EFFECTS OF SEA-LEVEL RISE ON COASTAL CITIES AND RESIDENTIAL AREAS

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Summary

The global sea-level rise projected to be between 14 cm and 80 cm by the end of the twenty-first century, especially where combined with local subsidence, may have serious effects on human societies in densely populated cities and residential areas that are located on coastal lowlands. Impacts expected from such a phenomenon are as follows (a) intensified flooding and submergence; (b) increased erosion of shorelines; (c) greater intrusion of saline waters into estuaries and coastal aquifers; and (d) drainage problems. Appropriate planning and action may minimize such adverse effects. Possible responses include the following (a) inaction, which implies no interference with nature; (b) accommodation, which means changing the way the land is used; (c) evacuation of the land as it becomes submerged; (d) holding the coastline using hard engineering structures or soft methods such as sediment replenishment; or (e) counterattack, which implies a combination of protection and reclamation measures. Anticipatory measures could minimize the forthcoming problems and lower the costs of mitigation measures. The concept of integrated coastal-zone management provides a good basis for an urban

policy taking into account the expected sea-level rise and setting up a program of action for a sustainable development.

1. Introduction

An increasing body of evidence suggests that, within the near future, global warming due to the greenhouse effect could lead to a substantial rise in sea level. As a consequence, since a large portion of the world's urban population lives in low-lying areas near the sea, such a phenomenon would have an important impact on human society. The expected eustatic or global sea-level rise is forecasted to be between 14 cm and 80 cm by the end of the twenty-first century, the best estimate being around 44 cm.

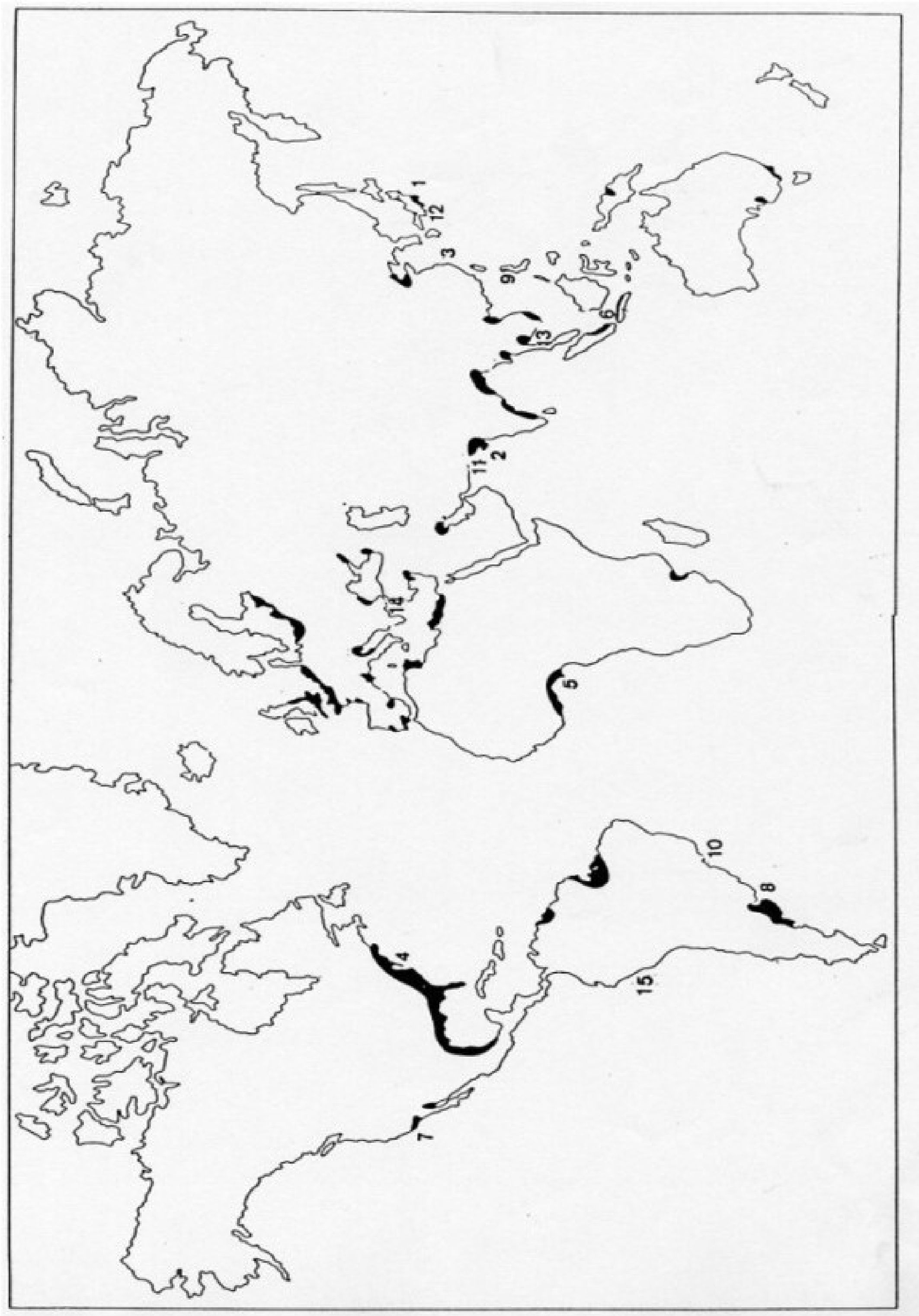

Figure 1. Areas vulnerable to the expected sea-level rise and coastal megacities include (a) Tokyo, (b) Bombay, (c) Shanghai, (d) New York, (e) Lagos, (f) Jakarta, (g) Los Angeles, (h) Buenos Aires, (i) Manila, (j) Rio de Janeiro, (k) Karachi, (l) Osaka, (m) Bangkok, (n) Istanbul, and (o) Lima.
(from Bird E.C.F. (1993). *Submerging coasts*, 184 pp. Chichester, West Sussex, UK: John Wiley and Sons Ltd. Reproduced with permission.)

Therefore, the present (2002) rate of mean sea-level rise of from 1 mm y^{-1} to 2 mm y^{-1} could amplify to a speed of 4 mm y^{-1} in the coming century. In that case, the vulnerability of coastal areas will be increased because sea-level rise will enhance the efficiency of natural hazards. Increase in mean surface temperature in the tropical oceans could also lead to greater frequency of hurricanes that already cause significant damage to property and human life. If sea-level rise may be compensated for, or even reversed on rapidly uplifting areas, such as the isostically emerging shorelines of Scandinavia and eastern Canada, it can be increased by natural subsidence. Accelerated subsidence in many low-lying urbanized coastal areas due to excessive withdrawal of water as well as oil or gas also promises to exacerbate the situation by amplifying the magnitude of sea-level rise locally. In such a situation, the combined global sea-level rise and continental subsidence will certainly have the greatest impact on human societies in the densely populated coastal cities and residential areas. What is already happening in diverse locations, such as Venice, Shanghai, and Bangkok, all sinking cities situated near a seashore, clearly shows the serious impacts to be expected from an accelerated sea-level rise. It also suggests the policy and the engineering responses that may be considered if the adverse effects of local sea-level rise are to be counteracted. From now on, it would be wise to revise current aims and attitudes in coastal development and management. As a general rule, planners and developers should be aware of the hazards threatening low-lying coastal areas, such as deltaic plains, lagoonal surroundings, and coral islands. Broadly speaking, coastal areas are experiencing a fast growth in population and a rapid trend of urbanization. Most of the present and projected megacities, defined as cities with a population exceeding 8 million people, are located in coastal settings where they are susceptible to the adverse impacts of an accelerated sea-level rise (Figure 1). Given the large scale of coastal urbanization and its expected rapid growth in developing countries during the next decades, this means that the problems related to the projected sea-level rise are a common concern that should be addressed in seaside planning, bearing in mind the concept of sustainable development.

2. Impacts of Sea-Level Rise on Coastal Urbanized Areas

The impacts of a more rapid pace of global sea-level rise which may affect developed low-lying coastal areas fall in four main categories: intensified flooding and submergence; increased erosion of shorelines; greater intrusion of saline waters into estuaries and coastal aquifers; and drainage problems.

2.1. Intensified Flooding

Large coastal urban centers located on low-lying coastal areas prone to flooding, such as estuaries and lagoon shores, deltaic plains, and salt marshes, are obviously vulnerable to sea-level rise. Initially, the coast may suffer episodic inundation, but later this may become permanent when vertical accretion is limited by lack of sediment input. High and low tide lines will advance landward, part of the present intertidal zone will become permanently submerged and, consequently, significant land loss is likely to occur. Estuaries will tend to enlarge, as well as coastal lagoons, as a result of the submergence of their shores. New lagoons may be formed by seawater incursion into coastal lowlands. A rising sea level is expected to cause extensive submergence of low-lying deltaic plains where there is no possibility of compensation through sediment accretion.

Such an adverse situation is due to a reduction of the sediment yield following the building of dams that impound sediment in reservoirs. Drowning is threatening urbanized areas that correspond to former salt marshes. Here, vertical accretion is obviously impeded and sea-level rise is enhanced by the natural compaction of peat under the weight of buildings. Such a phenomenon is already occurring in some districts of the city of Shanghai, China.

With higher sea level, more urban centers and residential areas are likely to be affected by storm surges, resulting in episodic or permanent inundation. Moreover, sea-level rise will induce a decrease of the return period of water levels associated with storm surges, even without considering any possible variation in storminess. For instance, it has been calculated that on the Ebro deltaic plain, in Spain, the water level of +1.40 m presently (2002) associated with a storm surge characterized by a return period of 75 y will have a return period of 7 y under a scenario with a sea-level rise of about 50 cm by the year 2100. On the central coast of the Netherlands, a 4 m surge is calculated to occur on average once in 250 y. If sea level were to rise by 1 m, a surge of only 3 m would be needed to reach the 4 m water level. Now the 3 m surge has a frequency of occurrence of approximately once in 50 y. Changes in storm frequency and possible modifications in storm tracks and tidal range associated with sea-level rise require revision of present surge recurrence curves.

2.2. Increased Erosion

Lateral erosion may be often the dominant mode of land loss when sea level is rising. Offshore sediment supply is depleted since the culmination of the postglacial transgression and fluvial sediment supply has been curtailed as a result of dam construction in recent times.

Figure 2. Beach erosion and encroaching sea on the deltaic coast of the Seman River, Albania

An accelerated sea-level rise combined with this low rate of sediment supply is likely to trigger erosion on shorelines that are presently stable or to enhance erosion on shorelines that are already retreating. As a matter of fact, coastal erosion is facilitated by a rising sea level that brings wave action to progressively higher levels and permits larger waves to reach and break upon the shore through deepening of nearshore waters. Erosion will increase further where the climatic changes that accompany the rising sea level lead to more frequent and severe storms, generating surges that will penetrate inland farther than they do now. Steep coasts cliffed into soft rocks and affected by high energy waves, as well as low coasts fringed by gravel or sand beaches, are likely to undergo accelerated erosion (Figure 2). Beach erosion is already prevalent on a global scale since more than 70% of the world's sandy shorelines are presently retreating, with only 10% are prograding and the remaining 20% stable. Coastal barriers that are already transgressive will continue to migrate inland and stationary barriers that prograded around the end of the postglacial transgression may become transgressive and thinning as a result of erosion along their seaward margin, with overtopping and landward-drifting dunes.

On coral reefs, small sandy islands of cays or motus type are also threatened by the projected sea-level rise (see *Effects of Sea-Level Rise on Coral Reefs*). Normally, coral reefs are capable through upward growth to keep pace with a rising sea level if they are healthy and not affected by pollution of coastal waters in the surroundings of developed areas. However, stressed, damaged, or unhealthy reefs may not be able to produce enough carbonate limestone to aggrade at the rate of sea-level rise and thus may drown. Also coral growth may be retarded or even impeded if sea surface temperature rises above 30 °C. Already, within the past few years, which were exceptionally warm, widespread severe coral bleaching and death episodes have occurred. If sea-surface temperatures continue to rise in the future, such bleaching events may become more persistent, inhibiting coral growth. Calcification of corals is also adversely affected by the reduction of the calcium carbonate content of surface seawater which is related to the rising atmospheric carbon dioxide. Together, these phenomena may lead to the drowning of reef flats. Yet coralline sandy islands, which are sometimes urbanized, as in the case of the south Pacific microstates such as Kiribati or Tuvalu, will be mainly vulnerable not because of the expected sea-level rise itself, but by erosion related to an increased frequency and severity of tropical storms and hurricanes due to a rise in atmospheric and sea temperatures.

Around the world, coastal recreation has become a major economic activity (see *Effects of Global Warming on Tourism*). Most coastal recreation centers are around beaches. Residential areas also line along receding cliffs. For example, in the United States, on the Atlantic and Gulf coast, barrier islands which are fragile landforms due to their low-lying nature and a shortage of sediment supply, are highly developed. They are both vulnerable to erosion and, in the case of beaches, to flooding during storms. In these regions, beachfront property has become some of the most valuable real estate in the country and indeed important cities, such as Atlantic City, Ocean City, Miami Beach, and Galveston have been built in unstable environments. Generally speaking, “cities on the beach" are directly threatened all over the world by the projected sea-level rise.

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Biographical Sketch

Roland P. PASKOFF was born in 1933. He is a French citizen, is married, and has two children. Currently he is professor emeritus of physical geography in the Department of Geography at Lumière Université, Lyon, France. His former positions have been at the University of Chile, Santiago (1962–

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