Climate Action in Cities

CoCHAP

Coastal Cities Resilience and Extreme Heat Action Project

Coastal Hazards in Cities Fact Sheets #1

Flooding

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Coastal Flooding in Cities

What is Coastal Flooding?

Coastal flooding[1] occurs when a low-lying coastal area (often dry) is abruptly inundated due to factors such as sea-level fluctuations, storm surges, and extreme tides, high waves at the shoreline and heavy rainfall.[i] It affects coastal communities, farmland, building, transportation routes, industry, other infrastructure and ecosystems like mangrove forests or salt marshes.

Particularly coastal cities and agglomerations (CCAs), defined as areas within 100 kilometres from the coast, that are home to approximately 2.4 billion people (40% of the world's population) are exposed to coastal flooding. [ii] Despite occupying a relatively small portion of the Earth's surface (between 4% in 2006 and 15% in 1998), CCAs play a crucial role in the economies of coastal countries.[iii] CCAs have often dense population, large-scale infrastructure and relatively more economic activity in a limited geographical location.

These cities are predominantly built up of complex concrete buildings and congested roadways, and often lacking sufficient green spaces, due to which, when there is excess water, the storm drains become ineffective, exacerbating infrastructural deterioration.

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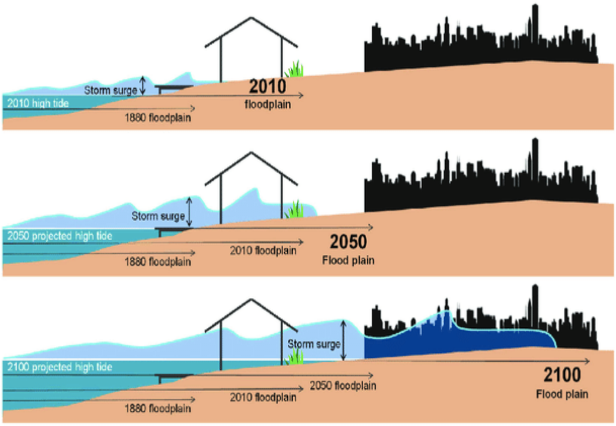
[1] IPCC, 2012: Glossary of terms. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the IPCC. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 555-564.

Figure 1: Illustration of the risk of coastal flooding under the present and future climates, Source



About 1.47 billion people, or 19 percent of the world population, are directly exposed to substantial risks during 1-in-100 year flood events[iv]. The majority of flood-exposed individuals, approximately 89% of those vulnerable to coastal flooding, reside in low- and middle-income countries. Specifically, around 1.36 billion people at risk are concentrated in South and East Asia, while China and India alone account for over a third of the global total, with 329 million and 225 million individuals respectively. Studies also presents the global estimates of the number of people exposed to high flood risks in interaction with poverty. Of the 132 million people who are estimated to live in both extreme poverty (under $1.9 per day) and in high flood risk areas, 55 percent are in Sub-Saharan Africa. [iv] About 587 million people face high flood risk, while living on less than $5.5 per day.[v]

Causes of Coastal Flooding:

Coastal flooding is caused by extreme total water levels due to relative sea level rises, tides, storm surge and high wave setup at shorelines.[i] The flooding can be associated with devastating impacts for coastal communities, farmland, buildings.[vi] [vil]

Natural Factors

- A low-lying coastal area is more exposed to coastal floods as the sea water can easily travel inland.
- Coast erosion occurs when coastal earth and sand are removed by wave action effectively moving the coastline inland. This can be accelerated by the damage or removal of natural vegetation or coastal eco-systems such as wetlands or mangroves.
- Subsidence is the lowering of the height of the land either due to natural processes like plate tectonics, earthquakes, or human activities like groundwater abstraction, mining, natural gas extraction, etc., causing the land to sink.
- Storm surge occurs when strong winds, often associated with strong storm systems including cyclones, push seawater up against a coastline significantly raising sea-levels which can result in coastal flooding.
- Tsunamis are caused by earthquakes in the ocean floor that rapidly shift a section of the ocean floor displacing large amounts of water that then results in very fast moving long ocean waves. Tsunamis have been the cause of the most severe and disastrous coastal flooding events. Tsunamis are unrelated to climate.

Anthropogenic Factors

- Human-induced climate change: Can aggravate natural factors and lead to increase in coastal flooding (see below)
- Urbanization and land use change: The construction of buildings, roads, and other infrastructure along coastlines can alter natural sediment transport processes, leading to increased erosion. Additionally, coastal development often involves the removal of natural vegetation, such as clearing of forests, mangroves, or other features such as wetlands and dunes, which are natural barriers against erosion.
- Sand Mining: Extraction of sand from beaches and coastal areas for construction and industrial purposes removes sediment that would otherwise contribute to shoreline stability, accelerating erosion rates.
- Pollution: Pollution from industrial and agricultural sources can degrade coastal ecosystems, weakening their ability to resist erosion. Climate change, driven by human activities such as burning fossil fuels, leads to sea level rise and changes in weather patterns, exacerbating erosion processes along coastlines.

- Vegetation such as mangrove trees can provide a barrier absorbing wave energy, lessening the impact of floods. Hence, when the vegetation is removed, the area is more prone to floods.
- Increased Storm Surges: An increase in events like storm surges can temporarily increase sea levels along coastlines. For the future (2021–2050), results show storm surge changes up to 20%. These are one of the major drivers of coastal floodings.

How does Climate Change intensify Coastal Flooding?

Climate change strongly impacts coastal region and will further increase sea levels and air temperatures in most coastal settlements (high confidence). Eextreme sea level, increased by both sea level rise and storm surge will increase the probability of coastal flooding (high confidence, IPCC 2021).

Coasts are subjected to sea level rise, changes in the frequency and intensity of storms, increases in precipitation, and warmer ocean temperatures. In addition, rising atmospheric concentrations of carbon dioxide (CO2) are causing the oceans to absorb more CO2 and become more acidic. This rising acidity can have significant impacts on coastal and marine ecosystems. [xii]

- Sea Level Rise: Global sea levels are rising. The oceans are warming due to climate change and cause the water to expand, contributing to global sea level rise over the past century (IPCC_AR6_WGI_Chapter02, p.94).
- Increase in heavy rainfall: Projected changes in precipitation show larger uncertainties, however, on a global scale heavy rainfall is projected to increase. Heavy rainfall accompanied by storm surge can intensify coastal flooding . Note that in addition, pluvial flooding will increase in coastal urban areas where extreme precipitation is projected to increase. (IPCC_AR6_WGI_Chapter11).

How does Coastal Flooding affect city systems?

According to the World Bank Report 2022, settlements exposed to the highest flood hazard level have increased by 122 per cent.[vii]

Physical Impacts

- Disruption in transportation: Roads, tunnels and bridges are impacted due to coastal flooding, causing disruption in transportation.

- Disruption in water supplies and sewage systems: It can disrupt essential services like water, sewage and power lines.
- Damage to buildings and residential areas: Flooding may lead to structural damages of Buildings, including homes, offices, and commercial structures due to erosion and corrosion processes.
- Economic losses: Floods can cause heavy economic losses due to damage to buildings and properties with additional costs of repair and maintenance.
- Tourism Impact: The economy of some coastal areas is dependent on tourism, which can be impacted by coastal floods by causing immediate disruption in services.
- Average global coastal flood losses in the 136 largest coastal cities in the world have been estimated to be approximatively US$6 billion.[viii]

Socio-Economic Impacts

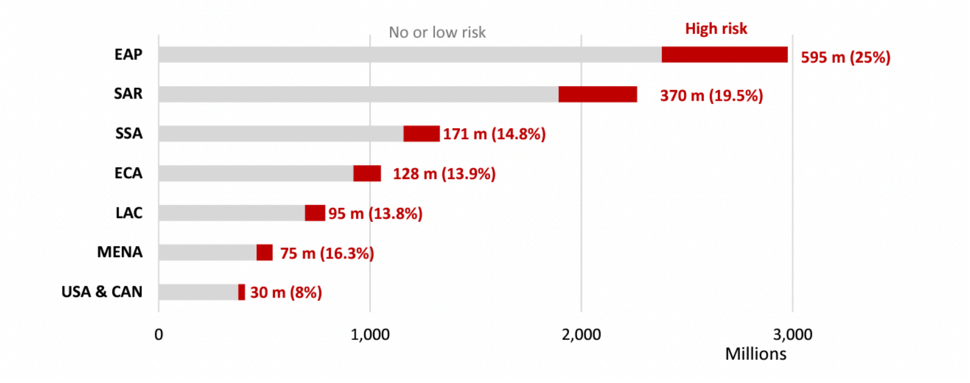
- Population Displacement: Due to impacts on infrastructures and utilities caused by the floods, communities can be displaced temporarily to safer areas. Low income and marginalized communities are often less able to recover and more likely to be displaced.
- Disruption in Livelihoods: Coastal communities dependent on local coastal areas for agriculture, fishing, etc can lose their livelihoods
- Social Stress and Mental Health: The disruption can lead to social disparity among communities and increased social stress, anxiety, and mental health issues among affected individuals and communities.
- Health Risks and safety concerns due to outbreak of diseases and limited access to health care and facilities, especially to waterborne diseases due to water contamination in the aftermath of the floods.
- Access to Clean Drinking Water: Floods can also hinder access to clean drinking water, and as utilities and services are disrupted.
- An estimated two million people have been killed in South Asia alone due to coastal flooding over the past 200 years. [x]

Environmental Impacts

- Habitat Alteration: Coastal floods can destroy or alter coastal habitats such as wetlands, marshes, and estuaries, which are critical for various plant and animal species
- Biodiversity Loss: Coastal flooding can lead to the displacement or loss of plant and animal species that are adapted to specific coastal habitats.

- Invasive Species: Floodwaters can carry invasive species into new areas, disrupting native ecosystems
- Water Quality Degradation: Floodwaters can introduce pollutants and sediment into the water supply system of coastal regions, degrading the water quality
- Disruption of Breeding and Nesting Sites: Flooding can destroy the breeding and nesting sites for birds, sea turtles, and other species
- Erosion and Coastal Land Loss: Coastal flooding can also cause erosion at times, leading to the loss of coastal land
- Vegetation and species loss due to saltwater intrusion: Sometimes floods can cause an increase in the salinity level of water in groundwater aquifers, impacting plants and animals loss in the coastal region
- Saltwater Intrusion: Relative sea level rise and associated coastal flooding RSL is also causing saltwater to intrude into freshwater sources along the coast, contaminating drinking water supplies and damaging agricultural land. In 2020, Hurricane Laura caused saltwater intrusion along the Gulf Coast of the United States, particularly impacting areas of Louisiana and Texas. The storm surge inundated coastal regions, leading to the contamination of freshwater sources and agricultural lands, highlighting the ongoing threat of saltwater intrusion in vulnerable coastal areas.

Figure 2: Number of people exposed to significant flood risk by region (and as share of total regional population), Source



Adaptation Strategies for Coastal Flooding

Community Level

- Establishing green infrastructures like the creation of permeable pavement, rain gardens, and green roofs to absorb and manage excess water xxi
- Rehabilitating and restoring damaged habitats to support native species that provide natural barriers such as dunes, mangroves, and wetlands, creation of oyster reefs to provide natural protection against flooding
- Effective management of stormwater drainage systems to manage excess water during floods
- Relocation of commuting and buildings in safer places in case of high flood risk zone
- Proper communication systems and building capacity of municipal staff and/or the general public regarding coastal flooding and its impacts on the community
- Monitor flood events and drivers by monitoring data for sea level, precipitation, temperature, and runoff, which can be incorporated into flood models to improve future flood predictions
- Establishments of early warning systems by detecting, analyzing, predicting and warning about coastal floods for timely decision-making and implementation
- Plan for emergency measures relating to extreme events like flooding, mainly to ensure that transportation access to and from affected areas of the community is maintained or restored as quickly as possible xxii
- Increase awareness and education among local communities and relevant stakeholders to enhance coastal adaptation and flood risk understanding and capacity for better cooperation
- Local community participation in the planning and implementation of adaptation measures

Municipal/Government Level

- Adaptation of flood management plans through grey protection solutions such as dams, dikes, channels, groynes, breakwaters, sea walls, jetties, artificial reefs, storm surge defences and barriers and promotion of green measures, including sustainable land use practices, managed retreat from flood-prone areas, improvement of water retention through preservation and requalification of floodplains and wetlands xxiii

- Maintaining water quality and availability by incorporating sea level rise into planning for new infrastructure eg. sewage systems, drinking water, wastewater utilities etc xxiv
- Maintain and restore wetlands by identifying high-priority wetlands and allowing coastal wetlands to migrate inland xxv
- Retreat from high-risk areas by removing infrastructures too close to the beach or rivers without proper authorization by providing compensation and demolition costs xxvi
- Beach and shoreface nourishment by artificially placing the sand on an eroded shore to maintain the amount of sand present in the foundation of the coast, to compensate for natural erosion and to protect the area against storm surge xxvii
- Dune construction and strengthening by planting grass, covering the face of the dune with plant debris, constructing fences along the seaward face to reduce wind speed on the surface and applying a combination of hard man-made structures topped with sand, dunes and vegetation. xxviii
- Rehabilitation and restoration of rivers and floodplains by improving water storing capacity in the floodplain, relocation of water-vulnerable land use types and activities to areas with lower flood risk, lowering of the floodplains, relocating dikes further inland, lowering levees along the rivers and deepening the summer beds
- Cliff strengthening and stabilization, changing the slope angle, and/or reducing cliff heights by removing unstable blocks, eliminating surface runoff and infiltration on the slope, securing unstable rocks to increase cohesion and stability and prevent slippage etc. It also includes adapting green measures like placing sand or pebbles at the foot of the cliff, managing existing vegetation to regain damaged areas, or establishing a vegetation cover on the slope to limit the risk of instabilities
- Building of storm surge gates and flood barriers to protect highly vulnerable urban areas and infrastructure where storm surges and sea flooding could have major impacts xxix
- Raising and advancing coastal land by creation of new port and harbour areas and safer urban embankments, planting vegetation to support natural accretion of land and extension of beaches beyond the natural coastline xxx
- Integration of climate change adaptation in coastal zone management plans by ensuring proper monitoring of the plan implementation, its periodic revision, as well as the refinement and improvement of outcomes according to the learning-by-doing approach

- Use of climate-resilient building materials and design such as water-resistant materials that are resistant to water damage
- Insurance and financial mechanisms to insure property owners from damage caused due to floods and establish funds to support adaptation projects and assist vulnerable communities

Case Examples

Case Example 1

The 34-hectare 'Qunli stormwater park' in the city of Harbin in northern China is one example of a successful sponge city. It collects, cleanses and stores stormwater while also protecting the native natural habitat and providing a beautiful green public space for recreational use.22 The Chinese government has implemented the idea of a sponge city in 16 pilot cities where the objective is to adopt innovations as a policy intervention. The government has allocated 400 and 600 million yuan (around €55 million) to implement this innovative water management strategy.) [xxxi]

Case Example 2

The city of Rotterdam in the Netherlands has successfully implemented various innovative strategies and projects to address the challenges of coastal flooding. It has developed water squares that serve as public spaces and temporarily store excess water during excessive rainfall. The city has constructed buildings and parks on floating platforms for flexible land use. Rotterdam also follows the "sponge city" approach by incorporating permeable surfaces, green roofs, and rain gardens to absorb and manage rainwater, thus setting an excellent example for mitigating and adapting to coastal floods. [xxxii]

Case Example 3

The Sundarbans, the largest mangrove forest in the world lying in the Delta region, shared by Bangladesh and India, has undertaken various adaptation measures to address the challenges posed by coastal flooding. It has adopted community-based adaptation measures where local communities are extensively involved in creating and implementing adaptation strategies. Both countries have invested in large-scale mangrove reforestation efforts. In Bangladesh, "floating gardens" have been develop
ped for food production during floods. Farmers have been trained to adopt climate-resilient agricultural practices, such as cultivating saline-tolerant crops to adapt to changing climate risks. [xxxiii]

Case Example 4

Singapore, known for its rapid urbanization and sophisticated infrastructure in South-East Asia, grapples with persistent flooding issues. This challenge, underscored by a significant incident in Orchard Road, a prominent shopping district, highlights the multifaceted nature of urban flooding, stemming not only from natural weather phenomena but also from human-related factors such as inadequate infrastructure upkeep and urban planning. To address this, Singapore initiated a river restoration project in Bishan-Ang Mo Kio Park, transforming a 2.7km concrete drainage channel into a 3km meandering natural river which function as flood plains. This helped in mitigating flooding while also rejuvenating the ecosystem to promote community engagement and efficient flood management. [xxxiv]

Case Example 5

In Jakarta, Indonesia, the Giant Sea Wall project is underway to mitigate the city's susceptibility to coastal flooding and sea-level rise. This ambitious infrastructure initiative involves the construction of a massive seawall along Jakarta's coastline, combined with urban revitalization projects and improved drainage systems. The project aims to protect millions of residents and vital economic assets from the increasing threat of inundation due to climate change. [xxxv]

End notes/references:

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