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# Coastal Disaster Risk in Southern Vietnam
# The Problems of Coastal Development and the Need for Better Coastal Planning

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# Coastal Disaster Risk in Southern Vietnam

## − the Problems of Coastal Development and the Need for Better Coastal Planning −

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## Abstract

The present paper would focus on lessons that have been learnt through field trips carried out in southern Vietnam and numerical analysis that will show how the lack of knowledge to understand either future environmental impacts or strong regulations are leading to increased risk in many coastal areas. The authors attempted to analyse the potential disaster risks associated with six natural hazards: tropical cyclones, storm surges, tsunamis, coastal erosion, topographical hazard and sea-level rise, and discussed the vulnerability of local communities to these threats in the context of rapid economic development. The authors pointed out that infrastructure investments made by tourist or other industries may exacerbate the potential disaster risks on adjacent areas, and the potential risks due to coastal disasters can become larger among the poorest members of the community, who often live in higher risk areas as their adaptive capacity and resilience it typically lower than richer members of the society.

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## 1. Introduction

The losses due to coastal natural disasters have been increasing throughout the Asia-Pacific region, due to a combination of greater exposure (due to population growth and a bigger share of it moving to coastal areas) and increases in the wealth of many countries. While developed countries, such as Japan, are learning a number of lessons from the Tohoku 2011 tsunami, developing countries such as Vietnam are starting to invest in infrastructure without careful consideration of possible environmental impacts and mistakes that other countries made long ago.

The present paper will focus on lessons that have been learnt through field trips carried out in Vietnam and numerical analysis that will show how the lack of knowledge to comprehend future possible environmental impacts and the absence of strong regulations are leading to increased risk in many coastal areas. Private investment, such as the building of jetties by hotel owners, can cause significant coastal erosion in other areas, often inhabited by poorer members of the community. This coastal erosion can exacerbate the risk due to natural disasters such as typhoons or (rare for the case of southern Vietnam) tsunamis, as a result of losing the protection offered by natural barriers. These events have been documented by the authors in their own research in Vietnam, and will be analyzed within the current climate change discourse.

The authors will bring all these issues into perspective by analyzing the current thinking of academics, policy makers and civil servants in Vietnam and what are currently considered to be the best way to optimize risk management in various types of Vietnamese coastal environment on the basis of natural and social science approaches. In fact, the factors leading to the vulnerability of the coast are quite complicated, as shown in **Fig.1**. In the present study, the vulnerability of coastal areas against coastal disasters has been discussed in the context of the typical model of a rapid development of the coastal zones, such as that of Vietnam at present.

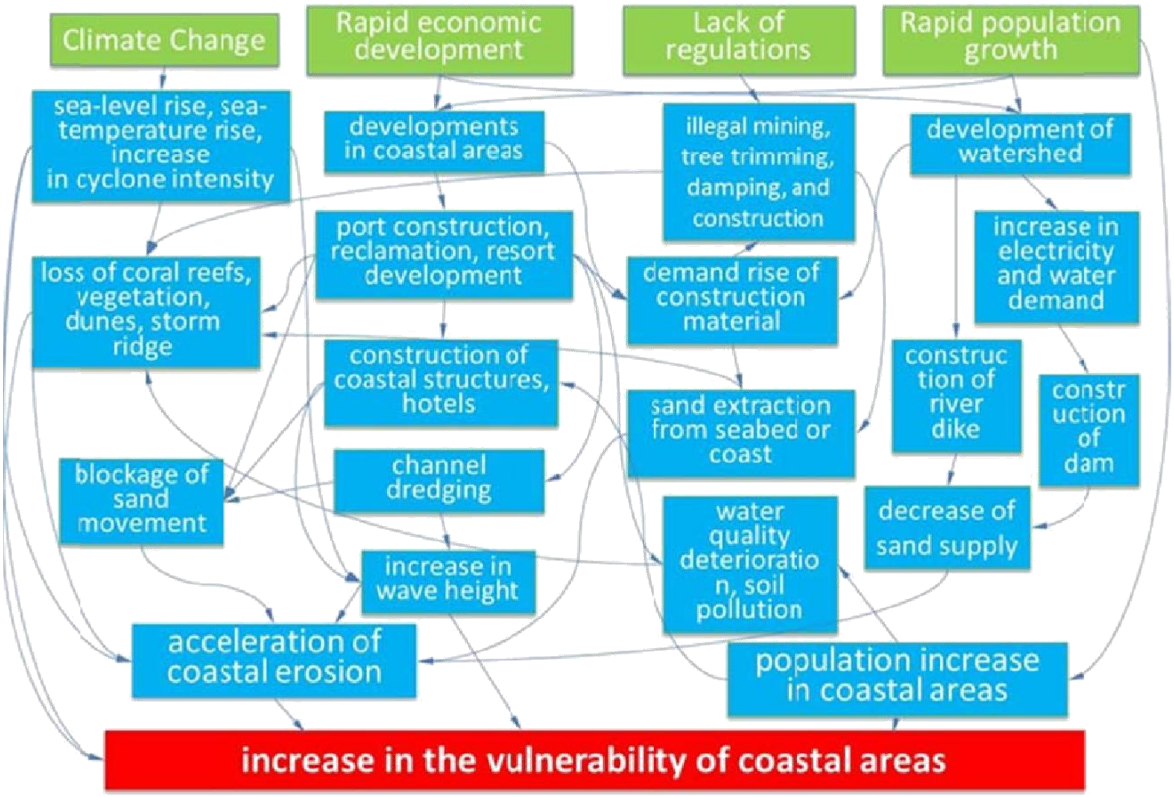


**Fig.1 Factors leading to the vulnerability of the coas t**

## 2. Analys is of natu ral hazards causing coastal disasters

The present paper dis cusses the ulnerabilit y of coasta areas in s uthern Vietnam, and analyses th e risks associated with tropical cy clone stor m surges, tsunamis a d other po tential ris s based o n numerical imulations and findin s from field surveys carried out by the authors.

### 2.1 Tropic al cyclones

The peak occurrence o f typhoon andfalls In Vietnam is normally d uring the m onth of O tober in th e central region and No vember in the South. There hav ing been roughly around 786 typhoons an d tropical st rms that a pproached or affecte d Vietnam during the 20th cent ury, of which 348 ar e typhoons ith wind speeds gre ter than 120 km/h. hese storm s typically do hit the mainland, especially the coastal provinces in the Nor th and the Centre of Vietnam ( Kleinen, 2 007). In th e present study, the so-called Best Track Da ta, obtained from The Joint Ty phoon Warning Center (JTWC), is used to analyze the typhoon tr acks aroun d the East Sea (South China Se ). The dat a consists of time, geographical po sition, min imum sea level press ure and maximum sustained win d speed in k nots of eac h typhoon hroughout its life. **Fi .2.1** shows more than 200 track s of tropical storm which developed in the East Sea and approache Vietnam's coasts in the past 60 years (from

1951 to 2010). The figures were separated into decades in order to identify any trends in the occurrence of tropical storms. In the figures, a diamond shape symbol is displayed when the tropical storm becomes a typhoon, in which the wind speed is greater than 64 knots (32.7 m/s). It appears that typhoons or tropical storms are much less frequent in the southern than in the northern and central parts of Vietnam. This is mainly due to the reason that the Coriolis effect, which initiates and maintains tropical storm rotation, is weaker in lower latitude. Nonetheless it appears that the number of tropical storms that hit southern Vietnam is noticeable and non-negligible, even though Vietnamese people generally think the southern coast of Vietnam is free from the threat of typhoons whereas the northern and central parts always suffer severe typhoons. **Table 2.1** again shows the number of tropical cyclones that passed around Vietnam's coasts in the last 6 decades. Each tropical cyclone was categorized into two latitude zones (N25°- 15° and N15°- 5°) according to point of where it disappeared, in order to identify trends in movement over time. MONRE (2009) points out that there are more typhoons with higher intensity and that typhoon tracks have had a tendency of moving southward in recent years. However, no clear evidence of this tendency can be seen from **Fig.2.1** and **Table 2.1**.

## 2.2 Storm surges

Vietnam, with 3,260 km coastline, is one of the most vulnerable countries against coastal disasters, especially storm surges caused by tropical cyclones. A storm surge is an increase in the level of sea water which is caused by high winds pushing on the ocean's surface combined with the effect of low pressure at the center of a weather system. Although there seems to be comparatively little research having been carried out on storm surges in the coasts of Vietnam until now, a series of studies have been made by Vietnamese researchers (i.e. Pham 1992) under United Nations Development Program (UNDP) projects. Pham (1992) gave an overview of storm surges in the northern coast of Vietnam from 16°N to 22°N. Ngueyen (2008) also performed a simulation of Typhoon Ling Ling (which made a landfall on the central coast of Vietnam in 2001) by using sophisticated numerical models. To the authors' knowledge, however, there are few studies that have evaluated the storm surge risk due to tropical storms to the southern part of Vietnam. Part of the reason for this seems to be that tropical storms occur less frequently in the southern part of Vietnam, whereas the northern and central areas of the country are frequently affected by tropical storms (GTZ 2003). However, it is important to remember that sometimes tropical cyclones venture into the southern part of Vietnam, as shown in **Fig.2.1**. The authors in the present paper thus attempt to analyze what are some of the potential dangers to some areas in southern Vietnam, and prove that disaster risk management in these areas should consider the potential for storm surges to affect low-lying areas.

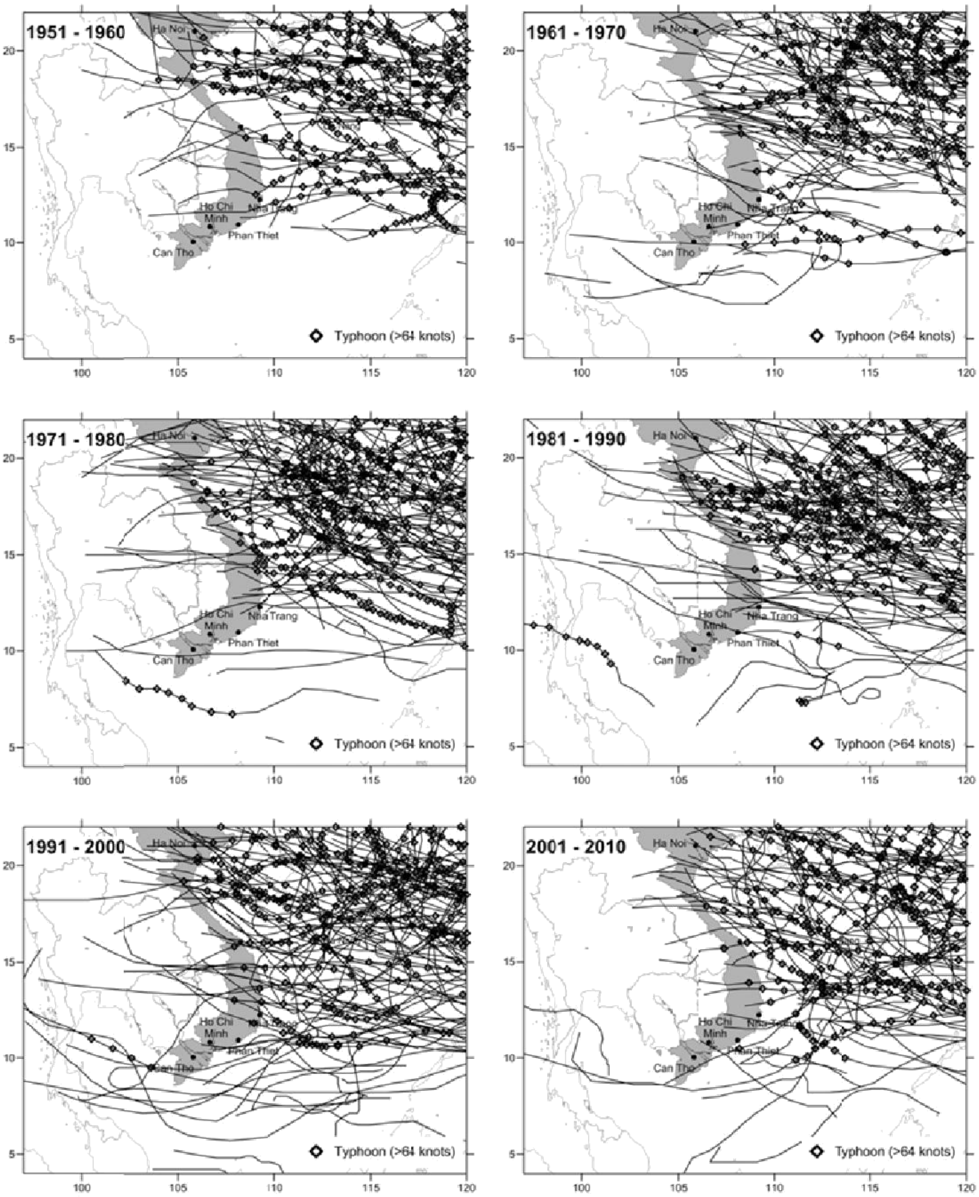


**Fig.2.1 JTWC Typhoon Best Tracks around East Sa from 1951 to 2010**

**Table 2.1 Number of tropical storms that approached Vietnam's coasts from 1951 to 2010, classifying according to latitude zone and period**

| Zone | 1951-1960 | 1961-1970 | 1971-1980 | 1981-1990 | 1991-2000 | 2001-2010 |
|---|---|---|---|---|---|---|
| North-Center (25°-15°) | 67 (70%) | 129 (67%) | 103 (76% | 100 (72%) | 106 (68%) | 94 (76%) |
| Center-South (15°-5°) | 29 (30%) | 63 (33%) | 33 (24% | 38 (28%) | 51 (32%) | 29 (24%) |
| Total Number of Tropical Storms | 96 | 192 | 136 | 138 | 157 | 123 |

### 3) Estimation of storm surge height in southern Vietnam

To estimate storm surge height due to past tropical storms, a series of simulations were performed for 5 selected tropical storms that approached the southern part of Vietnam in recent decades (**Fig.2.2**):

Typhoon Tilda, in November-December
1954 Typhoon Lucy, in November 1962
Tropical Storm Thelma, in November 1973
Severe Tropical Storm Linda, in October-November
1997 Typhoon Muifa, in November 2004

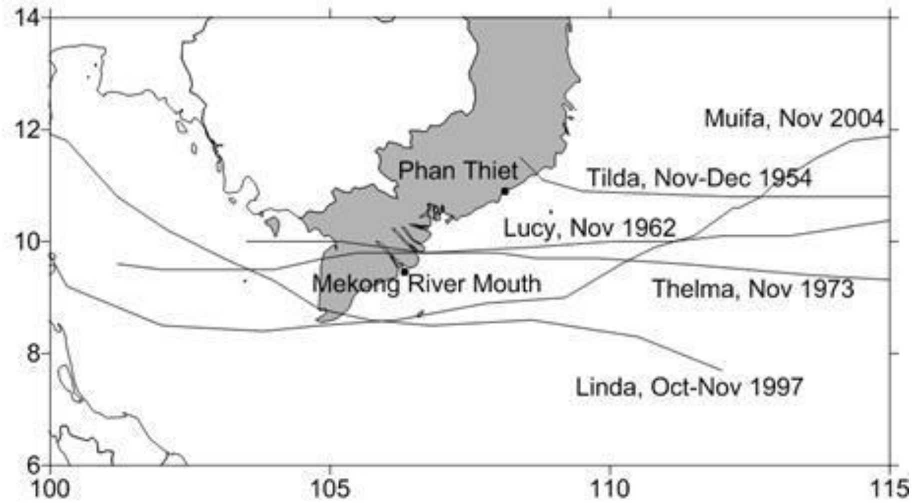


**Fig.2.2 The 5 selected tropical storms approaching the southern part of Vietnam**

Using this computer simulation, the sea water elevations were calculated for two different locations, one at Phan Thiet and the other at the Mekong River mouth. **Table 2.2** shows the highest storm surge elevations calculated at each of these points for the 5 selected storms. Most of the storm surge heights are less than 0.5 m, except for a 0.56 m at Phan Thiet during typhoon Lucy in 1962 and 0.70m at the Mekong River mouth during severe tropical storm Linda in 1997.

Table 2.2 Calculated storm surge heights during the past tropical storms

| Stations | Tilda 1954 | Lucy 1962 | Thelma 1973 | Linda 1997 | Muifa 2004 |
|---|---|---|---|---|---|
| Phan Thiet | 0.07m | **0.56m** | 0.28m | 0.36m | 0.28m |
| Mekong River Mouth | 0.05m | 0.30m | 0.09m | **0.70m** | 0.39m |

Note: contribution due to wave setup is not taken into account

The wave setup was calculated, for simplicity, by assuming that offshore waves propagate normal to the shorelines over a uniform slope, either 1/100 or 1/500, as identified by conducting a GPS bathymetric survey carried out by the authors themselves (**Fig.2.3**). As the water depth becomes shallower, wave setup becomes larger and reaches up to approximately 40 cm for Lucy and 30 cm for Linda, irrespective of slope.

Finally, it is estimated that the total storm surge height (including wave setup) could be nearly 1 m for both Lucy and Linda.

**Fig.2.3 Scenes of bathymetric survey at Phan Thiet city in Vietnam**

## 2.3 Tsunamis

There is a lack of understanding on the possible effects of tsunamis on the Vietnamese coast due to the limited record about past tsunami events in Vietnam. However, the UN Program Coordination Group on Natural Disasters and Emergencies (2011) pointed out that part of the Vietnamese coast can potentially be affected by a tsunami, though the probability of a tsunami event is relatively low.

After the 2004 Indian Ocean Tsunami, awareness on the possibility of tsunami disasters has spread to countries and areas which were generally not considered to be tsunami-prone before. Tsunamis in the East Sea, which could potentially affect the Vietnamese coast, has been investigated by a number of researchers (e.g. Liu *et al.*, 2007; Liu *et al.*, 2009; Megawati *et al.*, 2009; Dao *et al.*, 2009; Okal *et al.*, 2011). In these investigations, certain scenarios for possible tsunamis in the East Sea were presented and discussed. The Vietnamese Government also developed 25 scenarios for tsunami generations, which can be classified by the location of earthquake as follows:

- the Manila Trench (1-17)
- the Ryukyu Trench (18 and 19)

- the northwestern part of the East Sea and the southern part of Hainan Island (20 and 21)
- the northern part of the Philippines and the southern part of Taiwan (22-24)
- the western part of the East Sea and the middle part of the Vietnamese coast (25)

Following these scenarios, the Vietnamese government has started to prepare for the future possibility of tsunamis.

In the present paper, the authors carried out a numerical simulation for the possible tsunami assuming one of the worst scenarios for Vietnam's coasts.

### 1) Numerical simulation model

The Vietnamese coast faces the East Sea, which is surrounded by the southern part of China, Taiwan, the Philippines, Borneo, the Malay Peninsula and the Indochinese Peninsula. The East Sea is connected to the East China Sea, the Pacific Ocean, the Sulu Sea, the Java Sea, and the Indian Ocean through the Taiwan Strait, the Luzon Strait, the Mindoro Strait and the Balabac Strait, the Karimata Strait, and the Malacca Strait, respectively (**Fig.2.4**). These adjoining seas are connected to the East China Sea only thorough narrow straits so that tsunamis generated in one sea do not leak into another (Okal *et al.*, 2011). Thus, the most important tsunamis to consider for the case of the Vietnamese coast are those generated in the East Sea. Many locations in the East Sea are recognized as having a high potential to generate a devastating tsunami. For example, Okal *et al.* (2011) presented 14 scenarios of potential tsunamis in the East Sea and its adjoining seas. Among these scenarios, a tsunami generated by an earthquake taking place in the Manila Trench is recognized as one of the most potentially hazardous tsunamis (e.g. Liu *et al.*, 2009).

Hence, the authors carried out a numerical simulation about a tsunami generated by an earthquake taking place in the Manila Trench in order to clarify the characteristics of the tsunami on the Vietnamese coast. In this simulation, the hypothetical catastrophic earthquake scenario proposed by Okal *et al.* (2011) is used. The parameters of this fault model are summarized in **Table 2.3**. The moment magnitude ($M_w$) is obtained from the following equation:

$$\log \qquad 1.5 \quad 16.1$$

where $M_0$ is the seismic moment in dyne centimeters (Hanks & Kanamori, 1979). The seismic moment of this model is $1.0 \times 10^{29}$ (dyn·cm) and hence the moment magnitude is 8.6. It should be noted that more serious scenarios have been proposed for the Manila Trench (e.g. $M_w$ = 9.0 scenario proposed by Megawati *et al.* (2009)) and thus the scenario considered here is still not the worst one.

The governing equations of this simulation are the linear shallow water equations and a leap-frog scheme was employed to solve the equations. The initial water level movement is equivalent to the displacement of the seafloor which is calculated based on the set of formulas proposed by Mansinha and Smylie (1971). Bathymetry data is obtained from the General Bathymetric Chart of the Oceans (GEBCO) organized with a grid size of 30 seconds. The simulation is carried out on a 4.5 minutes (about 8.1 km) grid extending from 10°S to 26°N and from 95°E to 131°E (**Fig.2.5**).

### 2) Estimation of tsunami height in Vietnam

**Fig.2.6** shows the results of the numerical simulation. The maximum amplitude is around 2m along the western coast of Luzon Island and the middle part of the Vietnamese coast (**Fig.2.6 (a)**). This distribution of the maximum amplitude results from the directivity of tsunami. Although the heights of a tsunami are expected to be affected by various factors, such as refraction, diffraction and reflection by the bottom irregularities, and also by the form of a bay, the heights in the direction of the minor axis, as a rule, appear to be higher than those in the direction of the major axis of a fault (Hatori, 1963). Because the fault runs from north to south in this simulation, this results in high tsunami heights to the east and west sides of the fault. The first wave arrives to the middle part of the Vietnamese coast around 2 hours after the earthquake occurs and then gradually propagates to the northern and southern part of the coast (**Fig.2.6 (b)**). The area between the fault and the middle part of the Vietnamese coast is relatively deep; meanwhile the continental shelf, where the bathymetry is shallower than 200 m, spreads off the southern part of the Vietnamese coast. The velocity of the tsunami is given by $\sqrt{(gh)}$ (where $g$ is the gravitational acceleration and $h$ is the depth) and hence a tsunami propagates slower in shallow area of the southern part of the Vietnamese coast and in the Gulf of Thailand.

According to the results of the numerical simulation, the tsunami heights along the southern part of the Vietnamese coast are around 1 m or less (**Fig.2.7**) with the first wave reaching the coast at least 2 hours after the earthquake takes place in the Manila Trench.

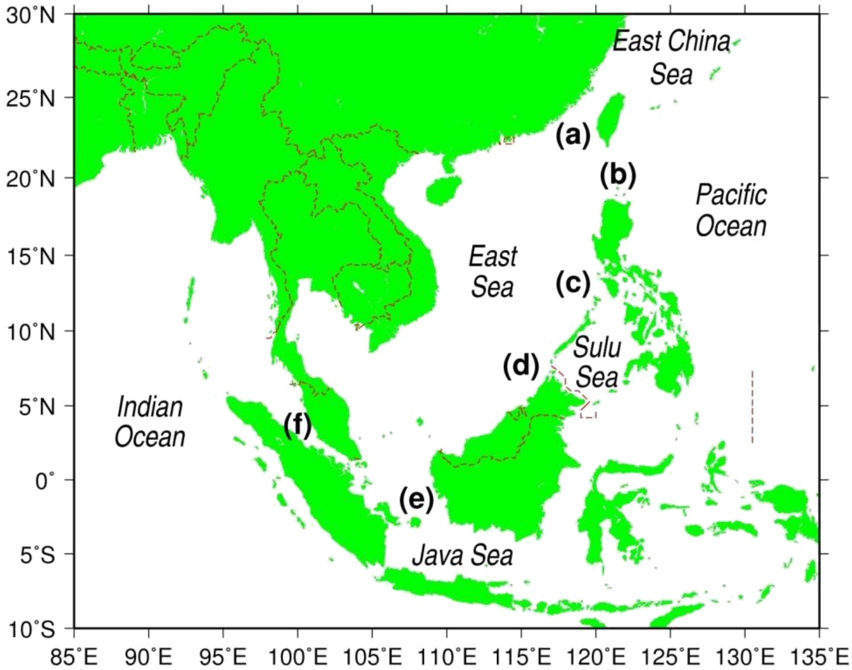


**Fig.2.4 The East Sea and surrounding seas and straits: (a) Taiwan Strait, (b) Luzon Strait, (c) Mindoro Strait, (d) Balabac Strait, (e) Karimata Strait, (f) Malacca Strait**

**Table 2.3 Fault parameters (Okal *et al.*, 2011).**

| | |
|---|---|
| Seismic moment (dyn·cm) | $1.0\times10^{29}$ |
| Location of the center top of fault | 16.0°N, 118.5°E |
| Depth of the top of fault (km) | 10 |
| Length (km) | 400 |
| Width (km) | 90 |
| Average dislocation (m) | 6 |
| Strike (degree) | 355 |
| Dip (degree) | 24 |
| Slip (degree) | 72 |

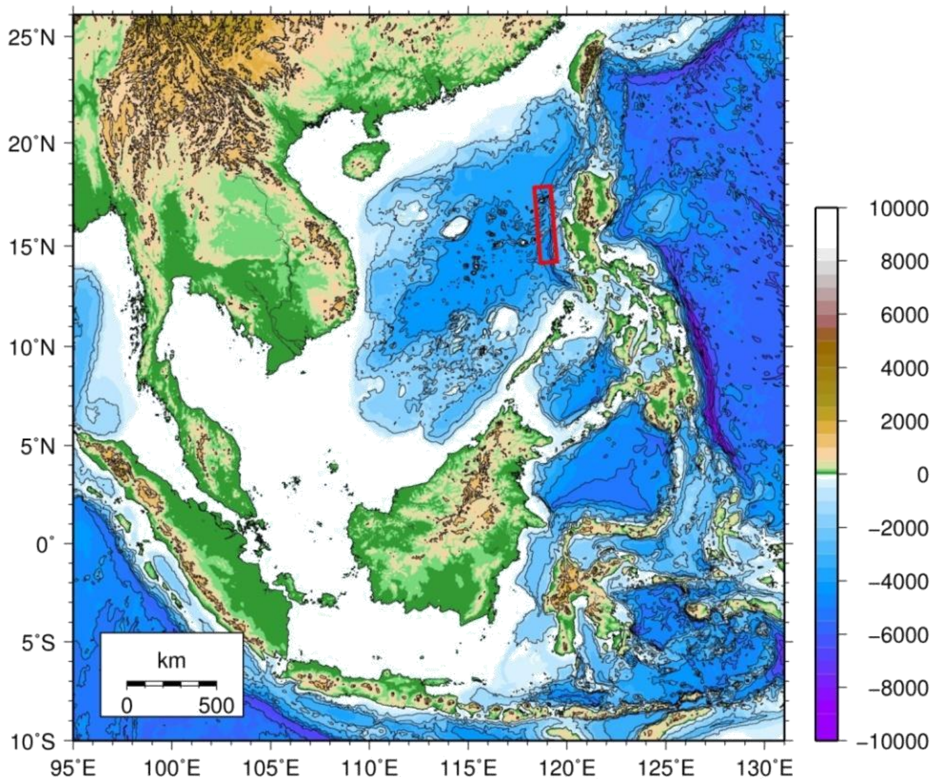


**Fig.2.5 Bathymetry of the computational area and the location of the fault (given by the red rectangle)**

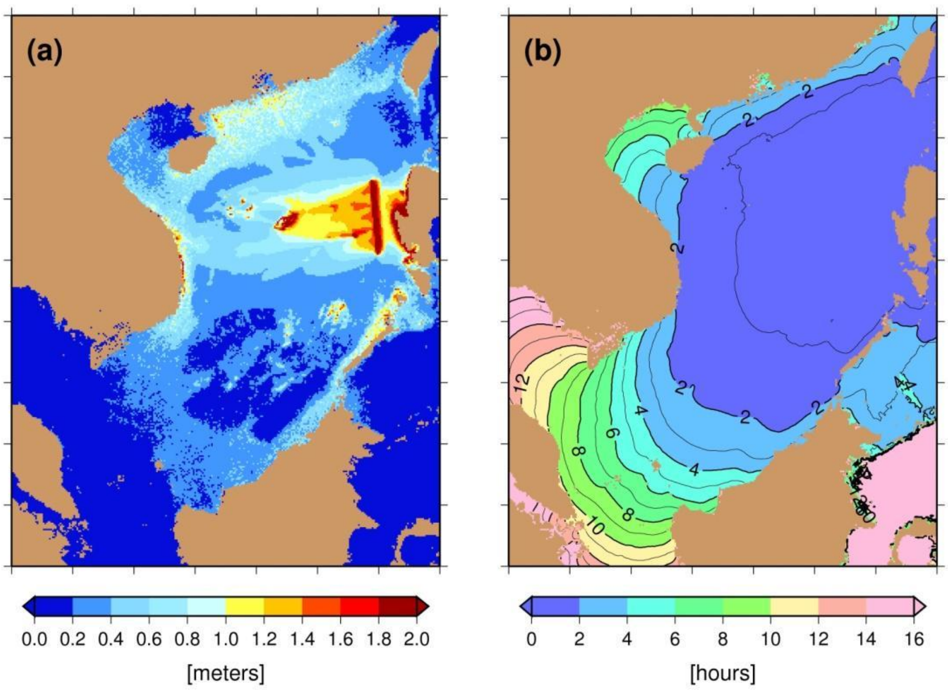


**Fig.2.6 Results of the numerical simulation: (a) the maximum amplitude, (b) the arrival time of the first wave**

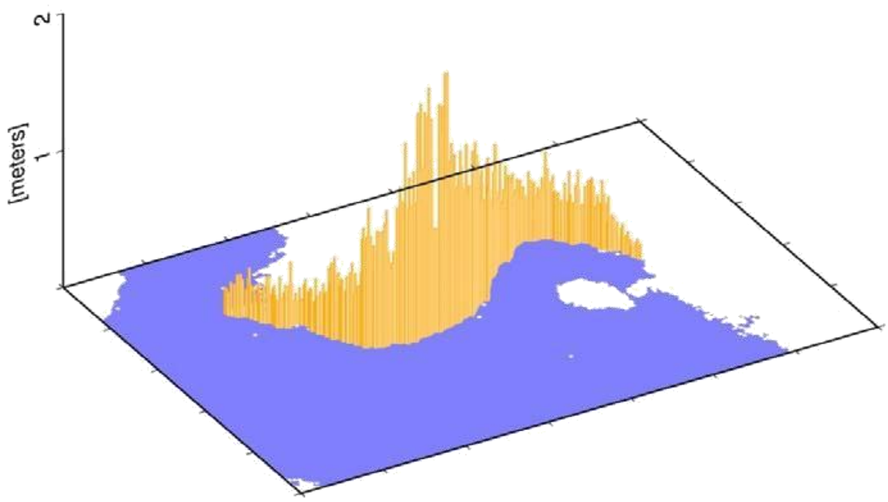


**Fig.2.7 Distribution of tsunami heights along Vietnamese coast**

## 2.4 Coastal erosion

It is feared that coastal erosion will be significantly exacerbated due to future climate-change effects such as sea-level rise and an increase in tropical cyclone intensity. However, even under the present climate it is possible to find how many places throughout the world are suffering from severe erosion problems. Especially, the rapidly-growing coastal cities in developing countries have been pulling in population from neighboring areas because of the various types of economic advantages they offer.

However, this socio-economical development patterns often do not consider the consequences that they may have on the natural environment and how this affects disaster resilience. A sandy beach can serve as a natural barrier against coastal disasters. If the beach is severely eroded, the vulnerability of local people against natural disasters will increase. **Fig 2.8** shows two cross-sections of the beach: before and after erosion. If the sand processes are not interfered with, then the sand profile will remain unaltered, which may reduce the energy of the waves along the shoreline, so that houses and other structures along the coast are generally protected by the sand. However, if the sand is lost, bigger waves will be able to reach the coastline reach and damage houses and other infrastructure. Therefore, it is important for us to understand how the beach serves as protection against natural disasters.

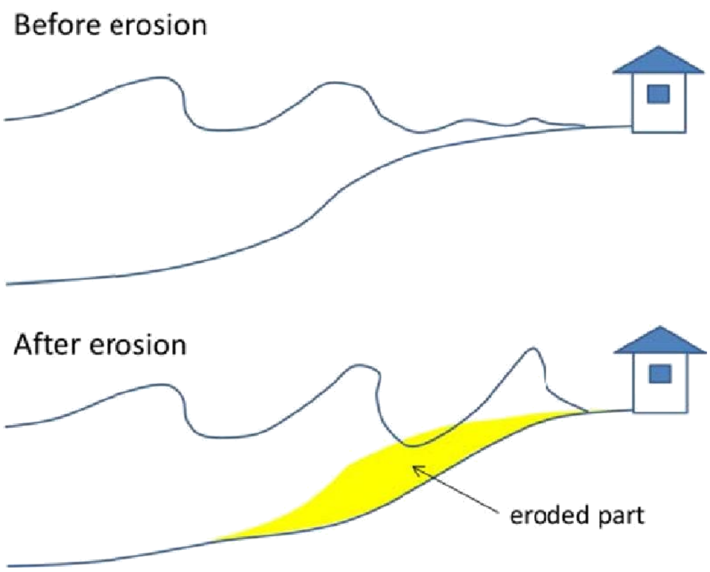


**Fig 2.8 Schematic illustratio n that show s the function of a sandy beach as natural barrier**

### 1) Field s urvey at a coastal c ity in Vietnam

Phan Thiet is the capital of Binh Thuan province in southeastern V etnam. The city is known as a fast growing c astal city which had a populati on of 189, 19 as of 2009 (General Statisti s Office of Vietnam 20 12), comp ared to 75, 41 in 1979 (Thomas Brinkhoff 2012). It is l ocated clo e to the se a and is frequently visited by tour sts, as it is famous fo r its beaut ful beache s and ocea n views an d other touris m infrastru cture. Phan Thiet is al so one of the most pr ductive fisheries in Vietnam wit h 50 thousand tons of fish caught per year. The town provides the local comm unity with food alon g with employment and export revenues.

The authors carried o t a field su rvey of this city durin g the dry season of Ja nuary 201 in order t o observe pr sent coasta l erosion problems. During the s urvey, a topographical survey wa carried out at two loca tions, Duc Long and Phu Trinh, which see m to be tw of the mo st vulnerab le locations against coastal disasters in the cit y.


**Fig 2.9 Depth contour off the coast of Phan Thiet (©Goo gle)**

**・Duc Lon g Area**

Duc Long is located near a beach which has been severely eroded in recent years (**Fig 2.10**). Although some of the residents have tried to stop the erosion, installing wooden piles an d sand bags, this has not been suc cessful in stopping the process. A questionnaire survey conducted in Januar y 2012 by the authors w ith local r sidents in Duc Long revealed that out of 17 responden ts, 35 % ( 6 people) had to elevate their house in the past and 24 % (4 people) had to move due to coastal erosion.

Using Google Earth to identify ch anges in c oastal areas, the shoreline appears to have retreated up t o 40 meters f rom 2001 t o 2010. **Fi g 2.11** show s the estim ated area that was eroded during this period, where approximately 4 ha of the sandy beac h had been lost along a 1.7 km stretch of the coastline. It is also clear that a large area of the coast adj acent to Duc Long has been landfilled within this period. Although a more careful assessm ent will be needed, it seems that the landfill and the t wo jetties at the river port stops the sand su pply from the river (Ca Ty Ri ver) mouth or other areas to th e downstrea m areas suc h as the Duc Long Area. As a san dy beach can serve as a natural barrier against coastal disasters such as storm surges, the situation of Duc Long clearly demonstrates how th e vulnerabili ty of coastal communities again st natural d isasters can increase if a beach is severel y eroded.

**Fig 2.10 Duc Long Area in Phan Thiet**


**Fig 2.11 Hatch with red c olor indicates the are as lost fro m 2001 to 2010 (©Google)**

**・Mui Ne Area**

Mui Ne is located to the east of Phan Thiet, and thus it can be considered that both areas share th e same coastal sedimen t issues a nd that the coastal processes are interlink ed. Judgin from past satellite images, it appears that the predominant direction of shoreline sedimen t transport is from east to west as sand accumulation can be often observed at the east sid e of jetties (**Fig 2.12**). Thus, it ca n be presume d that som e obstructions to shoreline sediment transpor such, as th e jetty in M ui Ne, ma y lead Phan T hiet to suff er from co astal erosio n.


**Fig 2.12 Location of two hotels in Mui Ne (©Google)**

This was c orroborated through the observation of the c hanges in t e coastline of two adjacent hotels in the area, that of Hotel West and East in M ui Ne (the hotel nam s are not t he real one s but aliases for the purpose of thi s study). T ese hotels are located on the far Westside o f Mui Ne and 2, 3 km from Phan Thiet. Com paring the coastlines from three satellite photos taken in 2006, 2009, and 201 0 respectivel y (**Fig 2.1 3**), a small sandy be ach remained in fron of both hotels in M arch 2006. However, it seems that the situation was bee n drastical y changed after a jetty (sand retaining groin) was constructed in 2 08 at Hot l East. The jetty of Hotel East was very e ffective to retain san d within the hotel area, and as a matter of fac t a wider sandy beach has been forming in front of th e hotel. One of the aut ors visited Hotel East in March 2008 and observed th at the jett was under construction and that a t the time the beach was sufferin from severe erosion (Upper left panel of **Fi g 2.14**).

During the field trip in January 2012, the r esearch tea m visited t is hotel and noticed uite a wid e beach (Up per right p anel of **Fig 2.14**). Th e hotel ma nager expla ined that the sand has recovere d naturally a ter the com pletion of the jetty without any further work (such as beach nouri hment). O n the other h and, it was obvious th t Hotel We st has lost sand since Hotel East started the constructio n of the jett . The cha nge in coa tline from 2006 to 2009 shows evidence that the jetty hindere d alongshore sediment transport fro m east to west and caused a loss of sand in front of Ho tel West. I n 2009, Hotel West also started construction of a new jett to prevent any furthe r erosion. A s a result, it appears th t the sand y beach is gradually recovering. In **Fig 2.13**, the pres ent coastlin e of Hostel West, as recorded usin g a portable GPS during the field survey on January 20 12, is also shown. Th e remaining photographs in **Fig 2.14** show ho since the jetty was c nstructed the beach of Hotel West has also been advancing in recent years.

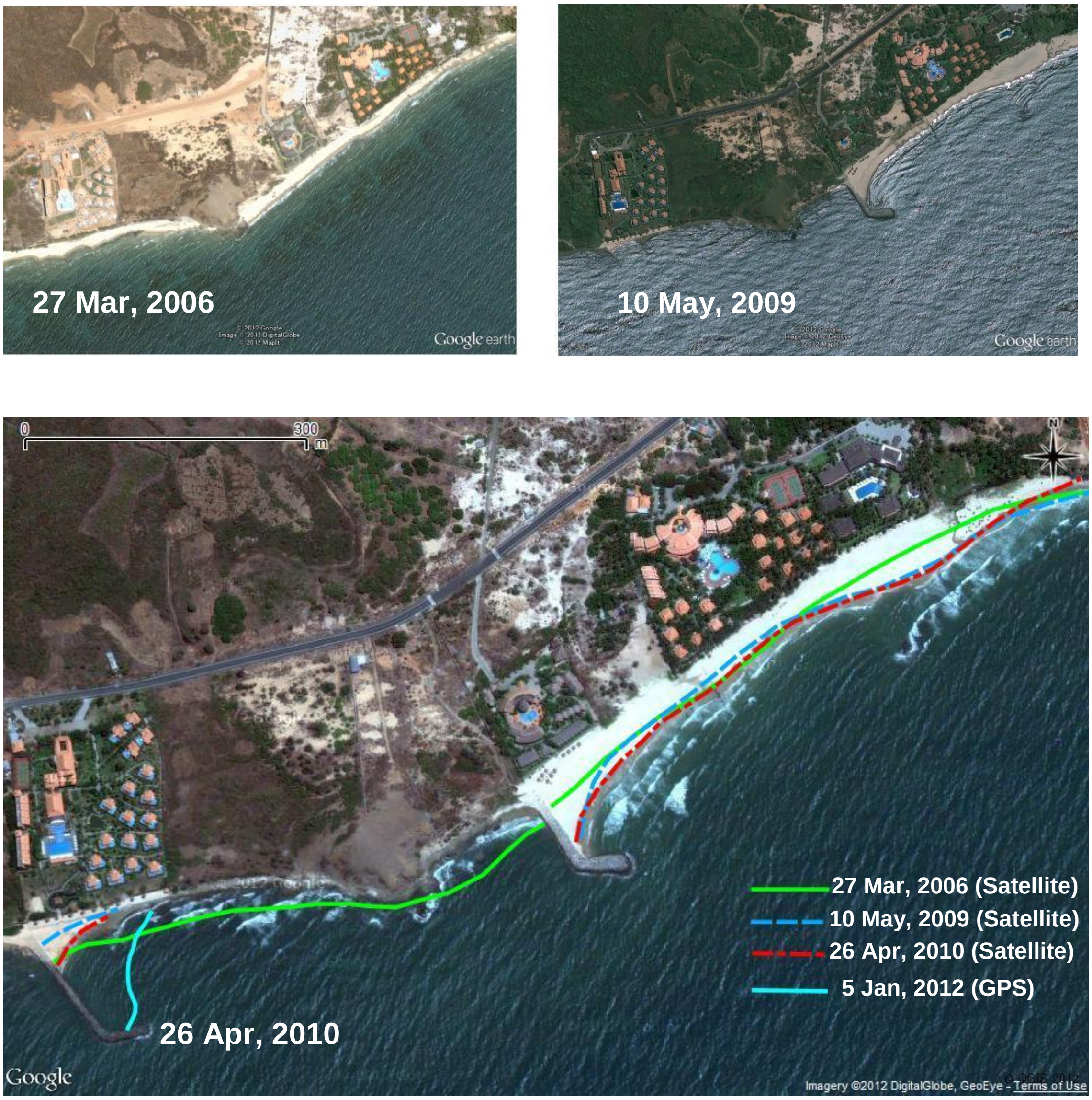


**Fig 2.13 Changes in the coastline of Hotels East and West from 2006 to 2010 (©Google)**

The protection of beaches against erosion is a fundamental issue for all resort hotels since hotels may be devalued due to the loss of a beautiful sandy beach. However, it is important to carefully consider the effects that constructing a jetty or other coastal protections may have, as they can often lead to further erosion to adjacent coasts. In particular, it is important to consider the effects that this will have in areas where the local residents have limited means to protect themselves against a retreating coastline, as the issues of coastal erosion typically affect disproportionately the poorer members of the community as these have limited financial means to either construct defenses or relocate.

According to the Vietnamese technical guides for sea dykes (e.g. "14TCN130-2002, Sea dyke, Guide for design"), groins should be installed in a way not to disturb the sediment transport system within the closed coastal system. In the case of Mui Ne, however, the groins have not been planned in such a manner due to the lack of public budget for carrying out a basic survey. As a result, hotel owners have constructed the jetties separately, hoping to protect their own resort beaches and eventually causing further erosion to neighboring areas. Even though local authorities could foresee such an adverse effect, they could not regulate the construction of jetties by hotel owners due to the lack of the laws relating to coastal management. One of the civil servants in the area mentioned how the "protection of my coast is to bring the erosion to my neighbor".

Photo taken on March 2008 by one of the authors (H. Takagi)

Photo taken on January 2012

Photo taken on January 2012

**Fig 2.14 Photos taken at Hotel East in Mui Ne on March 2008 and January 2012**

## 2.5 Topographical hazard

Since southern Vietnam has not suffered severe tropical storms as often as its northern parts, people living there tend to be less cautious about water-related disasters such as storm surge and river flooding. Consequently, densely-populated residential areas have been expanding even into places regarded as having a high potential for disaster risk due to their topographically characteristics.

Phu Trinh Area in Phan Thiet is one of such settlement on the banks of the Ca Ty River, formed of land reclaimed using oyster shell and other wastes (**Fig 2.15**). Although most of Phan Thiet is situated in low-lying areas, Phu Trinh is considerably lower than the rest of the city so it is sometimes inundated during the rainy season. During the field survey carried out by the authors, this area was determined to be 49 cm above Mean Sea Level, even though it was during the dry season.

Although the residents are to so me extent accustomed to river flo oding they are not so necessaril y aware that tropical storms can bring about a storm surge. Since this area of t he town is ocated onl y 1.5 km upstream of th e river mo uth, a large typhoon c ould cause a storm surge that wo uld progress up the river, damage the houses and potentially be fatal to many f its reside nts. It sho ld be note d also that the inhabitants of this area are generally quite poor, and that the quality of con struction of the houses is generally quite low, and hence the occurrence of a storm surge in this area could lead t o widespread devastation amongst this community.

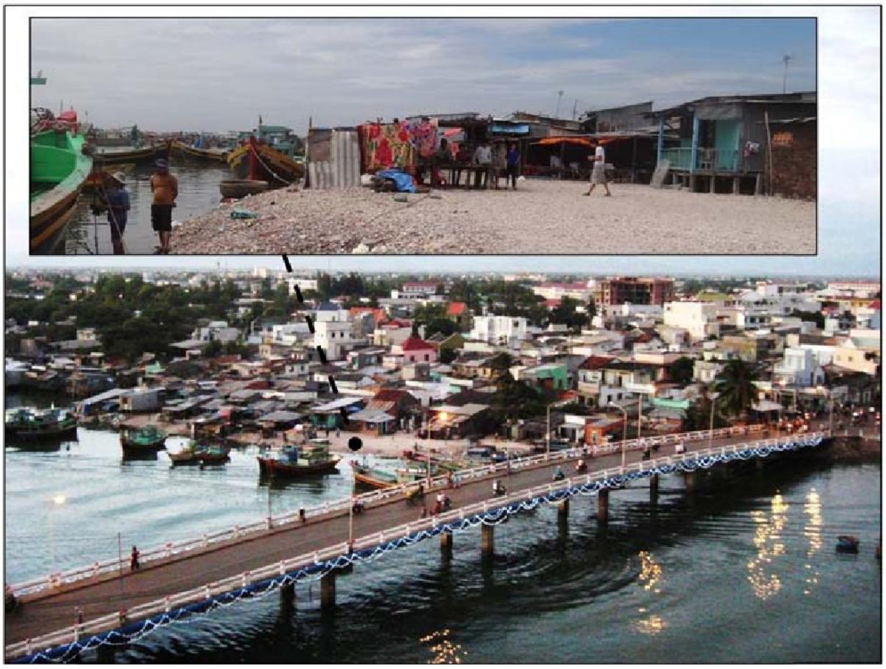

**Fig 2.15 Phu T rinh Area which is lo cated insid e a river b asin**

## 2.6 Sea-le vel rise

According to the IPC C Fourth Assessment Report (20 07), the global averag e temperature has rise n about 0.74 °C for the period of 1906 – 2005 and the warming tre d over the last 50 ye rs is nearl y twice that f or the previous 50 ye rs. The pa e of global average se a level rise gradually increased i n the course of the 20th century. Th e two majo r causes o sea level ise are thermal expansion and ic e melting. T e observed sea level d ata between 1961 – 2 003 showe an increas e in the av erage global sea level of about 1.8±0.5mm/year, in which the thermal expansi on contributed about 0.42±0.12 m/year and the ice melting co ntributed about 0.70±0.50mm/year. Satellit e data from TOPEX/PO SEIDON in the peri od of 1993 – 2003 s howed a raise in glob al sea lev ls of about 3.1±0.7mm /year, considerably fa ter than tha t of the 19 61 – 2003 period (IPC C 2007).

In Vietnam, during the last 50 ye rs (1958 – 2007), the annual average temperature incre se has bee n about 0.5 to 0.7°C (M ONRE 200 9). Winter temperatures increased faster tha n those in the summer and temperatures in the Northern climate zo nes increase d faster tha n those of Southern climate zones.

Data from tidal gauges along Vietnam coasts show that sea level increased at about 3mm/year during the period of 1993 – 2008, in line with the global average increases. In the past 50 years, the sea level at Hon Dau station has risen by about 20cm (MONRE 2009).

Using a coarse digital terrain model and global population distribution data, it is estimated that more than 1 million people will be directly affected by sea-level rise in 2050 in each of the Ganges-Brahmaputra-Meghna delta in Bangladesh, the Mekong delta in Vietnam and the Nile delta in Egypt (Ericson et al. 2005). Dasgupta et al. (2007) also created an inundation map under the scenarios of sea-level rise projected by the IPCC Third Assessment Report and revealed that Vietnam will be one of the countries most severely affected by sea-level rise.

The purpose of the present research is not to go into hypothetical consequences of climate change and sea-level rise in the future, but rather to focus on present problems. However, it should be noted that there is the fear that future sea-level rise and climate change will have a significant impact on low-lying coastal areas in Vietnam, exacerbating present problems.

## 3. Discussion on coastal disaster vulnerability

The maximum storm surge heights due to the largest tropical storms in the last 60 years were calculated to be approximately 1 m at Phan Thiet and the Mekong River mouth, which are smaller than those often observed in the northern and central parts of Vietnam. For instance, Sundström and Södervall (2004) show that the maximum storm surge height observed at Hai Hau in northern Vietnam between 1962 and 1991 was 1.6 m. **Fig.2.1** and **Table 2.1** show how the number of tropical storms that approach the coasts of the southern part of Vietnam is about one half to one third of those which approach the northern and central parts. In addition, it is also possible to see that tropical storm paths around Vietnam have not been moving southward over time, contrary to what some people believe perceptions that paths have changed due to climate change. While it is possible that paths will change in the future due to the advance of climate change, the randomness inherent in the movement of a tropical cyclone is a more important issue from the point of view of disaster risk management.

These facts mean that the possibility of disasters brought by tropical storms is considerably less in southern Vietnam than in northern and central Vietnam. However, this does not necessarily mean that southern Vietnam is less vulnerable against tropical cyclones. The factors that can lead to catastrophic human and economic losses are not only due to the physical impact of the typhoon itself, as could be witnessed for the case of Hurricane Katrina of 2005 in the United States. Social aspects such as land use and people's awareness against disasters are of great importance in considering the potential risk of disasters.

Phan Thiet city, for example, has not experienced in recent times a severe typhoon that has brought a significant storm surge into the area. Thus, the potential danger from such events is not necessarily something that the local population considers. Furthermore, it seems that rapid population growth (due in turn to the rapid economic growth in the area) has forced people to live in hazardous locations such as Phu Trinh Area in a low-lying riverbank and a severely eroded coast in Duc Long Area. Again it is important to emphasize that it is the poorest members of the community that live in such high-risk areas, and their limited economic means also mean that their adaptive capacity and resilience can be lower than richer members of the society.

The present study estimated that a storm surge as high as 1 m occurred at Phan Thiet in 1962 during the passage of typhoon Lucy over the area. A one-meter storm surge is not as large as that in the northern and central parts of Vietnam. However, the population living in the area in 1962 was limited, and hence it is probably that the losses would also have been limited. However, if a tropical storm of the same level as Lucy hits Phan Thiet city nowadays, it will probably cause severe damage to many of the vulnerable areas highlighted. It is also obvious that damage to these communities in the future will become larger when the effects of sea-level rise and climate change start to be felt more acutely.

Shibayama et al. (2008) carried out a field investigation after Cyclone Nargis in 2008, which caused the worst natural disaster in the recorded history of Myanmar, 84,500 people were killed and 53,800 went missing according to official figures. These authors pointed out that relatively small number of cyclones (on average 2 events every 10 years) have hit the southern coast of Myanmar compared to the high number of cyclones that hit the coast of Bangladesh, and that the route that Nargis traced is rather unique. They also revealed (based on interviews with local residents) that even though the situation was potentially catastrophic, most residents had not evacuated to areas near Yangon city prior to the event. They elucidated that two reasons were the main cause for this, namely the cyclone passed through the area in the late night to the early morning during which many of the inhabitants had been sleeping, and that there had been an underestimation or lack of perception of the dangers of a storm surge.

The situation that Myanmar experienced in the wake of Nargis could occur in the southern part of Vietnam in the future. Therefore, preparedness against storm surges should be emphasized in disaster risk management for the southern part of Vietnam.

Regarding tsunamis, the height of a possible tsunami wave to southern Vietnam wave is relatively small (less than 1 meter) and there is some delay between the occurrence of earthquake and the arrival of the first wave. However, there is still a great risk of the southern part of the Vietnamese coast suffering serious damage due to tsunamis due to the long breadth of the low-lying ground, the lack of past experience with this type of phenomena and the under-developed of tsunami mitigation measures:

Long breadth of low-lying ground: The southern part of the Vietnamese coast comprehends the Mekong Delta and thus entire area is low in height. In the field survey which the authors carried out in January 2012, many low-lying residential areas were found. Some of the most effective tsunami counter-measure strategies involve the evacuation of the population to adjacent hills of sufficient elevation; however this kind of strategy cannot be applied to such a wide low-lying area. In addition, there are many rivers and waterways running throughout this area, which allow the propagation of the tsunami further inland, thus affecting populations located a far distance from the coastline. It is thus necessary to examine what would be an appropriate evacuation plan using both evacuation buildings and shelters, according to more detailed simulations (which should include simulations of how the tsunami will propagate inland).

Lack of past experiences: The damage due to a tsunami often depends on past experiences and the information that the local population has obtained on what to do in these events. For example, it was reported that a tradition of oral histories about past tsunami disasters saved residents in Indonesia (McAdoo *et al.*, 2006) and the Solomon Islands (Fritz & Kalligeris, 2008). This traditional knowledge can be very important, though to the authors' knowledge, there has been no comprehensive investigation about past events and experiences in Vietnam. Further researches on past events in Vietnam are needed to prepare for future events and to teach the danger of tsunamis to residents. Researches on paleo-tsunamis (events occurred hundreds or thousands years ago) by using tsunami deposits (e.g. Minoura *et al.*, 2001; Nanayama *et al.*, 2003) are also important to understand the return period of tsunamis in this area.

Under-developed tsunami mitigation measures: There is no operational tsunami warning system in place in the East Sea region (Liu *et al.*, 2009). When an earthquake takes place close to the coastal area, people in this area can feel the ground shaking due to the earthquake and then become aware of the danger of tsunami. However, when an earthquake takes place far from the coastal area, such as an earthquake in the Manila Trench, it is difficult for residents to understand that a tsunami might be approaching unless a tsunami warning system is in place. There are over two hours between the occurrence of an earthquake in the Manila Trench and the arrival of a tsunami to the Vietnamese coast, and thus it is important to develop a warning system which can issue relevant information during this period of time to help residents evacuate.

The increasing pace of tourism and industrial development in coastal areas and future sea level rise due to the global warming will amplify the risk of both storm surge and tsunami. One more factor which should be emphasized is the threat posed by the construction of infrastructures without careful consideration of possible environmental impacts, installed by the tourist industry or other industries. Through the field survey, the authors revealed how sediment blockage caused by the land reclamation and hotel jetties lead to further erosion to adjacent coasts and may result in increasing in vulnerability to coastal disasters such as storm surges and tsunamis. In particular, it is important to consider the effects that this will have in areas where the local residents have limited financial means to protect themselves against a retreating coastline. The authors during their field surveys also conducted interviews with various local organizations and the local population. It is also important to consider that, despite the fact that many local people and other organizations attribute many of the coastal problems to climate change, many of them (particularly those of coastal erosion and tropical cyclone) do not appear to have climate change as its root. The increases in vulnerability to these and other coastal disasters originate from a comparatively weak legislation and coastal management practices, where alterations to some areas create problems in other areas further downstream. The inhabitants of some areas, thus, pay for what is being done in other areas of the coastline.

## 4. Conclusions

Carrying out field surveys and numerical simulation, the authors attempted to analyse the potential disaster risks in southern Vietnam associated with six natural hazards: tropical cyclones, storm surges, tsunamis, coastal erosion, topographical hazard and sea-level rise, and discussed the vulnerability of the local communities to these threats in the context of rapid economic development. Even though the probability that the communities in the southern coasts of Vietnam may encounter serious threats of coastal disasters such as storm surges and tsunamis is smaller than those in the other parts of country, the authors pointed out that infrastructure investments made by tourist or other industries may exacerbate the potential disaster risks to adjacent areas. The potential risks due to coastal disasters are typically larger among the poorest members of the community as they often live in higher-risk areas where the richer members of the community will refuse to live, and typically show lower adaptive capacity and resilience to extreme events. Irrespective of social background, preparedness against coastal disasters which would be promoted by means of both economic and social investments (education, etc) and this should take place in a system where the entire processes that take place in the coastal areas are considered (Integrated Coastal Management), particular vulnerable low-lying coastal areas.

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# Appendix

## Methodology of storm surge simulation

### 1) Numerical simulation model

The numerical simulations conducted are based on a computer simulation developed by the authors themselves. The shallow-water long-wave theory can be applied to phenomena such as storm surges and tsunami due to their long wavelength, as compared to the water depth. In the present study, the governing equations, which are the continuity equation and the momentum equations in the x and y directions respectively, are used in the model to simulate storm surge behavior (Bowden 1983, Kowalik and Murty 1993);

$$0 \qquad (1)$$

$$\frac{}{} \; \frac{^2}{} \; \frac{}{} \qquad {}_{7/3}\frac{2}{} \sqrt{\;^2 \quad ^2} \qquad \frac{}{} \quad \frac{}{}$$

$$\frac{}{} \; \frac{^2}{_2} \; \frac{^2}{_2} \quad 0 \qquad (2)$$

$$\frac{}{} \qquad \frac{}{} \; \frac{^2}{} \qquad {}_{7/3}\frac{2}{} \sqrt{\;^2 \quad ^2} \qquad \frac{}{} \quad \frac{}{}$$

$$\frac{}{} \; \frac{^2}{_2} \; \frac{^2}{_2} \quad 0 \qquad (3)$$

where and denotes the discharge flux, that is, the integrated flow volume from the sea bottom to the water surface; , the density of sea water; , the displacement of the water surface; and , the still water depth. (= ) denotes the total water depth; , Manning's roughness coefficient; , the Coriolis parameter; , the atmospheric pressure; , the wind shear stress on the water surface; and , the horizontal mixing coefficient.

Leap-frog and staggered grids are adopted to calculate **Eq.1** through **Eq.3** numerically. In order to stabilize the calculation process, the upwind difference scheme is used for the advection term in **Eqs.2** and **3** (e.g. Kowalik and Murty 1993).

The computational domain adopted is located between E99 and E112 degrees longitude and N6 and N14 degrees latitude (**Fig.A-1**). For the bathymetric data, a global 30 arc-second grid provided by the General Bathymetric Chart of the Oceans (GEBCO) was used, and uniform grids in a Cartesian coordinate system with a spatial interval of 3,000m were generated from the GEBCO data. GEBCO's global elevation models are generated by the assimilation of heterogeneous data types assuming all of them to be referred to mean sea level.

The atmospheric pressure inside a typhoon or other tropical storms is generally expressed by an empirical formula. For the case of the present model the Myers Formula was adopted (Myers 1954):

$$0 \quad \Delta \cdot \quad \frac{}{0} \qquad (4)$$

where $r$ denotes the distance from the center of the typhoon; $P_0$, the pressure at the center of the typhoon; $P$, the depression of pressure; and , the radius of maximum wind (the distance from storm center to the maximum wind). The value of is associated with maximum sustained wind speed (as maximum winds increase, the radius decreases) and can be calculated by the following equation proposed by Kato (2005):

$$_0 \quad 950:$$

$$_0 \quad 80 \quad 0.769 \quad 950 \quad _0 \qquad (5)$$

$$_0 \quad 950:$$

$$_0 \quad 80 \quad 1.633 \quad _0 \quad 950 \qquad (6)$$

Hence, the water surface elevation $r_1$ (cm) caused by a drop in static pressure can be easily calculated by using $P$ in **Eq.4** as follows:

$$\Delta \quad 0.991 \qquad (7)$$

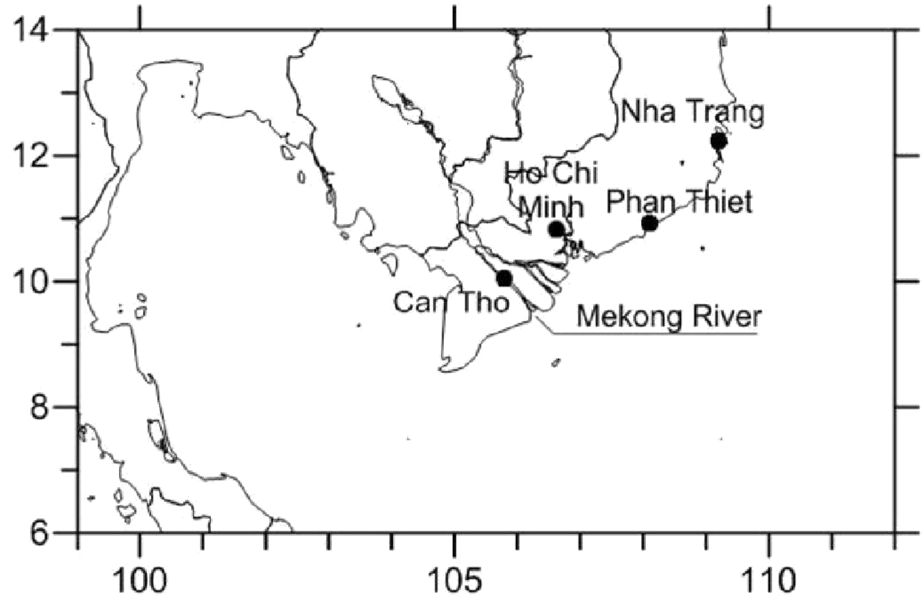
where is the normal atmospheric pressure, considered as 1013 hPa in the present research.

The wind speed at the sea surface is another important factor for the appropriate evaluation of the sea water level. The wind speed is expressed as the sum of two components, the gradient wind and the forward speed of the typhoon. The following expression is used in the present model for calculating the wind speed (Murota 1964);

$$1 \ \exp \quad 5 \ 10^5 \quad 2 \quad \frac{}{} \quad \underline{0.866 \ 0.5} \quad \exp \quad \overline{\underline{\Delta \ 0} \quad \underline{0} \quad \cdot \ 2} \quad 2 \quad 2 \qquad (8)$$

$$1 \ \exp \quad 5 \ 10^5 \quad 2 \quad \frac{}{} \quad \underline{0.866 \ 0.5} \quad \exp \quad \overline{\underline{\Delta \ 0} \quad \underline{0} \quad \cdot \ 2} \quad 2 \quad 2 \qquad (9)$$

Where $W_x$ and $W_y$ denote the wind speeds in the x- and y-directions, respectively; $F$ denotes the forward speed of the typhoon; $G$ denotes the gradient wind speed; and $C_1$ and $C_2$ are empirical coefficients.




**Fi g.A-1 Computational domain for storm su ge simulat ion**

### 2) Verific tion of the model

A numeric al simulatio n of tropical storm Linda in November 19 97 was performed to evaluate th e validity of the model ( **Fig.A-2**). inda was the worst st orm to hit the southern part of Vi tnam in th e past severa l decades. Severe tropical storm Linda for med on October 1997 in the East Sea an d eventually caused extensive damage to coa stal areas in southern Vietnam, k illing 3,11 1 people, as many fishermen and sailors wer e caught at sea in the path of th storm, unable to escape (UND P 2003).

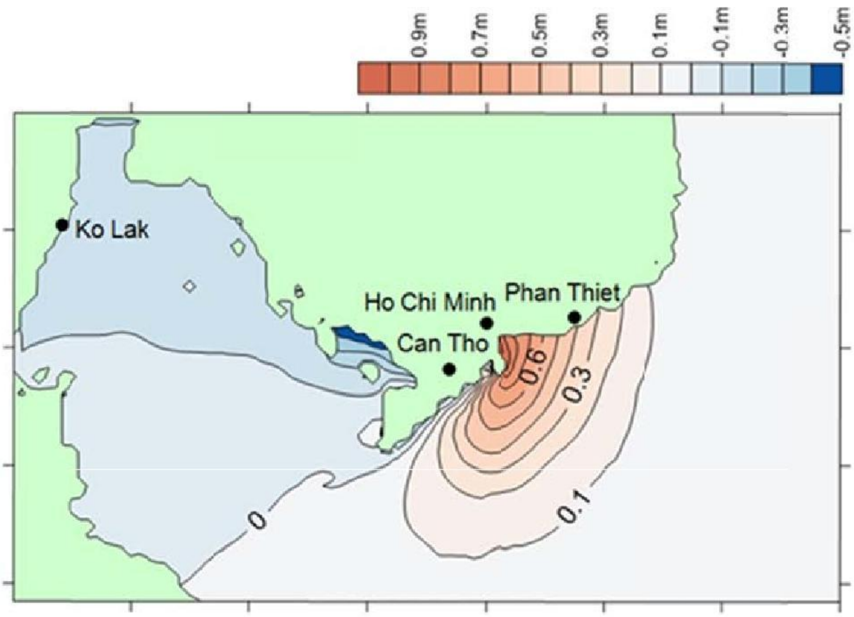



**Fig.A-2 Simulated storm surge height at the momen t Linda hit the southern coast o f Vietnam**

Since for t is storm there seems to be no tidal data freely available to the public, the water-elevatio n data at the tidal gauge station at Ko Lak in hailand w s used for verification (Phaksopa 2003). Th e comparison between the results of the si ulation an d the obse rved level s at this s ation (after subtracting the effects of the astr onomical tide) are giv en in **Fig.A-3**, which shows the simulation t o be accurate in terms b oth of the amplitude of the stor m surge an the time a t which it takes place. The observ ed levels at Ko Lak, however, s ow a longer duration in the high -tide peak than that of the simulation. Part o the reason for this se ems to be that the nu merical model does no t reproduc e the heavy recipitatio n that takes place duri ng the typhoon. Hence, the storm surge heig ht simulate d by a simple model such as the on e used in the present study needs o be carefu lly examined with dat a available at neighbori ng areas. F urthermore, it should e noted th t wave set up which occurs insid e the surf zo ne (which c an contrib te to incre asing the se a level in the areas ad jacent to th e coastline) is also not directly cal culated by the model.

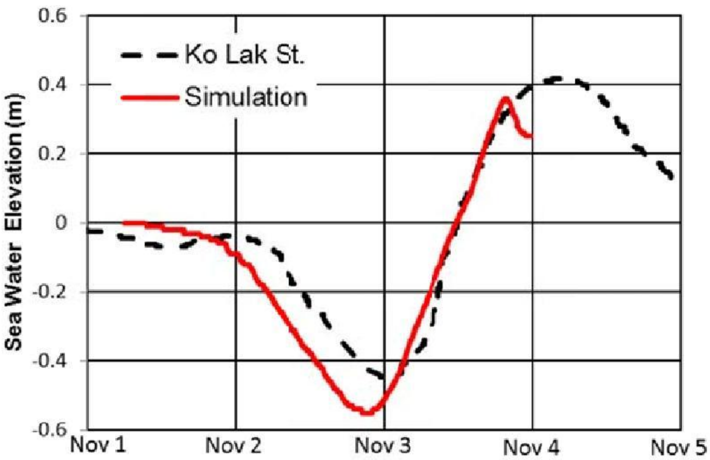



**Fig.A-3 Verificat on of the simulated sea-water e levation du ring Typh oon Linda in 1997**

### 3) Wave s etup

As mention ed in the previous section, the ri se of water due to wave-induced setup, which is ignore d in the pres ent simulati on model, can consid erably contributes to t he total height of a sto rm surge i n some cases. Hence, the wave-set up effect sh ould be tak en into account along with the s ction effect of the drop in pressu e and the wind effect . However, the simulation for th e wave field is not as simple as the model regarding atmosphe ric pressur e field and wind field. Therefore, the dat a retrieved from the ECMWF 40 Years Reanalysi provided by the European Centre for Medium-Range Weat her Foreca ts was us d to estim ate in a simple way the wave heights an d periods during the storms (**Fig.A-4**). The points for which this data was obtained are locate d approximately 110 km off the c ast of Phan Thiet an 150 km o ff the Mek ong River mouth. Th e wave heigh t and wav period at the peak of the storm was $H$=3.6m and $T$=9s off the c ast of Pha n Thiet for t yphoon Lu cy, and $H$=2.7m and =8.6s off the Mekon g River mo uth for sev ere tropical storm Linda. The cha ge in mea water lev el is denoted by an d can be evaluated by numericall y integrating the following differential equation from dee water toward the sho reline (Goda 2000).

$$\frac{1}{} \quad \frac{1}{8} \quad 2\ \frac{1}{2} \quad \frac{4\ /}{\sinh 4\ \ /} \qquad (10)$$

where denotes th e mean square of the heights of ra ndom wate r waves, *h* is the water depth, an d *L* the wave length.

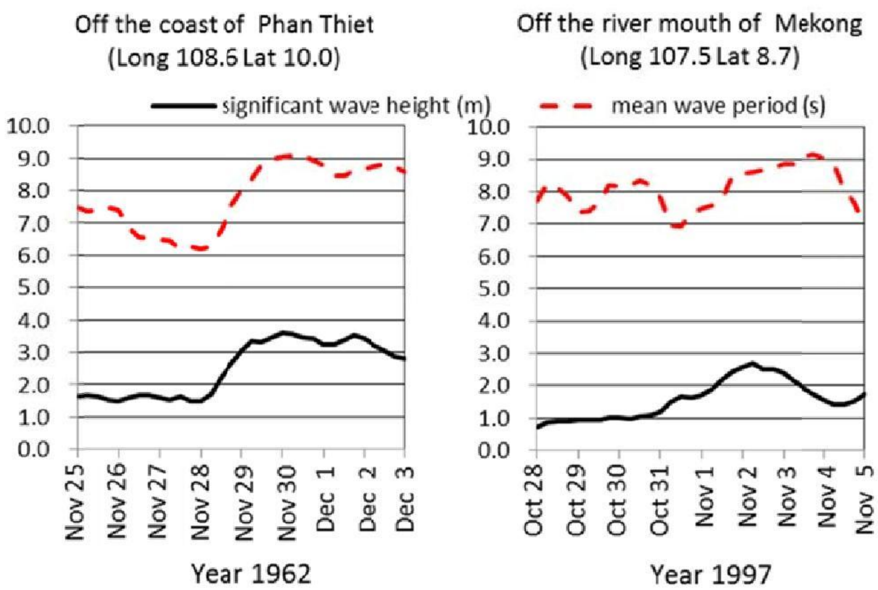



**Fig.A -4 Hindca sted wind- wave data retrieved f rom the E MWF 40 Years Rean alysis**

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