Assessment of Impacts of Sea Level Rise on Coastal Lagoons —Case Studies in Japan and Thailand—

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Abstract

Global warming is one of the most serious environmental issues of the present day. The average temperature is predicted to rise 1.7℃ to 3.8℃ by the end of the next century. Sea level is also projected to rise 15 cm to 90 cm during the same period.

In this paper the authors first present an example of the assessment of impacts of sea level rise of the lagoons in Japan. We also present the common methodology of vulnerability assessment and an original procedure to assess the impact of sea level rise on the Songkhla Lake in southern Thailand. Following this procedure we describe the natural and socioeconomic characteristics of the Songkhla Lake, and we identify major factors that control the development of each natural region. It is most important to clarify the natural and socioeconomic systems and also to identify the development factors at each natural region for the proper assessment of the impact of sea level rise.

I. Introduction

The study on Land-Ocean Interaction in the Coastal Zone (LOICZ) started in 1993 as one of the Core Projects of IGBP (International Geosphere Biosphere Programme). The objective of LOICZ project is to predict the change of coastal environment by global warming in the near future, and also to develop further sustainable ways of utilization of coastal areas. Four major fields of LOICZ research are proposed as follows (Yonekura et al., 1998):

(1) Effects of changes in external forcing or boundary conditions on coastal fluxes.
(2) Coastal biogeomorphology and global change.
(3) Carbon fluxes and trace gas emissions.
(4) Economic and social impacts of global change on coastal systems.

This study focuses on the fourth domain, i.e. to forecast how the responses of coastal systems to global change affect the habitation and usage of coastal environments. Hirai (1998), one of the authors, has discussed the impacts of sea level rise on the coastal lagoons in Japan and presented strategies against their responses. In that discussion, he emphasized that the impact would have various aspects depending on the natural and socioeconomic conditions at coastal area of each lagoon. Major thirty-four coastal lagoons in Japan were grouped into five types (namely from Type-A to Type-E) in terms of "artificial littoral shoreline" and "intensive land use in littoral lowland" (Figure 1).

The littoral lowland of type-A lagoon remains almost natural without any artificial structure or land use. This type of lagoon is very valuable in Japan and important especially for the protection of wild waterfowl. The Lake Kucharo, for instance, has been registered since 1989 as one of the designated lakes of Ramsar Convention. In the littoral lowlands of type-B, the rate of artificial littoral shoreline is very low, but about 40% of the area is used for grassland. In the case of type-A and -B lagoons, few environmental changes will be observed when sea level rises several tens of centimeters to 1 m.

Littoral shorelines of type-C and -D lagoons are partly artificial and urban or industrial land use is found in the littoral lowlands. Urbanization has been taking place rapidly for the last two or three decades. In the process of development planning around these types of lagoons, it is necessary to consider carefully the influences of lake level rise caused by sea level rise.

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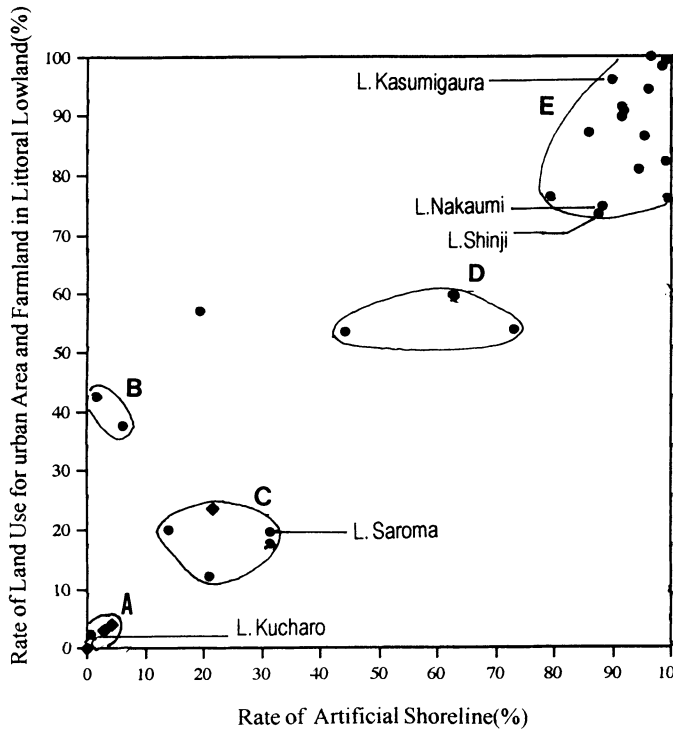

Figure 1. Relationship between "artificial littoral shorehine" and "intensive land use in littoral lowland" of lagoons in Japan

Source: Hirai (1998)

Type-E lagoons are transformed artificially to the greatest extent, and the littoral lowlands are intensively utilized. Almost all the littoral shoreline is artificially embanked with shore protections, and urban land use is predominant. In the case of this type of lagoons, the impact of sea level rise on the littoral lowland will be immense, causing serious damage to these areas.

For the sake of appropriate assessment of the impacts of sea level rise on coastal lagoons, it is most important to clarify the natural and socioeconomic characteristics of each lagoon and its littoral lowland. In this paper, the authors first show the common methodology of vulnerability assessment developed by the IPCC Coastal Zone Management Subgroup. And an original procedure is presented to assess the impacts of sea level rise on the coastal lagoons in developing countries. In this process, emphasis is laid on the identification of development factors at each littoral zone. Natural systems and socioeconomic systems in lacustrine lowlands are delineated to identify the relevant development factors, as shown in the case of the Songkhla Lake in southern Thailand.

II. Methodology of vulnerability assessment of the impacts of sea level rise

1. Common methodology of the vulnerability assessment by IPCC

The IPCC common methodology was developed by Coastal Management Subgroup of IPCC in order to promote vulnerability assessment in every country. Aiming at making assessment of vulnerability on both physical and human aspects, the common methodology consists of seven steps as shown in Figure 2 (Center for Global Environmental Research, 1996). According to this methodology, a case study area is selected and the scenario for sea level rise and climatic change is presumed at the first step. Based on the data of natural and socioeconomic systems (step-2), relevant development factors should be identified (step-3). And the assessment of physical changes and natural system responses will be conducted as the forth step.

Such physical changes may be recognized as inundation or displacement of lowlands, coastal erosion, intensification of coastal flooding, in-

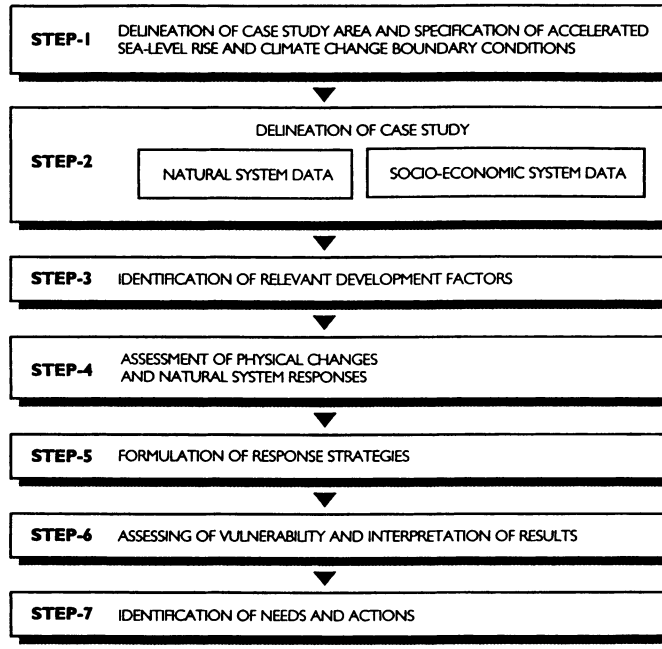

Figure 2. Common methodology of vulnerability assessment by IPCC
Source: IPCC (1992)

crease in salinity at estuary, salt water intrusion, change of tide, change of sedimentation patterns, decrease in the amount of light reaching sea bottom, and so on. On the other hand, the responses of natural system are supposed to be some impact on local ecosystems such as wetlands, tidal flats, mangroves, and coral reefs in the coastal zones. Such physical changes and responses of the natural system heavily depend on the natural or socioeconomic conditions of each lagoon or each coastal zone. That is to say, it is very important to identify the relevant development factors at each lagoon or coastal zone.

2. Original procedure of assessment of the impacts of sea level rise on coastal lagoons

Considering the importance of identifying relevant development factors, the authors show an original procedure to assess the impacts of sea level rise on coastal lagoon (Figure 3). This procedure consists of seven steps that start with collecting both general and detailed data on physical and human conditions at a study area (step-1 and step-2). The data on natural system is arranged from geomorphological and hydrological viewpoints. In the same way, the data on socioeconomic system is analyzed in relation to the land use pattern and water use conditions of the area (step-3).

Then the study area is divided into some homogeneous zones through integration of the data on natural and socioeconomic systems (step-4). After that, development factors in each zone will be identified and the impacts of sea level rise will be estimated (step-5). Then the assessment of the impact on the whole lagoon area will be made by the synthesis of assessment at each zone (step-6). Finally this procedure is supposed to be applied to other coastal lagoon areas (step-7). In this study, we discuss mainly step-3 and -4 of the procedure.

III. Natural systems in the lacustrine lowlands of the Songkhla Lake

1. Geomorphological conditions

It is very effective to know local geomorphological conditions not only for estimation of the area subject to inundation or erosion caused by sea level rise, but also for discussion about the relationship between natural and socioeconomic systems. In this study we classified our study area with such geomorphological units as follows; beach, erosional cliff, swamp, dune, beach ridge, littoral lowland, delta, Holocene lacustrine terrace, Pleistocene marine terrace, tower karst and hill or mountain. Two kinds of remote sensing

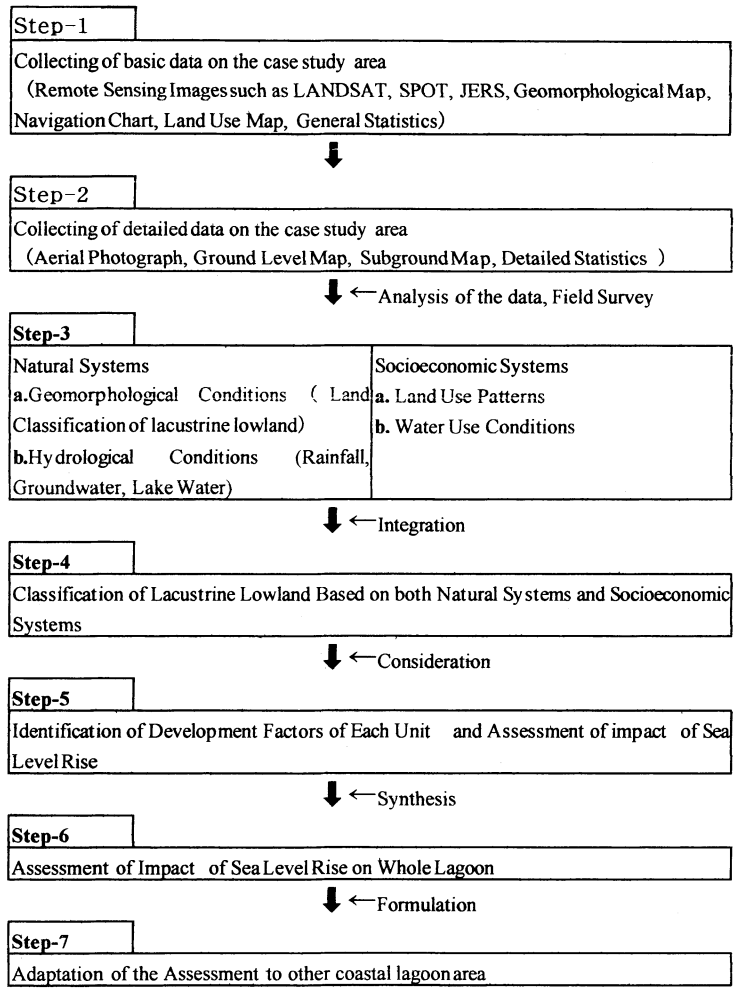

Figure 3. Original procedure of assessment of the impacts of sea level rise on coastal lagoon.

data, namely LANDSAT 5-TM images and JERS 1-VNIR images, were used to classify the topography in general. In addition, we measured actual topography in the field to prepare some cross sections of typical geomorphological units.

The Songkhla Lake, located on the eastern coast of the Malay Peninsula, is the biggest coastal lagoon in Thailand. Total area of the lake basin is about 1182 km^2 and six or seven times as large as Lake Kasumigaura in Japan. The lake is, however, very shallow and about only 1.1 to 1.8 m deep in the mean depth. It consists of three major basins; Thale Noi, Thale Luang and Thale Sap Songkhla. Thale Noi is a small lake north of Thale Luang. Thale Luang is the main lake, being separated from the Gulf of Thailand by a wide and long beach ridge plain. Thale Sap Songkhla is the southern part of the Songkhla Lake, which is linked to the sea through a narrow channel (Figure 4).

Littoral lowlands of the Songkhla Lake can be divided into five zones; (1) Beach ridge plain, (2) Thale Noi and its vicinity, (3) Western part of Thale Luang, (4) Deltaic lowlands of Thale Sap Songkhla, and (5) Holocene terraces and Pleistocene terraces.

(1) Beach ridge plain

A wide and long beach ridge plain is developed between the basin of the Songkhla Lake and the Gulf of Thailand. The width of the plain is 3 to 8 km, and its height is less than a few meters. The beach ridges are separated 200 to 300 m from each other in the northern part, but they become closer in the south, about 50 to 100 m or in a complex form (Pitman, 1985). Number of ridges

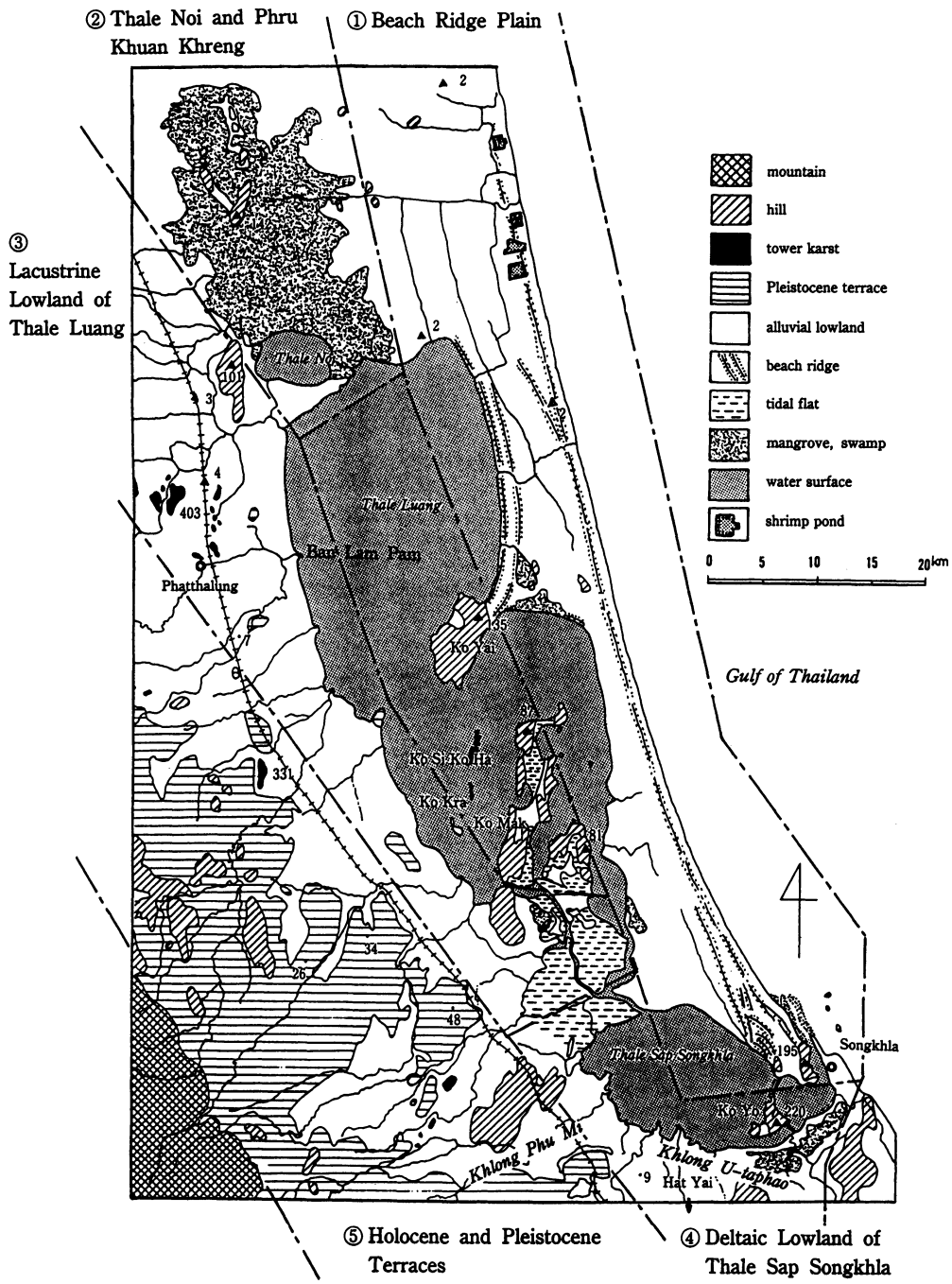

Figure 4. Geomorphological map of the Songkhla Lake Area
Source: Hirai (1995)

is reported at four in the north and eight in the south (Haruyama, 1995; Ookura et al., 1996), but we counted eight ridges in the middle part of the plain and nineteen in the southernmost part when measuring actual topography. These ridges can be grouped into 3 or 4 types by difference of their shapes. The height of the top of these ridges is about 2 to 3 m above sea level, being 1 to 2 m

higher than the lowlands between the ridges.

(2) Thale Noi and its vicinity

The area of Thale Noi itself is only 26 km^2, but a swampy area called Phru Khuan Khreng extends around the lake over 126 km^2. This huge swamp includes wetland covered with various kinds of aquatic plants, grassland, peat swamp forest, and tropical evergreen forest.

(3) Western part of Thale Luang

Marine or lacustrine lowlands lower than 10 m above mean sea level are developed along the western coast of Thale Luang. These lowlands are flooded every year because the lake level rises up to about 1 to 2 m at the maximum in the rainy season.

(4) Deltaic lowland of Thale Sap Songkhla

Present and former river deltas of the U-taphao River and the Phu Mi River are developed at the southern and western coast of Thale Sap Songkhla. The littoral shoreline of this zone is indented due to the development of natural levee along the diverged river courses. The height of this deltaic zone is so low, almost the same as the mean lake level, that the littoral lowland is often inundated by flooding every rainy season.

(5) Holocene and Pleistocene terraces

A Holocene marine or lacustrine terrace is seen at the height of below 4 m above mean sea level in the southern coast of Thale Sap Songkhla (Hirai, 1995; Haruyama, 1995). On the other hand, four kinds of Pleistocene marine terraces are developed at the height of 10 to 50m to the west of the Songkhla Lake. Among these marine terraces, the second lowest terrace (T2) covers this area most extensively at about 20m above mean sea level.

2. Hydrological conditions

Hydological data of the Songkhla Lake, both on the drainage basin and the lake systems, were collected to estimate the impacts of sea level rise, especially that of the physical changes such as intensification of flooding and increase in salinity.

(1) Hydrological conditions of the drainage basin

The study area is under tropical monsoon climate and the annual mean temperature of Songkhla City is 27.7℃ with little seasonal changes. The average annual precipitation of the basin is 2100 mm. Heavy rains are observed during the northeast monsoon season from October to December, because the dividing mountain ranges of the Malay Peninsula lie in the north-south direction to the west of the Songkhla Lake.

The groundwater of this area is found mainly in the following three types of aquifer (NESDB, 1985). Shallow but limited amount of groundwater is contained in the beach sand of the beach ridge plain east of the Songkhla Lake and also in the alluvial deposits of the western coast of Thale Luang. On the other hand, a large quantity of groundwater is contained in the deep gravel layers, which have been deposited in the bottom of ancient river channels formed at an early stage of basin development. The third type of aquifer is the fractures or solution cavities in the basal rocks or limestone in the west of the study area.

(2) The lake systems

The Songkhla Lake consists of three main lake basins; Thale Noi, Thale Luang and Thale Sap Songkhla, and it is connected to the Gulf of Thailand through a deep narrow channel to the east of Thale Sap Songkhla. The total lake area is 1082 km^2(Lake Biwa Institute and International Lake Environment Committee, 1988) to 1182 km^2(NESDB, 1985), with about 90 km length from north to south, and 25 km width from east to west. Total area of the drainage basin is 6999 km^2(Lake Biwa Institute and International Lake Environment Committee, 1988) to 8020 km^2 (NESDB, 1985).

Lake water level fluctuates usually from −0.3 m to +0.3 m above mean sea level. The annual flood peak level is commonly above +1 m, but the level rises up to about +2 m in the upper lake when extreme flooding occurs. There are almost no littoral banks or shore protections along the shoreline of the Songkhla Lake. The littoral shoreline is not defined so clearly as those of Japanese lagoons, and it generally retreats landward in the rainy season while it advances offshore in the dry season.

The lake systems of Thale Noi, Thale Luang and Thale Sap Songkhla are described in the report by NESDB (1985) as follows.

a. Thale Noi

Thale Noi has an area of 26 km^2 and mean depth of the lake is 1.1 m. This is the deepest part of the huge swamp of Phru Khuan Kreng. There is a low ridge between Thale Noi and Thale Luang at about 0.5 m above mean sea level, and a

connecting river flows across it. But at the time of flooding, two lakes connect with each other along this boundary for about 13 km.

b. Thale Luang

Thale Luang can be divided into northern and southern parts of the lake basin by the peninsula of Ko Yai, which is not a true island (*Ko*) but a land-tied island connected by tombolos.

The northern part of Thale Luang has an area of 491 km^2 and its mean depth is 1.8 m. The salinity of lake water is predominantly fresh, or lower than 1‰, but it increases above this level in August, September and November. In the years of low rainfall with long dry season or with few floods in the rainy season, its salinity is raised and may exceed 10‰. The waters of Thale Luang are usually very muddy because of fine suspended loads carried from catchment area or derived from bottom sediments by wave action.

The southern part of Thale Luang has an area of 267 km^2 and its mean depth is 1.2 m. The lake water is predominantly brackish, forming the transition zone between salty and fresh systems. Although the salinity level varies from year to year and from season to season, it usually stays at 5 to 15‰ and exceeds 20‰ in the dry season. In contrast, it becomes fully fresh in the rainy season. There are some rock islands in the southern part of Thale Luang, which suppress wave action and resuspension of bottom sediments.

c. Thale Sap Songkhla

Thale Sap Songkhla has an area of 190 km^2 and its mean depth is 1.4 m. The water quality is usually brackish or salty because this lake is connected to the Gulf of Thailand through a deep channel. The usual salinity level is 20–30‰, but it becomes fresh in the flood season, or in November, December and January.

At the southern and western coasts, the U-taphao River, which is the largest tributary stream, and the Phu Mi River flow into this lake. Therefore severe flood sometimes occurs in the littoral lowlands of this area. For example, lake level rose up to 1 to 1.2 m, inundating houses and farm gardens for two weeks in a severe flood in 1988.

2. Relationship between geomorphological and hydrological conditions

The features of natural systems in the Songkhla Lake are arranged in Table 1 from both geomorphological and hydrological viewpoints. The littoral lowlands around the Songkhla Lake area are divided into three geomorphological zones; swampy lowland, littoral lowland and deltaic lowland. They are deeply connected with the lake systems of Thale Noi, Thale Luang and Thale Sap Songkhla respectively. We can find some development factors of the study area to assess the impacts of sea level rise. The factors to be noted are as follows;

(1) Intensification of flooding at the southern coast of Thale Luang and the deltaic zone of Thale Sap Songkhla.
(2) Increase in salinity of both northern and southern parts of Thale Luang.
(3) Salt water intrusion to the groundwater at beach ridge plain, the western coast of Thale Luang and deltaic lowland of Thale Sap Songkhla.

Further investigation will be necessary on these matters.

III. Socioeconomic systems in the lacustrine lowlands of the Songkhla Lake

1. Land use

Land use is one of the most comprehensive indicators to understand local socioeconomic conditions, and is closely related with geomorphological and hydrological conditions. Land use patterns around the Songkhla Lake are classified as shown in Table 2 according to the "Land Use Map of Songkhla Lake Basin; 1996" prepared with GIS by the Laboratory of Land Reclamation at the Faculty of Natural Resources, Prince of Songkhla University.

According to the land use data on the catchment area of the Songkhla Lake (Lake Biwa Institution and International Lake Environment Committee, 1988), forest area occupied 24.7%, while agricultural land covered 73.0%, and settlement area reached only 2.3% in 1982. Agricultural land includes paddy field (35.3%) and rubber plantation (37.7%). Paddy fields are distributed mainly in the beach ridge plain and lacustrine lowland of the western coast of Thale Luang, while rubber plantations are found primarily on the Pleistocene terraces or hills in the west of the Songkhla Lake. But recently, rubber plantations are rapidly spreading by clearing natural tropical forest. Typical land use pattern in each geomorphological zone is described as follows.

(1) Beach ridge plain

Table 1. Geomorphological and hydrological conditions in the Songkhla Lake Basin

Geomorphological Conditions		Hydrogical Conditions				
		Mean Depth	Lake Level at Flood	Salinity in Lake Water	Groundwater	Precipitation
Beach Ridge Plain	Beach Beach Ridge Lowland between Ridges				Shallow Groundwater in Beach Sand	Extremely Dry in Dry Season
Swamp (Thale Noi and its Vicinity)	Swamp Grassland Peatswamp Forest Evergreen Forest	1.1 m		Fresh Water		
Littoral Lowland (Western Part of Thale Luang)	Northern Coast	1.8 m	0.5 m–0.6 m	Flood Season: Fresh Water Usually: Below 1‰ Dry Season: Above 10‰	Shallow Groundwater in Alluvial Deposits +	
	(Ko Yai: Land-tied Island) Southern Coast	1.2 m	1 m–2 m	Usually: 5–15‰ Dry Season: Above 20‰	Deep Groundwater in Frachures or Solution Cavities in Basal Rocks and Limestone	
Delta (Southern Coast of Thale Sap Songkhla)		1.4 m	1 m–1.5 m	Flood Season: Fresh Water Usually 20–30‰	Shallow Groundwater in Alluvial Deposits	
Terraces	Pleistocene Terrace Holocene Terrace Valley Bottom Plain					Heavy Rainfall in Rainy Season

Table 2. Classification of land use in the Songkhla Lake Basin

Water Surface		
Swamp		
Forest	Natural	Mangrove Forest Melaleuca Forest Peat Swamp Forest Tropical Evergreen Forest
	Artificial	Windbreak Forest
		Plantation
Agricultural Land	Paddy Field	
	Farmland	Cultivated Field Orchard
	Stock Farm Fish/Shrimp Farming Pond	
Urban Area	Residential Zone Commercial Zone Industrial Zone Public Zone Open Space	

In this beach ridge plain, settlements and orchards, especially of sugar palms, are situated on the ridges, and the lowlands between the ridges are utilized for paddy fields. But many shrimp ponds have been developed recently mainly in the northern coastal zone of this plain about 2.5 km width from the seacoast. These shrimp ponds were converted from paddy fields or fruit gardens. On the other hand, in the southern coastal zone of the plain near Songkhla City, a considerable area of lowlands between ridges has turned into wasteland without cultivation for the last 5 to 6 years. In addition to that, severe coastal erosion is taking place in this region. According to our interview with a resident in Ranot, he had to move his house twice in the last 10 years because the coast line has retreated about 35 to 40 m by erosion.

(2) Thale Noi and its vicinity

Thale Noi (28 km^2) and its vicinity (422 km^2) have been designated as a no-hunting area in 1975, and are famous for "Thale Noi Waterfowl Park" today. Although this zone is globally important for the protection of wild birds, some part of the forest in this zone has been cleared by local people for timber and fuel wood.

(3) Western part of Thale Luang

In this zone, lacustrine lowland is utilized mainly for paddy fields, but the farmers also grow many kinds of fruit trees and raise chickens and pigs. Some farmers began fish or shrimp cultivation in recent years. They made small ponds converted from paddy fields. This zone is characteristic of diversified farming, or so-called mixed farming.

The Khuan Rae River flows into the northern part of Thale Luang from the west, forming a small delta about 500 m in width, on which Lam Pam Resort was opened in 1992. There is an amusement complex with some restaurants, a campsite, a small park and so on. But its physical conditions are disadvantageous, as those facilities were almost submerged in December of 1997 when we visited. People say that lake level in the flooding season rises about 50 to 60 cm higher than usual.

On the other hand, along the western coast of the southern part, lacustrine lowlands are utilized for rubber plantations as well as paddy fields and fruit gardens. Although soil condition of such lowland is not suitable for rubber cultivation, the farmers try to grow rubber trees to earn more money by receiving government subsidies.

(4) Deltaic lowland of Thale Sap Songkhla

New settlements with detached urban type houses, or housing estates, have appeared along the former river course of the U-taphao River.

And it is remarkable that a great number of shrimp ponds have been built on a large scale one after another along the littoral lowland of the southern coast. On the other hand, a complex of government facilities, such as municipal hospital and college, was constructed recently in the lowland near the new bridge across the lake through Ko Yo. The built-up area with large factories and commercial buildings is rapidly expanding around this complex. These lowlands were formerly covered with mangrove and *melaleuca* forests.

(5) Holocene and Pleistocene terraces

Rubber plantation is the most predominant land use on the Holocene and Pleistocene terraces, but many "open lands" are recognized in the "Land Use Map of Songkhla Lake Basin; 1996". In this map, the land where old rubber trees, aged about 25 to 30 years, have been cleared and left without vegetation is assigned to "open land". In such "open land", the red soil covering terrace surface will be eroded by heavy rains, and this makes more fine materials flow into the Songkhla Lake in the rainy season.

2. Water use

It is necessary to make a comprehensive survey about actual water use conditions in the study area for assessment of impacts of sea level rise. But systematic data on water use in this area has not been collected yet. Accordingly only a brief note is presented here as inductive information obtained from interviews at each location during 1997/98 surveys.

(1) In the northern part of beach ridge plain, they can crop rice twice a year owing to the government irrigation system, which utilizes the water from Thale Luang. The pumping station is located on the northeastern coast of the lake. But they cannot use water when its salinity level rises over 1.5‰, as in the dry season of 1990. They say that such a problem arises about every ten years. In the coastal area, shrimp farmers use a large amount of seawater for shrimp cultivation, and polluted waste water is said to flow into irrigation canals or directly into the Gulf of Thailand.

(2) In the middle to southern part of beach ridge plain, local people use more rainwater because groundwater from shallow well is salty except in October. The communal irrigation system, which utilizes the lake water, is also suffering from salinity problem more seriously than the government system because of its lower location of water intake.

(3) In the delta of Phu Mi River on the western coast of Thale Sap Songkhla, they use two kinds of groundwater; from shallow aquifer and also from deeper one about 50m in depth. The former contains high salinity and is used only for general purposes, while the latter can be utilized for drinking and irrigation.

3. Socioeconomic characteristics of the Songkhla Lake area

Typical land use patterns and water use conditions in the study area are examined for each geomorphological zone (Table 3). Their socioeconomic characteristics and potential environmental problems are described as follows;

(1) Beach ridge plain

The area of shrimp ponds has been expanding rapidly for the last two decades from north to south along the coast of this beach ridge plain. In this area, many palm trees on ridges are dying because of the increase in salinity of groundwater. On the other hand, in the double-cropping area in the northern part of this plain, the increase in salinity of the lake water will be a serious problem when the sea level rises in future because the irrigation system of this area depends on the fresh lake water.

(2) Western part of Thale Luang

In this zone, rice cultivation is the most extensive and predominant land use for the moment, and normal flooding does not damage it severely. It is, however, necessary to pay more attention to the vulnerability of new types of land use against inundation. Some new types of land use, such as a resort area, fish farming ponds, grassland for dairy cattle and rubber plantations, have been introduced to the littoral lowland along the lake coast.

(3) Deltaic lowland of Thale Sap Songkhla

Rapid development of shrimp ponds on a large scale as well as urbanization in the suburbs of Hat Yai and Songkhla City are in progress with deforestation of mangrove and *melaleuca* forests. It is important to prevent water pollution caused by the waste water from shrimp farming and urban activities. At the same time, new urban areas should be protected from severe floods or long-term inundation.

(4) Holocene and Pleistocene terraces

Rubber plantations have spread from the top of

Table 3. Land use and water use in the Songkhla Lake Basin

Geomorphological Conditions		Land Use Pattern	Water Use Condition	Environmental Porblems
Beach Ridge Plain	Beach/Sand Dune	Shrimp Farming Pond	Pumping Up Sea Water	Water Pollution
	Beach Ridge	Settlement/Fruit Garden	Shallow Groundwater	Increasc in Salinity
	Lowland between Ridges	Paddy Field (Partly Waste Land)	North: Lake Water South: Rainfall/Farm Pond	Increase in Salinity
	Lacustrine Lowland East coast of Thale Luang	Melaleuca Forest (Partly Waterfowl Park)		
Thale Noi Swamp	Swamp Grassland Peat Swamp Forest Tropical Evergreen Forest	Partly Waterfowl Park (Partly Paddy Field) (Partly Used for Wood or Fuel)		
Thale Luang Lacustrine Lowland	Northern Coast	Paddy Field (Partly Fish Farming) Grassland Fruit Garden	River Water/Reservoir	
	Khuan Rae River Delta	Resort Area		Flood
	Southern Coast	Paddy Field Fruit Garden Rubber Plantation		
Thale Sap Songkhla Delta	Thale Sap Songkhla Southern Coast	Shrimp Farning Pond Public Space	Lake Water	Water Pollution Flood
	U-tapao River	Settlement		Flood
	Phu Mi River	Factories Truck Farm Rubber Plantation Paddy Field	River Water Groundwater	Water Pollution Increase in Salinity Flood
Terraces	Pleistocene Terraces Holocene Terraces Valley Bottom Plain	Rubber Plantation (Partly Deforestation) Paddy Field		Flood

Table 4. Development factors in the Songkhla Lake Basin

Geomorphological Zone	Distinctive Units	Development Factors
Beach Ridge Plain	Northern Coastal Lowland	Shrimp Farming, Water Pollution, Coastal Erosion
	Northern Lacustrine Lowland of Thale Luang	Irrigation System by Lake Water, Increase in Salimity
	Southern Lacustrine Lowland of Thale Luang	Bird Sanctuary, Preservation
	Southern Coastal Lowland	Urbanization, Waste Farmland, Reclamation
	Northern Lacustrine Lowland of Thale Sap Songkhla	Shrimp Farming, Water Pollution
	Spit South to the Outlet of Thale Sap Songkhla	Urban Area of Songkhla City, Coastal Erosion, Inundation
Thale Noi and its Vicinity	Thale Noi and its Vicinity	Waterfowl Park, Preservation
Western Part of Thale Luang	Northern Lacustrine Lowland	Mix Farming, Irrigation System by Reservoirs, Resort
	Southern Lacustrine Lowland	Rubber Plantation, Increase in Salinity of Groundwater
Deltaic Lowland of Thale Sap Songkhla	Delta of U-tapao River and Phu Mi River	New Housing, Flood, Water Pollution
	Northern Lacustrine Lowland of Thale Sap Songkhla	Urbanization. Flood, Water Pollution

Note: This is a tentative inventory according to the first general on-site survey.

the terrace to both hilly areas and lacustrine lowlands. Soil erosion may become more severe on the slopes and greater amounts of fine materials will flow into the lake and deposit there in the rainy season.

IV. Concluding Remarks

The final goal of this study is to make an assessment of the impacts of sea level rise on the coastal lagoons in developing countries. For the first step of this study, the authors presented an original procedure of assessment. And as a case study following that procedure, the data on both natural and socioeconomic systems in the lacustrine lowlands of the Songkhla Lake are collected and analyzed. According to our study, the lacustrine lowlands can be divided into eleven distinctive geographical units, and the development factors of each unit are identified tentatively as shown in Table 4.

Lacustrine lowlands of the Songkhla Lake are classified into four zones from geomorphological and hydrological viewpoints; Beach ridge plain, Thale Noi and its vicinity, Western part of Thale Luang, and Deltaic lowland of Thale Sap Songkhla. Each zone except Thale Noi and its vicinity consists of some distinctive sub-units with different land use patters and water use conditions. And development factors were reasoned from natural and socioeconomic features of each unit.

In order to carry forward this study for more precise assessment, it is necessary to identify the development factors more precisely with the help of more systematic data on both natural and socioeconomic systems. More detailed comparison with the case of lagoons in Japan as well as more intensive use of GIS data with discussions in the field survey would be helpful to elaborate the procedure of the assessment.

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