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Vulnerability to Climate Change and Sea Level Rise in the Asia and Pacific Region

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1. INTRODUCTION

It is concerned that climate change and sea-level rise would impose serious impacts on the natural environment and human society in the coastal zone. Primary impacts of sea-level rise are listed as inundation, exacerbation of flooding, beach erosion, and salt water intrusion to rivers and ground water aquifers. Since there exist many large deltas, coastal wetlands, coral reefs, and small islands in the Asia and Pacific region, it is crucial to predict the degree and range of the possible impacts of sea-level rise and climate change as a basis for preparing response strategies and measures. Identification of the most vulnerable areas from multiple viewpoints is another important task.

There have been a number of vulnerability assessment studies in global, regional, and national scales(e.g. Hoozemans *et al.*, 1993; Nicholls *et al.*, 1999). However, these have some common constraints. One of the constraints is that most studies look at only static changes in external forces, such as increase of mean sea level. Since the coastal environment is strongly affected by tropical cyclones and storm surges, it is important to take into account them in the vulnerability assessment. Another static nature of the previous studies is that the socioeconomic conditions are assumed to be unchanged from those of today in the assessment for the future. The Asia and Pacific region is expected to face high growth of population and economic activities. Therefore, for the coming 100 years, the target period of this study, population and human activities in the coastal zone must increase remarkably. It is needed to incorporate these changes into vulnerability assessments to make them more realistic. Furthermore, many previous studies are confronted with lack of data, even if they try to respond to the above problems.

In order to overcome such constraints, global datasets on climatic, environmental, and societal information were used in the present study. For the past decade, many efforts have been made to build global and regional datasets in terms of the basic geographic conditions, such as distribution of the land elevation, land use/cover, and population, and environmental parameters, such as coral reefs and wetlands. Collecting and using these datasets, we tried to incorporate the effects of storm surges induced by tropical cyclones, population growth up to 2100 into the regional assessment. This study aims at an Asia and Pacific assessment of vulnerability to climate change and sea-level rise through integration of the datasets by a geographic information system(GIS).

2. TARGET AREA AND GLOBAL DATABASE

The target area of this study is the whole Asia and Pacific region, which covers 30E to 165S, and 90N to 60S. Its land area and population are about 6.5 million km^2 and 3.8 billion people. Necessary information for the assessment was collected from global and regional databases, which include land elevation, population distribution, tracks and intensities of tropical cyclones, wetlands, etc as shown in Table 1. The spatial resolution of the data ranges from 1 degree × 1 degree to 0.5 minute × 0.5 minute in the longitudinal and latitudinal directions. All data were arranged uniformly on a common grid of 1 minute × 1 minute in the GIS. The calculation and analysis were all performed on this common grid.

3. METHOD OF ASSESSMENT

3.1 External forces

The external forces considered were sea-level rise, astronomical tide, and storm surge induced by

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Table 1. *Global databases used*

Parameter	Name	Organization	Resolution etc
Elevation	GTOPO 30	EROS Data Center (US EDC)	1:1,000,000 1/120 deg.
Population	Gridded Population of the World	CIESIN	1/12 deg.
Tide	Tide Table No.1 & 2	Hydrographic Dept. Maritime Safety Agency	1852 points
Cyclone	World-wide Consolidated Tropical Cyclones	World Weather Disk (US NOAA)	1842-1989
Wetlands	Major World Ecosystem Complexes	Global GRASS (US NOAA)	1 deg.
Coral Reefs	Reef Base 3	World Conservation Monitoring Center ICLARM	Over 7,000 coral reefs
Infrastructure	Digital Chart of the World	ESRI	1:1,000,000-1:25,000,000

a tropical cyclone. By combining these forces, four scenarios at two points of time, i.e. the present and 2100, for water level were set; 1) high tide level at present (no sea-level rise), 2) storm surge level at present (high tide+storm surge, no sea-level rise), 3) high tide level in 2100 (high tide+1m sea-level rise), and 4) storm surge level in 2100 (high tide+storm surge +1m sea-level rise). The levels for high tide and storm surge represent the water levels for the permanent inundation and episodic flooding.

Estimate of the future sea-level rise are given by IPCC(1996), which shows the increase of the mean sea level from 15 to 90cm in 2100 (Fig. 1). In the present study, 1m sea-level rise was taken for simplicity. The high tide levels in 1852 sites are listed in Tide Tables (Hydrographic Department, Marine Safety Agency, 1999a, b). They were used to interpolate the distribution of the high tide level along the whole coastlines in the Asia and Pacific region.

Storm surges strongly affect the coastal environment. The height of storm surge was calculated by Eq.(1), which represents suck-up of sea water and wind set-up by a tropical cyclone, but does not include the effect of wave set-up.

$$SS_{RP} = 0.991 \cdot \Delta P_{RP} + \frac{k \cdot U_{RP}^2}{10^3 \cdot S} \ln \frac{h_0}{h'} \quad (1)$$

where, SS_{RP} is storm surge height, ΔP_{RP} pressure decrease at the center of a cyclone, U_{RP} wind speed, k=4.8 × 10^{-2}, S mean sea bottom slope on the coast, h' water depth where the storm surge is calculated(=5 m), and h_0 water depth where the wind set-up begins. The parameters necessary to calculate the storm surge, such as pressure distribution and track of the cyclone, wind speed, and the velocity of the cyclone movement were estimated using the World-wide Consolidated Tropical Cyclones issued by NOAA in the US. Storm surges were calculated for all the cyclones recorded for 40 years from 1949 to 1989. Then the highest surge level in each coastal segment was taken as the storm surge scenario along the coastlines in the region. This means that the present study assumes that global warming will not change the tropical cyclones, thus storm surges, from those of the past 40 years in the future.

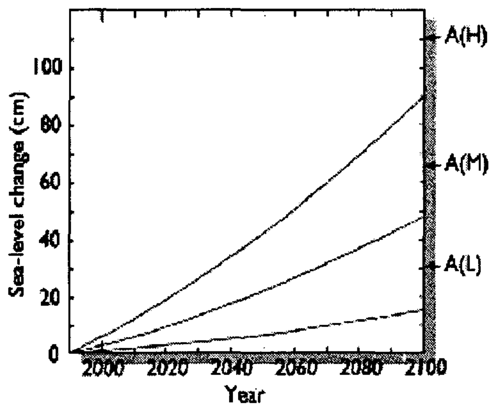


Fig. 1. Estimate of sea-level rise (IPCC, 1996)

3.2 Areas and population affected by inundation and flooding

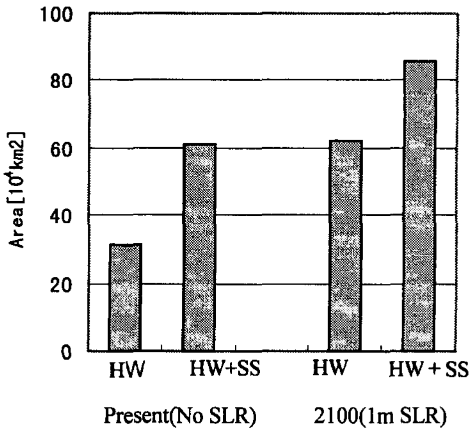
The areas affected by high tide and storm surge were calculated assuming that the areas below the water levels scenarios would be inundated or flooded. In reality, coastal dikes and seawalls may prevent the inundation. Moreover, the flooded areas by storm surge is often limited to the narrow coastal area due to the short retention period of a cyclone. Therefore, the area calculated in the present study is the possible maximum area of inundation or flooding, which indicates the degree of a potential risk in each coast.

Then the population in the affected areas were calculated. As the reference, the distribution of the population in 1994 was taken. For 2100, the population distribution is estimated by multiplying the growth estimate of World Bank by the present distribution country by country.

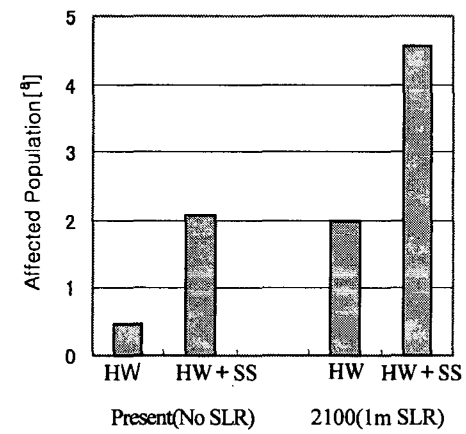
4. IMPACTS ON THE ASIA AND PACIFIC REGION

As mentioned above, the total land area of the target region is about 6.7 million km^2. The population in 1994 in the region is about 3.8 billion which is estimated to increase to 7.6 billion in 2100. Even today, the areas below high tide level and storm surge level, i.e. inundated and flooded areas, are 311 thousand km^2 or 0.48% of the total area and 611 thousand km^2 or 0.94% , respectively, as shown in Fig.2. They increase to 618 and 858 thousand km^2 (0.98% and 1.32%) by 1m sea-level rise. The flooded area increased by sea-level rise amounts to 247 thousand km^2. Regarding the affected people today, about 47 million people or 1.21% of the total population lives in the area below high tide level, while 270 million people or 5.33% live below storm surge level. These show that the Asia and Pacific region is already vulnerable to floodings by storm surge. If the mean sea level rises by 1 m and the present population is assumed to be unchanged, the above populations increase to 160 and 258 million(2.73% and 6.61%) respectively. When the population growth by 2100 is taken into account, they become about 200 and 450 million people. The increase in the population in the flooded area reaches 249 million.

Fig. 3 shows the distribution of the areas below storm surge level with 1m sea-level rise. The areas which may be affected seriously are deltas of Mekong River, Ganges and Brahmaputra Rivers, and Yangtze River, and the southern part of Papua New Guinea. The countries and areas where more than 10% of the national population is affected are Vietnam,



(a)Inundated and flooded areas



(b)Affected population

Fig. 2. Affected areas and population

Taiwan, Cambodia, Brunei, Bangladesh, Guam, etc.

The present assessment has several constraints. Accuracy of the land elevation vary with areas, which reflects the variation of accuracy in the source maps. The area below storm surge level is taken uniformly as the flooded area, while the flooding of storm surge occur mainly in the coastal areas as mentioned above. Though the resolution of the present analysis is 1 minute × 1 minute, which is rather fine for the regional analysis, small islands in the Pacific, such as Kiribati and Tuvalu, cannot be represented precisely. They need to be studied on a country basis and to be incorporated to the present analysis individually. In spite of such constraints, the present study can give us the degree and scale of the possible impacts of future sea-level rise and storm surges.

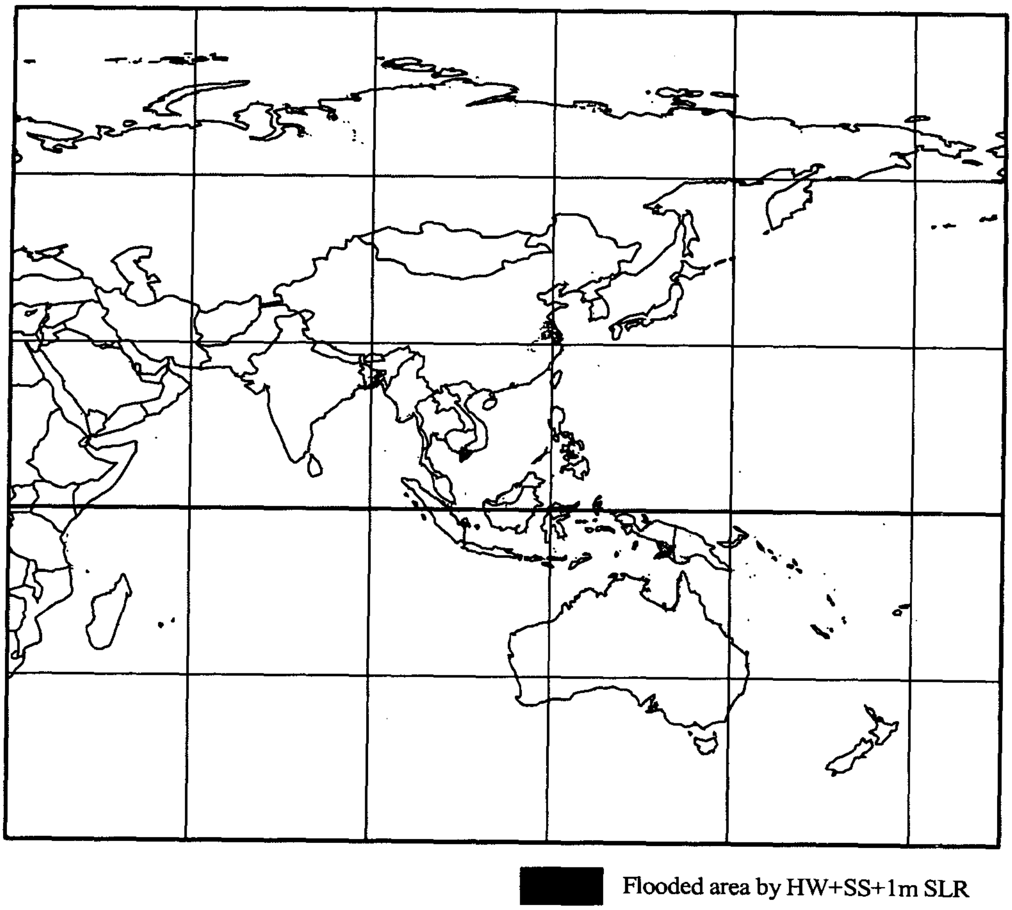


Fig. 3. Distribution of areas affected by storm surge and 1m SLR

These results can also lead us to a consideration of adaptation strategies. Vulnerability is an overall concept for a society to cope with the adverse effects of sea-level rise and climate change. It consists of several components, such as susceptibility and resilience to external forces and natural disasters, and capacity of the society to adapt to them. In face of the climate change, each country needs to take action to reduce its impacts, by engineering measures, institutional and planning arrangement, and other measures. The degree and range of the possible impacts identified in this study is quite large. On the other hand, the adaptive capacity of the society is not so high in the developing countries in the Asia and Pacific region. Therefore, the impacts would overwhelm the social counteraction and capacity of adaptation. The results indicate the necessity of the proactive consideration on how to strengthen the adaptive capacity in each country and the region on the whole. Furthermore, the international support is essential to this end.

5. CONCLUSIONS

In this study, a GIS-based system were developed to assess the vulnerability for the Asia and Pacific region. This system is effective to identify the areas to be affected by 1 m sea-level rise and storm surges, and to further determine the impacts on the coastal natural and socio-economic systems. The identified impacts is quite large and wide spread, which indicates that the Asia and Pacific region is very vulnerable to sea-level rise and climate change. The results also give a basis for the consideration of adaptation by showing the distribution of the possible impacts. We plan to collect more information to develop a system to perform a wider vulnerability assessment for the region. Moreover, if the results of national vulnerability assessment are incorporated in the system, we can draw a more detailed map of the vulnerability. In this sense, the present system can be a common platform for the regional cooperation for the vulnerability and adaptation assessment.

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