COMPENDIUM REPORT 2022

Causes, impacts, risk and mitigation of Urban Flood Management in India

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ABOUT THE RESEARCH PAPER

This Compendium report on "Causes, impacts, risk, and mitigation of Urban Flood Management in India" is an effort towards our endeavour to improve accountability and inculcate professional excellence in the areas of environment and sustainable development. The Compendium report gives a glimpse of various factors related to the Urban Flood, its causes, impacts and relevance concerning India in today's perspective. This Compendium report is an effort by the International Centre for Environment Audit and Sustainable Development, Jaipur, under the Comptroller and Auditor General of India, to provide a glimpse of one of the most frequent urban disasters faced by Indian cities in modern times.

Feedback

We strive for constant improvement and encourage our readers to provide their valuable feedback/suggestions. Please send us suggestions, comments, and questions about this Compendium report to iced@cag.gov.in.

DECLARATION

I, the undersigned, solemnly declare that the report "Causes, impacts, risk and mitigation of urban flood management in India" is based on my work under the supervision of Shri Pushkar Kumar, Director (T&R), iCED. I assert the statements made and conclusions drawn are an outcome of my research work. I further certify that the work contained in the report is original and has been done by me under the general supervision of my supervisor.

I. The work has not been submitted to any other institution for any other degree/diploma/certificate.
II. I have followed the guidelines provided by the institution in writing the report.
III. I concur with the modifications/corrections carried out during the report evaluation based on my inputs.
IV. Whenever I have used materials (data, theoretical analysis and text) from other sources, I have given due credit to them in the text of the report and in the references.

Dr Divya Singh

ACKNOWLEDGEMENT

I wish to express my deepest gratitude and sincere thanks to Ms Sayantani Jafa, Additional Deputy Comptroller and Auditor General and Director General, iCED, for giving her invaluable guidance throughout the research work. Secondly, I would like to express my appreciation to Shri Pushkar Kumar, Director (T&R) - for his valuable and constructive suggestions during the planning and development of this research work. Also, I offer my sincere appreciation for the help and feedback offered by Shri Anupam Srivastava, Senior Audit Officer (Sr. AO) and Shri Manoj Kumar, Assistant Audit Officer (AAO), iCED. This compendium would not have been possible without their generous support and constructive feedback.

FOREWORD

There has been an increasing trend of urban flood disasters in India over the past several years whereby major cities in India have been severely affected. India witnesses heavy rainfall during monsoons. Other weather systems also bring in a lot of rain to the country. Storm surges can also affect coastal cities/ towns. Sudden release or failure to release water from dams can also have a severe impact. Global climate change is resulting in changing weather patterns and increased episodes of high-intensity rainfall events occurring in shorter periods of time. Cities/towns located on the coast, on river banks, upstream/ downstream of dams, inland cities and in hilly areas can all be affected.

Storm water drainage systems in the past were designed for rainfall-related incidents. Over the decades these capacities have been exhibiting wear and tear whenever rainfall of higher intensity has been experienced. Further, the systems very often do not work to the designed capacities because of poor maintenance. Encroachments are also a major problem in many cities and towns. Natural streams and watercourses have formed over thousands of years due to the forces of flowing water in the respective watersheds.

Habitations grow into towns and cities alongside rivers and watercourses. As a result of this, the flow of water increases in proportion to the urbanization of the watersheds. Increased urbanization has led to large-scale encroachments on the natural drains and the river flood plains. Consequently, the capacity of the natural drains has decreased, resulting in flooding. Improper disposal of solid waste also contributes significantly to reducing their capacities. It is imperative to take better operations and maintenance actions.

As a recent initiative, iCED has commenced an Occasional Research Paper Series, to provide cutting-edge research inputs to the audit of the environment and sustainability in development.

This Compendium report on “Causes, impacts, risk and mitigation of Urban Flood Management in India” is a part of the series and contains ample information about urban floods in Indian cities, their causes, impacts and remedial actions needed to be taken for its prevention. Various case studies have also been illustrated in the report for the readers so that they can relate to the contents in a better way. It is hoped that the findings and recommendations presented in this compendium will be a valuable input to the various stakeholders. I sincerely hope that this Research Paper would also be helpful for policy makers and will guide readers about various aspects of urban floods in India, by reflecting a holistic approach to the issue.

It gives me immense pleasure to state that this research paper has been developed in time and for this, I would like to congratulate the author Dr Divya Singh, Research Associate, iCED. I would also like to appreciate the efforts made by Shri Pushkar Kumar, Director (T&R), iCED who has helped in developing this Compendium on Urban Flood Management in India.

13th July 2022
Jaipur

(Sayantani Jafa)
Additional Deputy CAG & Director General,
iCED, Jaipur

ABSTRACT

Urban floods have resulted in extreme fatalities and enormous economic losses in every country, making it a disaster of high vulnerability. Particularly in developing countries like India, where population density is high and the country has experienced significant population expansion in recent decades due to high migration to urban areas, there are many concerns regarding unregulated and unsustainable development. Increased population causes more urbanization, more impervious areas and greater surface runoff, as well as changes in topographical and drainage profiles, which increase water flow in proportion to the rate of urbanization.

There has been an increasing trend of urban flood disasters in India over the past few years whereby major cities in India have been severely affected. The states of Kerala, Madhya Pradesh, Karnataka, Maharashtra, and Gujarat were the most severely affected. In the year 2021, the state of Maharashtra faced widespread flooding in Mahad and Chiplun. It was caused by exceptionally heavy rainfall. Analyzing the causes, it has been observed that the main focus for urban flood mitigation should be runoff reduction and keeping the flood plains free from obstructions[1].

The present study gives an overview of floods and a compilation of the causes and impacts of urban floods in India. The long-term and short-term risks of urban floods to humans and the environment has also been analyzed in this compilation along with the urban flood management systems, and best practices around the world and in India which are based on available literature and guidelines for urban flood risk management have also been presented. Further, the case studies, audit findings, and recommendations in the compendium give the readers a holistic view of the problem of Urban Floods.

[1]https://researchtrend.net/ijet/pdf/Causes%20and%20Impacts%20of%20Urban%20Floods%20in%20Indian%20Cities%20A%20Review%20Drj6.pdf

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Chapter 1. Overview of Urban Flood

1.1. Background

Floods are the most frequent type of natural disaster and occur when an overflow of water submerges land that is usually dry. Floods are often caused by heavy rainfall, rapid snowmelt or a storm surge from a tropical cyclone or tsunami in coastal areas[2]. The Figure 1 shows different types of reported natural disasters globally between 1970-2019 with floods being the most frequent.

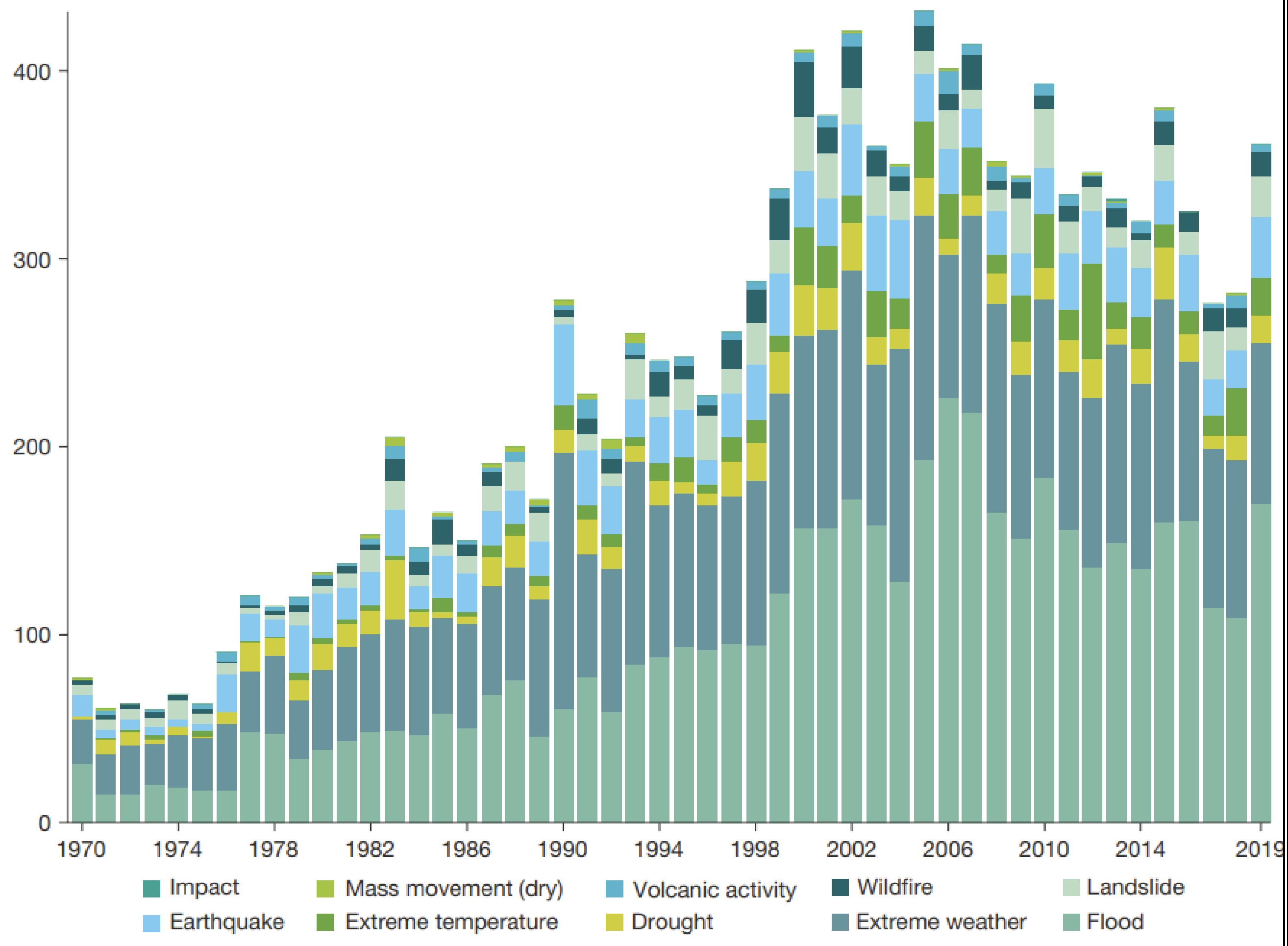

Figure 1: Global reported natural disasters by type, 1970-2019

Image Source: https://openknowledge.worldbank.org/handle/10986/35710

[2] https://www.who.int/health-topics/floods#tab=tab_1

Based on the satellite imagery, researchers studied 913 flood events from 2000 to 2018 and found a total inundation area of 2.23 million square kilometres, with 255-290 million people directly affected by floods (Figure 2).[3] Floods affect urban settlements of all types, including small villages, mid-sized market towns to major cities, megacities and metropolitan areas. Estimates place the economic losses caused by flooding over the past decade at US$656 billion (Figure 3). However, the direct economic costs are systematically underreported, and the actual losses are likely to be much higher. The data on economic losses are only available for thirty-seven per cent of registered disasters; the direct cost of most disasters (63 per cent) is unknown or not well documented[4].

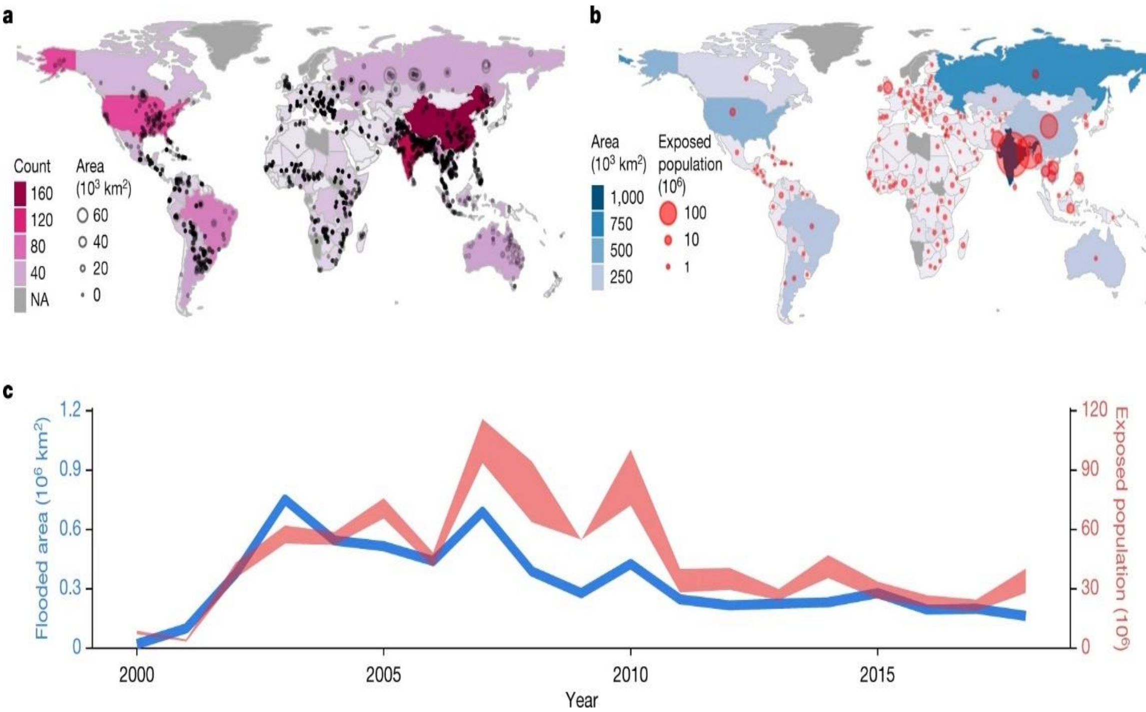

Figure 2: Summary statistics of the Global Flood Database

Image source: https://www.nature.com/articles/s41586-021-03695-w/figures/1

[3] Nidhi Jamwal, 2021. Water-related disasters dominate the globe; world population exposed to floods increased by 24% since 2000. Gaonconnection | Your Connection with Rural India. URL https://en.gaonconnection.com/floods-india-climate-change-maharashtra-bihar-madhya-pradesh-extreme-weather-rainfall-disaster-management-research/ (accessed 7.4.22).

[4] Wishart, Marcus, Wong, Tony, Furmage, Ben, Liao, Xiawei, Pannell, David, Wishart, Marcus, 2021. Valuing the Benefits of Nature-Based Solutions : A Manual for Integrated Urban Flood Management in China [WWW Document]. URL https://openknowledge.worldbank.org/handle/10986/35710 (accessed 7.4.22).

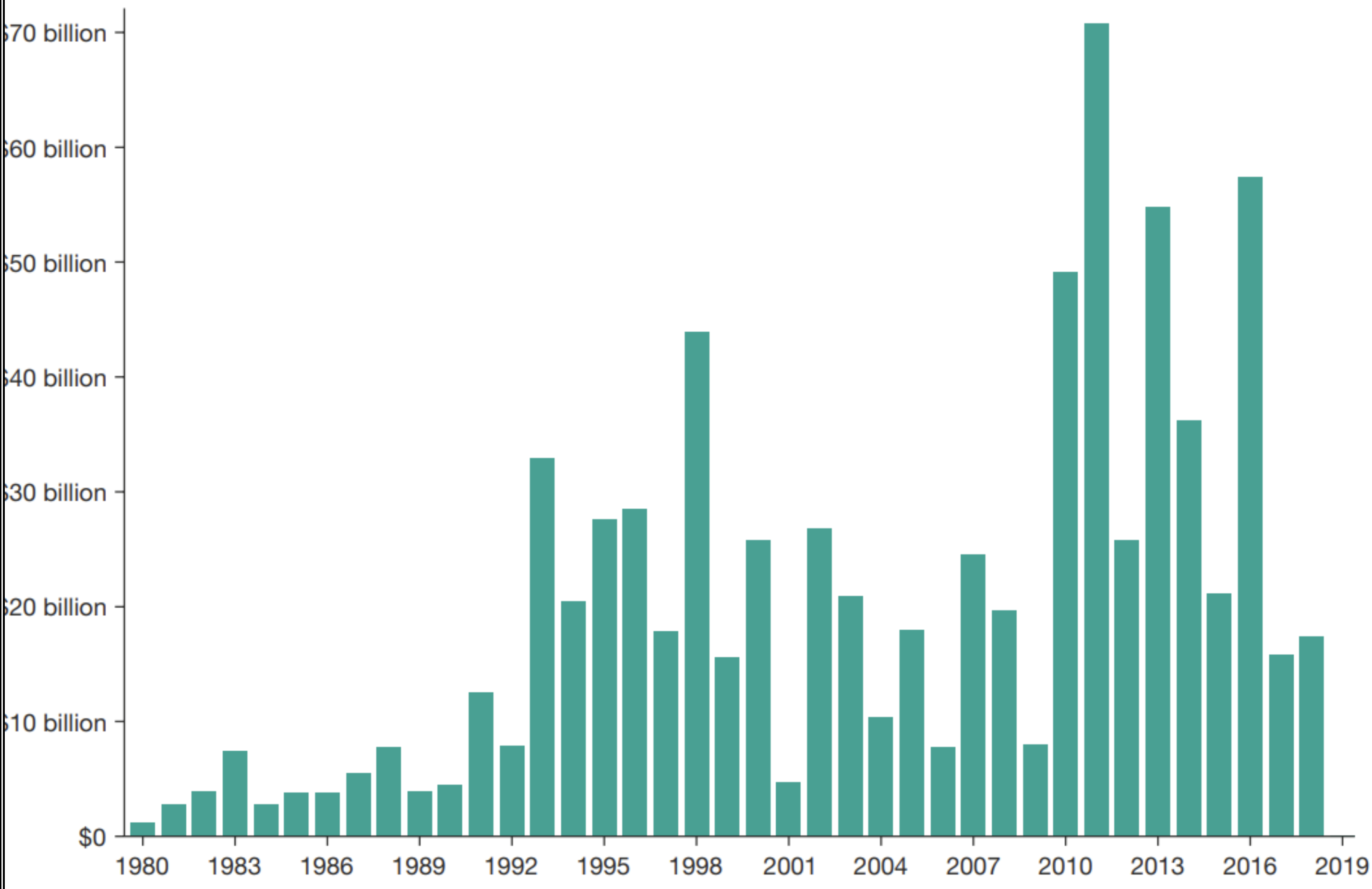

Figure 3: Damage as a result of global flood disasters in USD, 1980-2019

Image source: https://openknowledge.worldbank.org/handle/10986/35710

1.2. Impact of floods

Floods can influence the environment in more than one way, both negative and positive. Being a natural ecological process, flooding plays a key role in bringing about biological diversity and productivity in the affected area. Though floods can be devastating to population centres, they have always been an integral part of nature's renewal process, providing many long-term positive effects[5]. This includes

(1) Renewal of Wetlands.

(2) Returning nutrients to the soil

(3) Preventing erosion and maintaining land mass elevation

[5] Frankie Smith, 2018. How Are People Affected by Floods? [WWW Document]. Sciencing. URL https://sciencing.com/how-are-people-affected-by-floods-12510012.html (accessed 7.4.22).

(4) Recharge and replenish groundwater.

Floodplains along rivers and streams are among the most fertile regions known. Most of the so-called ‘cradles of civilization’ are within floodplains for this very reason (e.g., the Nile River, the Tigris–Euphrates River, among others)[6].

However, the human race is more concerned about the negative impact of flooding because floods can result in adverse environmental degradation besides causing short-term damage to life and property. Here are the ways that floods can impact the environment in the affected areas[7].

The Health of the wildlife and livestock: Floods can adversely affect the well-being of the animals and plants that are housed in forest areas. Similarly, farming and ranching habitats are also susceptible to the flood water that inundates their living areas. Heavy floods can even result in total loss of the wildlife and biodiversity in the affected region[8].

Dispersal of local pollutants: Flooding can lead to dispersal of local pollutants in the region and affect the quality of life of the livestock and humans residing therein. Some of these pollutants may be harmful chemicals, agricultural pesticides and industrial wastes that are otherwise localized in the areas of origin. But when mixed with flood water, they can reach far-off locations and contaminate the soil and water[9].

Chemical Contamination: Agricultural chemicals, including fertilisers and pesticides, as well as other pollutants such as paint, gasoline or diesel, can find their way into the habitats of wildlife. Affected soil and other sediments can become attached to grass or plants, even after the floodwater has receded, which in turn is ingested by grazing animals such as sheep and cattle[10].

1.3. Urban Floods

Urban flooding is the accumulation of floodwaters that results when the inflow of storm water exceeds the capacity of a drainage system to infiltrate water into the soil or to carry it away.

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[6] https://curry.eas.gatech.edu/Courses/6140/ency/Chapter8/Ency_Atmos/Flooding.pdf

[7] Science, jurisdiction=Queensland; sector=government; corporateName=Department of E. and, 2018. What are the consequences of floods? [WWW Document]. Office of the Queensland Chief Scientist. URL https://www.chiefscientist.qld.gov.au/publications/understanding-floods/flood-consequences (accessed 7.4.22).

[8] https://education.nationalgeographic.org/resource/many-effects-flooding

[9] Understanding The Environmental Impact Of Flooding, 2018. URL https://www.boostup.org/understanding-the-environmental-impact-of-flooding/ (accessed 7.4.22).

[10] pollutionsolutions, 2014. What Is the Environmental Impact of Flooding? Pollution Solutions Online [WWW Document]. URL https://www.pollutionsolutions-online.com/news/water-wastewater/17/breaking-news/what-is-the-environmental-impact-of-flooding/31633 (accessed 7.4.22).

When a natural landscape is transformed by urban development, its drainage pattern is disturbed[11]. Urban flooding is a major problem in many parts of the world and is one of the most natural disastrous events which takes place every year. Since the 1990s, urban flooding has become the most common and the most reoccurring natural hazard causing devastating impacts worldwide. More than 5,200 flash floods were recorded worldwide during 1980-2017 with more than 220,000 fatalities and global losses of $1,000 billion. Asia accounted for 45 per cent of these events, 74 per cent of total fatalities and 57 per cent of overall losses. The southern Asian megacities like Dhaka, Karachi, Kolkata and Mumbai housing more than 50 million people face a substantial risk of flood-related damage over the next century, as reported in a study by the World Bank Group[12].

In Asia, urban flooding is a frequent phenomenon. Almost every city is vulnerable to urban flooding in one way or another, and urban dwellers are at high risk. In urban environments, farmland, vegetation cover, and bare soil have been converted into built-up areas. As a result, water runs off of the concrete structures. This is known as pluvial flooding or urban flooding. In urban areas, with the rapid increase in impermeable surfaces and urban development, the likelihood of flooding has increased[13].

1.4. As a result of different combinations of causal factors, urban floods can basically be divided into four categories[14]:

- Local Floods
- Riverine Floods
- Coastal Floods
- Flash Floods

Floods in urban areas can be attributed to one or a combination of the above types. In order to manage urban floods, it is essential to understand the causes and impacts of each one of them.

[11] National Academies of Sciences, E., Studies, D. on E. and L., Board, W.S. and T., Affairs, P. and G., Program on Risk, R., States, C. on U.F. in the U., 2019. Framing the Challenge of Urban Flooding in the United States., Framing the Challenge of Urban Flooding in the United States. National Academies Press (US).

[12] https://openknowledge.worldbank.org/bitstream/handle/10986/28723/9781464811555.pdf

[13] Atta-ur-Rahman, Parvin, G.A., Shaw, R., Surjan, A., 2016. 3 - Cities, Vulnerability, and Climate Change, in: Shaw, R., Atta-ur-Rahman, Surjan, A., Parvin, G.A. (Eds.), Urban Disasters and Resilience in Asia. Butterworth-Heinemann, pp. 35–47. https://doi.org/10.1016/B978-0-12-802169-9.00003-3

[14] https://library.wmo.int/doc_num.php?explnum_id=7342

1.4.1. Local floods

Very high rainfall intensity and duration during the rainy season are sometimes caused by seasonal storms and depressions and exacerbated by saturated or impervious soil. Built environments like cities generate higher surface run-off that is in excess of local drainage capacity, thereby causing local floods. Urbanization leads to decreased rates of infiltration and increased surface runoff. Many urban drainage facilities are not in good shape due to a lack of cleaning and maintenance. Rubbish and debris tend to clog the bottlenecks of drainage facilities, thus reducing the drainage capacity and leading to increased surface runoff and backup effects, causing local floods[15].

Localised flooding occurs many times a year in slum areas because there are few drains, most of the ground is highly compacted and pathways between dwellings become streams after heavy rain. In small and medium towns and cities, the rapid development and the consequent infrastructure such as road building fails to account for the natural drainage systems without providing for cross-drainage works. Depending on the local hydro-geological situation, groundwater rising or subsurface flows can be other causes in the generation of local floods. Local floods are generally confined to rather small geographical areas and are normally not of long duration. However, in regions of extended rainy seasons (monsoon climates), local floods may last for weeks, resulting in widespread destruction[16].

1.4.2. Riverine Floods

River floods are triggered by heavy rainfall or snow melt in upstream areas or tidal influence from the downstream. Ground conditions such as soil, vegetation cover, and land use have a direct bearing on the amount of runoff generated. River floods occur when the river run-off volume exceeds local flow capacities. The river levels rise slowly and the period of rising and fall is particularly long, lasting a few weeks or even months, particularly in areas with flat slopes and deltaic areas. Failure or bad operation of drainage or flood control works upstream can also sometimes lead to riverine flooding. Urban areas situated in the low-lying areas in the middle or lower reaches of rivers are particularly exposed to extensive riverine floods. In most major river basins, flood plains are subjected to annual flooding. Often, urban growth expands over some of the floodplains, reducing the area into which floods can naturally overflow.

[15] https://training.fema.gov/hiedu/docs/fmc/chapter%202%20-%20types%20of%20floods%20and%20floodplains.pdf
[16] https://journals.sagepub.com/doi/pdf/10.1177/0956247808089156

Where parts of the city are below flood level and are protected by artificial levees, there is a risk that they may be breached and cause devastating urban flooding.

1.4.3. Coastal Floods

High tides and storm surge caused by tropical depressions and cyclones can cause coastal floods in urban areas located at estuaries, tidal flats and low-lying land near the sea in general. Coastline configurations, offshore water depth and estuary shape can influence the intensity of coastal floods. Moreover, high tides may impede the discharge of rivers and drainage systems, leading to local or riverine floods. Tidal effects in the estuarine reaches can keep the river levels high for long periods of time and sustain flooding. Thus the cities located in estuarine reaches have to bear the combined impacts of riverine as well as coastal floods due to storm surges and tidal effects. Coastal areas are exposed to sea erosion, which is particularly likely with the increase in sea roughness due to climate change. Tsunamis, mainly triggered by powerful offshore earthquakes, can also cause coastal floods though infrequently[17].

1.4.4. Flash Floods

Flash floods occur as a result of the rapid accumulation and release of runoff waters from upstream mountainous areas, which can be caused by very heavy rainfall, cloud bursts, landslides, the sudden break-up of an ice jam or failure of flood control works. They are characterized by a sharp rise followed by relatively rapid recession causing high flow velocities. Discharges quickly reach a maximum and diminish almost as rapidly. Flash floods are particularly common in mountainous areas and desert regions but are a potential threat in any area where the terrain is steep, surface runoff rates are high, streams flow in narrow canyons and severe thunderstorms prevail. Especially in densely populated areas, they are more destructive than other types of flooding because of their unpredictable nature and unusually strong currents carrying large concentrations of sediment and debris, giving little or no time for communities living in its path to prepare for it and causing major destruction to infrastructure, humans and whatever else stands in their way. Small streams in urban areas can also rise quickly after heavy rain due to higher run-off generated and the smaller time of concentration. Changes in the urban area and in storm intensity produce higher flows that exceed capacity of small culverts under roads designed for un-urbanized situation[18].

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[17] https://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/flood/coastal_floodingandstormsurges.html
[18]https://www.civilsdaily.com/mains/what-do-you-understand-by-the-phenomenon-of-cloud-burst-how-is-it-related-to-flash-floods-why-are-hilly-areas-more-prone-to-the-ill-effects-of-cloud-burst-250-words/

1.5. Urban Floods in India

Floods are a common occurrence in India (Figure 4), especially during the southwest monsoon season from June to September, and the northeast monsoon season from October to November[19]. Changes in climate over the Indian region, particularly during the southwest monsoon, would have a significant impact on agricultural production, water resources management and the overall economy of the country. Such climatic changes would also mean an increase in extreme weather events, droughts and floods[20].

There has been an increasing trend of urban flood disasters in India over the past several years. The most notable amongst them are Hyderabad in 2000, Ahmedabad in 2001, Delhi in 2002 and 2003, Chennai in 2004, Mumbai in 2005, Surat in 2006, Kolkata in 2007, Jamshedpur in 2008, Delhi in 2009 and Guwahati and Delhi in 2010. The most recent devastating ones were Srinagar in 2014 and Chennai in 2015. In recent past, the country has witnessed many catastrophic floods which led to irreparable damage to life, property, livelihoods and infrastructure. Some of the worst flood events which occurred in India are[21].

- Kerala (August 2018): The state received 2346.6 mm of rainfall from June 1, 2018, to August 19, 2018, in contrast to the expected 1649.5 mm. With more than 400 reported deaths, lakhs displaced from their homes and estimated economic losses of Rs.30,000 crore, the floods left an incredible amount of damage in their wake
- Tamil Nadu (November 2015): The city of Chennai recorded heavy rainfall in the month of November 2015. This eventually led to massive flooding and caused India over 50,000 crore rupees in losses. More than 500 people died, over 50,000 homes were structurally damaged, and over 1.8 million people were displaced.
- Jammu and Kashmir (September 2014): Flood caused by heavy rains, lasted for eight days. Jammu and Kashmir usually receives around 100mm of rain in September, but in the first four days of the month in 2014, the state had already received 400mm of rain, which led to the floods. The economic value of the damage was estimated to be between Rs 5000 crore and Rs 6000 crore.

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[19] Sushmita Panda, 2019. A watery tale: Six floods that rocked India | India News – India TV [WWW Document]. URL https://www.indiatvnews.com/news/india-a-watery-tale-six-floods-that-rocked-india-heavy-rains-imd-534320 (accessed 7.4.22).

[20] Jamwal, N., 2018. Changing rainfall patterns cause for worry in India. India Climate Dialogue. URL https://indiaclimatedialogue.net/2018/06/25/changing-rainfall-patterns-cause-for-worry-in-india/ (accessed 7.4.22).

[21] Ritika Tiwari, 2019. Six Floods That Devastated India | The Weather Channel - Articles from The Weather Channel | weather.com [WWW Document]. The Weather Channel. URL https://weather.com/en-IN/india/monsoon/news/2019-07-09-floods-rainfall-rains-flash-flooding-waterlogging-gutters-stagnant (accessed 7.4.22).

- Uttarakhand (June 2013): Heavy rain due to a cloudburst led to sudden flash floods and landslides in the northern part of Uttarakhand. The rains occurred a whole month before the monsoon season, they caught everyone by surprise. More than 100,000 people trapped in landslides, an estimated 4,094 were killed and over 5,700 were missing (and eventually presumed dead). The Uttarakhand floods are considered one of the worst natural calamities in India since the 2004 Indian Ocean tsunami Assam, July 2012, the monsoon rains started earlier and heavier than the previous year. The state got about 528mm rain, which was 28per cent more than its average annual rainfall. Over 124 people, including 70 children, died in the floods and about 2.2 million people were affected. The floods also inundated large parts of the Kaziranga National Park and affected its resident animals severely. It is estimated that over 560 animals died, including 14 rhinos.
    - Maharashtra (July 2005): Mumbai received about 944 mm rain in just 24 hours: a 100-year record. Over 1,000 people lost their lives in the deluge, while approximately 14,000 homes were destroyed. The city had to bear a direct loss of Rs 450 crore

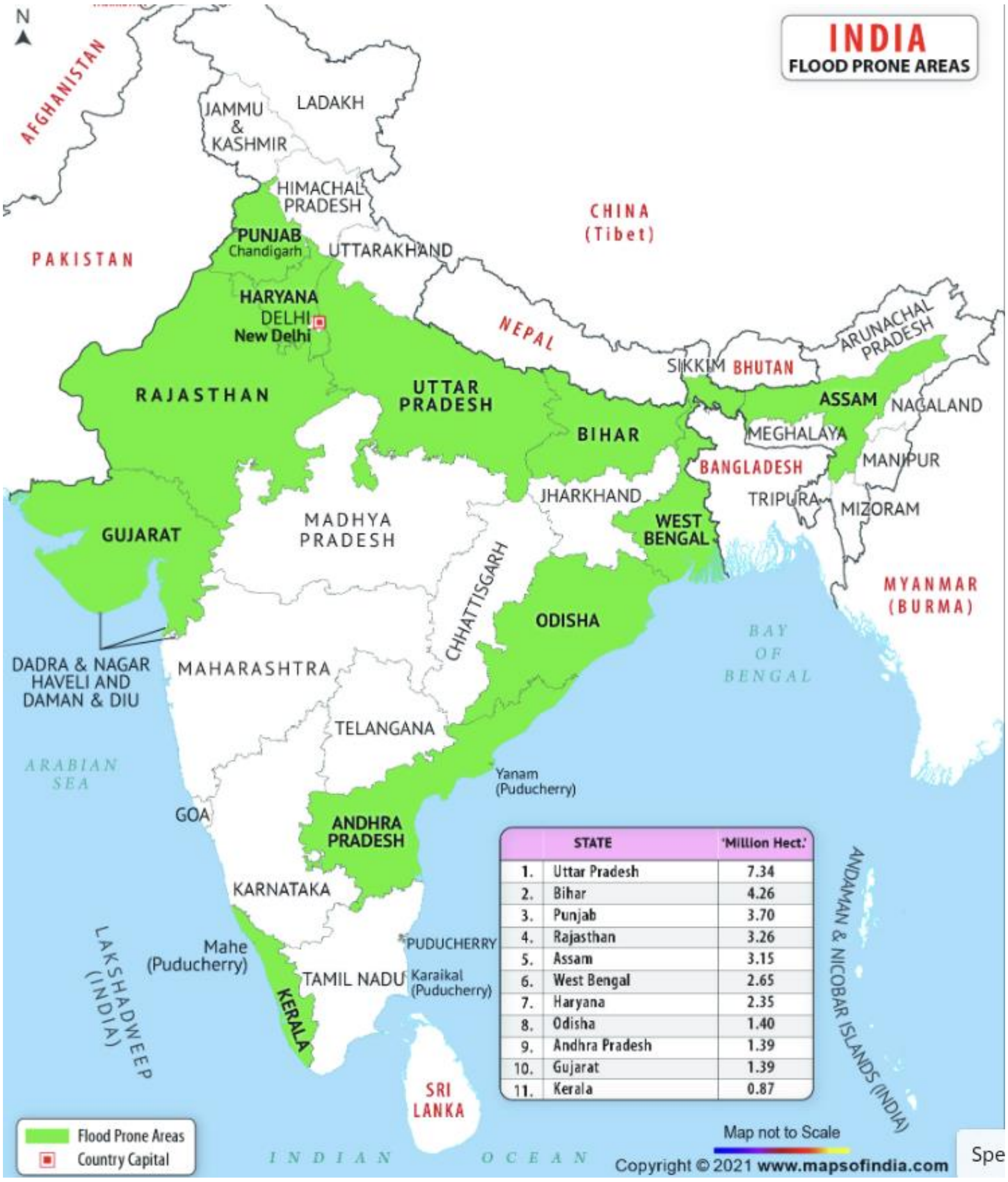

Figure 4: Top 10 flood prone areas in India

Image Source: https://www.mapsofindia.com/top-ten/geography/india-flood.html

1.6. Legal framework for Flood Management in India

Since the flood management is primarily in the domain of States, flood control and management schemes are planned, investigated and implemented by the State Governments with their own resources, according to the priority within the States.[22]

Central Government: The Department of Water Resources, River Development and Ganga Rejuvenation (DoWR, RD&GR), Ministry of Jal Shakti is responsible for laying down policy

[22] https://www.niti.gov.in/sites/default/files/2021-03/Flood-Report.pdf

guidelines and programmes for the development and regulation of the country's water resources. The Ministry provides technical guidance and conducts scrutiny, clearance and monitoring of the irrigation, flood control and multi-purpose projects (major/medium). The Ministry is also responsible for the operation of the central network for flood forecasting and warning on inter-state rivers, the provision of central assistance for some State Schemes in special cases and the preparation of flood control master plans for the Ganga and the Brahmaputra. The two-tier system for flood management in India is[23]:

1.6.1. <u>Central Government</u>

• Central Water Commission

• Ganga Flood Control Commission (GFCC)

• Brahmaputra Board (BB) •

National Disaster Management Authority (NDMA)

The Union Government has the following organisations to enable the State Governments in addressing flood problems in a comprehensive manner:

Central Water Commission

Central Water Commission (CWC), an attached office under the Department of Water Resources, River Development and Ganga Rejuvenation, is the apex organization for achieving the goal of furthering and promoting measures of flood control, conservation and utilization of water resources throughout the country in the areas of beneficial uses, irrigation and hydropower generation, flood management and river conservation. The CWC plays a direct role in real time collection of flood data, flood forecasting and dissemination of flood forecasts to the local administration for planning suitable administrative measures including evacuation of people from flood affected areas to safer locations.

Ganga Flood Control Commission

The Ganga Flood Control Commission (GFCC) was set up by the Government of India (GoI) in 1972 for preparation of comprehensive plan for flood management of the river systems in the Ganga basin including implementation, monitoring and performance evaluation of various flood management schemes and technical guidance to the basin States such as Bihar,

[23] https://cag.gov.in/en/audit-report/details/31347

Chhattisgarh, Delhi, Haryana, Himachal Pradesh, Jharkhand, Madhya Pradesh, Rajasthan, Uttar Pradesh, Uttarakhand and West Bengal.

The Brahmaputra Board (BB)

The Brahmaputra Board is a statutory body constituted in 1980 by an Act of Parliament with the objective of planning and integrated implementing measures for the control of flood and bank erosion in the Brahmaputra. The jurisdiction of the Board includes the States of Arunachal Pradesh, Assam, Meghalaya, Manipur, Mizoram, Nagaland, Sikkim, Tripura and part of West Bengal falling within the Brahmaputra Basin.

National Disaster Management Authority

The Government of India (GoI) set up National Disaster Management Authority (NDMA) in 2005 to implement a holistic and integrated approach to Disaster Management in India. NDMA is mandated to lay down the policies, plans and guidelines for Disaster Management to ensure a timely and effective response to disasters.

1.6.2. <u>State Government</u>

- Water Resources Departments
- State Technical Advisory Committees (STAC)
- Flood Control Boards,
- Irrigation Departments
- Public Works Departments

The State Level Mechanism includes the Water Resources Departments, State Technical Advisory Committees (STAC) and Flood Control Boards, Irrigation Departments and Public Works Departments. The States are required to investigate, plan, construct, maintain and operate all flood works.

1.7. Agencies playing role in Flood Management:

In India, a vast federal country with 28 states and eight union territories, the responsibility of flood control and management (Figure 5) is scattered across many agencies[24].

[24] https://www.orfonline.org/expert-speak/inadequate-storm-water-infrastructure-biggest-hurdle-in-urban-flood-resilience/

1. The water resources ministries of different states oversee flood control in consultation with the Central Water Commission (CWC). The main job of the Central Water Commission (CWC) is to procure data on hydrology at the national level – like river discharge measurement and water level in dams– to alert the states about any imminent or potential flood.
2. India Meteorological Department (IMD) provides rainfall or cyclonic event forecast which is used by all the agencies for preparedness to deal the floods. For the national-level response to disasters, there is National Disaster Management Authority (NDMA) which works under Prime Minister's Office (PMO) – and the National Institute of Disaster Management (NIDM) – a body under the Union Ministry of Home Affairs (MHA). The job of relief and rescue is carried out by the National Disaster Response Force (NDRF) with state counterparts.
3. NDMA is the topmost organization for disaster management in India. It has fallen short of successfully coordinating with state and district authorities. Rather many times, other government bodies are found to be filling the shoes. This is because of dispersed responsibilities for different disaster and no mandatory power to enforce its guidelines[25].
4. Government of India has implemented two major schemes viz. Flood Management Programme and Flood Forecasting Scheme towards Flood Forecasting, Control and Management. 1. Flood Management Programme: The scheme was sanctioned by the Cabinet in November 2007 with Central Assistance of Rs 8,000 crore in Eleventh Five Year Plan (2007-2012)[26].

[25] Sehra, V., Punia, M., 2020. Overcoming Barriers to Urban Flood Resilience: A Case of Hyderabad, India, Flood Impact Mitigation and Resilience Enhancement. IntechOpen. https://doi.org/10.5772/intechopen.93195
[26] https://www.niti.gov.in/sites/default/files/2021-03/Flood-Report.pdf

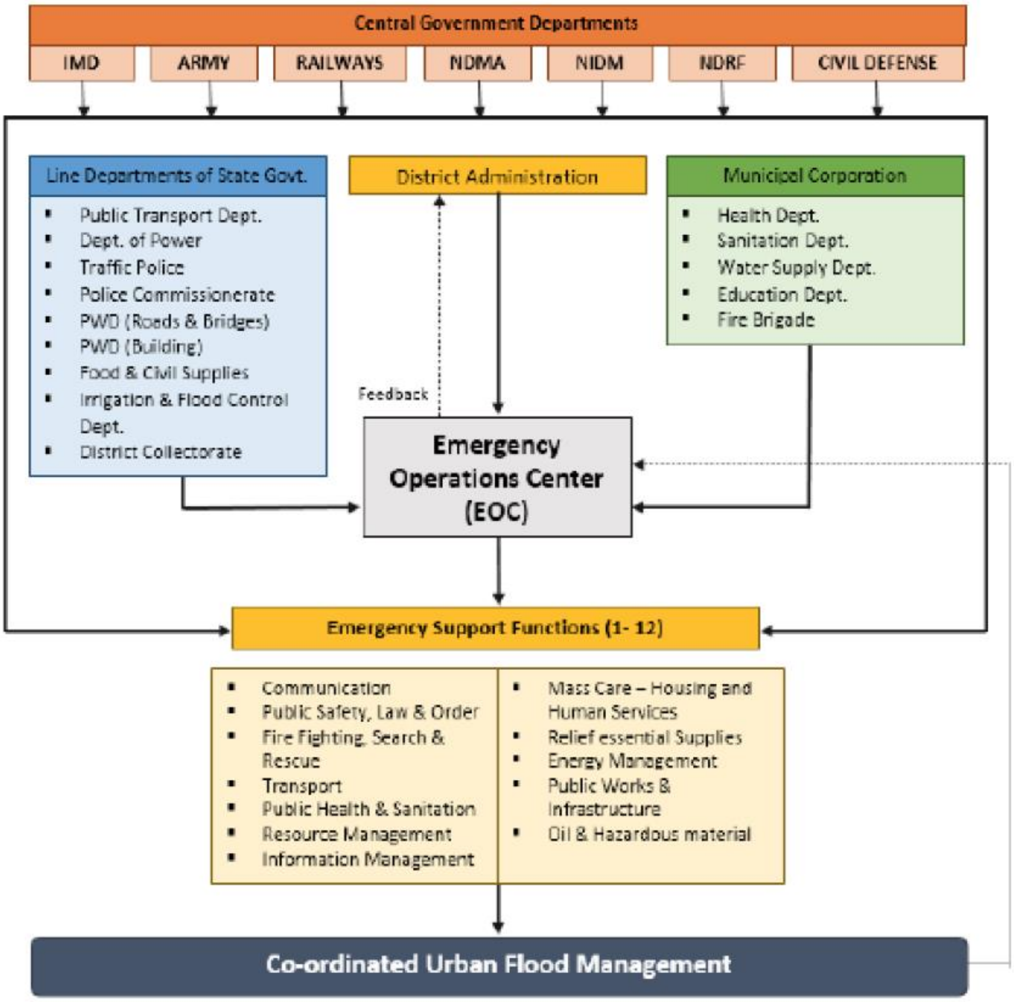

Figure 5: Co-ordination between agencies for urban flood management

Image Source: https://niua.org/sites/default/files/SOP_Urban_flooding.pdf

Chapter 2. Causes, Impacts and Risks of Urban Floods

Understanding the drivers behind urban floods is critical for reducing its devastating impacts to human and society. Urban floods have various adverse socioeconomic impacts, and can cause disruptions to city services (e.g., transportation, sewerage, communication and electricity supply) and damages to urban infrastructure[27]. There is a growing concern that risk of flooding will increase in many regions of the world, especially in those metropolitan areas where there are a large number of population and assets[28]. Among the various factors that contribute to increasing flood risks (Figure 6), changes in climate and urbanization are two of the most influential ones that challenge the current and future urban flood management strategies[29]. On one hand, climate change exerts large impacts on water cycle and patterns of precipitation extremes, on the other hand urbanization associated with population and wealth growth is one of the most common causes of increasing impervious surfaces and socioeconomic vulnerability in urban areas to floods[30] .

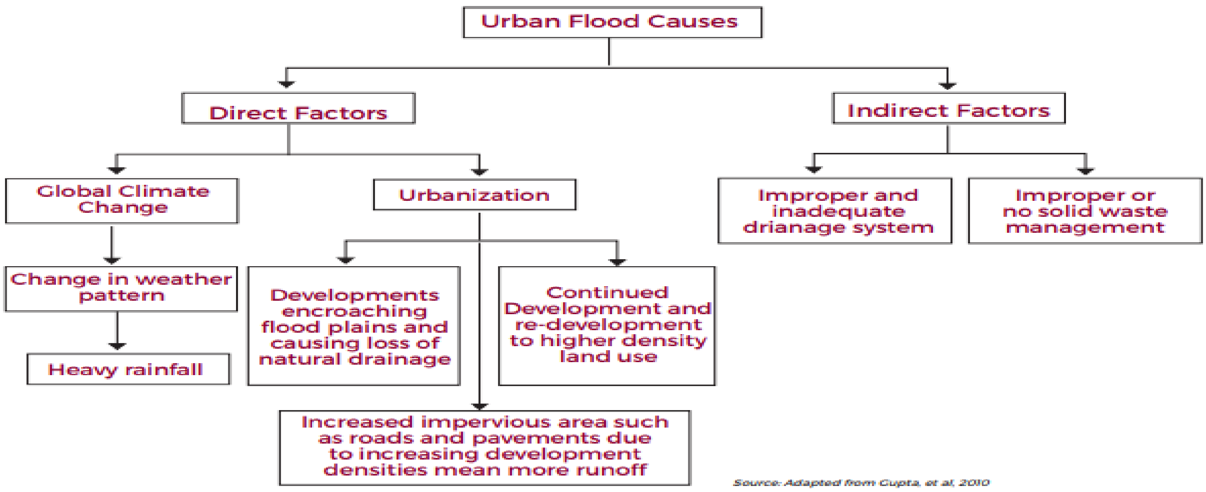

Figure 6: Urban Flood Causes

Image Source- https://smartnet.niua.org/sites/default/files/resources/FSper cent203_Urbanper cent20Flooding.pdf

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[27] Wu, X., Wang, Z., Guo, S., Liao, W., Zeng, Z., Chen, X., 2017. Scenario-based projections of future urban inundation within a coupled hydrodynamic model framework: A case study in Dongguan City, China. Journal of Hydrology 547, 428–442. https://doi.org/10.1016/j.jhydrol.2017.02.020

[28] Zhou, Q., Leng, G., Huang, M., 2018. Impacts of future climate change on urban flood volumes in Hohhot in northern China: benefits of climate change mitigation and adaptations. Hydrology and Earth System Sciences 22, 305–316. https://doi.org/10.5194/hess-22-305-2018

[29] Skougaard Kaspersen, P., Høegh Ravn, N., Arnbjerg-Nielsen, K., Madsen, H., Drews, M., 2017. Comparison of the impacts of urban development and climate change on exposing European cities to pluvial flooding. Hydrology and Earth System Sciences 21, 4131–4147. https://doi.org/10.5194/hess-21-4131-2017

[30] Mahmoud, S.H., Gan, T.Y., 2018. Urbanization and climate change implications in flood risk management: Developing an efficient decision support system for flood susceptibility mapping. Science of The Total Environment 636, 152–167. https://doi.org/10.1016/j.scitotenv.2018.04.282

Urban floods are caused by natural events and anthropogenic activities. In Indian cities flooding is becoming frequent due to both human factors and meteorological/hydrological factors, with the former factor being more predominant. Some of the issues contributing to urban floods are listed below[31]:

1. Planning issues: Increasing population, habitations coming up in low-lying areas, encroachment on drainage channels and immediate upper catchment of hilly urban areas.

2. Technical issues: Increased imperviousness leading to increased runoff as compared to drainage capacity, improper waste disposal resulting in clogged drains, high intensity – high load of runoff.

3. Meteorological issues: Exacerbated by changing climate, resulting in extreme events, NASA studies indicate that the urban heat island effect also results in increased rainfall over urban areas.

4. Policy issues: Lack of integrated flood control implementing agency

Some of the major causes are discussed below-

2.1. Direct Factors

2.1.1. Global climate change

Global climate models project a continuation of human-induced climate change during the twenty-first century and beyond and if the current Green House Gas emission rates are sustained, the global average temperature is likely to rise by nearly 5°C, and possibly more, by the end of the twenty-first century[32]. India's average annual mean temperature during 1901-2020 showed an increasing trend of 0.62°C per 100 years (Figure 7). This warming trend is highest during the post-monsoon season (0.88°C per 100 years) followed by the winter season (0.68°C per 100 years)[33]. Sea surface temperature (SST) of the tropical Indian Ocean has risen by 1°C on average during 1951–2015, markedly higher than the global average SST warming of 0.7°C, over the same period[34].

[31] https://smartnet.niua.org/sites/default/files/resources/FSper cent203_Urbanper cent20Flooding.pdf

[32] https://www.ipcc.ch/sr15/chapter/spm/

[33] https://climateknowledgeportal.worldbank.org/country/india/climate-data-historical

[34] Government of India, 2020. Assessment of climate change over the Indian region: A report of the Ministry of Earth Sciences (MoES), Government of India - India | ReliefWeb [WWW Document]. URL https://reliefweb.int/report/india/assessment-climate-change-over-indian-region-report-ministry-earth-sciences-moes (accessed 7.4.22).

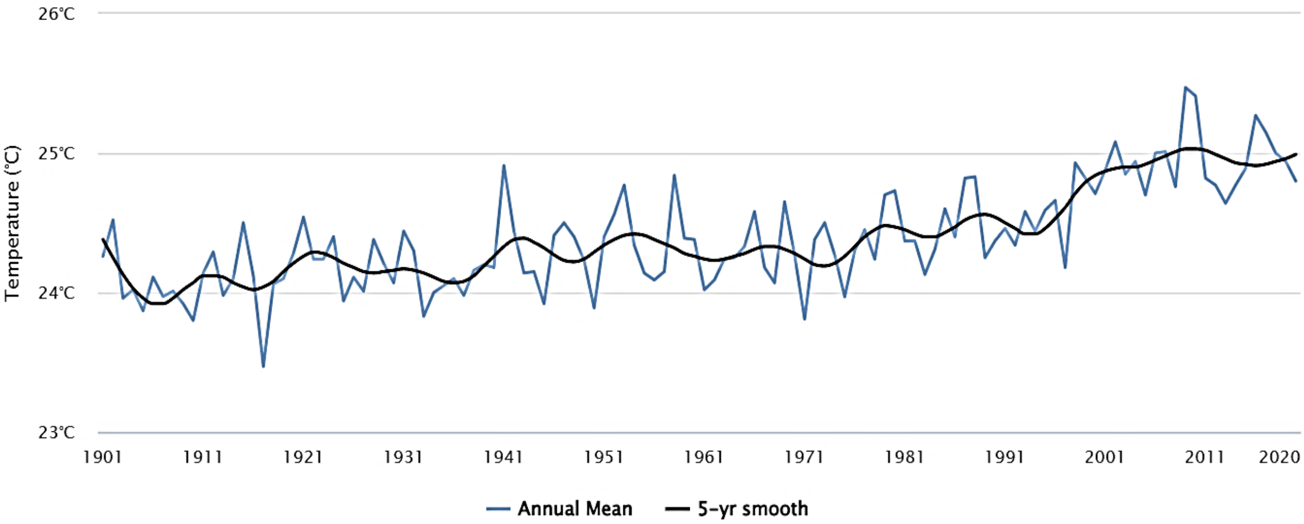


Figure 7: Observed annual mean temperature change of India for 19+01-2020

Image Source: https://climateknowledgeportal.worldbank.org/country/india/climate-data-historical

Climate change due to various anthropogenic events has led to changes in weather patterns which have led to extreme weather events like heavy storms, cyclones etc. Extreme precipitation amplification may increase the intensity and frequency of flooding. Increases in average atmospheric temperatures are one of the projected impacts of climate change. An increase in air temperature increases the amount of water that the air can hold, increasing the water available for precipitation[35].

One of the effects of Urban Heat Island is flash floods, which is a consequence of the increase of impervious areas. Floods are the most frequent disaster type and cause more humanitarian needs than other natural disasters[36].

[35] https://www.epa.gov/climate-indicators/weather-climate

[36] 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

Case Study

The year 2005 was recorded as the hottest year of the century. Incidentally, in the same year, the worst urban flooding was reported in Mumbai on July 26-27. During those two days, the city witnessed an unprecedented 944 mm of rainfall in 24 hours. In the same year, 10 severe urban floods were reported from across the country. Three-fourths of Chennai was inundated. It affected more than 500,000 people. In 2006, 22 cities in India reported floods. The increasing trend of urban flooding was carried into 2007, where the number of affected cities rose to 35. The entire Himalayan range is vulnerable because of rising temperatures. Each and every valley be it Kashmir, Kedarnath or Badrinath faces the threat of increased precipitation. According to the Jammu and Kashmir State Action Plan on Climate Change, 2013, minimum temperatures in the Himalayan region are projected to rise by 1 C-4.5 C. The number of rainy days in the region in 2030s may increase by five. The intensity of rainfall is likely to increase by 1-2 mm per day".

Sources:
https://www.researchgate.net/publication/332696866_Causes_of_Urban_Floods_in_India_Study_of_Mumbai_in_2006_and_Chennai_in_2015
http://www.indiaenvironmentportal.org.in/media/iep/infographics/Urban%20Nightmare/index.htm

2.1.2. Urbanization

Increased impervious area such as roads and pavements due to increasing development densities mean more runoff and Continued Development and re-development to higher density land use

Unplanned urbanization is another key cause of urban flooding. Some of the major hydrological effects of urbanization (Figure 8) are reduced infiltration due to paving of surfaces which decreases ground absorption and increases the speed and amount of surface flow [37]. Land use and other human activities also influence the peak discharge of floods by modifying how rainfall and snowmelt are stored on and run off the land surface into streams[38]. Construction of

[37] https://www.niti.gov.in/sites/default/files/2021-03/Flood-Report.pdf
[38] C. P. Konrad, n.d. Effects of Urban Development on Floods [WWW Document]. URL https://pubs.usgs.gov/fs/fs07603/ (accessed 7.4.22).

roads and buildings often involves removing vegetation, soil, and depressions from the land surface. The permeable soil is replaced by impermeable surfaces such as roads, roofs, parking lots, and sidewalks that store little water, reduce infiltration of water into the ground, and accelerate runoff to ditches and streams[39]. Urbanization coupled with encroachments, pollution which causes interference in the smooth flow of water in the drainage channels.

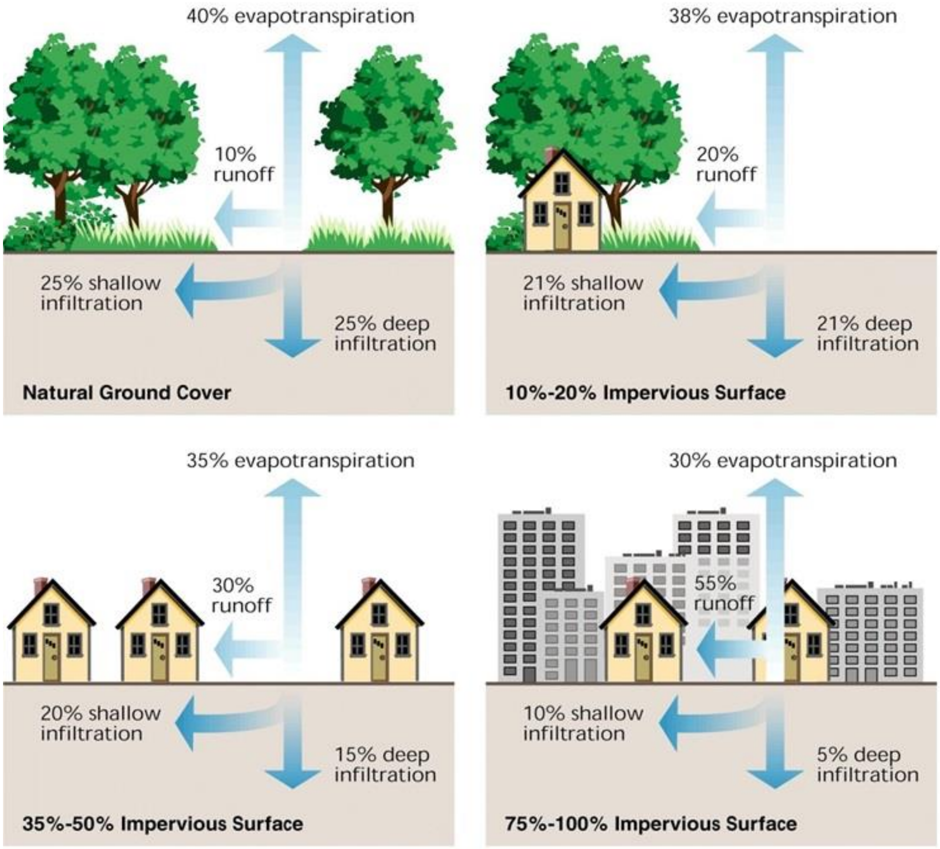


Figure 8:How increasing built-up area cause urban flooding

Image Source: https://eduindex.org/2021/08/04/urban-flooding-drowning-cities-and-increasing-vulnerability/

2.1.3. Encroachments and disappearance of flood plain

As per the Indian water portal report in spite of series of disastrous floods events in India like in Mumbai (2005), Kedarnath (2013), Srinagar (2014), Chennai (2015) and Kerala (2018) resulting from the human occupation of river floodplains, India is still without a legally mandated prohibition on such ingress into and violation of river's integrity[40]. Floodplains provide the space for rivers to spread their waters. Encroachments are also a major problem in

[39] Mukherjee, D., 2016. EFFECT OF URBANIZATION ON FLOOD - A REVIEW WITH RECENT FLOOD IN CHENNAI (INDIA). https://doi.org/10.5281/zenodo.57002
[40] https://www.indiawaterportal.org/articles/sad-state-floodplains

many cities and towns. Habitations started growing into towns and cities alongside rivers and watercourses. As a result of this, the flow of water has increased in proportion to the urbanization of the watersheds (Figure 9). When this space is missing due to encroachments, the river surges up and creates destruction[41]. India still lacks floodplain regulation and is more flood-related disasters. A 2018 report of the Comptroller and Auditor General of India (C&AG) attributed encroachment in the floodplains of Tamil Nadu rivers and failure to act on prime reason for the Chennai floods of 2015 which killed around 300 persons. The auditor went on to term the deluge as a "man-made disaster"[42]. In 2016, a report has found that 4,533 out of 27,899 acres of tanks in the city had been encroached. Since then, the action against the offenders, which includes government agencies has been sporadic[43].

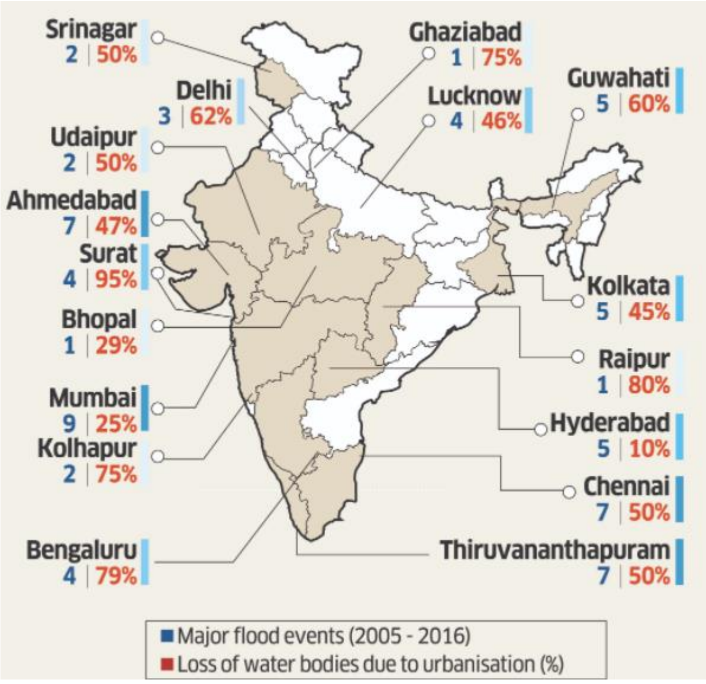


Figure 9: Flood incidences due to encroachments and loss of water bodies

Image Source: https://www.deccanherald.com/specials/insight/recurring-urban-floods-elicit-quick-fix-solutions-no-concrete-action-915697.html

Flood plains of the rivers in urban areas have witnessed construction activities (Figure 10) including unauthorized residential development[44]. The water level in the rivers prior to onset

[41] https://www.niti.gov.in/sites/default/files/2021-03/Flood-Report.pdf
[42] Manish Kumar, 2021. With poor regulation of floodplains, India is more vulnerable to flood damage [WWW Document]. Mongabay-India. URL https://india.mongabay.com/2021/07/with-poor-regulation-of-floodplains-india-more-vulnerable-to-flood-damage/ (accessed 7.4.22).
[43] https://www.deccanherald.com/specials/insight/recurring-urban-floods-elicit-quick-fix-solutions-no-concrete-action-915697.html
[44] https://mohua.gov.in/upload/uploadfiles/files/RCUPper cent20Guidelines.pdf

of monsoon remains usually low resulting in longer recharge period for the groundwater aquifers compared to the high pumping (discharge) rate[45].

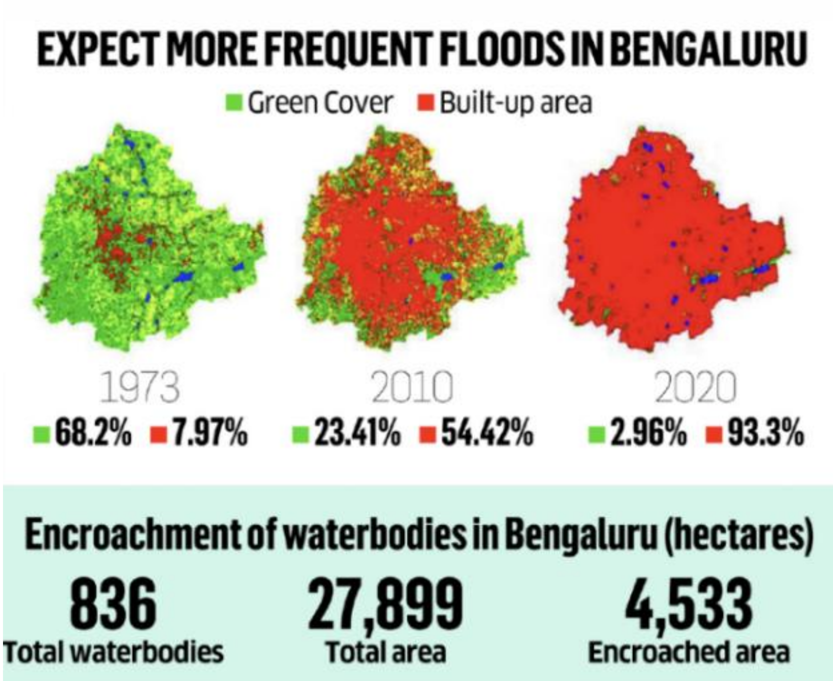


Figure 10: Increase in encroachment area of Bengaluru city India. 1973-2020

Image Source: https://www.deccanherald.com/specials/insight/recurring-urban-floods-elicit-quick-fix-solutions-no-concrete-action-915697.html

Policy framework for floodplains in India[46]

1. The Ministry of Water Resources in 1975 had issued a draft Model Bill on floodplains and asked the states to frame legislation. Land and flood management is a state subject.
2. The National Disaster Management Authority (NDMA) in 2008 also issued guidelines for states for floodplain zoning as an important "non-structural measure" to mitigate floods. It suggested that "areas likely to be affected by floods in a frequency of tem years should be reserved for green areas like parks, gardens and others while concrete structures should not be allowed there.".
3. Manipur was among the first to frame the Manipur Flood Zoning Act in 1978, while Uttarakhand came up with the Uttarakhand Flood Plain Zoning Act 2012. The Maharashtra government also created norms to regulate and talked about prohibitory zones in floodplains of its rivers. Only three states—Manipur, Rajasthan and Uttarakhand—have

[45] https://www.deccanherald.com/specials/insight/recurring-urban-floods-elicit-quick-fix-solutions-no-concrete-action-915697.html
[46] https://india.mongabay.com/2021/07/with-poor-regulation-of-floodplains-india-more-vulnerable-to-flood-damage/

enacted laws pertaining to floodplain zoning, while others, particularly the flood-affected Bihar and Assam, have shown varying degrees of opposition[47].

4. The 2021 report of the National Institution for Transforming India (NITI) Aayog Committee, for the formulation of strategy for flood management works in the country, also recommended floodplain zoning as an important non-structural measure to counter flood damages. The report also urged the Jal Shakti Ministry to impress upon the states the need to take measures to ensure floodplain zoning.
5. National River Conservation Authority (headed by the Secretary of the Ministry of Environment, Forests and Climate Change), and a State River Conservation Authority (headed either by the Chief Secretary or Additional Chief Secretary at the state level) classifies river stretches and tributaries in to three categories namely floodplain rivers, seasonal rivers and mountain rivers/hill streams[48].

[47] https://www.orfonline.org/research/from-policy-to-practice-charting-a-path-for-floodplain-zoning-in-india-66717/
[48] https://www.gktoday.in/topic/river-regulation-zones-rrzs/

Case Studies

Bengaluru: A study conducted on urban flood for Bangalore identified that the disappearance of waterbodies or sharp decline in the number of waterbodies in Bangalore is mainly due to intense urbanisation and urban sprawl. Many lakes were encroached for illegal buildings (54per cent). Field survey (during July-August 2007) showed that nearly 66 per cent of lakes are sewage fed, 14 per cent surrounded by slums and 72 per cent showed loss of catchment area[1]. A study by the Indian Institute of Science stated that the city (covering an area of 741 sq km) had 1,452 water bodies with a total storage capacity of 35 TMC during early 1800s. By 2016, the number of water bodies in the same area reduced to 194 with a storage capacity of 5 TMC[2].

A "Performance audit of Management of storm water in Bengaluru Urban area, 2021" report revealed that "Bengaluru witnessed large scale encroachment of lakes/drains and depletion of natural drainage systems. The changes in land use such as decrease in vegetation cover and open spaces and increase in built up area resulted in loss of inter-connectivity between water bodies impacting effective recharge of ground water and increase in runoff of storm water"[3].

Kerala: The Kerala floods are a tragic reminder of the cost that the nation is paying for its inability to enact a River Regulation Zone (RRZ). Till date, the state government has been successful in evicting only 1,890 out of the 2,626 identified encroachments[4]. In Kerala, the Supreme Court had to intervene and in less than a few days, the government brought down the buildings on encroached areas.

Chennai: The catastrophic Chennai floods in December 2015, which left 280 people dead, was caused by the encroachment of lakes and riverbeds[5].

Sources:

1. https://cdn.downtoearth.org.in/uploads/0.56859500_1457688308_Preview.pdf
2. http://wgbis.ces.iisc.ernet.in/energy/water/paper/ETR124/section3.html
3. https://cag.gov.in/uploads/download_audit_report/2021/2.%20Executive%20Summary061430463965e68.70381499.pdf
4. https://www.deccanherald.com/specials/insight/recurring-urban-floods-elicit-quick-fix-solutions-no-concrete-action-915697.html
5. https://www.news18.com/news/india/urban-floods-disarraying-life-the-ugly-truth-of-modern-india-1505341.html

2.2. Indirect Factors

2.2.1. Poor urban planning - Improper and inadequate drainage system

Over the last few years, a lot of efforts have been made by the Centre and the State Governments in the urban sector. However, urban planning, which is the foundation for the integrated development of cities, citizens, and the environment, has not received adequate attention[49]. Over the period 2001-2011, the urban population of India increased manifold (Figure 11), magnifying the risks that cities are already confronted with; particularly those associated with poverty, lack of basic services, slum formation, unplanned and unstable buildings, houses and infrastructures located in hazard-prone areas, pollution and environmental degradation[50].

Urban development can change the environment or ecosystem through, for instance, the expansion of paved, impermeable areas, which prevent rain from being absorbed by the soil thereby increasing flood hazards, particularly in low-lying areas. India has faced 649 disasters from 1915 to 2015. Out of these 649 events 302 disaster were caused by flood with on an average of 3 flood per year. This accounted approximately 47% of total disasters took place in India in the last 100 years[51]. Out of the total geographical area of 329 million hectares (mha), more than 40 mha is flood prone[52].

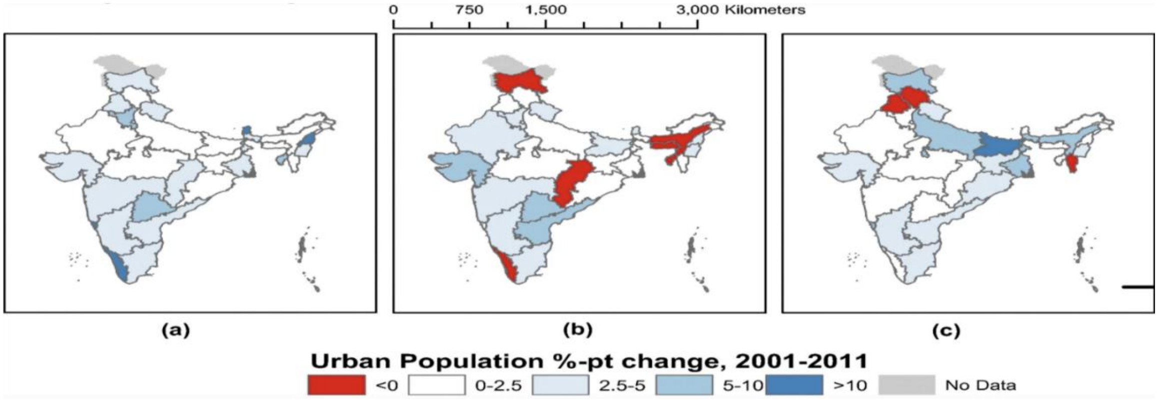


Figure 11: Change in urbanization by state, 2001–2011 a. Census of India b. Indiapolis c. MAGPIE (7.5 persons/ha)

Image Source: https://link.springer.com/article/10.1007/s11111-019-00329-2

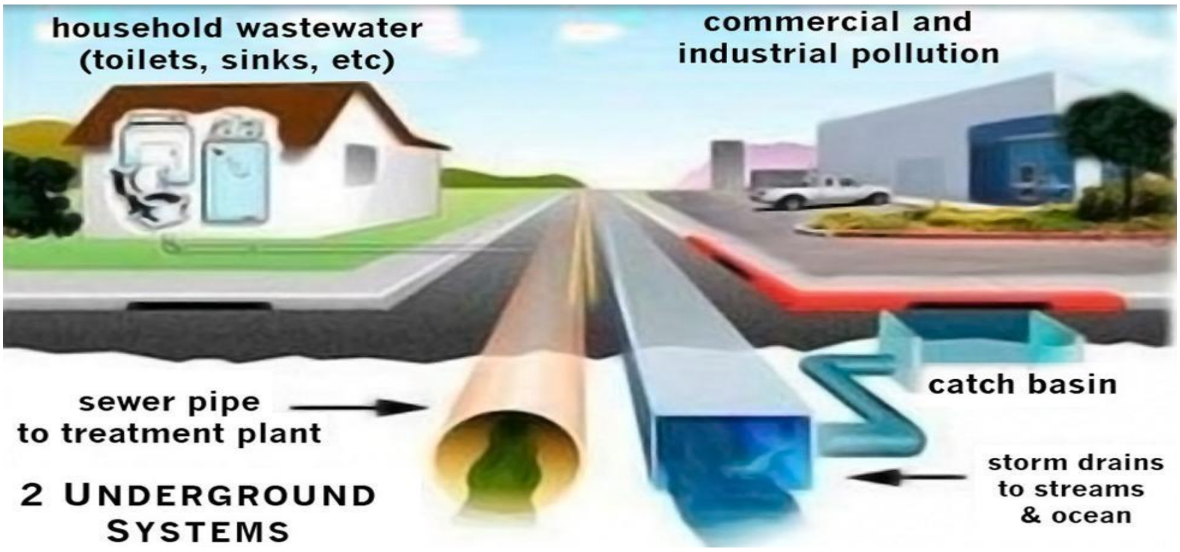
[49] Abd Elrahman, A.S., Asaad, M., 2021. Urban design & urban planning: A critical analysis to the theoretical relationship gap. Ain Shams Engineering Journal 12, 1163–1173. https://doi.org/10.1016/j.asej.2020.04.020

[50] UNDRR, 2013. Poorly planned urban development [WWW Document]. URL https://www.preventionweb.net/understanding-disaster-risk/risk-drivers/poorly-planned-urban-development (accessed 7.4.22).

[51] Flood Disaster in India: An Analysis of trend and Preparedness. Available from: https://www.researchgate.net/publication/292980782_Flood_Disaster_in_India_An_Analysis_of_trend_and_Preparedness [accessed Jul 04 2022].

[52] https://ndma.gov.in/Natural-Hazards/Floods

Urban water management systems, especially in cities, are largely based on traditional engineering approaches which aim to evacuate the runoff from the cities as quickly as possible rather than endeavour to store and reuse it. These are usually developed to rid the city of storm water as quickly as possible resulting in increased imperviousness in urban areas. Pluvial flooding — rain-driven flooding that results from the excess of natural or engineered drainage



capacity — has emerged as a critical issue in urban water management[53]. India's urban centres receive much heavier

Figure 12: Ideal scenario for storm water management

Image Source: https://www.quora.com/Which-are-the-cities-with-best-drainage-system-in-india

rainfalls and these outdated designs are not relevant now. The old and ill-maintained drainage system is another factor making cities in India vulnerable to flooding. Urban drainage systems have been constructed to provide carrying and conveyance capacities at a desired frequency to prevent urban flooding (Figure 12).

However, the design of drainage systems is often based on historical precipitation statistics for a certain period of time, without considering the potential changes in precipitation extremes for the designed return periods[54]. Therefore, it is important to investigate the performance of drainage systems in a changing environment and to assess the potential urban flooding under various scenarios to achieve better adaptations. The increasing encroachment in the city of

[53] https://www.downtoearth.org.in/blog/water/urban-flooding-around-the-world-where-is-india-placed--70765

[54] https://ascelibrary.org/doi/abs/10.1061/per cent28ASCEper cent29HE.1943-5584.0001064

Bengaluru and Chennai has blocked their drainage system of inter-locked water bodies and reservoirs turning them into flooding hotspots in every monsoon[55].

Case Study

Patna: During the period from 28th September to 1st October 2019, the city of Patna received about 400 mm of rainfall[1]. With all 39 sump houses remaining non-functional till October 1, at least 60 per cent of Patna faced water-logging. Clogged drains have been attributed as one of the main reasons for heavy waterlogging in the low-lying areas of the city. Experts have claimed that several tonnes of plastic and garbage and several tonnes of plastic and garbage are dumped in the open drains are dumped in the open drains by resident which prevent smooth flow of waste as well as rainwater[2]. As per a report by Indian Express "225 MLD sewage is generated in the city per day, half of which flows into the Ganga and remaining into ground water. The main identified problem is the sewage network system as only 20 per cent households are connected with the network and 50 MLD sewerage reaches up to STPs (sewage treatment plants). Around more than 80 per cent households have their own septic tanks or open discharge which itself is a threat to heath and sanitation. A choked drainage network and a punctured sewage system has led to floods and water logging in the city every year[3].

Sources:

1. https://imdpune.gov.in/hydrology/rainfall%20variability%20page/bihar_final.pdf
2. https://timesofindia.indiatimes.com/city/patna/sump-houses-ready-to-tackle-waterlogging/articleshow/92114970.cms
3. Santosh Singh, 2019. Patna Corporation admitted it failed, told HC before rains: 'Functioning in primitive way' | India News, The Indian Express [WWW Document]. URL https://indianexpress.com/article/india/patna-floods-municipal-corporation-high-court-bihar-floods-6067803/ (accessed 7.4.22).

Among the many reasons which cause urban flooding in such water courses / open sewers are

[55] https://cwp-india.org/wp-content/uploads/2021/05/REPORT-ON-URBAN-FLOOD-MANAGEMENT-DRAINAGE-AND-PLANNING.pdf

a) Encroachment of drain and reduction of flow area,

b) Improper maintenance of drainage /sewer system

c) Blockages of drainage channels by Untreated Solid Waste dumped along its flow path upstream of these sensitive points[56].

The most common reasons found for such blockages are

a) Accumulation of silt or dumped debris

b) Disposal of solid waste in the channel.

Poor and unplanned solid waste management and insensitive attitude among the upstream residents result in untreated solid waste being dumped into the open sewers[57]. Grey storm water infrastructure such as drains, pumps and outfalls are frequently overwhelmed by extreme rainfall events or high levels of storm water runoff from roads and streets.[58]

Cities continue to extend/expand storm water networks, clean/de-silt channels and separate sewage and storm water drains. These are all necessary activities and cities bear high costs to build storm water (grey) infrastructure, but repeated floods indicate that these actions are insufficient. The storm water drain shall be designed and constructed in such a way that the surface runoff water is diverted from the landfilling site and leachates from solid waste locations do not get mixed with the surface runoff water. To prevent floods, and formation of marshy conditions, provisions for diverting storm water discharge drains must be made.[59].

2.2.2. <u>Improper or no solid waste management</u>

During a flood, waste material and other debris collected by floodwaters can cause increased damage to property and after a flood, the deposition of waste can block access and be a source of toxins and breeding ground for disease[60]. In many urban areas in India after a short length of the flow of sewage underground (200mm to 1200mm diameter pipes), the sewage pipes are no longer able to take the large flow[61]. The combined sewage from these large pipes generally flows in open sewers – sewers that were originally storm water courses. These now carry sewage continuously and occasionally storm water from intense weather events. When these

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[56] http://wgbis.ces.iisc.ernet.in/energy/paper/iconswm_urban_flooding/introduction.htm
[57] http://wgbis.ces.iisc.ernet.in/energy/paper/iconswm_urban_flooding/results.htm
[58] https://en.gaonconnection.com/constructing-only-drains-and-pumps-to-resolve-climate-change-driven-storm water-issues-will-frequently-bring-indian-cities-under-water/
[59] https://cpcb.nic.in/uploads/MSW/SWM_2016.pdf
[60] https://www.witpress.com/Secure/elibrary/papers/FRIAR12/FRIAR12016FU1.pdf
[61] http://wgbis.ces.iisc.ernet.in/energy/paper/iconswm_urban_flooding/ufsw.pdf

are choked or encroached to a point of being too narrow, the water flow spills over its banks into nearby settlements. This occurs generally following high-intensity rainfall wherein the sewer /open storm drain can no longer take the large combined water flow[62]. Blockage in the drainage system by plastic was the primary cause for the 2005 floods in Mumbai which killed thousands (Figure 13). Severe floods have also affected countries like Bangladesh and Manila due to the clogging of plastic bags in the drainage system. Plastic bags were banned in Mumbai after these floods[63].

Figure 13: Plastic clogging of drains in Mumbai

Image Source: https://www.dnaindia.com/mumbai/report-mumbai-plastic-ban-goes-down-the-drain-bmc-blames-it-on-slum-dwellers-2754420

[62] http://wgbis.ces.iisc.ernet.in/energy/paper/iconswm_urban_flooding/ufsw.pdf

[63] https://www.cseindia.org/plastic-waste-will-the-new-rules-clear-up-the-clogged-mess-3705

Case Studies

Bengaluru: A study conducted on urban flood for Bangalore identified litter, building debris, sediments and solid waste are the main causes of blockages of the drainage system and subsequent flooding. A report mentioned "Disappearance of waterbodies or sharp decline in the number of waterbodies in Bangalore is mainly due to intense urbanisation and urban sprawl. Many lakes were encroached for illegal buildings (54 per cent). Field survey (during July-August 2007) shows that nearly 66 per cent of lakes are sewage fed, 14 per cent surrounded by slums and 72 per cent showed loss of catchment area. Also, lake catchments were used as dumping yards for either municipal solid waste or building debris. Another significant factor contributing to frequent flooding of low-lying areas and to unsanitary conditions in drains and lakes is the large and rapid accumulation of sediments in the drains, dumping of solid wastes, building debris and casual litter disposal on drains"[1].

Mumbai: The city of Mumbai is subject to many sources of flood risk including increased impervious areas and loss of storage within the city. A published report mentioned "Poor storm water drainage is, nevertheless, a major contributory factor to the severity of regular monsoon flooding. Indiscriminate dumping of solid waste combined with storm water and municipal wastewater often clogs the drainage system resulting in coastal flooding and inundation during monsoon months. In response to the 2005 flood the state put in place a ban on the sale and use of plastic bags. However, this has not yet been effective due to lack of awareness and enforcement"[2, 3].

Sources:

1. http://wgbis.ces.iisc.ernet.in/energy/water/paper/urbanfloods_bangalore/floods_city.htm
2. https://www.witpress.com/Secure/elibrary/papers/FRIAR12/FRIAR12016FU1.pdf
3. https://www.researchgate.net/publication/271422771_The_role_of_solid_waste_management_as_a_response_to_urban_flood_risk_in_developing_countries_a_case_study_analysis

Case study

Bengaluru: The capacity of the natural drains has decreased, resulting in flooding. Wetlands across Bengaluru have lost the 'flood absorbing capacity' due to increased human activities and damages to their contours. As per The Bruhat Bengaluru Mahanagara Palike (BBMP) Concretisation of the city has reduced the rate of water percolation into the earth from 60 per cent to 20 per cent[1].

Sources:

1. https://cag.gov.in/uploads/download_audit_report/2021/10.%20Full%20Report-061430461ae16f4.22975494.pdf

2.3. Cause identification for Indian cities facing flood every year:

Case Study

Mumbai: On 26th July 2005, the city of Mumbai received 944 mm of rainfall – (the average amount for the entire season, and a 100-year high). This, combined with high tides, set off a devastating flood in the city, much of which is built on low-lying land. The city's insufficient drainage system, unsustainable urbanisation, reduction of green cover and natural barriers are enlisted among the top reasons for the floods. Some of the major reasons were:

1. **Old drainage system:** Mumbai's drains are over a 100 years old and have a capacity to bear 25 mm of rain per hour, which is insufficient during high-intensity monsoons. The city's drainage system consists of 2,000 km of open drains along the road, 440 km of closed drains (such as below the footpaths), box drains, minor nallahs, major nallahs and 186 outfalls, or points where a waste stream is discharged directly into either the Mithi river or the Arabian Sea. Much of the drainage system, particularly in the suburbs, is restricted by unauthorised development contrary to the development plan or the development control rules[1].
2. **Poor management of solid waste**: During flood of the year 2005, 23 per cent of all drain defects were associated with obstructions such as water or sewer pipes which cause blockades, and another major barrier identified was strewn plastic bags and solid waste[2].
3. **Flood plain encroachment and shrinking rivers**: Rivers are constantly narrowed in Mumbai. The mouth of the original Mithi river was once several hundred metres wide which has reduced to only about 40 metres in width. In addition to this, city is also facing problems of "Slum encroachment" and construction of many residential complexes and government offices built on reclaimed or swamp land[2].

Case Study

4. **Urbanization**: The city lost 40 per cent of its mangroves between 1995-2005. The ratio of green spaces to total area has fallen from 46.7per cent in 1988 to 26.67 per cent in 2018. This has reduced the amount of rain water that can be percolated in the soil[3].

Sources:

1. https://mumbai.citizenmatters.in/explainer-why-mumbai-is-inundated-every-monsoon-20347
2. https://mumbai.citizenmatters.in/explainer-why-mumbai-is-inundated-every-monsoon-20347
3. https://www.orfonline.org/expert-speak/vertical-forests-solution-mumbai-climate-problem/

Case Study

Chennai: The havoc caused in Chennai by the 2015 November-December monsoon rains have brought into sharp focus the point that the city is woefully unprepared to handle a flood-like situation). The Chennai floods have thrown up some fundamental flaws in our system of urban planning. Chennai is one such area where an enormous watershed finally drains into the sea through its rivers and canals.

A report mentioned "Flood in Chennai cost India's economy an estimated $3 billion in losses, making it the worst disaster of its kind in terms of damage to the economy. Overall, the Chennai flooding was the eighth-most expensive natural disaster during that year"[1]. Another report says "The flooding in Chennai is a typical example of combination of human negligence and manmade disaster. The amount of rainfall recorded is the highest in past 100 years - 120cm (on Dec 5, 2015), the same has been predicted by all metrological agencies and NASA and written forecast (about El Nino) had been given to Tamil Nadu government prior to disaster , the magnitude of this disaster could have been minimized if precautionary measures were taken. In the past decades with the growing urbanisation demand for land has started to increase at an alarming rate, a total of 300 inland water bodies have been turned into housing , industrial building , IT parks and it is estimated that 1.5 lakhs buildings are constructed in illegal way. Higher rain coupled with poor drainage system and improper planning and alarming urbanisation are the main reasons for flooding in Chennai" [2].

The CAG report, 'Flood management and response in Chennai and its suburban areas', has revealed that the state's water resources department had allowed the indiscriminate discharge of water from the Chembarambakkam reservoir which burdened the Adyar river, leading to floods in the city and its suburbs. Moreover, the report has disclosed that the state was devoid of an Emergency Action Plan (EAP) and the government had failed to update its system and manuals as per the Central Water Commission's guidelines"[3].

Case Study

Another report says that "the encroachment of Pallikaranai marsh lands which was 5,000 acres once has shrunk to just 370 acres now. Because of the settlements, the entire ecosystem is under threat even though it is the only remaining wetland ecosystem on Chennai. Many water bodies, for instance, are used as dump yards"[4.]

Solid Waste Disposal & Vehicle Parking on Roads: As per a Report the highest per capita solid waste generation in India is in Chennai (0.6kg/day). Majority of solid wastes are dumped in a mixed form in low lying areas & in open areas by Chennai Corporation. There is a proper system of collection, segregation & disposal of wastes, it is a serious environmental concern which has to be addressed separately. Chennai witnesses 425 new vehicles on road every day causing pressure for motor able and parking space. Increase in impervious increasing the flood severity and later drought to follow. Increase in road space is accounting to only 3- 4 per cent when comparing with the developed cities like London (20-25 per cent)[5.]

Sources:

1. https://www.wsj.com/articles/BL-IRTB-31036
2. https://www.civilserviceindia.com/subject/Essay/reasons-for-chennai-rains1.html
3. https://cag.gov.in/webroot/uploads/download_audit_report/2017/Report_No_4_of_2017__Performance_Audit_of_Flood_Management_and_Response_in_Chennai_and_its_Suburban_Area.pdf
4. https://www.indiatoday.in/india/story/chennai-floods-2015-november-december-monsoon-rains-335697-2016-08-17
5. http://article.sapub.org/10.5923.j.arch.20120206.01.html

Case Study

Bihar: Bihar is drained by the Ganges River, including its northern tributaries Gandak and Koshi, originating in the Nepal Himalayas and the Bagmati originating in the Kathmandu Valley that regularly flood parts of the Bihar plains. The identified reasons recurring flood in the state are[1]:

1. The Sump House Factor: As many as 38 out of the 39 sump houses in the Patna Municipal Area failed to work as they were all found to be defunct due to some reason or the other
2. Sewer pipelines are being laid down in the entire city and this has led to damage of the previous drainage system by breaking drainage pipes, creating manholes, puddles and ditches which have further assisted the accumulation of water in the city
3. Desilting of the drains, were not done properly, as a result of which most of the water did not reach sump houses quickly
4. Uncontrollable urban expansion

Araria: Incessant construction over the natural drainage pathways in the Araria town of Bihar, without taking into account the soil type of the area has led to making once flood free zones into flood prone areas. Moreover, the improper and delay in linking the drainage systems plus the improper solid waste management combined to give clogged drains, accumulation of silt all increasing the water levels in the rivers. Lastly, scarce land and lack of efficient management of resources to provide people with basic civic amenities forced people to build on the floodplains, near rivers and develop their own coping mechanisms[2].

Sources:

1. https://thewire.in/urban/how-330-mm-of-rain-flushed-down-15-years-of-urban-development-in-bihar
2. https://www.researchgate.net/publication/326655201_Urban_Floods-A_Case_Study_of_Araria_Bihar

2.4. Impacts and risks due to urban floods

Urban areas are also centres of economic activities with vital infrastructure which needs to be protected at all times. Problems associated with urban floods range from relatively localized incidents to major incidents, resulting in cities being inundated from hours to several days. This includes loss of life and property, infrastructure damage and health hazards etc. The losses due to floods can be categorized into[64].

(1) Tangible losses: The losses that can be measured physically and can be assigned an economic value. Direct losses can be structural damage to buildings, property damage, and damage to infrastructure. Indirect - Economic losses, Traffic disruption, and emergency costs

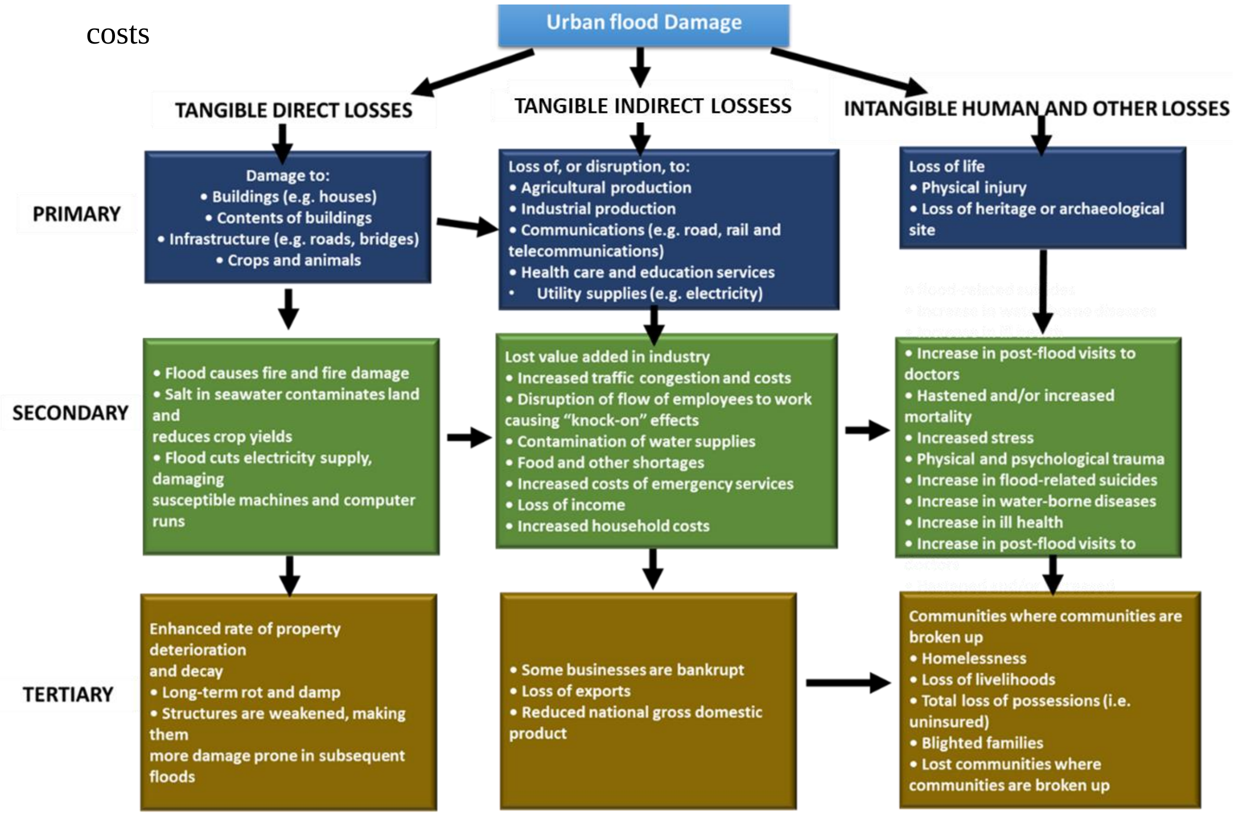

Figure 14: Categorization of Flood Losses

Image Source: https://library.wmo.int/doc_num.php?explnum_id=7342#:~:text=Givenper cent20theper cent20highper cent20spatialper cent20concentration,byper cent20yearsper cent20orper cent20evenper cent20decades

(2) Intangible losses: Intangible losses include loss of life, secondary health effects, and infections or damages to the environment which are difficult to assess in monetary terms since they are not traded. Direct losses can be casualties, Health effects, and ecological losses.

[64] https://www.civilsdaily.com/sansad-tv-urban-deluge-floods/

Indirect losses can be post-flood recovery processes and mental damage to the people. Figure 14 shows different categories of losses due to floods.

2.4.1. Impacts and risks on human life:

According to the World Health Organization (WHO), one of the worst health risks that are accompanied by flooding is contaminated water sources. Floodwaters can carry raw sewage, leaked toxic chemicals, and runoff from hazardous waste sites and factory farms. They can pollute drinking water supplies and cause eye, ear, skin, and gastrointestinal infections. When floodwaters recede, bacteria and mould may remain, increasing rates of respiratory illnesses, such as asthma. Flooding can also contribute to mental health problems, lead to economic loss (as in the form of lost business or wages), and uproot whole communities. Some of the sources through which humans might be at risk are:

1. **Poor sanitation and water quality**: Flood water is generally contaminated by various pollutants, such as sewage, human and animal faeces, pesticides etc. Industrial wastes and garbage fillings flow along the flood water and spread contamination. The pollutants also saturate the groundwater, and the waste-water treatment plants get flooded and malfunction. This results in backflows of raw sewage to homes, and also blockages in the private sewage disposal systems. All this acts as a favourable habitat for micro-organisms and vector insects, resulting in diseases[65].
2. **Contaminated food**: Floodwater carries away with it whatever is present on the ground and upstream. Human and animal waste, oil, dirt, bacteria and chemicals present in it, when comes in contact with food crops and edible items, make food unsafe to eat and harmful to human health. The power failures caused by floods damage stored food. Frozen and refrigerated floods become bacteria-prone and harmful for consumption. Floodwater also spoils the food packed in cardboard, plastic bags, jars and bottles. Toxicity of food increases due to its contamination[66].

3. **Pathogen risk**: Wet areas and stagnant pits encourage the rapid breeding of mosquitoes and flies. This causes an increase in vectors that become the easy mode of transmission of pathogens such as Plasmodium and many infections viruses, and hence the increased risk of the respective diseases. The vectors like rats and rodents also carry diseases causing harmful

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[65] https://www.researchgate.net/publication/327545787_Impact_of_Flood-Caused_Pollutants_and_Micro-_Organisms_on_Human_Health

[66] Trak, T., 2018. Impact of Flood-Caused Pollutants and Micro- Organisms on Human Health. International Journal of Science and Research (IJSR) 7, 1375–1377. https://doi.org/10.21275/17021803

viruses. Wet and damp areas also constitute the habitats for the rapid growth of moulds and mildews[67].

The immediate health impacts of floods include drowning, injuries, hypothermia, and animal bites. Health risks are also associated with the evacuation of patients, loss of health workers, and loss of health infrastructure including essential drugs and supplies[68].

2.4.2. Water-borne diseases:

There is an increased risk of infection of water-borne diseases contracted through direct contact with polluted waters, such as wound infections, dermatitis, conjunctivitis, and ear, nose and throat infections. However, these diseases are not epidemic-prone[69]. The major risk factor for outbreaks associated with flooding is the contamination of drinking-water facilities resulting in water-borne diseases such as typhoid fever, cholera, leptospirosis and hepatitis A. The only epidemic-prone infection which can be transmitted directly from contaminated water is leptospirosis, a zoonotic bacterial disease. The occurrence of flooding after heavy rainfall facilitates the spread of the organism due to the proliferation of rodents which shed large amounts of leptospires in their urine. Outbreaks of leptospirosis occurred in Brazil (1983, 1988 and 1996), Nicaragua (1995), the Krasnodar region, Russian Federation (1997), Santa Fe, USA (1998) Orissa, India (1999) and Thailand (2000).[70]

2.4.3. Vector-borne Infectious diseases

Vector-borne diseases are those that are transmitted through several parasites and pathogens such as mosquitoes. Some examples are dengue, malaria, chikungunya, etc. On the other hand, diseases such as cholera, typhoid, jaundice, leptospirosis, etc., that are caused by contaminated water are categorised as water-borne diseases[71]. With the surge in diseases during and after the flood, the need for awareness about preventive measures and precautionary steps are of utmost importance.

2.4.4. Mental health

Flooding can have effects on people's mental health and well-being. Most people can cope with the situation while few people may develop mental health problems. The effects of being

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[67] Trak, T., 2018. Impact of Flood-Caused Pollutants and Micro- Organisms on Human Health. International Journal of Science and Research (IJSR) 7, 1375–1377. https://doi.org/10.21275/17021803

[68] https://www.nhp.gov.in/health-impacts-of-flooding-and-risk-management_pg

[69][69] https://www.nhp.gov.in/health-impacts-of-flooding-and-risk-management_pg

[70] **Error! Hyperlink reference not valid.** Outbreak of infectious diseases during and after flood [WWW Document], 2019. . MyGov Blogs. URL https://blog.mygov.in/outbreak-of-infectious-diseases-during-and-after-flood/ (accessed 7.3.22).

[71] World health Organization, Floods and health: Fact sheets for health professionals, 2014, Retrieved from: https://www.euro.who.int/__data/assets/pdf_file/0016/252601/Floods-and-health-Fact-sheets-for-health-professionals.pdf

separated from family and friends, disruption to family life and daily routine and the loss of pets and possessions, moving to temporary accommodation, all can have an effect on the mental health of children. Symptoms can include[72]:

- Separation anxiety
- Irregular sleeping patterns/nightmares
- Behavioural problems such as becoming withdrawn
- Increased aggression
- Bedwetting
- Development of habit-forming behaviours such as routines/rituals about washing and academic performance may suffer

Snake bites: During flooding water enters the nesting holes of snakes, forcing them to come out in the open. The snakes then start looking for dry areas and may, unfortunately, come into close contact with humans inside their houses, hence the incidence of snake bites increase after flooding[73].

[72] https://www.nhp.gov.in/health-impacts-of-flooding-and-risk-management_pg
[73] https://www.nhp.gov.in/health-impacts-of-flooding-and-risk-management_pg and https://extension.missouri.edu/publications/agw1011

Chapter 3. Urban flood management and Best Practices

3.1. Why urban flood is recurring in India

Floods in Assam and the other North-Eastern States cause devastation of life and property, which is an annual problem in the region. However, floods are not restricted to North-eastern India, rather it affects many other areas in the country. The approach to flood management presently exercised in India needs to get a re-look and have an integrated strategy. Floods have been a recurrent phenomenon in many parts of India causing loss of lives, especially in rural areas[74]. Some of the reasons why urban flooding has become a recurring phenomenon are[75]:

1. The cities have been built with little to no regard for the natural topography and severely lack holistic action.

2. Even with provisions of rainwater harvesting, sustainable urban drainage systems, etc. in regulatory mechanisms like the Environmental Impact Assessment (EIA), Notification 2006 or building bylaws, adoption at the user end as well as enforcement agencies remains weak.

3. Public bodies' focus is largely on de-silting of storm water drains before monsoon and expansion of the over-burdened infrastructure, but at a crawling pace.

4. The major factor of recurrent urban flooding in Mumbai is the city's old drainage system, which is heavily silted and damaged.

5. Even the newer cities like Gurugram, have been terribly uninformed. It takes only one seasonal downpour to bring the city to a standstill.

As per the report based on the study on flood between 2000-2017 by the NGO "Seeds and Centre for Research on the Epidemiology of Disasters" based in the University of Louvain School of Public Health, Brussels, "Fifty-Six per cent of smart cities in India are said to be prone to floods that account for 77 per cent of all disasters in India"[76]. The same report highlighted the vulnerability of Indian cities while tackling climate change. Some examples are Dharamshala, a designated smart city under the central government's Smart City Mission saw

[74] Binay Singh, 2013. Floods a recurrent phenomenon in state. The Times of India. https://timesofindia.indiatimes.com/city/varanasi/floods-a-recurrent-phenomenon-in-state/articleshow/22088200.cms

[75] National Disaster Management Guidelines Management of Floods, National Disaster Management Authority Government of India, 2008, Retrieved from: https://nidm.gov.in/PDF/pubs/NDMA/3.pdf

[76] https://mediaindia.eu/politics/indian-smart-cities-and-urban-planning-drowns-under-repeated-floods/

flash floods[77]. Flood disaster management in developing countries is mostly reactive responding to prevailing disaster situations (emergency response and recovery).

Urban drainage systems, are usually developed to rid the city of storm water as quickly as possible resulting in increased imperviousness in urban areas[78]. The drain systems in many cities are outdated and have followed guidelines prescribed in the 'Manual on Sewerage and Sewerage Treatment' put together by the Central Public Health and Environmental Engineering Organisation (CPHEEO). According to the CPHEEO's guidelines, storm drains were designed for a rainfall intensity of 12–20 mm per hour, which is hugely undersized by the current rainfall standards. To fix this, in 2019, the Ministry of Housing and Urban Affairs (MOHUA) released a 'Draft Manual on Storm Water Drainage Systems', the latest drain design practices, which have to be followed and incorporated by state governments, and in turn, urban local bodies, in either replacing or retrofitting, and operation and maintenance of systems. It also puts out suggestions for budgeting and financing drainage projects. However, this is yet to be implemented, and is only suggestive in nature[79].

3.2. Steps to mitigate urban flood in India

After intense rainfall when the city floods, the major hit areas include difficulty in the transportation of goods and services, breakdown in the public service sector, schools closing, etc. These factors bring life in the city to a standstill. Floods in Urban India are a result of both natural and manmade factors. Hence comprehensive urban planning which reconciles both environment and economic needs is required. Mitigation and rehabilitation measures should be the main focal area in solving the problem of recurrent floods.

NDMA guidelines on urban flood management[80]:

1. **Creation of a National Hydro-meteorological Network:** In 2010, the National Disaster Management Authority (NDMA) issued guidelines on Urban Flood Management in India to create a National Hydro-meteorological Network.
2. **Use of technology: Use of Doppler Weather Radars** to be expanded to cover all urban areas in the country

[77] Bhattacharjee, R., 2021. Indian Smart Cities and urban planning drowns under repeated floods. Media India Group. URL https://mediaindia.eu/politics/indian-smart-cities-and-urban-planning-drowns-under-repeated-floods/ (accessed 7.3.22).

[78] Shivali Jainer, 2020. Urban flooding around the world: Where is India placed? [WWW Document]. URL https://www.downtoearth.org.in/blog/water/urban-flooding-around-the-world-where-is-india-placed--70765 (accessed 7.3.22).

[79] https://www.orfonline.org/expert-speak/inadequate-storm-water-infrastructure-biggest-hurdle-in-urban-flood-resilience/

[80] https://www.ilearncana.com/details/URBAN-FLOODING-IN-INDIA/1420

3. **Data collection: An inventory of the existing storm water drainage system to be prepared**. The inventory will be both watershed-based and ward-based
4. **Flood resilient infrastructure:** All future road and rail bridges in cities crossing drains are to be designed such that they do not block the flows resulting in the backwater effect. Every building in an urban area must have **rainwater harvesting as an integral component of the building utility**
5. **Land management:** Low-lying areas in cities have to be reserved for parks and other low-impact human activities
6. **Delinking of urban flood and rural flood:** Urban Flooding has to be dealt as a separate disaster, de-linking it from riverine floods which affect the rural areas.

3.3. Pre-Flood

As per the National Institution for Transforming India (NITI) Aayog's report on strategy for flood management, depending upon the nature of work, flood protection and flood management measures are broadly classified as under:

(a) Structural Measures (b) Non-Structural Measures[81]:

3.3.1. <u>Structural Measures for Flood Management</u>

The structural measures for flood control which bring relief to the flood-prone areas by reducing flood flows and attenuating the flood levels are:

a. A reservoir created behind a dam across a river

b. A natural depression suitably improved and regulated, if necessary

c. By diversion of a part of the peak flow to another river or basin, where such diversion would not cause appreciable damage.

d. By constructing a parallel channel by-passing a particular town/reach of the river prone to flooding.

3.3.2. <u>Non-Structural Measures for Flood Management</u>

The non-structural measures to mitigate the adverse impact of floods involve the following:

[81] Report of the Committee Constituted for Formulation of Strategy for Flood Management Works in Entire Country and River Management Activities and Works Related to Border Areas (2021– 26), NITI Aayog, 2021, Retrieved from: https://www.niti.gov.in/sites/default/files/2021-03/Flood-Report.pdf

a. Disseminating advance warning of the incoming flood through a flood forecasting system and facilitating the timely evacuation of the people to safer grounds.

b. Discouraging creation of valuable assets/settlement of the people in the areas subject to frequent flooding i.e. enforcing flood plain zoning regulation.

3.3.3. Forecasting

The expected results of urbanization include reducing infiltration, base flow, lag times, increasing storm flow volumes, peak discharge, frequency of floods, and surface runoff[82]. Some of the models used for understanding the impacts of urbanization on runoff are[83]

1. ArcView Soil and Water Assessment Tool (AVSWAT) hydrological model to assess the effects of climate change and urbanization on the runoff of the Rock Creek basin in the Portland metropolitan area, Oregon, USA.
2. OLPSIM (combined use of a spatial pattern optimization model) impact of land-use patterns on runoff in the watershed and sub-watershed scales for an urbanized watershed in Taiwan.
3. Conversion of Land Use and its Effects model (CLUE-s) and the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS).
4. MIKE SHE model to quantitatively assess the impact of land-use changes (predominantly urbanization) on the hydrology of the Gyeongancheon watershed in Korea.
5. Long-Term Hydrologic Impact Assessment (L-THIA) model to evaluate the effect of land use and land cover change on surface runoff in the Dardenne Creek watershed of St. Louis, Missouri.
6. Conversion of Land-use and its Effects (CLUE-s) model and Distributed Hydrology-Soil Vegetation Model (DHSVM) to examine hydrologic effects of various land-use change scenarios in the Wu-Tu watershed in northern Taiwan.

3.3.4. Measuring and monitoring urban flooding

This involves **s**upporting cities to assess flooding by sharing the tools and technologies to map cities' flood-prone areas. Flood maps are one tool that communities use to know which areas have the highest risk of flooding. As per Federal Emergency Management Agency (FEMA)[84],

[82] https://www.sciencedirect.com/science/article/pii/S0022169412005744?casa_token=86cqrLkz5hUAAAAA:l6dQzqjalmOXcap3oo0J0GQk9kNIzxtN_hjkHQ-_I_G1Lq0NQ8B1GuEKri9q_axq6lIh7IBrUQ

[83] Du, J., Qian, L., Rui, H., Zuo, T., Zheng, D., Xu, Y., Xu, C.-Y., 2012. Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China. Journal of Hydrology 464–465, 127–139. https://doi.org/10.1016/j.jhydrol.2012.06.057

[84] Flood Maps | FEMA.gov [WWW Document], n.d. URL https://www.fema.gov/flood-maps (accessed 7.3.22).

floods don't follow city limits or property lines. Using a flood map, one can see the relationship between the property and the areas with the highest risk of flooding. There is no such thing as a "no-risk zone," but some areas have a lower or moderate risk. As per a report,[85] the flood-prone areas in the country go beyond those mentioned in the central monitoring map. This demarcation, however, is based on estimates made in 1980 by Rashtriya Barh Ayog (RBA) or National Flood Committee formed four-decades ago. Around 40 million hectares of geographical area in India is vulnerable to floods, according to the body.

3.3.5. Watershed management

De-silting, timely cleaning and deepening of drainage channels have to be taken up along the whole river basin instead of just the urban areas (Figure 15). Catchment areas of water bodies need to be maintained well and should be free from encroachment and pollution, thus keeping the course of water free from obstructions. River-front water development plans help the primary and secondary stakeholders manage flood control plans more efficiently and create awareness about the benefits of maintaining a water resource[86]. A report says[87] "BMC, the richest municipal body in the country, spends around Rs70-100 crore every year just on cleaning drains. In Kolkata, waterlogging during the rains has become part and parcel of the city's identity. This isn't for the want of funds – the Kolkata Municipal Corporation's estimate of expenditure on sewerage and drainage for 2019-20 was Rs273.58 crore".

As per a report of the Comptroller and Auditor General of India (C&AG)[88], "During 2010-13, the flood control department removed 8,30,000 cubic meter of silt from Najafgarh and trunk one drains. Only about 1,00,000 cubic meters of it moved away". The report says, that under the Delhi master plan of 2001, authorities were supposed to prepare a master plan for drainage and a committee was set up for this purpose in 2005 but nothing happened till 2012[89].

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[85] https://www.downtoearth.org.in/news/climate-change/it-s-been-40-years-update-india-s-flood-map-now-78166

[86] https://edukemy.com/current-affairs/gazette/2021-11-16/urban-flooding

[87] Edit, T.O.I., 2021. Drained of ideas: Big cities need to upgrade water run-off systems to account for new patterns of rainfall. The Times of India.

[88] E-Journal CAG [WWW Document], 2015. URL https://cag.gov.in/uploads/journal/august-2015/visual-podcast.html (accessed 7.3.22).

[89] Josy Joseph, Read more at:, http://timesofindia.indiatimes.com/articleshow/37664866.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst, 2014. Delhi's drainage, desilting and flood control a big fraud: CAG. The Times of India.
Kerala: Press Trust of India, 2021. Audit Body CAG Finds Fault In K

Figure 15: Debris is removed from the Otteri Canal as part of the flood-prevention work ahead of the Northeast monsoon at Otteri in Chennai

Image Source: https://www.newindianexpress.com/cities/chennai/2021/oct/01/80-drains-and-waterbodies-across-chennai-desilted-2

3.3.6. Water-sensitive urban design and planning techniques:

These methods take into consideration the topography, types of surfaces (pervious or impervious) and natural drainage and leave very less impact on the environment. Vulnerability analyses and risk assessments should form part and parcel of city master plans. Tools such as predictive precipitation modelling can help do that and are also able to link it with the adaptive capacity of urban land use.[90]

Green solutions

The Green approach is being promoted by many cities globally. These approaches regard water (storm water, groundwater, and wastewater) as a resource that can be retained on a site, public space, or open space, for re-use or filtration (Figure 16). The amount of runoff can be reduced by reducing the area of hard surfaces and providing more green cover, conservation of water bodies and rainwater harvesting from built spaces[91]. Measures such as rain gardens, green roofs, bio-retention swales, artificial ponds and underground storage sumps can also enhance percolation and reduce runoff. Current guidelines have to be revised to drain runoff from up to 1:30 year per day rainfall, as opposed to the existing 1:10[92].

[90] https://www.downtoearth.org.in/blog/natural-disasters/urban-flooding-the-case-of-drowning-cities-and-rising-vulnerability-67203
[91] https://edukemy.com/current-affairs/gazette/2021-11-16/urban-flooding
[92] Soak Up the Rain: The Benefits of Green Infrastructure | US EPA [WWW Document], n.d. URL https://www.epa.gov/soakuptherain/soak-rain-benefits-green-infrastructure (accessed 7.3.22).

In the, last few years many Indian cities have started working on interventions aimed at flood-proofing and storm water management at various scales. Bhopal's green-blue smart city plan, Delhi's Masterplan 2041, Chennai's water as leverage initiative, all address at an urban policy and development guidelines scale. Other cities are experimenting with landscape design led solutions to tackle the flood fury such as Chennai and Bengaluru with recharge wells.[93]. Protecting the existing green cover, Reforestation, and removal of debris from catchment areas could help prevent soil erosion, which might further damage the resources of an urban settlement[94].

Water-sensitive urban planning and designing (WSUDP)

Water-sensitive urban planning and designing (WSUDP) is an approach that integrates and optimizes the use of available water sources and completes the water cycle by incorporating the following in planning and designing (Figure 17)[95].

• Protecting local waterbodies (lakes, ponds and wetlands) for supplementary water sources

• Storm-water management at public places, including open areas in cities through elements of landscape design (e.g. vegetated swales and buffer strips, bio-retention systems)

• Recycling and reusing wastewater naturally (low cost/low energy) and not treating it as a liability

• Increasing water-conservation approaches at various scales (buildings/ campus)—i.e. by adopting water-efficient fixtures, xeriscaping landscape (i.e. planting native species) and using water-efficient irrigation methods—thereby minimizing load on the municipal supply system and groundwater sources. On-site water conservation with Rainwater Harvesting (RWH) is also important to reduce water scarcity.

• Adding value to the social and ecological aspects of areas by planning and designing the built environment in accordance with community needs and water issues

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[93] Ashwathy Anand and Sindhuja Janakiraman, 2021. Creating a flood resilient Indian 'Sheher' through Water Sensitive Urban Design [WWW Document]. WRI INDIA. URL https://wri-india.org/blog/creating-flood-resilient-indian-%E2%80%98sheher%E2%80%99-through-water-sensitive-urban-design (accessed 7.3.22).

[94] Dominati, E.J., Robinson, D.A., Marchant, S.C., Bristow, K.L., Mackay, A.D., 2014. Natural Capital, Ecological Infrastructure, and Ecosystem Services in Agroecosystems, in: Van Alfen, N.K. (Ed.), Encyclopedia of Agriculture and Food Systems. Academic Press, Oxford, pp. 245–264. https://doi.org/10.1016/B978-0-444-52512-3.00243-6

[95] https://cdn.cseindia.org/userfiles/WATER-SENSITIVE-URBAN-dESIGN-pLANNING-practitioners-guide.pdf

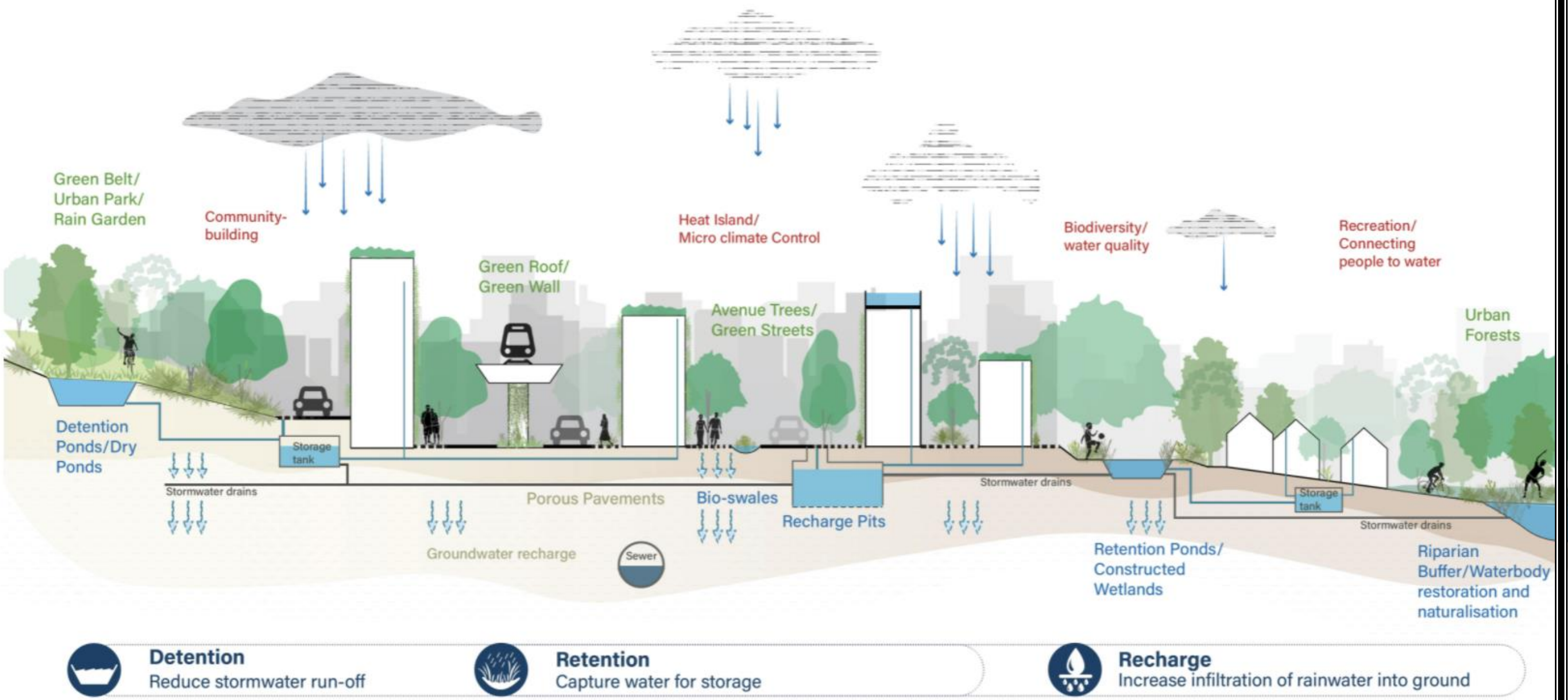

Figure 16: Using urban spaces for rainwater harvesting and groundwater recharge

Image Source: https://wri-india.org/blog/creating-flood-resilient-indian-per centE2per cent80per cent98sheherper centE2per cent80per cent99-through-water-sensitive-urban-design

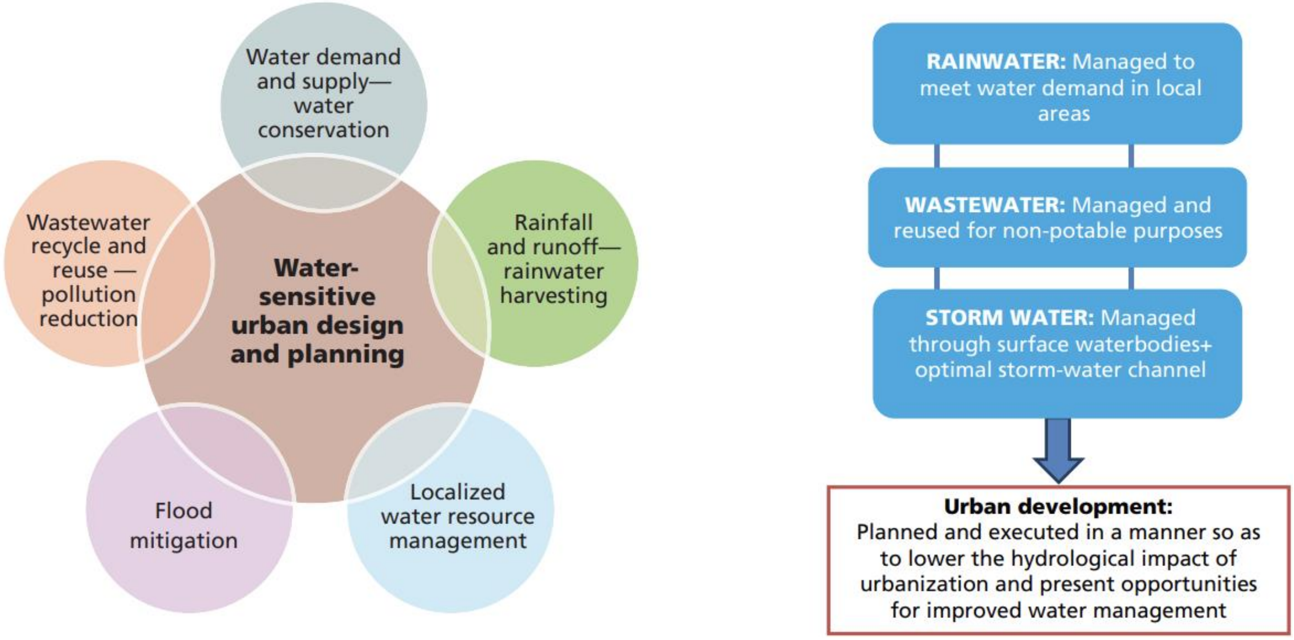

Figure 17: WSUDP: Integrating water-cycle management

Image Source: https://cdn.cseindia.org/userfiles/WATER-SENSITIVE-URBAN-dESIGN-pLANNING-practitioners-guide.pdf

3.4. Best practices around the world

3.4.1. Water-sensitive urban design (WSUD)-Australia

Water-sensitive urban design (WSUD) is an approach to planning and designing urban areas to make use of this valuable resource and reduce the harm it causes to our rivers and creeks[96]. One of the important factors in water-sensitive urban design is the use of multi-edge treatment. Edge refers to the perimeter of the water which can be effectively designed to create a space that can serve as an intersection among people, water, and aquatic wildlife. Some of the more common multi-edge treatments include boardwalks, platforms, steps, and embankments[97].

[96] Meng, X., 2022. Understanding the effects of site-scale water-sensitive urban design (WSUD) in the urban water cycle: a review. Blue-Green Systems. https://doi.org/10.2166/bgs.2022.026
[97] https://development.asia/explainer/transforming-asian-cities-using-water-sensitive-urban-design

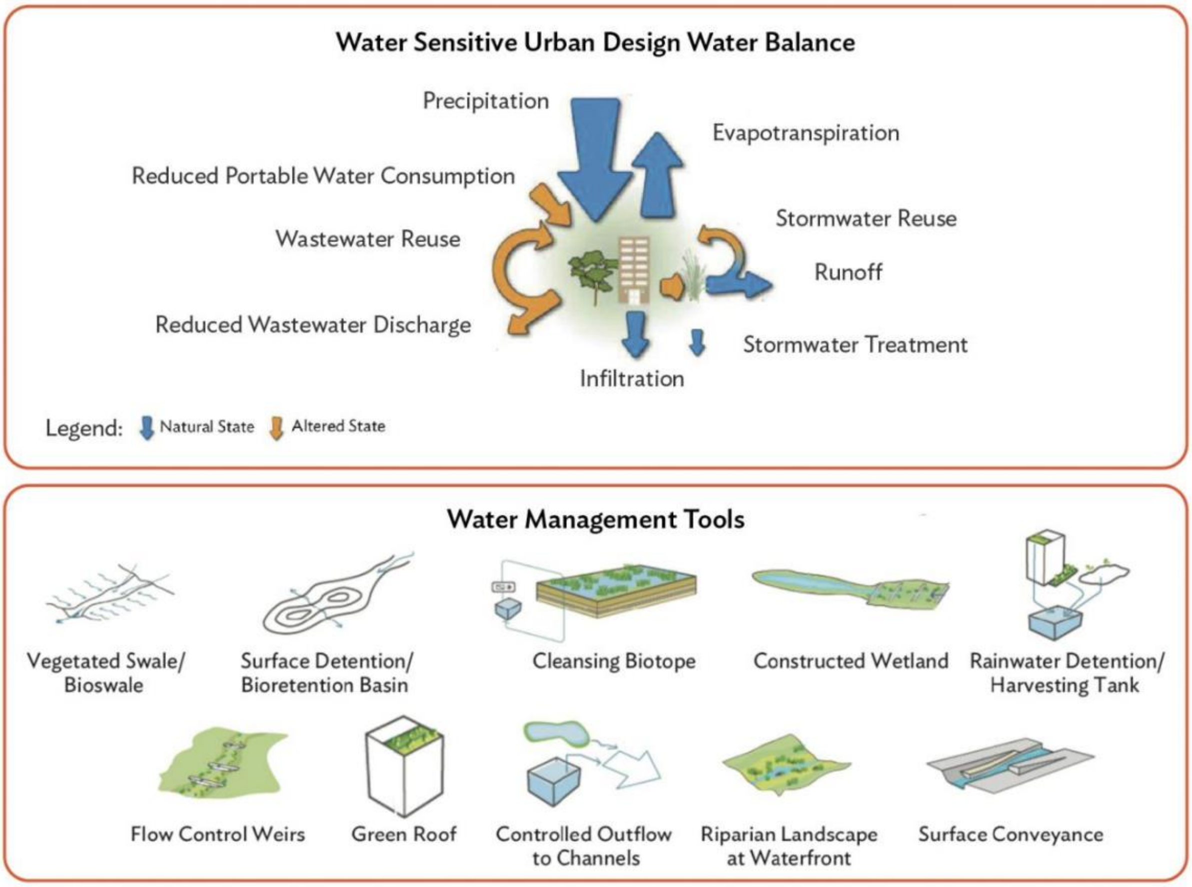

Figure 18: Water sensitive urban design and water management tools

Image Source: https://development.asia/explainer/transforming-asian-cities-using-water-sensitive-urban-design

WSUD is an important part of water cycle management. It is an approach that integrates whole of water cycle management into urban planning and design. WSUD aims create urban environments that allow the water cycle to function as it would naturally. This reduces the impact of development on the water cycle. Many different types of WSUD are used to reduce the volume of storm water and pollution that enters our waterways. Common types of WSUD include[98]:

3.4.2. Raingardens – above-ground and infiltration

Bio retention systems, also known as rain gardens, are vegetated soil filters that treat storm water by vertical percolation through a soil filter media (Figure 19). The use of saturated zones

[98] http://urbanwater.melbourne.vic.gov.au/melbournes-water-story/water-sensitive-urban-design-wsud/

underneath bio retention systems is likely to assist in helping plants survive extended dry periods and provides anaerobic conditions for denitrification[99].

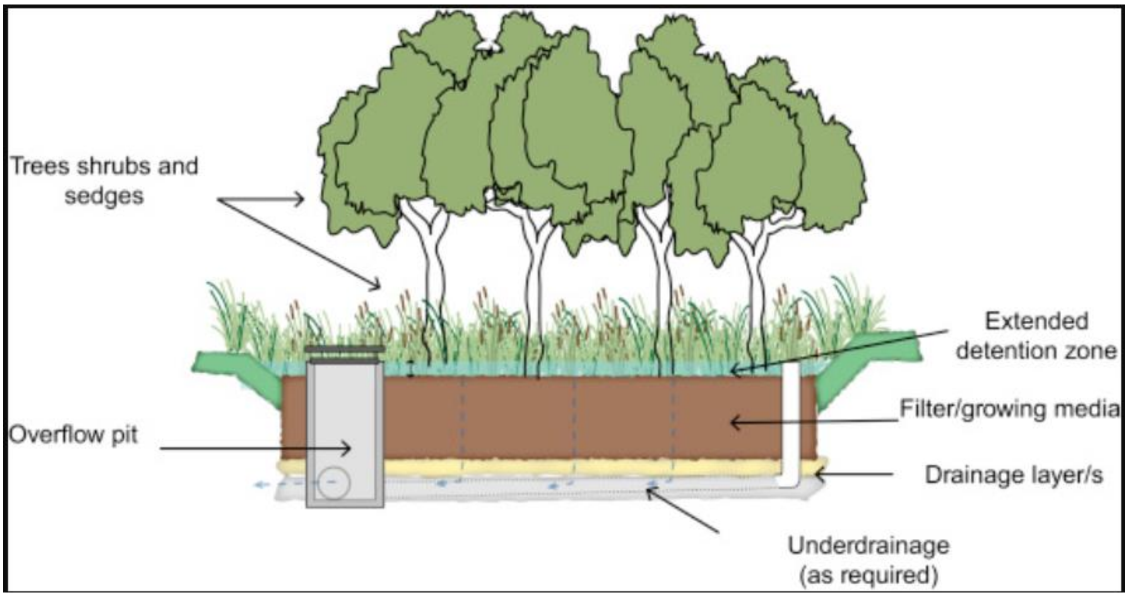

Figure 19: A schematic cross-sectional diagram of a typical bio retention system

Image Source: https://www.sciencedirect.com/science/article/pii/B9780128128435000022#s0075

Water quality is managed through a combination of filtration, sorption, transformation, denitrification, plant uptake, and exfiltration. One of the major benefits of bio-retention systems is in the slowing and reducing of runoff. A summary of recent research on the hydrologic benefits of bio-retention reported significant attenuation of peak flows and runoff volumes, with an average volumetric loss of 59 per cent across 116 monitored events[100]. Bio-retention systems are very versatile in terms of shape and size and can be integrated into a wide range of urban settings (Figure 20). Challenges in operation of raingarden includes[101] (1) if rain garden is not functioning properly, then there may be issues with drainage (2) rainwater runoff accumulation in the basin can lead to backups and flooding (3) an improperly designed basin can also lead to increased erosion rates.

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[99] https://cdn.cseindia.org/userfiles/WATER-SENSITIVE-URBAN-dESIGN-pLANNING-practitioners-guide.pdf
[100] https://blightanner.com.au/wp-content/uploads/2017/11/2017-11-08-Facing-the-MUSIC.pdf
[101] https://www.horstexcavating.com/news-and-blog/are-rain-gardens-a-good-solution-for-storm water-management/

Figure 20: Bio retention systems (rain gardens) integrated into urban settings

Image Source: https://www.sciencedirect.com/science/article/pii/B9780128128435000022#bib35

3.4.3. Swales

Swales are simple vegetated drains that convey runoff, while providing an opportunity for sedimentation, seepage, and reduction in flow velocity. Swales can come in a wide variety of styles, ranging from formal turf-lined systems to densely vegetated channels (Figure 21). Swales work by infiltrating runoff into underlying soils, enhancing sedimentation by slowing the flow of water and by filtration through the vegetation. Swales can be integrated with an underlying bio filtration trench for enhanced water quality performance. The vegetation in swales is passively irrigated by runoff, minimizing the need for irrigation in urban areas. As a green infrastructure measure, they contribute to mitigating urban heat island effects. If installed in open space or parkland, maintenance costs are minimized[102]. Limitations of swales are that they[103]:

1. have limited removal of fine sediment and dissolved pollutants
2. use more land area than kerb and gutter, and restrict certain activities like car parking

[102] https://www.sciencedirect.com/science/article/pii/B9780128128435000022#s0075

[103] https://www.melbournewater.com.au/building-and-works/storm water-management/options-treating-storm water/swales

3. require a sunny aspect for plant growth, which limits their application in shaded areas
4. are only suitable for gentle slopes of less than 5per cent gradient
5. require regular inspections

Figure 21:Examples of swales in Australia

Image Source: https://www.sciencedirect.com/science/article/pii/B9780128128435000022#s0075

3.4.4. Constructed wetlands

Storm water treatment wetlands are shallow vegetated water bodies that detain storm water runoff and slowly release it after rainfall events (Figure 22 and Figure 23). Storm water wetlands differ from wastewater treatment wetlands in that they tend to have more variable water levels (a result of the variable nature of rainfall) and also treat influent water with much lower and more variable nutrient concentrations[104]. The main disadvantage of constructed wetlands[105] is the requirement of a large amount of space, which is always the case either in the combination of various techniques of horizontal and vertical subsurface flow or the use of

[104] Hoban, A., 2019. Chapter 2 - Water Sensitive Urban Design Approaches and Their Description, in: Sharma, A.K., Gardner, T., Begbie, D. (Eds.), Approaches to Water Sensitive Urban Design. Woodhead Publishing, pp. 25–47. https://doi.org/10.1016/B978-0-12-812843-5.00002-2

[105] Makopondo, R.O.B., Rotich, L.K., Kamau, C.G., 2020. Potential Use and Challenges of Constructed Wetlands for Wastewater Treatment and Conservation in Game Lodges and Resorts in Kenya. The Scientific World Journal 2020, e9184192. https://doi.org/10.1155/2020/9184192

other innovations. Geographical characteristics and altitude differ from place to place thereby presenting another challenge for constructed wetlands

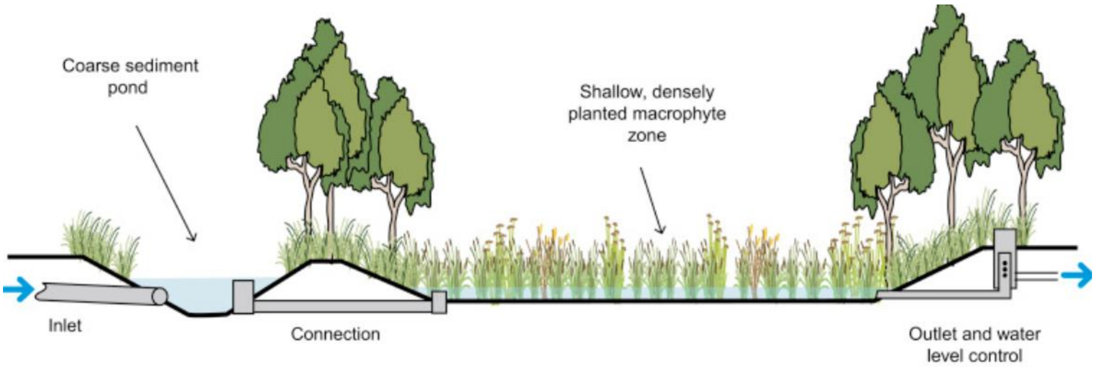

Figure 22: A schematic diagram of a typical configuration of a constructed wetland

Image Source: https://www.sciencedirect.com/science/article/pii/B9780128128435000022#s0075

Figure 23: Constructed storm water wetlands

Image Source: https://www.sciencedirect.com/science/article/pii/B9780128128435000022#s0075

3.4.5. Porous pavement

Porous asphalt is a simple way to increase the permeability of urban surfaces. Urban areas are typically covered by impervious surfaces, such as footpaths and roads, which prevent rainwater from soaking into the ground (Figure 24). As a result, soil moisture is lower than it should be, making it more difficult to grow trees and cool the city. Porous paving – also known as permeable paving – allows rainwater to pass through and infiltrate the soil below. This recharges soil moisture and groundwater. By directing storm water away from the drainage system, porous paving also reduces flood risk. Porous paving comes in a wide variety of finishes and styles, including the porous bluestone paving which we are currently installing in Melbourne's central city[106].

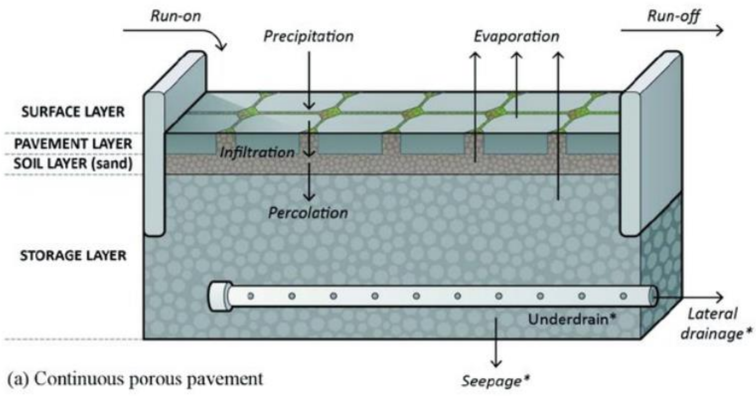

Figure 24:Continuous porous pavement

Image Source:
https://www.researchgate.net/publication/337836881_Choosing_the_LID_for_Urban_Storm_Management_in_the_South_of_Taiyuan_Basin_by_Comparing_the_Storm_Water_Reduction_Efficiency

3.4.6. Rainwater and storm water harvesting

A storm water harvesting and use system is a constructed system that captures and retains storm water for beneficial use at a different time or place than when or where the storm water was generated. A storm water harvesting and use system potentially have four components (Figure 25): collection system (which could include the catchment area and storm water infrastructures such as curb, gutters, and storm sewers), storage unit (such as a cistern or pond) treatment system: pre and post (that removes solids, pollutants and microorganisms, including any necessary control systems), if needed, and the distribution system (such as pumps, pipes, and control systems)[107]. The specific components of a storm water harvesting vary by the harvested storm water source (rooftops, low-density development, traffic areas, etc.) and the beneficial use of storm water (irrigation, flushing, washing, bathing, cooking, drinking, etc.). Commonly in storm water harvest and use, rainwater is differentiated from storm water and is defined as storm water runoff collected directly from roof surfaces which can have lower levels of pollutants and it often requires less treatment than other forms of storm water[108]. Challenges of rainwater harvesting[109]

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[106] http://urbanwater.melbourne.vic.gov.au/industry/treatment-types/what-is-porous-pavement/

[107]Fletcher, T., Deletic, A., Mitchell, V., Hatt, B., 2008. Reuse of Urban Runoff in Australia: A Review of Recent Advances and Remaining Challenges. Journal of environmental quality 37, S116-27. https://doi.org/10.2134/jeq2007.0411

[108]https://storm water.pca.state.mn.us/index.php?title=Storm water_and_rainwater_harvest_and_use/reuse_combined

[109] https://www.conserve-energy-future.com/advantages_disadvantages_rainwater_harvesting.php

(1) Unpredictable rainfall

(2) Initial high cost

(3) Regular maintenance

(4) Certain roof types may seep chemicals or animal droppings

(5) Storage limits. Rainwater harvesting is a system that is gaining momentum over time.

Areas that experience high amounts of rainfall benefit the most from this system and are able to distribute water to dry lands with ease[110].

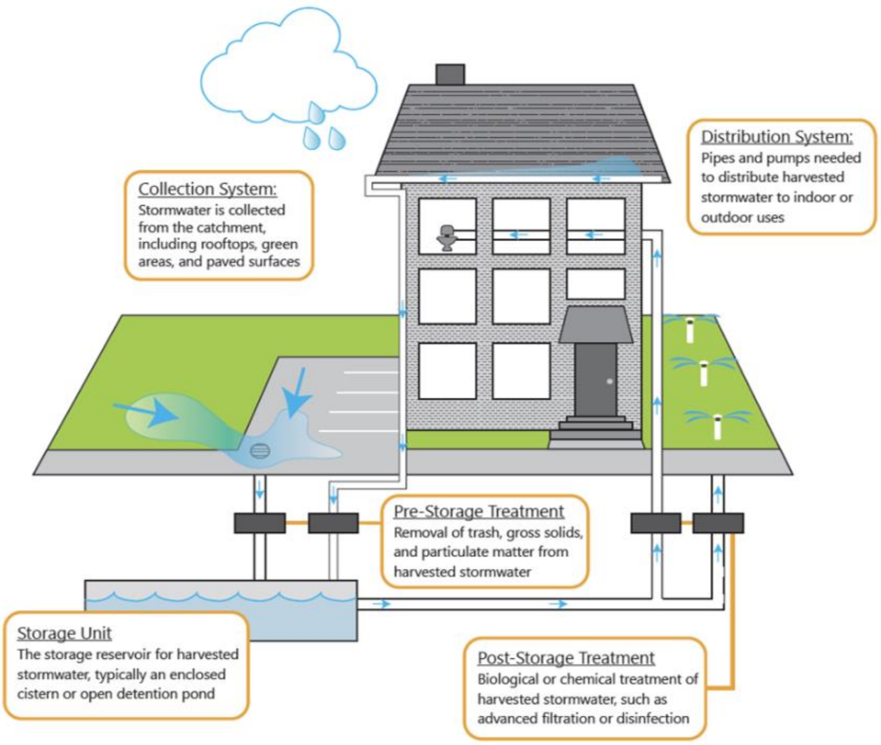

Figure 25: Example Storm water Harvesting and Use System Schematic

Image Source: (https://storm water.pca.state.mn.us/index.php?title=Storm water_and_rainwater_harvest_and_use/reuse_combined)

3.4.7. <u>Green infrastructure – green roofs, green facades and tree pits</u>

Green roofs and living walls are becoming an important component of water sensitive urban design systems, and their use around the world has increased in recent years. Green roofs can cover the impermeable roof areas that densely populate our urban areas, and through doing so, can provide many environmental, economic, and social benefits (Figure 26). In addition to

[110] https://www.conserve-energy-future.com/advantages_disadvantages_rainwater_harvesting.php

roofs, there are a number of bare walls that have the potential to be transformed into vegetated, living walls[111]. Green roofs, green facades, tree pits, living walls, permeable pavements, and wetlands are some of the commonly used WSUD technologies that aim to improve water quality reduce flood risk, and enhance biodiversity in urban areas. In **Green facades**, the vegetation is rooted in the ground and grows vertically on the wall. For indirect green façades, climbing plants grow vertically on trellises, cables, or mesh support systems without attaching to the surface of the building (Figure 26).

Disadvantages of Green Roofs are[112]

(1) A higher cost than traditional roofs

(2) A green roof will increase the weight load between 50 and 200kg/meter squared to an existing rooftop

(3) Needs extra maintenance

(4) Maintaining a green roof can be a difficult and is a tedious job

Figure 26: Green Roof at the Fairmont hotel and Green façade at the Hotel Boss in Singapore

Image Source: https://www.sciencedirect.com/science/article/pii/B9780128128435000204

[111] Beecham, S., Razzaghmanesh, M., Bustami, R., Ward, J., 2019. Chapter 20 - The Role of Green Roofs and Living Walls as WSUD Approaches in a Dry Climate, in: Sharma, A.K., Gardner, T., Begbie, D. (Eds.), Approaches to Water Sensitive Urban Design. Woodhead Publishing, pp. 409–430. https://doi.org/10.1016/B978-0-12-812843-5.00020-4

[112] https://www.bestaccessdoors.com/blog/green-roofs-the-advantages-and-disadvantages/

3.4.8. **Raingarden tree pits and Infiltration trenches**

Raingarden tree pits are set into the kerb and intercept and clean the water before it goes into the drain (Figure 27). The pit contains layers of substrate that work with the tree's root system to filter pollution from the storm water. This includes nitrogen, phosphorus and oils. Tree pits also include a rock mulch layer to retain moisture in the soil and prevent erosion during rain. A grate sits around the base of the tree, flush with the pavement. This protects the tree pit from damage and ensures that pedestrians don't trip over it. A pipe is located at the bottom of the well. It allows cleaned storm water to drain back into the drainage system[113]. Infiltration trenches are shallow excavated trenches filled with crushed stone or gravel that look aesthetically beautiful and are purely designed to filtrate the storm water through permeable soils into the groundwater aquifer (Figure 28). This is commonly used to treat runoff water from impermeable surfaces, such as parking lots and pedestrian pathways, on sites where there is limited or less space available for managing storm water[114].

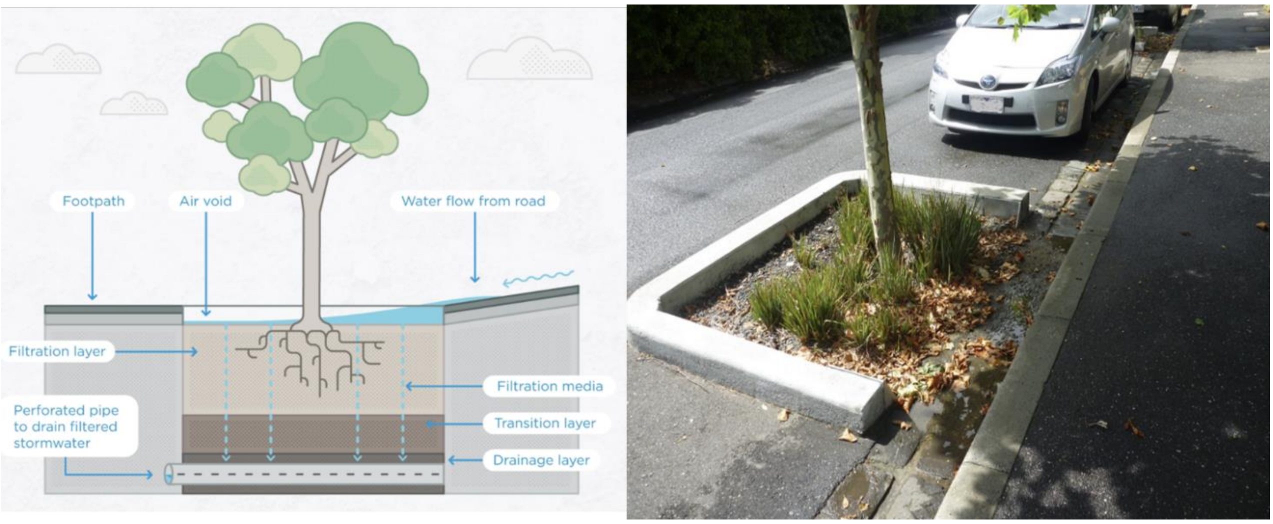

Figure 27: Water is diverted from the gutter an into the raingarden tree pit

Image Source: http://urbanwater.melbourne.vic.gov.au/industry/treatment-types/raingarden-tree-pits and http://www.ralfpfleiderer.com.au/in-street-raingarden-tree-pits/

113 http://urbanwater.melbourne.vic.gov.au/industry/treatment-types/raingarden-tree-pits/
114 https://archistudent.net/water-sensitive-urban-design/

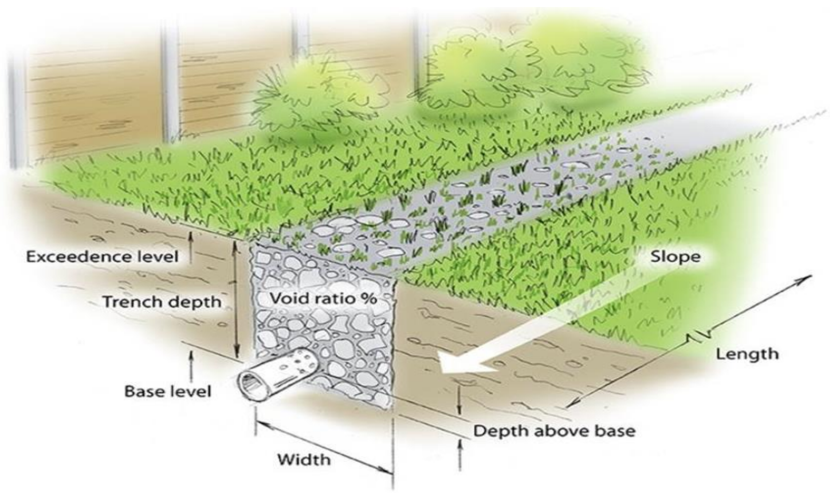

Figure 28: Schematic diagram of an Infiltration trench

Image Source: https://archistudent.net/water-sensitive-urban-design/

3.5. Case Studies

3.5.1. Low Impact Development (LID) /Green Infrastructure (GI) in the United States and New Zealand

The goal of green infrastructure and low-impact development practices is to develop land and manage storm water in a manner that imitates natural hydrology. In a mature forest setting, nearly all the precipitation disperses along the forest floor, where it infiltrates into the ground. It is soaked up by the roots of plants and tree, or evaporates (Figure 29). When forests and natural open spaces are cleared, and buildings, roads, parking areas and lawns dominate the landscape, much less water infiltrates than is soaked up by plants, less evaporates back to the atmosphere, and more becomes surface runoff[115].

Some of the benefits of LID development are[116]:

1. **Can help protect the environment**: Low Impact Development (LID) and Green Infrastructure techniques remove pollutants from storm water, reduce the overall volume of storm water, manage high storm flows, and replenish streams and wetlands.
2. **May reduce flooding and protect property**: Reducing impervious surfaces, increasing vegetation and dispersing and infiltrating storm water results in less runoff. This reduces the likelihood of flooding from large rain events.

[115] Green Infrastructure and Low Impact Development [WWW Document], n.d. URL https://dep.wv.gov/WWE/Programs/nonptsource/Pages/LID.aspx

[116] https://dep.wv.gov/WWE/Programs/nonptsource/Pages/LID.aspx

3. **Helps protect human health by more effectively removing pollutants from storm water**: Untreated storm water can be unsafe for drinking and swimming.
4. **Protects drinking water supplies:** rainfall infiltrates and recharges aquifers, rather than being treated as wastewater.
5. **Provides cost-effective alternatives to systems upgrades**: Land developed prior to the 1990's usually provided little, if any, storm water treatment. In many cases, green infrastructure and LID systems are much less expensive than costly storm water vaults or land-consuming storm water ponds.
6. **Can increase the appearance and aesthetics of communities**: LID and green infrastructure projects leave more trees and plants and have fewer impervious surfaces, which makes for greener developments and communities.
7. **Can increase public safety:** One of the hallmarks of these practices is more narrow streets. Studies show that when vehicle traffic is slowed, there are fewer pedestrian accidents and fatalities.
8. **Is good for the economy** Green infrastructure can help protect our natural resources and water quality and reduce sediment loads.

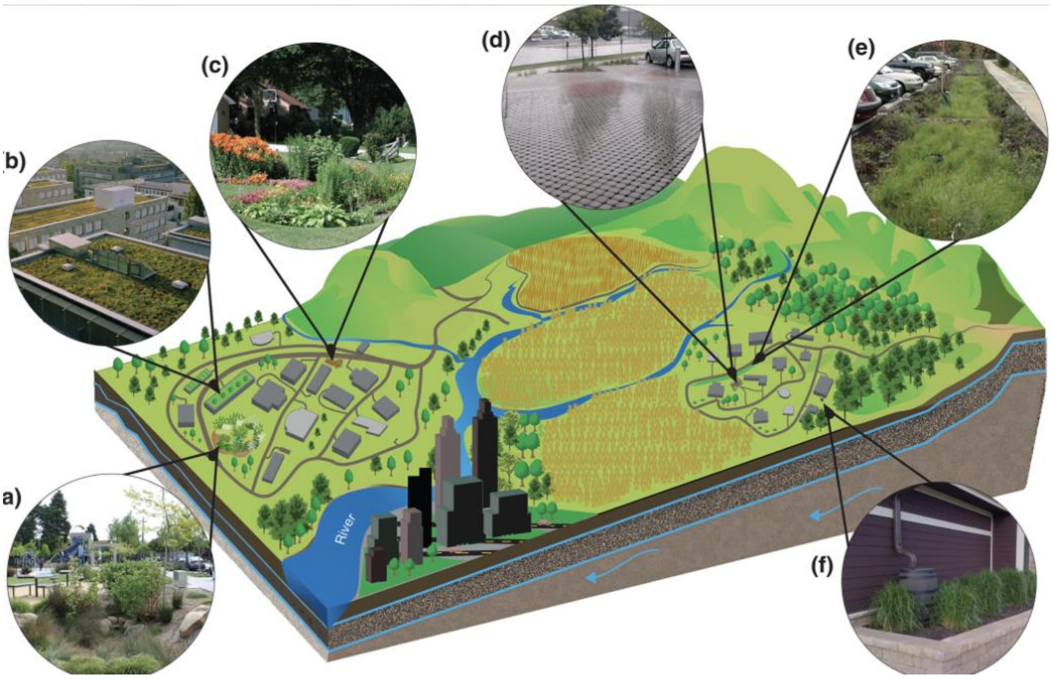

Figure 29: Schematic of low-impact development (LID) practices at the watershed scale: (a) bio retention system, (b) green roof, (c) rain garden, (d) permeable pavements, (e) a bioswale, and (f) rain barrel (Not to scale).

Image Source: https://wires.onlinelibrary.wiley.com/doi/10.1002/wat2.1254)

3.5.2. Sustainable Urban Drainage Systems (SuDS) in the United Kingdom

By mimicking natural drainage regimes, Sustainable Urban Drainage Systems (SuDS) aim to reduce surface water flooding, improve water quality and enhance the amenity and biodiversity value of the environment. Sustainable Urban Drainage Systems (SuDS) achieve this by lowering flow rates, increasing water storage capacity and reducing the transport of pollution to the water environment[117]. It also precludes rain from infiltrating the ground and recharge aquifers[118]. Sustainable Urban Drainage Systems (SuDS) are more sustainable than traditional drainage methods because they[119]:

1. Manage runoff volumes and flow rates from hard surfaces, reducing the impact of urbanisation on flooding
2. Provide opportunities for using runoff where it falls
3. Protect or enhance water quality (reducing pollution from runoff)
4. Protect natural flow regimes in watercourses
5. Are sympathetic to the environment and the needs of the local community
6. Provide an attractive habitat for wildlife in urban watercourses
7. Provide opportunities for evapotranspiration from vegetation and surface water
8. Encourage natural groundwater/aquifer recharge (where appropriate)
9. Create better places to live, work and play.

The disadvantages of Sustainable Urban Drainage Systems (SuDS) include a limited ability to treat water quality and a lack of adaptability to change, for example, the expansion of urbanised areas and increased frequency and severity of storm events due to climate change[120].

Some examples (Figure 30) of these Sustainable Urban Drainage Systems (SuDS) are

(1) Green roofs

(2) Bio retention areas

(3) Soakaways

(4) Pervious pavements

(5) Filter strips

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[117] https://www.bgs.ac.uk/geology-projects/suds/
[118] http://www.hidrologiasostenible.com/sustainable-urban-drainage-systems-suds/
[119] https://www.susdrain.org/delivering-suds/using-suds/background/sustainable-drainage.html
[120] Green, A., 2019. Sustainable Drainage Systems (SuDS) in the UK. pp. 69–101. https://doi.org/10.1007/978-3-030-11818-1_4

(6) Sands filters

(7) Infiltration trenches

(8) Infiltration basins

(9) Swales

(10) Detention basins.

Figure 30: Examples of SuDS

Image Source: http://www.hidrologiasostenible.com/sustainable-urban-drainage-systems-sud/

3.5.3. Decentralized Rainwater/ Storm water Management (DRWM) in Germany

Decentralized or semi-natural storm water management describes a concept for different approaches to rainfall in urban areas. Rainwater is not drained primarily through channel and pipe networks but retained locally, used, evaporated, infiltrated or throttled if needed. Decentralised rainwater infiltration and decentralized storm water treatment are partial aspects of storm water management[121]. The idea is to try to replicate natural systems by using cost-effective solutions with low environmental impact to manage polluted surface water run-off through the collection, storage, and cleaning before allowing it to be released slowly back into the environment. The main concept is to[122]:

[121] https://www.sieker.de/en/fachinformationen/dealing-with-rainwater/article/begriffe-der-rw-bewirtschaftung-77.html
[122] https://www.sieker.de/en/fachinformationen/dealing-with-rainwater/article/concept-of-decentralized-storm water-management-276.html

1. Retain water on site
2. Re-use storm water as a drinking water alternative, toilet flushing, irrigation
3. Improve the local climate and promote evaporative cooling
4. Recharge groundwater by promoting infiltration
5. Filter and clean through natural soil filtration
6. If necessary throttled to a water body or discharged through a drain.

3.5.4. Sound Water Cycle on National Planning (SWCNP) in Japan

Due to the progress of urbanization, the natural water cycle has been partially damaged. This has caused various problems to occur, e.g., instability of water flow in rivers, drying up of spring water, and deterioration of the ecosystem[123]. To solve these problems relating to water and to secure a sound water cycle, efficient planning should be developed (Figure 31), by reviewing the regional situation based on local characteristics and creating a master plan for recovery of the water cycle by synthetic diagnosis and evaluation of water cycle[124].

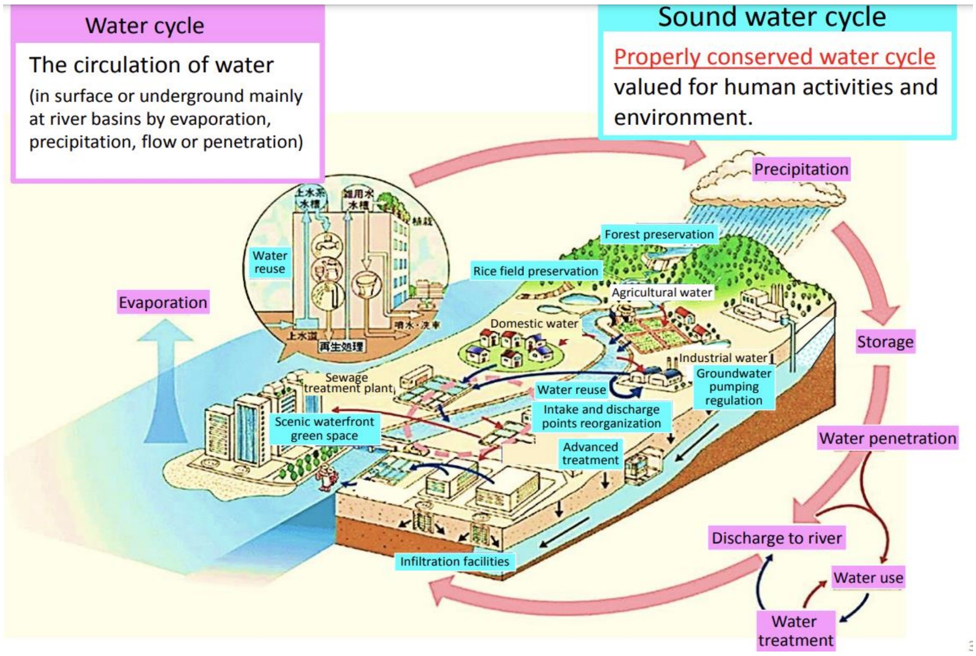

Figure 31: Difference between the water cycle and the sound water cycle

Image Source: https://www.narbo.jp/data/events/materials_6thgm/1_00.per cent20Keyper cent20Note_Mr.per cent20Mizukusa_MLITper cent20JAPAN.pdf

3.5.5. Sponge Cities in China

A 'sponge city' is a nature-based solution which uses the landscape to retain water at its source, slow down water flow and clean it throughout the process (Figure 32). The focus is to retain

[123] http://www.env.go.jp/en/water/wq/wemj/security.html
[124] https://www.kantei.go.jp/jp/singi/mizu_junkan/english/pdf/Overview_of_Basic_Plan_on_Water_Cycle(a4size)_EN.pdf

rainwater in urban areas by waterproofing the paved floor so that part of it evaporates and the rest is gradually drained as well as proofing the roads and pavements, more trees are planted and smart buildings are constructed to adapt to the city's sponge[125]. Existing urban areas often have to deal with flooding caused by heavy rain, high tides or swollen rivers, and sponge city design can mitigate or prevent such events by providing the area with the ability to naturally absorb the water (Figure 33 and Figure 34). The main features of the sponge city include being:

1. Environmentally adaptive
2. Systematic and comprehensive
3. Environmentally friendly

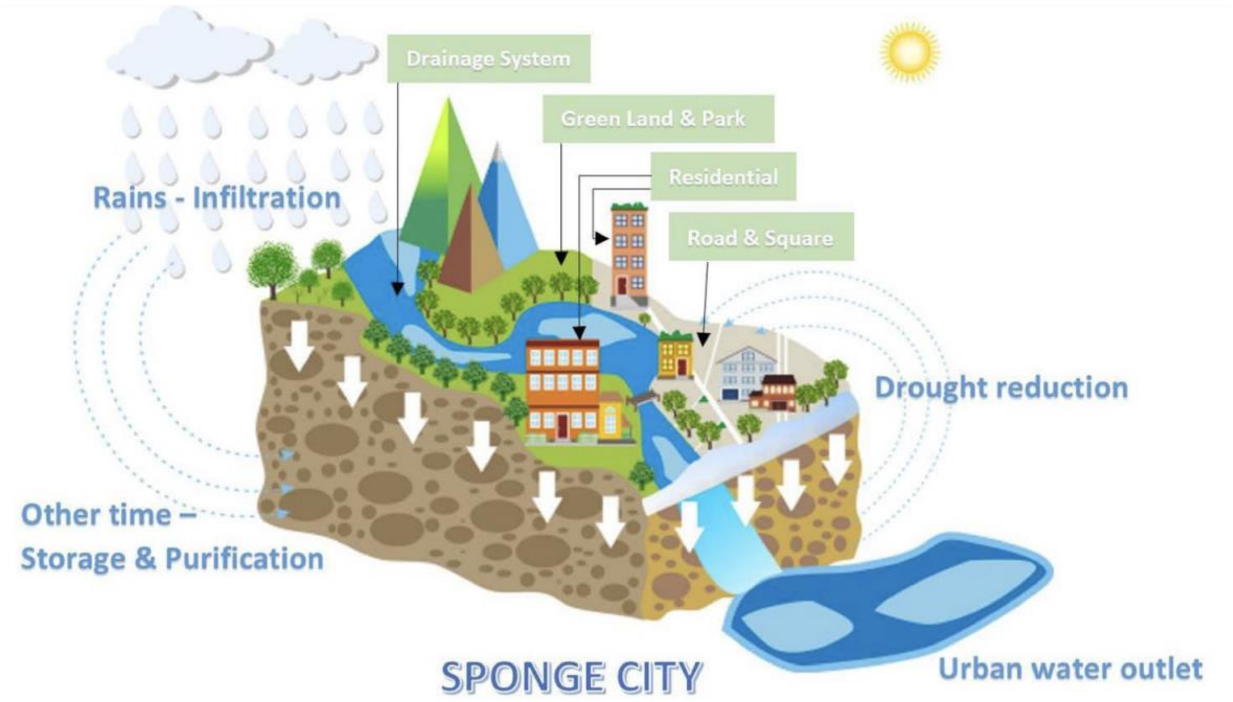

Figure 32: Schematic diagram of the Sponge city concept

Image Source: https://www.sciencedirect.com/science/article/abs/pii/S0264837717306130

Supplementing this approach with efficient channelling and storage systems can help to counter the frequency of water shortages, which can be particularly acute in large cities[126]. A sponge city needs to be abundant with spaces that allow water to seep through them. Instead of only impermeable concrete and asphalt, the city needs more[127]:

[125] https://www.euronews.com/green/2021/11/15/china-s-sponge-cities-are-a-revolutionary-rethink-to-prevent-flooding
[126] https://www.chapmantaylor.com/insights/what-are-sponge-cities-and-why-are-they-the-future-of-urban-design
[127] https://climatechampions.unfccc.int/what-are-sponge-cities-and-how-can-they-prevent-floods/

1. Contiguous open green spaces
2. Green roofs
3. Porous design
4. Water savings and recycling

Figure 33: Tianjin's Qiaoyuan park has been held up as an example of sponge city principles in action

Image Source: https://www.bbc.com/news/world-asia-china-59115753

Figure 34: Coastal wetlands and fishponds in China

Image Source: *https://www.chapmantaylor.com/insights/what-are-sponge-cities-and-why-are-they-the-future-of-urban-design*

Sponge city benefits:

There is a wide range of benefits associated with the implementation of sponge cities. These include[128]:

1. More clean water for the city. Replenished groundwater and thus greater accessibility to water resources for cities. This also entails greater water self-sufficiency which allows cities to increasingly rely on water sources from within their boundaries
2. Cleaner groundwater due to the increased volume of naturally filtered storm water. This means lower environmental and health costs due to considerable decrease in water pollution
3. Reduction in flood risk
4. Lower burdens on drainage systems, water treatment plant, artificial channels and natural streams. This also entails lower costs for drainage and treatment infrastructure
5. Greener, healthier, more enjoyable urban spaces. Greener urban spaces improve quality of life, create more pleasant landscape aesthetics and recreational areas that are enjoyable and

[128] https://www.worldfuturecouncil.org/sponge-cities-what-is-it-all-about/

attract people. This also means increase in land value due to aesthetically more pleasing, cleaner and healthier open spaces close to private properties

6. Enriched biodiversity around green open spaces, wetlands, urban gardens and

Sponge city challenges[129]:

1. Tackling already polluted ground water
2. To align the sponge city initiative (SCI)projects with infrastructure and urban renovation portfolios
3. Lack of reliable financing schemes

3.5.6. Early flood warning systems, India

IFLOWS-Mumbai: The Ministry of Earth Sciences (MoES) has developed this system with in-house expertise and coordination with the Brihanmumbai Municipal Corporation (BMC). The system can provide all information regarding possible flood-prone areas, likely height the floodwater could attain location-wise problem areas across all 24 wards and calculate the vulnerability and risk of elements exposed to flood[130]. IFLOWS is a monitoring and flood warning system that will be able to relay alerts of possible flood-prone areas anywhere between six to 72 hours in advance. The system can provide all information regarding possible flood-prone areas, likely height the floodwater could attain, location-wise problem areas across all 24 wards and calculate the vulnerability and risk of elements exposed to flood[131].

CFLOWS Chennai: Chennai Flood Warning System (CFLOWS), is India's first integrated coastal flood warning system. This is a Web GIS-based decision support system, integrating data and outputs, derived from weather forecast, hydrologic, hydraulic and hydrodynamic models. "Based on these models a flooded library, comprising 796 flood inundation scenarios, were developed corresponding to different rainfall return periods, tidal and water discharge conditions. A complete Web GIS-based decision support system has been built with six modules as per the requirement of Tamil Nadu Government and the system will be tested this monsoon[132].

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[129] Zevenbergen, C., Fu, D., Pathirana, A., 2018. Transitioning to Sponge Cities: Challenges and Opportunities to Address Urban Water Problems in China. Water 10, 1230. https://doi.org/10.3390/w10091230

[130] https://www.civilsdaily.com/news/i-flows-mumbai-flood-management-system/

[131] https://indianexpress.com/article/explained/explained-what-is-iflows-mumbai-and-how-will-it-benefit-the-maximum-city6455840/

[132] https://www.newindianexpress.com/good-news/2019/oct/18/chennai-becomes-first-in-india-to-get-an-intelligent-flood-warning-system-2049223.html

Urban Flood Mitigation, India

Gorakhpur City Resilience Strategy (CRS)[133]: Gorakhpur City is one of the most flood-prone cities in India, with an extreme event occurring every three–four years. The city has many water bodies, the largest of which is the Ramgarh Tal Lake, spread over 678 hectares in the south of the city. The Ramgarh Tal Lake plays an important role in the natural drainage pattern of the city. However, due to construction activities in the catchment area and sewage inflow, the lake's health has deteriorated. • The citizens of Gorakhpur took ownership to clean and manage the water body. • Strategies for the conservation of the lake are incorporated into the drainage master plan. • The waterlogged areas are recommended to be converted into green spaces for better management of urban runoff.

3.6. Post-Flood

After a natural disaster such as a flood, the potential for an outbreak of a communicable disease increases. (1) Interventions to deter the spread of the diseases must be implemented after a disaster[134]. Following measures can be taken to prevent communicable diseases from flooding[135]:

3.6.1. <u>Prevention of water-borne diseases</u>

Ensuring the uninterrupted provision of safe drinking water: It is the most important preventive measure to be implemented following flooding, in order to reduce the risk of outbreaks of water-borne diseases. Chlorination of water is an effective method for disinfecting drinking water.

1. <u>Chlorination of water</u>-Chlorination is the process of adding chlorine to drinking water to disinfect it and kill germs. Free chlorine is the most widely and easily used, and the most affordable of the drinking water disinfectants. It is also highly effective against nearly all waterborne pathogens. At doses of a few mg/litre and contact times of about 30 minutes, free chlorine generally inactivates >99.99per cent of enteric bacteria and viruses. Guidelines on water chlorination may be accessed at (https://www.cdc.gov/healthywater/drinking/public/water_disinfection.html?CDC_AA_refVal=httpsper cent3Aper cent2Fper cent2Fwww.cdc.govper cent2Fhealthywaterper cent2Fdrinkingper cent2Fpublicper cent2Fchlorine-disinfection.html)

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133 https://cdn.cseindia.org/gic/20.pdf
134 https://flooddiseases.com/
135 https://www.nhp.gov.in/health-impacts-of-flooding-and-risk-management_pg

2. Vaccination against hepatitis A: High-risk groups may be vaccinated with hepatitis A vaccines, such as persons involved in the management of drinking water, waste water or sewage, otherwise use of the hepatitis A vaccine for mass immunization is not recommended.
3. Prevention of leptospirosis: The risk of leptospirosis infection is minimized by avoiding contact with animal urine, infected animals or an infected environment. Where appropriate, protective clothing, rubber shoes and gloves should be worn and wounds covered with waterproof dressings to reduce the chance of infection, if exposure is likely, such as in occupational, floods or recreational exposure.

Adopting appropriate technology for anti-rodent operations with community awareness and participation. Creating awareness in the general community, risk groups and health care providers, so that the disease can be recognized and treated as soon as possible. The mapping of water bodies and human activities in water logged areas should be carried out. This will help to identify the high-risk population. Farmers may be educated to drain out the urine from the cattle shed into a pit, instead of letting it flow and mix with water bodies[136].

3.6.2. Prevention of vector-borne diseases

- Chemical Control
- Use of Indoor Residual Spray (IRS) with insecticides recommended under the vector-borne disease control programme
- Use of chemical larvicides in potable water
- Aerosol space spray during daytime
- Malathion fogging during outbreaks
- Personal Prophylactic Measures that individuals/communities can take up
- Use of mosquito repellent creams, liquids, coils, mats etc.
- Use of bed nets treated with insecticide
- Wearing clothes that cover maximum surface area of the body

3.6.3. Mental health mitigation

Psychological first aid can be provided by field workers, including health workers, teachers or trained volunteers, and does not always need mental health professionals. However psycho-social teams (psychiatrist, psychologists and psycho-social worker) may be needed for rapid

[136] https://www.nhp.gov.in/health-impacts-of-flooding-and-risk-management_pg

psycho-social assessment and community-based psycho-social care and referral services in affected community.

Health education[137]

- Promote good hygienic practice.
- Ensure safe food preparation techniques.
- Ensure boiling or chlorination of water.
- Vital importance of early diagnosis and treatment for malaria (within 24 hours of onset of fever)

3.7. Sendai Framework for Disaster Risk Reduction

The Sendai Framework for Disaster Risk Reduction 2015-2030 (Sendai Framework) was the first major agreement of the post-2015 development agenda and provides the Member States with concrete actions to protect development gains from the risk of disaster[138]. The Sendai Framework (Figure 35) works hand in hand with the other 2030 Agenda agreements, including The Paris Agreement on Climate Change, The Addis Ababa Action Agenda on Financing for Development, the New Urban Agenda, and ultimately the Sustainable Development Goals. As per United Nations Disaster Risk Reduction (UNDRR), "Sendai framework endorsed by the UN General Assembly following the 2015 and advocates for: The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries". Further implementation research of the Sendai Framework can contribute to the development of the broadly framed concept of health resilience according to the needs of people at risk in disasters, which can bridge the gap between the Sustainable Development Goals (SDGs) and this landmark UN agreement[139]. Establishment of Early Warning Alert and Response Network (EWARN)- The EWARN system is an enhancement of the existing routine syndromic surveillance system during and after disaster which is implemented by the Integrated Disease Surveillance Programme under Ministry of Health and Family Welfare, Government of India[140].

[137] https://ncdc.gov.in/showfile.php?lid=266
[138] https://www.undrr.org/implementing-sendai-framework/what-sendai-framework
[139] https://www.sciencedirect.com/science/article/pii/S2590061720300600#s0115
[140] https://www.nhp.gov.in/health-impacts-of-flooding-and-risk-management_pg

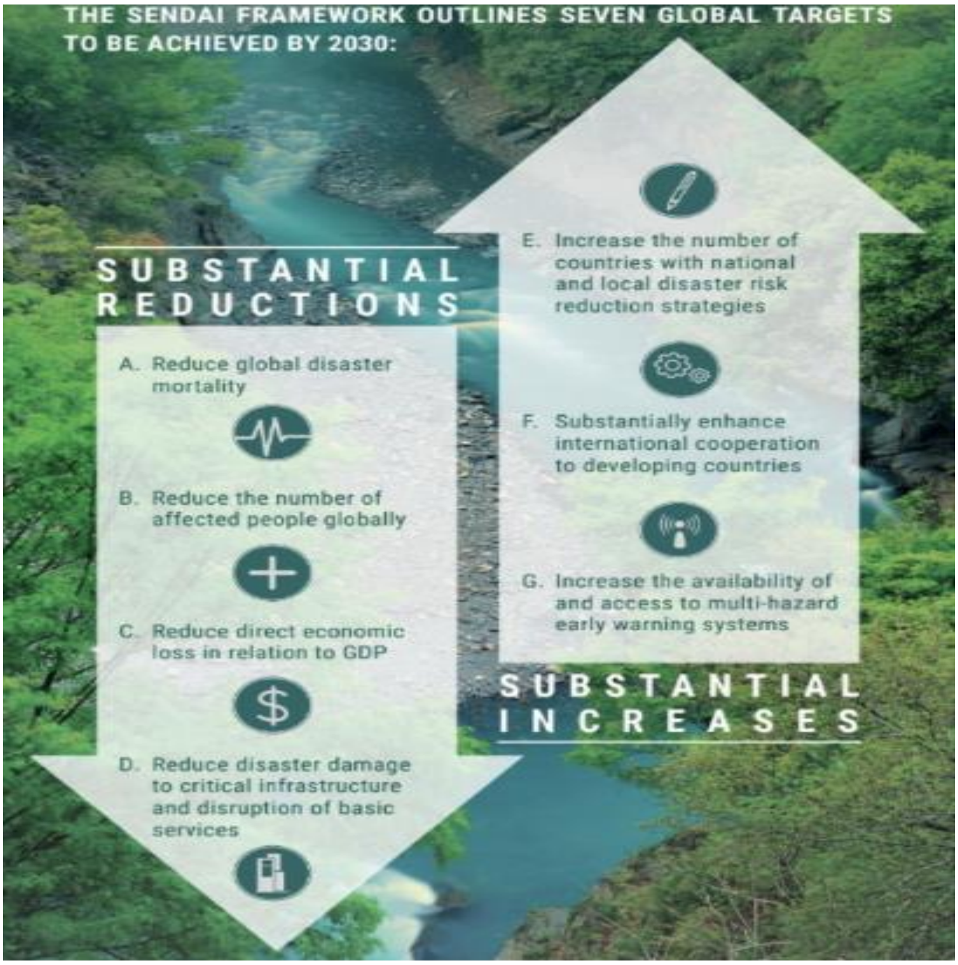

Figure 35: Global targets of Sendai Framework to be achieved by 2030

Image Source: https://www.undrr.org/implementing-sendai-framework/what-sendai-framework

United States Environment Protection Agency (USEPA): The details of the guidelines on (1) Prepare for flooding (2) During flooding (3) Recovery after flooding can be found on the website (https://www.epa.gov/natural-disasters/flooding).

World Health Organisation (WHO): Guidelines on food safety during the flood can be obtained on the website (https://www.who.int/westernpacific/emergencies/emergency-advice/food-safety)

Chapter 4. Audit Surveys and Major challenges for urban flood resilience in India

4.1. Performance audit of Management of storm water in Bengaluru Urban area (2021)[141]

Bengaluru witnessed **large scale encroachment of lakes/drains** and depletion of natural drainage systems. The city (covering an area of 741 sq km) had 1,452 water bodies with a total storage capacity of 35 TMC during the early 1800s. By 2016, the number of water bodies in the same area reduced to 194 with a storage capacity of 5 TMC. The current storage capacity which has further declined due to siltation is merely 1.2 TMC (2016). Out of 210 lakes under the jurisdiction of the Bruhat Bengaluru Mahanagara Palike (BBMP) as at the end of December 2020, 18 lakes with a total area of 254 Acres and 17 guntas were identified as disused lakes; making them vulnerable to encroachments and future conversions. The Bruhat Bengaluru Mahanagara Palike (BBMP) was yet to take action on 714 out of the 2,626 identified encroachments. **The completeness and reliability of the data on encroachments available with BBMP were low** as the audit noticed significant instances of encroachments, in addition to those recognised by the Bruhat Bengaluru Mahanagara Palike (BBMP). **Removal of encroachments was incomplete**.

- The State Government and Bruhat Bengaluru Mahanagara Palike (BBMP) **failed to consider urban surface runoff** (average annual rainfall being 969 mm during 2013-19) as a water resource despite the growing scarcity of water in the State/city. More than 40 per cent of properties under the purview of Bengaluru Water Supply and Sewerage Board (BWSSB) failed to adopt mandatory rainwater harvesting structures.
- The Bruhat Bengaluru Mahanagara Palike (BBMP) **did not possess fool-proof data on the total number/length and nature of different types of drains under** its jurisdiction. The absence of a comprehensive inventory of drains and their proper classification contributed to a lack of clarity on critical issues such as the extent of a buffer zone to be maintained, etc. This in turn hampered the maintenance of drains as many utility lines like electrical, telephone, optical cable, etc., were laid across the drains in many locations obstructing flow in the drains.

[141] https://cag.gov.in/uploads/download_audit_report/2021/10.per cent20Fullper cent20Report-061430461ae16f4.22975494.pdf

- Rampant mixing of sewage (780 MLD) with storm water is a serious problem.

4.2. Performance Audit on Preparedness and response to floods in Kerala, 2021[142]

The Comptroller and Auditor General of India (CAG) has picked holes in the flood management of the Kerala government, saying the flood plains in the state are yet to be demarcated and the flood plain zoning law is yet to be enacted. As per the report, the Kerala State Water Policy 2008 was not updated in accordance with the National Water Policy and lacked provisions for flood control and flood management in the state[143]. Some major findings of the audit are given below-

- Despite 275 flood forecasting stations having been set up by Central Water Commission (CWC) across the country by the year 2017, no flood forecasting stations had been set up by the Central Water Commission (CWC) in the State. The Government of Kerala had not furnished to the Central Water Commission (CWC) a list of reservoirs/ cities and towns requiring the setting up of inflow forecasting stations/ level forecasting stations.
- A project for obtaining real-time data on rainfall, streamflow etc. failed to deliver reliable data on real-time basis even after a lapse of five years.
- Pointing to the lack of a large-scale flood hazard map in the southern state, the agency said the state's Disaster Management Plan includes a flood susceptibility map not conforming to Central Water Commission (CWC) criteria for flood-prone areas[144].
- Only six rain gauges against the requirement of 32 were available for rainfall estimation in the Periyar basin.

4.3. Performance audit Union Government Schemes for Flood Control and Flood Forecasting Reports of Ministry of Water Resources, River Development & Ganga Rejuvenation, 2017[145]

The Performance Audit on "Schemes for Flood Control and Flood Forecasting" examined whether schemes for flood control and flood forecasting were efficient and effective; and whether the review and oversight mechanisms were effective. The audit sampled 206 Flood Management Programme projects, 38 flood forecasting stations, 49 River Management Activities and works related to Border Area projects and 68 large Dams, in 17 selected

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[142] https://cag.gov.in/uploads/download_audit_report/2021/Kerala_Au.I_Rep_6_2021-0618cb7f2db0035.98377057.pdf

[143] https://www.ndtv.com/kerala-news/cag-flays-kerala-govts-flood-management-2607145

[144] https://indianexpress.com/article/india/kerala/cag-kerala-flood-zoning-legislation-7618992/

[145] https://cag.gov.in/uploads/download_audit_report/2017/Report_No.10_of_2017_-_Performance_audit_Union_Government_Schemes_for_Flood_Control_and_Flood_Forecasting_Reports_of_Ministry_of_Water_Resources,_River_Development_&_Ganga_Rejuven.pdf

States/UT during 2007-08 to 2015-16. The Performance Audit showed that there were long delays in approval of Detailed Project Reports leading to technical designs becoming irrelevant at the time of actual funding. Some major findings of the audit report are given below-

- There were inordinate delays in 48 projects of four States ranging between two to 21 months in releasing first instalment of Central assistance to State Governments after approval of Empowered Committee.
- An amount of Rs600.92 crore along with interest of ` 18.30 crore recoverable as loan from the State Governments for not releasing the Central assistance within 15 days to the executing agencies, was not recovered by the Central Government.
- Funds amounting to Rs171.28 crore in six projects of five States were not utilised and remained parked for the period ranging between 15 months to more than 60 months. Funds amounting to Rs36.57 crore in three States were diverted by the implementing agencies for works not approved in the Detailed Project Reports.
- An expenditure amounting to Rs 18.12 crore incurred in the previous financial year before its approval by Empowered Committee was included in the cost of project in contravention of clause 4.10.3 of Flood Management Programme guidelines. Further, an amount of Rs19.99 crore was released in excess in two projects in Bihar and Uttarakhand.
- State Governments did not ensure submission of audited statements of expenditure and Utilisation Certificates within stipulated time before releasing Central assistance
- Flood management works were not taken up in an integrated manner covering entire river/tributary or a major segment of rivers/tributaries. There were delays in completion of the projects under Flood Management Programme.
- A large number of the telemetry stations installed during the XI plan remained non-functional, as such real time data for most of the period was not available.
- There were also huge delays in completion of all the projects under River Management Activities and Works related to Border Areas. Emergency Action Plans had been prepared for only a few large dams.
- Key recommendations of Rashtriya Barh Ayog such as scientific assessment of flood prone areas and enactment of Flood Plain Zoning Act have not materialised.
- Performance and concurrent evaluation were not done as per scheme guidelines[146].

[146] http://indiaenvironmentportal.org.in/content/445462/report-of-the-comptroller-and-auditor-general-of-india-on-schemes-for-flood-control-and-flood-forecasting/

- In four projects in Arunachal Pradesh and Uttar Pradesh, the actual quantity of work executed was below the approved scope of work. In four projects expenditure of Rs9.78 crores was incurred without the approval of the Competent Authority. GI wires valuing ` 25.40 crores remained unutilised in one project in Himachal Pradesh. Irregular grant of mobilization advance amounting to Rs80.36 crores in three States resulted in losses of interest of Rs15.84 crores. An expenditure of Rs34.51 crore was incurred on jeep track/inspection roads with Water Bound Macadam (WBM)/Bitumen (BT) surface over the flood embankment which was ineligible under FMP[147].

4.4. Report of the Comptroller and Auditor General of India on Performance Audit of Flood Management and Response in Chennai and its Suburban Areas, 2017

The Comptroller and Auditor General of India (CAG) held the state government responsible for the 2015 Chennai floods and called it a "man-made disaster." The report tabled in Tamil Nadu assembly on July 9, two-and-a-half years after the floods that killed 300 people, claims there was a serious failure in the operation of the Chembarambakkam reservoir, outside Chennai, from where 29, 000 cusecs of water was released against the recommended 12, 000 cusecs. The CAG report stated that the Tamil Nadu government allowed encroachment of lakes and river floodplains, leading to massive destruction. There was no coordination among departments and the Disaster Management Authority constituted in 2013, had not even met once till the floods happened. The report also observed that the state government failed to create two new reservoirs upstream of Chemberambakkam Lake, as recommended by an expert body and tardy implementation of restoration of water bodies' project[148]. Some highlights of the report are[149]

- The State lacked a law on Flood Plain Zone (FPZ) and an updated Water Policy to protect natural waterways. Frequency - based flood inundation maps, Emergency Action Plan for dams and Basin-wise comprehensive master plans were not prepared to respond to challenges posed by heavy rains.
- Failure of Water Resources Department (WRD) to create two new reservoirs in the upstream of Chembarambakkam Tank though recommended by Nucleus Cell for flood mitigation and

[147] https://cag.gov.in/webroot/uploads/download_audit_report/2017/Report_No.10_of_2017_-_Performance_audit_Union_Government_Schemes_for_Flood_Control_and_Flood_Forecasting_Reports_of_Ministry_of_Water_Resources,_River_Development_&_Ganga_Rejuven.pdf

[148] http://www.indiaenvironmentportal.org.in/content/457245/report-of-the-comptroller-and-auditor-general-of-india-on-performance-audit-of-flood-management-and-response-in-chennai-and-its-suburban-areas/

[149] https://cag.gov.in/uploads/download_audit_report/2017/Report_No_4_of_2017_-_Performance_Audit_of_Flood_Management_and_Response_in_Chennai_and_its_Suburban_Area.pdf

improper planning/non-completion of augmentation work across Kosastahalayar River resulted in non-achievement of envisaged water storage and flood control.

- Encroachment of tanks, lakes and river beds played a major role in causing the massive floods in Chennai. Despite the enactment of a law in 2007 to protect tanks from encroachment, the percentage of tanks encroached, kept increasing year after year.
- Eight projects taken up under Jawaharlal Nehru National Urban Renewal Mission, to provide new channels and strengthen existing channels in Chennai Metropolitan Area (CMA) could not be completed due to encroachments and lack of coordination between different departments, contributing to flooding in many areas.
- Inadequate coverage of Storm Water Drains (SWD) due to poor outlay, coupled with improper design and missing links in the Storm Water Drains (SWD) networks, contributed to flooding. Furthermore, the rainfall intensity adopted by Greater Chennai Corporation for designing Storm Water Drains (SWDs) was incorrect leading to the construction of lower capacity Storm Water Drains (SWDs) which also contributed to the floods of 2015.
- In 2014 and 2015, the annual desilting works of waterways in Chennai Metropolitan Area (CMA) had not commenced before the onset of the monsoon. Tamil Nadu government had not attached due importance to the desiltation work and had not bothered to release funds well before the monsoon and as a result, none of the sanctioned works could be completed before the onset of the monsoon. The non-execution of works before the monsoon hindered the free flow of flood water, thus contributing to floods in 2015.

4.5. Major challenges for urban flood resilience in India: Literature-based

- Increased frequency of heavy rainfall: A report by the Ministry of Earth Sciences (MOES), Government of India in June 2020[150], on Assessment of Climate Change over the Indian Region has mentioned that "increased frequencies of heavy rainfall on sub-daily and daily timescales has **enhanced flood risk all over India".**
- Monsoon unpredictability: A 2019 study of the South-West monsoon season depicted this unpredictability. It showed that on an average in June, India was almost 33 per cent rainfall deficient. By July, the average showed that it was 4.6 per cent more and by August 2019, this figure was in excess of the average by 35 per cent. This means we have **fewer rainy days and increased precipitation, leading to heavy rainfall in a few hours, putting**

[150] https://public.wmo.int/en/bulletin/flood-and-drought-management-through-water-resources-development-india

pressure on the existing urban drainage systems which have not been designed, nor augmented, to handle such extremes[151].

- **The drain systems in cities are outdated**: According to the Central Public Health and Environmental Engineering Organisation's (CPHEEO's) guidelines, storm drains were designed for rainfall intensity of 12–20 mm per hour, **which is hugely undersized for the current rainfall standards.**[152].
- **Flood vulnerability mapping** should be the primary step involved in risk reduction. Identification of the vulnerable areas can be done by analysing topography and historical data of inundations – extent and duration[153].
- Urban drain resizing: In 2018-19, the Indian Institute of Technology (IIT) Mumbai carried out a study of heavy rainfall days in 33 state capitals and Union Territories of India. Each city had witnessed rainfall of over 50 mm per hour, a trend which corresponded with floods on the same days in those cities. The study saw that **Bhubaneswar**, the capital of Orissa, on the east coast of India, received rainfall greater than 50 mm per day, 11 times during 2018-2019 and greater than 100 mm per day, six times during the monsoon. On 20th August 2018, Bhubaneshwar saw 190 mm per day of rainfall. Meanwhile, **Kolkata** witnessed rain of more than 50 mm per day 10 times, and more than 100 mm per day, three times during the season. On 25th June 2018, Kolkata saw 160 mm rainfall. Meanwhile **Mumbai**, which has been witnessing heavy short downpours, saw 50 mm per day rainfall, 12 times the normal and 100 mm per day, 9 times the normal during the 2018 monsoon. The city recorded a whopping 230 mm rain day on 24 June 2018. U**nless the drain capacities are increased, the flooding situation will not improve**[154].
- **Lack of data or maps of underground drains**: In many cities like Mumbai and Kolkata there are underground pipes which are over 100 years old. All urban local bodies need to do contour mapping of cities and drain mapping along with that which will tell them the existing situation of drains along with the new ones that need to be laid according to land contours to determine the natural flow of water[155].

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151 https://www.orfonline.org/expert-speak/inadequate-storm-water-infrastructure-biggest-hurdle-in-urban-flood-resilience/
152 http://cpheeo.gov.in/cms/manual-on-sewerage-and-sewage-treatment.php
153 Deepak, S., Rajan, G., Jairaj, P.G., 2020. Geospatial approach for assessment of vulnerability to flood in local self-governments.Geoenvironmental Disasters 7, 35. https://doi.org/10.1186/s40677-020-00172-w

154 https://www.orfonline.org/expert-speak/inadequate-storm-water-infrastructure-biggest-hurdle-in-urban-flood-resilience/
155 https://bengaluru.citizenmatters.in/cag-report-storm-water-drain-design-maintenance-issues-70468

- **Setting up operation and maintenance systems**: In addition, desilting works that clear nullahs and drains of plastic and garbage before every monsoon are very often done shoddily. Both the state and central governments need to implement the Ministry of Housing and Urban Affairs (MOHUA) manual which lays down protocols for such works.
- **Unconnected informal areas:** The informal areas and encroached settlements in cities are not connected through the storm water drain networks and very often the rainwater gets mixed up with sewage and garbage causing huge bottlenecks in the existing system. A consistent effort needs to be carried out either to prevent such areas from mushrooming or create networks connecting them.
- **Lack of funds**: There is very little money available for the upgradation of storm water drains, since most of the expenses are diverted towards operation and maintenance. While there are funds allocated for this through the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) scheme, which must be used, the Ministry of Housing and Urban Affairs (MOHUA) has encouraged cities to explore tapping private funds through Public-Private Partnerships (PPP) for this purpose.
- **Ramping up institutional capacity:** To effectively manage natural disasters, better coordination among different parastatal agencies is of utmost importance. At present, various government departments in India work in silos, in a hierarchical structure, mostly involving vertical communication leading to complications and delayed responses. This can cause enormous losses which could easily be averted with transparent and horizontal communication within and across departments[156].
- **Mainstreaming flood risks in urban planning:** There is increasing recognition that flood risk reduction, like other disaster risk reduction, should be ‘mainstreamed’ into the development process. Flood risks, therefore, need to be factored into various sectoral strategies and policies of the country[157].

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[156] https://www.preventionweb.net/news/making-indian-cities-climate-and-water-resilient

[157] https://library.wmo.int/doc_num.php?explnum_id=7342#:~:text=Givenper cent20theper cent20highper cent20spatialper cent20concentration,byper cent20yearsper cent20orper cent20evenper cent20decades.

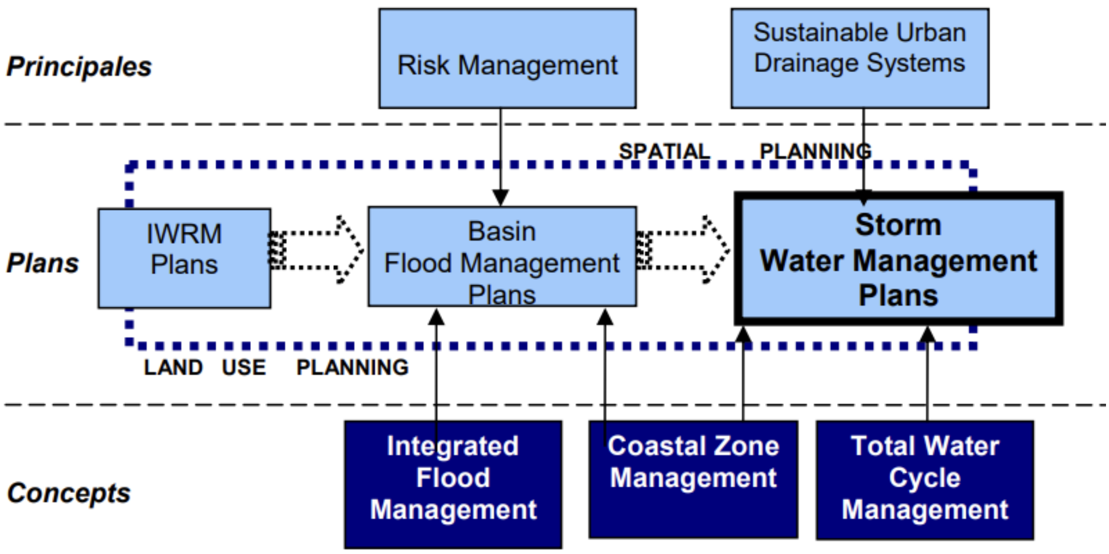

Figure 36: Urban Flood Risk Management: Conceptual Framework

Image Source: https://library.wmo.int/doc_num.php?explnum_id=7342#:~:text=Givenper cent20theper cent20highper cent20spatialper cent20concentration,byper cent20yearsper cent20orper cent20evenper cent20decades

Guidelines

1. Ministry of housing and urban affairs government of India, 2021, River centric urban planning guidelines (https://mohua.gov.in/upload/uploadfiles/files/RCUPper cent20Guidelines.pdf)
2. Reforms in Urban Planning Capacity in India, September 2021 (https://www.niti.gov.in/sites/default/files/2021-09/UrbanPlanningCapacity-in-India-16092021.pdf)
3. Urban Flood: Standard Operating Procedure (Ministry of Urban development. Government of India) (https://niua.org/sites/default/files/SOP_Urban_flooding.pdf)

Recommendations and Conclusion

Till the 1990s, Urban Flooding was considered as a concern of municipal and local governance only. Currently, it draws the attention of disaster and environmental scientists. Urban floods have attained the status of disaster due to high vulnerability and risks. Many Indian cities have experienced devastating floods in recent years which affect the routine life of residents and cause huge damage to life and property and fatalities and ultimately affected the economic growth of the country. Floods in Urban India are a result of both natural and manmade factors. Hence comprehensive urban planning which reconciles both environment and economic needs is required.

Therefore, it is essential to understand the various reasons for urban flooding and its plausible impacts on the urban environment in cities. Complexity of flood risk evolution process requires a clear understanding of the construct of the typology of various components of flood risks and the factors that mitigate or abate them[158]. Many sectoral development processes have profound influence on their management. The complex interaction between development processes and flood risk requires a clear conceptual framework which is supported by appropriate organisational and institutional mechanisms to develop and implement surface water management plans. A multiple mitigation approach would consider measures such as: preventing or restricting new or inappropriate development or activities in the flood plain; removal of certain structures from the floodway; flood proofing of structures in the flood plain; introduction of structural measures such as levees, dams and constructed channels; controlling land use practices within the basin; and applying flood forecasting and warning systems linked with response mechanisms[159]. Reluctance towards flood preparedness and mitigation measures may be the result of lacking hazard knowledge or of fatalistic attitudes. Moreover, dependence on too much external support can reduce the individual responsibility to deal with problems in a proactive manner[160]. Mitigation and rehabilitation measures should be the main focal area in solving the problem of recurrent floods. Following issues need to be addressed while developing and implementing such plans.

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[158] https://edukemy.com/current-affairs/gazette/2021-11-16/urban-flooding

[159] https://www.un.org/esa/sustdev/publications/flood_guidelines.pdf

[160] https://library.wmo.int/doc_num.php?explnum_id=7342#:~:text=Givenper%20cent20theper%20cent20highper%20cent20spatialper%20cent20concentration,byper%20cent20yearsper%20cent20orper%20cent20evenper%20cent20decades.

1. Structural measures: removal of encroachments in the flood plains and subsequent construction of a flood wall. Detention/holding ponds are an effective way of reducing flooding in cities like Mumbai, although the availability of land for the design capacity is always a challenge. Bio retention basins were also examined but were found unsuitable for heavy rainfall intensity. Rain gardens have been constructed in Hyderabad, India, with a depth varying from 400 to 500 mm and have shown excellent performance during the monsoon season[161] .
2. A good representation of the basin topography is an important asset in flood forecasting, emergency action and mitigation. A digital elevation model (DEM) or digital terrain model (DTM) for the basin should be developed as part of any GIS[162].
3. Channel Improvement A channel can be made to carry flood discharge at levels lower than its prevailing high flood level by improving its discharge carrying capacity. Channel improvement aims at increasing the area of flow or the velocity of flow (or both) to increase its carrying capacity. Channel improvement has not been resorted to widely in India mainly because of the high costs involved and topographical constraints. However, it is of advantage to take up such work for local reaches[163]
4. Strict control on the land use will reduce the tangible and intangible losses, especially in hill towns, coastal towns and flood plain areas.
5. It is important to coordinate civil society action with government mitigation programmes. Local communities should also be encouraged to document disasters and events at their level in any way possible for future research on flood mitigation and to increase local empirical knowledge of flooding[164].
6. Diversion of Flood Water Diverting all or a part of the discharge into a natural or artificially constructed channel, lying within or in some cases outside the flood plains is a useful means of lowering water levels in the river. The diverted water may be taken away from the river without returning it further downstream or it may be returned to the river some distance downstream or to a lake or to the sea[165].

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[161] Gupta, K., 2020. Challenges in developing urban flood resilience in India. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 378, 20190211. https://doi.org/10.1098/rsta.2019.0211
[162] https://www.un.org/esa/sustdev/publications/flood_guidelines.pdf
[163] https://nidm.gov.in/PDF/pubs/NDMA/3.pdf
[164] https://www.un.org/esa/sustdev/publications/flood_guidelines.pdf
[165] https://nidm.gov.in/PDF/pubs/NDMA/3.pdf

7. Awareness to be created about flood preparedness and mitigation measures along with response drills. People participation from all economic classes in the decision-making processes for flood reduction policies should happen with experts on a regular basis.

8. A nature-based and green solutions approach promoted by many cities globally. These approaches regard water (storm water, groundwater, and wastewater) as a resource that can be retained on a site, public space, or open space, for re-use or filtration. They help reduce the stress placed on a city's drainage during intensive rainfalls and can have co-benefits related to maintaining sustainable waterways and improving urban amenity. Common strategies can include permeable pavements, rain gardens, rainwater catchment tanks, detention ponds/basins, wetlands, swales, multi-purpose reservoirs, and other green infrastructure solutions[166].

9. Flood mitigation in urban landscape should integrate ecological approaches combining the watershed land-use planning with the regional development planning. This includes engineering measures and flood preparedness with the understanding of ecological and hydrological functions of the landscape[167].

[166] http://ripublication.com/ijerd20/ijerdv10n1_01.pdf

[167] http://wgbis.ces.iisc.ernet.in/energy/water/paper/teri_urbanfloods/urban_floods.pdf

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