of a modern state. They are complementary to each other and not counterposing. If improperly handled and imbalances are created, they do become counterposing to one another. Though the public perception (about 85% of the respondents) is in favour of strengthening national defence, their attitude is conditioned by the imbalances that occurred due to the stifled nature of development as seen in agriculture, industry, S&T and defence. Thus, there is a demand for cut-down in defence expenditure, unless otherwise the nation wants to do business in the military hardware. Expenditure in defence *can be brought down by strengthening peace movements*, imparting military training to the civilians to develop para-defence systems and improving country's diplomacy and foreign relations.

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Impact of extreme events on coastal zones and small islands in the context of climate change

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The paper presents a review of the current state of knowledge on the likely impacts of extreme weather and climate events on coastal zones and small islands in the context of climate change. Possible response options, including prevention, preparedness and adaptation, are indicated.

At first glance, there appears to be little in common between the gradual onset and complex impacts of climate change and the unheralded onset and direct impacts of extreme events. While the magnitudes of the anticipated global warming and consequent sea level rise may be somewhat less than those indicated in the First Assessment Report[1] of the Intergovernmental Panel on Climate Change (IPCC), it is the extreme events and/or climate surprises that need to be taken seriously. It appears that more emphasis has to be placed on changes in frequency and/or intensity of various extreme or threshold events, particularly the extremes of temperature and precipitation, and the hazardous coastal events such as cyclones and storm surges. Such events would dominate the effects in coastal zones. The small islands would, however, appear to be highly vulnerable to accelerated sea level rise as well.

Definitions

Coastal zone: Coastal zone includes both the area of land subject to marine influence and the area of sea subject to land influence. Coastal zones are very valuable parts of the economies – both the affluent and subsistence economies. Coastal habitats provide important areas for fish and wildlife, including many endangered species. Coastal zones filter and process agricultural and industrial wastes and provide a buffer for the inland areas against cyclone and wave damages.

Small islands: Islands less than 200 km^2 in area are defined as small islands and those with area less than 20 km^2 may be called very small islands. This categorization is not entirely arbitrary and is significant in the sense that while the larger islands generally have geological features and problems similar to those found in continental regions, the small and very small islands have their own characteristics and rather unique problems. The major conglomerates of small islands are in the Pacific, the Atlantic (Caribbean), the Indian Ocean, and the territories of Indonesia and the Philippines.

Physical changes

Tegart *et al.*[2,3] have documented the potential impacts

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of climate change based on the studies conducted for preparing the 1990 Assessment[1] and the 1992 Supplement[2] Reports for IPCC. Among the likely physical changes in coastal zones and small islands as a result of possible climate change, the potential for, and magnitude of, accelerated sea level rise (ASLR) appears to be the greatest, especially for small islands. The projected ASLR (of the order of half a metre by the year 2100) would result in (i) substantial land inundation with especially significant impacts on coral atolls, (ii) considerable loss in agricultural activity in low-lying areas of coastal zones and small islands, (iii) coastal inundation and erosion resulting in degradation and loss of natural protective features such as dunes and mangroves apart from property damages, (iv) increased backwater effects reducing drainage from coastal streams, and (v) severe damage to surface and ground water sources due to increased intrusions of salinity. Nevertheless, as mentioned above, the major changes would be due to extreme events and climate surprises, which would also result in sudden rise of sea level apart from the other physical changes.

Accelerated sea level rise (ASLR)

Estimates of the combined effects of oceanic thermal expansion and land ice changes that could be induced by global warming involve considerable uncertainty[5]. These uncertainties are: (i) the rates of greenhouse gases (GHGs) emissions and the related changes in atmospheric concentrations and radiative forcings, (ii) feedbacks in the climate system as they affect the climate sensitivity to a given change in radiative forcing, (iii) transfer of heat from the surface to deeper waters in the oceans, (iv) regional and seasonal changes in climate, (v) model uncertainties in the computed response of ice sheets and glaciers to climate changes, and (vi) changes in ocean circulations for which adequate models are yet to be validated. Among these, thermal expansion appears to be the most significant long-term change[6]. It needs to be recognized at this stage that the ongoing research may, in the near future, result in new projections for the magnitude and the consequent physical changes due to ASLR resulting from climate change.

Enhanced extreme events – cyclones, storm surges, and heavy rains

The IPCC 1992 Supplement[4] cautioned that confidence in regional climate change patterns based directly on global climate model (GCM) output was low and that there was no consistent evidence of change in the variability of storminess. The position remains the same at present. In order to tackle this uncertainty, the models have to refine the horizontal resolution apart from other improvements.

Evans[7] made a comprehensive study of the envisaged impacts of enhanced greenhouse warming on tropical cyclones with special reference to the Australian region and concluded that in the overall, according to the present GCM simulations, preferred cyclogenesis locations remain unchanged but the potential maximum intensity could increase with the caveat that the environmental effects are ultimately the limiting factors on actual cyclone intensity and that motion will remain largely unchanged. Later work, for example, by Raper[8] indicates that there is no convincing evidence to support a relationship between sea surface temperatures (SSTs) and cyclone intensities and that an increase in SSTs may not necessarily lead to increase in the intensity of cyclones. As regards the frequency of cyclones, the link with SST appears to be through the prevailing atmospheric conditions to which both the SSTs and the tropical cyclone frequencies are closely related. Although SSTs could increase in the future due to climate change, the model predictions indicate only small changes in circulation, usually within the range of the past natural variability. There is some indication for certain areas (like the USA mainland) that the number of hurricanes striking the coast in recent years is a bit less than the average number based on the statistics of the past 100 years or so.

While evaluations of the possible impacts on coastal and estuarine surge levels due to climate change involve complex site-specific analyses, the impacts of possible ASLR on storm surge levels can be assessed on the basis that the storm surge height above the sea level plane for a given wind shear stress will be lower with higher sea level positions, where an off shore shelf is characterized by a horizontal sea bed. In the more common situations of sloping shallow offshore shelves and varying basin configurations, no direct general relationships can be deduced in terms of sea level positions and the relative differences of surge heights for given wind forces[9].

As regards heavy rain events, various lines of evidence suggest an increase under enhanced greenhouse conditions. This will probably be accompanied by an increase in deep convection and a decrease in more widespread light rain and number of rainy days in middle latitudes. These changes, coupled with increased evaporation, would result in significant reductions in the return period of floods as well as droughts[10].

Snow and ice accumulation and ice outflow

It is generally accepted that as the cause of sea level rise, the thermal expansion of oceans will dominate over the other two factors, viz. the melting of nonpolar glaciers in places like the Himalayas and New Zealand and changes in the volume of ice and snow in Antarctica

and Greenland. Practically all the GCMs suggest that an increase in precipitation over Antarctica will occur with global warming[11]. This should lead to some increase in the rate of accumulation of snow as has been observed over the recent decades in a study of ice cores[12]. The contribution of this to changes in sea level is small. Nevertheless, the complex question of snow and ice accumulation and ice outflow in Antarctica is important to the long-term question of sea level rise because the West Antarctic ice sheet, being marine-based, is potentially unstable and vulnerable to climate change. If it were to disintegrate, it would contribute about 6 m to sea level rise but such an event would occur only over many centuries[13]. Even then, this possibility is considered sufficiently significant and major research projects have been taken up[14]. Ice sheet instabilities cannot explain all aspects of the long-term climate dynamics and ocean instability needs to be taken into account but it is the ice sheet instability that seems to trigger ocean instability.

Lightning from violent thunderstorms

Lightning strikes from violent thunderstorms are very hazardous to electric power installations, aircraft, forest and the people. Even when widespread fire does not occur, lightning can cause serious damage to forests, thereby enhancing the spread of insects and diseases apart from the economic loss. According to a recent study[15], initial model results show that for a doubling of carbon dioxide scenario, global lightning activity would increase by approximately 25%. Among the climatic variables that have an impact on dangers of wildfires, relative humidity is the most important. This underlines the need for site-specific studies of the relative impacts due to increased lightning and the likely changes in relative humidity regimes locally.

Ecological impacts

The various global scenarios of sea level rise indicate an accelerating rise with no prospect of stabilization. If the seas continue to rise, coastal erosion will also accelerate and become more widespread as any compensating sedimentation declines. It will encounter, reshape, and in due course submerge the raised beaches. Because of the complexities of coastal environments and their along-shore variations, a great deal of sector-specific research is still needed to assess the extent of the geomorphological and ecological changes that will occur as the sea level rises. In assessing the nature and extent of possible changes, it is useful to classify coasts into several categories such as steep and cliffed coasts, beach fringed coasts, deltaic coasts, swampy coasts, estuaries and coastal lagoons, intertidal and near-shore areas, coral reefs and reef islands, and man-made coasts. An excellent discussion of the impacts of the rising sea level in coastal regions is given by Bird[16].

Socioeconomic impacts

In coastal zones and small islands, as indeed elsewhere as well, the socioeconomic impacts of climate change are both on the local environment and on the human societies. Those on the local environment can be analysed in terms of (a) ice and snow, (b) oceans and coasts, (c) hydrological cycle, (d) natural hazards, and (e) ecosystems and vegetation. Similarly, the possible impacts of climate change on the local human societies can be assessed in terms of (a) water resources, (b) food and agriculture, (c) coastal and island dwellers, (d) health and (e) economic activity. In actuality, the impacts occur in more complex ways and impacts in one sector affect/create further impacts in other sectors. Coastal zones and small islands are likely to suffer erosion, coastal flooding, inundation, agricultural losses, and damages to water resources and other essential infrastructure. Ironically, certain impacts could lead to a clash of interest. For example, as a result of rise in ground level temperatures due to global warming, beach seasons in coastal or island resorts would be extended bringing in more revenues – probably much more than the costs of controlling erosion and inundation that may be caused by sea level rise on account of climate change. Higher SSTs may enable new swimming areas to be developed where sea water is at present too cold to swim. On the other hand, in certain cases, adverse impacts would get accentuated such as flooding from inland waters and storm surges and rising sea level from the ocean side.

Response options – prevention, preparedness, insurance

Prevention

It is debatable if the potential impacts of climate change can be 'prevented'. Appropriate adaptation or abatement efforts are possible and should be encouraged although cost–benefit considerations will apply especially in countries with weak economies. Reduction in the emission of GHGs (including methane from garbage dumps), energy conservation, adoption of cleaner energy and manufacturing technologies, and control of atmospheric pollution (especially that from automobile exhausts) are a few of such strategies that are widely recommended.

As regards wildfires or bushfires, one technique for prevention is to light small fires (called hazard reduction burns) that consume the fuel so that during subsequent

bushfire, there is less fuel and hence less likelihood of a large uncontrollable fire[17].

Preparedness

It is possible to reduce the losses significantly if the existing knowledge and the known adjustment systems are employed[18]. These authors have listed a wide variety of available tools as follows:

Long-term
- Controlling investment, planning and development
- Management of land, resources and infrastructure
- Education and training
- Public information
- Hazard insurance
- Weather modification
- Structural engineering works
- Hazard-resistant constructions

Immediate pre-impact
- Monitoring
- Predicting
- Warning
- Shelters
- Evacuation and relocation

Impact and immediate post-impact
- Emergency management
- Hazard-fighting
- Search, rescue and salvage
- Disaster relief
- Loss compensation and rehabilitation

Insurance

The international insurance industry is already faced with a significant increase in insurance outflow due to natural disasters/extreme events during the last few decades. There are increasing demands on the insurance industry owing to the increasing population and value-added property. This is much more apparent for coastal zones, especially in affluent countries and in tourist areas, although insurance still does not command much presence in small islands except where high-value property and infrastructure are involved. The present problems faced by the insurance industry would increase if climate change results in an increase in frequency or intensity of extreme events. Meanwhile the available scenarios and projections of climate change and its impacts would tend to increase insurance premia rates, especially in coastal zones and small islands. Reinsurance would become a major and regular practice in such areas because of the magnitude of economic risk being very high and beyond the capacity of one insurer.

Adaptation options

General options

If strategies to limit the emission of GHGs are successful, the impacts on coastal zones and small islands would also be reduced. However, even if the limitation strategies succeed, there will be impacts due to climate changes already set in motion. Moreover, it is likely that initially limitation would be partial at best. Consequently there are some urgent requirements form coastal adaptation, which can be considered in the from of the following activities:

(a) Improved understanding of the climate change science and likely implications for sea level rise and other impacts such as cyclones.
(b) Monitoring of sea level and coastal change.
(c) Vulnerability studies to identify areas most likely to be prone to extreme events and sea level rise.
(d) Site-specific impact assessments.
(e) Forward planning.
(f) Public awareness.
(g) Development of a full range of coastal adaptations, including nonstructural or nonengineering options.

Specific options

In specific terms, the adaptation options for coastal zones and small islands fall into three categories, viz.

(a) Retreat: Abandon vulnerable areas and resettle.
(b) Accommodate: Adjust to the impacts, including ASLR.
(c) Protect: the vulnerable areas, especially those with large populations, high-value property and precious natural resources, and strategic installations.

An excellent discussion of the available adaptation options is given in the Report of the Coastal Zone Management Sub-Group of IPCC Working Group III[19] which also lists a very large number of references on the subject.

Social and cultural implications

People inhabiting coastal zones and small islands have distinct life-styles with characteristic social and cultural ethos. The adaptation option should not unduly strain their social and cultural values.

Sensitivities and thresholds

Definitive prediction of future climate seems impossible because a number of uncertainties are involved. Some can be reduced but others, especially those related to

future human behaviour, climate surprises and catastrophic geological or geophysical events, cannot be anticipated adequately. As future climate cannot be predicted satisfactorily (at present in any case), assessing the possible impacts of climate change requires the use of sensitivity studies over a range of possible values for relevant climatic variables. This approach enables response surfaces to be plotted showing the value of the property or the outcome considered as a function of a range of possible values of the climatic variables. Response surfaces are particularly useful because the effect of any chosen climate change scenario can be read off the graph without the need for new calculations. Examples of response surfaces are shown by Whetton *et al.*[11].

Another approach could be through calculation of quantitative indices that combine the state of climate and the economic activity into a useful number which may be regarded as an 'econoclimatic' indicator.

Conclusions

Coastal zones and small islands are very vulnerable to climate change, especially changes in extreme weather and climate events. The confidence in regional climate change patterns deduced from global climate models (GCMs) is low at present and considerable progress will have to be made before the output products of GCMs can be applied at regional or local scales. Hence, there is need for site-specific assessments of the likely impacts of climate change (especially those of extreme events)in coastal zones and small islands so that locally applicable response strategies and policy options could be developed.

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