Climate Action in Cities
CoCHAP

Coastal Cities Resilience and Extreme Heat Action Project

Coastal Hazards Fact Sheets

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Coastal Flooding in Cities
Coastal Landslides in Cities

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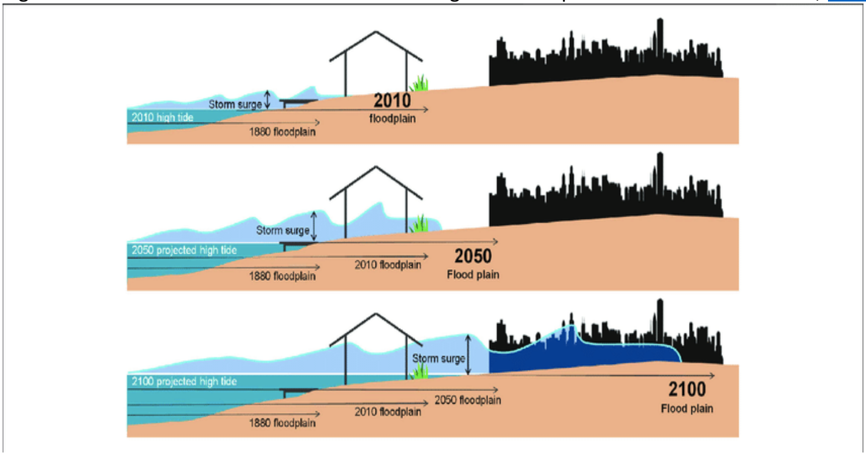
Coastal Flooding in Cities

What is Coastal Flooding?

Coastal flooding 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.

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



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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.

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 (IPCC, 2021). 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 (CO_2) are causing the oceans to absorb more CO_2 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

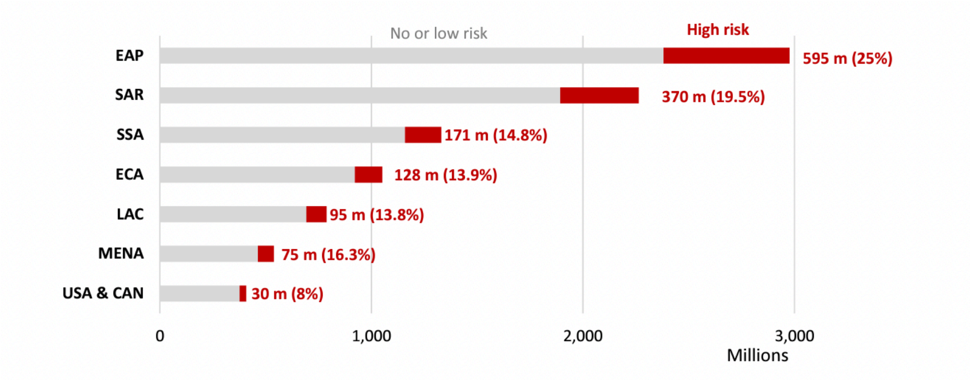
- Population Displacement: Due to impacts on infrastructures and utilities caused by the floods, communities can be displaced temporarily to safer areas. Low income and marginalized communities are often less able to recover and more likely to be displaced.
- Disruption in Livelihoods: Coastal communities 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]

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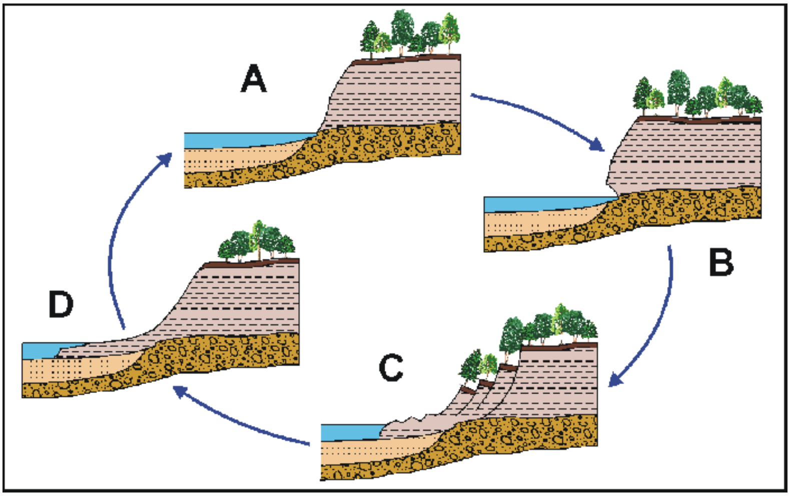
Coastal Landslides in Cities

What is Coastal Landslide?

The mass movement of materials like soil, rocks and debris downhill due to gravity is called a landslide.[i] This movement is often accompanied by water when the materials are saturated. When the stability of the mass of material is reduced due to water infiltration, removal of vegetation, or removal of material and the land mass can no longer resist the force of gravity, landslides can occur.[ii] The landslides can occur rapidly or gradually depending on the type of material, the cause of the instability, and steepness of the slope.

The development of coastal landslides can be associated with different processes and is illustrated in Figure 1. Sea level is gradually rising along coastal areas. This increase in sea level enables waves to erode beaches and flats at the base of coastal bluffs (cliffs) (Fig. 1A). Erosion removes material from the base of a coastal bluff, causing the bluff face to become steeper (Fig. 1B). The sediments at the base of the bluff help to stabilize it, and when these sediments are removed, the bluff becomes destabilized. At this point, only the strength of the bluff material itself prevents collapse. (Fig. 1C).

Figure 2: Figure showing the possible cycle of a coastal landslide, Source



Landslides can have a devastating impact, causing loss of life, destruction of infrastructure and housing stock, and blockage of critical transport routes. (IPCC, 2021, AR6, WG1, Chapter 12).

An estimated 4.8 million people were affected between 1998 and 2017, and more than 18,000 deaths were reported due to landslides (not restricted to coastal landslides).iii It has been found that landslide impacts are more severe in lower income countries, where between 1950 and 2011, debris flows killed an average of 23 people per event in developing countries, compared to 6 fatalities per flow in higher income countries.iv

Causes of Coastal Landslide

Coastal landslides are a result of a complex interplay between different factors and often a consequence of coastal erosion. Natural forces contributing to landslides include earthquakes and heavy rainfall, which are sometimes compounded by human activities such as construction and deforestation or other land cover change. Sea level rise exacerbates coastal erosion, weakening coastal cliffs and increasing instability. Geological factors, including rock and soil composition and weathering, further influence the susceptibility of coastal areas to landslides.

Natural Factors

- Wave Action: The intensity and frequency of waves hitting coastal cliffs can erode and weaken them over time, leading to instability and potential collapse.
- Heavy Rainfall: Excessive rainfall can saturate soils and rocks, reducing stability , and leading to landslides.
- Geological Factors: The occurrence of landslides is highly related to the type, composition, and stability of rocks and soils of the area. Easily eroded rock or mixed material are more likely to result in landslides than more resistant and cohesive rocky cliffs. Earthquakes: Natural factors like earthquakes also cause landslides by disrupting slope stability sufficiently to precipitate a landslide.

Anthropogenic Factors

- Human Activities: Human activities like urbanization, construction and infrastructure development, deforestation, mining, etc., can disturb the natural balance and destabilize the land, making it prone to landslides.
-

How does Climate Change impact Coastal Landslide?

Climate change will affect the stability of natural and engineered slopes and have an impact on landslides, however the nature, extent, magnitude and direction of changes in the stability conditions and in the location, number, intensity of landslides in response to the projected climate changes is less clear[v].

- Increased Precipitation: Climate change can lead to heavy rainfall in some areas and drought in some. Heavy rainfall can destabilize coastal cliffs or steep slopes as well as produce flooding which can rapidly erode material resulting in landslides. During strong storm events, storm surge can combine with heavy rainfall to further increase landslide risk. The sixth assessment report on IPCC confirms that precipitation will increase over much of Asia (high to medium confidence).[vi]
- Increased coastal erosion: Erosion makes the land surface weaker and destabilises it, making it more prone to landslides.[vii]
- Sea Level Rise: As sea levels rise, the base of coastal slopes is exposed to higher water levels. The constant action of waves, currents, and tides can erode and undercut the bottom of these slopes, triggering landslides.[viii]
- Thawing Permafrost: Thawing permafrost due to higher temperatures can destabilize coastal slopes in Arctic and subarctic regions. Permafrost acts as a natural stabilizer, and when it melts, it can lead to increased landslides along coasts. [ix]
- Extreme Heat Events: When extreme heat events occur, the land becomes dry, and together with excessive rainfall , the land can become unstable as it cannot hold excess water. The extreme heatwave caused landslides along the Jurassic coast of the beach in the UK in August 2022. The heat caused the rocks to expand, disturbing the balance and causing a landslide.[x]
- Human Development and land use change: Human activities like construction, and infrastructure development can degrade natural coastal stability and increase landslide potential.[xi]
- Land cover change: Vegetation plays a crucial role in slope stability by anchoring soil and rock masses, reducing erosion, and absorbing rainfall.

Changes in vegetation cover due to factors such as deforestation, forest fires, and invasive species can weaken slope stability and increase the susceptibility of coastal areas to landslides.

How does Coastal Landslide affect city systems?

Physical Impacts

- Loss of Critical Infrastructure: Landslides can damage or destroy critical infrastructure such as hospitals, schools, and communication networks, disrupting essential services and hindering recovery efforts. [xii] [xiii]
- Roads and Transportation Networks: Landslides can affect connectivity and cause disruptions in roads, bridges, and other transportation infrastructure; roads near eroding coastlines may become unstable or collapse.
- Utilities, Water Supplies and Sewage Systems: It can disrupt essential services like water, gas, sewage and power lines.
- Buildings and Residential Areas: Landslides causes the collapse or structural damage to buildings and houses.
- Environmental Degradation: Coastal landslides can lead to environmental degradation, including soil erosion, sedimentation of water bodies, and degradation of coastal ecosystems.

Social Impacts

In July 2021, a coastal landslide occurred in Atami, a city southwest of Tokyo. The landslide caused 80 people to be trapped and missing from a torrent of mud, trees and rocks ripped, killing at least four people.[xiv] The disaster led to evacuations, displacing residents, and disrupting their lives. The incident highlighted the vulnerability of communities built on steep slopes near the coast.

- *Loss of Life and Injury:* The collapse of land can result in human fatalities and injuries.
- *Displacement and Relocation:* Due to the occurrence of landslides, communities of coastal land may be forced to relocate to safer areas, causing disruption in daily life and adding mental and emotional stress.
- *Livelihood Threats:* The livelihood of coastal communities relying heavily on agriculture and forest areas can be impacted.
- *Community Disruption and Social Inequity*: Displacement can fragment communities and cause social inequity as they are forced to start their lives elsewhere.

Ecosystem Disruption

In 2016, Hurricane Matthew triggered a coastal landslide in the city of Baracoa, Cuba. This event resulted in habitat destruction, particularly affecting coastal vegetation and mangroves.[xv] In 2017, a large coastal landslide occurred in Tokyo Bay, Japan. The landslide destroyed coastal defense structures, infrastructure, and habitats. This event highlighted the vulnerability of coastal ecosystems to rapid changes caused by landslides, potentially leading to shifts in species distribution and overall ecosystem health.[xvi]

- Habitat Destruction: Coastal erosion results in alteration and loss of vegetation, soil, and other physical features. Trees and plants are uprooted, soil is displaced, and rock debris can cover the ground, altering the landscape and causing disruption in species habiting the area.
- Erosion and Sedimentation: The movement of soil and debris during a landslide can lead to soil erosion and sedimentation in nearby water bodies.
- Water Pollution: Due to erosion and sedimentation, landslides can introduce pollutants from the eroded soil and debris into rivers, lakes, and coastal waters. This pollution can harm aquatic life and affect marine ecosystems.
- Altered Coastal Dynamics: Changes in coastal geomorphology due to coastal erosion can affect the breeding and nesting grounds of species like turtles and shoreline birds.
- Loss of Biodiversity: Alteration in the habitat of plant and animal species can result in the loss of keystone species
- Carbon Release: Landslides can release carbon stored in vegetation and soils, contributing to greenhouse gas emissions and climate change.

Figure 2: Landslide causing a 150ft section of Highway 1 to wash away into the sea. Source

Adaptation Strategies for Coastal Landslide

Community Level

- Planting and restoring native vegetation in slopes, can help bind soil together and reduce erosion.[xvii]
- Build barrier walls along the slopes of the hills to block the debris of the landslide falling onto the roads and houses.[xviii]
- Following landslides, timely stabilization of affected sites can help reduce sedimentation of streams, prevent further landslides and mudflows, and re-establish the livelihoods of local communities.[xix]
- Engage community members to map areas with a high landslide risk and encourage vulnerable communities to plan relocation.
- Monitor and research landslide patterns, frequency, and the impacts on lives and property.
- Community engagement by involving local communities in the planning and implementation of conservation efforts and raising awareness about the risks of coastal landslides
- Educate and create awareness among local communities about landslide risks, their causes, and the importance of adaptation through community workshops, training, information campaigns, and programs in schools and communities
- Collaboration and networking through combined workshops and engagements by bringing in residents, technical experts, environmental experts, businesses and local leaders, local and municipal government bodies together for consultation on landslide risk management.
- Establish early warning systems to monitor and create communication systems about landslides to alert residents to potential threats.[xx]

Municipal/Government Level

- Application of slope stabilization techniques or solutions like retaining walls, slope terracing, soil reinforcement through methods like geotextiles and retaining grids to stabilize slopes and prevent landslides.[xxi]
- Initiate shifts in land use policies demarcating certain areas as ‘no development zones and construction restricted zones.[xxii]
- Establish proper drainage systems to divert water away from slopes to prevent accumulation of excess water in the soil[xxiii]

- Elevate buildings and infrastructure and implement coastal setbacks for communities that are at risk of being severely affected by both landslides and rising sea levels.[xxiv]
- Strengthening and proper planning of road and transportation, water supply and sewage systems in case of emergencies in landslide prone areas
- Develop and enforce land use plans and zoning regulations that restrict construction in high-risk landslide areas. This can help prevent new development in vulnerable zones and reduce the potential impacts of landslides on communities.[xxv]
- Fund research and innovation initiatives aimed at developing new landslide adaptation technologies, materials, and strategies.
- Participate in international agreements and conventions that address coastal landslide risk, promoting cooperation and shared knowledge.

Case Examples

Case Example 1
The area between Tijuana, Mexico and San Diego, California, faced landslide challenges due to its location on steep coastal land. Their proactive collaboration led to successful coastal landslide adaptation measures. The joint effort of both cities included conducting geotechnical assessments to identify landslide-prone areas, establishing early warning systems, improved data sharing and communication, and adequate drainage systems and slope stabilization measures that successfully significantly reduce the risk of coastal landslides, protecting communities.[xxvi]

Case Example 2
Mumbai, located along the Arabian Sea coastline, has made some progress in reducing coastal landslide risks. The city faced landslide challenges due to rapid urbanization, hilly terrain, and monsoon rains. With the combination of scientific assessments like landslide vulnerability assessment, infrastructure improvements like applying slope stabilization measures and drainage infrastructures, community engagement, and disaster preparedness, the city successfully reduced the risk and impact of coastal landslides.[xxvii]

Case Example 3
The Hurricane Maria struck Puerto Rico in 2017 that triggered over 70,000 landslides across the island. These landslides disrupted transportation routes, toppled homes from steep hillsides, and resulted in both direct and indirect loss

of life. The USGS led the efforts to produce landslide hazard maps for the main island of Puerto Rico following Hurricane Maria through the Puerto Rico Landslide Hazard Mitigation Project. The project aims to address the pressing threat of landslides on the island through comprehensive risk mapping. infrastructure improvements, and community engagement. The maps are used by planners for land use decisions and emergency managers for hazard mitigation plans. To reduce loss from future landslides, the USGS and the University of Puerto Rico-Mayagüez instrumented 15 slopes across the main island and share near real-time data with emergency managers and the public[xxviii].

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