

COASTAL EROSION

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Summary

Almost all of the world's shorelines are retreating in a landward direction—a process called shoreline erosion. Sea level rise and the reduction of sand supply to the shoreline by damming of rivers, armoring of shorelines and the dredging of navigation channels are among the major causes of shoreline retreat. As sea levels continue to rise, sometimes enhanced by subsidence caused by oil and water extraction, global erosion rates should increase in coming decades. Three response alternatives are available to "solve" the erosion problem. These are construction of seawalls and other engineering structures, beach nourishment and relocation or abandonment of buildings. No matter what path is chosen, response to the erosion problem is costly.

1. Introduction

Coastal erosion is a major problem for developed shorelines everywhere in the world. Such erosion is regarded as a coastal hazard and is a common focus of local and national coastal management. It is essential to consider the different types of coasts separately when studying rates and mechanics of erosion.

The problem is truly global in scope. The coastal erosion crisis is human-induced in one sense, because if no one lived near the shore there would be no problem. Shorelines may be retreating and land may be lost, but in many countries this is acceptable because stopping erosion is not economically feasible. Once buildings line a shoreline, coastal erosion becomes a coastal erosion problem.

Prevention of land loss in countries such as Japan and Taiwan, where land area is at a premium, is a high priority, and massive structures are routinely built and maintained to hold back the sea, even in undeveloped areas. In USA many shorelines are lined with buildings that were constructed in spite of well-documented, significant erosion rates. When buildings are eventually threatened by erosion, attempts to stabilize the shoreline often damage the beaches, so the conflict amounts to a fundamental question. Which should we save, buildings or beaches?

Shoreline erosion is best-termed shoreline retreat. The beach, the most visible and valuable part of most shorelines, is not really eroding, but is simply changing its position in space. However, the term erosion is deeply engrained in the scientific literature and in the media, so we will use the term erosion to describe the process, which moves shorelines in a landward direction. In addition, it is important to note that coastal erosion in the natural system does not damage recreational beaches.

Rates of erosion vary widely and some sandy shorelines are accreting. On sandy (as opposed to rocky) shorelines, retreat rates of 1 m, plus or minus 0.5 m, per year are common. The largest remaining barrier island in Taiwan (Wai Sun Ding) is eroding at up to 75 m per year while those on the barrier islands of the Mekong Delta in Vietnam are building seaward. Shorelines in front of glacial sandurs in Iceland are advancing at 4 m per year.

However, probably 80 to 85% of the world's shorelines are retreating. Some shorelines retreat at a steady rate such as the 2 m per year in South Nags Head, NC. Others such as some rocky coasts are stable for years and erode only during the largest storms. Every imaginable scenario between steady and sporadic erosion rates occurs somewhere.

2. Causes of Erosion

2.1. Sea Level Rise

Causes of erosion are many and complex. One of the most widely publicized and perhaps the least understood is relative sea level rise. It is very difficult to separate and quantify the impact of sea level rise on shorelines. The extent of erosion also depends on the size and the degree of consolidation of the material at the shoreline, wave energy, frequency of storms, the type of shoreline i.e. barrier island versus sand flat (versus rocky) and the slope of the surface across which the shoreline is retreating. Some argue that sea level rise is not responsible for any portion of the current erosion rates but this is clearly a minority view.

The Bruun Rule is often touted as a quantitative approach to predict the amount of shoreline movement caused by a given sea level rise. It is virtually the only model that

makes such a claim but it is doubtful that it works. The rule does not take into account loss of sand onshore or offshore, the slope of the upland surface over which the shoreline must move, and the rule assumes a beach/shoreface system of unconsolidated sand, uncomplicated by rock layers. Mathematically the rule assumes that the rate of shoreface retreat depends on the slope of the shoreface or lower beach but no such relationship is known.

Evidence that sea level rise is impacting shoreline retreat at present is reflected in the behavior of undeveloped barrier islands which, on both the Atlantic and Gulf coasts of USA, are eroding on both the open-ocean and lagoon sides. This island narrowing can be interpreted as a response to sea level rise because barrier islands can migrate in a rising sea, but to do so effectively the islands must be narrow enough to be completely overwashed in storms. Clearly the islands could not have been narrowing for long or they would not exist. Something has recently changed and most likely it is the commencement of a global sea level rise within the last hundred years.

The rise in sea level (usually determined by tide records) varies from place to place. Along the North American East Coast, about 1 ft. per century (0.3 cm/yr.) is a common figure. The Mississippi Delta shoreline may be dropping at 4 times that rate (1 cm/yr.), and along portions of the Pacific Coast of Colombia, sea level may be locally rising at 10 ft. per century (2.5 cm/yr.). On the other hand, in glacial rebound areas, such as Juneau, Alaska, sea level is dropping in response to the retreat of the Mendenhall Glacier.

The causes of the current sea level rise are not completely agreed upon. Certainly a combination of melting of glaciers in lower latitudes (alpine glaciers), subsidence of continental shelves due to the recent arrival of the water mass after the last glacial epoch, and thermal expansion of the surface layers of the oceans due to atmospheric heating, all contribute to the rise. Human induced subsidence is locally very important such as on the Niger Delta in West Africa where extraction of both oil and water is causing the land to sink. Up to 2 m of local subsidence has occurred along the shores of Galveston Bay near Houston, Texas, due to extraction of water for use by oil refineries. Extraction of natural gas, before it was halted, caused sinking of the Dutch barrier islands at a significant rate.

Huge potential for sea level rise resides in the West Antarctic ice sheet, especially the portion that resides on the continental shelf. The ice sheet is partially floating and partially grounded, and if significant breakup occurs, a maximum of 6 m sea level rise is a possibility.

The consequences of sea level rise include flooding, salt-water intrusion, and increased rates of shoreline retreat. Flooding which also involves shoreline retreat, will be most important in areas of very low land slope (1:10 000) such as that of northeastern North Carolina and the Mississippi Delta. At risk on the delta are many square miles of wetlands. The delta of the Ganges-Brahmaputra rivers that makes up most of the country of Bangladesh is a particularly susceptible area. What makes the Bangladesh situation critical is the huge population of fishers and farmers living on the lower delta. Sea level rise may cause a huge loss of land and wetlands on the Mississippi Delta, but

unlike in Bangladesh, only a small number of people are threatened.

The effects of saltwater intrusion can be seen along the margins of Pamlico Sound, North Carolina, where the mainland shoreline is rimmed by dead and dying trees. Often the immediate cause of vegetative changes is the forcing up of the fresh water table ahead of the invading, rising seawater.

Shoreline erosion along all types of shorelines is occurring even where sufficient elevation and steepness are present to avoid simple inundation. In such cases, which make up most of the world's shorelines, the impact of sea level rise on coastal retreat can be viewed as a process of raising the base level of storm waves, causing incremental landward advance of wave-caused erosion.

The direct role of humans in causing global sea level rise is widely assumed to be global production of excess CO₂ causing the Earth's atmosphere to act like a greenhouse and to heat up. Over the past two decades a number of studies have predicted a eustatic sea level rise due to the greenhouse effect. The models used to predict the relationship between global warming and sea level rise are fraught with many unknowns and cannot be viewed as definitive predictions. The models' predicted sea level rises range from 0.5 to 2 m by the year 2100. If the higher figure is nearly correct, our society will probably not be concerned with seashore recreational areas on barrier islands. Rather concern will be focused on the need to preserve major coastal cities! The lower figure will generate and maintain a perceived chronic coastal erosion problem that will magnify the societal debate over beaches vs. buildings.

2.2. Sand Supply

Each shoreline reach has a unique combination of sand sources. The most important ones are rivers, eroding cliffs adjacent to the beaches, and the adjacent continental shelf. There are a number of local sources of sediment for shorelines as well. Longshore transport of sand from adjacent beaches is often very important. Calcium carbonate in the form of tests and shells produced by local marine organisms and pushed ashore by wave activity is a major component of many shorelines in warm climates and where dilution by local rivers is unimportant. Examples of such a calcareous sand supply include parts of the Hawaiian Islands, Puerto Rico and other Caribbean Islands, and the Yucatan Peninsula in Mexico. In contrast, along the tropical Pacific coast of Colombia, dilution of calcareous skeletal fragments by river sediment flowing from the nearby Andes Mountains is extreme and produces a shoreline sediment with little calcium carbonate content. Along the Abu Dhabi barrier island shoreline, oolites produced by inorganic precipitation in ebb tidal delta shoals at inlets provide a constant supply of CaCO₃ to local beaches.

The sediment contribution of the continental shelf is provided by the onshore transport of fair weather waves. In most sediment budget analyses the continental shelf contribution is counted as the amount of sediment not accounted for from other sources. Different sources of sediment may provide material of widely varying grain size. Eroding drumlins in New England will release a wide range of material from boulders to sand as will an eroding coral reef. Eroding dunes on barrier islands, on the other

hand, will release well-sorted, fine-grained sand.

By far the most important impact on sediment supply leading to coastal erosion is that of humans. Such interference with the flow of coastal materials has increased dramatically in recent decades, leading increasingly, in wealthy countries, to artificial replacement of beach sand by pumping or trucking "new" sand to the beaches, a process called beachfill, beach nourishment or beach replenishment.

On a regional scale, the damming of rivers is the greatest cause of coastal erosion by humans. On the US East Coast and other estuarine coasts where the river valleys have recently been flooded by the Holocene sea level rise, rivers dump their loads at the heads of the estuaries far from the shoreline. In these situations, cut-off of the sand supply by dams is of no consequence. But where rivers empty directly into the sea without a large estuary as a sediment sink, as on the US Pacific coast, the cut off of sediment by dams leads directly to coastal erosion. Mining of construction sand from beaches and in river mouths is another important cause of erosion.

This problem is particularly severe on deltas. The Nile, Niger and Mississippi deltas exhibit extensive land loss and coastal erosion directly attributable to upstream dams. On the Ganges-Brahmaputra delta, diking of delta lobes to provide agricultural areas, prevents annual buildup of sediment necessary to counteract natural subsidence due to compaction of muds. Eventually on perhaps a scale of several decades, this can lead to permanent land loss when dikes are inevitably removed in major floods.

On the lower Mississippi Delta, artificial levee construction has prevented annual spillover of sediment-laden waters, reducing the sediment supply to both marshes and beaches, leading to considerable land loss. It seems to be an inevitable result of human occupation of river flood plains and deltas, that sediment supply to the coast will be altered and reduced. Adding to the coastal sand supply problem is very widespread sand mining. No sand is cheaper and easier to obtain for the construction of buildings in the coastal zone than beach sand. Sand mining operations are deceptively small in scale.

Often this mining takes the form of a truck load here, a wagon load there, and even wheelbarrow loads of sand which, when totaled can amount to a large sand loss to beaches. Sand loss from beach mining occurs in all societies, but is a particular problem in developing countries. In Nigeria, mining of sand in lower river mouths is a problem leading to erosion. Sand accumulations on the up-drift sides of jetties are sometimes mined on a very large scale as in Portugal, but this is far less damaging to sand supplies than the removal of sand from natural beaches and river mouths.

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Biographical Sketches

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