Assessment of Impacts of Sea Level Rise on Tam Giang-Cau Hai Lagoon Area Based on a Geomorphological Survey Map

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Abstract

A big flood disaster hit the Tam Giang-Cau Hai lagoon area in 1999. More than 700 people were killed and many houses were broken and washed out by very high flood in the riverside and coastal lowland. We are apprehensive that such a flood might occur more frequently if the sea level rise caused by the global warming continues as it is.

The purpose of this study is to forecast how the sea level rise affects both natural and socioeconomic systems of the Tam Giang-Cau Hai lagoon area in Central Vietnam, and to make proper adaptive strategies against the impacts of future sea level rise and to mitigate flood disaster. To assess the impacts of sea level rise on coastal lagoons, the data on the physical system is organized from geomorphologic and hydrological viewpoints, while the data on the socioeconomic system is analyzed in relation to some specific land use patterns and water use conditions. Then the study area is divided into seven homogeneous zones mainly based on landform classification, and development factors in each zone are identified. The impacts of sea level rise are estimated and some response strategies against the impacts are proposed as follows.

(1) In the valley plain along the Huong River the maximum flood level should be higher than at present. It is required to establish some alarm and refuge systems against extraordinary flooding. (2) In the urban area of the Hue City the ground level is so low that this area would suffer from severe flooding more frequently. Some civil engineering work is needed to protect the city against deep inundation and thick sedimentation. (3) In the back marsh behind the inner ridged plain, paddy fields will be seriously damaged by long-term and deep inundation. It is supposed that aquaculture is more adaptive than paddy field. (4) The inner ridged plain is higher than 4 m above sea level, so it is supposed not to be affected by the future sea level rise. (5) In the lacustrine lowlands along the lagoons, the whole area except the Holocene lacustrine terraces will be submerged by sea level rise of 1 m. So people should set up some refuges or shelters from the flooding. (6) In the outer ridged plain, coastal erosion will become increasingly severe. And low and narrow places of the barrier beach will be easily washed out by a heavy flood. It is most important to estimate the area which will suffer from erosion. (7) In the southern lacustrine lowland of the Cau Hai lagoon, people need to pay attention not only to possible inundation but also to the debris flow from back slope caused by a heavy rain.

I. Introduction

Global warming is one of the most serious environmental issues at present. According to the IPCC fourth assessment report presented in 2007, the global surface temperature has increased 0.74℃ over the last 100 years and will increase from 1.8 to around 4℃ by the end of this century. In the same way, the mean sea level has risen 17 cm over the last century and is projected to rise from 18 to 59 cm by the end of this century compared to the level at the end of the last century. And it worries us greatly that the scale of tropical cyclones will be larger or stronger.

In a lagoon area, barrier beaches and sand dunes, deltas and back marshes, tidal flats and mangrove or melaleuca forests are widely developed. But the heights of these lowlands are only a few meters from the present sea level, and most of them are made of soft sediments. So a large part of lacustrine or coastal lowlands in a lagoon

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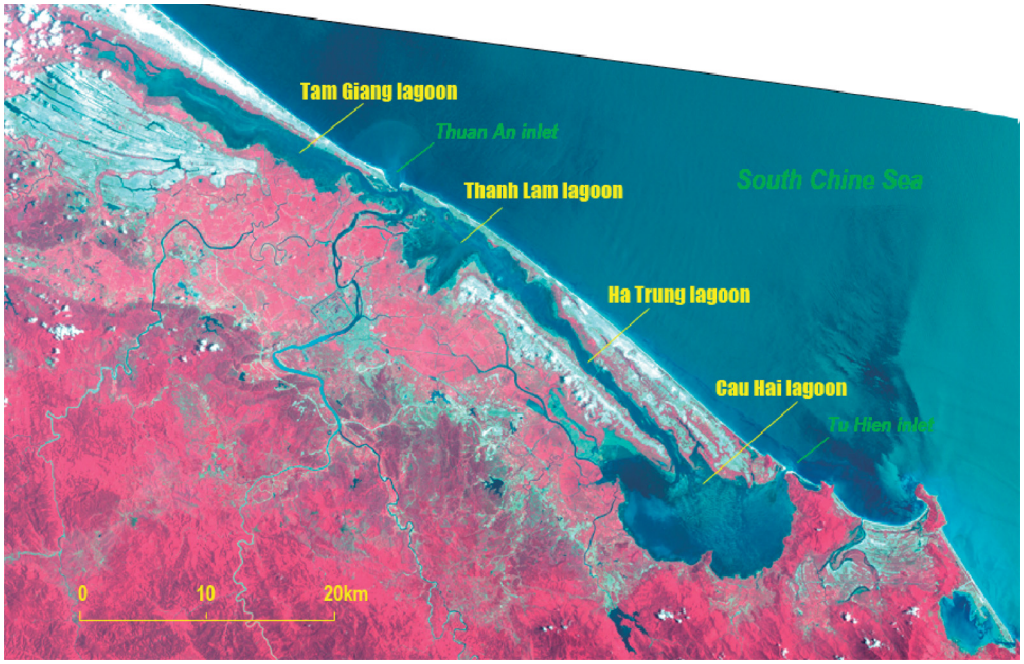

Fig. 1. Tam Giang-Cau Hai lagoon area (Landsat 7 ETM: 21 April, 2003)

area is very vulnerable to flooding and coastal erosion even in the present situation. So if the rise of sea level continues, floods or erosion will be more serious in such a lagoon area. In addition, salinity of the lagoon water will increase and salt water will intrude into the freshwater aquifer, causing people to be largely unable to use ground water for drinking and cooking. Thus, the impacts of sea level rise on a lagoon area will not be limited to the natural environment, but will also have a serious effect on the socioeconomic system in each local community.

So it is very important and necessary to study the impacts of sea level rise, and to make proper response strategy and adaptation against such impacts in each area. One of the authors, Hirai, has investigated some coastal lagoon areas of Japan, Thailand and Vietnam to assess the impacts of sea level rise on the coastal plain and lacustrine lowlands (Hirai *et al.*, 1999; Hirai, 2000, 2001, 2002, 2003). In this paper the authors present a case study of the Tam Giang-Cau Hai lagoon area in Middle Vietnam, where a big flood disaster occurred in 1999.

II. Tam Giang-Cau Hai Lagoon and the Big Flood Disaster in 1999

In the coastal plain of Central Vietnam, there are many lagoons with barrier beaches and sand dunes along the coasts from Quang Binh Province to Phu Yen Province. Above all, in the coastal plain of Tua Thien Hue Province, there is a series of big lagoons, namely Tam Giang, Thanh Lam, Ha Trung and Cau Hai lagoon.

The total area of this lagoon system is about 250 km^2 and the mean depth of each lagoon is very shallow, about 1m or 2 m deep. The lagoon water is normally linked to the South China Sea through two inlets, namely the Thuan An inlet off the mouth of Huong River and the Tu Hien inlet located in the northernmost part of the Cau Hai lagoon. Between these lagoons and the South China Sea, there is a narrow and long barrier beach with sand dune, about a few hundred meters to 4 km in width, but its ground level is very low, only a few meters to a maximum of 30 m (Fig. 1).

In November 1999 a big flood hit this area. More than 700 people were killed by a very high flood both of the riverside and lacustrine lowlands, or were killed by debris flows in the moun-

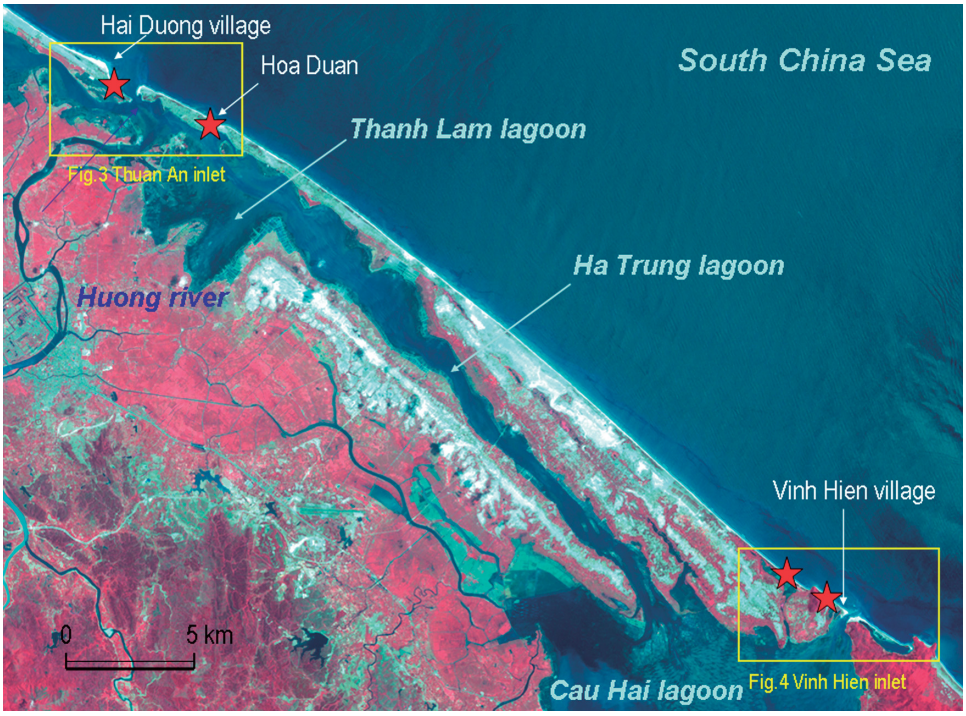

Fig. 2. Location of the washout of barrier beach (red star mark) at the 1999 flood

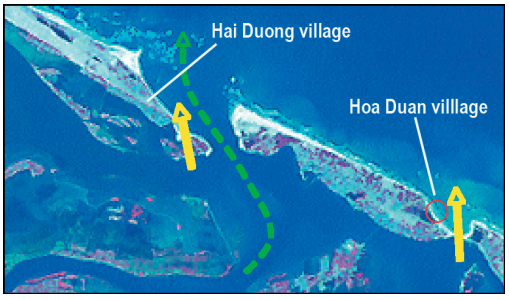

Fig. 3. Thuan An inlet in November 2000

Fig. 4. Vinh Hien inlet in November 2000

(Green broken line is original waterway before the flood and yellow line shows the flash flow at the flood.)

tain area. In the lagoon area the highest water level at the flood reached to 4 m above the mean sea level. Consequently some places of the barrier beach near the original two inlets were washed out by a strong flash flow from the lagoon to the open sea (Hirai *et al.*, 2001; Fig. 2).

At the places of washouts of barrier beach, some houses were broken and a line of Casualina (Phi Lao) trees as a windbreak on the beach was washed away directly by the flash flow. This flood directly not only caused big damages at that time, but also some remarkable physical and socio-economic changes occurred in this area after the flood. Severe coastal erosion occurred in the northwestern beach of each collapsed place of the barrier beach, and shrimp farming developed rapidly in the lagoon water and lacustrine lowlands.

In the northwestern beach of Hoa Duan, which is one of the washouts, rapid coastal erosion occurred just after the flood, and five private houses and five small resort hotels collapsed due to severe coastal erosion. Also in the northwestern beach of Hai Duong village, beach and sand dunes were eroded to some ten meters in width,

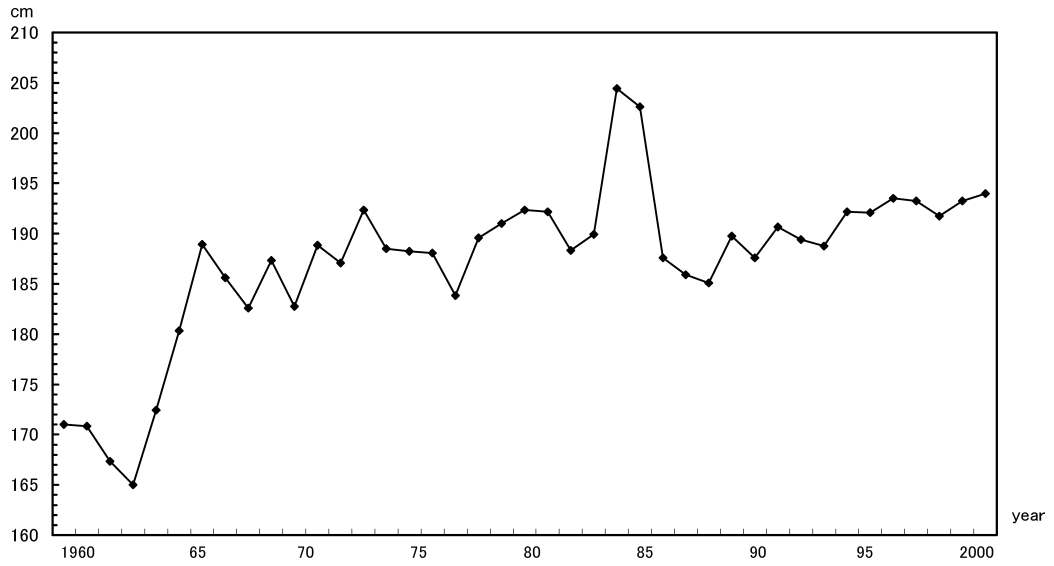

Fig. 5. Sea level change at Hon Dau station from 1960 to 2000 (annual mean)

some kilometers in length, and consequently a lighthouse and twenty houses fell down into the sea (Fig. 3). In the same way, at the northwest beach of Vinh Hien inlet newly opened after the flood, people of Vinh Hien village had to move inland to live and get some fresh groundwater, because coastal erosion occurred about some ten meters in width every winter season after the flood (Fig. 4).

Why was the barrier beach washed out at so many places and why did the severe coastal erosion occur and continue for about four years after the flood? The main factor of the washout of the barrier beach was a heavy rainfall more than 2,000 mm in a week and remarkably high water level of the lagoon at about 4 m above the mean sea level. But the background of the washout is considered to be continuous coastal erosion from the 1960s in this whole coastal area.

On the other hand, the trigger of the severe coastal erosion after the flood is the occurrence of deep depressions about 5 m or more in depth by strong flash flow at the time of the flood. The beach sand moved into this depression by the coastal current from northwest to southeast every winter season, so the northwestern beaches were eroded very rapidly after the flood until drifting sand filled up the depressions.

The flood of 1999 was the biggest in the last forty-six years in this area. But it is considered that such big floods will occur more frequently if the sea level continues to rise at the current rate. According to the tidal data at Hon Dau station near Haiphong in the Gulf of Tonkin (Bac Bo), the annual mean sea level has risen about 18cm over the last forty years (Fig. 5). This sea level rise is about twice the speed of that represented in the IPCC fourth assessment report.

The authors conducted an assessment study of the impacts of sea level rise in Tam Giang-Cau Hai lagoon area to mitigate the flood disaster in the future. The methodology for the assessment of impacts of sea level rise is explained below. We will discuss about the impacts of sea level rise on this area, and propose some strategies of response.

III. Methodology for the Assessment of Impacts of SLR

The methodology to assess the impacts of sea level rise on coastal lagoons, shown in Fig. 6, consists of five steps (after Hirai *et al.*, 1999). The procedure starts with collecting both general and detailed data such as topographic maps, remote sensing images, aerial photographs, statistics on natural and socioeconomic conditions and so on (Step-1). And both natural and socioeconomic systems of the study area are described. The data on the natural system is collected mainly from geomorphologic and hydrological viewpoints. In the same way, the data on socioeconomic system is analyzed in relation to specific land use and water use (Step-2).

Then the study area is divided into some homo-

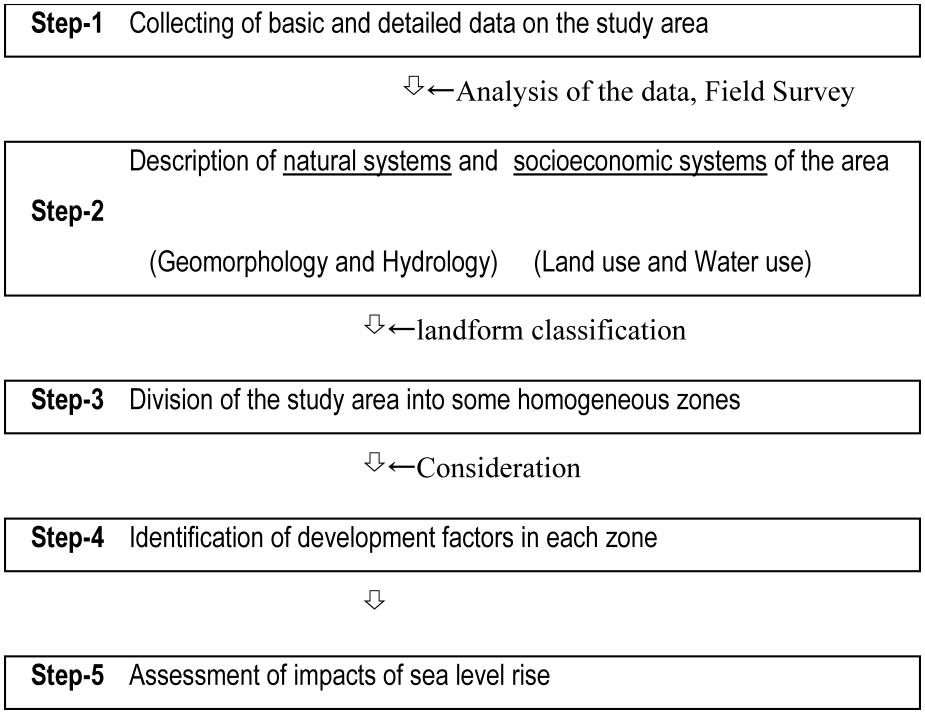

Fig. 6. Procedure for assessment of impacts of sea level rise (after Hirai *et al.*, 1999)

geneous zones through integration of the data on natural and socioeconomic systems (Step-3). In this step, landform classification is the most practical way to divide the area, because the impacts of sea level rise, such as inundation, coastal erosion, flooding and salinity change, heavily depend on local landform or microtopography of each area. In the next step, "development factors" in each zone are identified (Step-4). "Development factors" in step-4 means some specific characteristics of each zone, which may control, promote or limit the development of each area in the future. After identification of "development factors" of each zone, some impacts of sea level rise can be estimated.

In this procedure "division of the study area by landform classification" and "identification of development factors in each zone" are most important.

IV. Landform Classification and Identification of Development Factors

We made "A Geomorphological Survey Map of Hue Lagoon Area in the Middle Vietnam Showing Impacts of Sea-level Rise" to assess the impacts of sea level rise in the future and to mitigate flood disaster in this area. This geomorphological survey map presents landform classification and some specific land use. Landforms in this area are classified into a. mountain and hill; b. Pleistocene terraces; c. inner and outer ridged plains; d. sand dune; e. lacustrine terrace and lowland; f. valley plain; g. natural levee; h. back marsh; i. reclaimed land. Three types of shrimp ponds are marked as a particular land use to consider vulnerability against the impacts of SLR. The first type of shrimp ponds are those built in lacustrine lowland before the flood, the second are built in the paddy field after the flood, and the third are built in the lagoon after the flood. We also conducted a fact-finding survey on hydrological conditions, such as the state of regional groundwater and the state of flooding in 1999.

After the fieldwork, we divided the study area into seven geomorphological zones mainly based on landform classification and particular land use. That is (1) Valley plain along the Huong River; (2) Urban Area of Hue City; (3) Back marsh behind the inner ridged plain; (4) Inner ridged plain; (5) Lacustrine lowland along Tam Giang, Thanh Lam and Ha Trung lagoons; (6) Coastal

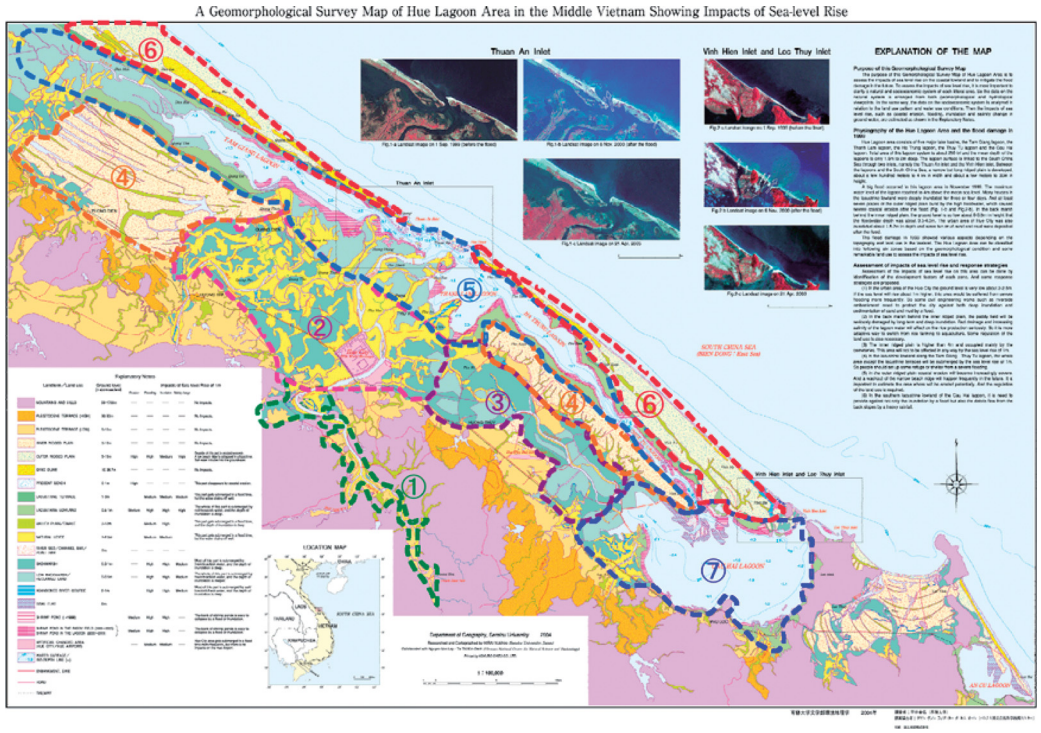

Fig. 7. Regional division of the study area for the assessment of impacts of SLR and the mitigation of flood disaster

①Valley plain, ②Hue City, ③Back marsh, ④Inner ridged plain, ⑤Lacustrine lowland, ⑥Coastal sand dune, ⑦Cau Hai lagoon

Table 1. Geomorphological zone and development factors in the Tam Giang-Cau Hai lagoon

Geomorphological zone	Development factors
①Valley plain	very high flood
②Hue City	dense population, world heritage
③Back marsh	reclaimed land, bad drainage, rice farming
④Inner ridged plain	cemetery area
⑤Lacustrine lowland	low ground level, lacustrine terrace, rice farming, shrimp farming
⑥Outer ridged plain	coastal erosion, new type of shrimp farming
⑦Cau Hai lagoon	debris flow, changes of inlets

sand dune and (7) Lacustrine lowland of Cau Hai lagoon (Fig. 7, see the attached original map).

After the division of the study area, development factors of each zone area were identified by analyzing collected data and field survey (Table 1).

(1) Valley plain: In the middle reach of the Huong River, at Dinh Mon and Vo Xa villages, the maximum water level of the flood in 1999 was 13.1 m above the ordinary river surface, while the normal flood level every year is about 8.2–8.9 m. Generally the maximum flood level is so high in the valley plain that many houses are often flooded.

(2) Urban area of Hue City: There are about 250,000 people in the urban area of Hue City.

And the ruins of the palace of the Nguyen Dynasty (1802–1945), which are located at the left bank of the Huong River, have been registered as one of the World Heritage by UNESCO. This area of which ground level is very low at about 1–2 m high was damaged by severe inundation and thick sedimentation of sand and mud at the flood in 1999.

(3) Back marsh behind the inner ridged plain: The ground level of the back marsh behind the inner ridged plain is very low at about 0–0.5 m in height. Some part of this area is reclaimed land which is below 0 m in elevation. Major land use of this area is paddy field, which was inundated deeply to about 3.5–4.0 m in depth and damaged by salt water by the flood in 1999.

(4) Inner ridged plain: The inner ridged plain is higher than 4 m above sea level and occupied mainly by many cemeteries.

(5) Lacustrine lowland along lagoons: Lacustrine lowland along the lagoons is very low, about 0.5–1 m. The maximum water level of the flood in 1999 reached over 3.0 m, thus many houses and the whole paddy field were deeply inundated for three or four days. After the flood many shrimp ponds have been made both on the lacustrine lowland and in the lagoon water.

(6) Outer ridged plain: Outer ridged plain consists of barrier beach, sand dune and long swale in the middle. Low and narrow parts of the barrier beach near the original two inlets were washed out (Fig. 3 and Fig. 4). And after the flood the rapid coastal erosion occurred in the beach and sand dune, and consequently many houses including a lighthouse fell down into the sea as mentioned in the chapter 2.

(7) Lacustrine lowland of the Cau Hai lagoon: In the southern lacustrine lowland of the Cau Hai lagoon, many people died from debris flows from the steep slope of mountains behind their villages in the last flooding.

V. Assessment of Impacts of SLR and Response Strategies

Assessment of the impacts of sea level rise on this area can be done by identification of the development factors of each zone as mentioned before. Some response strategies against the impacts are proposed as follows (Table 2).

(1) Valley plain: In the valley plain along the Huong River the maximum flood level in the future will be higher then the present without any countermeasures against big flooding. So in this area it is required for the local people first to establish some alarm and refuge systems against extraordinary flooding.

(2) Urban area of Hue City: If the sea level will rise about 1m higher, this area would suffer from severe flooding more frequently. So in this area some civil engineering works such as riverside embankment of flood way should be done to protect the city against both deep inundation and sedimentation.

(3) Back marsh behind the inner ridged plain: If the sea level rises further, paddy fields in this area will be seriously damaged by long-term and deep inundation. In addition, bad drainage and increasing of salinity of the lagoon water will seriously affect rice production. In this case it is

Table 2. Impacts assessment and response strategies in Tam Giang-Cau Hai lagoon area

Geomorphological zone	Impacts assessment	Response strategy
①Valley plain	severe flooding	alarm and refuge system against the flood
②Hue City	flooding	Flood control works such as embankment of flood way
③Back marsh	deep and long-term inundation	regulation of land use, switch from rice farming to aquaculture
④Inner ridged plain	(no impact)	(nothing)
⑤Lacustrine lowland	severe flooding, salinity change	temporary refuge, sustainable aquaculture
⑥Outer ridged plain	severe coastal erosion, washout of barrier beach	regulation of land use, retreat to the inland
⑦Cau Hai lagoon	flooding, debris flow, salinity change	alarm and refuge system against the debris flow, forestation

more adaptive to switch from rice farming to aquaculture of fish or shrimp farming. Some regulation of land use is also necessary in this area.

(4) Inner ridged plain: This area wasn't damaged anywhere by the flood in 1999. There will be no impact of sea level rise of around 1 m on this area.

(5) Lacustrine lowland along lagoon: The whole of this area except the Holocene lacustrine terraces will be submerged by sea level rise of 1 m. So people should set up some refuge or shelter from severe flooding. It might be better for them to convert their main productive labor from rice farming to aquaculture in order to adapt further.

(6) Outer ridged plain: In this area coastal erosion will become increasingly severe in the future, and low and narrow places on the barrier beach will be washed out more frequently by floods. Furthermore rapid and severe coastal erosion will occur around such washouts. People cannot protect their land and houses by any countermeasures; therefore they have to move inland. So in this case it is most important to estimate the area which will suffer from the erosion. Some regulation of land use is also required.

(7) Cau Hai lagoon: In this area they need to pay attention not only to the inundation of the lowland but also to the debris flow from back slope by a heavy rainfall. So they need some alarm and refuge system against the debris flow, and forestation in the drainage area is required.

VI. Conclusions

Sea level rise in the future will affect not only natural systems but also socioeconomic systems in Tam Giang-Cau Hai Lagoon area. So it is very important to assess the impacts of sea level rise more clearly, in order to prepare some response strategies and risk management plans against the impacts of SLR, especially against a flood disaster. We can contribute to such assessment or preparation by using a geomorphological survey map.

"A Geomorphological Survey Map of Hue Lagoon Area in Middle Vietnam Showing Impacts of Sea-level" (attached original map) was made based on geomorphological land classification and some particular land use. And each landform or land use unit is evaluated for its vulnerability to future sea level rise of 1 m, as "no impact", "medium" and "high". Four kinds of impacts, such as erosion, flooding, inundation and salinity change, are assessed by every landform unit or land use. By using this map, we can evaluate which area is most vulnerable to sea level rise, and make proper response strategies and risk management plans against the impacts of sea level rise.

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