Climate Action in Cities
CoCHAP

Coastal Cities Resilience and Extreme Heat Action Project

Coastal Hazards in Cities Fact Sheets #3

Landslides

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Coastal Landslides in Cities

What is Coastal Landslide?

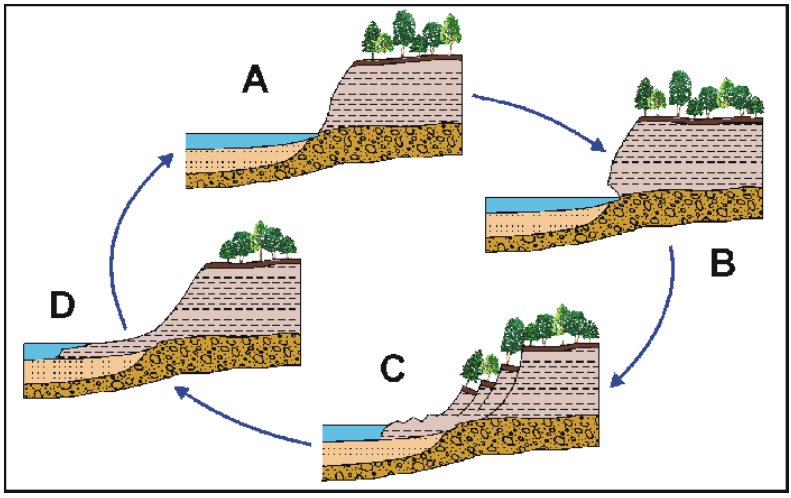
The mass movement of materials like soil, rocks and debris downhill due to gravity is called a landslide[1].[i] This movement is often accompanied by water when the materials are saturated. When the stability of the mass of material is reduced due to water infiltration, removal of vegetation, or removal 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).

Landslides can have a devastating impact, causing loss of life, destruction of infrastructure and housing stock, and blockage of critical transport routes. [iii]

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



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).iv 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.[v]

Causes of Coastal Landslide

Coastal landslides are a result of a complex interplay between different factors and often a consequence of coastal erosion. 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.
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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[vi].

- 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).[vii]
- Increased coastal erosion: Erosion makes the land surface weaker and destabilises it, making it more prone to landslides.[viii]
- 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.[ix]
- 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. [x]
- 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.[xi]

- Human Development and land use change: Human activities like construction, and infrastructure development can degrade natural coastal stability and increase landslide potential.[xii]
- 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. [xiii] [xiv]
- 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.[xv] 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.[xvi] 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.[xvii]

- 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.[xviii]
- Build barrier walls along the slopes of the hills to block the debris of the landslide falling onto the roads and houses.[xix]
- 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.[xx]
- 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.[xxi]

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.[xxii]
- Initiate shifts in land use policies demarcating certain areas as 'no development zones and construction restricted zones.[xxiii]
- Establish proper drainage systems to divert water away from slopes to prevent accumulation of excess water in the soil[xxiv]
- 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.[xxv]
- 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.[xxvi]
- 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.[xxvii]

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.[xxviii]

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[xxix].

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