B-12 Studies on comprehensive assessment of impacts of sea-level rise and adaptation (Abstract of the Interim Report)

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1. Introduction

Due to global warming, approximately 9 to 88 cm sea-level rise is anticipated by the year 2100. Given that it occurs, various direct physical effects come into existence. These effects include submergence of coastal area, increasing danger of inundation, water level rise of rivers, salinization of rivers and groundwater level rise. It is also pointed out that these physical effects directly and indirectly affect various environmental systems, such as nature, society and economy of the coastal area.

It is therefore needed to clarify how sea-level rise affects natural environment of the coastal area and how to cope with them. It is also needed to develop technology to conserve, restore and create ecosystem along shorelines, such as lagoon, mangrove forest and swamp being lost by the pressure of human activities. Further, it is sought to predict and assess bad effects of the sea-level rise on urban activities, facilities of social infrastructure and buildings of the coastal urban area and consider how to cope with them. For this, it is an urgent task to conduct studies on them in each field. Results from these studies are used to visualize vulnerability of the local area by developing various indices and maps using GIS (Geographic Information System). Thus methodology for further understanding the status of the local area has to be developed.

2.Research Objective

This study is conducted to assess overall vulnerability to sea-level rise in Asia and the Pacific region and discuss appropriate measures that should be taken in the individual element. To this end, vulnerability of a country and an area to sea-level rise is identified, and appropriate measures for the local area are proposed to help develop measures against future global warming.

In order to deploy this research, methodology for each specific field of different scale is integrated into a hierarchy of the research components. In the case study, coastal area of the entire Indochina is captured as the representative of the large-scale study of Asia and the Pacific region, in which an assessment of the overall vulnerability is made, and appropriateness of the vulnerability is validated in the vulnerability map produced by using GIS (Geographic Information System). Study objectives of the individual field of the specific area are to define locality of coast erosion, ground subsidence, etc. as well as characteristics of targeted systems. Appropriate measures are also proposed together with vulnerability mapping of the characteristics of the targeted system.

3. Results and Discussions

3.1 Sub 1: Study on impact assessment of sea-level rise and its adaptation for coastal natural environment and ecosystem

3.1.1 Study on impact assessment of coastal natural environment and adaptation

The purpose of this study is to indicate basic information for the evaluation of influences of sea-level rises on coastal regions and their adaptation. To understand the dynamics of natural systems and their responses in relation to sea-level changes is one of important knowledge for the evaluation of influences of sea-level rises. Moreover hazard maps showing where which kinds of impacts occur in the coastal zones those impacts are basic information for the evaluation and adaptation. The Chao Phraya delta, Thailand, Mekong and Song Hong (Red River) deltas, Vietnam, and lagoon-small delta systems in the middle of Vietnam are studied for these purposes. Holocene isopach map, Holocene delta evolution and stratigraphy in the coastal plains were clarified. Recent delta evolution with a progradation rate of 10-20 km/ky (10-20 m/y) for the last 2,000 years was shown based on geological and geomorphological field surveys including borehole analyses. For the evaluation of current coastal erosion, the natural evolutional system of deltas will give important knowledge to understand their system.

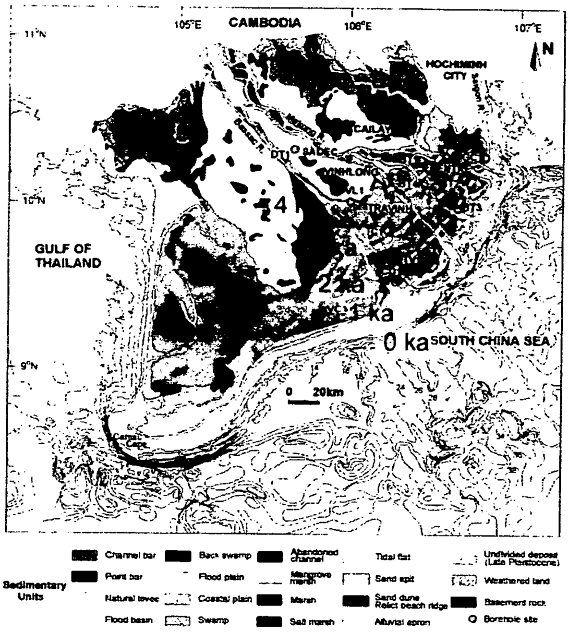


Fig. 1 Geomorphological map of the Mekong delta, Vietnam and delta progradation for the last 4,000 years.

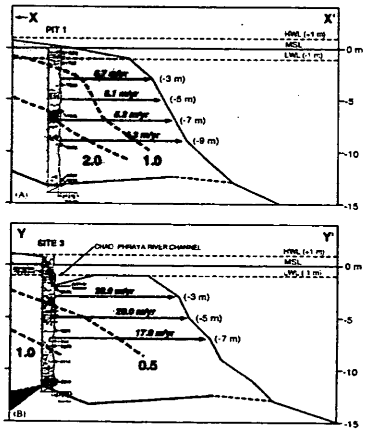
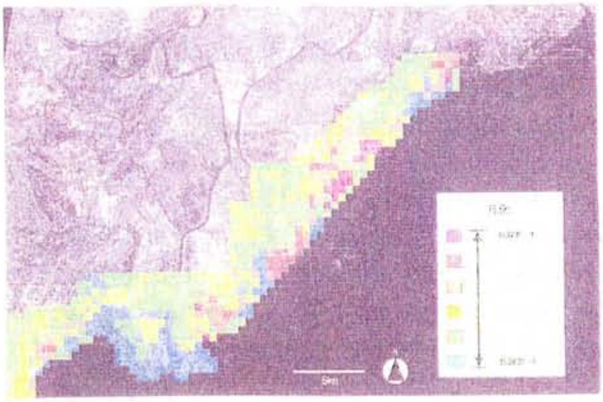


Fig.2 Delta progradation and cross section of the Chao Phraya delta, Thailand, during the past 2,000 years.

Coastal erosion with a maximum of 700-m retreat at the river mouth of the Chao Phraya occurred between 1970-1990 due to the subsidence by ground water pumping and mangrove deforestation.

For the evaluation of the sea-level rise affects both natural and socio economic systems and to make proper adaptive strategies against the impacts of future sea-level rise and mitigate flooding disaster, the Tam Giang-Cau Hai lagoon area in the Middle Vietnam and the coastal zone of the Song Hong (Red River) delta were investigated from geomorphologic and hydrological viewpoints.

Seven geomorphological zones and development factors in each zone were identified in the Tam Giang-Cau Hai lagoon area. The impacts of sea-level rise of about 1m were estimated and some response strategies against the impacts were proposed.



Recent coastal changes in 1990s detected from satellite imagery with other relevant data were compiled as coastal hazard maps, particularly for coastal erosion.

Fig. 3 Coastal hazard map for coastal erosion at the coastal zone of the Song Hong (Red River) delta, Vietnam. Each are is 500 m wide.

3.1.2 Study on impact assessment of sea-level rise for coastal ecosystem and adaptation

There are three major part of result for this group output which are "Vulnerability assessment", "Establishment of impact assessment", and "Testing adaptation method."

To clarify the argument for the vulnerability assessment, dominant processes in the forests and its modeling were mainly discussed. The most significant process is tide and tidal current through a creek and a swamp of mangrove forests. It is necessary to conduct a field observation to correct missing data for the modeling. Ngao creek, Ranong, Thailand (c.a. 7km long, 2,000ha wide) and Nadara River, Iriomote Island (c.a. 400m long, 6ha wide) were selected as field observation stations. Geographical survey, water quality measurement, oceanographic instrument deployment were organized.

As shown in Figure 3.1, a "Vulnerability assessment map" for Ngao Creek was done. Them map is an integration of satellite and aerial photograph, geographical survey results, hydraulics, and biological data, etc.

Adaptation measures are tested by conceptual model for evaluation. There are three major adaptation measures. The measures are "Action item of Shoreline Re-location", "Action for Erosion", and "Action for Fresh water runoff."

Restoration of abundant shrimp ponds is one of big and hopeful measures for SLR due to global warming. Long term monitoring of forests structure supports high success late of the restoration of an abundant shrimp pond in suitable condition such as water quality and sediment quality.

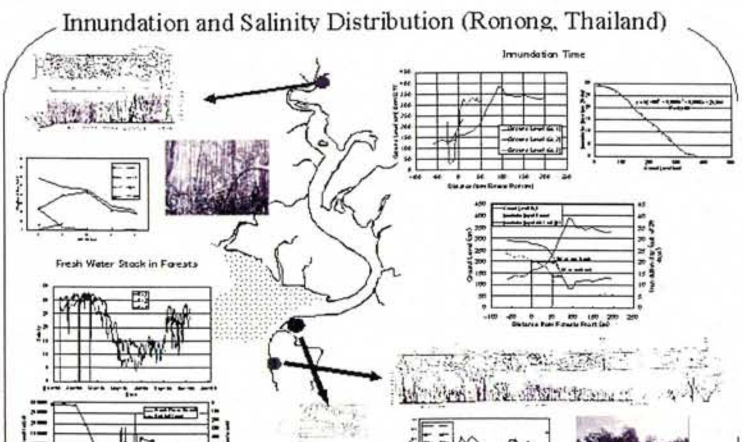


Fig.3 "Vulnerability assessment map" for Ngao Creek, Ranong, Thailand

3.2 Sub 2: Study on impact assessment of sea-level rise for city in coastal area and adaptation

Purpose of this research is to establish an applicable method for assessment of impact of SLR to coastal urban area in developing countries where secondary data available is very limited, through utilizing available satellite images (macro approach) and basic standard index obtained from detailed measurement of sample buildings, based on identification of zones of building/urban types and zones of contour level (micro approach).

We chose Indonesia as a field, where almost nothing is revealed on this issue, because more than 80,000 km of seacoast contains variety of human settlements, implying the applicability of methods elaborated. At first, we tried to sum-up total resources and related human time invested to the assets existing on the zone where contour is lower than 1, following the simple scheme of SURVAS, through co-operation between National Institute for Land and Infrastructure Management Japan (NILIM) and Research Institute for Human Settlement Indonesia (RIHS). Then we tried to refine, through estimating the future estimated coastal line from existing highest sea water level appended by sea-level rise, through considering the partial loss that shall occur through more frequent and deep inundation. Finally, we discussed about possible alternative adaptation through best of which net loss shall be estimated as sum of reduced loss and cost for adaptation itself. Local seminar / workshop will contribute for accumulating existing information related, as well as disseminating the result of this study.

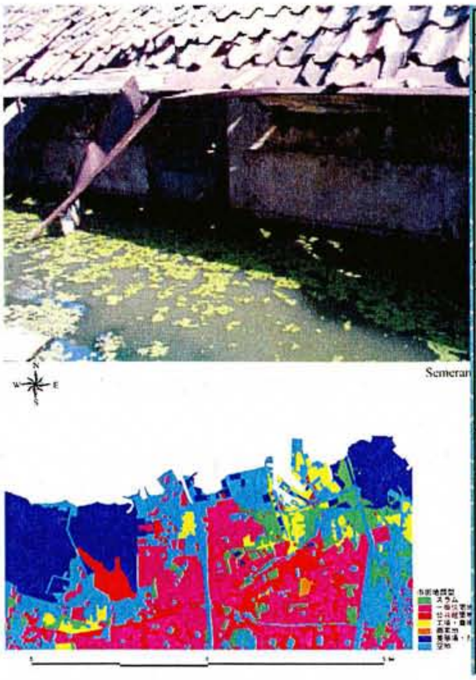
At first, fact-finding survey was undertaken for identifying the possible problems and phenomena caused by future sea-level rise, in 6 sample cities that have different characteristics (2000). In Semarang city, land subsidence has already lowered several districts under sea-level where houses were already abandoned. This kind of inundation is called 'ROB' in local language. Other households are paying individual efforts to adapt for more frequent and deeper inundation through appending soil onto floor, cutting the foot of doors and furniture, and finally re-building with reclaiming the house lot. We conceived those phenomena similar to what will be caused by SLR. In another city, Makassar, shortage of land drove people to build houses in the sea, by setting posts supporting platform-type houses.

In each investigated city, densely inhabited areas consist of traditional houses comprising different relation to environmental water with each other, however similar to surrounding rural area of each city. We identified three types, namely, (1) Landed house, (2) Platform house on soil and (3) Platform house on water. (2) and (3) are familiar and flexible to inundation. However, sometimes increasing population density changes the use of space under the platform of (2) into dwelling space, causing vulnerable situation against inundation.

Next step was measurement of 84 sample buildings in 7 cities, namely Jakarta, Semarang, Surabaya, Denpasar, Mataram, Makassar and Banjarmasin (2001). Their past damages caused by inundation were also monitored. Major building materials of each type of houses and amount of them for 1 unit of building was calculated for each building type. Labor for building a unit was also counted as a resource invested. Combining with building density, these resulted basic unit index per hectare.

Analysis of satellite image was undertaken in parallel, by using Landsat 7 (Makassar), SPOT (Banjarmasin) and IKONOS(Jakarta and Semarang). Images are calibrated to UTM coordinate on GIS, and areas of each urban/building types are identified and measured as polygon data. Especially, IKONOS with highest resolution (1m) enabled identification of each small building, and detailed typological analysis. Contour zones are also identified as polygon, based on singular points with height notation, found in maps provided by national mapping authority (BAKOSURTANAL, 1:25,000 for cities in Jawa island, and 1:50,000 for cities in other islands). As a result, cross tabulation of urban type (land use) and contour was undertaken.

Combining these results, simple evaluation of total investment in the area where land is lower than 1m was summed up.



DENSITY
BUILDING DENSITY : 182 units/ha
HOUSEHOLD DENSITY : 255 household/ha

PER BUILDING UNIT
MATERIAL USE / UNIT :
- timber 4.5 m3 / unit
- brick 4,000 pieces / unit
- cement 1,000 kg / unit
MANPOWER INVESTED / UNIT : 4 man-month (carpenter & assistant)

PER HECTAR
MATERIAL USE / HA
- timber 819 m3 / ha
- brick 728,000 pieces / ha
- cement 182 tons / ha
MANPOWER INVESTED / HA : 728 man-month

FOR TOTAL AREA BELOW 1 M CONTOUR : 22.9 ha, all un-planned housing area
LOST LAND : 22.9 HA
BUILDING : 4,168 UNITS
HOUSEHOLDS AFFECTED : 5,840 households (need to move out)
MATERIAL USE
- timber : 18755 m3
- brick : 16,672,000 pieces
- cement : 4167.8 tons

MANPOWER INVESTED : 16,671 man-month

Fig 4 Field Measurement -> Macro data on GIS -> Assessed total impact to a city

In the final year (2002), examples of projects and public works for flood control etc. in Semarang and Makassar were monitored, which could be chosen as alternative ways for adaptation for SLR in future. Reclamation, provision of polder and pump, relocation and construction of multi-story buildings are included as cases. Based on these data, discussions in local government and local workshops were tried out, inviting resource persons, governmental officials in charge, and trees for problems and solutions were defined.

By using satellite image with high resolution, identification of land use and building typology is possible. Basic unit indexes and method for obtaining them is also applicable to various coastal cities. In case of cities where fields sampling survey is not applicable, the basic unit index of city among these, which contains similar urban/building type would be applicable for rough estimation.

In this research, we defined the basic unit index in the form of amount of materials and labor force (or man date), instead of price. It is because direct questioning of price of buildings is difficult. However, this basic data can be applicable to other Asia-pacific cities where building type is almost similar but prices of materials and labor are different. This will also prevent us from possible under-estimating the amount of impact which relatively very low price of materials and human time in developing countries implies.

3.3 Sub 3: Study on vulnerability index and vulnerability mapping for sea-level rise

3.3.1 Study on index development for vulnerability evaluation

a) Purpose of the research

The purposes of this research are

1) to collect and analyze information about natural disaster including extreme climate or weather events and those influence on human system from the international database,
2) to specify a range of complex influence caused by both the extreme climate or weather events expected to be generated frequently in the short-term and the long-term sea-level rise which global warming brings about, and
3) to develop vulnerability index system and apply it to the Asian coastal region.

b) Impacts of the natural disasters

We collected track data of cyclones in the north Indian Ocean and typhoons in the west Pacific Ocean. The period of the former cyclones data ranges from 1945 to 2000, and the period of the latter typhoons ranges from 1945 to 2000.

Using Geographical Information System (GIS), analysis on the tracks of cyclones and typhoons was conducted, and a probability of passage of cyclones and typhoons was calculated and plotted in the Asian map.

While collecting the past extreme climate or weather events and the information about the occurrence and influence of natural disasters centering on the Asian area, the feature of such natural disasters was examined. Consequently, in the Asian region, the number of occurrence of rainstorms and floods has increased for the past some decades and it is thought that the increase tendency of rainstorms and flood will cause increased number of death and disaster victims and future possible rise in the sea-level will expands influence further.

c) Development of framework of vulnerability index system to evaluate impacts of sea-level rise in the Asian region

Geographical feature, society and economic data, or countermeasures of affected area in the Asian region are examined based on a vulnerability index which is developed using the weather information, altitude of coastal lowlands and the degree of high density of population and so on.

While developing the index with which the vulnerability of the coast is expressed from these data, it aims at pinpointing a vulnerable area over present and the future using this index.

Fig. 5 shows the framework of vulnerability index system that was developed through discussion among researchers in this project. Potential coastal areas were first selected using high tide and future sea-level rise. Three potential coastal areas are as follows:

1) Coastal areas affected by historical high tide and 1 m sea-level rise
2) Coastal areas affected by 1m sea-level rise
3) Coastal areas affected by historical high tide, 1m sea-level rise, and passage of cyclones and typhoons

A definition of a vulnerability index is as follows:

$$VI = \Sigma W_i \times F_i(\text{subindex } i)$$

i=1, elevation, i=2, cyclones and typhoon passage frequency, i=3, high-tide areas. Fi( ) is a damage function that converts physical scale into risk (0 - 1).

In this research, weight of each subindex is set to equal, namely VI is calculated as an average of calculated risks.

		①Elevation	②Coastal line	③Population	④Typhoon	⑤High tide	⑥Landuse	Remarks
Potential affected areas	Data (spatial resolution)	・GTOPO30 (30"=1km) ・Global Map	・DCW ・(NOAA)	・Landscan (1km)	・Tracks (1946-2000) West Pacific, North Indian Sea (1 arc deg.)	・Tide ・High tide (historical Max.)	GLCC (Agr. & Urban) (1km)	
	Study area (direct affected area)							
	①Permanent submerged area	・Elevation				・Tide+SLR1 m		Overlay
	②Temporally submerged area	・Elevation				・Tide+SLR1 m+High tide		Overlay
	③Area affected by typhoon passage	・Elevation			・Prob. of typhoon passage	・Tide + SLR1 m+High tide		Damage funciton
	Damage function	・DF of Elevation			・DF of typhoon passage	・DF of high tide		
	Indexing	・index1			・index2	・index3		
	weighting	VI=w1 ×index1 + w2 × index2 + w3 × index3						
	Potential affected areas selected by the ①、②、③ criteria							
Indirectly affected areas	Population affected							
	①VI and population affected(1995)			・Population of vulnerable areas				
	Areas affected							
	①agri. Land						・Agri. Areas	
	②Urban areas						・Urban areas	
	Economic damage estimated	Future research themes						

Fig.5 Framework of Vulnerability Index

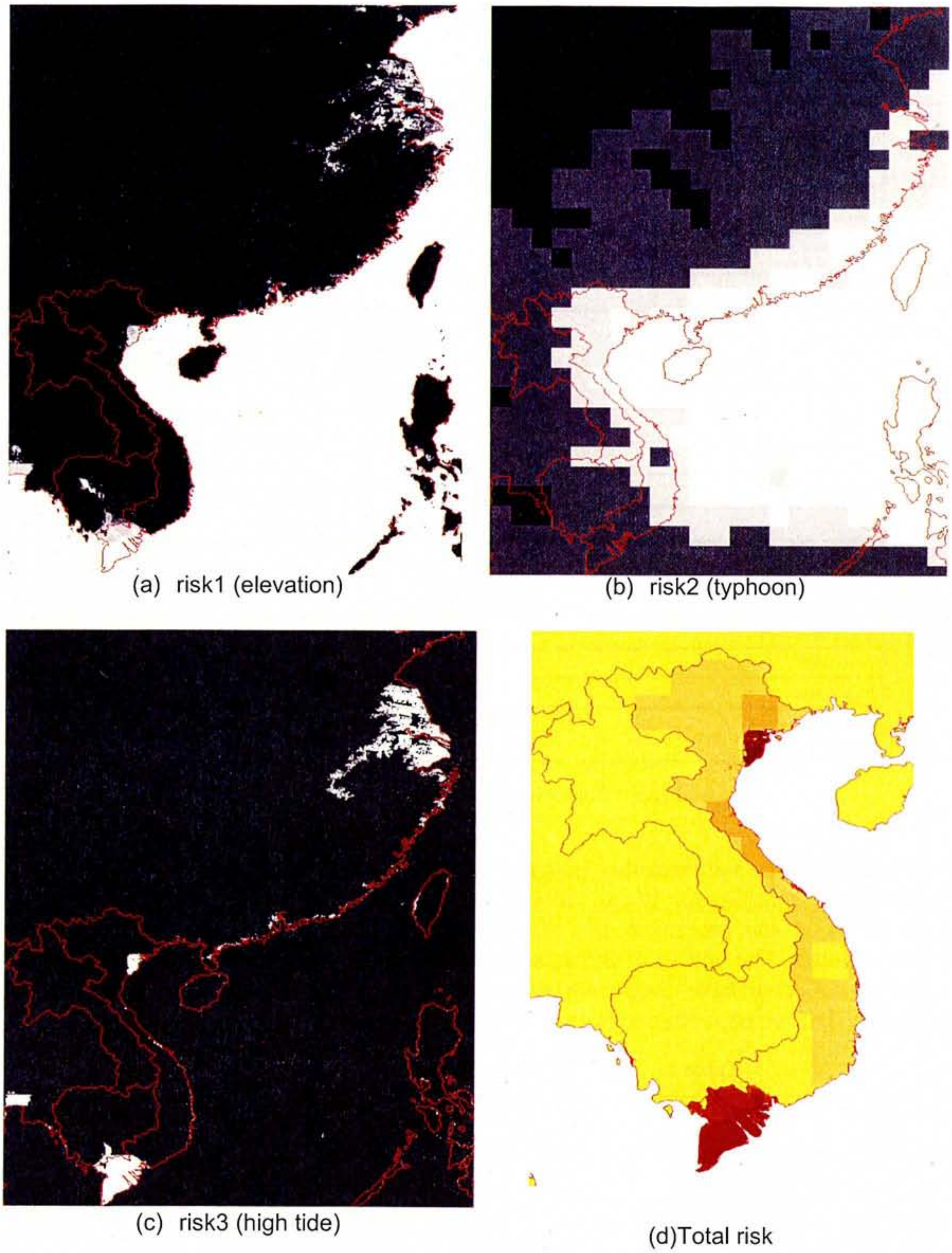
d) Application of the vulnerability index (VI) to Asian coastal region.

Development a database for VI calculation.

We collected and processed data and information which are distributed from various research institutes. The outline of the data collected in this research is listed in Table 1. Most of the data collected have their own spatial precision, but for index calculation, spatial resolution of data are converted to basic spatial resolution of 30 arc seconds data.

Table 1 Database for vulnerability index

Data Item	Contents	Temporal/spatial resolution	Grid resolution	References
Temperature anomalies	Monthly temperature anomalies map	Month/1 arc deg.	Latitude/longitude 1arc deg.	UNEP/GRID
Precipitation anomalies	Monthly precipitation anomalies map	Month/1 arc. deg.	Latitude/longitude 1 arc deg.	UNEP/GRID
Elevation	Digital Chart of the World (DCW)	Latitude/longitude 20 arc second	Latitude/longitude 30 arc second	GTOPO30
Boundary	Costal line, national boundary, river, road etc.	1:100Million～1:1000Million	Line information	UNEP/GRID
Population	Population, area, density	1990 and 1995, latitude/ longitude 2.5 arc minutes	Latitude/longitude 2.5 arc minutes	CIESIN Population Database
	Population	1995, world, continent	Latitude/longitude 30 arc seconds	LANDSCAN
Landuse	IGBP category	Latitude/longitude 30 arc seconds	Latitude/longitude 30 arc seconds	GLCC



(a) risk1 (elevation) (b) risk2 (typhoon)

(c) risk3 (high tide) (d)Total risk

Fig.6 Calculated risks in Vietnam as an example of VI

Application of the VI to the Asian coastal areas

The VI was applied to the Asian coastal region, and an example of the resultant output is shown in Fig. 6. Fig.6 shows 1) calculated risk of elevation, 2) calculated risk of cyclone and typhoon passage, and 3) calculated risk of high-tide. Based on these three risks, VI was calculated for Vietnam areas.

From the result, it is concluded that in Vietnam, northern and southern coastal areas are very vulnerable to future sea-level rise and high tide induced by extreme weather events like typhoons. In addition to these areas, coastal areas in the mid Vietnam are also vulnerable mainly because of some possibility of landing and access of typhoons, which sometimes bring heavy rain and flood in these coastal regions.

e) Conclusion

A new vulnerability index for assessing coastal regions was developed and applied to the Asian coastal region. Damage functions of physical parameters such as elevation and typhoon passes should be formulated based on more sophisticated method. However, this VI is a useful tool to identify a potential coastal area where is very vulnerable to future sea-level rise induced by global warming and occurrence of extreme events such as high-tide and heavy rain induced by typhoon and cyclones.

3.3.2 Study on vulnerability mapping for sea-level rise by GIS

An analysis of the study was made to understand how sea-level rise gives impacts on socio-economic systems and natural environment by constructing geographic information database in Asia and the Pacific Regions which collects and integrates data of population, road, railroad, air navigation facilities, power cable, telephone line, coral reef and mangrove in addition to using digital elevation model (DEM).

At first, maximum high-tide deviation in Asia and the Pacific coastal region was calculated by using existing typhoon database. Then, result of calculation, tide deviation at high tide and calculated value of future sea-level rise were added. The added value was compared with elevation data of Asia and the Pacific Region to estimate the potential damage

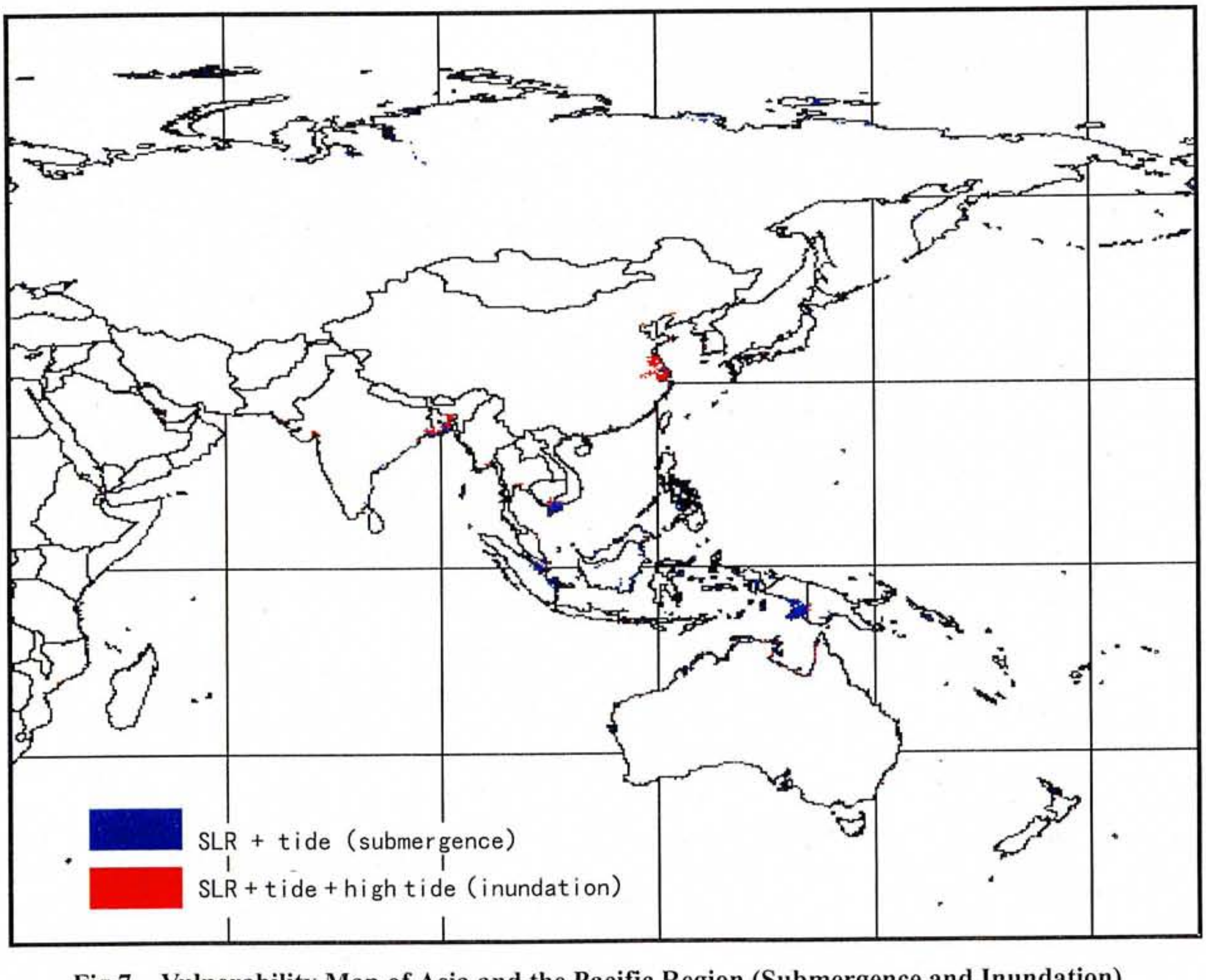


Fig.7 Vulnerability Map of Asia and the Pacific Region (Submergence and Inundation)

from inundation. At the same time, vulnerable areas were extracted and identified by producing vulnerability map of Asia and the Pacific Region (Fig. 7). The vulnerability map indicates a possibility of large-scale submergence in the following areas: Cambay Bay (India)、Ganges estuary(Bangladeshi), Yangon, Menam Chao Phraya estuary (Thailand), Mekong estuary, Southern Malay Peninsula (Singapore), Eastern coast of Sumatra, Borneo, Southern Irian Jaya of New Guinea, Carpentaria Bay (Australia), Chang Jiang estuary. In Japan, it also indicates a possibility of submergence in northern Ise Bay and northern Tokyo Bay. It became obvious that Asia and the Pacific Region is an area vulnerable to damage in the global perspective.

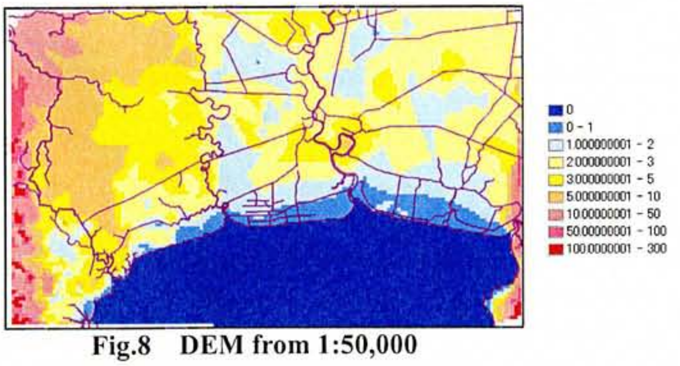


Fig.8 DEM from 1:50,000

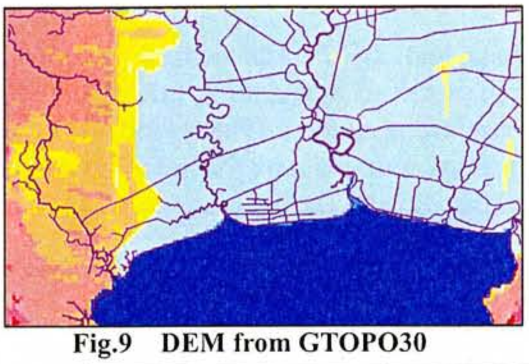


Fig.9 DEM from GTOPO30

Next, We produced digital elevation model (DEM) from the topographic map at 1:50,000 scale selecting Menam Chao Phraya estuary as the study area, and comparison was made between this data and GTOPO30 of approximately 1km resolution. From the result, it was found that the area of 3 to 5 meters high, which cannot be easily interpreted in the GTOPO30, could be discriminated in this model. At the same time, digital elevation model produced from topographic map at 1:50,000 were found to be useful to accurately assess the vulnerability of low and flat land.

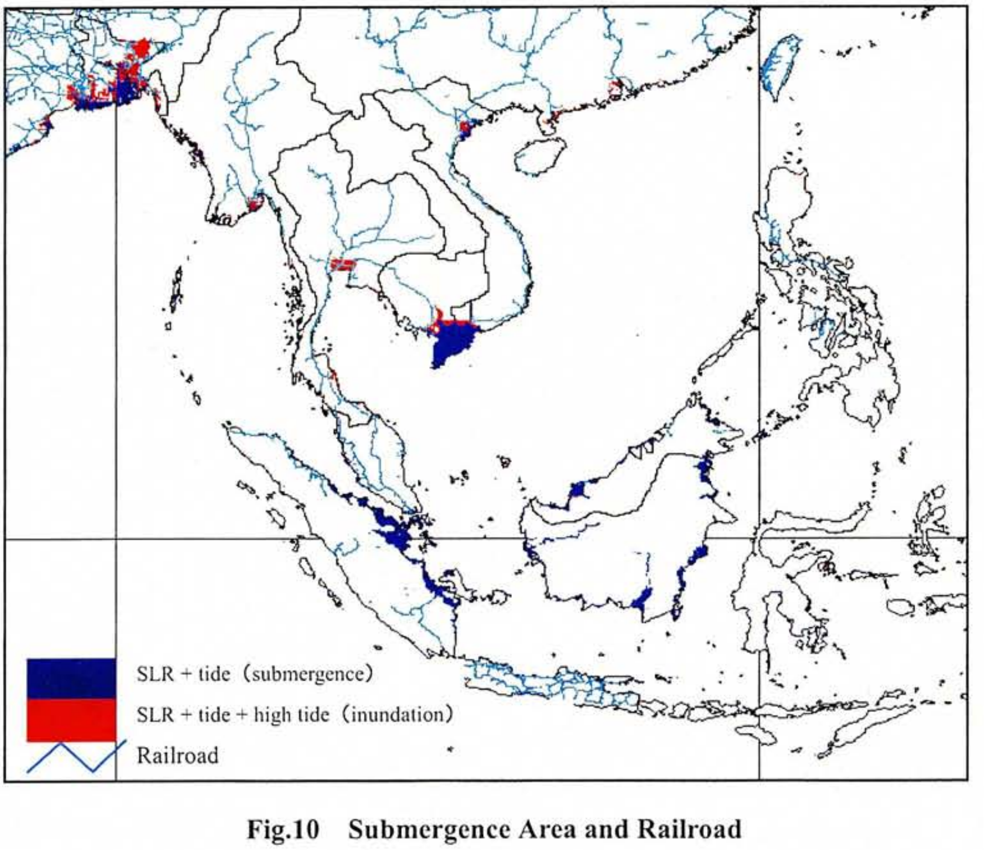


Fig.10 Submergence Area and Railroad

Further, we analyze the distribution of infrastructures that would be submerged by sea-level rise (e.g. Fig.10). We also produced land use distribution maps and industrial production distribution maps of northern Ise Bay. Then, amount of loss on land asset by use and amount of loss on production by industries were calculated. Environmental value of coastal area was assessed by creating an environmental economic assessment model which calculates the amount of damage to the environment caused by sea-level rise by applying the function of distance from the coast with an analysis based on a questionnaire survey result carried out in Japan.

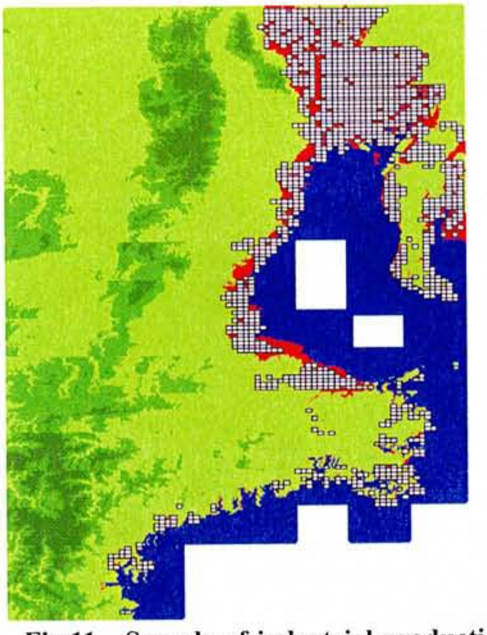


Fig.11 Sample of industrial production distribution map

This study demonstrated that Asia and the Pacific region is one of the vulnerable regions in the world and that areas particularly vulnerable are largely distributed in this region. This assessment was made to clarify the possibility of future danger that existing facilities face, and to serve as a reference that could lead to an action and a more detailed assessment. In the future, more detailed assessment is needed on the basis of these results so that different regions can cope with future sea-level rise according to a planned measure.

In the days ahead, declination of water ingression needs to be considered to make a detailed analysis of respective regions. To this end, detailed geographic information such as elevation data becomes necessary. For the extraction of areas vulnerable to sea-level rise in large areas such as Asia and the Pacific Region and the whole world, GTOPO30 is considered to be useful. However, sufficient topographic information on delta and coastal plain, which is essential to assess the impact of sea-level rise, could not be obtained sufficiently from GTOPO30. Digital elevation model (DEM) produced from topographic maps in medium or larger scale such as 1:50,000 will be useful for an accurate assessment of these vulnerabilities in the future. However, sand dune near the coast is not fully expressed even in the model produced for this study. It is expected that a method shall be developed for producing DEM to take this into account.

From the perspective of socio-economy, it is thought that land use and industrial structure gradually change parallel to sea-level rise, and planned adaptation is expected from the social point of view. In the future, it is sought that dynamic land use model and socio-economic model shall be developed taking the time-series changes and characteristics of respective regions into account and that analysis should be made by using these models.

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