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CLIMATE CHANGE IN SOUTH AND SOUTH-EAST ASIA: SOME IMPLICATIONS FOR COASTAL AREAS

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Abstract

The impacts of climate change on coastal areas in South and South-East Asia could be severe. Assuming no adaptation and existing population, a one-meter rise in sea level could displace nearly 15 million, 7 million and at least 2 million people from their homes in Bangladesh, India and Indonesia, respectively. Millions of more people are threatened in Viet Nam. In view of the high probability of climate change, but the high uncertainty of its magnitude, adaptation to these threats requires a flexible and integrated approach. Continued investigation and implementation of no regret and low-cost anticipatory adaptation would be prudent.

KEYWORDS: *sea-level rise, tropical cyclones, subsidence, deltas, coastal wetlands, South and South-East Asia*

1. INTRODUCTION

South and South-East Asian countries with coastal areas have reason to feel threatened both physically and socioeconomically by climate change, particularly sea-level rise. The studies concerning the potential consequences of a one-meter rise in sea level for the low-lying deltaic plain of Bangladesh (Broadus *et al.*, 1986; Milliman *et al.*, 1989) were among the first analyses to draw attention to the serious and adverse consequences of sea-level rise and hence global climate change. Other countries in the region, particularly India, Viet Nam and China have similar heavily populated deltas which are at risk from sea-level rise (IPCC, 1990). The other countries of this region have large populations on coastal plains which are also at risk to sea-level rise. Furthermore, these countries have expanding populations and economies and further rapid development along the coast is to be expected (WCC'93, 1994). Without any adaptation, these trends would suggest significant outmigration from these vulnerable coastal areas with uncertain economic and social implications. Therefore, there are considerable benefits to planning future developments to minimize the adverse impacts of climate change, including sea-level rise.

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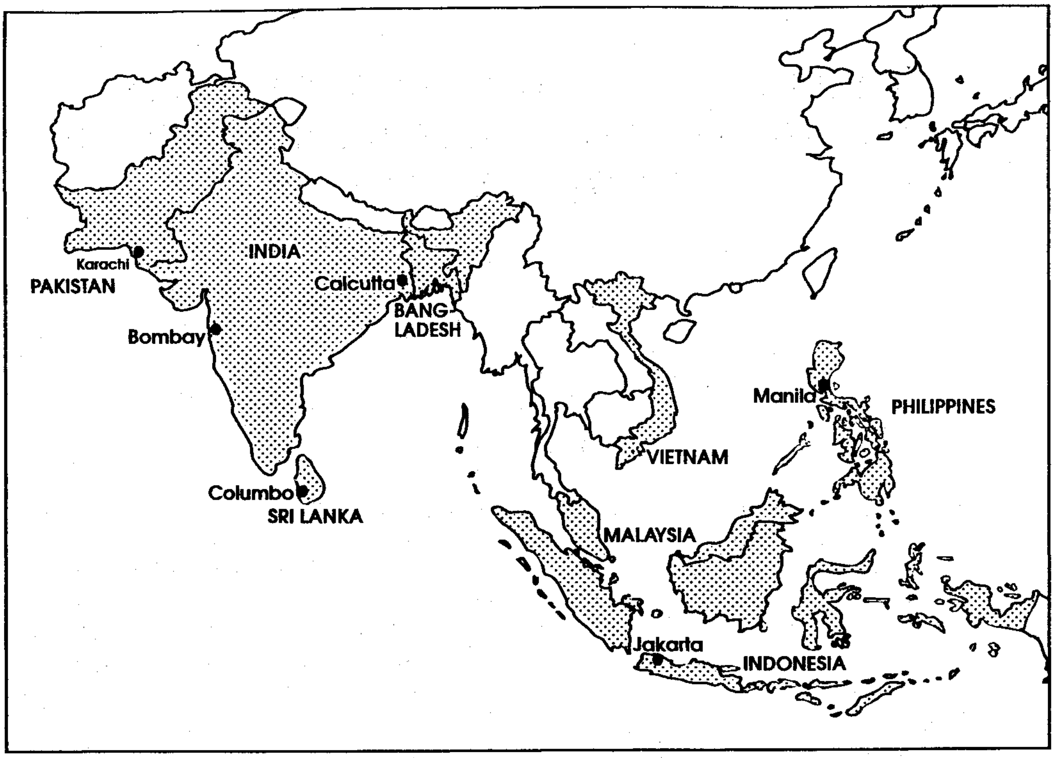

Figure 1. The study countries and selected coastal cities

From 1992 to 1994, the Asian Development Bank (ADB) funded a Regional Study of Global Environmental Issues in eight Asian-Pacific countries to assist the participating countries to build effective national strategies to respond to climate change, including coastal implications (Qureshi and Hobbie, 1994). National study teams were established to carry out these studies, and results have been presented for Bangladesh (Asaduzzaman, 1994), India (Pachauri, 1994), Indonesia (Sari, 1994), Malaysia (Chiang, 1994), Pakistan (Qutub, 1994), the Philippines (de Guzman, 1994), Sri Lanka (Gunatilleke, 1994) and Viet Nam (Sinh, 1994) (Figure 1). The data presented in this paper comes from the national study team reports, unless otherwise stated. This paper represents a brief synthesis and overview of the findings for coastal areas and builds on the recently published analysis of Topping *et al.*(1994). Simple aggregation is difficult because the studies differed in detailed methodology and many could not complete a national assessment with the limited time and funds available to them. Further, these studies should be seen as a beginning rather than an end.

When considering potential impacts of climate change, it is useful to consider *susceptibility*, or the likely physical and human changes without any human adaptation, and *vulnerability*, or the ability of society to cope with those changes (*cf.* The Common Methodology in IPCC, 1992). To illustrate these distinct, but related concepts, the Netherlands has a high susceptibility to accelerated sea-level rise because 10 million people already live below present sea level. However, it has a low vulnerability, except for coastal ecosystems, because Dutch society can easily adapt to such changes (*e.g.* Hillen and de Haan, 1993). Susceptibility is easier to determine than vulnerability and only qualitative and semi-quantitative statements about

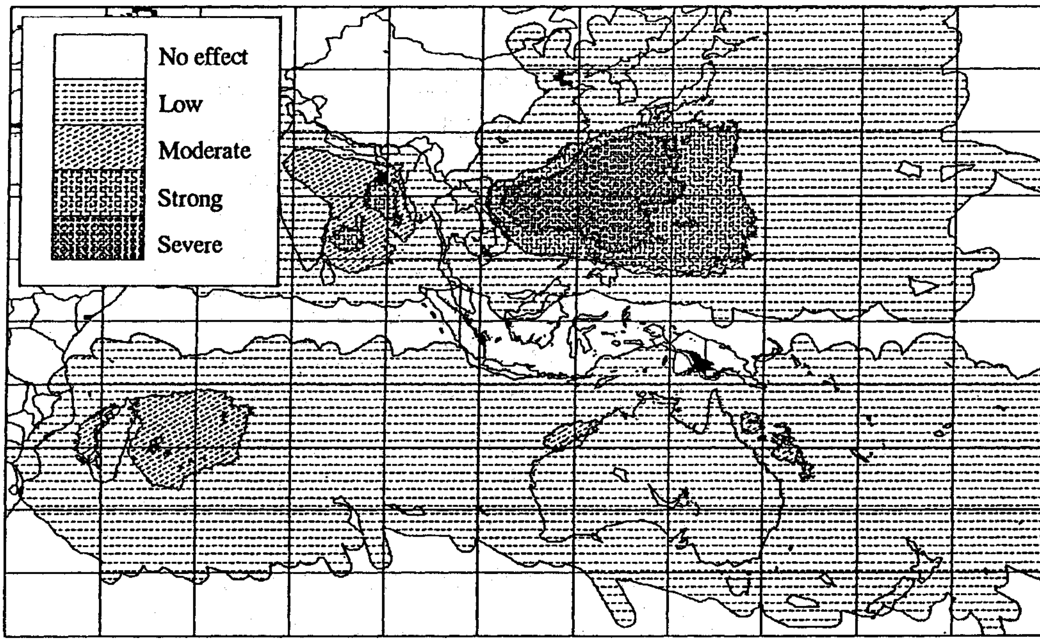

Figure 2. Distribution of the degree of cyclone intensity

vulnerability are possible based on the existing studies. It should be noted that increasing susceptibility translates into increasing vulnerability unless concurrent adaptive measures are undertaken.

2. EXISTING COASTAL PROBLEMS

The eight country studies all identified extensive existing coastal problems as shown below. These are significant in the present context because in all cases these problems will be exacerbated by the impacts of climate change.

2.1 Impacts of tropical cyclones

South and South-East Asia is a region where tropical cyclones are frequently generated causing significant adverse effects on the coastal societies: areas of existing cyclone genesis are shown in Figure 2. Of the nearly 1.9 million deaths associated with severe tropical cyclones over the past two centuries, about 800,000 (42%) have occurred in Bangladesh and over 500,000 (27%) have occurred in India (Table 1). As coastal populations grow, the likelihood of major fatalities increases, reinforcing the need for action to safeguard these vulnerable populations. Particularly in Bangladesh, improved ways to forecast storm surges (*e.g.*, Flather and Khandker, 1993) and protect the vulnerable population is an issue of high priority.

Table 1. Deaths associated with cyclone disasters (Adapted from Topping et al., 1991, with additional data from Pachauri, 1994)

Year	Location	Deaths
1970	Bangladesh	300,000
1937	India	300,000
1881	China	300,000
1923	Japan	250,000
1897	Bangladesh	175,000
1991	Bangladesh	138,000
1876	Bangladesh	100,000
1847	India	75,000
1864	India	50,000
1833	India	33,000
1822	Bangladesh	40,000
1780	Antilles	22,000
1839	India	20,000
1789	India	20,000
1965	Bangladesh	19,279
1963	Bangladesh	11,468
1876	Bangladesh	10,000
1977	India	8,547
1963	Cuba-Haiti	7,196
1900	Texas	6,000
1960	Bangladesh	5,149
1960	Japan	5,000
1969	India	1,000
TOTAL		1,896,639

2.2 Loss of coastal wetlands

Coastal wetlands, particularly mangroves, occur widely in the region (Table 2), particularly in deltaic settings and along low-energy coasts. They provide important resources to subsistence-based economies. Particularly, they provide nursery areas for most of the region's fisheries which in turn provide a large proportion of the region's animal protein. However, coastal wetlands appear to be under threat in all the study countries, largely due to direct reclamation which is often for aquaculture. In Bangladesh, extensive mangroves survive in

Table 2. Existing area of mangroves. (Source: National study team reports)

Country	Area (ha)	Comments
Bangladesh	577,285	The Sundarbans
India	424,000	
Indonesia	4,000,000	
Malaysia	636,000	
Philippines	38,000	500,000 ha existed in the 1920's
Sri Lanka	12,180	Incomplete inventory -- the study area comprised 18% of the coast
Viet Nam	200,000	Mekong delta contains 117,350 ha

the national preserve of the Sundarbans. In Malaysia, all extensive areas of mangroves could disappear before accelerated sea-level rise is manifest, just based on current reclamation plans. In the Philippines, only 38,000 hectares, of the 500,000 hectares of mangroves present in the 1920's remain today. Continuation of these trends will lead to significant changes to both coastal ecosystems and lifestyles for many coastal residents.

Therefore, it remains somewhat uncertain what area of coastal wetlands will survive to experience the adverse impacts of sea-level rise (*cf.* Hoozemans *et al.*, 1993; Nicholls and Leatherman, 1995a). The reclaimed areas remain susceptible to the impacts of sea-level rise, unless they are artificially raised.

2.3 Human modification of sediment budgets

Construction of upstream dams and mining of rivers for sand is reducing sediment input into the coastal sediment budget in many locations. This translates into coastal erosion. Such activities appear to be making a major contribution to beach erosion in both Sri Lanka and Malaysia, which conflicts with the growing importance of beach-based tourism in some of these areas.

Due to human modifications, many of the rivers flowing into deltaic areas are also carrying less water and sediment than in former times (*cf.* Milliman *et al.*, 1989; Nicholls and Leatherman, 1995a). An extreme example is the Indus delta in Pakistan, which has seen a reduction of sediment input to one-fifth of the values 50 years ago (Qutub, 1994). In unregulated catchments and deltas, sediment availability is a key element in delta maintenance: at equilibrium, deposition of sediment offsets local subsidence and maintains the land elevation (Boesch *et al.*, 1994). Human activities generally act to reduce sediment supplies within the catchment, primarily by the construction of dams, and within the delta by engineered flood control structures. Therefore, increased rates of subsidence (high rates of relative sea-level rise) are likely in many deltaic settings in the coming decades, a factor which needs to be evaluated more carefully.

2.4 Anthropogenic subsidence

Groundwater mining in recently-deposited sedimentary deposits can cause rapid and essentially irreversible land subsidence (Holzer, 1985). Many coastal cities in the study countries are built on such deposits. Any subsidence of coastal areas produces a local rise in relative sea level (the land falls relative to the sea). Given the positive correlation between population density and water demand, this problem is more likely to occur in densely populated areas. Parts of a number of cities in Asia, the so-called 'below-zero' cities, already require the protection of extensive systems of dikes and pumped drainage to prevent flooding and even total inundation, including Tokyo, Osaka, Shanghai (Wang *et al.*, 1995) and Taipei.

Jakarta in Indonesia is experiencing rapid subsidence: about 40 to 90 cm between 1978 and 1990 (Sari, 1994). If these trends continue land elevation in parts of Jakarta will drop over 3 meters by 2070, although this must be considered a very uncertain projection. Manila in the Philippines is also experiencing a relative rise in sea level of 1.4 cm/yr, largely due to rapid subsidence caused by excessive extraction of groundwater (de Guzman, 1994). Continued rapid urbanization throughout the region will maintain or even increase the tendency for groundwater extraction: the population of Jakarta and Metro Manila is projected to increase from 9.2 million and 8.8 million people in 1990 to 17.2 million and 16.1 million people in 2010, respectively (UN Population Division, 1993).

3. CLIMATE CHANGE AND COASTAL AREAS

3.1 Sea-level rise

Over the last century, global sea level appears to have risen about 1.8 mm/yr (Douglas, 1991). There is a wide consensus that global warming will lead to an accelerated rate of rise in sea level due to the melting of land-based ice and thermal expansion of sea water (Warrick and Oerlemans, 1990). However, the magnitude of that rise is subject to some uncertainty. Warrick and Oerlemans produced scenarios of a rise ranging from 0.3 to 1.1 m, with a best estimate of a 0.66-m rise by 2100. While revisions to these scenarios have been lower (Wigley and Raper, 1992; Warrick, 1993), a significant acceleration in sea-level rise is still forecast with a best estimate of about 0.5-m rise by 2100, while a rise of up to 1.0 m remains feasible.

In addition to global trends in sea level, it is vital to consider vertical land movement: a fall in land elevation due to subsidence exacerbates global sea-level rise and vice versa (Douglas, 1991; Nicholls and Leatherman, 1995b). The net change in sea level considering both land uplift/subsidence and global sea level is termed relative sea-level change. As the rate of land uplift/subsidence varies from place to place so does the rate of relative sea-level change and the highest rates of relative sea-level rise are expected in areas prone to subsidence. Therefore, if possible, global sea-level rise scenarios should be transformed into local relative sea-level rise scenarios (*e.g.*, see Sari, 1994; Wang *et al.*, 1995). In the ADB studies a range of global sea-level rise scenarios of up to 1-m by the year 2100 was utilized. In general, vertical land movements were not considered due to insufficient knowledge – identifying a data gap which urgently needs to be filled.

A rise in sea level has five major impacts which can be offset or augmented by other factors such as sediment supply: (1) land loss by inundation (or submergence beneath high tide); (2) land loss by erosion (or physical removal of sediment); (3) increased flooding and storm damage; (4) salinization of surface and ground waters; and (5) higher water tables (National Research Council, 1987).

3.2 Tropical cyclones

Given the large loss of life and destruction associated with tropical cyclones, changes in their strength and location raises strong concern in the region (McLean and Mimura, 1993). It has been argued that global warming could increase the frequency and number of these storms (Emmanuel, 1988), although Houghton *et al.* (1990) did not find the evidence compelling. Therefore, based on our present knowledge, only arbitrary scenarios of change can be constructed for the purposes of sensitivity analysis.

3.3 Enhanced precipitation events

Global climate model simulations of the enhanced greenhouse effect indicate the possibility of a decrease in the return period for heavy rainfall events (Gordon *et al.*, 1994; Whetton *et al.*, 1994). Simulations for South and South-East Asia suggest that heavy rainfall events with a 10-year return period under current conditions, may have a five-year or smaller return period under doubled CO2 conditions. This would intensify flooding, including low-lying coastal areas where the base level will be increasing due to sea-level rise. While more assessment of the practical importance of this general increase in rainfall intensity is required (Topping *et al.*, 1994), it suggests a need for increased drainage capacity, particularly in coastal areas.

4. IMPLICATIONS OF CLIMATE CHANGE

Given its greater certainty, the implications of sea-level rise is considered most here, with more limited discussion of the other aspects of climate change that have been raised.

4.1 Land loss and people displaced

The major problem which the national study teams considered was land loss due to sea-level rise and associated issues. Assuming no adaptation, estimated land loss and the present population of these areas are given in Table 3. For a one-meter rise in sea level, land loss in Bangladesh, India, Indonesia and Malaysia could be 29,846 km^2, 5,763 km^2, more than 34,000 km^2 and 7,000 km^2, respectively. In Viet Nam, 5,000 km^2 of land could be inundated in the Red River delta, while 15,000 to 20,000 km^2 of land is similarly threatened in the Mekong delta. Presently, these susceptible areas form the homes to millions of people, most notably in Bangladesh where nearly 15 million people could be displaced by a one-meter rise, whereas in Viet Nam the threatened population in the deltas is in the millions, but poorly quantified. In the Philippines, substantial populations appear susceptible to displacement. In terms of the relative size of the threatened area and population, Bangladesh and (more tentatively) Viet Nam appear to face larger problems than their neighbors. Much of the threatened land is in deltaic settings and as discussed earlier, these impacts could be exacerbated by human modifications to the sediment budgets of these areas.

Based on the national population trends, significant growth of these susceptible populations would be expected, but as climate change progressively degrades the environment in these coastal areas, migration of people away from the coast (environmental migrants – sensu Shurke [1993]). Therefore, the future population in these areas depends critically on the adaptation options selected.

Table 3. Land loss and existing population displaced for various sea-level rise (SLR) scenarios and no adaptation. n.a. – not available. (Source: National study team reports)

Country	SLR Scenario	Land Loss		People Displaced	
	(cm)	km^2	%	millions	%
Bangladesh	45	15,668	10.9	5.5	5.0
Bangladesh	100	29,846	20.7	14.8	13.5
India	100	5,763	0.4	7.1	0.8
Indonesia	60	34,000	1.9	2.0	1.1
Malaysia	100	7,000	2.1	>0.05	>0.3
Pakistan	200	1,700	0.2	n.a.	n.a
Viet Nam	90	>20,000	>6.1	n.a.	n.a.

4.2 Flooding

In addition to simple inundation, increased flooding of low-lying coastal areas is a major potential impact as a result of four interacting factors: (1) a likely rise in sea level; (2) a likely change in storm surge occurrence; (3) a likely change in peak flows in coastal rivers; and (4) a likely increase in the intensity of precipitation events. The interaction between these changes is important, but unfortunately, there are too many uncertainties to create meaningful scenarios which consider all four factors.

In Bangladesh, maximum surge heights of 4.8 + 1.0 meters (20-year return period) to 7.8 + 1.8 meters (100-year return period) already occur east of the main outlet of the Ganges-Brahmaputra-Meghna river (Asaduzzaman, 1994). Based on assumptions concerning propagation of these surges, over 12,000 km^2 of land is already at risk of flooding during cyclonic storms, including a high risk zone of 9,000 km^2 where the depth of flooding is likely to exceed 1 meter. The population of this high risk zone exceeded 5 million people in 1991. The high risk zone will expand as sea level rises, and the possible intensification of tropical cyclones raises further concern (Flather and Khandker, 1993). India and Viet Nam are similarly threatened. In the Red River delta, despite 700 km of sea and river mouth dikes, about 250,000 hectares and 2 million people are threatened by flooding (Sinh, 1994). In the Mekong River delta, the sea dike system is not complete and about 1,000,000 hectares of land are vulnerable to flooding. A 90-cm rise in sea level will raise flood heights up to 400 km upstream in the Mekong River and 200 km upstream in the Red River. This will impede the effectiveness of gravity-based drainage in both deltas and require that most of the drainage be carried out by pumps. In Karachi, increased flooding is threatened by a combination of more intense rainfall events and higher base levels due to sea-level rise (Qutub, 1994). Similar problems will probably be widespread in low-lying coastal areas in the region.

4.3 Agricultural impacts

Agriculture plays a major role in the economies of the countries of South and South-East Asia, generating 21% to 42% of GDP (Suppiah *et al.*, 1994). A significant proportion of this agriculture is practiced in susceptible coastal areas, particularly rice production in low-lying deltaic areas (*cf.* Hoozemans *et al.*, 1993). In addition to direct land loss, agricultural impacts will depend extensively on changing hydrological conditions, particularly salinization.

In Bangladesh, it is projected that a 45-cm rise in sea level will cause annual losses of over 2.6 million metric tons of rice (Asaduzzaman, 1994). A one-meter rise could cause losses of about 9.5 million tons of rice, or about 50% of potential production from the eight coastal districts which will experience total or partial inundation. In Indonesia, agriculture is concentrated along the coast and hence susceptible to sea-level rise (Sari, 1994). A reconnaissance estimate suggests that a 60-cm rise in sea level could inundate about 800,000 hectares of rice fields and about 1,000,000 hectares of marshlands currently used for tidal rice fields. In Malaysia, it is estimated that a one-meter rise in sea level could inundate 100,000 hectares (or 2%) of agricultural land (Chiang, 1994). Most of these agricultural areas are simple polders protected by coastal bunds: little impact would occur for rises up to 20 cm, above which significant impacts would occur. In Sri Lanka, saltwater intrusion is already affecting about 15,000 hectares of paddy fields in the Galle district (Gunatilleke, 1994), so this area is susceptible to accelerated sea-level rise. In Viet Nam, large areas of land would be affected by salinization in addition to land loss, this area amounting to over 2,000,000 hectares (Sinh, 1994). However, the potential losses in terms of rice production are uncertain.

4.4 Impacts on coastal aquaculture

Coastal aquaculture is widely practiced in the region and, as already noted, these areas have often been created by reclamation of coastal wetlands. Therefore, they are susceptible to sea-level rise. In Indonesia, brackish water shrimp and fish ponds are increasingly common on the coasts of West, Central and East Java, Aceh, and South Sulawesi (Sari, 1994). In addition to the effects of sea-level rise, higher temperatures will cause higher evaporation rates and hence higher salinities in the ponds, unless more fresh water can be added. Higher salinities will slow shrimp growth and raise mortality rates. It is tentatively estimated that a 60-cm rise in sea level could destroy 300,000 hectares of fish ponds without significant adaptation. Presently, these ponds generate an annual income of about U.S. $1 billion dollars.

4.5 Impacts on coastal ecosystems

While coastal wetlands are already declining due to direct human destruction and indirect affects such as a long-term decline in the sediment loads in rivers, any surviving wetlands seem almost universally vulnerable to accelerated sea-level rise (*cf.* Hoozemans *et al.*, 1993; Nicholls and Leatherman, 1995a). The increasingly intense utilization of land adjacent to these wetlands means that inland migration (conversion of low-lying upland areas to wetlands as sea levels rise) will be increasingly prevented by flood control structures.

One of the largest mangrove forests in the world, the Sundarbans presently covers about 5,800 km^2 in Bangladesh (Asaduzzaman, 1994) (and an additional area in West Bengal, India [Pachauri, 1994]). It is already threatened by increasing salinities due to upstream freshwater diversions for other uses. Given a 45-cm rise in sea level, it is estimated that 4,350 km^2 of mangroves would disappear and the surviving area would only contain salt-tolerant species, whereas given a 1-m rise it is predicted to be totally lost. In Indonesia, it is estimated that a 60-cm rise in sea level would destroy 1 million hectares of mangrove forests (or 25% of the existing area of mangroves) (Sari, 1994). In Malaysia, it is doubtful if any substantial areas of mangroves will survive to be inundated, based on existing trends (Chiang, 1994). Pakistan, has extensive areas of mangroves in the Indus delta which are already suffering from reduced sediment and freshwater input from the Indus (Qutub, 1994). Viet Nam has extensive areas of mangroves and swamps which are vulnerable to inundation (Sinh, 1994). Given a 90-cm rise in sea level, 250,000 hectares of about 400,000 hectares is likely to be lost.

Another possible impact of climate change on coastal ecosystems is more frequent coral bleaching due to higher sea temperatures. As tropical marine organisms typically live in habitats with temperatures close to their upper limit of tolerance, even a slight rise in water temperatures might have a grave effect on their vitality, growth and reproductivity rates. Coral bleaching is already a problem in Indonesia (Sari, 1994) having implications for biodiversity and many commercial fisheries (*cf.* Holligan and deBoois, 1993).

Therefore, the impacts of climate change on coastal ecosystems could have major impacts on coastal fisheries and the subsidence populations that they support. A better understanding of the implications of declining wetland area on fishery stocks is required. As studies in Louisiana demonstrate, the response of fishery stocks can be very non-linear, showing little change or even increased abundance prior to a rapid collapse (Browder *et al.*, 1989; Boesch *et al.*, 1994).

The ability of coastal ecosystems to respond to sea-level rise also needs to be measured more widely to better understand their potential for survival given accelerated sea-level rise on a meaningful scale for coastal management. It has been argued, based on studies in Bermuda, that any acceleration in sea level will cause massive losses of mangroves (Ellison and Stoddart, 1991; Ellison, 1993), but the widespread application of this conclusion has been challenged (Snedaker *et al.*, 1994). Asian field studies of mangrove response to sea-level rise would provide important data for improved modeling efforts in this regard.

4.6 Coastal erosion and impacts on coastal tourism

Coastal tourism is an important and expanding industry in the region, particularly in Sri Lanka, Malaysia and Indonesia. As most of these tourists come from outside the region, this constitutes an important contribution to the overseas earnings of these countries. At the same time, erosion of sandy coasts is reported widely in the region and this would be exacerbated by sea-level rise and more frequent or more powerful tropical cyclones.

In Malaysia, erosion is already up to 15 m/yr in some locations (Chiang, 1994). The national government has taken a national perspective of the problem, classifying the presently-eroding coast into three categories: (1) sites of critical erosion where shore-based facilities are in imminent danger (145 km); (2) sites of significant erosion areas where facilities are expected to be endangered within 5 to 10 years if no remedial action is taken (246 km); and (3) sites that are generally undeveloped with consequent minor economic loss if coastal erosion continues unabated (975 km). A 30-cm rise in sea level will convert 246 km of coastline showing significant erosion into critical erosion areas. Given a 1-m rise in sea level, it is tentatively forecast that all of the 1,400 km of coastline that are presently eroding will be transformed to critically-eroding areas. Coastal tourist facilities that appear particularly vulnerable are located at Port Dickson, Penang and Kuala Trengganu and beach nourishment would be necessary to both maintain recreational beaches and protect tourist infrastructure. Tourist infrastructure also appears threatened on Bali, Indonesia (Sari, 1994). In Sri Lanka, erosion is already a widespread problem and this will be exacerbated by an acceleration in sea-level rise (Gunatilleke, 1994). Most existing hotels are built less than 15 meters from the beach, so the tourist industry appears highly vulnerable to such erosion.

5. POSSIBLE ADAPTATION MEASURES

The more adverse impacts of climate change on coastal areas are some decades away, and their actual magnitude has a high uncertainty. Therefore, only "no-regret" responses which can already be justified by present conditions (climate change simply reinforces that justification), or low-cost anticipatory responses which increase flexibility in the face of an uncertain future will be most appropriate in the next few decades (Nicholls and Leatherman, 1995a; 1995b). In addition, given the serious existing problems of the coastal zone in this region and the fact that they generally exacerbate vulnerability to climate change, solving these problems in an integrated manner with longer term problems is an important contribution to adaptation to climate change (Vellinga and Klein, 1993; WCC'93, 1994).

5.1 Types of response

IPCC (1990) defined three generic responses to climate change: (1) retreat; (2) accommodate; or (3) protect. A more comprehensive list is: (1) do nothing; (2) planned retreat; (3) accommodate; or (4) protect. Do nothing is often what is being done today with no strategic view of the coastal zone. In contrast, a planned retreat is an active policy decision to abandon land rather than protect it, and to be most effective will often require long-term planning. An example of a planned retreat, is a building setback from the coast. Accommodation is a policy which changes how the land is used as climate change occurs. Two examples are raising homes on piles above higher flood elevations, or allowing agriculture to change to crops which better tolerate waterlogging or higher salinities. Lastly, protection is a policy decision to counter the impact of climate change through structural means, either with hard structures, or soft approaches such as beach nourishment. Some ADB country studies considered a 'counter-attack' strategy in which protection is combined with reclamation – such a policy may be seen as an extreme version of protection. The appropriate response will vary on a site by site basis and will depend on a combination of physical and socioeconomic conditions.

5.2 Timing of responses: anticipatory versus reactive adaptation

In addition to the question, how to respond, there is the question of when to respond? It is often prudent to anticipate problems associated with sea-level rise rather than simply react to change (Nicholls and Leatherman, 1995a; 1995b). The impacts of accelerated sea-level rise will depend on both the magnitude of global sea-level rise *and* the human responses to that change. A "do nothing" policy with no anticipatory adaptation may lead to unwise decisions, such as construction in areas vulnerable to sea-level rise. This is particularly the case in coastal areas that are experiencing rapid population growth and development. In contrast, a well-planned response that seeks to anticipate the physical impacts of sea-level rise in a timely fashion will minimize such problems and should result in a wider range of options for future generations and lower costs for reactive responses. Anticipatory adaptation requires a long-term institutional perspective.

5.3 Examples of anticipatory action

Anticipating sea-level rise is not a new engineering or coastal management practice – the Thames flood barrier in London anticipated the existing rate of rise of the high water level for 50 years (until 2030) (Gilbert and Horner, 1984). Considering accelerated sea-level rise is a more recent development. Some actual examples include considering accelerated sea-level rise in the design height of *new* seawalls in the Netherlands and Britain, the design of gravity drainage for a new sewage plant at Boston so that the costs of pumping can be avoided given a 46-cm rise in sea level (see Nicholls and Leatherman, 1995b) and enlarging coastal building setbacks in some Australian states to include erosion expected due to accelerated sea-level rise (Caton and Eliot, 1993). In Hong Kong, the West Kowloon reclamation has been designed with a surface elevation 0.8 m above earlier reclamations to give a safety factor for accelerated sea-level rise (Yim, 1995). Future reclamations in Hong Kong are expected to be similarly designed.

We would encourage such routine anticipatory adaptation in the design of long-life, high value coastal infrastructure such as ports and related projects such as drainage method and capacity. Selection of an appropriate sea-level rise scenario for design purposes depends on a number of factors, including the time frame, cost, and implications if the scenario is exceeded. Given the uncertainty concerning future sea-level rise and coastal climate, it is important that the design of coastal infrastructure should maximize flexibility and allow for incremental upgrade or modification – changing conditions should be an accepted feature of the coastal zone. For instance, the design of coastal bunds in Malaysia allows routine raising of the crest elevation (in response to subsidence) (Chiang, 1994): similar upgrade is possible to global sea-level rise.

Land use planning is another form of anticipatory adaptation, particularly in areas that are developing rapidly. For instance, areas that are prone to inundation, erosion or flooding should be avoided if other choices exist. Building setbacks are a sensible policy with or without climate change as most sandy shorelines are already eroding worldwide (Bird, 1985). The key decision is an appropriate setback distance which will integrate a number of factors such as likely recession rates and the likely life of coastal buildings.

5.4 Adaptation options in the region

In terms of adaptation strategies, the ADB studies generally observed a need for capacity building and further research and policy development, as well as recognizing that a policy of universal protection may be unrealistic from both an economic and environmental perspective. As sea level rises, so major coastal cities will need to be protected – the subsiding city of Jakarta will probably required improved protection before many other urban areas. However, in other sectors, sufficient information to make decisions is not yet available. For instance, the question "Will coastal tourism be a viable industry if it is dependent on beach nourishment to maintain beaches?" cannot be answered without an assessment of land- and marine-based sand resources. In turn, the answer to this question will influence other coastal policies such as building setbacks. In Sri Lanka, possible nourishment of tourist beaches that have been indirectly depleted by sand mining raises other policy questions and potential conflicts.

Control of coastal flooding is already a major objective in some of the countries, particularly Viet Nam (Sinh, 1994). Upgrade of this infrastructure to allow for climate change would seem likely as is the case in China (Han *et al.*, 1995a). However, as many of the most vulnerable areas are deltaic plains, all the impacts of sea-level rise will need to be countered,

Table 4. Accretion and erosion in coastal Bangladesh from 1972 to 1991 (from Asaduzzaman, 1994). Areas are given from west to east.

Area	Erosion (km^2)	Accretion (km^2)
Sundarbans	74.73	14.45
Bhola area	69.63	329.49
Noakhali-Chittagong	494.39	587.04
Cox's Bazaar	33.43	8.88
TOTAL	672.18	939.86

which will necessitate improved water and coastal zone management. In Bangladesh, no regret responses such as improved flood warning and management for coastal cyclones would be prudent (Asaduzzaman, 1994).

Given that many coastal areas are subsiding at rather high rates – a better understanding of present and future subsidence rates is urgently required, particularly for deltaic areas. More generally, improved groundwater management with a primary goal of exploiting this resource without causing subsidence should be a primary goal in all subsidence-prone coastal areas. Given the identified problems in Manila and Jakarta, controlling subsidence should be given a high priority in both cities.

As already discussed, deltaic areas such as Bangladesh naturally exist in a dynamic balance, with sediment input from the river, sediment storage within the delta, and sediment removal by marine processes. It is also natural that there will be a net accretion in some parts of the delta and net erosion elsewhere (*e.g.*, Table 4). The sediment storage offsets both subsidence and global sea-level rise. In Bangladesh, local people have used sedimentation on a small scale to raise land elevations for centuries. More recently, sedimentation has been exploited for more large-scale land reclamation (Koch, 1986), contributing to the net gain of land shown in Table 4. Therefore, it is worth considering if this natural process can be harnessed and managed to counteract the effects of sea-level rise at the delta scale (Asaduzzaman, 1994)? Similar strategies have been advocated in the Huang Ho (Yellow River) delta (Han *et al.*, 1995b) and the Mississippi delta (Boesch *et al.*, 1994). Given the large number of deltas in the region (Figure 3), this constitutes a response which may have widespread application.

Raising land levels will offset all the impacts of sea-level rise and reduce the need for improved water management. Evaluation of the feasibility of this approach will require much fundamental research.

6. FURTHER WORK

6.1 Improved vulnerability assessments to climate change

The ADB country studies have established a crucial need for much more detailed vulnerability assessments in most coastal countries within the Asian Pacific region that can contribute towards improved coastal zone management. These studies should follow the IPCC Common Methodology (IPCC, 1992; WCC'93, 1994) and use a range of global sea-level rise scenarios

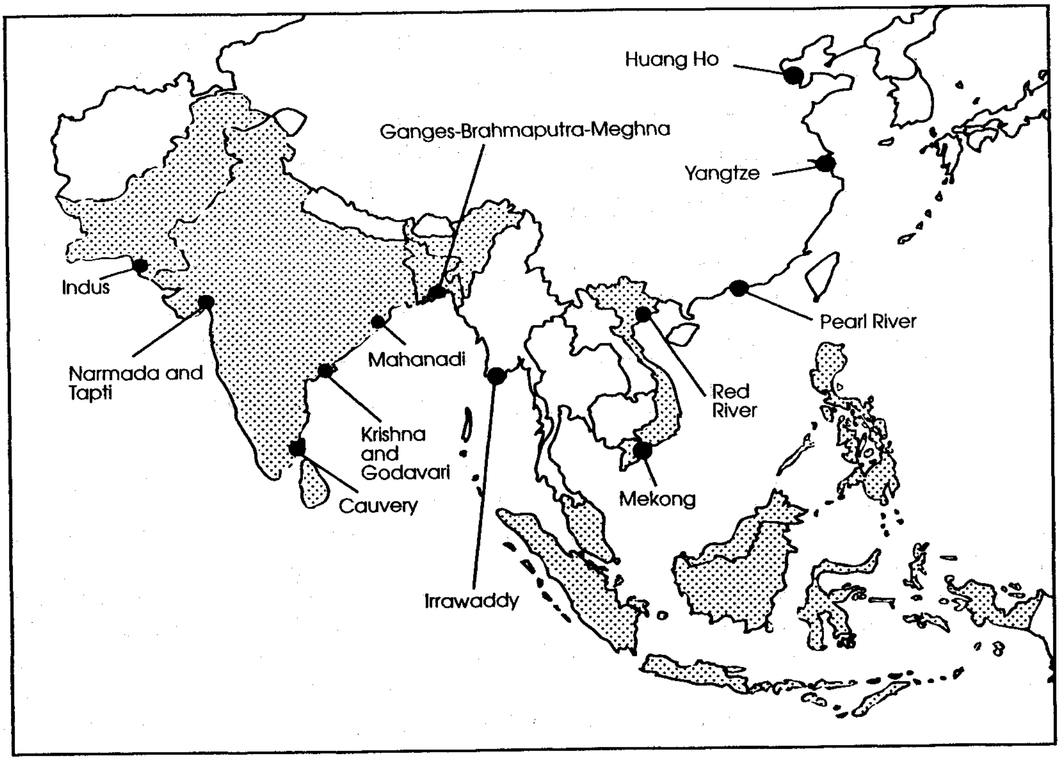

Figure 3. Major deltas in both the study and neighboring countries

(say 0.3-m, 0.5-m and 1.0-m by 2100) which embrace current scientific projections. Likely subsidence or uplift as well as issues such as human modification of sediment budgets should be addressed.

Some countries within the region may require technical assistance or financial resources in carrying out these studies. It is essential that adequate talent and resources, national, regional, and international, be mobilized to ensure that policy makers have a site-specific understanding of what may be at risk from climate change and sea-level rise and how they may most effectively respond. Such assessments should addressed the key questions concerning vulnerability such as (1) the dependence of local society on the coast, (2) social and cultural traditions, (3) the likely effect of development plans and population growth on the coast and, given this analysis, (4) how can society best cope with the coastal implications of climate change?

6.2 Regional co-operation

As this review has shown, however, coastal regions of Asia share many common vulnerabilities which may benefit greatly from international cooperation at the regional or sub-regional level (see also Topping *et al.*, 1994). In particular, policy-makers and coastal planners require improved climate scenarios for enhanced greenhouse conditions, including variability and long-term changes to tropical cyclones, to disruptions associated with the ENSO phenomenon and perturbations in the monsoon (*cf.* CSIRO Climate Impact Group, 1994). Cooperation among regional scientific institutions to resolve these uncertainties combined with improved monitoring of climatic and environmental trends in the region would of great value in this regard.

International cooperation on catchment plans for some of the big deltas in the region also needs to be considered if major upstream rivers cross international boundaries. The most obvious example is the Ganges-Brahmaputra-Meghna system of Bangladesh where 90% of streamflow is generated in other countries (Asaduzzaman, 1994). Effective long-term planning of these deltas, particularly adaptation based on improved sediment and water management, requires long-term cooperation and planning of the entire catchment.

7. CONCLUSIONS

The coastal areas of South and Southeastern Asia will change substantially in the coming decades with or without climate change. Separation of existing coastal problems from the potential coastal impacts of climate change is meaningless: in general climate change exacerbates existing problems, rather than creating fundamentally new problems. Further present human action and growing population is often exacerbating the same problems. Therefore, solving today's coastal problems increases the resilience of the coastal zone in the face of climate change and is an important adaptation to climate change (Vellinga and Klein, 1993; WCC'93, 1994). In view of the high probability of climate change, a long-term perspective is required in today's planning in the coastal zone. Integrated approaches which address both today's problems and potential long-term problems are needed so that the coastal populations of the region can maximize the benefits of their location into the foreseeable future.

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