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Catalogue of Best Practices for

Building Flood Resilience

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A catalogue of best practices for building flood resilience

Developed by:
Climate Centre for Cities, National Institute of Urban Affairs (NIUA) in association with The World Bank. This catalogue was co-funded by the European Union - South Asia (EUSAR) Capacity Building for Disaster Risk Management (DRM) and the Global Facility for Disaster Reduction and Recovery (GFDRR).

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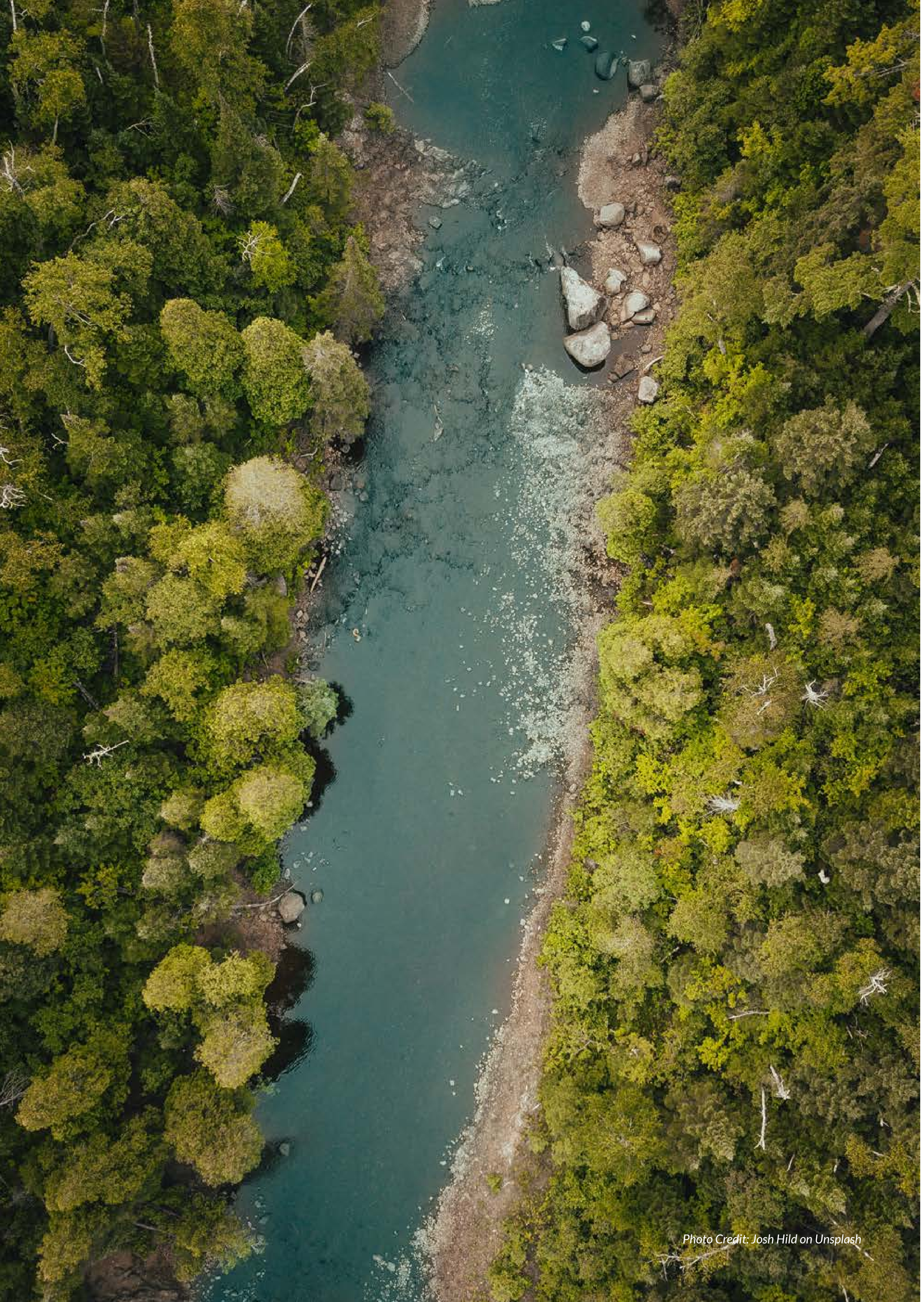

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Rapid urbanization and extreme climate events make cities vulnerable to water related risks like floods, water stagnation and water scarcity. Building flood resilience in cities is crucial for not only mitigating these risks but also improving the quality of lives. Our work at the Ministry of Housing and Urban Affairs, Government of India focuses on sustainable, people-centric and climate resilience approach, driven by innovation, digital governance and partnership. Along with this, it is important to learn from the worldwide successful practices for adopting relevant mitigation measures and for scaling up flood management initiatives. The Climate Centre for Cities within the National Institute of Urban Affairs, the World Bank Group and the Global Facility for Disaster Reduction and Recovery have partnered for introducing the much-needed best practices for building flood resilience. This catalogue provides various measures for mainstreaming flood risk management that can be prioritised in cities based on their risk profile. Contextual replication of measures is crucial for a successful intervention and I hope the catalogue can better inform cities to adopt appropriate flood measures.

Mr. Kunal Kumar
Joint Secretary & Mission Director (SCM),
Ministry of Housing and Urban Affairs, GoI

Climate-induced disasters like extreme rainfall can lead to flash floods and water stagnation resulting in significant loss of lives and damage to infrastructure. This scenario is increasing in the last decade and many Indian cities are frequently experiencing climate-induced flooding. There is a pressing need for cities to invest in building resilience and take appropriate actions to mitigate flood risks. The catalogue of best practices in building flood resilience is developed as a ready reference with an umbrella of solutions to support cities' select relevant flood interventions based on their need. While the World Bank Group is one of the largest multilateral providers of climate finance to help developing nations address climate risks, there is a need to identify appropriate measures for city-level investments. I hope this catalogue informs cities to invest in scaling up successful actions and replicating contextual interventions for building flood resilience.

Auguste Tano Kouamé
Country Director, India
The World Bank

Photo Credit:Pok Rie from Pexels

“

Climate Centre for Cities at the National Institute of Urban Affairs is working towards building climate actions in cities through capacity building, action research, innovation and partnerships. With many of our cities experiencing increased flooding, mainstreaming flood resilience within urban development is the need of the hour. To inform this need and with an intent to inspire cities and urban practitioners for identifying flood measures through the learning from real-world examples, this catalogue for building flood resilience is developed. The catalogue is a good compilation of the flood mitigation knowledge from 30 interventions across India and the world. Various components that inform project decision making such as risk profile, feasible scale of intervention, key stakeholders involved, cost of the intervention and potential for scaling up are captured graphically. Interventions are grouped into four major categories that is nature-based solutions, planning, technology and infrastructure to illustrate the various approaches that have worked and the outcomes that help cities mitigate floods.

”

Mr. Hitesh Vaidya
Director,
National Institute of Urban Affairs (NIUA)

“

Urban flooding poses an unprecedented threat to cities and their residents. Major cities across the world have experienced major flooding events over the past few years. Climate change and the consequent intensification of the hydrological cycle add another layer of uncertainty and risk for decision-makers on how to design and maintain infrastructure, invest in early warning systems, and risk-based land use planning that can withstand these massive shocks. The size and scope of the problem, especially in light of the rapid urbanization underway in the developing world, means that no one city or country has all the solutions. Learning from each other and adapting global solutions to the local context will enable us to build green, resilient, and inclusive cities.

”

Mr. Abhas K. Jha
Practice Manager, South Asia DRM & Climate Change
The World Bank


Photo Credit: Pavlo Rekun on Unsplash

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Guide to Read the Document

Title with the city name

Geoclimatic environment

Start date of the intervention

Photo of the intervention or an indicative representational photo.

Outcomes of the intervention are listed here. Implemented interventions have demonstrated outcomes but development of flood resilience plans and strategies prioritize actions with an aim to achieve set outcomes. To capture outcomes in a standard way, a list of outcomes that are essential for building flood resilience are used as reference. This includes 'increased ground water recharge', 'reduced water pollution', 'reduced soil erosion', 'reduced soil subsidence', 'improved water quality', 'reduced water scarcity', 'data informed policy and planning', 'enhanced coordination among stakeholders', 'empowered communities that can take flood mitigation actions', 'safeguarding livelihoods' and 'overall improvement in building flood resilience'. Additionally, resilience co-benefits such as 'carbon sequestration', 'improvement in the natural environment', 'reduced urban heat island', 'improved air quality', 'transformed public space', 'enhanced biodiversity', 'increasing livelihood opportunities', 'improved tourism' and 'enhanced amenity value' are also included.

The water risk profile of cities with respect to pluvial flood, fluvial flood, storm surges, variability in rainfall, high intensity rainfall (including cloud burst), rise in sea level and water scarcity are indicated here. The highlighted icons indicate the risk profile of the city.

The scale of intervention is indicated here. Neighborhood level interventions are small scale measures implemented at ward levels. City level interventions are measures implemented across the city. Regional interventions are measures that are beyond a city's jurisdiction.

Stakeholders involved in the project planning, implementation and monitoring including consultations are indicated here. The stakeholders include communities, international/ local Non-Governmental Organizations (NGOs) or Civil Society Organizations (CSOs), academic and research institutions, private players or businesses, city government which includes the municipal corporations and/or other line departments, and national/ state government and/ or other departments.

The 7 resilience qualities of the intervention are indicated here. Well-conceived interventions incorporating measures for anticipated failures are ROBUST. A participatory approach adopted to engage with all stakeholders in conceiving interventions are INCLUSIVE. Interventions that evolve and adapt to changing circumstances are FLEXIBLE. Interventions that leverage the available resources and capacities are RESOURCEFUL. Interventions that embed learning from the past are REFLECTIVE. Interventions that incorporate spare capacity to address disruption are REDUNDANT. Interventions that build common consensus on the outcome and promote exchange of information are INTEGRATED.

Approximate cost of intervention is highlighted across three ranges of less than INR 10 million, INR 10 million to 1 billion and above INR 1 billion. The rationale followed to indicate the cost in the absence of available data is that the interventions related to developing plans and strategies along with basic non-structural measures is less than INR 10 million. Large scale non-structural measures, small scale structural measures and some of the technology related interventions are between INR 10 million to 1 billion. Large scale structural measures are above 1 billion. (The cost of interventions are indicative)

With an intention to highlight the replicability of intervention in other cities, a range of 1 to 5 is used to indicate the potential for scaling up.

Level 1 – Interventions that are time intensive, high cost with limited co-benefits and city specific measures that are difficult to replicate in other cities.

Level 2 – Interventions that are time intensive, high cost with limited co-benefits but can be replicated in other cities.

Level 3 – Interventions that are time intensive and high cost but result in multiple co-benefits and can be replicated in other cities.

Level 4 – Interventions that are time intensive but are cost effective, result in multiple co-benefits and can be easily replicated in other cities.

Level 5 – Interventions that are time and cost effective, result in multiple co-benefits and can be easily replicated in other cities.

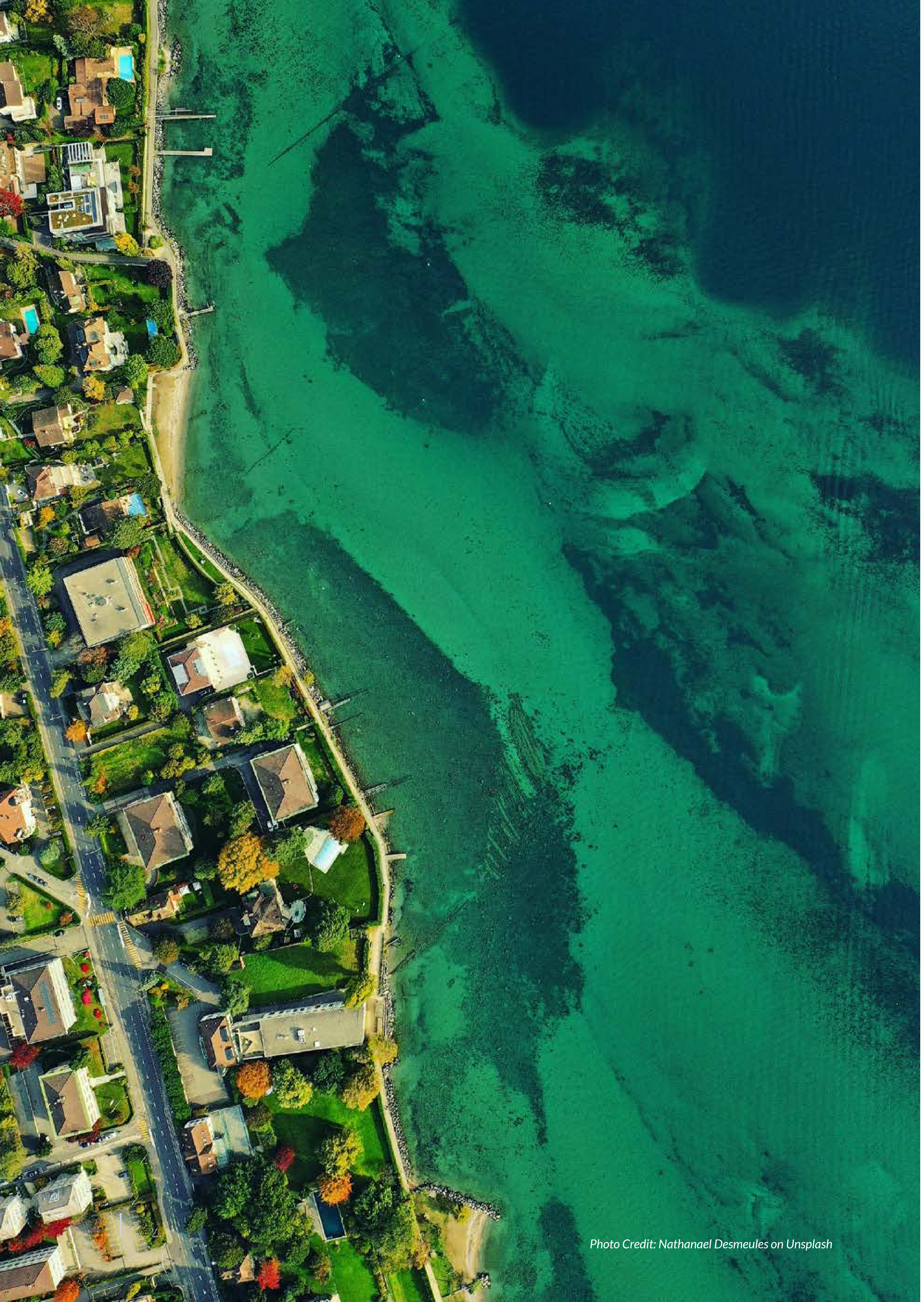


Photo Credit: Nathanael Desmeules on Unsplash

Introduction

Urbanization in India has led to 31% of its total population residing in cities and urban areas contributing to 63% of the national GDP[1] in 2011. The current projection indicates that the population in cities will increase to 40%[2] of the total population, in parallel the percentage GDP contribution is also expected to increase to 75%[3] of the national GDP. In this context, resilience of cities depends on effective functioning of complex infrastructure networks such as water, energy, sanitation, transport along with physical infrastructure such as housing, hospitals and educational institutions. The intensity of water related shocks and stresses faced by cities in India are beginning to pan out with increasing frequencies. Such events disrupt the socio-economic activities in a city and cause damages to critical infrastructure in addition to impacting the lives and livelihood of citizens. Every year, around 75 lakhs hectares of land is impacted by floods resulting in the loss of more than 1,600 lives and damages to houses and public utilities exceeding over Rs.1,800 crores.[4]

Many factors contribute to flooding in cities. Weather related events like prolonged rainfall, cloud burst, sea level rise and storm surges can expose cities to floods. Such events that cause flooding in cities are increasing due to climate change. The Sixth Assessment Report (AR6) by the Intergovernmental Panel on Climate Change (IPCC) highlights an increase in the frequency and magnitude of floods in India. The report also projects varying monsoons with erratic rainfall patterns that can cause floods. Additionally, sea level rise due to global warming is another reason compounding the flood risks, particularly for coastal cities. While the exposure to flooding in cities is projected to increase significantly, other factors like urban development and management play a crucial role in determining the vulnerability of cities to flooding.

Urbanization related development like construction in low lying areas, natural drainage and flood plains along with inefficient storm water network are key for flooding and water logging. Further, with urban development, the area of impervious surfaces that deter ground water absorption are increasing, green cover that can absorb and divert flood water is decreasing and water bodies that have the potential to store flood water are disappearing. The outcome from such unplanned development patterns have resulted in severe flooding across many cities in the country. Moreover, water related management in cities like storm water management and maintenance of water bodies like rivers, lakes and canals are important. Efficient management can reduce the risk of flooding but an ineffective management can increase the vulnerability of cities to flooding.

Many cities experience the dual challenge of flooding and water scarcity in a cyclic manner throughout the year. In order to overcome these challenges, there are numerous development measures that cities can adopt to build flood and water resilience. Some of the measures which have been successfully implemented by Indian and Global cities towards mitigating floods and building water resilience are showcased in this document. The intent is to create a basket of solutions that Indian cities can choose based on their need and priorities. Emphasis on replicability and scalability of interventions in the context of Indian cities has been considered while selecting the interventions. Additionally, the cost of implementation, scale of intervention and types of stakeholders involved in implementing flood measures are provided to help city officials plan for similar actions. Please read the section on 'guide to read the document' for further details. Overall, the interventions are categorized into the four themes namely Nature Based Solutions, Planning, Technological and Infrastructural Interventions.

1 *Ministry of Housing and Urban Affairs, Govt of India, 2015. Smart Cities: Mission Statement and Guidelines. [Online] Available at: https://smart-cities.gov.in/themes/habikon/files/SmartCityGuidelines.pdf [Accessed March 2021].*
2 *Department of Economic and Social Affairs, United Nations, 2018. World Urbanization Prospects 2018. [Online] Available at: https://population.un.org/wup/Country-Profiles/ [Accessed March 2021].*
3 *Ministry of Housing and Urban Affairs, Govt of India, 2015. Smart Cities: Mission Statement and Guidelines. [Online] Available at: https://smart-cities.gov.in/themes/habikon/files/SmartCityGuidelines.pdf [Accessed March 2021].*
4 *National Disaster Management Authority, [Online]. Available at: https://ndma.gov.in/. [accessed on 23 March 2021]*

Nature based Solutions

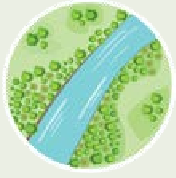
Nature-based Solutions (NBS) are non-structural interventions that "protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits."[5] In the context of urban flooding, NBS interventions can help in reducing the impact of floods by diverting and retaining flood water besides slowing down the flow of water. NBS is a cost-effective approach for mitigating floods and the interventions have multiple other benefits such as improving the water and soil quality, reducing heat island effect, improving urban spaces that can be used for recreation and enhancing urban biodiversity. Cities can develop an appropriate blend of various NBS interventions to maximize benefits while minimizing costs.

The NBS interventions covered in this document include:

Wetland Restoration

River / lake Restoration

Reviving Ecological Area



Riparian Vegetation Restoration

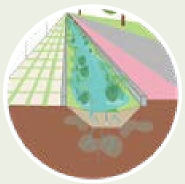
Mangrove Restoration

Restoring Natural Drainage Terrain

Restoration includes a variety of ecological, physical, spatial and management interventions aimed at restoring the natural state and functioning of the ecosystem. The outcome of restoration includes co-benefits such as enhancing biodiversity, reducing flooding and soil erosion, reducing urban heat island effect and an overall improvement of the urban environment.

Bioremediation of water bodies

Bioremediation is a process followed to improve the quality of water wherein microbes are introduced in the water body to break down the pollutants.

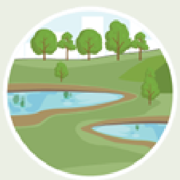


Bio-swales

Bioswales are landscape vegetation designed to convey stormwater while removing debris and pollution.

Recharge wells

Recharge well is a technique to use rainwater for replenishing the ground water.

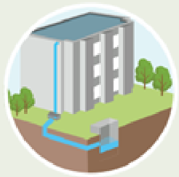


Retention Ponds

Retention ponds act as additional water storage ponds that capture surface runoff from rainfall.

Bioretention Systems

Bioretention system is a landscaped depression that not only captures surface run off but also treats the water.



Rain Water Harvesting

Rain water harvesting techniques include a wide array of interventions that stores surface run off water and/or recharges groundwater.

Green roofs and walls

Measures taken to grow vegetation on roofs and walls to reduce the indoor temperature of buildings. They can also double up as rain water harvesting measures.

Permeable Ground Surfaces

Increasing permeable surfaces in the city, especially of footpaths and other green areas can help reduce the surface run off and replenish ground water to an extent.

5 Cohen-Shacham, E., Walters, G., C. Janzen, and Maginnis, S. 2016. Editors: Nature-based Solutions to address global societal challenges. International Union for Conservation of Nature (IUCN). Gland, Switzerland. https://portals.iucn.org/library/sites/library/files/documents/2016-036.pdf

Planning interventions

Mainstreaming actions for building flood resilience requires appropriate policy regulations at national, state and city level. Along with regulations, strategic planning is crucial to ensure multi-sectoral and multi-stakeholder coordination for successful implementation of flood resilience measures. Studies indicate that poor planning and urban management are expected to cost Indian cities somewhere between USD 2.6 and USD 13 Billion annually.[6] With increasing risks to floods, a coordinated approach informed by risk assessment, and socio-economic and spatial vulnerabilities can shape land use and steer long term development for building flood resilience. Planning can help cities achieve short and long-term impacts in the physical environment by systematically incorporating NBS, increasing green cover and demarcating flood zones etc. For instance, the National Water Policy (2002) adopted by the National Water Resources Council stresses the need for developing master plans to control floods. The Standard Operating Procedure (SOP) for flood management by the Ministry of Housing and Urban Affairs (MoHUA) provides a framework for cities to better manage floods. Such plans, guidelines and frameworks are important for cities to develop a roadmap for strengthening flood resilience.

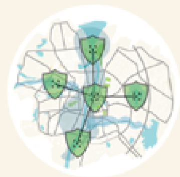
The planning interventions covered in this document include:

Urban River Management Plan

The National Mission for Clean Ganga (NMCG) and the National Institute of Urban Affairs have developed a framework for developing Urban River Management Plan (URMP) to help river cities systematically and holistically plan for interventions required to revive and maintain the rivers within their limits in a sustainable manner.

River Basin Management plan

River basin management plan provides a road map for conserving, managing and developing river water, river basin and related resources to achieve maximum socio, economic and environmental benefits.



Flood Resilience Strategy

Flood resilience strategy or flood mitigation plans define the short, medium and long-term measures to be adopted for strengthening flood resilience. The roles and responsibilities of various agencies and stakeholders are also defined in this strategy.

Plan for interlinking rivers and canals

Plan for interlinking rivers and canals includes large scale infrastructure related intervention to support efficient management of water resources. The intent is to address floods, water shortages, groundwater recharge and irrigation.

Community based Flood Management Plan

Community level plan engages local communities in all the phases on a flood - prevention, mitigation, preparedness, response and recovery. This process sensitizes vulnerable communities and empowers them to take appropriate actions for addressing flood risks.

6 Mani, M. et al., 2018. South Asia's Hotspots: The Impact of Temperature and Precipitation Changes on Living Standards, Washington. D.C.: World Bank Group.

Technology interventions

With increasing risk of flooding, data driven decision-making for flood risk management is proving to be significant. With the advancement in technology, improvements in computational flood models and flood forecasting have emerged in the last two decades. This has enabled cities to develop appropriate policy regulations, planning measures and prioritize investment options. Further, integrating these models with Geographical Information System (GIS) can help identify spatial vulnerabilities and inform emergency flood management. Technology can also be leveraged to streamline coordination across various government departments, communities and businesses to take timely action in events of a flood. Many cities have demonstrated the use of technology interventions in successfully monitoring, forecasting, assessing risk, communicating warnings and informing preparedness activities for floods.

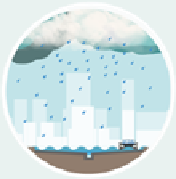
The technology interventions covered in this document include:

Hydrodynamic modelling

Hydrodynamic model can use historical data and weather projections to inform where inundation can happen along with the depth of inundation. In addition to regular monitoring, this information can support in visualizing future scenarios as well. Overall, such models can inform in planning for efficient flood management.

End to End Early Warning System

End to end early warning system is a comprehensive system that includes flood monitoring, forecasting and prediction, communication with people from vulnerable areas and relevant departments for initiating preparedness.



Cloudburst Management

Cloudburst is an event in which heavy rainfall occurs in a short duration of time. Cloudburst management includes a combination of measures to absorb, store, and transfer stormwater for minimizing flooding.

Community based Early Warning System

Community-based early warning system engages local communities in collecting and analysing flood related information and communicating warning messages with the community. The intent is to enable and empower communities to take actions for both mitigating floods and emergency management.

Data driven flood management

Data plays a key role in forecasting flood models, identifying vulnerable hotspots, planning for flood insurance programs etc. which can inform flood mitigation and emergency flood management. Adopting a data informed decision making can help cities develop a comprehensive strategy for flood management.

Flood control centre

Flood control centres are dedicated centres that regularly monitor the occurrence of a flood and water levels in water bodies, maintain flood mitigation infrastructure and communicate early warning messages.

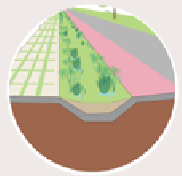
Infrastructure interventions

Infrastructure interventions are physical measures that, "….. reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or system."[7] In the context of flooding, infrastructure interventions are structural and engineered solutions that act as flood barriers, convey storm water and also store the water. Some of the commonly used structural flood measures include reservoirs, embankments and levees. These measures not only support in detaining run off water from vulnerable places but also consume less land space. Hence, they are a viable option in areas with high concentration of population and assets to reduce the impact of floods. In addition to building flood resilience, such interventions can be designed as multipurpose structures or buildings that provide recreational and public spaces. Some of the infrastructure interventions are high on cost and need to be planned and designed to have high impact on mitigating floods. Some of the infrastructural interventions may also require regular maintenance for efficient functioning. Overall, the selection of structural measures needs to be made carefully as they change the pattern of environment and can disturb the natural ecosystem if not implemented properly.

The infrastructural interventions covered in this document include:

Reservoirs

Reservoirs are large lakes created by the construction of dams to store fresh water.



Swales

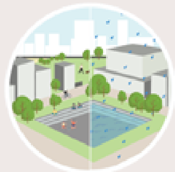
Swales are channels that convey runoff water and can also be designed to store storm water.

Rentention area

Detention/ retention tanks contain stormwater for limited time of period.

Underground Storage Structures

Various other underground structures can be built to store stormwater.

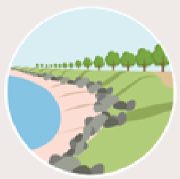


Water Squares

Water squares double up as public structures that temporarily store surface stormwater.

Comprehensive Drainage Network

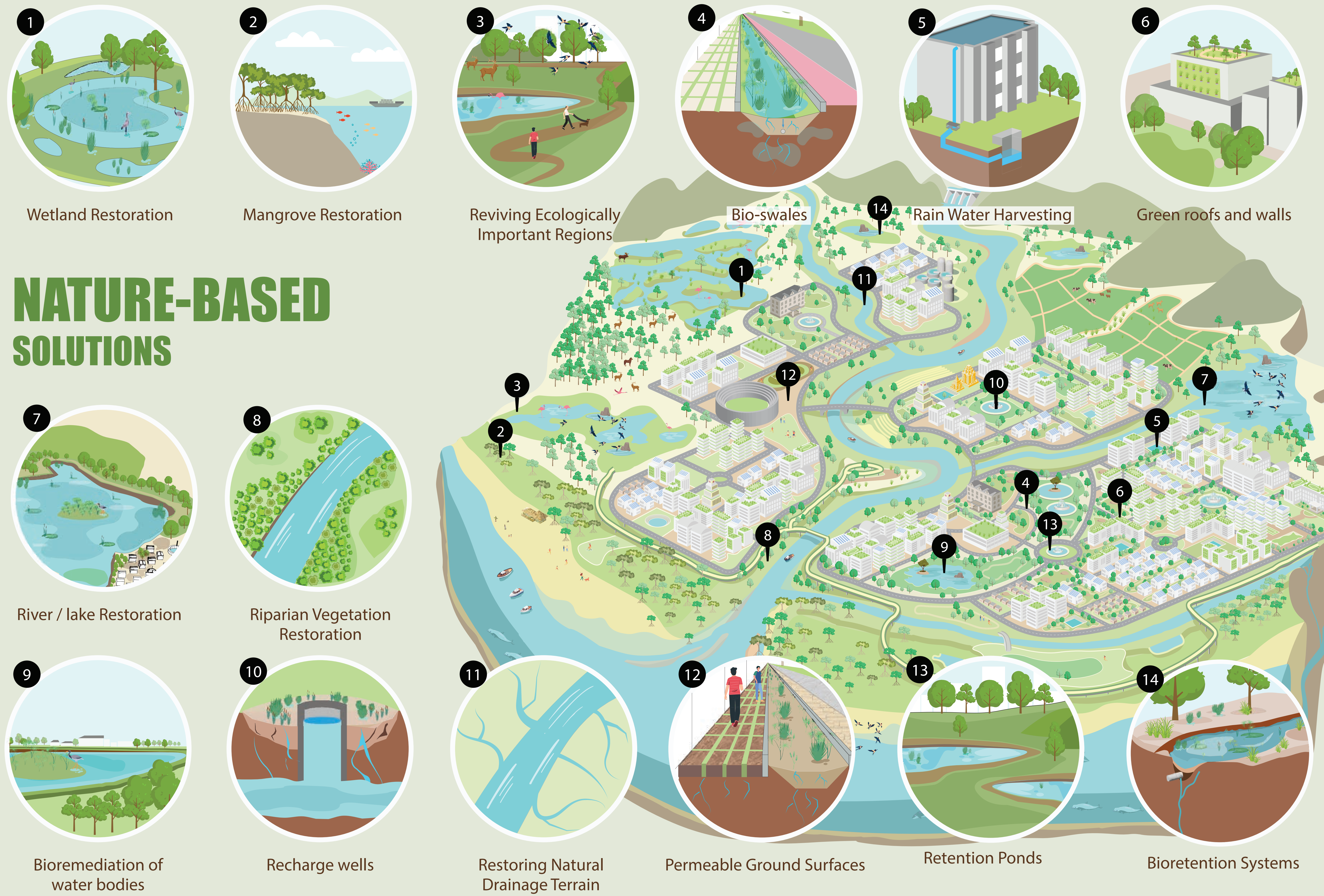
Comprehensive Storm Water Drainage (SWD) network covering all parts of the city, especially vulnerable hotspots are crucial for mitigating floods. Canal widening and deepening can be adopted to accommodate for the return period of rainfall for various periods. In addition, addressing solid and wastewater management in the city, specifically if connected to the SWD network is crucial to enhance the functioning of the network during a flood.



Flood mitigation structures

Flood mitigation structures like dykes, embankments and levees are built along water bodies or low-lying areas to prevent flooding.

7 UNDRR. 2022. *Structural and non-structural measures. United Nations Office for Disaster Risk Reduction. [Online] https://www.undrr.org/terminology/structural-and-non-structural-measures (Accessed on 2nd Aug, 2022)*


NATURE-BASED
SOLUTIONS
1 Wetland Restoration
2 Mangrove Restoration
3 Reviving Ecologically Important Regions
4 Bio-swales
5 Rain Water Harvesting
6 Green roofs and walls
7 River / lake Restoration
8 Riparian Vegetation Restoration
9 Bioremediation of water bodies
10 Recharge wells
11 Restoring Natural Drainage Terrain
12 Permeable Ground Surfaces
13 Retention Ponds
14 Bioretention Systems

Traditional Rainwater Harvesting, Alwar

Hot- Dry Climate Zone
Landlocked City

Community owned Johads

1985

Alwar is one of the water scarce districts in Rajasthan. Alwar and its neighbouring districts were dependent on the piped water supply system for their commercial, industrial and drinking water needs. Additionally, a traditional practice of building earthen percolation ponds to harvest rainwater also locally known as Johads has been in practice for managing water supply. Johads are strategically located at the deepest point that blocks natural drainage for collecting rainwater. Over the years, many Johads were lost due to improper management and maintenance. This has resulted in water scarcity and acute water shortages in the region. Realising this, the city government decided to revive old Johads and construct new ones to augment the supply of piped water systems.

To support the local government, local NGOs worked extensively with local communities to sensitise and engage them in adopting rain water harvesting measures and particularly to revive the lost Johads. Through participatory planning, designing and implementation process, Johads (the earthen dams) were restored. To capture the rainwater, Johads were rejuvenated before the onset of the monsoon. To build Johads, check dams were built either around the contours of slopes or in low lying areas. Mud and rubble masonry was used to build the embankment on three sides to hold the water and the side that collected water was left open. After the monsoon, Johads were successful in collecting rainwater and recharging the groundwater aquifers in the region.


View of small Johad in Rajasthan
Photo Credit: Amar singh kangarot, Wikipedia

In addition, other traditional practices to recharge groundwater like Anicut (a dam made of cement and stone), Bandh (a dam made of concrete and earth) and Talab (a pond structure with earthen embankments) were also revived by the communities. Following the example of Alwar, many districts in Rajasthan adopted measures to rejuvenate and revive their traditional water harvesting structures/ systems.

As a continued effort to address water management in the area, village panchayats in Alwar district established water parliaments (committee). The intent was to meet regularly and discuss water related challenges and take appropriate decisions for efficient water resource management. This has increased the ownership of communities in managing water resources and water consumption. Presently, more than 3,000 rainwater harvesting structures are present in Rajasthan and most of them are managed by the local communities

Details of this case study are referred from IWP & ICLEI. 2020. Integrated Urban Water Management Case Studies. India Water Partnership. [Online] Available at https://cwp-india.org/wp-content/uploads/2020/08/Compendium-of-Case-Studies-on-Integrated-Urban-Water-Management.pdf (accessed 11th May, 2022)

Additional information is available on Suutari. A and Marten.G. 2005. Water Warriors: Rainwater Harvesting to Replenish Underground Water (Rajasthan, India). Eco tipping points. [Online] available at https://ecotippingpoints.com/our-stories/indepth/india-rajasthan-rainwater-harvest-restoration-groundwater-johad/ (accessed 12th May, 2022)

Outcomes

- *Increased groundwater table*
- *Improved water quality*
- *Reduced water scarcity*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | **Water Scarcity**

Scale of Intervention

Neighbourhood | City | **Region**

Stakeholders

Community | **NGO/CSO** | Academia/ Research | Private/Business | **City government/ departments** | National government/ departments

Flood Resilience Characteristics

Robust | **Inclusive** | Flexible | **Resourceful** | **Reflective** | Redundant | **Integrated**

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

River Restoration, Chennai

Hot- Dry Climate Zone

Coastal City

Conservation, maintenance and development of eco-sensitive spaces

2006

Chennai, the capital city of Tamil Nadu is a coastal city that has many water bodies including rivers, lakes, traditional and religious ponds and canals. Three rivers (Kosasthalayar, Cooum and Adyar) flow towards the east coast and among the many canals in the city, the Buckingham Canal traverses parallel to the coast. Together, these water networks support a wide variety of flora and fauna. The rivers and canals drain the stormwater into the Bay of Bengal. However, in the last three decades, due to increased development and construction, the impervious surfaces within the city increased from 29.53% in 1991 to 64.4% in 2013. This has led to increased runoff during extreme rainfall events resulting in flooding and water stagnation especially along the low-lying areas. Additionally, the continuous disposal of solid waste and wastewater into the water bodies not only obstructed the flow of water but also resulted in a health hazard in the surrounding areas of these water bodies.

With an intent to mitigate urban flooding and improve the water quality in these water bodies, the Government of Tamil Nadu formed the Chennai Rivers Restoration Trust (CRRT) in 2006. The main goal of CRRT was to mitigate floods through climate-adaptive infrastructure and maintain the water quality in its riverine stretches. To achieve these goals, the trust initiated the Adyar Eco Park project.

The first phase of the Adyar Eco Park project, locally known as 'Tholkappia Poonga' was taken up for the restoration activities. The activities carried out between January 2008 – January 2010, include desilting to increase the carrying capacity of the water bodies, arresting sewage discharge from outfalls, development of eco-pathways, increasing vegetation cover surrounding the water bodies and preservation of the fauna diversity.

The second phase of the Adyar Eco Park project covered the ecological restoration of the Adyar river estuary (the transitional area where freshwater mixes with saltwater) and focused on flood mitigation and improving the water quality in its riverine and estuarine stretches. The second phase included water body restoration though widening of channels to increase the carrying capacity that can accommodate excess water, clearing of solid waste and debris for mitigating floods, preservation of habitat through mangrove plantation, and improved solid waste management and sanitation.

Around, 1,00,000 saplings of 24 mangrove species were planted to help preserve the natural habitat and mitigate floods. Additionally, improvement in water quality was achieved by excavating about 2.80 lakhs cubic metres of sludge and debris from the water bodies. This has helped in maintaining the ecological function of the creek.

It has now been measured that the Adyar creek has 59% more water storage capacity post-restoration. The intervention has also been able to manage the flood risks and maintain desired water quality in its riverine and estuarine stretches.

Details of this case study are referred from 'Chennai River Restoration Trust. 2020. Welcome to Chennai Rivers Restoration Trust. Current projects. [Online] Available at https://www.chennairivers.gov.in/ (accessed 28th May, 2022)

Adyar Ecological Restoration Park, Chennai
Photo credit: Idea design

Outcomes

- *Enhanced biodiversity*
- *Improved flood resilience*
- *Improved water quality*
- *Improved natural environment*
- *Transformed public space*
- *Enhanced biodiversity*
- *Reduced water pollution*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academic/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Mangrove Management, Mumbai

Warm Humid Climate Zone

Coastal City

An Institutional Approach

2012

Maharashtra's coastline including Mumbai Metropolitan Region (MMR) caters to a diverse range of marine ecosystems including mangroves, corals, mudflats and sandy shores. The ecosystem currently acts as a barrier and protects the inland from coastal risks such as cyclones, tsunamis and storm surges. The population of MMR is currently around 24 Million and increasing. The resulting construction activities along the coastal areas is leading to the depletion of mangroves which expose the city to increased flooding risks. Further, improper waste management resulting in water pollution impedes the functioning of marine ecosystems.

Effective mangrove management is the most cost-effective system to tackle the water related disasters and safeguard urban infrastructure from damages. Realising the above situation, the Government of Maharashtra prioritized to protect and conserve the mangroves ecosystem in the region.

An institutional approach was adopted by the state government for the effective mangrove management. Coastal communities were also involved in the process to promote increased livelihood opportunities and thereby ensuring sustainability of the initiative.

In 2012 a 'Mangrove Cell' was constituted by the Forest Department of the Maharashtra Government to manage the mangroves along the coast of Maharashtra. In addition, Mumbai Mangrove Conservation Unit (MMCU) was established in 2013 under the Mangrove Cell for managing the ecosystem within the city limits (Mumbai Metropolitan Region). Several measures were undertaken by the Mangrove Cell for the protection of mangrove ecosystem. These include:

- The mapping of mangrove cover annually to inform the formulation of appropriate action for the increased or decreased mangrove cover.
- Formulation of bylaws to help protect the mangroves from various development activities.
- Capacity building and awareness campaigns for a range of stakeholders from organisations to the communities has created awareness regarding the conservation of mangrove cover.
- Conducting large scale activities such as mangrove plantation, afforestation for improving the natural environment, clean-up campaigns for clearing waste and reducing the water pollution were incorporated.
- Generation of livelihood opportunities for the dependent communities was also a focus. The 'Mangrove Conservation and Livelihood Generation' scheme initiated in 2017 has resulted in providing livelihood opportunities for 3,000 beneficiaries within coastal districts of Maharashtra through subsidies.
- Promotion of ecotourism has helped create livelihood opportunities for the local communities. The development of ecotourism also helps conserving coastal biodiversity.

View of Thane Creek Flamingo Sanctuary (TCFS) and the Mumbai Metropolitan Region
Photo Credit: Mangrove Foundation Annual Report 2020-21

The state government of Maharashtra has co-funded and implemented various coastal ecosystem protection programmes and awareness programmes in partnership with international, multilateral and private organisations. Mangrove and Marine Biodiversity Conservation Foundation of Maharashtra (Mangrove Foundation) was set up in 2015 to implement various programmes such as mangrove conservation, development of livelihood activities, ecotourism, research and outreach. The status of the programmes and projects is being monitored regularly and published in the annual report. Ongoing projects along with funding details are also published in the report. It is observed that these interventions have resulted in an increase of mangrove cover by 36% from 2015 to 2017 resulting in conservation of over 200 species of birds (including migratory species) which are an integral part of the marine ecosystem.

Details of this case study are referred from 'Mangrove Foundation. 2020. Mangrove and Marine Biodiversity Conservation Foundation of Maharashtra. Annual Report 2020-21.' [Online] Available at https://mangroves.maharashtra.gov.in/Site/SiteInfo/Pdf/Mangrove_Foundation_Annual_Repport_2020-21.pdf (accessed 17th May, 2022)

Additional information is available at 'Mangrove Cell, Government of Maharashtra. 2020. Mangrove foundation. Mangrove and Marine Biodiversity Conservation Foundation of Maharashtra.' [Online] available at https://mangroves.maharashtra.gov.in/Home/Index (accessed 17th May, 2022)

Outcomes

- *Improved natural environment*
- *Enhanced biodiversity*
- *Improved flood resilience*
- *Reduced water pollution*
- *Increased livelihood opportunities*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/Research | Private/Business | City government/departments | State government/departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Yanweizhou Park, Jinhua

Temperate Climate Zone

River City

Flood resilient ecological development

2014

Every year, Jinhua experiences frequent floods during the monsoon season. Methods adopted by the city government to control such floods including building high concrete flood walls along the riparian flood plains and riverbanks failed to mitigate the risks. Instead, these methods further exacerbated flooding and water stagnation over the years. After several failed attempts, the recent initiatives which were undertaken especially for wetland management has proven to be effective to manage flooding events and improve the local ecosystem. One of the successful examples of wetland management adopted by Jinhua is Yanweizhou Park developed in 2014.

'Yanweizhou' is a 26 Ha of natural riparian wetland at the heart of the city where 2 tributaries (Wuyi and Yiwu rivers) converge to form Jinhua river. In the past, around 20 hectares of the riparian wetland was fragmented and destroyed by sand quarries and construction activities. Therefore, with an intent to protect these wetlands and mitigate flood risk, the city has adopted a resilient wetland management system using nature based interventions.

The objective of Yanweizhou Park development was to conserve the wetlands for flood control by creating a natural ecosystem around existing built structures.

Aerial view of the Yanweizhou Park
Photo Credit: Turenscape

Four key design interventions were considered while protecting these wetlands and they include:

- Preservation of the habitat in the wetland by minimising structural measures such as embankments and impervious surfaces (e.g. concrete construction) along the flood plains and improving percolation (decreasing runoff) by plantation of native trees.
- Instead of investing on high flood walls, they chose to adopt flood control approaches such as managing floodplains to channelize excess flood water to the wetland. In addition, 'cut and fill' strategy was adopted to create terraced river embankments.
- The built and natural spaces were integrated with increasing plantation, creating terraces of planters, increasing use of gravels, creating floodable areas and circular bio-swales that increased the recharge of ground water and improved the water quality.
- The functional public spaces were created through connecting pathways, pedestrian bridges, creating terraces and planting beds, concentric pavements and circular bio-swales.

Such ecological measures can be easily replicated around wetlands to achieve the dual purpose of maintaining the ecosystem and building urban flood resilience.

Details of this case study are referred from 'Turenscape, 2022. Jinhua Yanweizhou Park.' [Online] Available at https://www.chinese-architects.com/en/turenscape-haidian-district-beijing/project/jinhua-yanweizhou-park (accessed 29th July, 2022)

Outcomes

- *Improved natural environment*
- *Transformed public space*
- *Improved water quality*
- *Enhanced biodiversity*
- *Reduced soil erosion*
- *Improved flood resilience*

Water Risk Profile

Pluvial Flood | **Fluvial Flood** | Storm Surges | Variable Rainfall | High Intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | **Private/Business** | **City government/ departments** | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | **Resourceful** | **Reflective** | Redundant | **Integrated**

Cost of the Intervention

₹ | **₹₹** | ₹₹₹

Potential for Scaling Up

Chulalongkorn Centenary Park, Bangkok

Tropical Climate Zone

Coastal City

Demonstrating ecological flood intervention through park development

2017

Bangkok is known as the 'Venice of East' because of its intricate network of waterways. As a result of rapid urbanisation, this capital city has witnessed an increase in the construction activities which is blocking the natural waterways resulting in increased flood risk. Further, being situated in the delta of Chao Phraya river makes the city highly prone to sea level rise. Currently, the city is believed to be sinking at a rate of 2 centimetres every year. It is also predicted that parts of the city are likely to be below sea level by 2030. This may cause further damages to the existing infrastructure and disrupt the city's economic activities. In addition, the city also experiences storm surges and extreme rainfall. Therefore, building flood resilience is of great significance to the city and leveraging existing open spaces to address the same has been explored by the city administration.

In order to find the best ecological intervention and demonstrate how a public park can help in mitigating flood risk, the city organised a design competition for the 4.45 hectares of land donated by the Chulalongkorn University. The key interventions that emerged from the competition included the integration of green roofs, wetlands, detention lawns and retention ponds. Some of the actions that were undertaken as a part of this initiative include the following.

- Since the land was flat, a gradual slope of 3-degree was created to better manage surface run-off. At the highest point, a large green roof of around 5,200 sq. m. was designed which doubled up as a public space with museums and parking areas. Using the slope roofs, underground tanks were created for storing rainwater.
- At the lowest point, retention ponds and wetlands were created to retain excessive rain water. A series of cascading weirs and ponds were constructed to slow down the runoff water. This process naturally filtered water and this was reused for the park irrigation. Detention ponds were also created around low elevation zones of the park. Along with this, 8 outdoor classrooms were built using locally available pervious materials and indigenous plants. The use of 300 native plants and trees has helped in protecting local biodiversity and reducing urban heat island effect.
- In addition, around 1.3 km of 4 lane roads around the park was reduced to 2 lanes to promote the use of non-motorized transport.

An aerial view of the Chulalongkorn Centenary Park
Photo Credit: Landezine International Landscape Award

Most importantly, the park in the heart of the city was designed to hold around a million gallons of water. This was designed taking into account the 50-year return period of precipitation. The park was developed by converting the large grey areas to blue-green areas to improve its natural environment. Besides, the park currently boasts of a space with great views of the Bangkok skyline and this has led to the increased value of some of its surrounding properties.

Details of this case study are referred from 'LILA- Landezine International Landscape Award. 2022. Chulalongkorn University Centenary Park.' [Online] available at https://landezine-award.com/chulalongkorn-university-centenary-park/ (Accessed on 30th May, 2022)

Outcomes

- *Improved flood resilience*
- *Transformed public space*
- *Enhanced biodiversity*
- *Reduced urban heat island effect*
- *Improved flood resilience*
- *Enhanced amenity value*
- *Improved air quality*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ ₹₹ ₹₹₹

Potential for Scaling Up

Water Garden, New Orleans

Tropical Climate Zone

City with water bodies

Mirabeau's resilient water gardens

New Orleans is situated along the Mississippi river in the USA and has a history of cyclones and storm surges. In 2005, one of the severe flooding events that occurred due to Hurricane Katrina had almost 80% of the city flooded and impacted the majority of its population. The event also led to subsidence especially in the low-lying areas which further damaged the city infrastructure. The existing storm water drainage system was incapable of channelising the runoff from extreme rainfall events and resulted in flooding. To tackle the challenge of limited capacity of stormwater drainage, a neighbourhood level flood resilient strategy was adopted by the city of New Orleans. Further, the strategies of innovative site design and storm water management features were integrated in the Greater New Orleans Urban Water Plan.

Importantly, Mirabeau Garden was developed as a Water Garden to divert and store the excess storm water from the city drainage system thereby preventing localised flooding. 10 hectares of land was donated to the city of New Orleans by the Congregation of St. Joseph. The intent was to transform it into a water garden that can become a recreational and educational amenity for reducing the flood risks of the city. The water garden was developed into two phases of landscape development and flood mitigation.

The design objective of the water garden included creation of detention ponds in low lying areas of the site for collecting around 10 million gallons of stormwater. While the sand layer allows water percolation the organic soil layer stabilises the ground and prevents subsidence. This technique also improves the water quality and helps convert feculent flood water into clear water. The clear water is reused for purposes other than drinking.

Another objective of this project was to mitigate the floods and create awareness through nature based solutions for flood resilience. The Mirabeau water garden has an integrated water management system which has led to increased property value of the surrounding neighbourhood. The garden has also become a public asset and an awareness hub on flood mitigation.

In 2018, Foreign Exchange Management Act (FEMA) awarded the city USD 12.5 Millions* in federal assistance through the Hazard Mitigation Grant Program (HMGP) to reduce flood risks. In addition, this project is expected to receive additional federal financing from the National Disaster Resilience Competition (NDRC) sponsored by the US Department of Housing and Urban Development (HUD) to enhance the ongoing work, especially the landscape design.

Details of this case study are referred from 'City of New Orleans. 2018. Mirabeau Water Garden. Fact Sheet. Gentilly Resilience District.' [Online] Available at https://www.nola.gov/resilience-sustainability/resources/fact-sheets/mirabeau-factsheet/ (accessed 18th May, 2022)

** Amount taken as is from the reference.*

Collection of excess storm water in the Mirabeau Water Garden
Photo Credit: Waggonner & Ball Architecture/ Environment and Dezeen

2018

Outcomes

- *Transformed public space*
- *Improved flood resilience*
- *Improved water quality*
- *Reduced soil subsidence*
- *Enhanced amenity value*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academic/Research | Private/Business | City government/departments | National government/departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Wetland Management, Kolkata

Warm Humid Climate Zone

Coastal City

An institutional framework for wetland management

Kolkata is located on the banks of Hooghly river and on the coast of Bay of Bengal thereby making it highly vulnerable to flooding due to cyclones and storm surges. The East Kolkata Wetlands (EKW) listed in the Ramsar list of 'Wetlands of International Importance' acts as a natural barrier and protects the city from possible flood risks. EKW is located on the eastern fringe of Kolkata and spreads across an area of 12,500 hectares. It is one of the largest natural resource recovery systems in the world with integrated aquaculture, horticulture and agriculture.

Over the years, urban development in this region has disturbed the functioning of these natural wetlands. Additionally, improper solid waste management in the area has led to increased water pollution and siltation. Further, encroachment along the wetlands has reduced the extent of inundation leading to increased risk of flooding. It was therefore crucial for the government and local administration to manage the EKW to maintain the natural ecosystem and also address the risk of flooding.

For the preparation of East Kolkata Wetland Management Plan, East Kolkata Wetland Management Authority (EKWMA) was constituted under the EKW (Conservation and Management) (Amendment) Act 2017. A management framework was prepared for the period of 2021-26 with a dedicated budget of around USD 14 Millions*. The framework targets land use management, sewage management, maintenance of the ecosystem, improve livelihood opportunities, strengthen community participation and stakeholder engagement, and assess and monitor the system along with the development of sectoral plans. Based on the framework, the following actions were implemented.

- To strengthen the governance, reorganisation of EKWMA was initiated to empower their role towards result oriented wetland management. EKWMA was made responsible for demarcating wetlands boundary, conducting research and assessment, preparing annual reports, building capacity and spreading awareness, and bi-annual review of the activities to ensure the plan is implemented properly. About 32% of the total budget has been allocated for implementing the above measures.
- Initiatives around water management and pollution abatement were undertaken to focus on preventing solid waste and plastic pollutants entering the wetlands. These included actions such as dredging of silted canals, solid waste segregators, establishment of plastic waste recycling system and creation of no plastic zone around the wetlands. Currently EKW treats around 900 MLD sewage from Kolkata. About 22% of the total budget has been allocated for the implementation of these measures.
- Rejuvenation of species and habitats through regular monitoring and mapping was undertaken. These include measures to improve the habitat of indigenous plant species, waterbird species, indigenous fish species, amphibians and reptile species. EKW acts as a carbon sink to 3,500 tonnes of CO_2 every year and potentially offsetting 60% of Kolkata's carbon emission leading to improved air quality. About 19% of the total budget has been allocated for the implementation of these measures.
- Sustainable resource development and livelihood enhancement initiatives were carried out to improve the productivity of aquaculture, horticulture and agriculture in the region. In addition, measures were taken to strengthen health infrastructure by building community health centres. About 27% of the total budget has been allocated for the implementation of these measures.

View of East Kolkata Wetlands
Photo credit: N K Realtors

Details of this case study are referred from 'Department of Environment, Government of West Bengal. 2021. Integrated Management Plan of East Kolkata Wetlands (Management Action Plan 2021 – 2026).' [Online] Available at http://ekwma.in/ek/wp-content/uploads/2021/08/Integrated-Management-Plan-of-East-Kolkata-Wetlands-2021-2026.pdf (accessed 17th May, 2022)

The additional information is available at 'East Kolkata Wetlands Management Authority. 2022.' [Online] Available at http://ekwma.in/ek/ (accessed 17th May, 2022)

** 1USD = 77.9 INR*

Outcomes

- *Improved natural environment*
- *Enhanced biodiversity*
- *Improved flood resilience*
- *Reduced water pollution*
- *Reduced carbon emissions*
- *Increased livelihood opportunities*
- *Improved air quality*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academic/Research | Private/Business | City government/departments | State government/departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

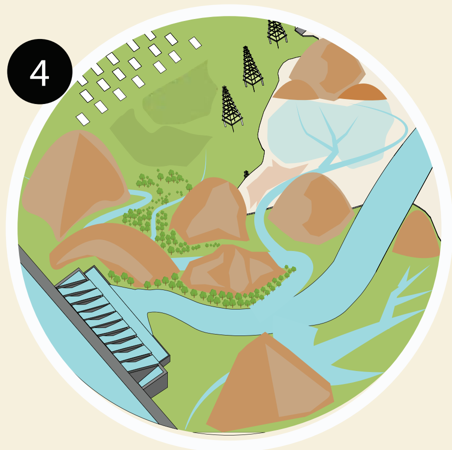
Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

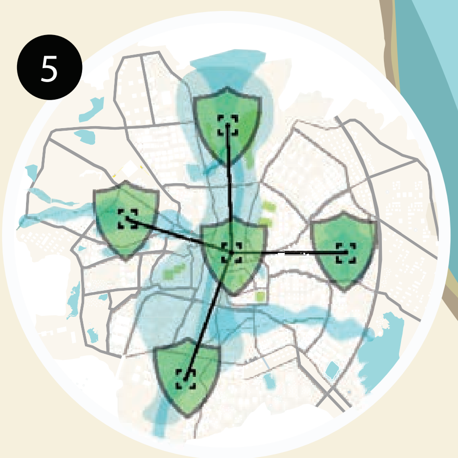
PLANNING
Interventions

River Basin Management plan



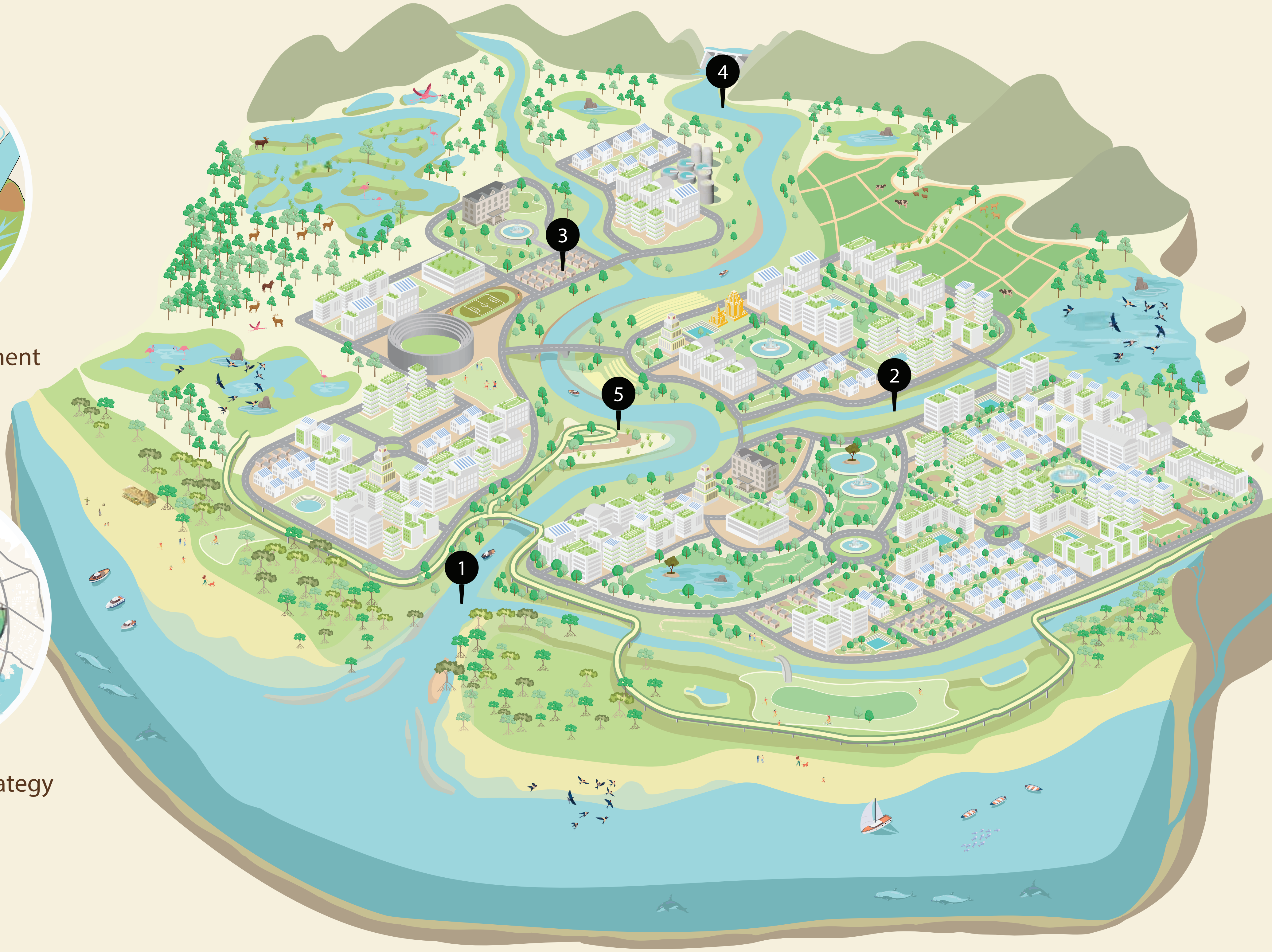
Urban River Management Plan

Plan for interlinking rivers and canals



Flood Resilience Strategy

Community based Flood Management Plan



Lake Conservation, Udaipur

City with water bodies
Hot- Dry Climate Zone

Rejuvenating water sources in the region

Udaipur also known as the city of lakes, is predominantly dependent on its key lakes namely Fatehsagar, Pichola and Jaisamand along with the Mansi Wakal dam on the Mansi River for its drinking water needs. The quality of water in these lakes has deteriorated over the years and resulted in eutrophication and sedimentation. The main reason for this was the illegal disposal of untreated sewage into the lakes. Also, variability in annual rainfall impacts the quantum of storage in these lakes.

In order to safeguard the water sources and improve the quality of water in these lakes, the city government of Udaipur established a lake conservation society, named 'Jheel Samverdhan & Vikas Society (JSVS). Some of the measures undertaken by JSVS include but are not limited to:

Conduct preliminary assessment of the lakes through hydrological and limnological (study of inland aquatic ecosystems) studies. With an understanding of the status of the lakes, relevant interventions to abate pollution were formulated.

Building of sewerage network around the lakes to avoid the disposal of untreated wastewater into lakes. This was funded by the National Lake Conservation Plan (NLCP) scheme under the Ministry of Environment, Forest and Climate Change.

Catchment conservation of the Pichhola watershed comprising of 16 villages over an area of 12,702 hectares was undertaken. This helped in water augmentation and reduced the dependence on groundwater. Further, an oxidation pond established in the Pichhola lake helped in addressing the eutrophication challenge and control the growth of water hyacinth.

The society also established an institutional arrangement for the maintenance of lakes and conducted awareness programs to help citizens realise the importance of water conservation.

These integrated measures led to the success of conserving and managing water in the city and its surrounding. Following its success, several similar interventions are undertaken by the government to conserve small ponds and restore other small lakes.

Details of this case study are referred from IWP & ICLEI. 2020. Integrated Urban Water Management Case Studies. India Water Partnership. [Online] Available at https://cwp-india.org/wp-content/uploads/2020/08/Compendium-of-Case-Studies-on-Integrated-Urban-Water-Management.pdf (accessed 11th May, 2022)

Aerial view of Lake Palace in Udaipur
Source: Wikimedia

2000

Outcomes

- *Improved water quality*
- *Increased groundwater table*
- *Reduced water pollution*
- *Informed policy and planning*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ ₹₹ ₹₹₹

Potential for Scaling Up

Room for the River, Netherlands

Coastal Country with Water Bodies

Temperate Climate Zone

Strategy for Urban River Management

2007

In Netherlands, 25% of its land is situated below sea level making two third of the country vulnerable to the risk of floods, rise in sea level and storm surges. Situated at the delta of the Rhine, Meuse and Scheldt rivers, parts of western and northern Netherlands experiences subsidence in the range of 15-20 cm per year. While the country has historically experienced flooding, focus on protecting areas adjoining the rivers from regular flooding was crucial.

The traditional approach included, river diversion through construction along floodplains to reduce the flow capacity of rivers. A few of the techniques such as creating more space in the flood plain area were successful in reducing the floods and normalising water level. With this learning experience, Room for the River programme was initiated in 2007 by the national government. The main objective of Room for the River programme was to manage water levels in the river by adopting nature based solutions to regulate flood water. The goal was to ensure protection against flooding and contribute to the improvement of carrying capacity of the river. Further through the intervention, the discharge capacity of the rivers was also increased considering the climate change challenges. The programme identified around 30 projects along the rivers. Some of the nature based solutions implemented under this are as follows,

- Deepening the low flow channel by excavating the riverbed to increase the carrying capacity.
- Removing or modifying hydraulic obstacles to increase the floodplain discharge capacity.
- Locally shifting the dykes by relocating them inland to widens the floodplain. This provides additional space for the river and aid in minimising the soil subsidence. Further setting up of dykes on a large scale to create more room for the river. Creating a separate route, bypass or high-water channel with dykes along the river to channelise excess water and safeguard infrastructure.
- Creating retention reservoirs as a temporary water storage area by lowering the dykes and creating polders. This reduces the runoff and creates space for excess flows during extreme (water flow) situations.
- Reducing lateral inflow by storing the water upstream in retention reservoirs to manage the peak water flow.
- Improving land use planning along the floodplain by promoting forestation and creating buffer zones.
- Promoting creation of depended grounds (polders) to facilitate river water to flow into them and creating elevated farms or dwelling mounds, also known as terps, to protect during high water and storm surges.
- Integration of architectural interventions such as construction of weir to enhance aesthetics and to act as a mechanism to absorb water pressure. These also cater to increase fresh water supply and provide water network for transport.

View of room for the river program, Nijmegen city, Netherland
Photo credit: Dutch Water Sector

The projects were implemented at a cost of USD 2.3 billions*, including identification of contextual solutions for each river. Most of these projects were completed in 2019 and were implemented by engaging citizens, specifically those who were residing along the floodplain area. Keeping in mind the return period of 100 years the 'Room for the River' programme has inspired many countries to adopt such flood resilient interventions.

Details of this case study are referred from 'van Alphen, S. 2020. Room for the River: Innovation, or Tradition? The Case of the Noordwaard. In: Hein, C. (eds) Adaptive Strategies for Water Heritage. Springer, Cham.' [Online] available at https://doi.org/10.1007/978-3-030-00268-8_16 (Accessed on 6th June 2022)

and Royal Haskoning DHV. 2022. Room for the river. Available at: https://global.royalhaskoningdhv.com/projects/room-for-the-river-the-netherlands (Accessed 25th June, 2022)

** 1USD = 1EUR*

Outcomes

- *Improved flood resilience*
- *Reduced soil subsidence*
- *Informed policy and planning*
- *Improved citizen engagement*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ ₹₹ ₹₹₹

Potential for Scaling Up

Sponge City Concept, China

Tropical Climate Zone

Mainstreaming Nature-Based Solutions in the National Policy

2013

China has witnessed rapid urbanisation since 1980 due to an expansion of economic activities. Over time, the densely populated cities have increased their impervious surfaces due to construction of buildings, roads and allied infrastructure facilities. On a parallel front, these cities witness heavy summer rainfall which have intensified in the last few decades due to climate variability and change. The existing stormwater drainage networks in most cities cannot handle extreme rainfall induced runoff and hence result in floods. Further, the increased use of impervious surfaces limits the recharge of groundwater. It is estimated that around 1% of GDP is lost due to the damage occurring from floods every year. In order to address the urban floods, the national government prioritized water management as a key priority in urban development. The country aimed to shift from the conventional engineering techniques to comprehensive and structured nature-based solutions for urban water management.

In 2013, China came up with the Sponge City Concept (SCC) inspired from other similar worldwide practices to address urban floods. The concept emphasises on upgradation and transformation of the urban spaces and infrastructure which would act like "sponges" to absorb rain water. This will further increase the groundwater table and minimise the risk of flooding. The increased use of permeable materials enhances storage and discharge capacity, and reduce the urban heat island effect thereby contributing to improved quality of lives.

Accordingly, in order to implement the SCC, the State Council of China published the 'National Guidelines' on Sponge City Programme (SCP) setting standards for implementation. The programme was supported by 3 major national government departments of China namely the Ministry of Housing and Urban-Rural Development (MOHURD), the Ministry of Finance and the Ministry of Water Resources. The National Guidelines are based on three principles, (i) follow the ecological and natural cycle, (ii) guide and develop through planning, and (iii) follow government guidance and people's engagement.


Haikou Fengxiang Park acts as Sponge in Haikou, Hainan, China
Photo Credit: Turenscape

The target is to develop 20% of the urban areas for absorbing and utilising 70% of the precipitation by 2020 and 80% of precipitation by 2030. The central government selected 16 cities in 2015 and 14 cities in 2016 as pilot cities for the implementation of the Sponge City measures. The Ministry of Finance facilitated funds for the initial 3 years of implementation. Every year USD 51 Millions* for each city, USD 63 Millions* for each provincial capital and USD 76 Millions* for each municipality under central government was facilitated.

National Guidelines recommended city municipal governments to adopt and develop their own sponge city action plan and promote public-private partnership and franchising approach. The promotion of public-private participatory approach helped raise funds as well as maintain the quality of green infrastructure.

In order to monitor the performance, cities are being evaluated on the basis of 7 indexes and 6 indicators. The report published in 2017 saw Chizhou, Wuhan Jinan and Nanning as better performing cities in implementing the sponge city concept. The integration of Sponge City Concept into national policy guided cities to mainstream the ecological measures into planning as well as monitoring the low impact developments.

Details of this case study are extracted from 'Y. Peng and K. Reilly. 2021. Using Nature to Reshape Cities and Live with Water: An Overview of the Chinese Sponge City Programme and Its Implementation in Wuhan. Grow Green.' [Online] available at https://growgreenproject.eu/wp-content/uploads/2021/01/Sponge-City-Programme-in-Wuhan-China.pdf (Accessed on 1st June, 2022)

** 1 USD = 1 EUR*

Outcomes

- Improved natural environment
- Improved flood resilience
- Increased groundwater recharge
- Reduced urban heat island effect

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ ₹₹ ₹₹₹

Potential for Scaling Up

Flood Resilient Communities, Dakar

Tropical Climate Zone

Coastal City

Building Community Action

Dakar, the capital city of Senegal, experiences flooding during the monsoon season every year. Several low-income neighbourhoods in the city have inadequate drainage systems resulting in localized water stagnation and thereby impacting the livelihood (disruption to economic activities) and health (water borne and vector borne diseases) of residents in these areas.

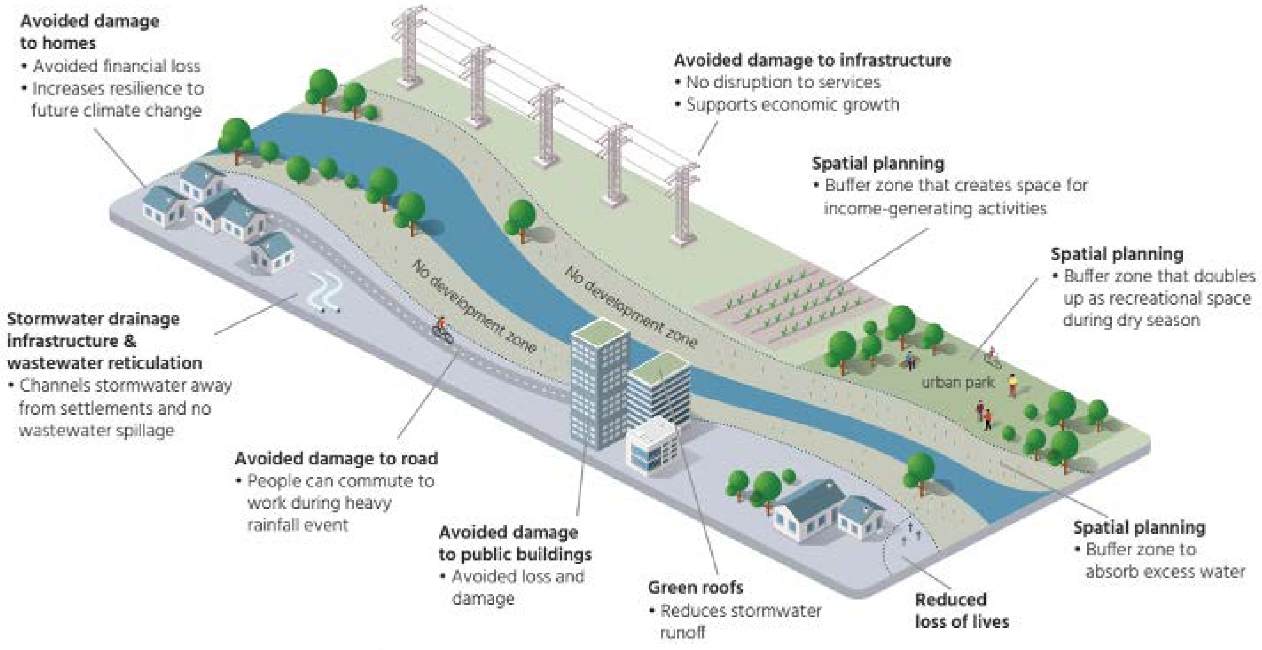
To address flooding, the low-income communities in the flood risk areas have developed a high level of community action and self-organization. Leveraging this strong community network the 'Vivre avec l'eau' (live with water) initiative was initiated across 10 vulnerable communities with support from the UK Department for International Development (DFID). The initiative was informed by the experiences and know-how acquired by the communities. Based on the inputs from the flood affected communities, an integrated community flood response plan was developed. Some of the significant outcomes were:

- To divert and collect rainwater, large drainage systems coupled with landscape interventions to increase the greenery were implemented. Through this process, the flood water was converted into a public good.
- Recycling and waste management programmes were implemented to prevent waste from clogging the newly established drainage system. This approach not only ensured the efficient functioning of the drainage system but also provided livelihood opportunities for the communities. For instance, a school wall was constructed with eco-bricks (bottles filled with solid waste).
- Decentralized sewerage systems were constructed with an intent to prevent the contamination of flood water. This addressed the risk of water and vector borne disease outbreak in case of flooding.
- Based on the topographic and Geographic Information System (GIS), and the expertise of local communities a local flood contingency plan was developed. At-risk areas were identified in advance, local communities were informed to take necessary precautions and a chain of response to mitigate flooding was developed. This helped in streamlining communication between various government departments and stakeholders to better plan for and respond to flooding.

Through community engagement and empowerment, strategic planning, and nuanced understanding of flood risks and solutions, the community level flood intervention in Dakar was made successful.

Details of this case study are referred from 'Philippa Thornton. 2018. Community-based Action against Flood Risks in Dakar. weADAPT.' [Online] Available at https://www.weadapt.org/placemarks/maps/view/40316 (accessed on 30th May, 2022)

2015



Flood management interventions in Dakar
Photo credit: Same as reference

Outcomes

- *Improved flood resilience*
- *Transformed public space*
- *Enhanced amenity value*
- *Increased livelihood opportunities*
- *Streamlined communication with the communities*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ ₹₹ ₹₹₹

Potential for Scaling Up

Water Resilience, Cape Town

Temperate Climate Zone

Coastal City

Holistic Strategy for Managing Water Demand

Cape Town in South Africa has witnessed severe drought over the last few years. Learning from these experiences and to plan for the future, Cape Town developed a comprehensive Water Strategy in 2019 with a vision to become water sensitive by 2040. In 2020, the city of Cape Town benchmarked its water management approaches through City Water Resilience Framework (CWRF). The CWRF is a system-based approach to assess the range of factors that impact water resources and provides comprehensive strategies for water management in the context of urban resilience.

The assessment was undertaken through multi-stakeholder consultations including citizens, business, and academic institutions. These consultations helped the city in identifying the challenges within their existing water management system using qualitative and quantitative indicators. The process also helped in stakeholders prioritising the critical challenges and identifying opportunities to address the same. Some of the identified opportunities includes:

- Reviewing policy and governance structure to embed water-sensitive designs in the urban landscape and promote blue-green infrastructure.
- Creating a data platform to include detailed information of informal settlements. The intent was to implement data informed decision making to improve service delivery and prioritise water resilience as part of city planning and budgeting.
- Co-funding interventions of water infrastructures was enabled by setting up a task force with key representatives from all relevant departments and stakeholders.
- The utility master plan was prepared for identifying services required for the next 20 years. These services include the improvement and provision of water, and wastewater treatment plants and stormwater drainage network. This master plan was created with an intent to enable informed decision making to ensure better planning with cost-effective investments.
- The concept of 'net zero water' buildings was promoted to increase the recycle and reuse of rainwater and use of pervious materials in landscape to recharge groundwater. With the promotion of circular economy for water, the city witnessed co-benefit of reduced water bills and reduced demand on water sources.

As a result of increased multi-stakeholder engagement, Cape Town has been able to diversify funding sources for building water resilience. This approach has also helped mainstream integrated planning addressing various water dependent systems together.

View of Berg river dam, Cape Town
Photo credit: Daniel Saaiman, Wikimedia

Details of this case study are referred from 'Beane G et, al. 2020. City Water Resilience Assessment, Cape Town. Water Resilience Profile.' [Online] Available at https://www.resilienceshift.org/wp-content/uploads/2020/01/Cape_Town_WaterResilienceProfile_FINAL.pdf (accessed 1st June, 2022).

For additional details please refer to the 'United Nations. 2022. City Water Resilience Approach.' [Online] Available at https://sdgs.un.org/partnerships/city-water-resilience-approach-cwra (accessed 1st June, 2022).

Outcomes

- Reduced water scarcity through enhanced water management
- Enhanced coordination through multi stakeholder engagement
- Informed policy and planning

2019

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | **Water Scarcity**

Scale of Intervention

Neighbourhood | **City** | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | **Private/Business** | **City government/ departments** | National government/ departments

Flood Resilience Characteristics

Robust | **Inclusive** | Flexible | **Resourceful** | Reflective | Redundant | **Integrated**

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Flood mitigation Plan, Kochi

Warm Humid Climate Zone

Coastal City

Rejuvenation of the canal system to mitigate floods

Kochi, the coastal city in Kerala has numerous canals that pass through the city. The canals function as storm water drainage network as they help in channelising the storm water into the back waters. However, in the recent years, the efficiency of the canal system in functioning as storm water drainage has been disturbed. Dumping of solid waste and draining wastewater into the canals, and construction of small culverts have obstructed the flow of water in the canals. Additionally, encroachment along parts of the canal network makes the maintenance (cleaning and desilting) process difficult. These conditions exacerbate the flooding situation in Kochi. In 2019, Kochi experienced extreme rainfall and the reduced water carrying capacity of the canals was found to be the key reason for flooding. Rejuvenating the canal system was identified as one of the key measures that needed to be undertaken to help manage flood water. To address this, the Kochi Municipal Corporation (KMC) focused on several flood resilience projects under the flagship program of 'Operation Breakthrough' launched by the Government of Kerala.

This program was carried out in two phases. The first phase focused on the formation of a technical committee involving experts from various government departments in the city. This committee focused on identifying the causes for flooding by dividing the city into 74 sections. Preliminary assessments were conducted by a team of technical personnel from the Public Work Department, Irrigation and Water Department. Following this, actions such as cleaning, removal of encroachment, desilting and renovation of major canals were prioritised.

View of a canal in Kochi
Photo credit: Cochin Smart Mission Limited

The second phase focused on implementing the resilience actions identified by the technical committee. The government of Kerala allocated around USD 3.2 million* to carry out structural measures to address the risk of flooding. These included:

- Desilting, widening the canal width and addressing the encroachment on Thevara Kayal and Changadampokkuthodu canals were prioritised. This helped to restore the flow of water in the canals.
- The renovation and cleaning of 4 canals (Koithara, Karanakodam Thodu, Edapalluthodu and Ambanattuchirathodu) included clearing vegetation that blocked the canals, clearing the deposited concrete debris, demolishing and reconstructing the culverts that blocked the canals, and widening the width of the canals to enhance the carrying capacity of the canals were also undertaken.

With the implementation of these measures, the KMC observed that the flooding and water stagnation incidents in and around these canals reduced to a great extent in the following year. Further, rejuvenation of the Mullassery and Thevara- Perandoor canals are in the pipeline.

Details of this case study are referred from Irrigation Department, Ernakulam. 2021. Report on Flood Mitigation Kochi'. [Online] Available at https://irrigation.kerala.gov.in/sites/default/files/2021-08/kochi-flood.pdf (accessed 28th May, 2022)

** 1 USD - 77.9 INR*

Outcomes

- *Improved flood resilience*
- *Enhanced coordination*
- *Informed policy and planning*

2019

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | State government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

River Centric Master Plan, Kanpur

Warm Humid Climate Zone

River City

Integration of river management plan into planning process

Kanpur situated along the riverbanks of Ganga and Pandu is highly vulnerable to flooding. The increasing migration of people to the city fostered by its industrial activities has further led to the challenge of improper waste management resulting in pollution of the Pandu river. Addressing water pollution of the river was of concern to the city. Like many other cities in India, river management is mostly handled as a separate project. Even the Master Plan of Kanpur 2021 did not manage to incorporate aspects of urban water management within its process. Thereafter, Kanpur decided to prepare a River Centric Master Plan to integrate the rivers in the development landscape of the city by aligning with the guidelines of Urban River Management Plan (URMP) introduced by the Ministry of Jal Shakti under the National Mission for Clean Ganga (NMCG).

In 2021, the URMP of Kanpur was published by the Kanpur Municipal Corporation. The process followed to develop the URMP involved three major activities. They are:

- Setting up of a core working group
- Conducting baseline assessment
- Organising stakeholder workshops to capture their needs and options.

The baseline assessment was conducted to capture the existing status. Further analysis was done to identify key challenges based on which objectives were prioritised. These were done through a number of formal and informal workshops facilitated by the National Institute of Urban Affairs (NIUA) and NMCG to create awareness around URMP framework and seek inputs from the different stakeholders for undertaking possible interventions.

The stakeholder consultation process led to the core working group proposing 19 tangible and practical actions, under 10 objectives for managing the two rivers. The process also led to the identification of agencies responsible for implementation with tentative costs and the source of funding for each intervention. The total budget estimated for the implementation of 19 interventions was USD 7.17 millions*. Each project-based intervention has a distinct funding stream including ULB funding, funding from urban missions, and funding from other sources including grants. The current URMP is an evolving document with clear monitoring indicators to measure the status of its implementation and its progress.

View of Ganga river in Kanpur
Photo Credit: Same as reference

Some of the measures proposed under the current URMP to manage the floods in Kanpur includes:

- Rain water harvesting to enhance the groundwater table.
- Revival and rejuvenation of the existing water bodies and buffer areas to improve the water quality and conserve biodiversity, respectively.
- Defining clear land use of river and its floodplain to control development activities along river stretch.
- Addressing solid waste management to reduce the pollution.

Through the development and actions for implementation of URMP, Kanpur has successfully demonstrated one of the ways to integrate urban river management into the planning process. The URMP laid the groundwork for shared governance, with citizens taking a more active role in managing the city's natural assets thereby instilling a sense of ownership not only in the nature based systems but also in the process. The URMP model is currently being replicated in 97 towns along the Ganga Basin (towns with a population greater than 1 Lakhs).

Details of this case study are referred from 'NMCG, NIUA, KNN. 2019. The Urban River Management Plan, Kanpur.' [Online] available at https://niua.in/intranet/sites/default/files/2265.pdf (Accessed on 7th June 2022)

Additional details are available at 'Namami Gange. 2022. Re-imaging Urban Rivers. Addressing the Urban Drivers of River Health in the Ganga River Basin.' [Online] available at https://urbanrivers.niua.org/project-thrust-areas-page#block-pilotinginkanpur (Accessed on 7th June 2022)

** 1 USD = 77.9 INR*

Outcomes

- *Informed policy and planning*
- *Improved natural environment*
- *Enhanced biodiversity*
- *Increased groundwater table*
- *Reduced water pollution*
- *Enhanced coordination through stakeholder engagement*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

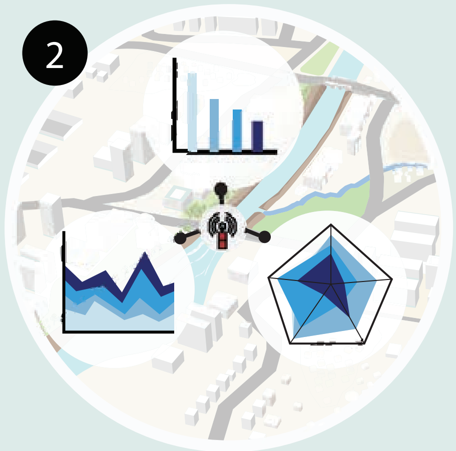
₹ ₹₹ ₹₹₹

Potential for Scaling Up

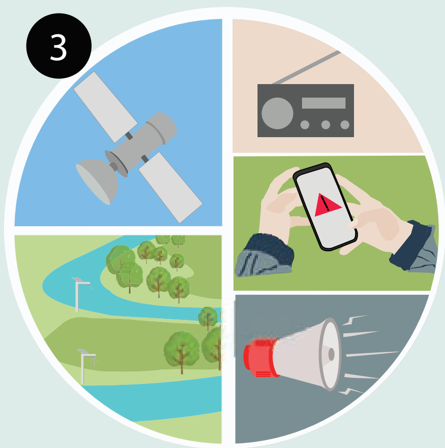
2021

TECHNOLOGY
Interventions

Community based Early Warning System



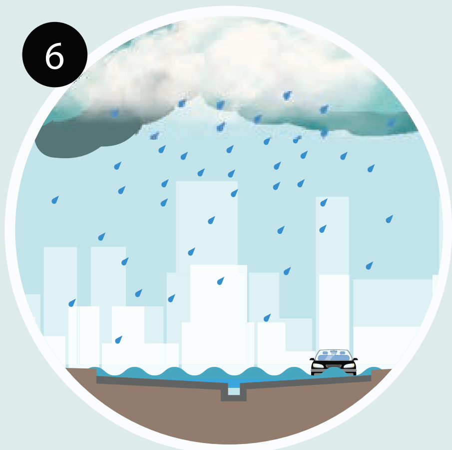
Data driven flood management



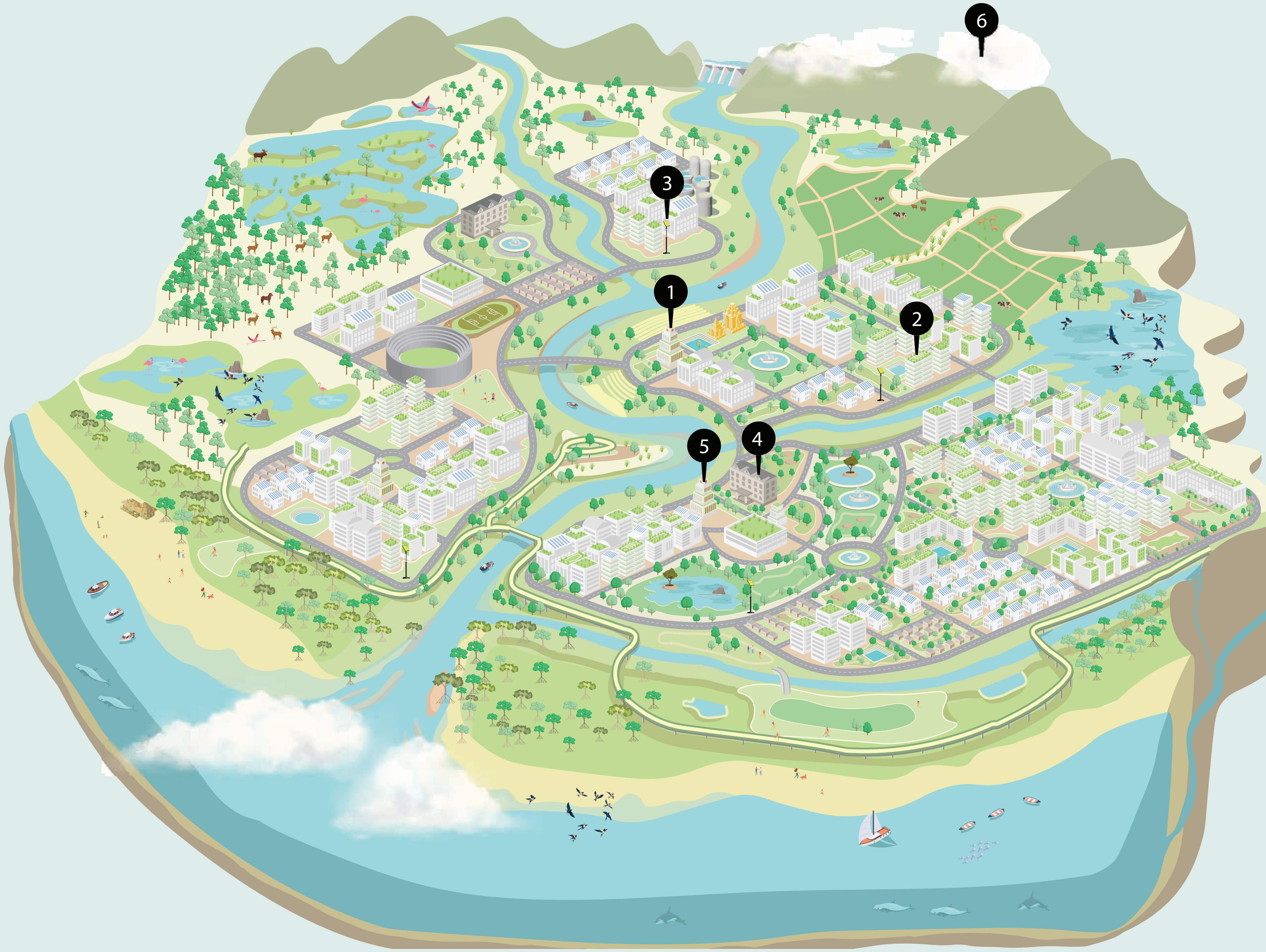
End to end Early Warning System

Hydrodynamic modelling

Flood control centre



Cloudburst Management



Flood Control Centre, Bangkok

Tropical Climate Zone
Coastal City

Data informed decision making

Bangkok, the capital of Thailand, is a coastal city located in the delta of the Chao Phraya River. The risk of flooding is an annual concern for the city, especially in the monsoon season. The devastating flood in 2011 left most parts of the city submerged in water for over 2 months. High intensity rainfall, overflow from the river, high tides from the sea and low efficient drainage system were key for the flooding.

The Bangkok Metropolitan Authority (BMA) has implemented various measures to mitigate floods. The city has increased the efficiency of drainage systems and has built underground tunnels to drain water in areas where drainage systems were not feasible. Alternative measures like flood walls and dykes are also constructed. In addition, the city adopted an approach of data informed decision making wherein it has established a Flood Control Centre (FCC). The centre is instrumental in monitoring the occurrence of a flood, maintaining the drainage systems and providing early warning to better prepare for a flood.

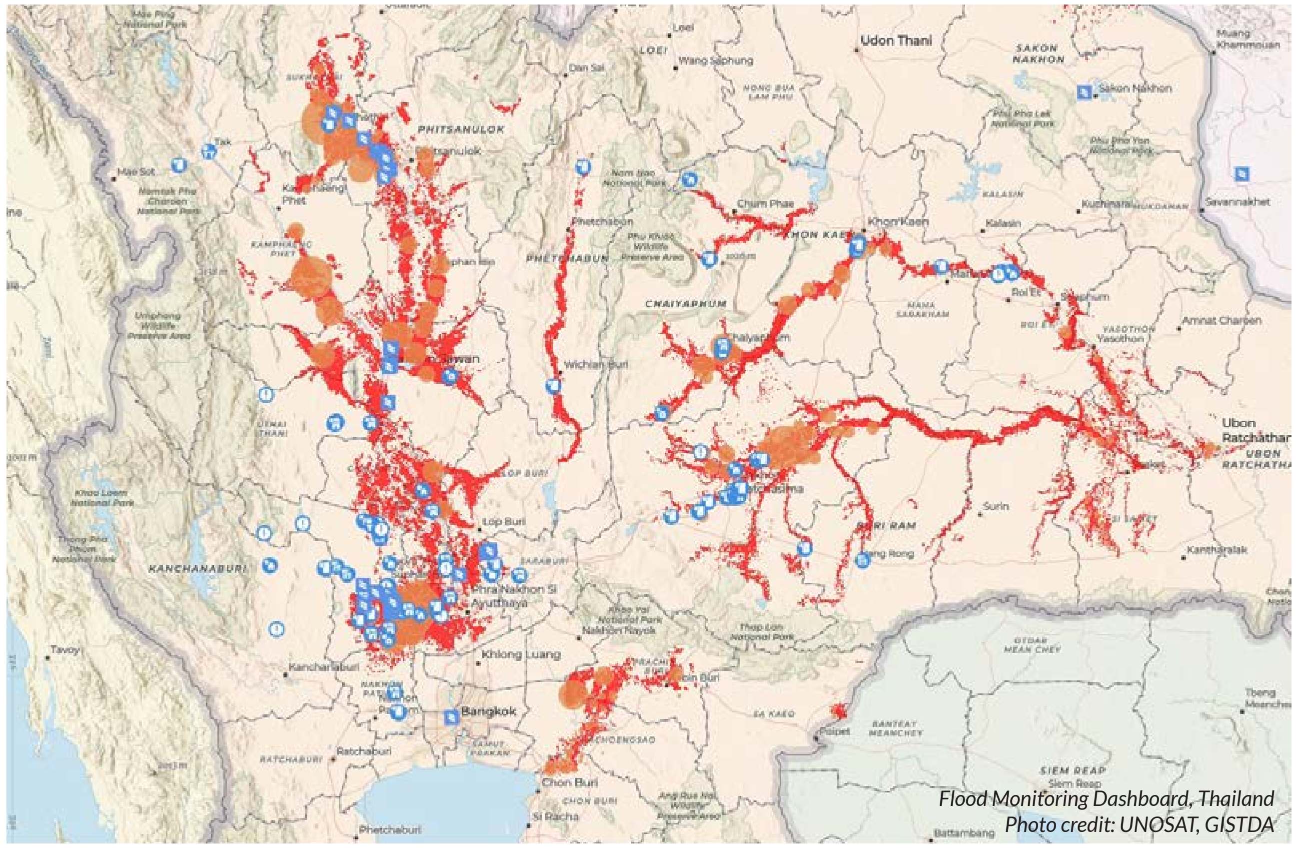
The FCC provides systematic and efficient management guidance for flood mitigation.

- The FCC has a master station and 69 remote sites covering an area of 1,000 sq.km across the city. The remote sites collect hydrological data such as rainfall levels, water levels in the drainage systems, canals and the Chao Phraya River, pump status and the water quality. This information is automatically transmitted in cyclic mode to the master station via a telemeter system over Ultra High Frequency (HCF) radios. The master station collects and monitors this information from all the remote sites. The situation of flood and drainage systems are monitored on a real-time basis to inform decision-making during a flood.
- For taking appropriate and timely actions to mitigate flooding, the city has adopted a decentralisation approach wherein city officials are given the authority to remotely monitor the water gates and pumps of the canal and river with guidance from the FCC. Over the years, with improvement in the quality of information and coordination, the BMA and local departments are able to make more effective flood mitigation decisions and implement tasks based on more accurate data.
- Alert systems are embedded within social media for better outreach.
- FCC has also provided evidence based data for improving planning regulations to protect green areas that have potential to retain flood water.

This approach has the potential to be embedded within the Command and Control Centres (ICCCs) for monitoring flood risk and mitigating flooding.

Details of this case study are referred from 'Phamornpol.K. 2022. Flood Mitigation and Management in Bangkok Metropolitan Area. Department of Drainage and Sewerage. Bangkok Metropolitan Administration.' [Online] Available at https://www.unescap.org/sites/default/files/S3b4_Thailand.pdf (accessed 05th June, 2022)

Please refer the following for additional information: 'Institute of Developmental Studies (IDS). 2007. Governance Screening for Urban Climate Change Resilience-building and Adaptation strategies in Asia. Assessment of Bangkok City, Thailand.' [Online] Available at https://www.ids.ac.uk/download.php?file=files/dmfile/Bangkok.pdf (accessed 16th June, 2022)



Flood Monitoring Dashboard, Thailand
Photo credit: UNOSAT, GISTDA

Outcomes

- *Data informed flood preparedness*
- *Evidence based policy and planning*
- *Enhanced early warning communication with citizens*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/Research | Private/Business | City government/departments | National government/departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ ₹₹ ₹₹₹

Potential for Scaling Up

1990

Bioremediation of Lakes, Delhi

Temperate Climate Zone

City with water bodies

Revival of a historical lake, Hauz Khas

2007

Delhi, the capital city of India, has many water bodies including lakes, marshes, wetlands and rivers. The city has over 1,000 lakes, among which the Hauz Khas lake is a prominent one and is of historical importance. Initially, this lake was used as a water reservoir catering to the water needs of its neighbouring communities. With the increase of the piped water network, the utilization of the lake for drinking water purposes reduced. Along with improper management over the years, the untreated wastewater was discharged into the lake leading to the deterioration of its water quality including growth of algae and increased foul odour. With an intent to conserve the lake, a process of bioremediating the lake was undertaken by the Delhi Development Authority (DDA) and a private organization, JM Enviro technologies.

Natural in-situ treatment through an Anoxic Bioremediation Technology (ABR) was adopted to conserve the lake. In this method, selective anaerobic and facultative bacteria that consume sludge by decomposing the large organic molecules into simpler ones were introduced in to the lake. Within a month of initiating this process, the quality of water started to show noticeable improvement. Bioremediation proved to be an effective approach for controlling odour, addressing sludge and other solid contents from the untreated wastewater along with oxidation of the water.

The local community also played an active role in reviving and cleaning up the lake. Several workshops organised in the neighbourhood strengthened the civic sense and created awareness on the roles and responsibilities of local communities. Local residents were also trained on the cleaning and restoration processes which helped in regular maintenance of the lake and in sustaining the bioremediation process.

A view of wetland in the Hauz Khas lake
Photo credit: C-Cube, NIUA

Further, wetlands that act as natural biofilters were created to ease the maintenance process. These wetlands have the capacity of purifying over 2 million litres of water per day. Moreover, they attract a variety of birds to the lake creating an ecosystem of its own.

The capital cost for the ABR intervention was approximately 7380 USD* with operation and maintenance cost of 3590 USD*/ acre / year. Additionally, the creation of artificial floating wetlands was made possible through crowd funding and corporate sponsorship. Following the success of Hauz Khas lake conservation, the ABR approach is currently being replicated in other lakes in Delhi

Details of this case study are referred from IWP & ICLEI. 2020. Integrated Urban Water Management Case Studies. India Water Partnership. [Online] Available at https://cwp-india.org/wp-content/uploads/2020/08/Compendium-of-Case-Studies-on-Integrated-Urban-Water-Management.pdf (accessed 11th May, 2022) and CSE. 2022. Anoxic Bioremediation in Hauz Khaz Lake, New Delhi. Decentralised wastewater treatment. [Online] Available at https://www.cseindia.org/anoxic-bioremediation-in-hauz-khaz-lake-new-delhi-3793 (accessed 19th May, 2022)

** 1 USD = 77.9 INR*

Outcomes

- Improved natural environment
- Transformed public space
- Enhanced biodiversity
- Reduced water pollution

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Cloudburst Management, Copenhagen

Temperate Climate Zone

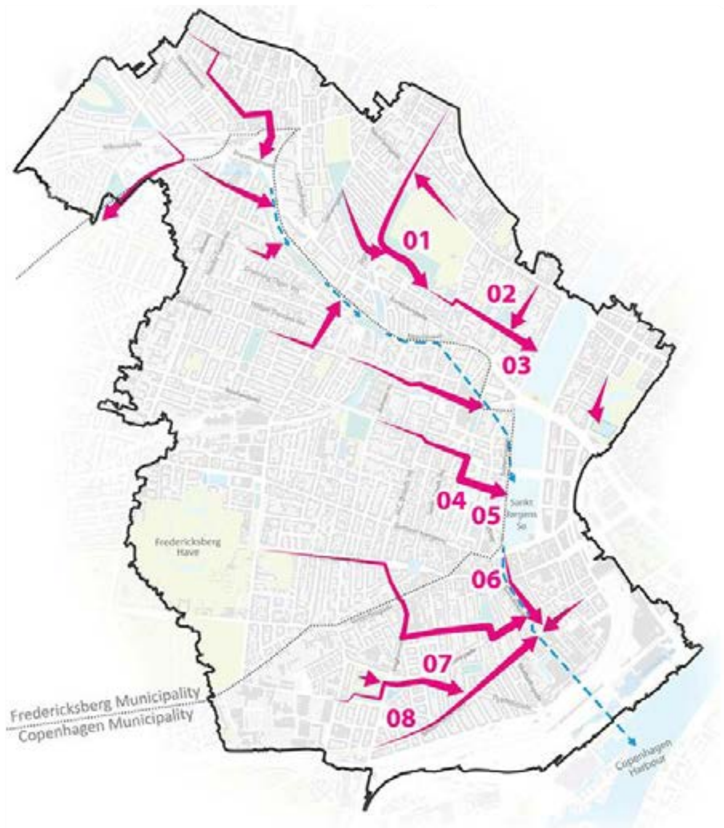
Coastal City

A 20 years adaptation plan

2012

The capital of Denmark, Copenhagen is vulnerable to flooding, sea level rise and extreme rainfall events. The storm water sewage system in the city has a capacity for extreme rainfall with a return period of 10 years. Further, some of the recent modelling efforts have projected an increase in sea level rise by 1m in next 100 years. This poses a high risk for storm water to flood the city and damage infrastructure services. Therefore building resilience was crucial for the city to manage current and future risks.

While the Danish Meteorological Institute (DMI) defines an extreme rainfall event as 15 mm precipitation in 30 minutes, during the July 2011 event, the city of Copenhagen witnessed more than 50 mm of precipitation within 30 minutes. This event proved to be a turning point leading to the development of a cloudburst management plan for implementing mitigation and adaptation to build resilience for future extreme events.



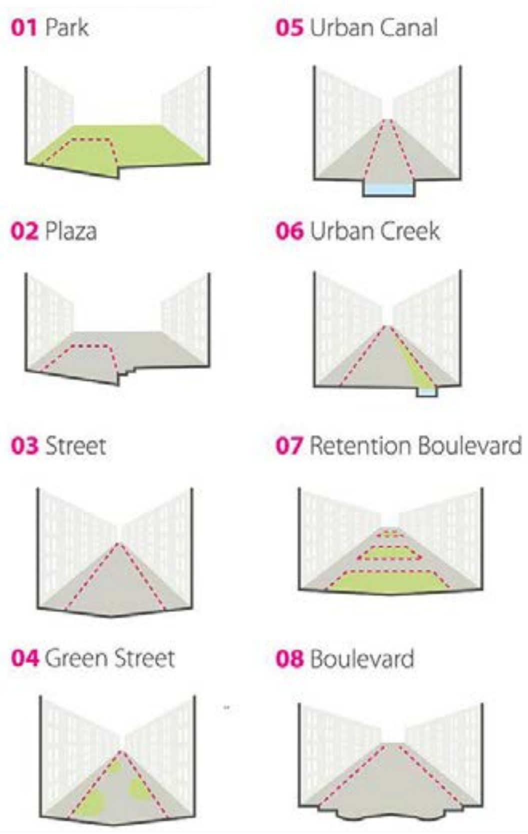


Photo Credit: Cloudburst Management Plan, Copenhagen

The cloudburst management plan provides measures for the management of flood risk due to cloud burst.

- A climate adaptation plan was developed to map a holistic approach. The adaptation plan was designed for a period of 20 years wherein initiatives were ranked based on the priorities. For prioritising the measures, the city was divided into 26 local water catchment areas of around 10 sq.km. These areas were further assessed based on risk, implementation potential and coherence with the urban development projects for synergising impacts.
- To address the insufficient conventional piped system, blue-green infrastructural measures were adopted. These proved to be adaptable and interactive solutions compared to the conventional infrastructure system. These measures help store the stormwater and drain the excess water into water bodies, thereby reducing the flood risks.
- The estimated cost of implementing the adaptation plan by 2033 is estimated to be USD 1.09 Billions*. A combination of public and private investments are currently being considered for implementing the measures.

Details of this case study are referred from 'Miljø Metropolen. 2012. The City of Copenhagen Cloudburst Management Plan. Online] Available at https://en.klimatilpasning.dk/media/665626/cph_-_cloudburst_management_plan.pdf (Accessed on 10th May, 2022)

Please refer the following for additional information: 'CSE. C-GINS: Compendium of Green Infrastructure Network Systems. 2022. Cloudburst Management Plan for Copenhagen, Denmark.' [Online] available at https://cdn.cseindia.org/gic/11.pdf (Accessed on 10th May, 2022)

** 1 USD = 7.058 DKK*

Outcomes

- Improved natural environment
- Transformed public space
- Informed policy and planning
- Enhanced biodiversity
- Improved flood resilience

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Data Informed Flood Preparedness, Da Nang

Tropical Climate Zone
Coastal City

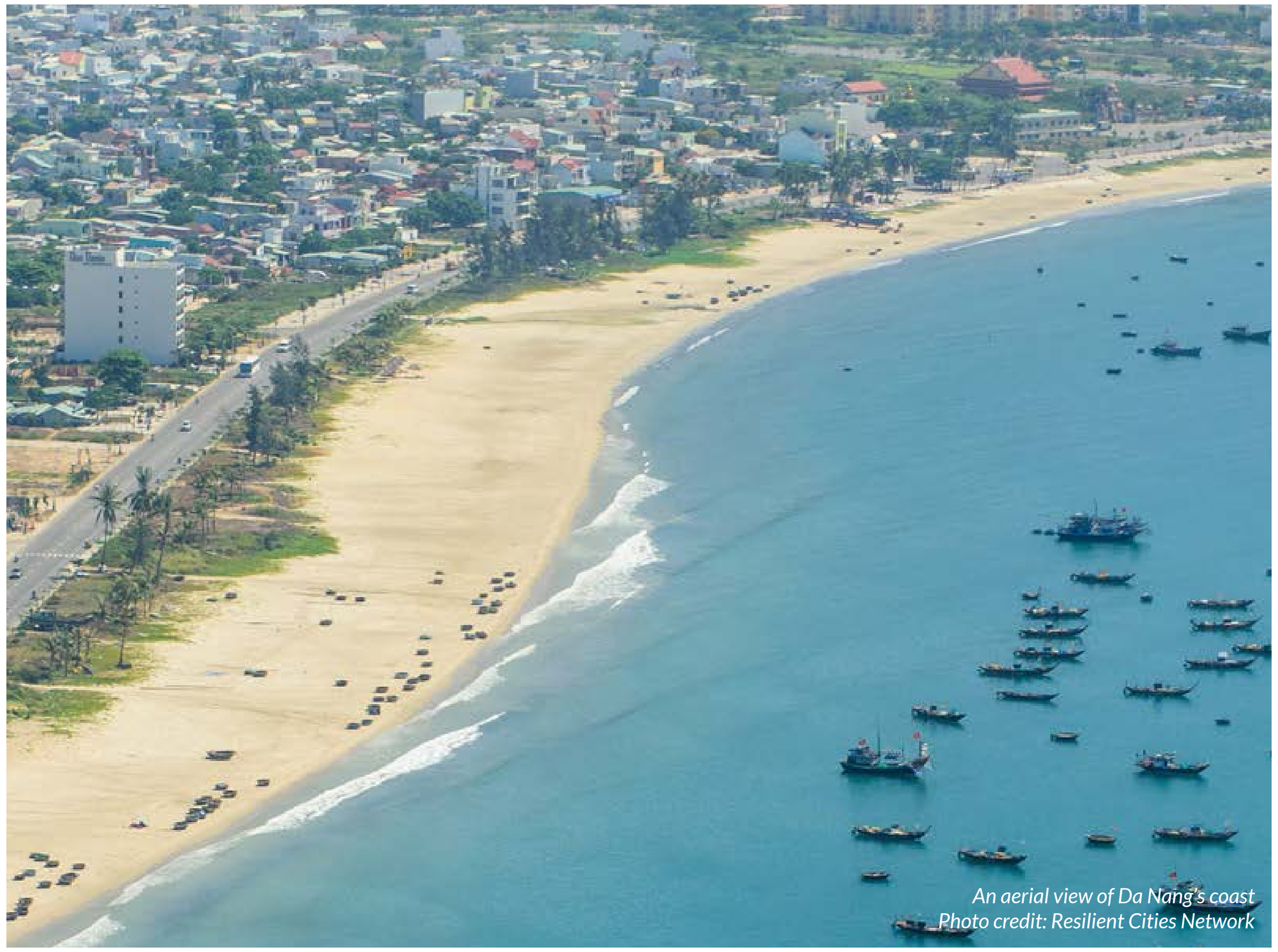
Flood reduction and climate-resilient housing

2013

Da Nang, a coastal city in Vietnam is most prone to disasters such as floods, cyclones and storm surges. The city gets flooded due to inadequate water storage capacity along the downstream of rivers, insufficient carrying capacity of storm water drainage network and development within the low-lying areas and along natural drainage that obstruct the natural flow of rain water. For instance, Xangsane typhoon in 2006 impacted around 14,000 houses. These households living in the risk prone areas often struggle to rebuild and repair their damaged houses.

With a focus to build flood resilient housing for the vulnerable communities, a short-term strategy of promoting basic services was initiated by the city government. The main objectives were to improve the housing quality to sustain storms, ensure additional financial resources for disaster response, improve employment/livelihoods, and ensure protection against disasters. As the part of the strategy, some of proposed interventions include vulnerability assessment to streamline insurance of properties in those areas.

For the vulnerability assessment, a data-driven strategy was conceptualised and implemented. A Visual Climate Adaptation Platform (VCAP) was developed and Geographic Information System (GIS) maps of existing housing conditions along with the vulnerability and periodic damages caused by various disasters were mapped as a part of the master planning process.



An aerial view of Da Nang's coast
Photo credit: Resilient Cities Network

Insurance coverage was scaled up to support the communities in re-building or repairing the damaged houses. In association with Swiss Re (a leading wholesale provider of reinsurance, insurance of risk transfer) and in consultation with financial institutions, other stakeholders in the city, a detailed financial risk analysis was conducted to insure against frequent disaster by the municipal corporation as a part of their annual spending and also budget for additional financial aid to cater to the post disaster relief.

Further, in collaboration with international development banks namely The World Bank and the Asian Development Bank a housing insurance scheme was designed and pilot tested across selected communities. This approach helped 245 low-income households to rebuild and repair their houses with a budget of approximately USD 0.25 Million*. The result of providing financial assistance in building resilient housing proved successful and the 245 houses developed through this initiative were resilient during Typhoon Nari in 2013 and did not experience any major physical damages.

Details of this case study are referred from '100 Resilient Cities and the Da Nang city Government. 2013. Resilient Da Nang, Resilience strategy for Da Nang city, Vietnam.' [Online] Available at https://resilientcitiesnetwork.org/downloadable_resources/Network/Da-Nang-Resilience-Strategy-English.pdf (accessed 30th May, 2022)

For additional details, please refer to the 'ADB. 2016. Incentives for reducing disaster risks in cities. Philippines. Asian Development Bank.' [Online] Available at https://www.adb.org/sites/default/files/publication/185616/disaster-risk-urban.pdf (accessed 30th May, 2022) and 'UNFCCC. 2022. Building Storm-Resistant Houses, Vietnam. United Nations Climate Change. United Nations Framework Convention on Climate Change.' [Online] Available at https://cop23.unfccc.int/climate-action/momentum-for-change/urban-poor/building-storm-resistant-houses (accessed 30th May, 2022)

** Budget amount taken as is from the reference.*

Outcomes

- Improved flood resilience
- Informed policy and planning
- Safeguarding infrastructure

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/Research | Private/Business | City government/departments | National government/departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Community Based Early Warning System, Semarang

Tropical Climate Zone
Coastal City

Community Based Flood Forecasting and Warning System

Semarang, the capital of Central Java Province in Indonesia is a coastal city with relatively flat topography and is vulnerable to both, tidal and flash floods. The large proportion of the city's population lives in the low elevation coastal zone making them vulnerable to tidal floods. Further, the areas inundated with tidal floods have also increased over the years.

Semarang has 4 drainage systems among which the region around the Bringin drainage is most vulnerable to flash floods. In light of climate variability, the city is projected to experience high intensity precipitation in the monsoon season increasing the exposure of the city to flash floods.

To build flood resilience, Semarang developed a city resilience strategy wherein the need for a flood early warning system and flood forecasting modelling was identified. Aligning to the resilience strategy, Semarang established a flood early warning system for tidal foods and flood forecast system for flash floods. Together, they enable disaster preparedness, particularly community-level disaster preparedness in the city.

Semarang established an early warning system for tidal floods where satellite data is being used to monitor the tidal variation on a daily basis by the Indonesian Agency for Meteorology, Climatology and Geophysics. In case of a tidal flood, coastal communities are informed beforehand through communication channels such as short messaging service, alarms and loudspeakers. This provides them with sufficient respite time to prepare for the impacts of the floods and evacuate accordingly.

The early warning time for a flash flood is relatively short ranging from a few minutes to a couple of hours. The warning system uses a flood forecasting model to simulate the impending floods, keeping in mind the Bringin catchment area and hydraulic characteristics of the Bringin river was developed. The forecast provides information on possible flooding areas (including transport routes) and options for peak flow reduction across the floodplains, through strategic management of discharge points along the river channel. The flood forecast model is used to generate warning to the local communities and provides respite time for vulnerable communities to prepare and evacuate if needed. The flood forecast model is a joint initiative by the department for water resource management, the Semarang office of the Meteorology, Climatology and Geophysics Service, and the Faculty of Engineering of Diponegoro University.

Community engagement is an important component of the above mentioned early warning and flood forecasting system. Risk mapping exercises are conducted on a regular basis to document the knowledge of local communities and identify potential features of communication and coordination including but not limited to identification of possible evacuation routes and management of flood protection shelters. Through these preparedness efforts the communities are better equipped to act in case of floods.

With the engagement of local universities, communities, NGOs and relevant government departments across city, provincial and national government, this intervention seeks to leverage the abilities and expertise of different stakeholders to enable coordinated actions.

Community engagement for flood preparedness, Indonesia
Photo credit: Asian Disaster Preparedness Center

Details of this case study are referred from 'Asian Disaster Preparedness Center (ADPC). 2015. Bringing early warning to communities. Asian Disaster Management News. Page 10-14 [Online] Available at https://www.adpc.net/igo/category/ID798/doc/2015-a17Hx3-ADPC-Asian_Disaster_Management_News_Volume_21_(Web).pdf (accessed 05th June, 2022)

Outcomes

- *Early warning system enabling improved flood preparedness*
- *Enhanced coordination among various stakeholders for flood preparedness*
- *Empowered communities that are better informed to take action during a flood*

2013

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Hydrodynamic Modelling, Jakarta

Tropical Climate Zone

Coastal City

Flood reduction and climate resilient development pathways

2015

Jakarta, the capital city of Indonesia has a history of flooding incidents. The high risk of flooding is due to its geographical location. In addition to being a coastal city, Jakarta is located on a deltaic floodplain and has 13 rivers flowing through it. As a result of climate variability and climate change, the city has been increasingly experiencing extreme rainfall occurring over a short period of time. Rivers and drainage systems are not able to maintain their carrying capacity resulting in flooding due to overflow of excess water.

Recognizing the disaster risk, the government of Jakarta seeked support from the UN Climate Technology Centre and Network (CTCN) for evaluating appropriate technologies and methods for flood reduction and building flood management capacity among stakeholders including decision makers for enabling climate resilient development.

CTCN adopted the following approach to build the flood resilience for Jakarta:

- Conduct a socio-cultural survey to examine perceptions of flooding, levels of acceptable risks and preferred adaptation options
- Develop a hydrodynamic flood model to evaluate risks and inform structural and policy interventions to reduce the risk of flooding
- Conduct a series of technology transfer workshops to increase local capacity in developing high resolution hydrodynamic model and exploring various scenarios
- Develop policy and planning recommendations to reduce risk and vulnerability
- Develop a roadmap to sustain and expand the project using additional funding.

Hydrodynamic modelling of Jakarta
Photo credit: BMT Environmental and Climate Solutions

A tailored hydrodynamic flood model proved beneficial for Jakarta. The model was used to inform policy and planning options to reduce flood risk of vulnerable populations, taking into consideration the socio-economic vulnerabilities. The knowledge on developing a high resolution hydrodynamic model was transferred to the city officials. This has helped in sustaining the approach of using technology for building flood resilience. This enhanced capacity of relevant government agencies has further helped them develop action plans to mitigate flooding and reduce flood related losses and damages.

Details of this case study are referred from 'Climate Technology Centre & Network - CTCN. 2017. Hydrodynamic Modelling Report. Hydrodynamic Modelling for flood reduction and climate resilient infrastructure development pathways in Jakarta. [Online] Available at https://www.ctc-n.org/sites/www.ctc-n.org/files/finalreportmodel_final_revised_16june.pdf (accessed 19th May, 2022)

Please refer the following for additional information: 'CTCN- UNEP. 2015. Hydrodynamic modelling for flood reduction and climate resilient infrastructure development pathways in Jakarta.' [Online] Available at https://www.ctc-n.org/technical-assistance/projects/hydrodynamic-modelling-flood-reduction-and-climate-resilient (accessed 23rd May, 2022)

Outcomes

Evidence based policy and planning

Enhanced capacity of city officials in making data informed decisions

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/Research | Private/Business | City government/departments | National government/departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Flood Forecasting and Early Warning System, Kolkata

Hot-Dry Climate Zone

Coastal City

Comprehensive city level flood forecasting

2018

Kolkata the capital city of West Bengal is one of the most flood prone coastal cities in the world. The reason for flooding is multi-fold. The deltaic topography of the region and an increase in extreme rainfall along with urbanization challenges such as encroachment of water bodies, inadequate storm water drainage systems, inadequate solid waste management blocking the tidal channels and a lack of flood preparedness makes the city and surrounding areas vulnerable to recurring flooding.

In order to mitigate floods, Kolkata Municipal Corporation (KMC) with technical assistance from Asian Development Bank focused on flood management by establishing a city level Flood Forecasting and Early Warning System (FFEWS). The FFEWS is a city level early warning system designed to visualize the real time information on temperature, air quality and water stagnation and other climate related data using 400 sensor nodes.

These ultrasonic sensors were installed across vulnerable hotspots and near critical junctions including but not limited to canals, water pumping stations, traffic junctions and schools. Communities were also involved in the process wherein residents agreed to install shop-front sensors in commercial areas.

The sensors captures real time information on various environmental parameters and uploads it on a centralised cloud server for processing. This data collected can be visualized on a GIS platform. The warnings are made available to the public especially in risk prone areas and with vulnerable community groups through mobile notifications, radio and television broadcasts. Further, there is potential to develop various flood scenarios with the collected data to inform future flood risk.

The comprehensive FFEWS is an effective intervention to monitor and disseminate flood risk data. With the provision of crowdsourcing, this data can be made accessible to large group of people through smart phones and other digital interfaces.

Details of this case study are referred from (ADB), Asian Development Bank. 2018. Kolkata Gets India's First Comprehensive City-Level Flood Forecasting and Warning System. 27 September. ADB. [Online] Available at https://www.adb.org/news/kolkata-gets-indias-first-comprehensive-city-level-flood-forecasting-and-warning-system (accessed 09th June, 2022) and ADB & KMC. 2018. Toward Resilient Kolkata . India first comprehensive city level Flood Forecasting and Early Warning Systems (FFEWS). [Online] Available at https://www.adb.org/sites/default/files/publication/452576/toward-resilient-kolkata.pdf (accessed 09th June, 2022)

Map of Kolkata Municipal Corporation showcasing forecasting and early warning system sensors
Photo credit: Same as reference

Outcomes

- *Improved flood resilience*
- *Enhanced coordination*
- *Safeguard livelihoods*
- *Empowered communities*
- *Informed policy and planning*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ ₹₹ ₹₹₹

Potential for Scaling Up

Flood Early Warning System, Guwahati

Warm Humid Climate Zone
River City

A fully automated early warning system

Guwahati is one of the important economic and commercial centres in the Northeast of India. The city is situated on the bank of Brahmaputra river and several of its tributaries pass through the city. This exposes the city to floods during heavy rainfall. The city is prone to recurrent floods and some of the areas stays inundated for several hours damaging infrastructure and affecting mobility and livelihood. Decrease in the inland wetlands that can absorb excess storm water due to encroachment, blockage of the storm water drainage network due to inadequate solid waste management and lack of regular maintenance of these drains further increases the risk of flooding.

In order to strengthen flood preparedness and reduce the losses and damages resulting from floods, the Guwahati Municipal Corporation (GMC) focused on establishing an early warning system. The Flood Early Warning System (FEWS) was developed by The Energy and Resources Institute with the support of National Disaster Management Authority in collaboration with Indian Meteorological Department (IMD), North Eastern Space Application Centre and TERI-SAS for GMC. This addresses issues of water logging and urban flooding via deploying a near real time solution on experimental basis to inform the administration on impending flooding over the city. It is the first of its kind urban solution in the entire north eastern region of the country.

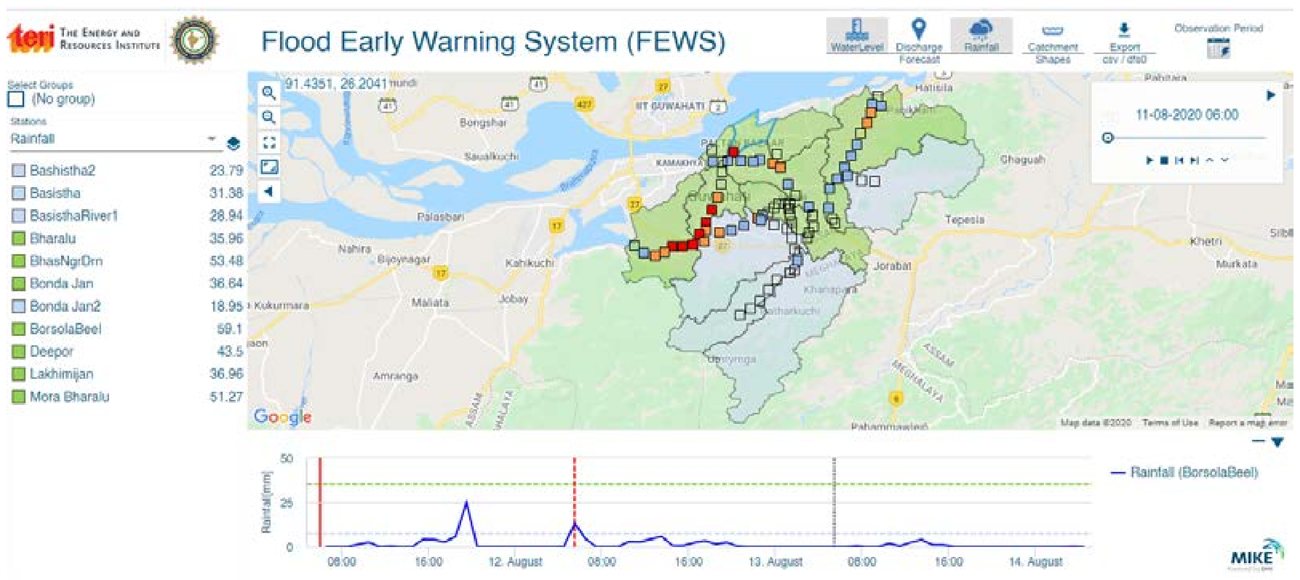
FEWS has five main components to facilitate the accurate and timely dissemination of the information to the end user and nodal agencies. They include monitoring weather forecast, compiling data, developing hydrologic and hydrodynamic modelling, developing flooding information and disseminating flooding details. Weather forecast comes from two data sets of five day hourly rainfall forecast from Global forecast System (GFS) and Weather research and forecasting (WRF) models. This information is provided by IMD through File Transfer Protocol (FTP) based data terminal and the data is downloaded into the system for modelling.

The modelling component of FEWS is a combination of a hydrological model which deals with the rainfall runoff simulation and the hydrodynamic models deals with the water flow in a channel. The models provide information of inundation extent, velocity and the depth of the flood water at 3m spatial resolution. The flood information is developed in the form of spatial maps showing flood depth and inundated areas along with a bulletin that get disseminated through the web portal. Apart from that flood warning is provided through SMS and other approved methods to the end user.

The FEWS setup has a Graphical User Interface (GUI) that provides holistic information on city wide flood hotspots using Hydro River Model simulation by capturing real-time forecast of rainfall via IMD. The web based interface is fully automated and simulates the forecasted event as per the IMD rainfall prediction with a lead time of 72 hrs on hourly basis. This provides sufficient time to initiate emergency actions.

FEWS has helped Guwahati in assessing the dynamic nature of its water bodies and monitor vulnerable hotspots to take flood mitigative actions using advanced technological monitoring and modelling. The pilot test of the FEWS in Guwahati was able to achieve the intended results and has demonstrated potential to scale up in other cities.

Details of this case study are provided by The Energy and Resources Institute and the web based interface of the forecast is accessible here - http://fews.teriin.org



Web based interface of FEWS
Photo credit: The Energy and Resources Institute

Outcomes

- Improved flood resilience
- Enhanced coordination informed by flood forecast and monitoring models
- Safeguard lives and infrastructure through efficient early warning

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

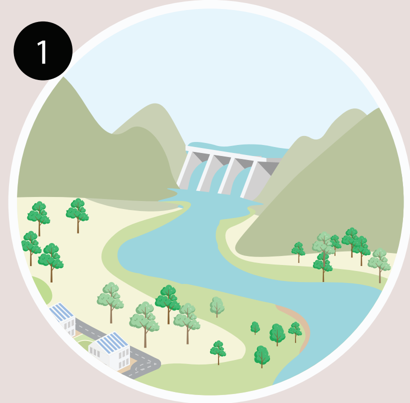
Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

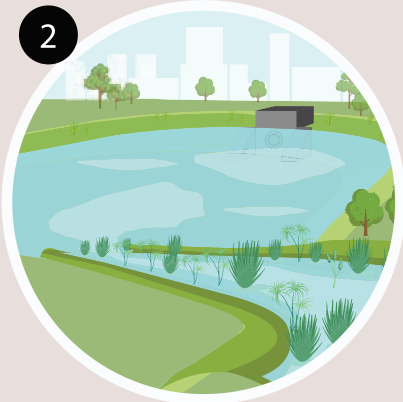
₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

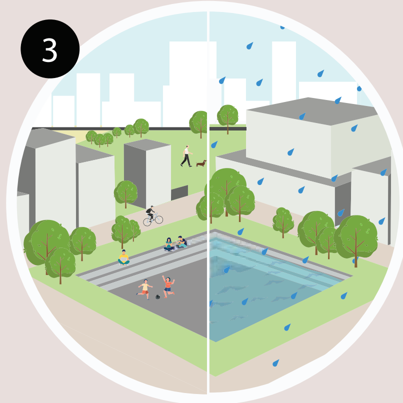
2020



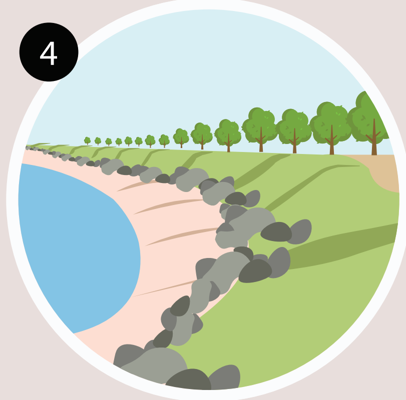
Reservoirs



Rentention area

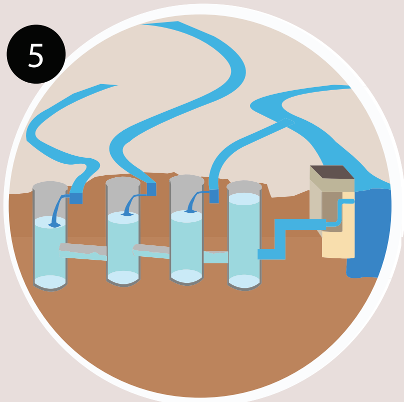


Water Squares

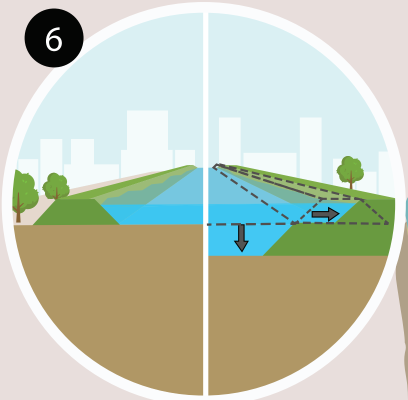


Embankments

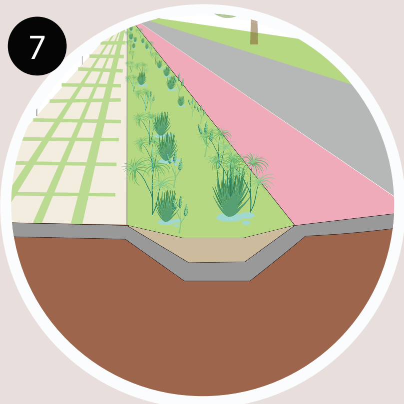
INFRASTRUCTURE
Interventions



Underground Water Storage

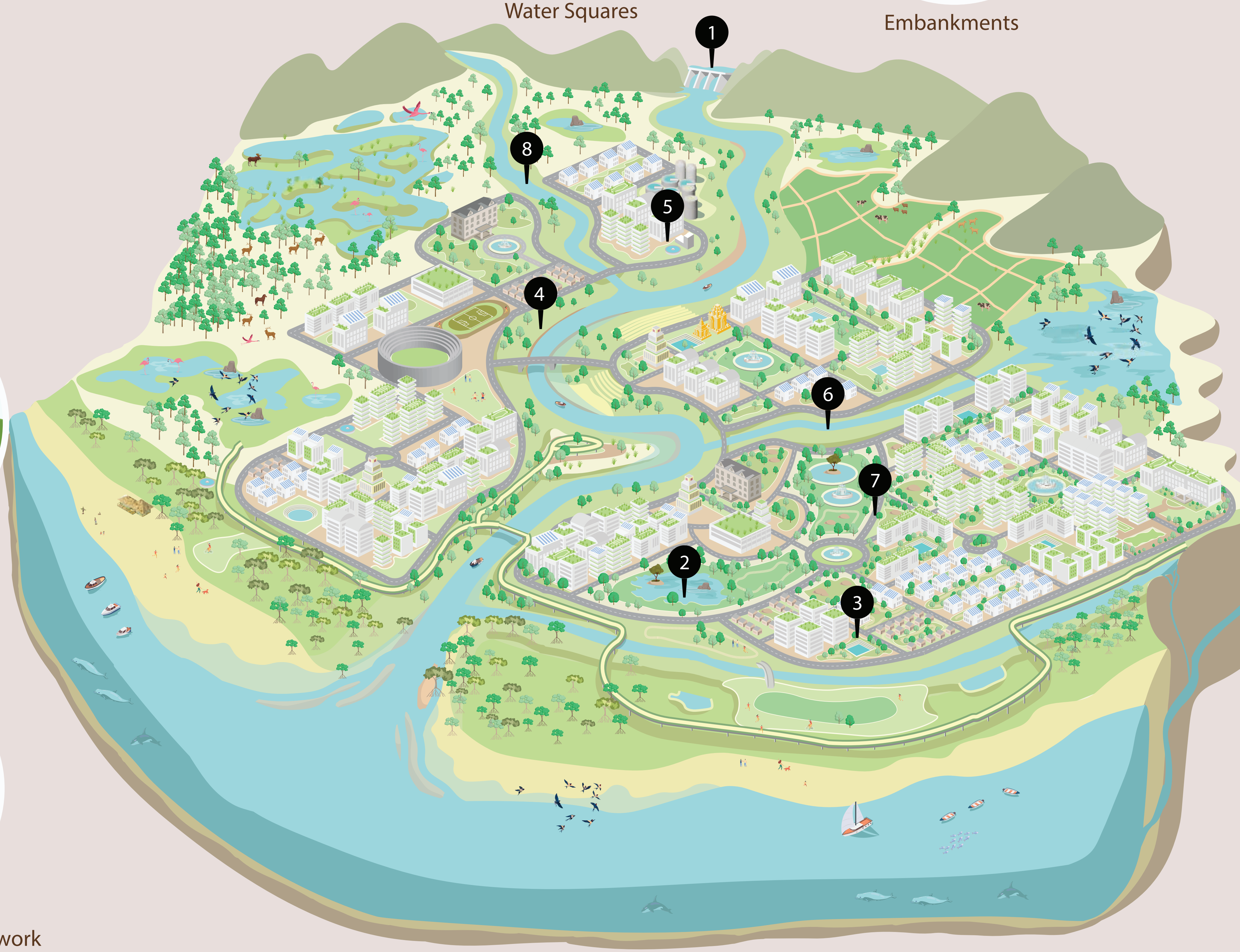


Canal widening and deepening



Swales

Comprehensive Drainage Network



The Nile River Basin Management

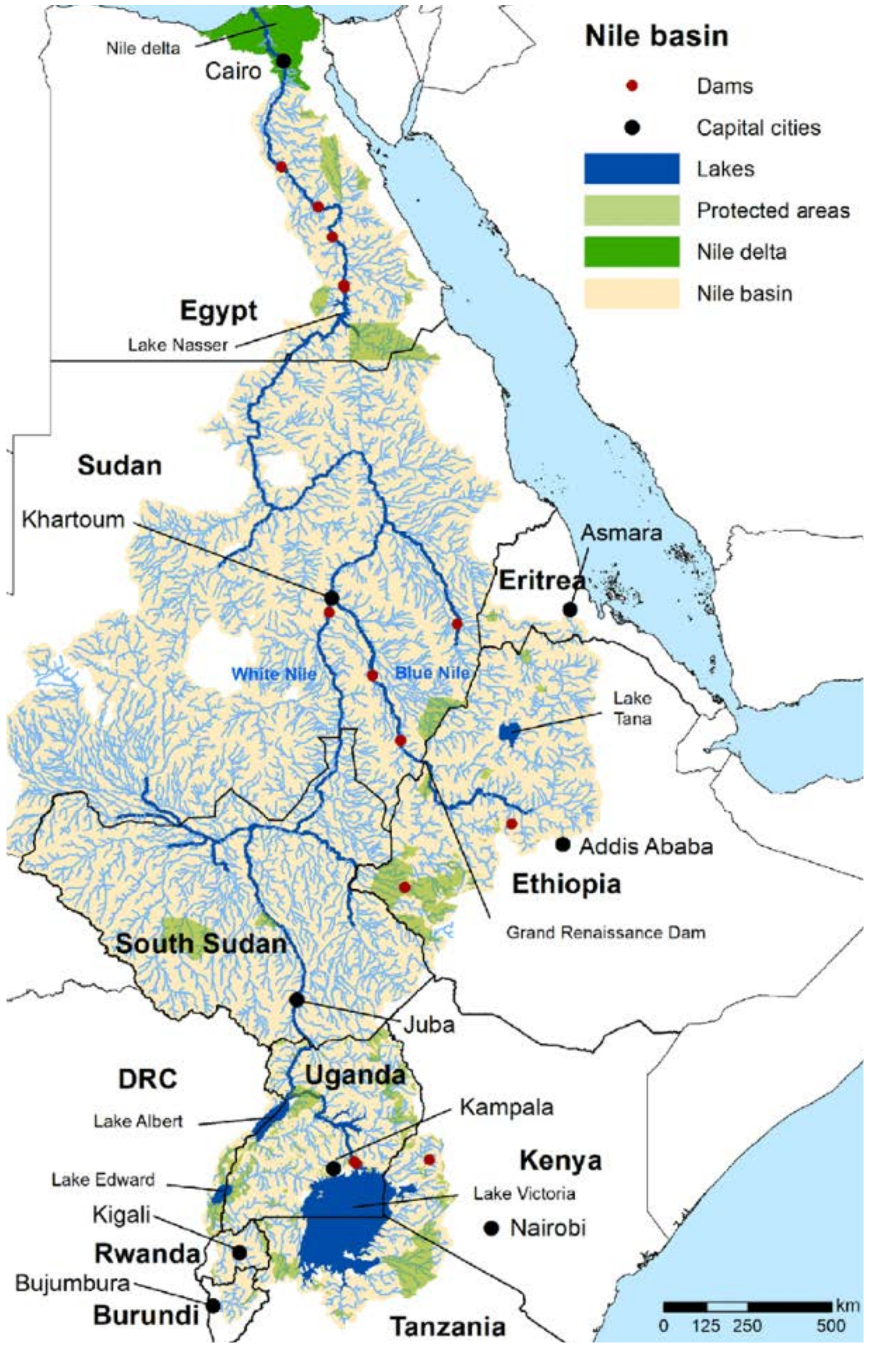
River Cities

Tropical Climate Zone

Structural and Natural Approaches for River Basin Management

The Nile River is 6825 km in length from its source in Lake Victoria in Uganda and Tanzania to its mouth at the Mediterranean Sea. Its drainage basin is about 3,349,000 sq. km covering about one-tenth of Africa and includes land from 10 different countries. The river is influenced by the seasonal patterns of its three main tributaries, the White Nile, Blue Nile and the Atbara. Every year, in the months of August and September, extreme rainfall in the upstream of the Nile River causes flooding in the downstream. The flooding has shown evidence of increasing intensity over the years and mud buildings which are majorly located in the downstream of the river are most impacted. Building collapse, loss of property and damage to transport infrastructure affected thousands of people. To minimise the impact of flooding and mitigate the risk, cities in and around the Nile River basin have adopted the following measures:

- Cities along the Nile River have built flood reservoirs with levees that are proving to be effective. The levees play a key role in managing the flow of the river. If the levees are removed the river channel would spread over 10 miles in its width thereby increasing the flood plain.
- Flood insurance provided by the Government of Sudan and other donor agencies for existing developed areas has discouraged development in flood-prone that does not have access to flood insurance. Local communities have also agreed to not construct any new infrastructure in flood prone areas.



River basin map of Nile and Mississippi rivers
Photo credit: Same as reference

- Currently, satellite images are being used to assess the extent of damage from floods. This is used to evaluate insurance payments and also to identify strategic measures for flood mitigation.
- Nature based solutions such as plantation of vegetation along the river are being adopted to control sedimentation and runoff, thereby minimising some of the problems related to flooding and erosion downstream.
- In urban areas, additional measures such as construction of concrete embankments, flood-gates, drainage channels and pumping stations to safeguard critical infrastructures are being considered.
- Dredging is also carried out regularly to increase the flow depth across the river to facilitate navigability.

With collective and forward-looking planning, the above measures have helped the cities around the Nile River basin to build flood resilience and minimise flood related losses and damages especially in areas that are particularly at risk.

Details of this case study are referred from 'Warburton.P, 2002. River Basin Management: The Nile and Mississippi. Geofile.' [Online] Available at https://www.jkgeography.com/uploads/1/0/8/4/108433405/mississippi_and_the_nile.pdf (accessed 18th May, 2022)

Outcomes

- *Improved flood resilience through the adoption of natural and structural measures.*
- *Planting vegetation along the river specially in the high-risk areas has reduced soil erosion.*
- *Communities are better informed to take action in order to mitigate flooding.*
- *Safeguard lives and livelihoods.*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/Research | Private/Business | City government/departments | National government/departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

1968

Water Management Strategy, Singapore

Tropical Climate Zone

Coastal Country

Achieving water security through a comprehensive water management system

2001

Singapore is an island country in Southeast Asia with limited freshwater resources, natural aquifers and lakes. As a result, it imports water from the Linggiu Reservoir on Johor river from the neighbouring country, Malaysia. While this reservoir can supply up to 60% of Singapore's water needs, there have been numerous occasions where the water levels in the reservoir have reduced drastically due to prolonged dry spells. Hence, water security is a concern for Singapore and therefore the country has been promoting water as a necessary resource, an economic asset and an environmental treasure to address its water needs.

In order to achieve water security and promote sustainable water consumption, Singapore has adopted three key strategies i.e. collect every drop of rain water, reuse waste water and desalinate seawater. Following this strategy, Singapore diversified its water supply in four different ways, these include: local catchments to harvest rainwater, NEWater that recycles wastewater, desalinated seawater and imported water. It is the goal of Singapore to become self-sufficient, with 40% of water from recycling, 30% from desalination, and 20% from rainwater collection in future.

The local catchment involves collecting rainwater on a large scale and these reservoirs function as a sustainable source of water supply. Three-fourth of the country is in the rainwater catchment area and an extensive drainage system diverts this rainwater into the water reservoirs. This system of extensive storm water drainage and reservoirs also mitigates flooding in the country. The country has five main reservoirs (Marina Reservoir, Upper Seletar Reservoir, Bedok Reservoir, Lower Pierce Reservoir and MacRitchie Reservoir) that capture rain water. They are also designed to cater to the needs of public as recreational spaces that not only improve the quality of life but also protect the local biodiversity.

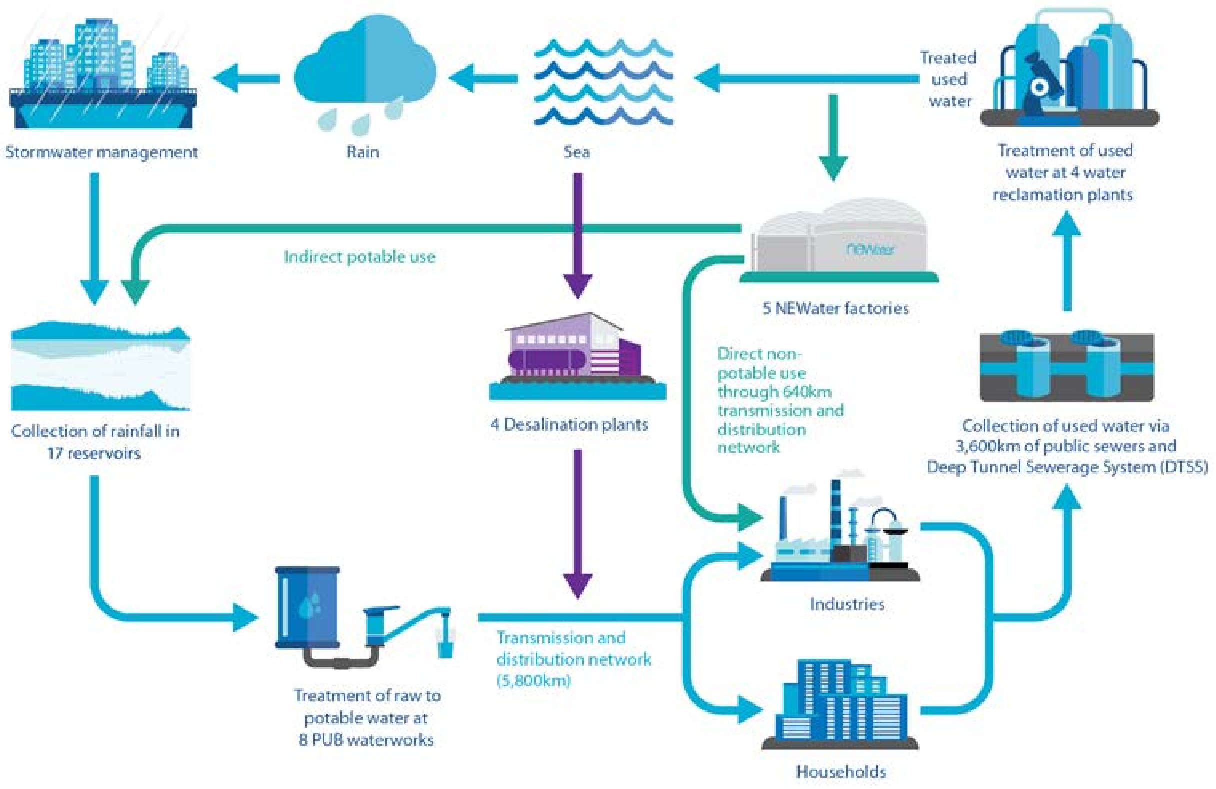


Illustration representing Water Management process in Singapore. Photo Credit: PUB, Singapore's National Water Agency

NEWater is a method to recycle waste water. It is produced by purifying wastewater through advanced membrane technology and ultraviolet disinfection. The resulting water is extremely clean and reused as potable water. NEWater currently provides for approximately one-third of Singapore's water needs.

Desalination of seawater is a very energy-intensive process but with technological advancements and by using reverse osmosis process, Singapore made desalination a viable option. Lastly, the country focuses on reducing its dependence on imported water as it has an agreement to use water from the Johor river until 2061.

With an intent to mitigate the water stress, Singapore has established a comprehensive water management system by diversifying its water sources (local catchment, NEWater, desalinated and imported water). These sources of water supply are known as the Four National Taps and together they provide the country with a resilient water management strategy to address the water demand and become self-sufficient.

Details of this case study are referred from 'WWF. 2012. Singapore Water Management. Water scarcity prompts water self-sufficiency. Water scarcity prompts water self-sufficiency.'[Online] Available at https://wwf.panda.org/wwf_news/?204587/Singapore-water-management (Accessed on 10th May, 2022) and 'Singapore's National Water Strategy. 2022. Singapore Water Story. [Online] https://www.pub.gov.sg/watersupply/singaporewaterstory (Accessed on 10th July, 2022)

Outcomes

- *Reduced water scarcity*
- *Enhanced biodiversity*
- *Improved natural environment*
- *Improved tourism*
- *Interactive public and recreational spaces*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ ₹₹ ₹₹₹

Potential for Scaling Up

Flood Management Programme, Japan

Tropical Climate Zone

River City

Comprehensive flood management measures on the Tsurumi River

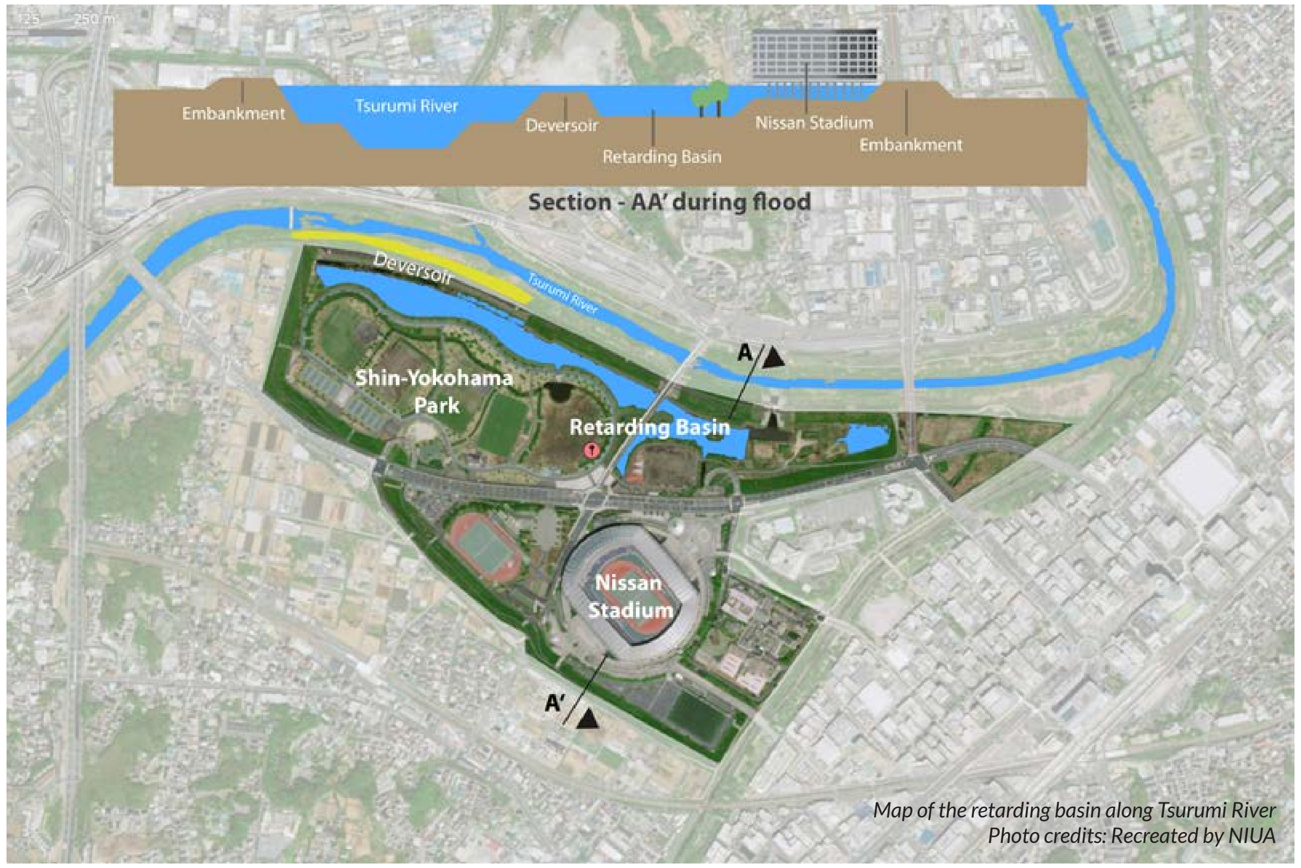
2003

Tsurumi River traverses through the districts of Kanagawa and Tokyo in Japan. The river is known as a flood-prone river due to its low gradient and meandering nature. However, the flooding risks have increased with urban development encroaching the river basin. Around 85% of the basin was encroached due to construction. This has led to an increase in the flow of water into the river and reduced the time taken for the river to reach peak discharge resulting in flooding.

In response to a series of floods that occurred, a comprehensive flood mitigation program was developed for the Tsurumi River basin. The intervention was implemented by Ministry of Land, Infrastructure, Transport and Tourism, and the City of Yokohama. The focus was to develop a multipurpose retarding basin. Retarding basins were used to temporarily store storm water during heavy rainfall and low lying areas were usually developed into retarding basins.

The retarding basin consists of a system of levees, overflow embankment, land space to store storm water and a sewage gate. Two set of levees were built. One between the retarding basin and neighbouring land and another separation levee between the retarding basin and the river. These system of levees allow the water to flow into the basin and stored temporarily. The retarding basin can capture a maximum of 3.9 million litres of water and has been successful in protecting the surrounding neighbourhood and the communities downstream from flooding. After heavy rainfall and receding flood situation, the water is discharged back into the river through the sewage gate.

The information on the water levels and flow rate in the river are monitored on a real time basis and the details are made publicly available on the internet for taking measures in a timely action.



Map of the retarding basin along Tsurumi River
Photo credits: Recreated by NIUA

Recreation facilities including a stadium was built besides the retarding basin and the entire area was protected by an embankment. The stadium is also elevated on columns to avoid any damage in case water overflows from the retarding basin.

In the following years, this area has experienced extreme fluvial events, however, the subsequent flooding due to these events has reduced drastically. While the intervention was intended to respond to once in every 150 year floods, the implemented retarding basin has the capacity to respond to flood with a greater return periods.

Further, educational courses for students and local residents on disaster preparedness are also conducted here by the Tsurumi River Administration Centre in the recreational areas. Apart from attracting visitors the recreational centres currently provides a platform for generating public awareness to understand and manage flood risks including measures for safe evacuation.

Details of this case study are referred from 'Tokyo Development Learning Center, Government of Japan and the World Bank. 2017. Enriching and Protecting Communities through Flood Water Storage. The case of Tsurumi river.' [Online] available at https://programme.worldwaterweek.org/Content/ProposalResources/PDF/2017/pdf-2017-7137-4-Japan%20Project%20Brief_Tsurumi.pdf (accessed 28th May, 2022)

Outcomes

- *Improved natural environment*
- *Transformed public space*
- *Improved flood resilience*
- *Enhanced coordination*
- *Inform policy and planning*
- *Empowered communities*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Cheonggyecheon Restoration Project, Seoul

River City

Tropical Climatic Zone

Revitalizing a lost stream

Cheonggyecheon is a modern recreational neighbourhood in downtown Seoul, South Korea with a natural stream running across it. The Cheonggyecheon restoration project was centred on revitalising this stream as it was converted to a highway overpass for accommodating the increasing vehicular traffic in the capital. The presence of informal settlements, dilapidating infrastructure combined with traffic congestion resulted in an unfavourable living environment with increased health risks especially due to air and noise pollution. In order to address this situation, the city government decided to revive this corridor. A budget of USD 90 millions was allocated to address the challenge of ageing infrastructure. Instead of retrofitting the existing infrastructure, the city government chose to demolish the highway and bring back the lost stream of 3.6-mile in the centre of Seoul.

2005

Some of the significant approaches adopted to revive the stream and develop an ecological and recreational corridor were:

Inclusive and integrated approach:

- The intent of demolishing the highway was opposed by various stakeholders. In order to bring them on board and make this an inclusive process, extensive stakeholder consultations were conducted. The value in restoring the Cheonggyecheon stream over investing in retrofitting the expressway was highlighted during these consultations. Further, the co-benefit of creating an improved living environment and overcoming some of the challenges such as air pollution, noise pollution, traffic congestion and urban heat island effect was also emphasised.
- During the construction, the business owners and street vendors who were temporarily relocated were provided with financial support through subsidies and special arrangements.
- The restoration was planned to create a vibrant public space. Natural habitat for terrestrial and aquatic life was prioritised by incorporating native willow swamps, shallows and marshes in 29 locations.
- 95% of the concrete and asphalt and the scrap iron recovered from the demolished highway was reused in the construction of new infrastructure along the river. This has helped in demonstrating the successful management of construction and demolition waste resulting in reduced cost of restoration.

Resilient approach:

- In order to revive the water flow within the stream, treated water from the Han River and underground water from subway stations were fed into the stream.
- To reduce the risk of flooding, flood proofing was done by constructing embankments that can withstand a 200-year return period floods and manage a flow rate of 118mm/hr.
- Vertical walls were built around the stream to act as a flood defence for the city.

The restoration project increased the overall biodiversity by 639% and has been successful in restoring wildlife fish species, birds, insects and plants. Further, the wetlands at the junction of various waterways running into the Cheonggyecheon stream is designated as an ecological conservation area. The non-motorized connectivity was improved and the city has been able to achieve 35% reduction in air pollution. Cheonggyecheon also became a venue for diverse cultural events firmly positioning the stream as a place for culture and recreation. By fostering an effective urban paradigm shift in converting a highway into a blue-green belt, the Cheonggyecheon itself became an attractive element of the city, drawing not only locals but also tourists which directly contributes to Seoul economy.

Cheonggyecheon Restoration Project
Photo credit: Landscape Performance

Details of this case study are referred from 'Landscape Performance Series. 2010. Cheonggyecheon Stream Restoration Project. Case Study Brief. ' [Online] Available at https://www.landscapeperformance.org/case-study-briefs/cheonggyecheon-stream-restoration#/sustainable-features (accessed 25th May, 2022).

Outcomes

- *Transformed public space*
- *Improved natural environment*
- *Reduced carbon emissions*
- *Improved air quality Enhanced biodiversity*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ ₹₹ ₹₹₹

Potential for Scaling Up

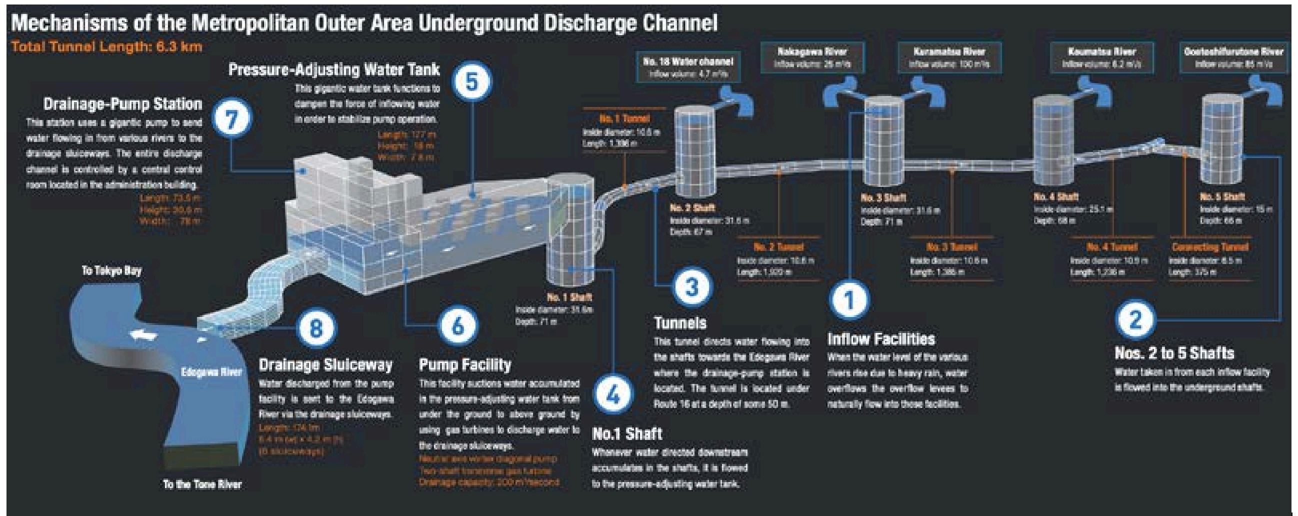
Underground Flood Defence System, Tokyo

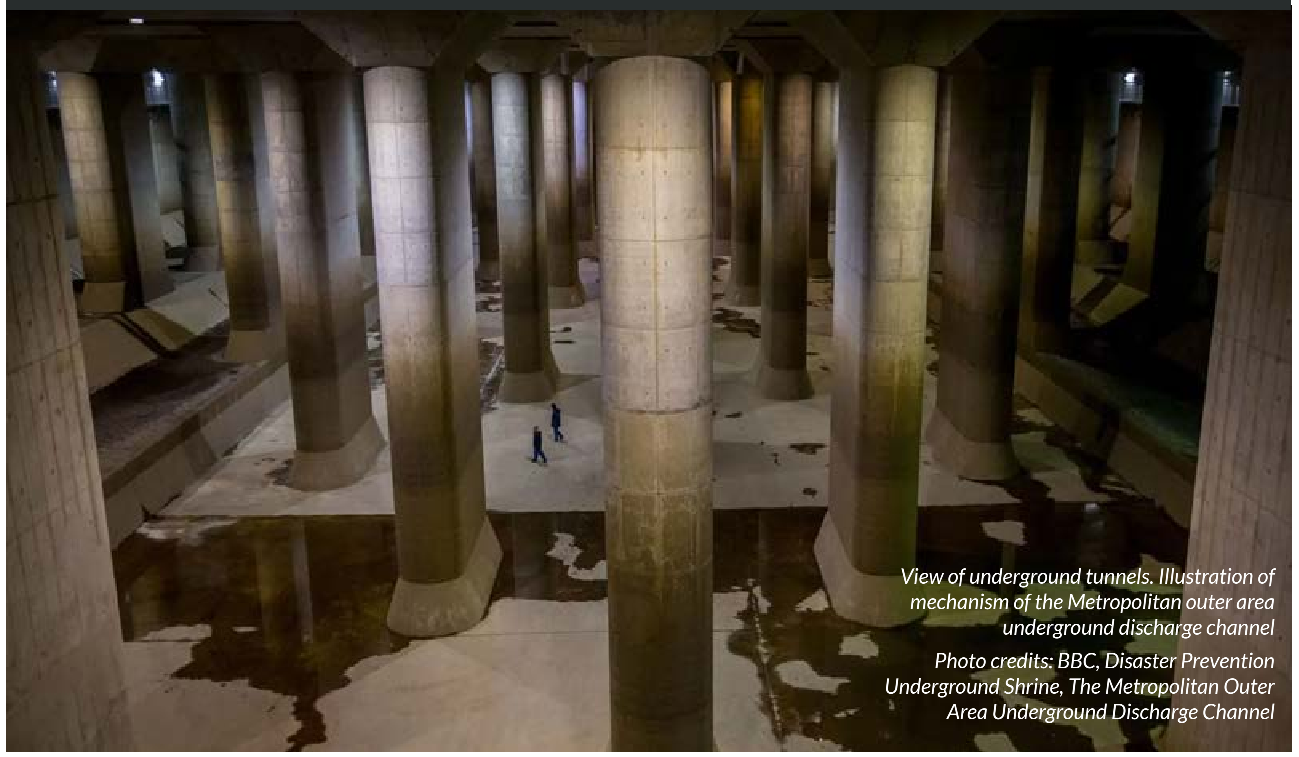
Underground tunnel for flood mitigation

Coastal City *Tropical Climate Zone*

2005

Tokyo, the capital city of Japan is located on the Kanto Plain (the largest plain in Japan) with five river systems (Edogawa, Nakagawa, Arakawa, Kandagawa, Megurogawa and Tamagawa) and dozens of other small rivers within the catchments. Every year during the monsoon, the rivers swell making the city prone to severe flooding. Additionally, the storm water drainage system in the city does not have the capacity to accommodate the run off during extreme rainfall. To mitigate the risk of flooding, the city administration decided to build a flood defence system using latest advancement in infrastructure development.





View of underground tunnels. Illustration of mechanism of the Metropolitan outer area underground discharge channel

Photo credits: BBC, Disaster Prevention Underground Shrine, The Metropolitan Outer Area Underground Discharge Channel

Tokyo undertook the construction of an underground floodwater diversion facility called the Metropolitan Area Outer Underground Discharge Channel (MAOUDC). This is a system of underground tunnels that function as a channel to divert and manage flood water. The excess water from rivers in and around the city are collected through five containment silos that is connected to a 6.3 km long central tunnel located 50 meters beneath the surface. Each of the containment silos are large enough (30m wide and 70m high) to accommodate the excess flood water. The system is comprised of pumps and water tanks to divert overflowing flood waters into the underground silos and tunnels. The tunnels are designed in such way that it reduces the runoff of excess water and stores it in water tanks. Once the flow within the river systems returns to normal, the stored water is pumped back into the Edo river that is connected to the Tokyo Bay.

This flood defence system has helped redirect rainwater during extreme events (including typhoons). The implementation of the system was undertaken over a period of 17 years with a budget of USD 2 Billion*. This system has been operational for over a decade and has been successful in storing flood water and reducing the risk of water stagnation around the city. The damages resulting from floods have been considerably reduced (halved) in comparison to losses before establishing the defence system. When not in use, the tunnels are open to tourists and visitors to spread awareness about the importance of disaster management.

Details of this case study are referred from 'Metropolitan Area Outer Floodway. 2022. Edogawa River Office. Ministry of Land, Infrastructure, Transport and Tourism, Japan. [Online] Available at https://www.ktr.mlit.go.jp/edogawa/edogawa00402.html (accessed 27th July, 2022)

and Ortiz, A. 2018. An intricate system of dams, levees and tunnels defends the Japan's capital. Will it be able to cope with climate change? he underground cathedral protecting Tokyo from floods. Japan: Untold Stories. BBC. Available at : https://www.bbc.com/future/article/20181129-the-underground-cathedral-protecting-tokyo-from-floods (Accessed 25th June, 2022)

** Amount taken as is from the reference.*

Outcomes

- *Improved flood resilience*
- *Enhanced amenity value*
- *Improved tourism*

Water Risk Profile

Pluvial Flood | Fluvial Flood | **Storm Surges** | Variable Rainfall | **High intensity rainfall** | **Rise in sea level** | Water Scarcity

Scale of Intervention

Neighbourhood | **City** | Region

Stakeholders

Community | NGO/CSO | Academia/Research | Private/Business | **City government/departments** | National government/departments

Flood Resilience Characteristics

Robust | **Inclusive** | Flexible | Resourceful | **Reflective** | Redundant | **Integrated**

Cost of the Intervention

₹ ₹₹ **₹₹₹**

Potential for Scaling Up

Kibera Public Space Project, Nairobi

Tropical Climate Zone
Landlocked City

Flood resilience in informal settlements.

2006

Kibera is the largest informal settlement in Nairobi, Kenya and is home to over 1,25,000 residents. With the settlement being along the Ngong River, the risk of flooding during heavy rainfall is high. More than 50% of the households were flooded in 2015. Further, flood water mixing with sewage and storm water leads to a higher risk of vector-borne disease outbreak post flooding.

In addition to being exposed to floods, lack of basic services in the settlement further exacerbates the vulnerability of the people. The storm water drain network is also limited and does not cover the entire settlement. Further, irregular solid waste collection and lack of sanitation services result in constant clogging of these limited drainage channels. Overcrowded spaces and inadequate public space to support the local socio-economic activities is also of concern during the flood recovery phase.

Recognizing the challenges experienced in Kibera, a local organization, Kounkuey Design Initiative (KDI) worked with the community for managing their flood risks and improving the quality of life. The aim was to develop a network of community-designed and managed public spaces where flood protection can be ensured through the development of green and grey infrastructure combined with essential services and amenities.

Firstly, the inadequate storm water drainage was addressed by developing new drainage infrastructure that mitigated flood risk of 8,000 households. In 2016, KDI signed a memorandum of understanding with the County Department of Public Works to address flood risks along the Ngong River. Local flood protection and flood warning systems were installed to provide early warning signals to the residents.

Redesigned public spaces in Kibera
Photo credit: Same as reference

A buffer zone of natural vegetation was created along the river and flood mitigation measures such as gabion and wire walls with green infrastructure was built, especially around vulnerable areas and multi-functional spaces. Multi-functional spaces such as sanitation and laundry facilities that double up as spaces for small businesses and recreation, and community hall that serves as a gathering space, school and place of worship were developed to enhance the socio-economic activities in the settlement.

Multifunctional spaces also played an important role in addressing other social issues such as crime, poverty, and lack of recreational spaces for children. Resident-managed programs, many led by women and youth, generated income for the maintenance of these spaces besides building the skills required by the community to maintain these actions. While focusing on flood resilient development, each area was designed to meet the specific needs of residents with focus on women and children.

With continued engagement from KDI, another important step was undertaken to engage with the Nairobi Metropolitan Services to receive approval for a Special Planning Area (SPA) for Kibera and to integrate the settlement into formal city planning practices. The SPA provides an opportunity to integrate flood resilience plans in municipal development plans and provides an avenue to embed the concerns of Kibera's residents.

Details of this case study are referred from 'Galvin. M and Maassen. A. 2021. In Nairobi, Residents Redesign Public Spaces to Build Flood Resilience. World Resources Institute.' [Online] Available at https://www.wri.org/nairobi-public-spaces-build-flood-resilience (Accessed on 10th May, 2022)

Outcomes

- *Improved basic services like sanitation, solid waste, sustainable drainage, health and hygiene.*
- *Improved flood resilience*
- *Transformed public space*
- *Improved quality of life*
- *Increased livelihood opportunities*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Waterproof city, Rotterdam

Coastal City

Temperate Climate Zone

Delta plan and tidal park programme

2008

Rotterdam is a thriving port city located in the delta of the Rhine and the Maas Rivers. The city is geographically located in an area which is below sea level and as a result the low-lying island city has the risk of being impacted by sea level rise and storm surges especially during high tides. In the recent past, the city is also witnessing extreme rainfall and cloud bursts resulting in the flooding of urban areas situated along the delta. Increased runoff and limited discharge to the sea is the key reason for flooding. Further, several parts of the city have inadequate stormwater storage capacity and poor drainage networks coupled with densely built urban areas that leads to water stagnation.

With an intent to become a waterproof (flood proof) city by 2025, Rotterdam adopted resilient measures including but not limited to increasing the water absorption rate, strategically delaying water stagnation in identified areas and capturing the rainwater. Some of the key actions implemented are:

- Underground water storage spaces (also known as water squares) are built across the city. This includes an underground museum car park with a water storage capacity of 10,000 m3 along with integration of 'blue-green corridors' (watercourses and ponding areas) into the urban landscape. These blue-green corridors are designed to facilitate groundwater replenishment while minimising urban flooding. They also enhance biodiversity and provide additional public space for recreation.
- The drainage and storage capacity of the urban water system in the city has been improved to deal with extreme rainfall by incorporating 'sponge function'. This includes installing 130,000 m2 of green roofs and green facades, reducing impervious pavements and increasing vegetation in streets and neighbourhoods. Such measures were effective even in densely built-up areas.
- The city has built several outer-dykes and inner-dykes with an intent to provide multi-layered flood protection from sea-level rise. Along with the construction of dykes, various wetland related ecosystem services like enhanced water storage, water flow regulation, water filtration and soil formation have also been restored. Such ecosystem services have improved the quality of water and provided a public space with improved ecological connectivity.

All these measures have led to better drainage networks and decreased flood risks in the city.

Details of this case study are referred from 'Oppla. Rotterdam - NBS for building a waterproof city.' [Online] Available at https://oppla.eu/rotterdam-nbs-building-waterproof-city (accessed 18th May, 2022)

Water storage area in Rotterdam
Photo credit: Oppla

Outcomes

- *Improved drainage system with increased storage capacity of rain water*
- *Improved flood resilience*
- *Replenishment of groundwater naturally*
- *Improved natural environment with the integration of blue green corridors*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall

High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business

City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful

Reflective | Redundant | Integrated

Cost of the Intervention

₹ ₹₹ ₹₹₹

Potential for Scaling Up

Storm Water Drainage, Delhi

Composite Climate Zone

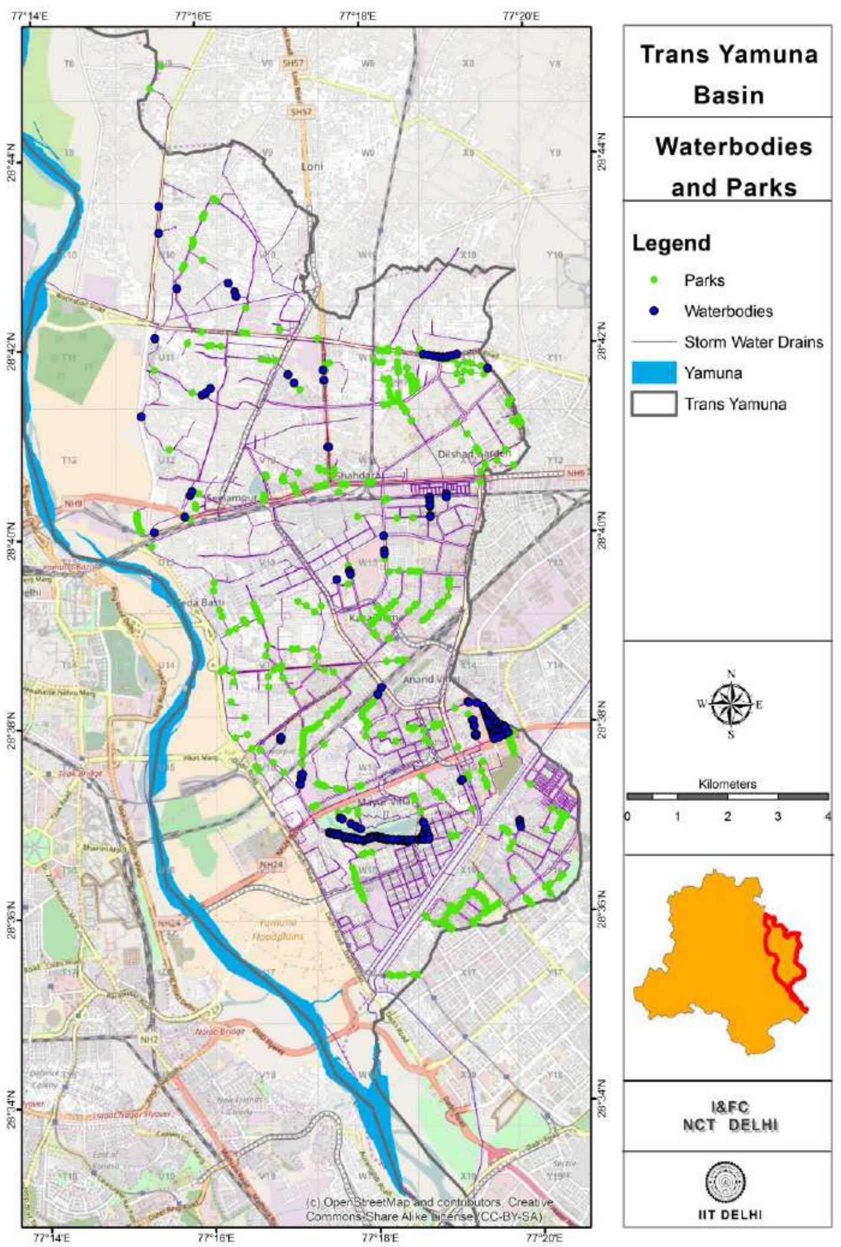
River City

A comprehensive drainage master plan for NTC region of Delhi

2018

Delhi, the capital city of India experiences water logging and flooding annually even during events of moderate rainfall during the monsoon season. Blockages within the drainage system and inadequate storm water drainage network are some of the key reasons for such incidents panning out frequently. While the National Capital Territory (NCT) has three major drainage basins (Najafgarh, Barapullah and Trans-Yamuna), increased impervious surfaces, encroachment, and dumping of solid waste and draining wastewater into the drains result in the blockages and reduces the water carrying capacity of the storm water drains. Hence, the need to address the Storm Water Drainage (SWD) infrastructure to minimize water stagnation was realized and the city government focused on developing a Drainage Master Plan for the NCT to inform and prioritise actions.

Scientific analysis of the storm water drainage system was conducted by assessing the connectivity, flow directions and missing details like outfalls, invert levels, dimensions by the Indian Institute of Technology (IIT), Delhi. Data on the location of pumps, their capacity, operation policies, etc. were collected. Extensive data through surveys and on ground observation were also documented. With these details, flood models were developed to simulate floods in order to capture the performance of the drainage infrastructure and validate the model using flooding hotspots. Various consultations with respective line departments were conducted to understand the gaps in maintaining the SWD infrastructure.



Map illustrating Yamuna River basin with surrounding water bodies, parks & storm water drains
Map credit: Same as reference

The Geographical Information System (GIS) framework based master plan embedded with the Storm Water Management Model developed by IIT, Delhi helped analyse the flood risks in NCT. This has in turn helped the responsible departments and city officials to adopt timely decisions and implement Standard Operation Procedures (SOPs) to mitigate the flooding situation. To alleviate the flooding conditions some of the major recommendations provided and undertaken to make the stormwater infrastructure more efficient were:

- Regular desilting of SWD and addressing encroachment, sanitation, solid waste management, and construction and demolition waste management were prioritised.
- Applying corrective measures to faulty and dilapidated drainage infrastructure and introducing low-cost flood mitigation measures such as rejuvenation of water bodies, rainwater harvesting using parks and low impact development options were considered.

The strict enforcement of above mentioned recommendations along with penalties are being considered by the city government to ensure smooth and organized functioning of the city's stormwater management system.

Details of this case study are referred from IIT Delhi. 2018. 'Drainage Master Plan for NCT of Delhi. Department of Irrigation & Flood Control, Government of Delhi. [Online] Available at https://yamuna-revival.nic.in/wp-content/uploads/2020/01/Drainage-Master-Plan-prepared-for-IFC-Department-GNCTD-by-IIT-Delhi-July-2018.pdf (accessed 6th June, 2022).

Outcomes

- *Improved flood resilience*
- *Enhanced coordination*
- *Informed policy and planning*

Water Risk Profile

Pluvial Flood | Fluvial Flood | Storm Surges | Variable Rainfall | High intensity rainfall | Rise in sea level | Water Scarcity

Scale of Intervention

Neighbourhood | City | Region

Stakeholders

Community | NGO/CSO | Academia/ Research | Private/Business | City government/ departments | National government/ departments

Flood Resilience Characteristics

Robust | Inclusive | Flexible | Resourceful | Reflective | Redundant | Integrated

Cost of the Intervention

₹ | ₹₹ | ₹₹₹

Potential for Scaling Up

Notes:

Notes: