbanisation, and encroachment on water bodies contribute to the widespread destruction of the water drainage systems. Surprisingly, conventional urban planning often overlooks sediment transport and management. The continuous, unregulated development of natural resources persists in 2023. Moreover, the specific characteristics of tropical regions, especially in the Indian Ocean area, significantly influence the effectiveness of urban planning and sediment management. This research note emphasises the need for localised plans in the Indian Ocean tropics to address urban flooding, considering unique socio-economic conditions. It underscores the importance of sediment management in urban planning and advocates for an integrated approach to enhance management strategies.*

Keywords: Urban Flooding, Chennai Floods, Sediment Management, Urban Planning, Tropical Waters, Urbanization, Unplanned Development, Encroachment, Floodplains, Sediment Transport, Drainage Systems, Stormwater, Sediments, Silt, Soil Erosion, Dams, Water Storage, Floods, Climate Change, Smart Cities, Early Warning Systems, Spatial Planning, Integrated Urban Management.

Chennai Floods

On December 4, 2023, Cyclone Michaung hit Chennai, a city in southern India with a population of 8.6 million, causing significant devastation. The cyclone resulted in at least 20 casualties, leaving tens of thousands of residents stranded[1]. Over two days, from the 24 hours ending at 8:30 am on December 4 to the same time on December 5, Chennai district experienced nearly 400 mm of average rainfall, as reported by TNSDMA[2]. This event has prompted discussions on mitigating the impact of flash floods in the future.

The recent floods triggered by Cyclone Michaung revived distressing memories of the December 2015 floods. Those floods, caused by a mix of severe weather and mismanagement of the city's reservoirs, resulted in the deaths of over 200 people and displaced more than 1.8 million individuals[3]. The estimated damages and losses ranged from nearly ₹200 billion to over ₹1 trillion, making the 2015 floods one of that year's most expensive natural disasters[4]. Experts note that cyclone-induced flooding submerged significant parts of the city in 1943, 1978, and 2002.

Based on previous flooding incidents in Chennai, it's widely accepted that the city experiences flooding due to a combination of factors, including its coastal location, flat terrain, extensive urban development on water bodies, and the impact of climate change on weather patterns. Urban flooding has become a recurring issue in major Indian cities, with increased instances observed since the Mumbai mega-disaster 2005. Other South Asian cities like Dhaka, Islamabad, and Rawalpindi also face frequent flooding[5]. This study examines the challenges and vulnerabilities in the planning system that contribute to urban flooding, focusing on sediment management perspectives.

Urban Flooding

[1] Chennai Floods: What is the way forward for a developing Chennai vulnerable to flooding? Retrieved From: https://www.hindustantimes.com/india-news/chennai-floods-what-is-the-way-forward-for-a-developing-chennai-vulnerable-to-flooding-101702468906228.html
[2] Making sense of the 2023 Chennai floods: A comparison with 2020, 2021 and 2015. Retrieved From: https://www.thehindu.com/data/making-sense-of-the-2023-chennai-floods-a-comparison-with-2020-2021-and-2015-data/article67624274.ece
[3] Chennai Floods: What is the way forward for a developing Chennai vulnerable to flooding? Retrieved From: https://www.hindustantimes.com/india-news/chennai-floods-what-is-the-way-forward-for-a-developing-chennai-vulnerable-to-flooding-101702468906228.html
[4] 2015 South India floods. Retrieved From: https://en.wikipedia.org/wiki/2015_South_India_floods
[5] Gupta, A. K., & Nair, S. S. (2010). Flood risk and context of land-uses: Chennai city case. *Journal of Geography and Regional Planning*, *3*(12), 365.

Urban flooding is not a novel occurrence, as evidenced by historical instances such as the ancient civilisations of Harappa and Mohenjo-Daro, celebrated for their urban planning, being wiped out by flooding and climate change, as affirmed by recent research[6]. Flooding, characterised by the overflow of water beyond the usual boundaries of a stream or body of water or the accumulation of water in non-submerged areas due to drainage, signifies the aftermath of intense rainfall, river overtopping, or storm surges. Urban flooding occurs when urban landscapes cannot absorb excessive water following prolonged periods of heavy rain.[7]

The National Disaster Management Authority (NDMA) states that urban flooding differs significantly from rural flooding due to the impact of urbanisation on catchments. Developed catchments result in a surge in flood peaks, ranging from 1.8 to 8 times, and increase flood volumes up to 6 times. This leads to rapid flooding, characterised by faster flow times. During the rainy season, rivers naturally overflow from their minor beds to occupy floodplains. Over time, irregular occurrences of this phenomenon prompt settlements in floodplains, making the population susceptible to flooding.[8]

Flood hazards can arise from factors like heavy rainfall, dam failures, tides, or cyclonic surges. The growing frequency and severity of flooding are attributed to soil impermeabilisation and the construction of storm drain systems. Urban development introduces obstacles to runoff, such as sanitary landfills, bridges, inadequate drainage, and clogs. As cities expand, there is an increase in peak flows and frequency due to enhanced runoff capacity through conduits and canals, along with surface impermeabilisation. This development also increases sediment production from unprotected surfaces and solid waste generation.[9]

Prominent Indian cities such as Kolkata, Chennai, Surat, Bangalore, and Hyderabad have experienced recurring flooding in recent decades. The threat of urban flooding in these cities is expected to intensify due to the ongoing global climate change and the escalating pace of urbanisation in the country. Many flood-prone Indian cities also grapple with water scarcity during dry seasons, highlighting a significant paradox in the current urban water management

[6] Report on Urban Flood Management: Drainage and Planning. Retrieved From: https://cwp-india.org/wp-content/uploads/2021/05/REPORT-ON-URBAN-FLOOD-MANAGEMENT-DRAINAGE-AND-PLANNING.pdf
[7] Report on Urban Flood Management: Drainage and Planning. Retrieved From: https://cwp-india.org/wp-content/uploads/2021/05/REPORT-ON-URBAN-FLOOD-MANAGEMENT-DRAINAGE-AND-PLANNING.pdf
[8] Urban Floods. Retrieved From: https://ndma.gov.in/Natural-Hazards/Urban-Floods
[9] Urban Flood Management. Retrieved From: https://www.floodmanagement.info/floodmanagement/wp-content/uploads/2020/06/Cap-Net-WMO-Urban-Flood-Management.pdf

approach. There is a pressing need to enhance traditional engineering methods in urban management systems to address local demands effectively.[10]

Unique Tropical Conditions

The distinctive characteristics of tropical regions, particularly in the Indian Ocean area, play a crucial role in shaping the execution and success of urban planning and sediment management strategies. Therefore, it is essential to closely examine these unique features to fully grasp the consequences and devise comprehensive plans to address urban flooding.

Climatic Conditions:

The primary rainy season in India occurs during the southwest monsoon from June to September, contributing to 70-75% of the annual rainfall. Urban flooding in India is primarily a result of intense rain during this season. Within the monsoon system, additional synoptic systems like vortices (low-pressure areas, depressions, and cyclones), troughs, and east-west wind shear zones in the lower troposphere significantly amplify the monsoon rainfall[11]. Following the retreat of the southwest monsoon, the northeast monsoon begins around mid-October, bringing substantial rain to the southern parts of peninsular India. During this northeast monsoon period, heavy rainfall is frequent in these areas.[12]

The Bay of Bengal experiences numerous cyclones during the rainy season,[13] potentially impacting the shores of the Arabian Sea when monsoon winds shift. The significant temperature variation between the Arabian Sea and the Bay of Bengal, characterised by varying salinity and temperature due to river runoff, contributes to these effects. Additionally, cloudbursts and rapid and heavy localised rainfall events occur during the monsoon season in orographically dominant regions like India's Himalayas, northeastern states, and Western Ghats[14]. Flash floods resulting from cloudbursts have substantially damaged villages and cities in the Himalayan regions of Kashmir and Ladakh, with mud and debris swiftly sweeping through residential areas, causing extensive harm to numerous homes.

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[10] Report on Urban Flood Management: Drainage and Planning. Retrieved From: https://cwp-india.org/wp-content/uploads/2021/05/REPORT-ON-URBAN-FLOOD-MANAGEMENT-DRAINAGE-AND-PLANNING.pdf

[11] Management of Urban Flooding. Retrieved From: https://nidm.gov.in/pdf/guidelines/new/management_urban_flooding.pdf

[12] Management of Urban Flooding. Retrieved From: https://nidm.gov.in/pdf/guidelines/new/management_urban_flooding.pdf

[13] Indian Ocean. Retrieved From: https://web.archive.org/web/20010802084832/http://oceanographer.navy.mil/indian.html

[14] Management of Urban Flooding. Retrieved From: https://nidm.gov.in/pdf/guidelines/new/management_urban_flooding.pdf

The freshwater system in India presents a unique scenario, with rivers in the Indian subcontinent transporting approximately 2500 million tonnes of suspended sediments annually. This accounts for 15-20% of the global sediment flux, with around 70% originating from the Ganga-Brahmaputra and Indus rivers. The remaining sediment comes from rivers in the peninsula, mainly influenced by rocks like those in the Deccan Traps. Approximately 53% of India's land area experiences soil runoff, with high erosion areas observed along rivers like the Yamuna, Chambal, and Mahi in western Indian states. The Himalayan and lower Himalayan regions face severe erosion due to activities like tree cutting, road construction, mining, and farming on steep slopes. Major river areas often suffer from substantial floods and carry significant sediment loads. Research on suspended sediment movement in Himalayan rivers indicates that rivers originating from the mountains generally transport more sediment than those flowing from slopes or plains.[15]

Socio-Economic Characteristics:

Presently, approximately 40% of the global population resides in tropical regions. The population of India's tropical region alone is expected to approach the combined population of the U.S. and Europe. Beyond rapid population growth, the region is witnessing an increase in affluence as more people escape poverty. This growth, coupled with expansive agriculture, occurs in an area rich in biodiversity and endemism[16]. While this presents business and investment opportunities due to rising consumption and a diverse workforce, it also places unprecedented strain on the world's environment and natural resources. Effectively addressing sustainable development in the tropics is a paramount global challenge.[17]

In tropical regions, the absence of frost and continuous heat enables life and reproduction year-round, as the usual limiting factor of winter is nonexistent. The constant conditions facilitate diverse life forms, including plants, insects, birds, microbes, animals, and crops. However, fierce competition ensues, leading to only a select few individuals of each species surviving in any given location. This sets the stage for rapid evolutionary changes to seize new

[15] Kale, V. S. (2002). Fluvial geomorphology of Indian rivers: an overview. *Progress in physical geography*, *26*(3), 400-433.

[16] Drescher, J., Rembold, K., Allen, K., Beckschäfer, P., Buchori, D., Clough, Y., ... & Scheu, S. (2016). Ecological and socio-economic functions across tropical land use systems after rainforest conversion. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1694), 20150275.

[17] Why do the tropics matter? Retrieved From: https://www.jcu.edu.au/state-of-the-tropics/why-do-the-tropics-matter#:~:text=Currently%20around%2040%25%20of%20the,will%20live%20in%20the%20region.

opportunities. Rising populations and consumption have given rise to political and social challenges, resulting in conflicts over land use[18]. Local communities and indigenous groups struggle to retain control over their traditional lands, while corporations, often foreign, seek more land for agriculture, livestock, or resource extraction. Simultaneously, conservationists and environmentalists are battling to safeguard rainforests, coral reefs, and crucial ecosystems from degradation.[19]

Climate analysts highlight the heightened vulnerability of tropical regions to climate change, with increased intensity and frequency of heat waves. Projections indicate a significant rise in extreme heat events in these areas. The impact of climate-related heat extends to cities, posing a future threat of elevated heat exposure for a growing urban population. Large cities in Latin America, India, and Southeast Asia are witnessing sprawling development, contributing to urban warming. Urban heat is influenced by infrastructure, with constructed surfaces amplifying temperature more than natural ones. Green spaces within cities can mitigate urban heating effects. A recent study focusing on Delhi utilised remotely sensed surface temperature to confirm an increase in temperature corresponding to an expansion in impervious surfaces.[20]

Due to the unique characteristics of tropical regions, specialised strategies are necessary for managing urban flooding and related issues. However, as noted by Celso Furtado in 1963, existing technology is predominantly designed for temperate climates, making it challenging to adapt readily to the tropics with their distinct set of resources. Kenneth Boulding also emphasised that development, like economics, has primarily been tailored to Temperate Zone environments. Imposing techniques developed for temperate zones in the tropics, whether in engineering, agriculture, or economics, can lead to disastrous outcomes[21]. Therefore, it is crucial to thoroughly understand local conditions and tailor plans accordingly.

Sediment-Related Reasons for Urban Flooding

[18] Kamarck, A. M. (1976). *The tropics and economic development*. The John Hopkins University Press.
[19] Booming populations, rising economies, threatened biodiversity: the tropics will never be the same. Retrieved From: https://news.mongabay.com/2014/07/booming-populations-rising-economies-threatened-biodiversity-the-tropics-will-never-be-the-same/
[20] Marcotullio, P. J., Keßler, C., Quintero Gonzalez, R., & Schmeltz, M. (2021). Urban growth and heat in tropical climates. *Frontiers in Ecology and Evolution*, *9*, 616626.
[21] Kamarck, A. M. (1976). *The tropics and economic development*. The John Hopkins University Press.

In recent years, India has witnessed a growing incidence of urban flood disasters, particularly affecting significant cities. We will delve into the specific issues contributing to these urban flooding challenges.

Encroachment on Floodplains:

Government agencies and experts attribute the rising frequency and damages from floods in India to encroachments in the floodplains of rivers. A 2018 Comptroller and Auditor General of India (CAG) report pointed to encroachments in Tamil Nadu's river floodplains as a critical factor in the 2015 Chennai floods[22]. Large settlements are emerging in low-lying zones in urban areas, often encroaching on drainage channels, with houses constructed over nullahs and drains. Rajendra Singh, known as the "waterman of India," linked the unprecedented flooding of the Yamuna in July 2023 to widespread construction and encroachments altering the river's natural path. Singh emphasised that addressing the high silt levels required dredging, and while short-term solutions involve desilting, the long-term solution necessitates the removal of significant encroachments.[23]

Encroachment in the upper catchments of hilly urban areas has led to severe flooding in the floodplains of cities surrounded by hills. Unplanned urbanisation and encroachment on natural drainage channels, including rivers, streams, and lakes, disrupt the natural water flow. Construction on floodplains and the obstruction of waterways further worsen the issue.[24]

Increase in sediment and solid material:

Urban development significantly amplifies sediment production within the watershed due to construction activities, land clearing for housing, and the creation of streets, avenues, and highways. Surface erosion results in the degradation of areas, forming substantial ravines, particularly in fragile soils[25], with depths of up to 30m and widths of 50m. Urbanisation often increases impervious surfaces like roads, parking lots, and buildings, hindering water infiltration into the soil and causing more runoff. Sediment erosion from construction sites or

[22] With poor regulation of floodplains, India is more vulnerable to flood damage. Retrieved From: https://www.preventionweb.net/news/poor-regulation-floodplains-india-more-vulnerable-flood-damage

[23] Encroachments led to Yamuna's flooding in Delhi. Retrieved From: https://www.hindustantimes.com/cities/delhi-news/experts-call-for-demarcation-of-yamuna-s-floodplain-zone-and-removal-of-encroachments-amidst-rising-water-levels-101690222932364.html

[24] Urban Flooding in India: Causes, Impact & Solutions. Retrieved From: https://www.nextias.com/blog/urban-flooding-in-india/

[25] Urban Flood Management. Retrieved From: https://www.floodmanagement.info/floodmanagement/wp-content/uploads/2020/06/Cap-Net-WMO-Urban-Flood-Management.pdf

denuded landscapes further contributes to sedimentation in water bodies, exacerbating the risk of flooding.

During a flood, the accumulation of waste and debris from floodwaters can lead to heightened property damage. After the flood, deposited waste obstructs access, posing toxin threats and creating a breeding ground for diseases. Intense rainfall overwhelms sewer and storm drain capacities, with plastic blockages identified as the leading cause of the devastating 2005 Mumbai floods. Similar issues have impacted countries like Bangladesh and Manila, with plastic bags clogging drainage systems[26]. A comprehensive watershed management plan involving sediment removal and dredging to restore water depth is essential to address sediment buildup in water bodies.

Drainage Systems:

A significant factor contributing to urban flooding in Indian cities is the insufficient drainage infrastructure. Many urban areas lack adequately designed stormwater drainage systems capable of managing intense rainfall. Rapid city expansion without proper planning results in impervious surfaces such as roads and buildings, hindering water absorption into the ground and overwhelming inadequate drainage systems. The concretisation of drains exacerbates flooding by preventing water percolation into the ground.[27]

Clogs in drainage channels diminish the discharge capacity of urban conduits, rivers, and lakes. Sediments on various urban surfaces enter the drainage system, carrying pollutants contaminating stormwater. Obstructions like bridge backfilling, piles, inadequate drains, and clogged conduits can impede runoff. The accumulation of solid material reduces runoff capacity and obstructs urban retention systems for local runoff control. The effectiveness of street sweeping and the maintenance of inlet catch basins or gully pots limit the sediment entering the system. In developing countries with more sediment and weaker urban management, sediment in the drainage system significantly affects its performance. Poor operational practices, mainly neglecting clearing drains from the outlet end in minor drains, result in minimal net benefits.[28]

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[26] Causes, impacts, risk and mitigation of Urban Flood Management in India. Retrieved From: https://iced.cag.gov.in/wp-content/uploads/Series2.pdf

[27] Why Indian Cities Still Unprepared for Flooding. Retrieved From: https://www.newsclick.in/why-indian-cities-still-unprepared-flooding

[28] Management of Urban Flooding. Retrieved From: https://nidm.gov.in/pdf/guidelines/new/management_urban_flooding.pdf

As urbanisation and densification progress in the watershed, sediment production may be reduced. Issues arise in the drainage system, stemming from inadequate maintenance and poorly designed structures that don't consider clogging in narrow sections. Urban development often occupies natural stormwater runoff areas, posing risks to residents and upstream regions with limited space for excess water. In certain cities, some over a century-old underground drains face the risk of collapse due to ageing and increased traffic loads.[29]

Inadequate Knowledge of Local Sediment Dynamics:

Frequent evaluations of sediment transport, deposition, loads, erosion rates, and water quality are crucial in effective watershed and sediment management. These assessments provide valuable data to improve management strategies over time. Given the dynamic nature of watersheds, an adaptive management approach is vital, allowing for the responsive handling of evolving conditions, emerging challenges, and potential impacts of climate change.

Regrettably, research on suspended sediment, particularly in Eastern Himalayan rivers, faces limitations due to an inadequate gauge network, restricted data availability in the public domain, and hydrological disruptions caused by dam construction or extreme hydrometeorological events[30]. The challenge lies in obtaining comprehensive and current sediment dynamics data in India. Some areas lack monitoring infrastructure, such as sediment gauging stations and equipment, making accurate and continuous data collection difficult. Rapid changes in land use, urbanisation, and climate can significantly impact sediment dynamics, surpassing the capabilities of monitoring systems and resulting in data gaps. The absence of comprehensive data poses challenges in formulating effective policy frameworks.

Soil Erosion:

[29] Management of Urban Flooding. Retrieved From: https://nidm.gov.in/pdf/guidelines/new/management_urban_flooding.pdf

[30] Prokop, P. (2023). Preliminary assessment of the suspended sediment dynamics in the Sikkim–Darjeeling Himalayan river. *International Journal of Sediment Research*.

Approximately 53% of India's land area experiences soil runoff[31], with high erosion affecting areas along the Yamuna, Chambal, Mahi, and other west-flowing rivers in western states. The Himalayan and lower Himalayan regions face more severe erosion due to activities like heavy tree cutting, road construction, mining, and farming on steep slopes. Major river areas frequently encounter massive floods and transport substantial sediment. The Kosi River creates a significant yet unstable alluvial fan composed of sand. Research on suspended sediment movement in Himalayan rivers indicates that mountain-flowing rivers carry more sediment than those flowing from slopes or plains.[32]

Eroded soil particles, transported by runoff, can reach stormwater drains, rivers, and other water bodies. Sediment accumulation in drainage channels reduces capacity, heightening flood risks during heavy rainfall. Urban areas with drainage systems ill-equipped for rapid runoff face the potential of flash flooding. Stormwater carrying eroded soil and debris can obstruct drainage systems, worsening flooding problems. Illegal mining of river sand and quartzite for construction depletes natural riverbeds, causing soil erosion and reducing water retention capacity in water bodies, amplifying water flow speed and scale, particularly during intense downpours.[33]

Dams and Reservoirs:

Dams and reservoirs, vital for water storage and hydropower, face a risk of sedimentation. The sediment budget's significant outcome is the reservoirs in the catchment exhibiting high simulated sediment trapping efficiency[34]. The Central Water Commission of India acknowledges the economic impact, estimating an annual 1.5% reduction in reservoir storage capacity due to sediment accumulation. Activities like dam construction, river flow redirection, and resource extraction can result in coastal erosion, subsidence, and changes in the freshwater-saltwater interface. While large-scale dams limit nutrient deposition through seasonal flooding, they protect riverside settlements from severe floods. However, increased sediment deposition

[31] Narayana, D. V., & Babu, R. (1983). Estimation of soil erosion in India. *Journal of Irrigation and Drainage Engineering*, *109*(4), 419-434.

[32] Romit Kaware. Research Note. Tropical Waters and Unique Characteristics: Indian Freshwater Systems. Maritime Research Center, Pune.

[33] Illegal sand mining in river beds blamed for flood fury in Bihar's East and West Champaran. Retrieved From: https://www.hindustantimes.com/patna/illegal-sand-mining-in-river-beds-blamed-for-flood-fury-in-bihar-s-east-and-west-champaran/story-PUuQbOw8pjj24sWYCxpLVI.html

[34] Koster, G. (2013). *Mapping runoff and erosion to reduce urban flooding and sediment flow towards sea, A case study on the Playa catchment, Bonaire* (Doctoral dissertation, MSc. Thesis. Water Resources Management Group, WAGENINGEN University).

can contribute to more flooding, causing various issues such as property damage, water contamination, crop loss, social upheaval, temporary displacement, and even loss of life.[35]

Many cities and towns, both small and large, are situated along the banks of rivers. Floods in these rivers result in the flooding of the adjacent floodplains, exacerbated by urban expansion into these areas, limiting natural overflow space. Some cities are positioned downstream or upstream of dams and reservoirs. Those downstream can face flooding due to excess water releases. Additionally, cities upstream of dams may be affected by rising backwater levels if water release is unexpectedly withheld during flood seasons. Instances of sudden, unnotified water releases have led to significant loss of life and property.[36]

Overgrazing:

Excessive grazing by livestock can deplete vegetation cover, including grasses and other plants, which is crucial for stabilising soil and preventing erosion[37]. The absence of vegetation makes the soil more vulnerable to erosion. Healthy vegetation enhances soil permeability, facilitating water infiltration into the ground. Overgrazing, however, can compact the soil, reducing its capacity to absorb water and increasing surface runoff during rainfall. Livestock grazing on river banks, farming on treeless steep slopes, and lacking riparian vegetation contribute to high sediment levels in waterways. These areas become unstable over time, prone to slips and erosion, especially during floods[38]. Reduced vegetation and compacted soil increase the likelihood of rainwater flowing over the surface rather than being absorbed. This heightened surface runoff can transport soil particles, nutrients, and pollutants, leading to sedimentation in water bodies and potential clogging of drainage systems.

Climate Change:

The prevailing belief is that global warming will continuously increase extreme rainfall events, significantly impacting flood risk worldwide. According to the recent Intergovernmental Panel on Climate Change (IPCC) special report, global warming may reach 1.5 °C between 2030 and

[35] Romit Kaware. Research Note. Basics of Sediment Management. Maritime Research Center, Pune

[36] Management of Urban Flooding. Retrieved From: https://nidm.gov.in/pdf/guidelines/new/management_urban_flooding.pdf

[37] Koster, G. (2013). *Mapping runoff and erosion to reduce urban flooding and sediment flow towards sea, A case study on the Playa catchment, Bonaire* (Doctoral dissertation, MSc. Thesis. Water Resources Management Group, WAGENINGEN University).

[38] How may agricultural activities increase sediments in waterways? Retrieved From: https://niwa.co.nz/our-science/freshwater/tools/kaitiaki_tools/impacts/sediment/causes/sediment

2052. This warming is expected to increase the intensity and frequency of extreme precipitation. Large cities with intricate drainage networks are increasingly challenged by rising flood volumes, posing infrastructure failure risks, property damage, and potential loss of life[39]. Global climate change alters weather patterns, leading to more frequent high-intensity rainfall events within shorter durations. Additionally, the imminent threat of sea-level rise further endangers coastal cities. Various regions, including coastal towns, river banks, areas upstream/downstream of dams, inland cities, and hilly regions, are susceptible. The projected impacts of climate change include increases in average atmospheric temperatures. Urban Heat Island effects contribute to flash floods due to the expansion of impervious areas[40]. Floods are the most recurrent natural disasters, causing higher humanitarian needs than others[41].

Sediment Management and Urban Planning

Urbanisation is rapidly transforming India's landscape due to structural changes spurred by liberalisation since the mid-90s. The push for cities as 'engines of growth' to attract investments led to land law reforms, making land readily available for real estate projects and fostering competition among towns. Initiatives like the Jawaharlal Nehru Urban Renewal Mission (JNNURM) and the Smart City Mission (SCM) further reinforced this trend, focusing on the project-oriented development of complex infrastructure. However, this rapid urbanisation has resulted in encroachments on urban commons and water bodies, disruption of water channels, alteration of water contours, and conversion of open spaces into housing projects[42]. Urban development master plans often lack restrictions on settling in flood-prone areas or government-owned spaces near rivers[43]. Even settling in medium-risk regions that are less often flooded can lead to significant damage during floods. Sunita Narain, director of the Centre for Science and Environment, attributes unprecedented floods in the Chennai metropolitan region to unregulated urbanisation. According to Narain, major cities like Delhi, Kolkata, Mumbai, Chennai, and Srinagar have not adequately considered existing natural water bodies, building over many of them and obstructing the smooth flow of water, prioritising land for buildings over water.[44]

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[39] Sun, X., Li, R., Shan, X., Xu, H., & Wang, J. (2021). Assessment of climate change impacts and urban flood management schemes in central Shanghai. *International Journal of Disaster Risk Reduction*, *65*, 102563.
[40] Climate Change Indicators: Weather and Climate. Retrieved From: https://www.epa.gov/climate-indicators/weather-climate
[41] Molina, L.E.T., Morales, S., Carrión, L.F., 2020. Urban Heat Island Effects in Tropical Climate, Vortex Dynamics Theories and Applications. IntechOpen. https://doi.org/10.5772/intechopen.91253
[42] 2015 South India floods. Retrieved From: https://en.wikipedia.org/wiki/2015_South_India_floods
[43] Tucci, C. E. (2007). Urban flood management. *WMO and Capnet*.
[44] 2015 South India floods. Retrieved From: https://en.wikipedia.org/wiki/2015_South_India_floodss

Urban planning can be defined as an intervention aimed at organising urban aspects to create outcomes aligned with a desired way of life. Social, cultural, political, and ideological factors shape urban planning concepts. While ancient cities and civilisations thrived without formal urban planning institutions, the origins of urban planning in India can be traced back to the Bronze Age, notably during the Indus Valley Civilization[45]. In this civilisation, the cities of Harappa and Mohenjo-Daro exhibited advanced town planning, including efficient water supply, rainwater harvesting, sewerage systems, and grid-iron patterns on streets[46]. In the developing world, planning is often theoretical and lacks formal influence on how cities are planned in India. Planning initiatives in India are typically ad-hoc, context-specific, and influenced by prevailing sociocultural factors, resulting in distinct styles and structures across regions like Rajasthan, Bihar, and Tamil Nadu[47].

Defining urban areas in the Indian context poses challenges, such as the classification of census towns that, despite being functionally urban, lack urban development and master plans, highlighting the issue of unplanned urbanisation. There's also a notable gap between urban planning theory, primarily rooted in Western concepts and the realities of Indian urbanism. Indian urbanism is characterised by informality, autoconstruction of cities, and retrofitting, often overlooked by Western-centric planning theories. The tendency to emulate Western cities is evident in initiatives like the "Smart City Mission," where redevelopment projects in Delhi, such as East Kidwai Nagar and Naoroji Nagar, disregard historical neighbourhoods and mature trees in favour of modernisation. These gaps in urban planning contribute to poorly planned cities that don't adequately address the needs of their citizens. To rectify the issues in Indian cities, a bottom-up approach to urban planning with public participation is essential, addressing the unique challenges and characteristics of Indian urban areas[48].

Addressing sediment issues in urban areas is crucial for creating an acceptable living environment. Soil erosion and sediment deposition are environmental challenges comparable

[45] India is not producing enough town planners to make our cities more liveable. Retrieved From: https://www.downtoearth.org.in/blog/governance/india-is-not-producing-enough-town-planners-to-make-our-cities-more-livable-86564

[46] REFORMS IN URBAN PLANNING CAPACITY IN INDIA. Retrieved From: https://www.niti.gov.in/sites/default/files/2021-09/UrbanPlanningCapacity-in-India-16092021.pdf

[47] What is the difference between urban planning in India and other foreign countries with respect to education as well as implementation? Retrieved From: https://www.quora.com/What-is-the-difference-between-urban-planning-in-India-and-other-foreign-countries-with-respect-to-education-as-well-as-implementation.

[48] Urban Planning and the Curious Case of Indian Cities. Retrieved From: https://nickledanddimed.com/2022/01/31/urban-planning-and-the-curious-case-of-indian-cities/

to poorly maintained streets, dilapidated buildings, cluttered billboards, inefficient land use, and air and water pollution. Moreover, sediment has direct and indirect impacts on urban and non-urban streams. Coarse sediment transport issues arise when a stream's transport capacity doesn't align with the input supply, leading to aggradation or degradation[49]. Sediment exacerbates floodwater damage to homes, stores, and factories. The complex nature of sediment-related environmental problems often goes unnoticed, as sediment measurements are costly, and erosion, movement, and deposition occur in a dynamic and intricate environment.[50] [51]

Traditionally, flood risk management and river ecosystem conservation have not been integral parts of urban planning, primarily due to the compartmentalisation of academic fields. Professionals dealing with flooding and water quality often come from disciplines like river engineering, hydrology, geology, chemistry, or geophysics. Conversely, urban planners are typically trained in architecture, traditional landscape design, road engineering, or social sciences. This disconnect from water management is a significant flaw in the existing urban planning system. Unplanned urban expansion leads to impoverished areas lacking adequate housing, services, and infrastructure, making vulnerable populations, particularly children, the elderly, and women, more susceptible to floods. The most effective approach to managing urban floods is to adopt an integrated strategy that combines urban planning and sediment management.[52]

Way Ahead

Addressing urban flooding in Indian cities requires the development of an integrated approach. The following suggestions can be incorporated into this integrated approach.

Early Warning Systems: Creating a forecasting and early-warning system is crucial for anticipating and mitigating flooding in urban areas. This system should involve real-time collection and transmission of weather and hydrological data through computerised networks,

[49] Gupta, A. K., & Nair, S. S. (2010). Flood risk and context of land-uses: Chennai city case. *Journal of Geography and Regional Planning*, *3*(12), 365.
[50] Guy, H. P. (1970). *Sediment problems in urban areas*. US Department of the Interior, Geological Survey.
[51] Sediment Attributes and Urban Development. Retrieved From: https://environment.govt.nz/assets/Publications/Files/sediment-attributes-and-urban-development-literature-review.pdf
[52] Abdrabo, K. I., Kantosh, S. A., Saber, M., Sumi, T., Elleithy, D., Habiba, O. M., & Alboshy, B. (2022). The Role of Urban Planning and Landscape Tools Concerning Flash flood risk reduction within arid and semiarid regions. *Wadi Flash Floods: Challenges and Advanced Approaches for Disaster Risk Reduction*, 283-316.

satellites, or radar. The information is then sent to a forecasting centre for reception, processing, and modelling, facilitating timely warnings to public systems, including schools, hospitals, and infrastructure. These warnings aid in evacuating and protecting the population at risk during emergencies or flooding events.[53]

Data Collection and Sharing: Efficient local hydro-meteorological data networks must be established and reinforced to comprehensively address urban flooding challenges. This involves ensuring the availability of reliable, high-quality data for local organisations to design effective urban flood management systems. Continuous and automated sampling over an extended period, utilising acoustic, optical, or nuclear measurements, is preferable to enhance understanding of sediment flows into the sea[54]. Urban infrastructure data models should be developed with a geospatial approach, incorporating procedures for data standardisation, collation, quality checks, and annual updates. Establishing a dedicated high-bandwidth communication channel is essential for timely information sharing with institutions and relevant authorities at the local level, focusing on sharing information with states and vulnerable cities.[55]

Stakeholder Consultations: Improving the current management system involves community engagement and implementing non-structural measures to build flood-resilient communities and reduce compounded risks. Institutional-level awareness is essential, requiring the development of specially designed public awareness programs. Public representatives, such as Municipal Ward Members, MLAs, and MPs, who have close connections with grassroots communities, should be actively involved and enlisted for regular participation in awareness generation programs[56].

Spatial Planning: Spatial planning[57] is increasingly recognised as a crucial tool for managing urban flood risk due to its ability to regulate long-term space use. Effective land use allocation,

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[53] Tucci, C. E. (2007). Urban flood management. *WMO and Capnet*.

[54] Koster, G. (2013). *Mapping runoff and erosion to reduce urban flooding and sediment flow towards sea, A case study on the Playa catchment, Bonaire* (Doctoral dissertation, MSc. Thesis. Water Resources Management Group, WAGENINGEN University).

[55] Management of Urban Flooding. Retrieved From: https://nidm.gov.in/pdf/guidelines/new/management_urban_flooding.pdf

[56] Fitriyati, N., Arifin, H. S., & Kaswanto, R. L. (2022, November). Flood resiliency approach for urban planning: critical review and future research agenda. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1109, No. 1, p. 012009). IOP Publishing.

[57] Abdrabo, K. I., Kantosh, S. A., Saber, M., Sumi, T., Elleithy, D., Habiba, O. M., & Alboshy, B. (2022). The Role of Urban Planning and Landscape Tools Concerning Flash flood risk reduction within arid and semiarid regions. *Wadi Flash Floods: Challenges and Advanced Approaches for Disaster Risk Reduction*, 283-316.

guided by coordinated regulations, can mitigate or prevent exposure to natural hazards in current and future scenarios. Establishing a National Database for Mapping Attributes is proposed, providing accessible information for mapping attributes at the ward/community level to relevant departments and stakeholders. Integrating hardware and software will ensure compatibility and interoperability of computing, visual, and networking infrastructure, enabling micro-level analytical tools for planning and executing risk reduction activities by Urban Development Authorities at various levels.

Awareness: Incorporating disaster-related education into the curriculum is essential, emphasising the distinction between Urban Flooding and rural riverine floods. Collaborative efforts between the Ministry of Housing and Urban Affairs, the Ministry of Education, and state governments are crucial in developing high-quality educational materials, textbooks, and field training programs for urban flooding. Utilising case histories of significant flood events will provide valuable insights. Recognising human factors like improper waste disposal and construction debris is vital. Initiatives focusing on awareness from a young age are crucial for instigating change[58].

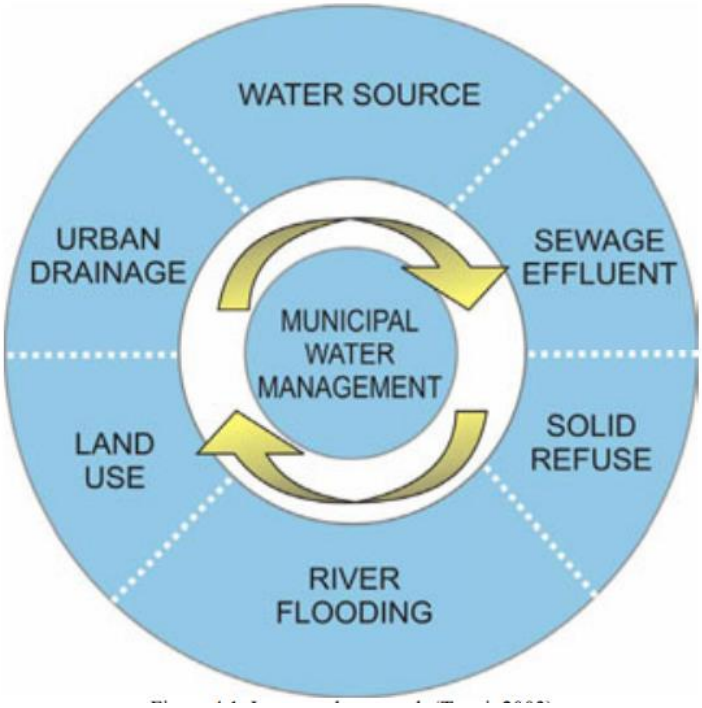

Figure: Integrated Approach for Water Management[59]

[58] Management of Urban Flooding. Retrieved From: https://nidm.gov.in/pdf/guidelines/new/management_urban_flooding.pdf
[59] Tucci, C. E. (2007). Urban flood management. *WMO and Capnet*.

Sustainable Urban Planning: Cities should adopt sustainable urban planning practices, considering the natural topography and hydrology and preserving water bodies and floodplains. Integrating sediment management and constructing flood-resilient infrastructure with minimal interaction with water contours is essential. Enhanced drainage systems are crucial for minimising and combating urban flooding. Improved water management practices, including waste collection and segregation, are necessary[60]. A comprehensive approach is needed, focusing on climate-resilient strategies and a strict prohibition on occupying water bodies, rooted in a pro-people approach, to mitigate the challenges of urban flooding effectively[61].

Conclusion

Cyclone Michaung's impact on Chennai in December 2023 led to significant devastation. The event, reminiscent of the 2015 floods, prompted discussions on mitigating future flash floods. Chennai's vulnerability to flooding arises from coastal locations, flat terrain, and urban development on water bodies. Similar events are seen to occur in major cities across India. This study explores the planning system's challenges, focusing on sediment management, to address recurring urban flooding issues in major Indian cities.

We then try to understand the meaning of urban flooding and its general effects. Urban flooding, a recurrent issue, is not new, as evidenced by historical instances like Harappa and Mohenjo-Daro. Triggered by factors such as heavy rainfall, dam failures, and urban development, flood hazards often affect Indian cities like Kolkata and Chennai. The National Disaster Management Authority highlights the impact of urbanisation on flooding, emphasising the need to enhance traditional engineering methods in urban management systems amid ongoing climate change and rapid urbanisation, addressing the paradox of flooding and water scarcity.

One of our primary focuses is on the distinctive features of tropical regions, particularly in the Indian Ocean area, which significantly impact urban planning and sediment management. India's primary rainy season, the southwest monsoon and the subsequent northeast monsoon, contribute to urban flooding. Cyclones in the Bay of Bengal, cloudbursts, and heavy local rainfall events exacerbate flooding risks. India's major rivers, with substantial sediment

[60] Tucci, C. E. (2007). Urban flood management. *WMO and Capnet*.
[61] Why Indian Cities Still Unprepared for Flooding. Retrieved From: https://www.newsclick.in/why-indian-cities-still-unprepared-flooding

transport from the Himalayas and Gangetic plains, face sediment erosion challenges. Moreover, the socio-economic landscape, marked by rapid population growth and increasing migration, poses environmental strain from the uncontrolled city growth. The tropical regions receive continuous heat throughout the year, enabling diverse life forms to flourish with high agricultural production levels, but this triggers conflicts over land use. Moreover, climate change intensifies heat waves, affecting urban areas. Managing urban flooding in the tropics requires specialised strategies. Then, we emphasised recognising the limitations of existing technology designed for temperate climates and the need for localised technological solutions.

Consequently, we highlight the major causes of urban flooding linked to sediment management. Urban flooding in India is increasingly prevalent, driven by several interconnected factors. Encroachments on floodplains contribute to rising flood frequency, with settlements obstructing natural drainage channels. Sediment production escalates with urban development, leading to surface erosion, ravine formation, and increased impervious surfaces hindering water infiltration. Poorly designed drainage systems and inadequate maintenance amplify flooding risks, with clogs and sediment obstructing conduits. Thus, a limited understanding of local sediment dynamics hampers effective management, compounded by the absence of comprehensive data. Soil erosion, exacerbated by tree cutting and mining activities, introduces sediment into water bodies, affecting drainage channels and elevating flood risks. Overgrazing by livestock depletes vegetation, increasing soil vulnerability to erosion and surface runoff. Moreover, dams and reservoirs face sedimentation challenges, impacting storage capacity and potentially causing downstream flooding. The added effects of climate change intensify extreme rainfall events, contributing to flooding risks, while rising sea levels threaten coastal cities.

Thus, we can understand that the complex interplay of encroachments, sediment increase, drainage system inadequacies, limited knowledge, soil erosion, dam impacts, overgrazing, and climate change heightens urban flooding risks in India. Addressing these multifaceted challenges necessitates comprehensive strategies, which include sustainable urban planning, effective sediment management, improved drainage infrastructure, and climate-resilient measures. Policymakers and urban planners must collaborate to develop adaptive management approaches, incorporating local conditions and scientific insights to mitigate urban flooding and enhance resilience in the face of evolving environmental conditions.

India's rapid urbanisation, driven by economic reforms, has led to unplanned development, encroachments on water bodies, and inadequate consideration of natural water flow. Initiatives like the smart city mission focused on infrastructure development but often neglected flood-prone areas. Cities like Delhi, Kolkata, Mumbai, Chennai, and Srinagar have witnessed unprecedented floods due to unregulated urbanisation. The historical significance of urban planning in the Indus Valley Civilization contrasts with the ad-hoc and context-specific nature of contemporary Indian planning. Western concepts generally influence current planning and lack understanding of local issues and public participation. Often overlooked, sediment issues in urban areas contribute to environmental challenges and exacerbate flood damage. The disconnect of the existing urban planning system from water management highlights the need for an integrated approach combining urban planning and sediment management to effectively address the challenges of urban floods. A bottom-up approach with public participation is crucial to align planning strategies with the unique characteristics of Indian urban areas.

We then conclude by hinting at how the integrated system could look like. Addressing urban flooding in Indian cities requires a comprehensive integrated approach. Implementing early warning systems and utilizing real-time data collection and forecasting is crucial for timely evacuation and protection during flooding events. Establishing efficient local hydro-meteorological data networks enhances understanding sediment flows and supports effective urban flood management. Stakeholder consultations, including community engagement and non-structural measures, are vital for building flood-resilient communities. Spatial planning, guided by coordinated regulations and a national database, can mitigate exposure to natural hazards. An integrated, context-specific approach with a focus on sediment management practices would contribute to a holistic and sustainable solution for urban flooding challenges in India.