Songklanakarin J. Sci. Technol.
33 (4), 469-476, Jul. - Aug. 2011

SONGKLANAKARIN JOURNAL OF SCIENCE AND TECHNOLOGY
http://www.sjst.psu.ac.th

*Original Article*

# Coastal vulnerability assessment: a case study of Samut Sakhon coastal zone

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Received 25 March 2011; Accepted 1 August 2011

**Abstract**

The Samut Sakhon coastal zone (~41.8 km), which was selected as a study area due to its low-lying topography, has been increasingly impacted by climate change and erosion processes affecting the local community. This study examined the vulnerability area in this region by combining a physical process vulnerability index (PVI) and a socio-economic vulnerability index (SVI). Four physical variables (coastal slope, coastal erosion rate, mean tidal range, and mean wave height) and four socio-economic variables (land use, population density, cultural heritage, and roads/railways) were employed. The result was a single vulnerability indicator of a coastal vulnerability index (CVI) showing that the high vulnerability area, covering an area of 1.3 km$^2$ (0.45% of total study area), was located in Ban Bo, Ka Long, Bangyaprak, Bangkrajao, Khok Kham, Na Kok, and Puntainorasing. The moderate vulnerability area covered an area of 28 km$^2$ (9.5% of total study area), the low vulnerability area 180 km$^2$ (60.56% of total study area), and the very low vulnerability area 88 km$^2$ (29.52% of total study area). The CVI map indicated that it was highly differentiated and influenced by socio-economic indicators, rather than physical indicators. However, comparison between the different results of the PVI and SVI can contribute to understanding the variability and constraints of vulnerability. The results of this investigation showed that the study area was more correlated with aspects related to socio-economic characteristics than physical parameters.

**Keywords:** coastal vulnerability index, physical process vulnerability, socio-economic vulnerability, Samut Sakhon coastal zone, GIS

## 1. Introduction

Problems associated with climate change or global warming have impacts throughout the world. Global warming has resulted in a global sea level increase of approximately 1.8 millimeters per year beginning in the last century (Douglas, 1997). The increased sea level has resulted in increased erosion of coastal areas, which has caused some people to become homeless. Therefore, the sea level increase has become a crucial issue, and the problems related to erosion are very severe in some areas.

Research carried out by Sommart *et al*. (2008) on the rate of long-term sea level change in the area of the Gulf of Thailand using average annual data from 1940–2003 found that the rates at Sattaheep Bay Station, Chonburi, Mutpone Island Station, Chumphon, and Seechang Island Station, Chonburi, had increased 0.22, 0.51, and 0.81 millimeters per year, respectively. The problem of coastal erosion in Thailand is a silent disaster occurring every day. Of the coastal areas of Thailand, approximately 599 kilometers, or 21%, of the total of 2,667 kilometers, are associated with these serious problems. The most critical areas have been the Upper Gulf of Thailand with five provinces, Chachoengsao, Samutprakarn, Bangkok, Samut Sakhon, and Samut Songkarm. Along the 120 kilometers of coast in these areas, 82 kilometers, or 68%, with an average erosion rate of 12-25 meters per year, have been affected during the last 30 years (Jarupongsakul *et al*., 2008).

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The occurrence of coastal erosion in the Upper Gulf of Thailand has been considered a critical problem requiring urgent solutions as well as investigation of various dynamics of the problem to arrive at appropriate solutions. Thus, research related to defining areas vulnerable to erosion to identify the level of impact, along with the acquisition of coastal erosion rate, should be performed to create maps illustrating the vulnerability of coastal areas in Samut Sakhon. In this study, the coastal vulnerability index (CVI) was assessed by applying physical process variables and socio–economic variables to weight the vulnerability from available data. Furthermore, geographic information system (GIS) and remote sensing technologies were applied to identify areas that were vulnerable based upon the weighting of the vulnerability of each variable. This study also examined CVI tools and analyzed the vulnerability index for coastal areas in Samut Sakhon. By identifying areas associated with vulnerability in the format of a map, this research will contribute to the process of planning to prevent coastal erosion at the provincial level.

## 2. Description of the Study Area

Samut Sakhon presents a coastal plain topography, approximately 1.00 to 2.00 meters above the sea level. The lower area of the province, located in Muang District, includes 41.8 kilometers of coastline. The characteristics of this province provide opportunities for marine fisheries, coastal aquaculture, and salt production. To clarify the boundary of the study area for the present research, addressing vulnerability assessment of the coastal area in Samut Sakhon province (Figure 1), and to conduct this research corresponding to the physical process and socio-economic data for the study, the researchers selected a study area based upon the extent of eight sub-districts adjacent to the sea.

Considering the factors of geomorphology associated with the vulnerability value, as in related research (Hammar-Klose *et al*., 2003), the sandy beach area or mudflat area present the highest value of the vulnerability index. Hence, the study area was appropriate for this research due to its mudflat character, which was vulnerable to erosion. The study area is also an important area regarding socio-economic aspects, as there are communities, important historical sites, temples, tourist attractions, aquaculture, agriculture areas, fisheries, and other marine life habitats are located in the area.

## 3. Method

The coastal vulnerability index is a concept created by Gornitz (1990) to assess the risk of rising sea levels on the east coast of the USA. Gornitz created a database for analysis of coastal disasters. In 1999, Thieler and Hammer-Klose developed a new application of Gornitz's CVI. By modifying and reducing the number of variables, the CVI method made more effective. The CVI concept has been developed, advanced, and adapted to be pertinent to area characteristics

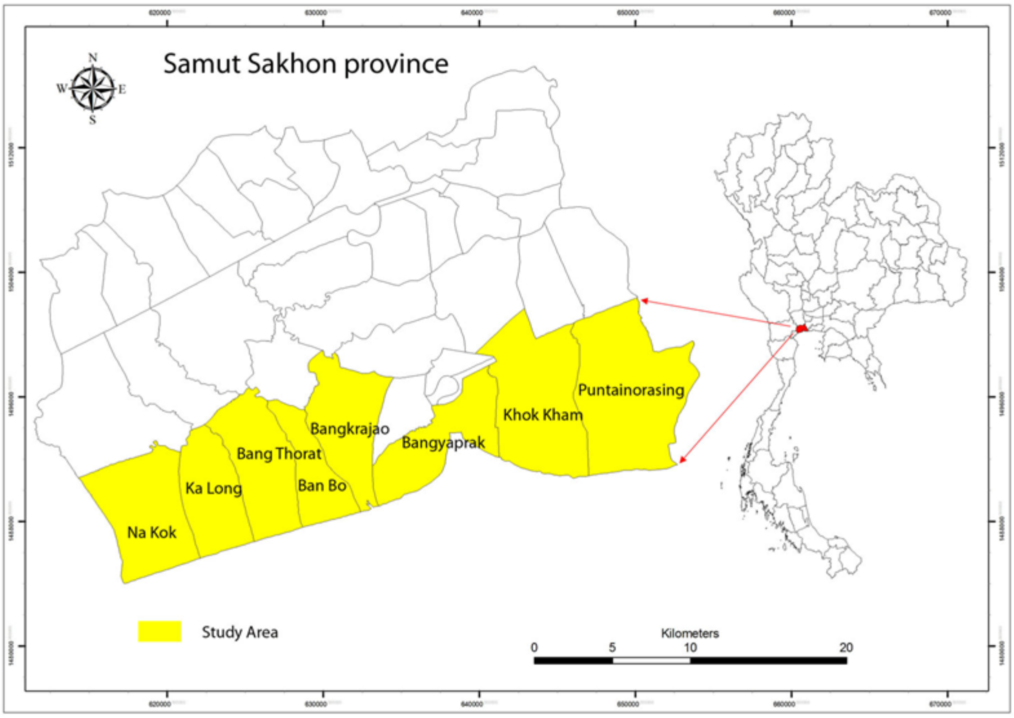


Figure 1. Study area.

and available parameter data. Several integrative studies on coastal vulnerability have been developed (McLaughlin, 2002; Hammar-Klose *et al*. 2003; Clauio F. Szlafsztien, 2005; Gardiner *et al.*, 2007; McFadden *et al*. 2007).

This study applied the reference parameters to determine the coastal vulnerability index. This method adjusted some indices in accordance with existing data and consistent with the physical characteristics of the study area. There are eight variables that can be classified into two groups: 1) physical process variables and 2) socio-economic variables. The physical process variables include (a) shoreline erosion rate, (b) slope, (c) mean tidal range, and (d) mean wave height. The socio-economic variables include (a) population density, (b) land use, (c) roads and railways, and (d) cultural heritage. These parameters are derived from GIS, remote sensing, and numerical data. The data products used for the study in deriving each of these parameters are provided in Table 1. They were used to calculate the coastal vulnerability index presented in Table 2. Each variable from these two categories was evaluated for weighted scoring and was categorized into classes from 1 to 5 based upon the relative vulnerability (with 5 representing the most vulnerable value, 4 more vulnerable, 3 moderately vulnerable, 2 less vulnerable, and 1 the least vulnerable).

Each variable then generated a weighted score in accordance with its significance and relevance in determining the vulnerability of coastal areas to erosion. These layers were subsequently overlaid, and the scoring of each variable was calculated and included in the Physical Process Vulnerability Index (PVI) and Socio-Economic Vulnerability Index (SVI). The Coastal Vulnerability Index (CVI) was derived by combining of both of these indices.

In the process of weighting each variable the Analytical Hierarchy Process (AHP) was used to evaluate the weighting value ($W_n$) of each variable based on expert scoring. To collect feedback from experts on the subject of the importance of factors causing the vulnerability of the coastal region in the study area, a questionnaire was employed to acquire outcomes for later use in the weighted scoring of each factor by Pairwise Comparison Analysis. In this study, three steps were involved in calculating the CVI (Figure 3): (1) data input and preprocessing; (2) data storage and data processing; and (3) output.

The values and ranking assigned for each of the considered parameters and the steps for generating the CVI are described in Table 2.

### 3.1 Weight values

Weight values were collected through a questionnaire given to two groups of experts, including physical and socio-economic experts. Computation of the weight value ($W_n$) followed the analytic hierarchy process (AHP) using pairwise comparisons. The results for the weight value of each variable are listed in Tables 3 and 4.

After determination of the weight value for each variable, the researcher multiplied the weight values by the values of vulnerability for each aforementioned variable.

Table 1. Data used in this study.

| Parameter of data | Data summary | Data source |
|---|---|---|
| Shoreline erosion rate | LANDSAT TM5 for 2000, 2003, 2006, and SPOT for 2007 were performed in GIS using the Digital Shoreline Analysis System (DSAS) extension to analyze the shoreline erosion rate. | GISTDA |
| Slope | Orthophoto at a 1:4,000 scale, Spot height, and Contour | Royal Thai Survey Department, Land Development Department, and the planning and sub-regional plan report of the Department of Public Works and Town & Country Planning, Ministry of Interior. |
| Mean tide range | Tide range data from 1988-2006 | Hydrographic Department, Royal Thai Navy |
| Mean wave height | Wave information from wind data calculation | Meteorological stations |
| Population density | Population and building area data | Office of Social Development and Human Security, Samut Sakhon Province and 8 Sub-District Administrative Organizations (SAO) |
| Land use | Land use in 2007 | Department of land development |
| Cultural Heritage | Buffer cultural heritage | Department of land development |
| Roads/Railways | Buffer roads/railways | Department of land development |

Table 2. Classification of vulnerability variables.

| | Order of coastal vulnerability | | | | |
|---|---|---|---|---|---|
| | very low | low | moderate | high | very high |
| | 1 | 2 | 3 | 4 | 5 |
| Variables | >.2 | .2 - .07 | .07 - .04 | .04 - .025 | <.025 |
| Coastal Slope (%) | <1.0 | 1.0 – 1.94 | 2.0 – 4.0 | .1 – 6.0 | > 6.0 |
| Mean Tide Range (m) | < .55 | .55 - .85 | .85 – 1.05 | 1.05 – 1.25 | >1.25 |
| Mean Wave Height (m) | >2.0 | 1.0 -2.0 | -1.0 – 1.0 | -2.0 - -1.0 | < -2.0 |
| Coastal Erosion Rate (m/yr) | No pop | 1-200 | 201-500 | 501-1000 | > 1001 |
| Population density (people) | Absent | | | | Present |
| Cultural Heritage | Absent | | | | Present |
| Roads/Railways | Water sources | Meadow in | Mangrove | Aquaculture | City |
| Land Use | Pond | coastal area | | Salt | Industrial |
| | Open space | | | exploitation | community |
| | | | | site | Traveling |
| | | | | Agriculture | attraction |

Adapted from USGS (1999) and McLAuglin *et al.* (2002).

Table 3. Weight values from experts (physical process parameters).

| | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Weight |
|---|---|---|---|---|---|
| Slope | 0.51 | 0.54 | 0.08 | 0.25 | 0.35 |
| Tide | 0.05 | 0.10 | 0.04 | 0.25 | 0.11 |
| Wave | 0.28 | 0.09 | 0.55 | 0.25 | 0.29 |
| Erosion | 0.17 | 0.27 | 0.31 | 0.25 | 0.25 |

Table 4. Weight values from experts (socio-economic parameters).

| | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Weight |
|---|---|---|---|---|---|
| Pop Density | 0.13 | 0.41 | 0.11 | 0.32 | 0.24 |
| Cultural- heritage | 0.09 | 0.16 | 0.52 | 0.32 | 0.27 |
| Roads/railways | 0.07 | 0.10 | 0.06 | 0.03 | 0.07 |
| LU | 0.71 | 0.34 | 0.31 | 0.32 | 0.42 |

$$\Sigma\, Physical\,\mathrm{Pr}\,ocess\,Variables = w_1x_1 + w_2x_2 + w_3x_3 + w_4x_4$$

$$\Sigma\, Socio\!-\!economic\,Variables = w_1x_1 + w_2x_2 + w_3x_3 + w_4x_4$$

$$\downarrow$$

$$\mathbf{CVA} = \frac{\Sigma\ \text{Physical Process Variables} + \Sigma\ \text{Socio - economic Variables}}{2}$$

Figure 2. Coastal vulnerability equation, where $W_n$ is the weight value of each variable, and $X_n$ is the vulnerability score of each variable.

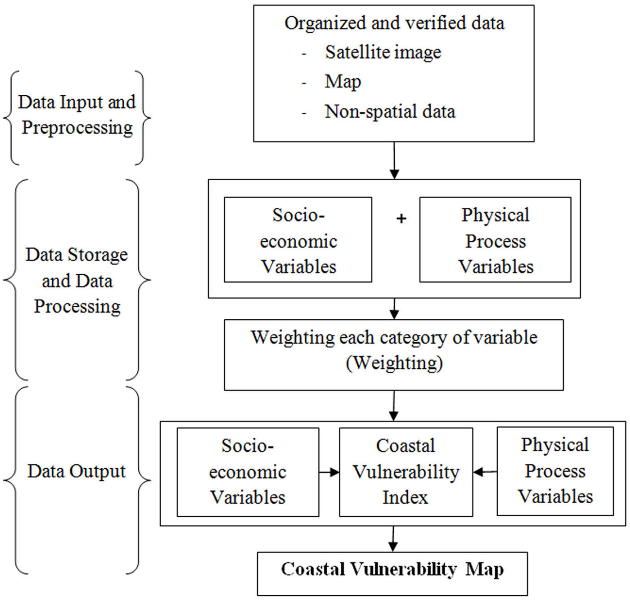


Figure 3. Research procedures.

## 4. Results and Discussion

After assigning the vulnerability value based upon each variable collected for the study area, the CVI was calculated using the equation shown in Figure 2. The CVI is divided into very low, low, moderate, high, and very high vulnerability categories (Figure 4). The high vulnerability area, covering an area of 1.3 km$^2$, or 831 rai (0.45% of total study area), was located in Ban Bo, Ka Long, Bangyaprak, Bangkrajao, Khok Kham, Na Kok, and Puntainorasing (Figures 5, 6, and 7). The major parameters affecting vulnerability were land use, slope, erosion rate, population density and cultural heritage. The moderate vulnerability area, covering 28 km$^2$, or 17,675 rai (9.5% of total study area), was located in Bangyaprak, Khok Kham, Bang Thorat, Puntainorasing, Ka Long, and Na Kok Ban Bo. Additionally, the low vulnerability area covered 180 km$^2$, or 112,765 rai (60.56% of total study area), and the very low vulnerability area 88 km$^2$, or 54,963 rai (29.52% of total study area).

The results for the specific physical process variables index (Figure 4a) did not vary within the entire study area

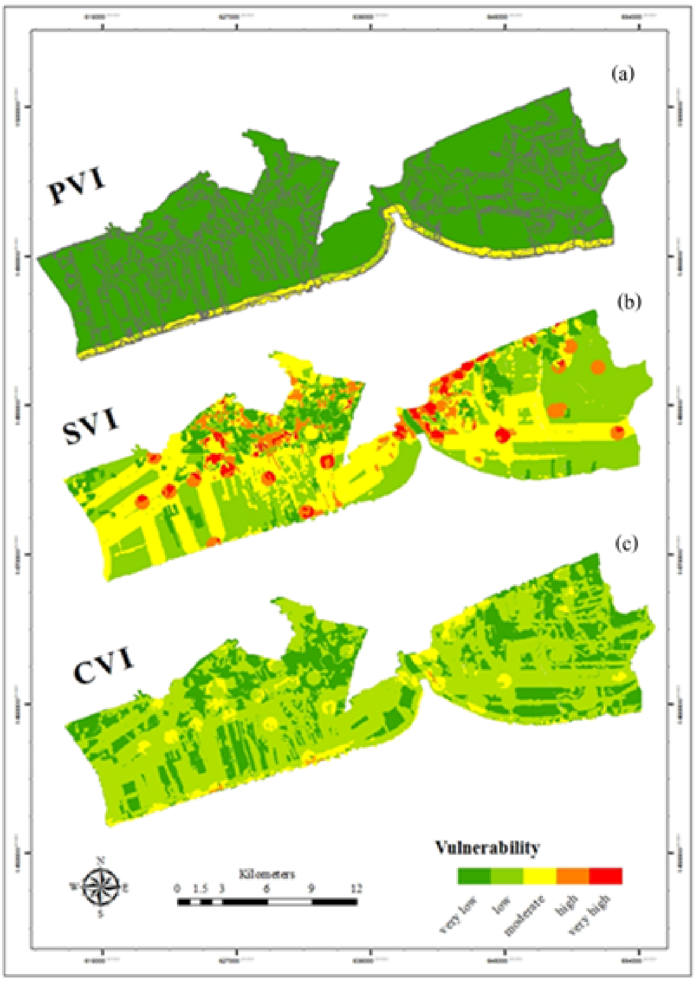


Figure 4. Vulnerability of the Samut Sakhon coastal zone based on physical process (PVI) and socio-economic (SVI) indicators and their integration into coastal vulnerability (CVI).

due to the detailed data collected related to wave height, tidal range, and erosion rate. The result represented only the shoreline segment and therefore did not contribute to the variance in the PVI. In contrast, the data related to socio-economic aspects varied across the study area due to the parameters associated with humans, land use, transportation, and cultural heritage (Figure 4b). The socio-economic variables were the major factors resulting higher in vulnerability rather than the physical process variables. Moreover, the socio-economic variables were more pertinent factors affecting the coastal vulnerability index (Figure 4c). In addition, socio-economic changes occurred more often and more rapidly than physical process changes (Szlafsztien, 2005). Thus, researchers should consider socio-economic data along with physical variables; moreover, additional parameters, including both physical and socio-economic variables (e.g., sediment supply, coastal defenses, climatic, and oceanographic data), should also be addressed. This would increase the accuracy and clarity of results related to coastal vulnerability. Nevertheless, comparison between different PVI and SVI results can contribute to understanding the variability in and determinants of vulnerability. An assessment of vulnerability in each area based upon both groups of variables should be implemented for the purpose of designing policy and mitigation measures to increase their flexibility and specificity. The results of this investigation showed that vulnerability in the study area was more correlated with aspects related to socio-economic characteristics than physical parameters.

However, it is important to understand that either singularly or collectively the physical and social indicators only represented the conceptualization of vulnerability as an exposure measure (Boruff *et al*., 2005). In addition, the socio-economic data employed here were at the district and sub–district level, whereas the physical attributes were at a shoreline-segment scale. Furthermore, the physical data included both longer term conditions (e.g., erosion rate) as well as daily averages (e.g., mean tidal range), while the social data represented a snapshot for one census year, 2007. In this regard, the CVI was merely a static indicator of conditions at a single point in time, rather than a dynamic representation of them (Boruff *et al*., 2005).

Based on fieldwork performed to verify the accuracy of the eroded areas by comparing the analyzed results with the actual conditions in the areas in eight sub-districts, the results of the analysis are consistent with what was observed in the actual areas, as follows:

As shown in Figure 5 and observed in the fieldwork, areas in Khok Kham and Puntainorasing are characterized by coastal erosion problems because sand sausages of approximately four kilometers length have been constructed. Over the long term, hard structures can result in coastal erosion of nearby areas (Rattanamanee *et al*., 2008). This result in the PVI map shows high vulnerability at some points.

As can be seen in Figure 6 and the SVI and CVI maps, Ban Bo is an area of high vulnerability because it includes communities in the coastal zone. In addition, as shown in the PVI and SVI maps, Bangkrajao is an area of high vulnerability because it is a residential area and exhibits a high rate of erosion associated with signs of sand sausages. Furthermore, from Figure 7 and the SVI, it can be observed that Ka Long is an area of high vulnerability because it is a residential area, which thus causes high vulnerability of the CVI.

## 5. Conclusions

The CVI map shows which areas exhibit different vulnerabilities based on data for eight variables: slope, coastal

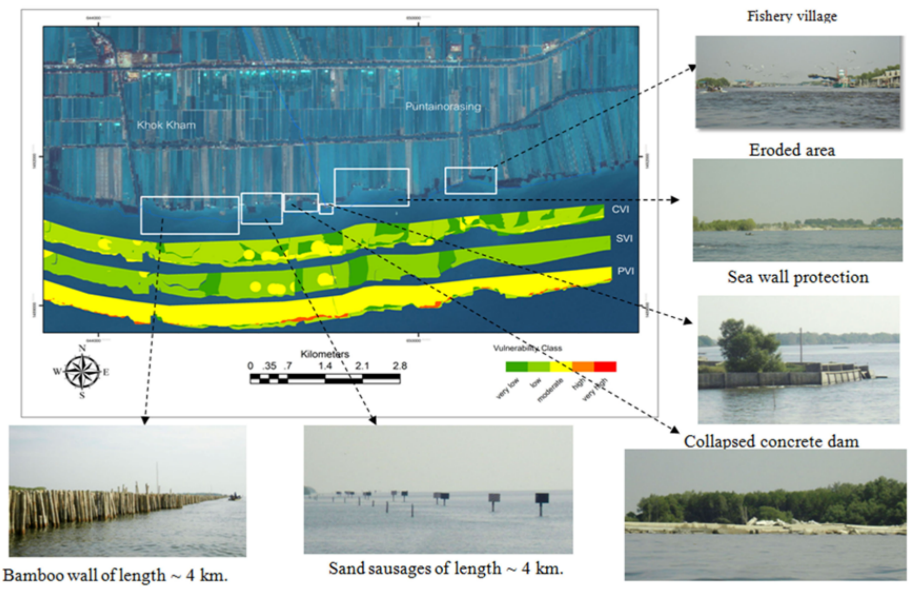


Figure 5. Ground survey in Samut Sakhon province (East coast).

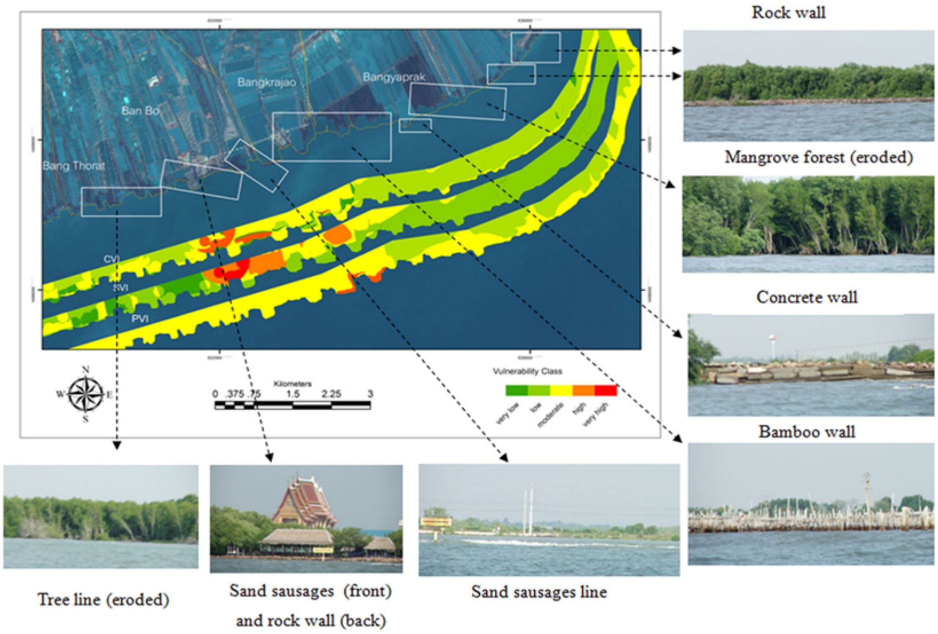


Figure 6. Ground survey in Samut Sakhon province (West coast).

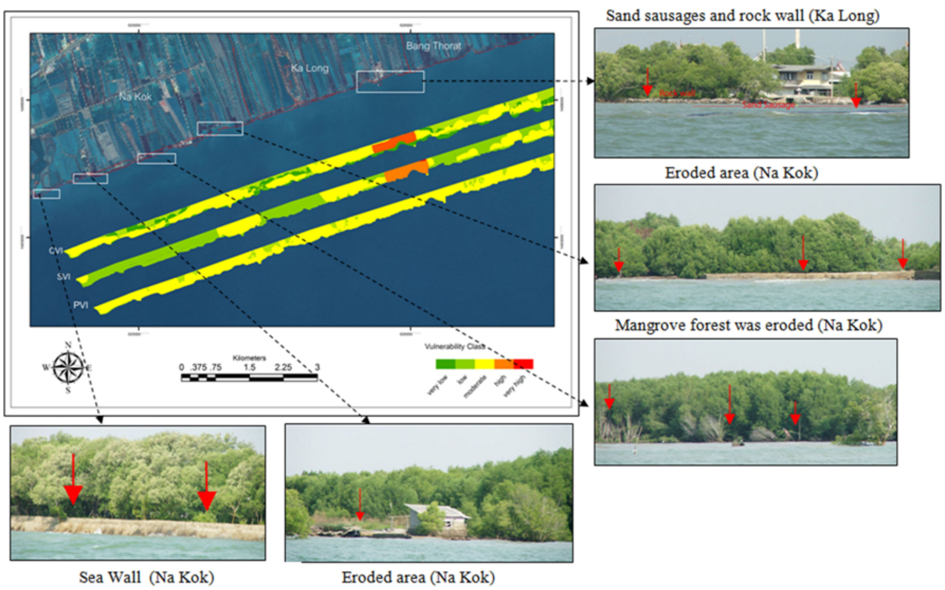


Figure 7. Ground survey in Samut Sakhon province (West coast).

erosion rate, mean wave height, mean tidal range, land use, population density, cultural heritage, and roads/railways. Indicating the vulnerability level of the coast GIS is used to show a more accurate picture of vulnerability. The CVI analysis revealed that 0.45% of the total area was associated with high vulnerability, and these areas were located in Ban Bo, Ka Long, Bangyaprak, Bangkrajao, Khok Kham, Na Kok, and Puntainorasing. The significant parameters leading to high vulnerability were land use, slope, erosion rate, population density, and cultural heritage.

The slope and erosion rate variables were important parameters for coastal vulnerability due to the fact that erosion and slope varied in some areas. However, the remaining variables, including mean wave height and mean tide range, did not vary with respect to vulnerability along the coastline (~41.8 km). This is not a particularly long coastline, so only one value was obtained for the data for both of them.

The purpose of this coastal vulnerability assessment was to provide a preliminary overview in the form of a coastal vulnerability map to identify each vulnerable area. The decision can be rapidly made to prevent initial planning of the area. However, a shortcoming of some of the data employed is related to the clarity of the study results because there was a lack of information and limited data available for some variables, which affected the corrected vulnerability ranking. In addition, some of the variables should be adjusted to suite area conditions, such as the cultural heritage ranking, due to the fact that they were unable to be compared with respect to the degree of importance for each place. They form part of the cultural resources and are irreplaceable (McLaughlin *et al*., 2002). Therefore, in the present study, these variables were ranked by scoring using two values: (absent = 1 and present = 5). Nevertheless, most of the data obtained were general temples, which based on historical value less than other archaeological place or historical monuments. It may be able to rank lower scores to resolve a vulnerability value with a score that is too high in existing cultural heritage. Furthermore, the roads/railways variable was set similarly as the ranking of the cultural heritage variable. These variable assessments to weight vulnerability were focused on the routes being economically significant, but it was possible to adjust the data by division into main roads, secondary roads or local roads to identify various levels of vulnerability.

In addition, the accuracy of this study would be improved if the design of the table used for the classification of coastal vulnerability variables was appropriate for each area in the country to allow a correct analysis of coastal vulnerability more specifically based upon different coastal types and exposure. Although it cannot determine the fixed vulnerability classification, it can be used to determine the initial vulnerability. The results can then be used to examine and minimize coastal erosion in future studies.

Problem solving measures can employ the results of this study to help select vulnerability areas requiring erosion prevention, which can be combined with local approaches to improve eroded areas. The results of this study can also be applied in many areas to counter shoreline erosion. However, solutions may be implemented in different ways depending upon the characteristics of the shoreline. Vulnerability maps can show the intensity of the vulnerability of the shoreline and its distribution in the study area, which should be addressed in the implementation of protective measures in the primary plan.

**Acknowledgements**

The author appreciates the Mangrove Educational Center on the East Coast of Mahachai Bay, Samut Sakhon, for their encouragement, and the center for Toxicology, Environmental Health and Management of Toxic Chemicals under Science & Technology Postgraduate Education and Research Development Office (PERDO) of the Ministry of Education for providing a scholarship. The accomplishment of this paper can be succeeded to the extensive support and guidance from A. Limsakul, N. Pumijumnong, and. S. Jirakajohnkool.

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