GEOSYNTHETIC-AIDED ADAPTATION AGAINST COASTAL INSTABILITY CAUSED BY SEA-LEVEL RISE

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ABSTRACT

Among the impacts of global warming, sea-level rise (SLR) poses the greatest threat to the stability of human habitation along coastlines. Areas along coasts and rivers have been affected by SLR, underscoring the need to assess the vulnerability of coasts and the effectiveness of riverbanks. It is therefore necessary to develop countermeasures to mitigate the influences of strong and persistent SLR for coasts and river levees. Among the options available for countering these threats, the application of geosynthetics is a promising strategy, not only for coastal structures but also for river levees that are affected by wave action, which is sometimes severe enough to produce storm surges. Geosynthetics are designed in accordance with natural, social, and economic circumstances of the region. For example, low-cost construction materials such as jute and palm tree fiber are available as natural geosynthetics for the construction of infrastructure where greater strength and resilience are needed. Artificial geosynthetics must be selected to meet the requirements of each infrastructure project. This report presents a proposal of a procedure for selecting natural and artificial geosynthetics, particularly for adaptive measures against increasing erosion and inundation attributable to SLR. In addition, the report presents a discussion of the application of traditional and advanced geosynthetics as adaptive measures against coastal and river erosion even when severe earthquakes strike coastal areas.

Keywords: Sea-level rise, natural and artificial geosynthetics, adaptation, coast, great east japan earthquake

INTRODUCTION

To cope with climate-change triggered events in Asia–Pacific regions that are vulnerable to climate change, the application of geosynthetics is a promising strategy, not only for coastal structures but also for river levees that encounter wave actions, which are sometimes so severe that they produce storm surges. One option is the use of geosynthetics that can be designed in accordance with natural, social, and economic circumstances of the regions that are vulnerable to climate change. For example, inexpensive construction materials such as jute and palm are available as natural geosynthetics for the construction of infrastructure where greater strength and resilience are needed. Artificial geosynthetics are expected to be selected increasingly to meet the requirements of infrastructure projects. A procedure is proposed for selecting natural and artificial geosynthetics, particularly for adaptive measures against increasing erosion and inundation attributable to SLR. Additionally, we should discuss the application of traditional and advanced geosynthetics as adaptive measures against coastal and river erosion, drawing upon lessons from recovery from the devastating Great Eastern Japan Earthquake and Tsunami of 2011. This strategy might be appropriate for coastal regions experiencing marked land subsidence triggered by crustal movements following an earthquake.

COLLAPSE OF COASTAL DYKES AT HAI HAU, VIETNAM

Coastal retreat in Vietnam has been severe, mainly because of climate change. As an example presented in Fig. 1, annual amounts of retreat during 1905–1960, 1960–1973, and 1973–1992 were 30–50 m, 20–35 m and 10 m, respectively, on the Hai Hau coast of the northern Vietnam, presented in Fig. 2.

Because of the severe retreat, coastal dyke collapse has frequently occurred, about once every 7–10 yr. (Cong et al., 2009), as depicted in Fig. 3. Figure 4 shows that devoting attention to old churches as symbolic monuments might illustrate the destruction caused by the progressive retreat of the Hai Hau coast. Unfortunately, the remaining symbolic churches finally collapsed in 2010.

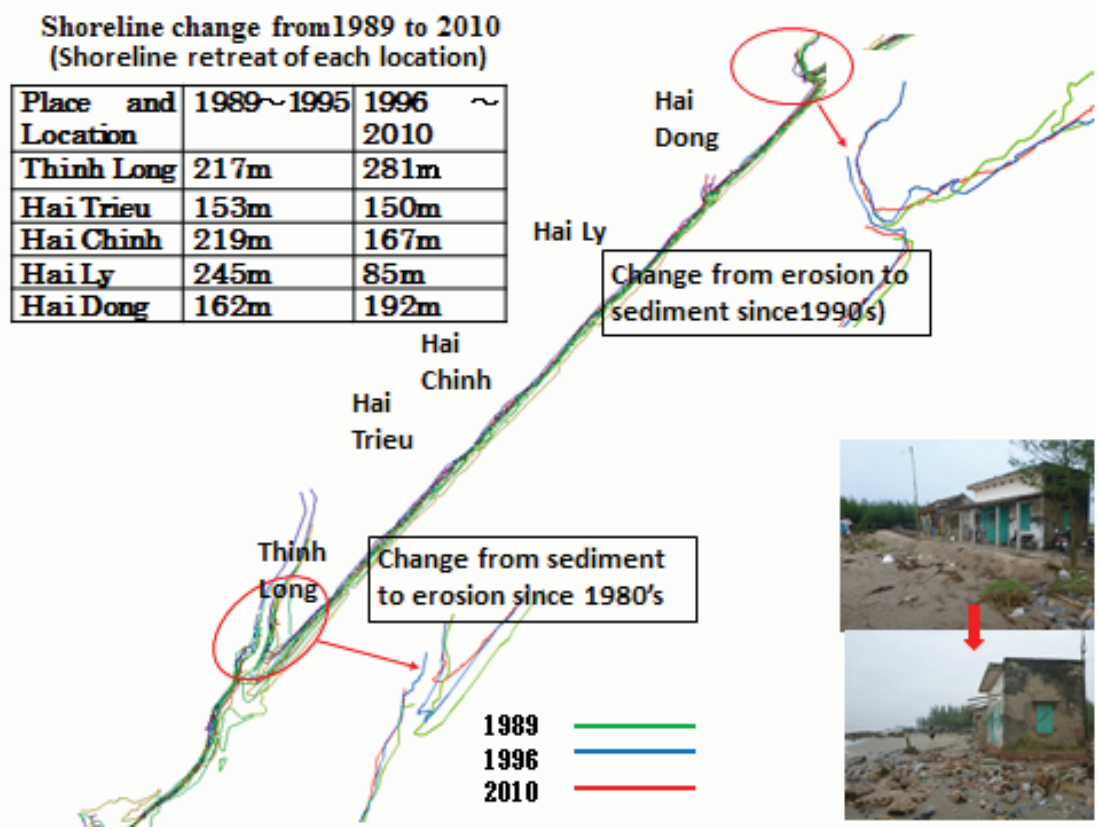


Fig. 1 Shoreline retreat in Hai Hau coast

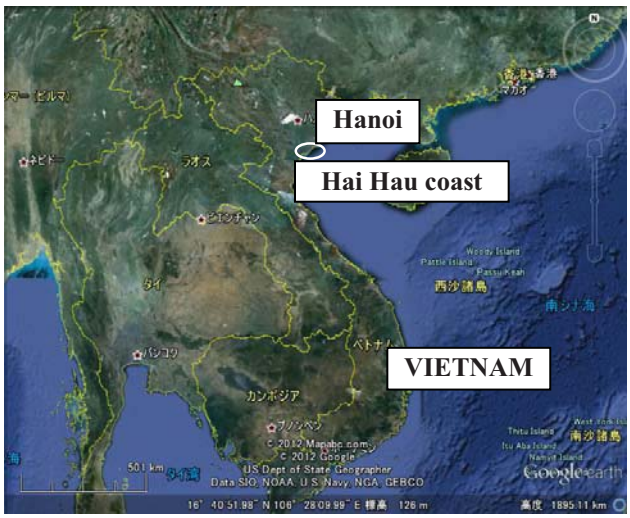


Fig. 2 Location of Hai Hau coast in Vietnam

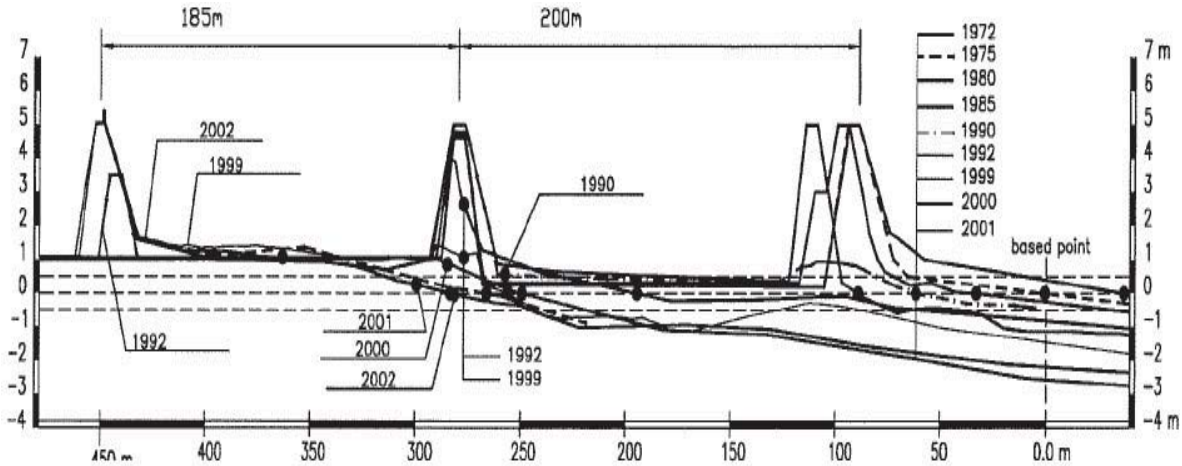


Fig. 3 Overlapping cross-shore profiles from 1972 to 2003 at Hai Lay/ Hai Trieu section (Cong et al. 2009)

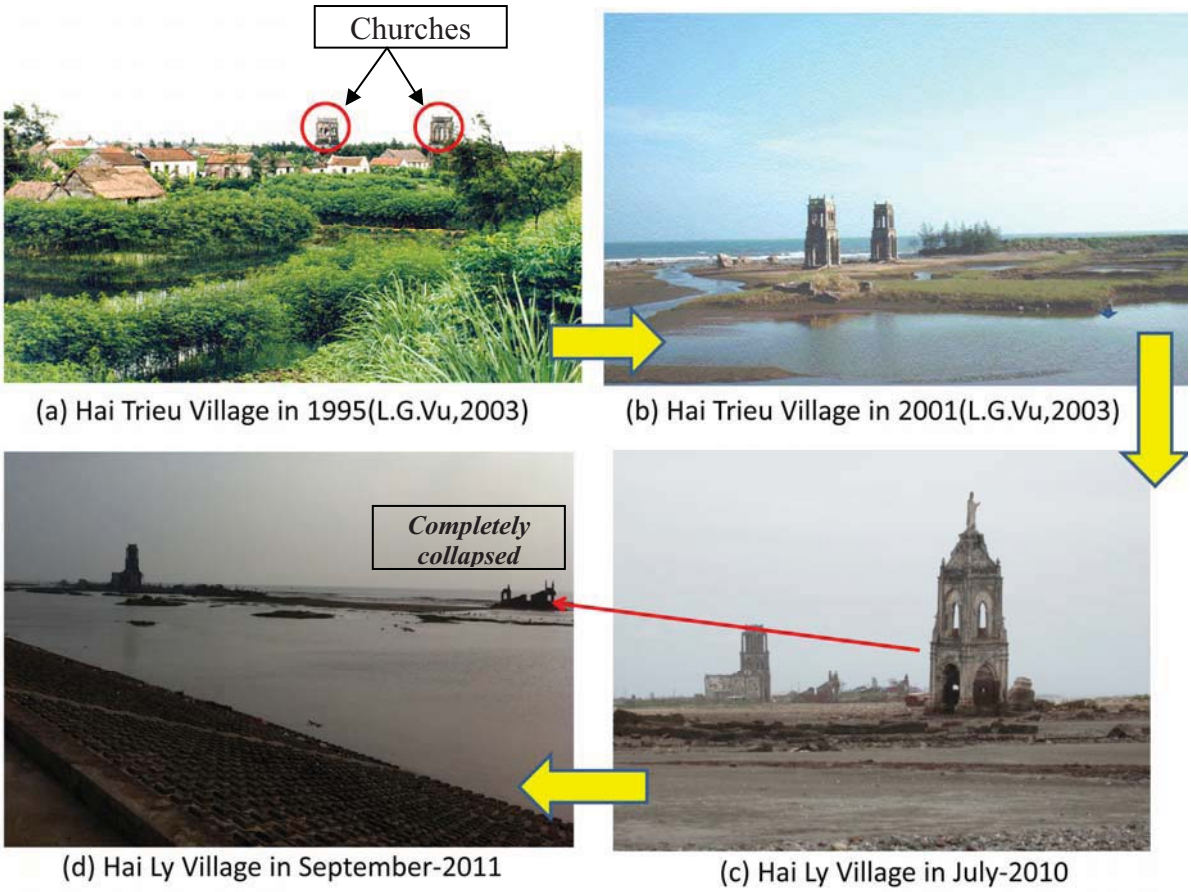


Fig. 4 History of erosion process in Hai Hau coast, Vietnam

COASTAL STABILITY IN THE CONTEXT OF CLIMATE CHANGE

Recognition of Climate Change

During the 50 years of 1958–2007, the annual average temperature in Vietnam increased about 0.5–0.7°C. Winter temperatures increased faster than those of summer. Temperatures in northern areas increased faster than those in southern areas. The annual average temperature during four recent decades (1961–2000) was higher than that of three prior decades (1931–1960). Annual temperatures for 1991–2000 in Hanoi were 0.8°C higher than the average for 1931–1940 (MONRE, 2009).

The relative sea level rise in Vietnam has been calculated mainly from tide-gauge data collected at four stations: Hon Dau (Quang Ninh province – northern Vietnam), Da Nang, Qui Nhon (central Vietnam) and Vung Tau (southern Vietnam). The longest tide data series was taken at Hon Dau station during 1960–2000, during which a sea level rise of 1.9 mm per year was recorded (Hanh and Furukawa, 2007). Nguyen Ngoc Thuy (1995) analyzed two tidal gauges in the northern coast at Hon Dau and at Hai Hau. The result shows that, from the 1950s to the 1990s, the average rate of SLR was 2.24 mm/y.

Tropical cyclones are a common climatic event in northern Vietnam. The so-called typhoon season often starts in June and ends in October. About 13% of all tropical cyclones strike the northern coast. Tropical cyclones, especially typhoons, engender severe loss of property and fatalities. For instance typhoon PAT (23 October 1998) left 500,000 homeless and 90 dead along the north coast. The most recent data for the annual number of tropical cyclones (Fig. 5) show no clear trend in the number of cyclones during the 1960s–1990s. A marked reduction occurred during 2000–2004, with a subsequent rapid increase from 2005 to the present. Such a rapid change has not been observed at any other period of time during 1961–2008. Not all of the fluctuation can be attributed to climate change, but it is evidence demonstrating the more complicated variation of extreme events at coasts, and their occurrence in greater numbers.

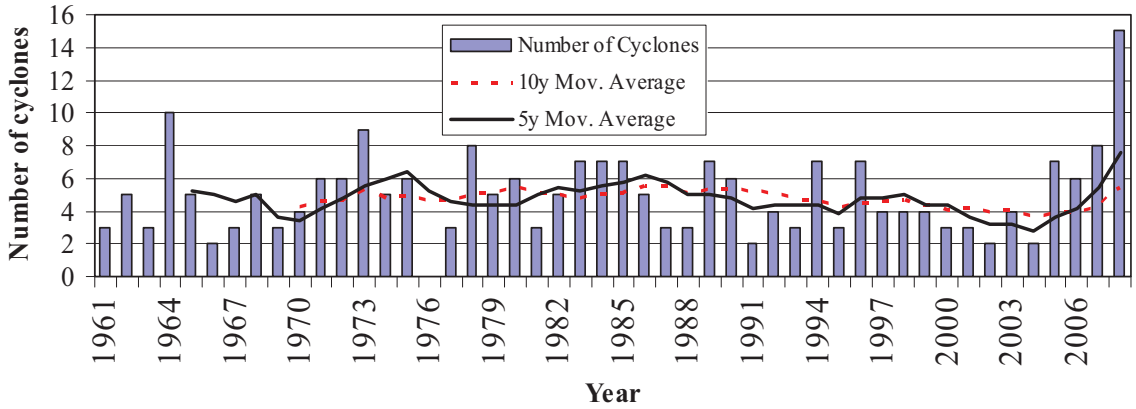


Fig. 5 Number of tropical cyclones attacked Vietnam coast (1961-2008)
(Data source: Website of Vietnam National Center for Meteorology and Hydrology)

Impacts of Extreme Events on Coastal Stability

Wave strikes on dikes change strongly depending on the wave heights. The average wave height produces 0.15–0.3 kgf/cm^2. Storm waves with height of 3.2 m can put a load of 0.8 kgf/cm^2 on the dike surface. According to the calculations of Duc (2003) waves in typhoons and storm surges with a height of more than 2 m can produce minor seadyke (constituted mainly by soils and rocks) failures, even in average tides. Concrete seadykes can be unstable when extreme wave heights in typhoons run up over the dike top. Therefore SLR not only engenders stronger pressure on seadykes but also strengthens the seawater run up during typhoons and storm surges. Moreover, strong winds and heavy rainfall occurring in a typhoon raise the seawater level. A strong typhoon can raise the water level 1.1–3.2 m (Table 1). Typhoon Damrey struck during a high spring tide causing disastrous damage to seadykes, mangroves, shrimp ponds, and infrastructure. A large area of paddy fields was inundated and salinized. A few hundred thousand people were displaced.

Table 1 Level of storm-surge in typhoons

No.	Typhoon	Date	Landed place	Raise of water level (m)
1	ROSE	13/08/1968	Nam Dinh	2.56
2	RUTH	19/10/1973	Thanh Hoa	2.50
3	JOE	23/08/1980	Hai Phong	1.94
4	KELLY	04/07/1981	Nam Dinh, Ninh Binh	2.50
5	WARREN	28/08/1981	Thai Binh, Nam Dinh	1.15
6	NANCY	18/10/1982	Thanh Hoa	3.20
7	PAT	23/10/1988	Hai Phong	0.78
8	DOST	12/06/1989	Hai Phong	1.92
9	PHYLIPS	02/07/1996	Nam Dinh, Ninh Binh	1.10
10	DAMREY	26/9/2005	Nam Dinh, Hai Phong	2.5-3.0

CURRENT COASTAL PROTECTION IN VIETNAM

Adaptation Using Conventional Techniques and Locally Available Materials

Seadykes, mainly constituted by soils, were very commonly constructed in the 1980s. Their construction is simple. Therefore, the dykes are easily eroded and severely damaged in a typhoon. Dykes of such type are still used in some parts of Hai Hau coast as in Hai Chinh and Hai Dong communes. To reinforce the dykes, groins are used. The groins are built of concrete reinforced with steel tubes of 10 cm thickness, diameter of 1 m, and placed continuously at a depth of 0.5 m under the tidal flat, to a height of 1.5 m with sandbags inside. The distance between links is 80 m (Fig. 6a). Mangrove forest is an effective measure against coastal erosion. A hundred meters of mature mangrove can reduce 0.1 m of wave height. However, the forests cannot be used in areas of severe erosion. Mangrove areas are now being replanted in Hai Dong (Fig. 6b) where coastal sediments are now accreting. With investments from PAM and the government from 1998 up to the present day, the seadyke system in Hai Hau has been reinforced intensively. The seadyke height has been improved by 4.5–5.5 m. Footings were placed at 1.5 m depth, and the dyke was reinforced by lines of tripods and covered by polygonal pre-cast concrete of 100 kg mass, even reaching 200 kg on the slope of 1: 2.2–3 (Fig. 6c). In segments of soil dykes, standby blocks of limestone are disposed nearby for emergency rehabilitation in bad weather conditions (Fig. 6d).

(a) Revetment and groins

(b) Mangrove plantation

(c) New concrete dike

(d) Standby limestone blocks

Fig. 6 Conventional adaptation in Hai Hau coast, Vietnam

Application of Geosynthetics

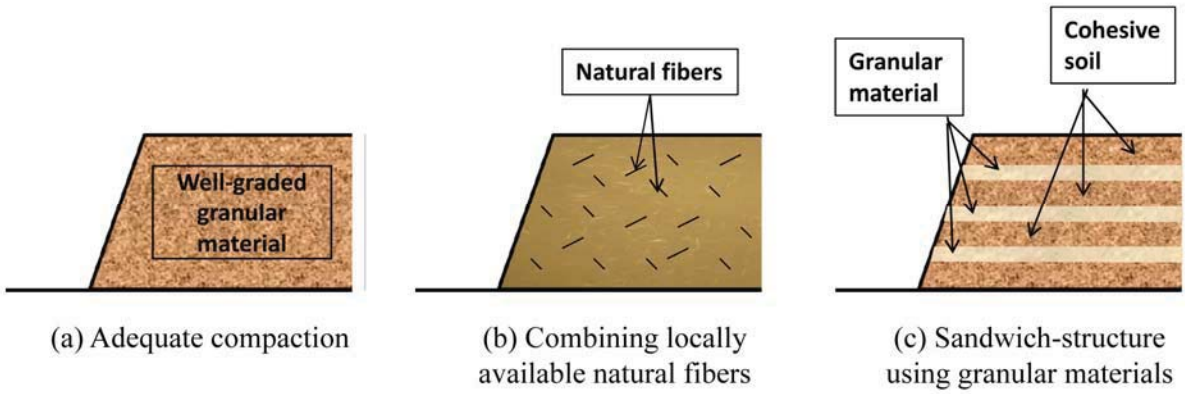
Instead of conventionally used adaptation against climate change, use of geosynthetics was proposed around 1970 and has been adopted in Vietnam for protecting river dykes and coastal levees under severe storm and inundation. A recommendation was made to adopt geosynthetics as adaptation to climate change, as summarized in Table 2 (Duc et al., 2012). However, for coastal areas, few case histories illustrate so-called good practices. For geosynthetics application to function correctly, geosynthetics and traditional measures must be combined in accordance with the level of driving forces. Furthermore, locally available natural geosynthetics should be included in development of adaptive measures. Sato et al. (2012) attempted to combine palm tree fibers with sandy soils to reinforce river dykes, which is currently under laboratory investigation.

Matsushima et al. (2010) presented a case study of the successful use of jute inclusions in soils used for local agricultural road embankments to resist climate change events as depicted in Fig. 6. However, this case occurred in Bangladesh, not Vietnam.

From a perspective of cost savings, as portrayed in Fig. 7, several measures can be used for reinforcement dykes and embankments, including the usage of locally available materials described above. Adequate compaction is fundamentally important but sometimes difficult, particularly when aiming at high compaction such as 90–95% of maximum dry density of soil. Sandwich structure dykes portrayed in Fig. 7c are suitable for construction of dykes using cohesive soils. Therefore, locally available granular materials are promising for the formation of sandwich layers among cohesive soil layers (Yamazaki et al., 2007; Yasuhara et al., 2012).

Table 2 Suggested preventive measures against coastal erosion with utilization of geosynthetics (modified from Duc et al., 2012)

Driving factors	Consequences	Required measures	Supporting measures regarding the erosion rate			
			< 2 m/y	2-5 m/y	5-10 m/y	> 10 m/y
Typhoon	Increase erosion rate	Raise height of dikes Concrete revetment with geotextile Land-use planning	Mangrove	Groynes (geotube) Mangrove	Groynes (geotube) Seadike toe protection with geobag	Groynes (geotube) Seadike toe protection (geobag) Breakwater (geotube) Internal standby dike Evacuation
Sea level rise Sediment deficit	Instability of seadikes					



(a) Adequate compaction (b) Combining locally available natural fibers (c) Sandwich-structure using granular materials

Fig. 7 Some options of reinforcement for dykes

Multiple Protection Against SLR

Actually, the use of only a single countermeasure such as the dyke reinforcement described above is insufficient for long-term protection, particularly against severe weather conditions following storm surges or typhoons. As one solution, multiple protection can be proposed as shown in Fig. 8, which depicts three combined countermeasures: an off-shore wave-eating facility, near-shore measures (mangrove plantation is popular in the developing countries), and a dyke reinforced with locally available techniques and materials.

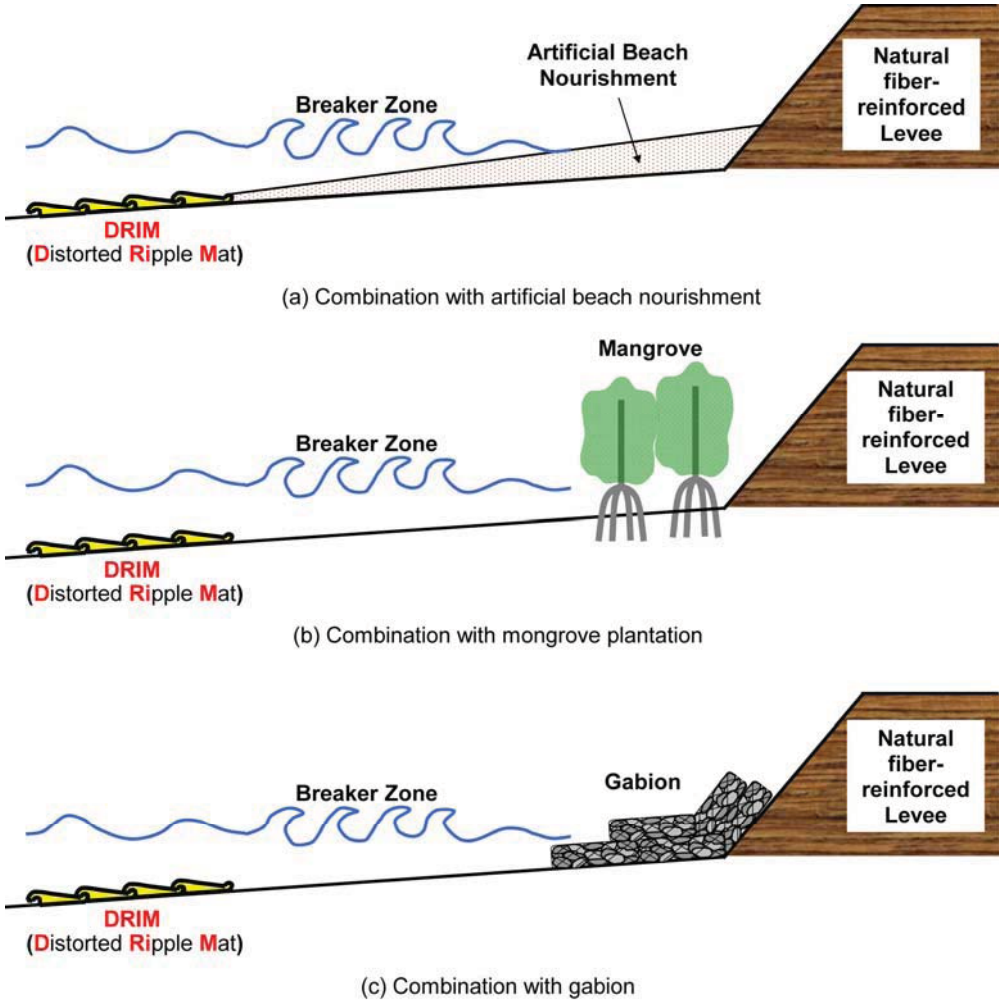


Fig. 8 Examples of multiple protection of coasts including levees reinforced with naturally available materials (DRIM was proposed by Irie et al., 1993)

POTENTIAL ADAPTIVE MEASURES IN THE MEKONG DELTA

Mekong Delta and Sea Level Rise

As shown in Fig. 9, the Mekong Delta comprises of 13 provinces with a land area of 39,712 km^2, making up 12.1% of the country by area. The population of the delta was about 17.3 million people in 2010, accounting for 21% of Viet Nam's population. The Mekong Delta is an especially important socio-economic region for the country. As a percentage of Viet Nam's production, agricultural output of the delta accounts for 50%, exported food productions are about 90%, fruit trees and aquaculture products are about 70%. Due to its location in a low lying area with strong tides from both the East and the West, the coastal zone provinces of the Mekong Delta are highly vulnerable to the effects of future sea level rise. In the past 50 years, the level rose by 20cm as observed by the Hondau monitoring station in Hai Phong province. Based on the data from 1979 to 2006 from the VungTau gauging station, the high tide sea level at this station rose 130 mm.

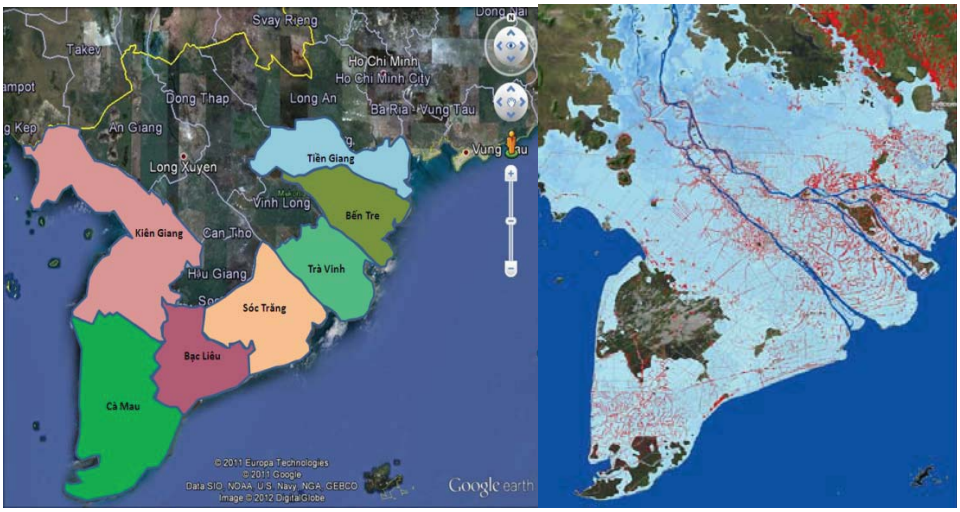


Fig. 9 Coastal provinces in Mekong Delta (left) and simulation of flood 2000 with 450mm sea level rise

The effects of climate change, which have been projected, are likely to result in an increase in the number of sea storms and whirlwinds. Furthermore, the strength of storm-related disasters is likely to increase significantly. In addition to the sea level rise, coastal erosion in the area is likely to increase considerably. The development of storage reservoirs upstream of the Mekong River, for example those in China, Myanmar, Laos, etc, has changed the flow profile during the dry season and flood season, reducing sedimentation in the Mekong Delta. This not only exacerbates the coastal erosion but also degrades the ecosystem. The coastal cajuput and mangrove forest remaining in the narrow areas would likely to be flooded; the subgrade would be scoured or its nutrient content would be diminished. In recent years, development by the sea has increased dramatically, increasing potential damage and loss of life when natural disasters occur in these coastal areas.

Coastal infrastructure, such as port and sea dykes, are more vulnerable due to the effects of wave action, which results from increased water depth, coupled with coastal erosion and the disappearance of the protective forest belt. Many sea dyke sections are already below acceptable safety standards, partly due to insufficient crest elevation but also because of forces on the body of the structures and increased seepage flows that exceed the initial design value. The sea dykes at Tien Giang and some sections of the sea dykes at CaMau and Soctrang are typical samples of this situation (see Fig. 10). To reduce socio-economic damage and to mitigate risks to people and property, focus on coastal areas is critically needed.

Fig. 10 Coastal line erosion at Soctrang province

Application of Geosystem in Mekong Delta

The function of coastal protection structures is mainly to protect the land from the adverse effects of high water levels and waves. These functional requirements determine, for instance, the layout of the structure as well as the required crest levels. Erosion protection revetments applied for shoreline in the Mekong Delta areas include gabions, concrete (interlocked) blocks, Geo-systems (Geo-Tubes, Geo-Container, Sand mattress), concrete sheet piles (See Fig. 11). New types of revetments have been developed by Vietnamese experts (interlocked block by Phan Duc Tac, 1994; Sand mattress by Trinh 2002) to reduce construction costs. Structures, such as breakwaters where wave reduction is the main objective have been applied at port areas. The use of prefabricated concrete block is a common method for bank protection in shore and river banks. However, protection with concrete blocks is expensive and not a natural solution.

Fig. 11 Interlocked mattress (left) and Breakwater structure (middle) and the beach with concrete blocks (right)

Coastal protection using geo-tubes (Fig. 12)

The first geo-tubes with sandfill have been implemented for the protection of the coast of Locan, which is in the province of BaRia-VungTau, from seasonal erosion. With support from French experts, the department of science and technology of BaRia-VungTau, has carried out the planning and installation of geo-tubes that are built by coastal soft soldering and are perpendicular to the shoreline. Erosion of the shoreline in this location stopped after two years and the sand tubes were no longer observed to be filling after 5 years. The success of this experiment promotes the installation of such sand tubes at different locations in the region. A similar demonstration was built in the coastal areas of Binhthuan province using a soft solution to prevent coastal erosion. Unfortunately this project was not successful. After the first year of installation, the sand tubes shifted and ruptured due to the onslaught of waves. These tubes did not guard the coast from erosion and in fact hindered tourism and aquatic activities like swimming.

Fig. 12 Erosion controlled by using geo-tubes at Locan (left) and wrong design and unsuitable material at Binhthuan (right) in Vietnam

The success and failure of geo-tubes depend largely on the ability and experience of the engineering consultancy. The tubes need to be designed appropriately in order to stabilize the action of waves and currents, thereby adjusting coastal flow patterns with the aim of preventing erosion due to the waves. The sand tubes are applied in a way to reduce the energy of the breaking wave, limiting the erosion of the coastal forest strip.

The other application of geo-tubes is to reinforce the embankment for flood control in Hochiminh city (See Fig. 13, Nguyen and Trinh, 2011). Some section of existing dikes have been reinforced by using geo-tubes to avoid failure of dike bodies due to overflow.

Fig. 13 Reinforcement of existing dikes by geotubes in HCMC

In application of tubes, the sand container flowing considerations are basic issues:

- Permeability of geotextiles for rapid release of water
- Maintaining the stuffing material in the tube
- Capacity to withstand pressure during pumping sand materials
- Resistance to puncture and tear
- Robustness against the effects of UV rays

The main factors considered when designing are:

- Shape and size of sand tube with the circumference, stuffing material level, and construction equipment (bottom open door of the barge)
- Stable velocity in deep waters,
- Impact of the drop and power devices drop
- Strength of geotextile
- Required size block design
- Hydraulic stability

Application of sand mattresses (Fig. 14)

The river bank composition in the Mekong Delta region is mostly young alluvium with low erosion resistance (critical velocity from 0.5 to 0.8 m/s). As a result, erosion occurs mostly on the canal and river system even though flow velocity in this region is not large. Sand mattresses has been developed (Trinh, 2002) and tested on the Saigon River. They will be applied for river erosion protection as a low-cost solution (see Fig. 15).

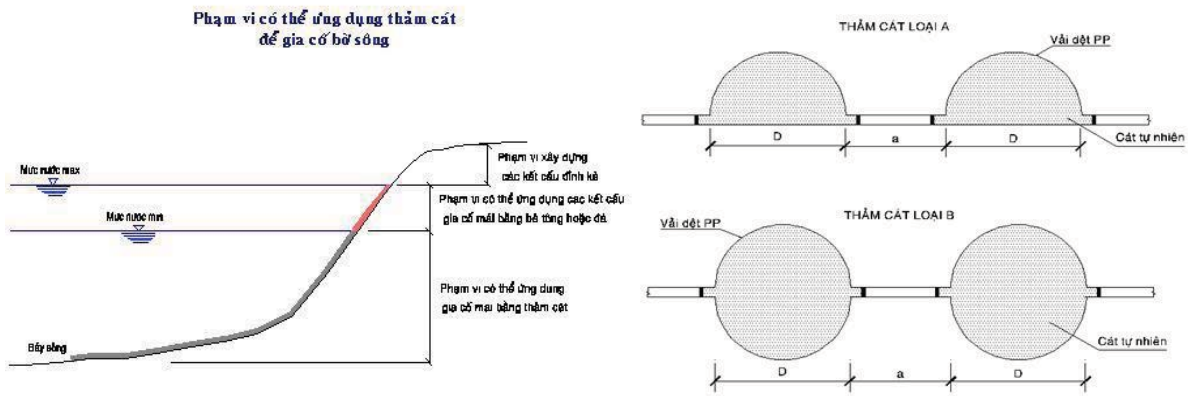


Fig. 14 River bank protection design (left) and cross-section of mattresses types (right)

The size of the sand mattresses can be determined based on hydraulic condition of the rivers. In small and medium rivers, mattresses of 300-500 mm in diameter can be applied. Installation of sand mattresses may apply depending on device capabilities and the scope of work. Sand mattresses can also be installed through simple construction by the householder or householder group.

Fig. 15 Sand mattresses installation (left) and after 18 months (right)

GEOSYNTHETICS APPLICATION FOR GREAT EAST JAPAN EARTHQUAKE REMEDIATION

The Great East Japan Earthquake in 2011 posed several difficult issues. Among them, significant land subsidence along coastal areas triggered by crustal movement following an earthquake is an important issue to be resolved from an engineering perspective.

Figure 16 portrays a typical scene of a coastal area in Watanoha, Ishinomaki, Miyagi, which suffered from land subsidence of around 1.0 m.

Soil bags covered by woven geosynthetics were apparently placed along the coast as a temporary reconstruction measure. This soil bag is called a "Weather-resistant large-scaled soil bag" and the design manual is available (Civil Research Center, 2012). The situation of collapse of sea walls and land subsidence immediately after the earthquake is presented schematically in Fig. 17. Because this bag is a temporary adaptation, construction of permanent countermeasures will be necessary in the near future. An important problem in this case is that the damaged area is normally returned to its original state. This goal presents a barrier to adoption of new techniques including the use of geosynthetics. To overcome this barrier, it is necessary to establish a new concept, such as reinforcing reconstruction, which implies strengthening of the original infrastructure situation.

In addition to land subsidence, marked SLR has affected the area, as depicted in Fig. 18. Therefore, this situation is useful for land use planning if we draw variations of land subsidence and SLR over

time as shown in Fig. 19. Establishment of a long-term monitoring system is necessary.

Another necessary issue is construction of countermeasures against inundation caused by combining land subsidence and SLR. For successful execution of countermeasures, the authors propose reinforcement techniques combining soil bags with geosynthetics as presented in Fig. 20, which is a temporary countermeasure, not a permanent one. To upgrade the reinforced seawalls with geosynthetics, other work such as injection of concrete into soil bags should be undertaken as presented in Fig. 21. Regarding these techniques, although the validity of combined reinforcement of this kind against severe storms has been proved in laboratory tests (Yasuhara and Recio-Molina, 2007; Yasuhara et al., 2012), they should be combined with other techniques, particularly for use against strong earthquake motions and tsunamis.

Fig. 16 Typical scenery of the coastal area under land subsidence

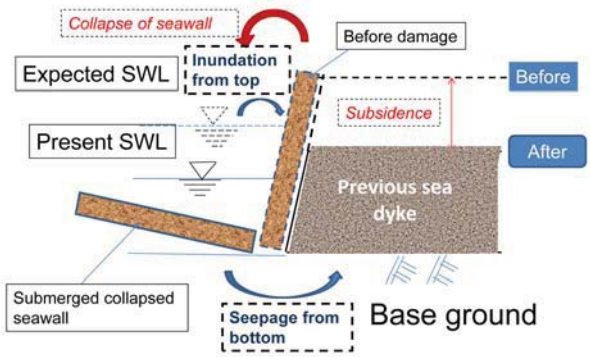


Fig. 17 Situation of collapse of sea walls and land subsidence immediately after the earthquake

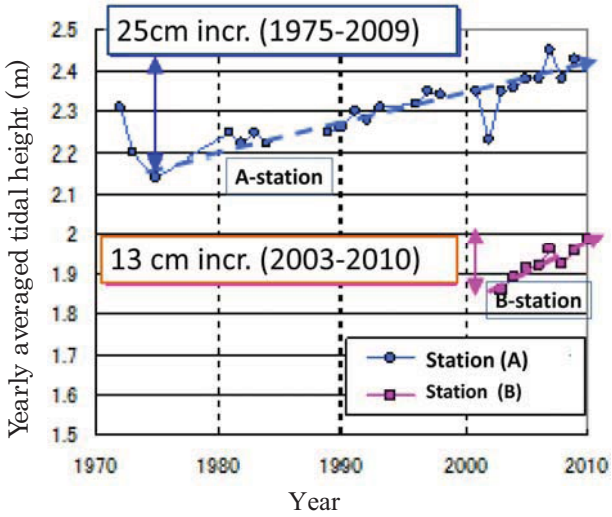


Fig. 18 Variations of tidal level with time in two locations

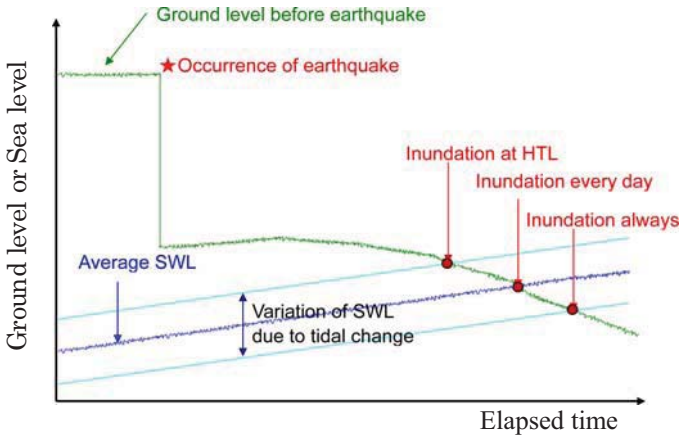


Fig. 19 Key sketch for variations of LS and SLR with time

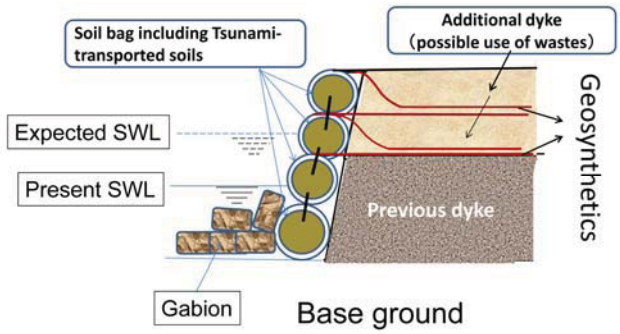


Fig. 20 An example of reinforcing reconstruction using soil bags and geosynthetics

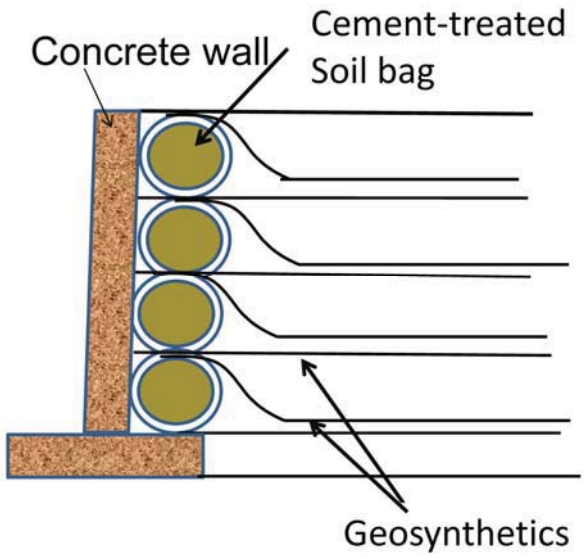


Fig. 21 Compound sea wall reinforced with geosynthetics

CONCLUSION

This report described a procedure for selecting natural geosynthetics, particularly for adaptive measures against increasing erosion and inundation attributable to SLR. In addition, this report emphasized the application of locally available materials as adaptive measures against coastal and river erosion.

Based on these experiences, case studies showed applications of geosynthetics were combined with soil improvement using cement, suggesting their use as adaptive measures, and drawing upon lessons from the recovery from the Great East Japan Earthquake and Tsunami of 2011. This strategy might be appropriate for coastal regions experiencing SLR in addition to land subsidence triggered by crustal movement following the great earthquake on 11 March 2011.

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APPENDIX

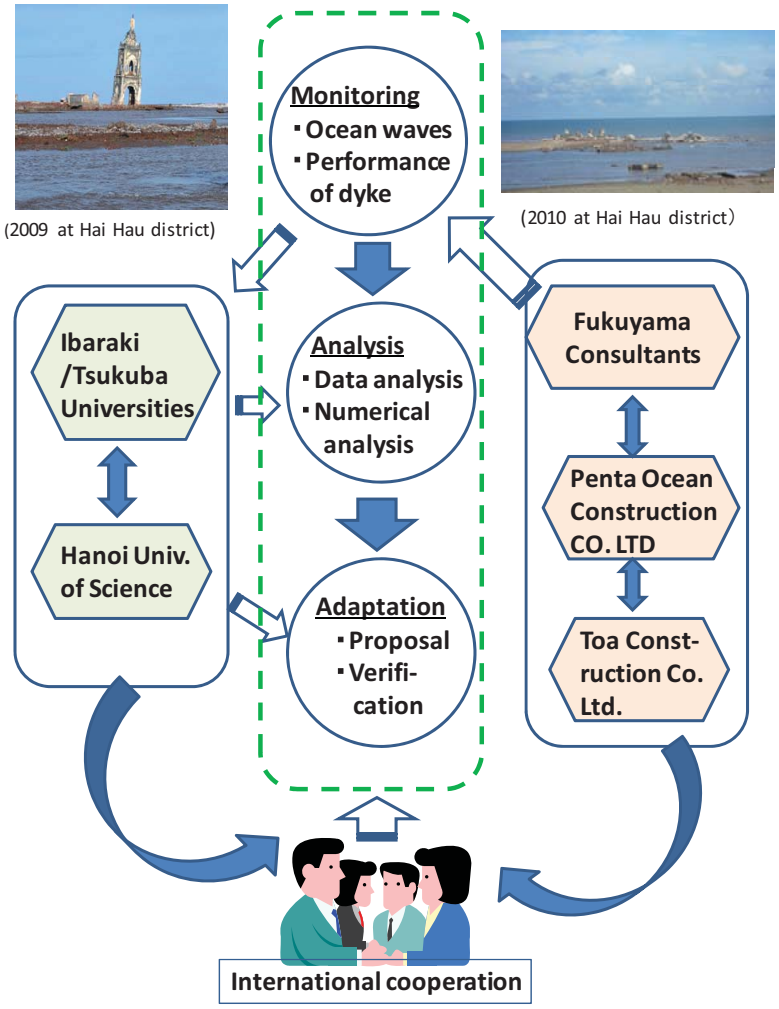

Fig. A1 Outline of the project for integrated monitoring system for climate change adaptation (supported by MEXT)

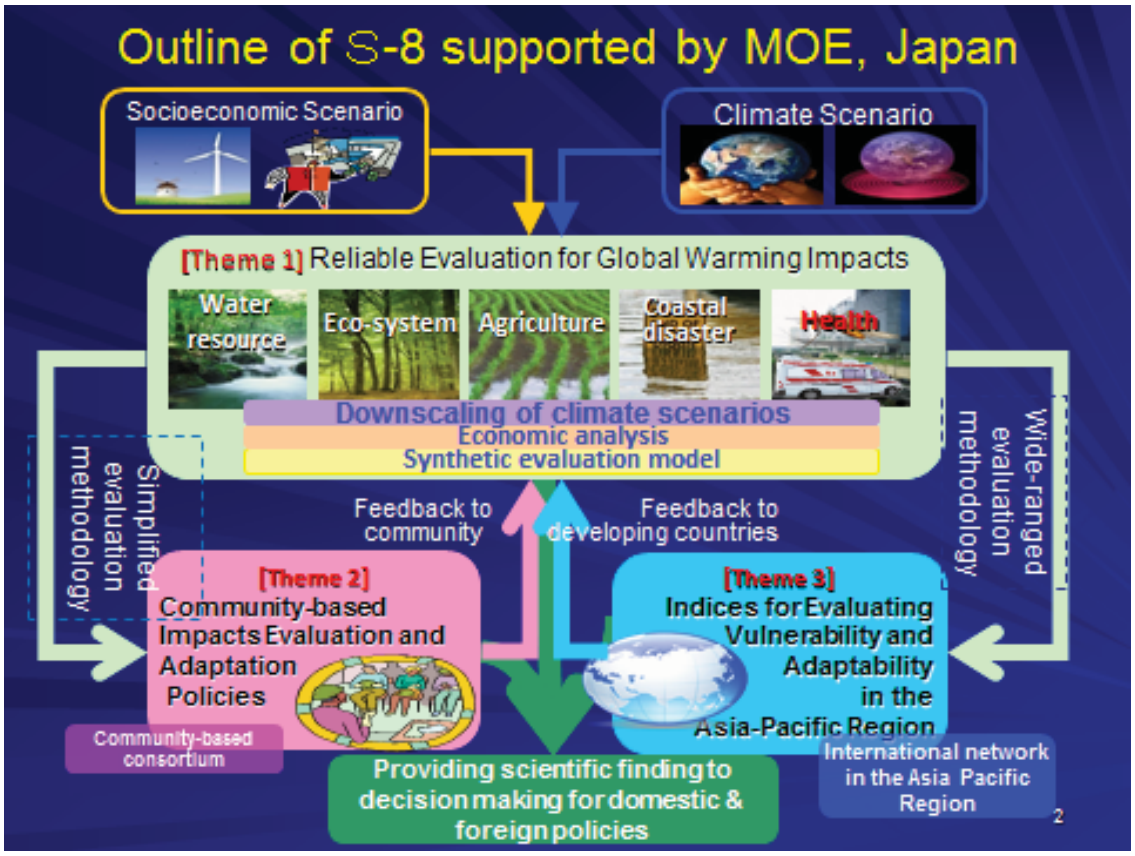

Fig. A2 Outline of strategic project (S-8) for climate change adaptation (supported by MOE)