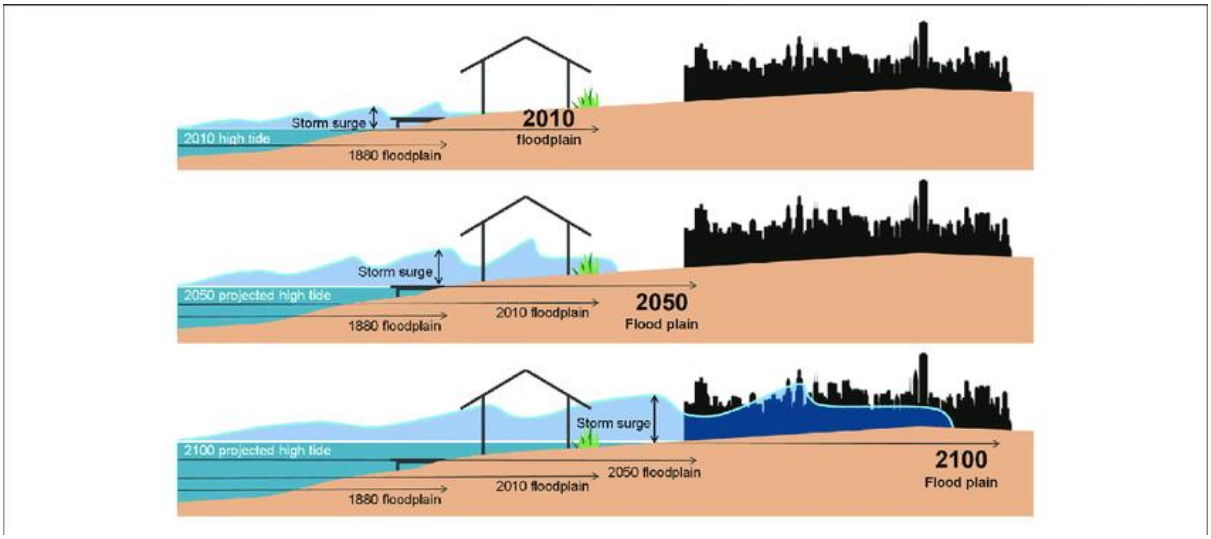
Coastal hazards Fact Sheets #1: Coastal Flooding in Cities

What is Coastal Flooding?

Coastal flooding occurs when a low-lying coastal area (often dry) is abruptly inundated by a short-term increase in water level due to storm surges and extreme tides. [i] It is usually a natural process in the coastal area dynamics affecting areas like salt marshes and mangrove forests. [ii] Coastal areas are home to about 2.4 billion people (40% of the world's population) and provide high economic value to coastal countries. [iii] Coastal cities are more vulnerable to coastal flooding due to dense population, large-scale infrastructure and relatively more significant activity in a limited geographical location. Cities are primarily built up of complex concrete buildings and roadways, congested and usually lack green spaces, due to which, when there is excess water, the storm drains become ineffective, and there is deterioration of infrastructures.

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



Source:(https://www.researchgate.net/figure/Schematic-illustrating-the-risk-of-coastal-flooding-under-the-present-and-future_fig4_355059364)

About 40 million people, i.e. 0.6% of the global population, are exposed to a 1 in a 100-year coastal flood event across cities.[iv] The exposure is concentrated in a few of the cities, and most of the cities lie in a delta. As of 2005, the top ten cities in terms of exposed population are estimated to be Mumbai, Guangzhou, Shanghai, Miami, Ho Chi Minh City, Kolkata, Greater New York, Osaka-Kobe, Alexandria, and New Orleans.[v] Cities located on deltas are particularly vulnerable to impacts from increased storm surges and flooding events. They are the Nile in Egypt, Incomati in Mozambique, Ganges-Brahmaputra-Meghna, Bangladesh, Yangtze in China, Cillwung in Indonesia, Mekong in Vietnam, Rhine-Meuse in The Netherlands, Danube in Romania, California Bay-Delta in USA and Mississippi in USA.[v]

Causes of Coastal Flooding:

The major causes of coastal flooding are dependent on factors such as the height of land above sea level, degree of erosion and subsidence, vegetation removal and storm surges.[vi]

- A low-lying coastal area is more vulnerable to coastal floods as the sea water can easily be swept inland.
- Erosion occurs when materials like earth and sand are transported from their place of origin due to natural forces like wind or water weakening or removing the area altogether.
- Subsidence is the movement of underground land either due to natural processes like earthquakes, erosion or man-made activities like mining, natural gas extraction, etc., causing the land to sink.

- Vegetation such as mangrove trees hold the sediment and absorbs water, lessening the impact of floods. Hence, when the vegetation is removed, the area is more prone to floods.
- Natural sea phenomena like tsunamis and cyclones also contribute to coastal flooding.

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 percent.[vii]

1. **City Infrastructures**
   - 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: Buildings, including homes, offices, and commercial structures are damaged due to floodwaters.
   - 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 coastal areas is dependent on tourism up to a great extent, which can be impacted by coastal floods.

Average global coastal flood losses in the 136 largest coastal cities in the world have been estimated to be approximatively US$6 billion.[viii]

2. **Social Impacts**
   - Population Displacement: Due to impacts on infrastructures and utilities caused by the floods, communities are forced to get displaced.
   - Disruption in Livelihoods: Communities dependent on agriculture, fishing, etc and contamination caused by flooding can disrupt the livelihood of people.
   - Migration and Relocation: Low-income communities can lack the necessary resources to adapt. Hence, they are forced to migrate or relocate to new places.
   - Loss of Cultural Heritage: Flooding can also, in some cases, threaten traditional practices, indigenous knowledge, and cultural heritage associated with land and water use of local communities in the coastal area.
   - 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.

   According to the Internal Displacement Monitoring Centre, about 3.6 million Indians were displaced annually between 2008 and 2018, most due to flooding from monsoon rains, the heaviest in South Asia in absolute terms. [ix] An estimated two million people have been killed in South Asia alone due to coastal flooding over the past 200 years. [x]

3. **Ecological Disruption**
   - 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

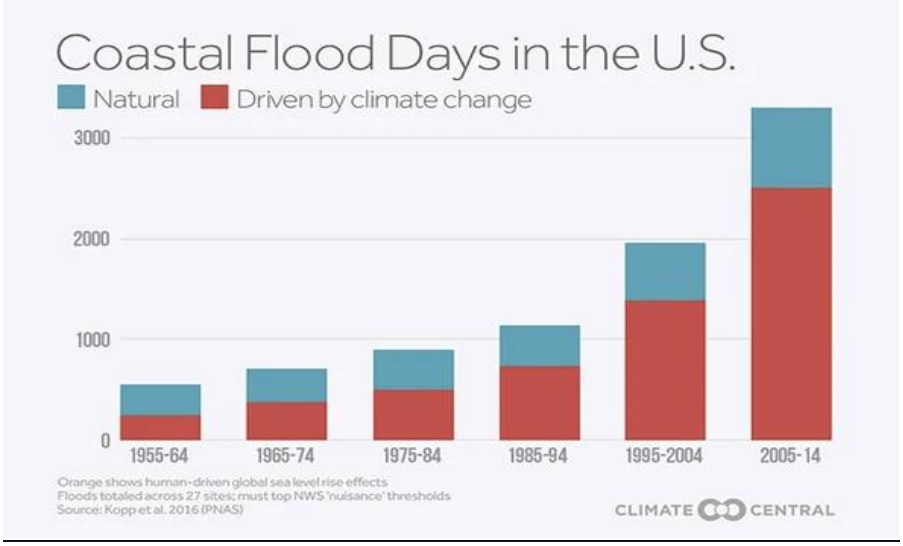
- Disruption of Breeding and Nesting Sites: Flooding can destroy the breeding and nesting sites for birds, sea turtles, and other species
- Erosion and Coastal Land Loss: Coastal flooding can also cause erosion at times, leading to the loss of coastal land
- Vegetation and species loss due to saltwater 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

How does Climate Change impact Coastal Flooding?

Findings based on Coastal DEM, a US-based climate research and communications organisation, have projected that 36 million people in India could face annual coastal flooding by 2050 if global CO2 emissions are not cut drastically. [xi] Climate change can worsen the problem that the coastal areas already face. 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 gas and become more acidic. This rising acidity can have significant impacts on coastal and marine ecosystems. [xii] There have been evidences of extreme events and disasters linked to climate change.

- **Sea Level Rise**: As per IPCC's Sixth Assessment Report (AR6), the mean rate of sea level rise stood at 1.3 [0.6 to 2.1] mm per year from 1901 to 1971. It then rose to 1.9 [0.8 to 2.9] mm per year from 1971 to 2006, and subsequently escalated to 3.7 [3.2 to 4.2] mm per year from 2006 to 2018, with a high level of confidence. [xiii] In the US, coastal Louisiana has seen its relative sea level rise by eight inches or more in the last 50 years, which is about twice the global rate. [xvi] Tanzania and Ghana in African subcontinent have reported severe impacts of climate change on the coasts through rain-induced flooding and sea-level rise in recent times. [xv]
- **Increased Storm Surges:** An increase in events like storm surges can temporarily increase sea levels and higher water levels along coastlines, causing coastal flooding. A global flood database based on in situ measurement and satellite remote-sensing during 1985–2015 shows that floods have increased 4-fold and 2.5-fold in the tropics and northern mid-latitudes, respectively. [xvi]
- **Changes in Precipitation Patterns**: Climate change can lead to heavy rainfall in some areas and drought in some. In places where there is heavy rainfall accompanied by storm surge, there can be occurrence of coastal floods. The sixth assessment report on IPCC confirms that precipitation will increase over much of Asia (high to medium confidence).[xvii] An example of this is a series of recent storms in the United Kingdom that have led to severe flooding, with the equivalent of one month of rain in 48 hours in some locations, according to reports. [xviii]
- **Coastal Erosion and Land Loss:** Rising sea levels and intense storms can accelerate erosion in coastal areas. Eroded shorelines are more vulnerable to flooding when coupled with the destruction of natural barriers like vegetation.
- **Melting of Glacier Lakes and Polar Ice:** There is a worldwide growth in the number, total area and total volume of glacial lakes by around 50% between 1990 and 2018 due to the global increase in glacier melt rate. [xix] The melting of glaciers and polar ice contributes to rising sea levels. This rising sea level can exacerbate the problem of coastal flooding.

Figure 2: Graph showing increasing trend in coastal flood in the US across different time frames



Source: https://www.scientificamerican.com/article/new-data-reveal-stunning-acceleration-of-sea-level-rise/

Adaptation Strategies for Coastal Flooding

Community Level

- Adoption of nature-based solutions such as restoring wetlands, creating oyster reefs, and planting vegetation to mitigate flooding impacts [xx]
- 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 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 developed 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]

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