การวิเคราะห์ต้นทุน-ผลประโยชน์ของแนวทางการปรับตัว ต่อการกัดเซาะหาดทรายในประเทศไทย

Cost-Benefit Analysis of Adaptation Options on Sandy Beach Erosion in Thailand

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บทคัดย่อ

การวิจัยนี้มีวัตถุประสงค์หลักในการศึกษาการกัดเซาะพื้นที่หาดทรายในระดับประเทศจากการเพิ่มขึ้นของระดับน้ำทะเล ผ่านการวิเคราะห์ต้นทุน-ผลประโยชน์ (Cost-Benefit Analysis: CBA) ของแนวทางการปรับตัวแต่ละรูปแบบในพื้นที่ศึกษา 3 แห่งคือ หาดแหลมแม่พิมพ์ (จังหวัดระยอง) หาดบ้านเกาะฝ้าย (จังหวัดนครศรีธรรมราช) และหาดปากเมง (จังหวัดตรัง) การวิเคราะห์ครอบคลุมผลกระทบทางด้านเศรษฐกิจอันประกอบด้วยพื้นที่หาดทรายที่ลดลง การอพยพของประชาชนในพื้นที่ และการเปลี่ยนแปลงของจำนวนและรายได้ของนักท่องเที่ยวในพื้นที่หาดทราย โดยใช้ข้อมูลทุติยภูมิและข้อมูลจากการลงพื้นที่ศึกษาในพ.ศ.2557 และดำเนินการวิเคราะห์ผ่านภาพจำลอง 3 ภาพจำลองในอนาคตภายใต้กรอบการวิเคราะห์ของอายุโครงการเป็นระยะเวลา 22 ปี (ระหว่างพ.ศ.2557-2578) ผลการศึกษาพบว่า แนวทางที่ 2 การถมทรายชายหาดโดยไม่บูรณการกับแนวทางอื่นไม่เหมาะสมในการดำเนินการปรับตับในพื้นที่ที่มีอัตราการกัดเซาะสูง เช่น หาดบ้านเกาะฝ้าย และหาดปากเมง โดยแนวทางที่อาจเหมาะสมคือ กำแพงกันคลื่น และการประยุกต์ใช้โดมกันคลื่นใต้ทะเลควบคู่กับการถมทรายชายหาด สำหรับพื้นที่หาดแหลมแม่พิมพ์แนวทางการบูรณะหาดทรายถือเป็นแนวทางที่เหมาะสม เนื่องด้วยเป็นพื้นที่ที่มีอัตราการกัดเซาะต่ำ อย่างไรก็ตามการปรับตัวโดยใช้โครงสร้างแข็งส่งผลต่อการปรับตัวตามธรรมชาติของหาดทรายและขัดขวางการเคลื่อนย้ายของตะกอนตามสมดุลธรรมชาติ รวมถึงเปลี่ยนแปลงการไหลเวียนของคลื่นและลม ดังนั้นการประยุกต์ใช้โครงสร้างแข็งควรดำเนินการภายใต้ความระมัดระวังและคำนึงถึงลักษณะเฉพาะของแต่ละท้องที่และกระบวนการตามธรรมชาติ ทั้งนี้ชุมชนท้องถิ่นและผู้มีส่วนเกี่ยวข้องสามารถใช้ผลการศึกษาภายใต้กรอบการวิเคราะห์ CBA จากการวิจัยนี้ในการปรับตัวรองรับผลกระทบจากการกัดเซาะหาดทรายได้ในอนาคต

คำสำคัญ : แนวทางการปรับตัว, การกัดเซาะหาดทราย, การวิเคราะห์ต้นทุน-ผลประโยชน์, การเพิ่มขึ้นของระดับน้ำทะเล

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Abstract

This study focuses on the effects of rising sea levels on sandy beach erosion in Thailand. The cost–benefit analysis (CBA) method was utilized to evaluate the economic impact of various adaptation options in three study areas: Laem Mae Phim beach in Rayong Province, Ban Ko Fai beach in Nakhon Si Thammarat Province, and Pak Meng beach in Trang Province. The aspects of sand loss, forced human migration, and tourism flows and revenues were evaluated using secondary data and data from field studies conducted in 2014. These were modelled through three scenarios over a 22-year project lifetime (2014-2035). The results of the CBA reveal that Scenario 2 (beach nourishment) is not an appropriate adaptation option for sandy beaches that are significantly eroded (Ban Ko Fai and Pak Meng beaches), while other options, such as sea walls, wave attenuation domes with beach nourishment, and artificial reefs, are likely suitable. At Laem Mae Phim beach, the beach nourishment option is likely to be sufficient due to the lower rate of erosion. These CBA results could aid various stakeholders and local communities as they are forced to adapt to beach erosion in Thailand. Nevertheless, the application of hard structure options must be undertaken with caution due to the potential adverse effects.

Keywords : adaptation option, beach erosion, CBA method, sea-level rise

Introduction

Sandy beaches can be affected by coastal erosion. As a consequence, their tourism and recreational value will fall. Thailand has approximately 320,000 square kilometers of maritime zone, 2,800 kilometers of shoreline, and 23 coastal provinces. Furthermore, the country has a number of renowned and attractive beaches, including Laem Mae Phim beach, Patong beach, Pattaya beach, Sa Ri beach, Railay beach, and Pak Meng beach. Negative impacts to the tourism and overall economy of Thailand will be substantial if these valuable beaches are destroyed by coastal erosion, (National Research Council of Thailand, 2012).

Adaptation is one of the strategies available to confront the future effects of climate change (including sea-level rise (SLR) induced beach erosion). It aims to build resilience within sectors and communities without causing further problems. In the case of adaptation to SLR and beach erosion, the three available options are: (1) retreat: human migration due to coastal erosion; (2) accommodation: impact avoidance by raising buildings or cultivation of flood or salinity-tolerant plants; and (3) protection: seawall or dike construction or strengthening, or beach nourishment (Nicholls, 2003). Thailand has implemented strategies for adapting to coastal erosion in several areas, including Samut Prakan Province, Pak Phanang and Hua Sai districts in Nakhon Si Thammarat Province, and certain provinces along the coast of the Andaman Sea (Boonma & Saelim, 2011). Various measures were conducted among these areas (e.g., setback determination/promotion, and beach utilization regulations)

(Stanford Law School, 2015). Some examples of setbacks distance was showed in Table 1. Nonetheless, these strategies have not as yet succeeded in alleviating beach erosion in Thailand.

Therefore, this research aims to examine the erosion of sandy beaches in Thailand due to SLR and attempts to recommend adaptation options emerging from the cost-benefit analysis (CBA) approaches (with and without adaptation strategies) under various climate change scenarios.

Table 1 Examples of setbacks distance

State	Setbacks distance (m)	Reference line
Maine	22.86	Sea-sonal mean high water
Alabama	36.58 - 137.16	Sea-sonal mean high water
North Carolina	More than 36.58 or 60 times of erosion rate per year	Vegetable line
New York	7.62 plus 40 times of erosion rate per year	Sand dune line

Source: Revised from Sandy beach: Vanished natural heritage (Prince of Songkhla University, 2011)

Methods

Adaptation Options

The Intergovernmental Panel on Climate Change (2014) defines adaptation as a process of adjustment to the actual or expected climate and its effects. Adaptation options refer to a range of strategies, measures and actions that are available and can be categorized as structural, institutional, or social. In the context of adaptation (to climate change and also coastal system), several factors must be considered, including exposure, vulnerability, sensitivity, risk, impact, adaptive capacity, and socioeconomic factors. Vulnerability refers to the propensity or predisposition to be adversely affected, and consists of three components: exposure, sensitivity, and adaptive capacity. Various factors (both natural and socioeconomic, including policies) can influence the level of, and variation in, sensitivity and adaptive capacity (Office of Natural Resources and Environmental Policy and Planning, 2013; Intergovernmental Panel on Climate Change, 2014).

A study by the Department of Marine and Coastal Resources (2009) outlined four adaptation options available to protect coastal areas from erosion : (1) natural options, such as mangroves, beach forests, coral reefs, and sea grass restorations ; (2) soft structural options (best suited to low population density areas and low rates of coastal erosion), such as vegetation, beach nourishment, sand sausages or geo-tubes, and bamboo ; (3) hard structural options (best suited to areas with high rates of coastal erosion), such as seawalls, groins, breakwaters, jetties, and headlands ; and (4) legal options, including proper coastal protection legislation and cooperation actions from several sectors. Moreover, studies on Patong and Kamala beaches in Phuket Province and Pattaya beach in Chonburi Province demonstrated that the soft structural option of beach nourishment, combined with the natural option of planting coconut trees (accompanied with surface water drainage, including landscape design and improvement), may be one of the most suitable adaptation options for sandy tourist beaches (Boonyobhas, 2011; Wattanaparueda & Lhuglog, 2006). In terms of hard structural options, Rattanamamee (2006) under the SMART project (Chalatat beach in Songkla Province) claimed that artificial reefs can reduce and absorb storm waves, reducing longshore sediment transport without affecting the coastal landscape and beach tourism. A summary of the adaptation options available in Thailand is set out in Table 2 (Kraipanon, 2011). Researchers tend to select some of these adaptation options (depending on their particular area of study) to analyze using an economic evaluation approach (such as CBA).

Table 2 Summary of adaptation options on coastal erosion in Thailand

<table>
<tr><th>Coastal type</th><th>Mud flat</th><th>Rocky coast/Sandy beach</th></tr>
<tr><td>Adaptation options</td><td>Bamboo revetment (natural/artificial)</td><td>Sea wall</td></tr>
<tr><td></td><td></td><td>Revetments</td></tr>
<tr><td></td><td>Concrete-pole breakwater</td><td>Riprap</td></tr>
<tr><td></td><td></td><td>Gabion</td></tr>
<tr><td></td><td>Concrete-pole breakwater and used car tires as breakwater</td><td>Groin (T/ Fish-tailed groin)</td></tr>
<tr><td></td><td></td><td>Submerged groin</td></tr>
<tr><td></td><td>Rubble-mound</td><td>Beach nourishment</td></tr>
<tr><td></td><td></td><td>Sand bypassing</td></tr>
<tr><td></td><td>Geo-container/soft rock</td><td>Headland control</td></tr>
<tr><td></td><td></td><td>Artificial reef</td></tr>
<tr><td></td><td></td><td>Tripod/tetrapod</td></tr>
<tr><td></td><td colspan="2">Offshore/detached breakwater</td></tr>
<tr><td></td><td colspan="2">Submerged-detached breakwater</td></tr>
<tr><td></td><td colspan="2">Geotextile/geotube</td></tr>
<tr><td></td><td colspan="2">Jetty</td></tr>
<tr><td></td><td colspan="2">Floating breakwater</td></tr>
</table>

Study areas and field studies

Laem Mae Phim (in the Kram subdistrict of Rayong Province), Ban Ko Fai (in the Khanap Nak subdistrict of Nakorn Si Thammarat Province), and Pak Meng (in the Mai Fat subdistrict of Trang Province) were selected as the study areas for this beach-scale analysis of adaptation options using the CBA method. During two separate field trips, from March 30 to April 2, 2016 and from June 16 to June 18, 2016, the researcher gathered a range of information and data, such as current adaptation options, erosion status and rate, tourism activities, transportation, and the livelihood of the local inhabitants, including some data for the CBA. These data affirmed the most appropriate choice of beaches to include in this analysis. First, in Rayong province, Laem Mae Phim beach was selected over the other contender, Mae Ram Phueng beach, given its greater evidence of erosion and some adaptation options including the higher tourism activities. Second, in Nakhon Si Thammarat Province, Ban Ko Fai beach was a more appropriate subject for study than Chancheng beach due to its high erosion rate and range of evidence of erosion, despite the fact that it offers no tourist activities at present. Finally, in Trang province, Pak Meng beach was selected because it has greater tourist activity and shows more evidence of erosion than Chao Mai beach. Location of the study areas are shown in Figure 1.

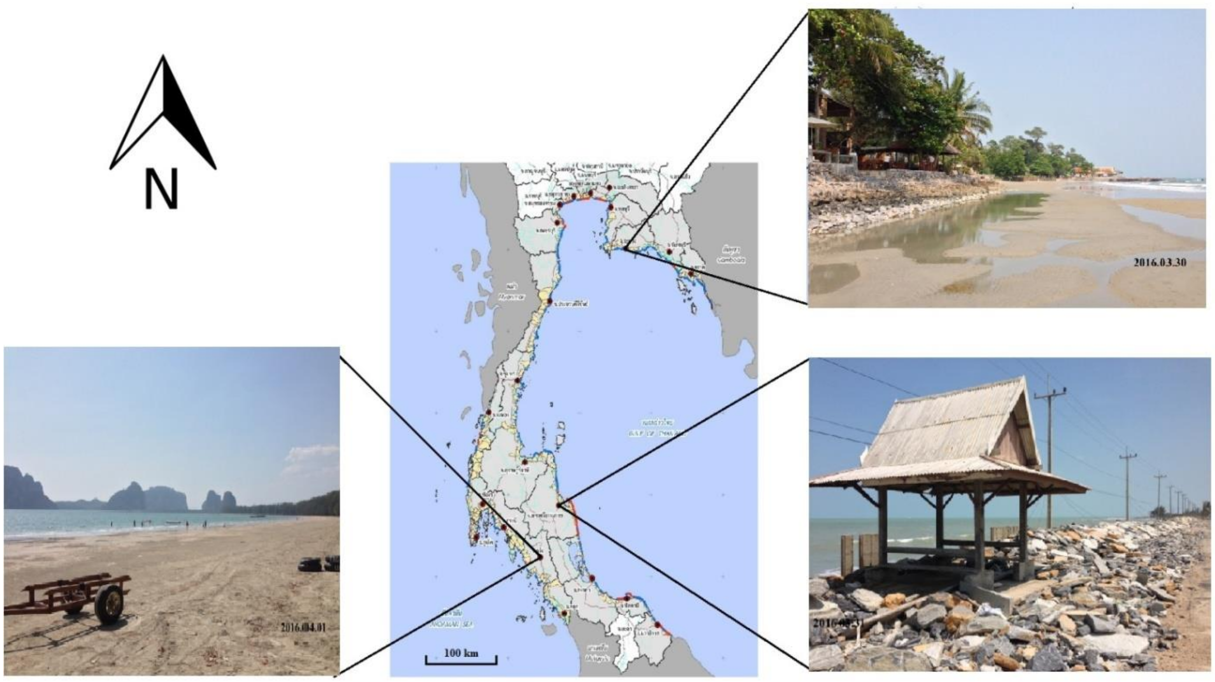

Figure 1 Locations of the three study areas in Thailand.

CBA and adaptation options

The secondary data in relation to the three study areas used in the CBA were collected from several organizations. Data reflecting the cost of adaptation under various scenarios were collected from the Department of Marine and Coastal Resources (2013), Van Rijn (2010), Prince of Songkla University (2008), and from the field. Benefits (e.g., decrease in sand loss, decrease in forced human migration, and increase in tourism revenue) were calculated using the following equations.

DSL	=	SLA x LP	
	=	[z* R * E_f] x LP	(1)

Where :

DSL	=	Decrease in sand loss (baht)
SLA	=	Sand loss area (km^2)
LP	=	Land price as Market price in 2014 (baht)
z	=	The segment length (km)
R	=	Coastal erosion rate (m per year)
E_f	=	Erosion factor

Remarks : Market prices of land in 2014 were used for calculations since the research was conducted in year 2014.

DFPM	=	NOM x MCPM	
	=	[SLA x (PETS/AOB)] x [TRC + HRC+ LIC]	(2)

Where :

DFPM	=	Decrease in forced people migration (baht)
NOM	=	Number of migrants (people)
MCPM	=	Migration cost per migrant (baht per person)
PETS	=	Population employed in (beach) tourism sector (people)
AOB	=	Area of beach (km^2)
TRC	=	Transportation cost (baht per person)
HRC	=	House/infrastructure rebuilding cost (baht per person)
LIC	=	Loss of income per capita as opportunity cost of migrating (baht per person)

ITR	=	NOTA x EPT	
	=	NOTA x [FDE + ACE + TRE + REE + SOE]	(3)

Where :

ITR	=	Increase in tourism revenue (baht)
NOTA	=	Number of tourist arrivals (thousand people)
EPT	=	Expenditure per tourist (baht per person)
FED	=	Food and drink expenditure (baht per person)
ACE	=	Accommodation expenditure (baht per person)

TRE	=	Transportation expenditure (baht per person)
REE	=	Recreation expenditure (baht per person)
SOE	=	Souvenir expenditure (baht per person)

Number of tourist arrivals (thousand people) was calculated using the equation below (revised from Hamilton *et al.,* 2004) :

$$\ln A_i = 5.97 + 2.05 \times 10^{-7} Area_i + 0.22\, T_i - 7.91 \times 10^{-3}\, T_i^2 + 7.15 \times 10^{5} Coast_i + 0.80 \ln Y_i \qquad (4)$$

Where:

ln Ai	=	Number of tourist arrivals (thousand people)
Area	=	Land area of sandy beach (km^2)
T	=	Annual average temperature (°C)
Coast	=	Length of coastline (km)
Y	=	Per capita income
i	=	Indexes destination beach

The three scenarios mentioned in Table 3, including the "do-nothing scenario" (Scenario 0 or Baseline Scenario), of the three study areas were analyzed using the four steps of the CBA economic evaluation approach (revised from Tubpun, 1998) and four assumptions of the CBA in this study (Table 4).

Table 3 The 3 scenarios analyzed with the Economic Evaluation approach

Scenario number	Adaptation options
1	Current adaptation option (business as usual; BAU)
2	Potential adaptation option: soft-structural option (beach nourishment)
3	Potential adaptation option: hard-structural option (artificial reef)

Table 4 Steps and assumptions of the CBA analysis

CBA steps	Assumptions
(1) Study and identify boundary and objective of each option	(1) The number of tourists increases with population and income, and tourists prefer holidays at a temperature of 25 °C. There is no beach tourism if the warmest month is below 15 °C; 65 percent of tourists spend their holidays in coastal areas (sandy beaches in a strip 1 km in length); and 25 percent of their expenditure is profit (Hinkel *et al.*, 2013).
(2) Identify and measure cost and benefit of each option in each year	(2) Other variables in Equation (4) (temperature, length of coastline, and per capita income) were assumed to be constant over the time of analysis to investigate the effects of beach erosion on beach-related tourism (through change of sandy beach areas).
(3) Evaluate costs and benefits in monetary terms	(3) The boundary of analysis is the subdistrict (of each study area) and the main objective of each adaptation option is to alleviate beach erosion problems while not adversely affecting tourism (by preserving the beach landscape).
(4) Compare costs and benefits in terms of net present value (NPV), benefit–cost ratio (B/C ratio), and internal rate of return (IRR)	(4) The project lifetime is 22 years (refer to hard-structure lifetime), initiated in 2014. It includes one year (2014) for preparation, one year (2015) for construction, and 20 years (2016–2035) for operation. In the case of beach nourishment without other integrated adaptation measures, sand will be refilled every five years (Department of Marine and Coastal Resources, 2013).

Net present value (NPV), benefit–cost ratio (B/C ratio), and internal rate of return (IRR) were calculated using the following equations (Tubpun, 1998).

$$NPV = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+i)^n} \quad (5)$$

$$B/C = \frac{\sum_{t=1}^{n} \frac{(B_t)}{(1+i)^n}}{\sum_{t=1}^{n} \frac{(C_t)}{(1+i)^n}} \quad (6)$$

$$IRR = i;\ \left(NPV = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+i)^n} = 0 \right) \quad (7)$$

Where :

NPV	=	Net present value (baht)
BCR	=	Benefit–cost ratio
IRR	=	Internal rate of return (percent)
B_n	=	Benefit/Revenue of year n (baht)
C_n	=	Cost of year n (baht)
n	=	Project life time (year)
i	=	Discount rate or interest rate (percent)

Results

The values set out in the tables above were calculated using two discount rates: the social rate of time preference (SRTP) and the social opportunity cost rate (SOCR) (see Tubpun, 1998). In practical terms, SRTP is represented by the interest rate of government bonds, and SOCR by the minimum loan rate (MLR), after tax and inflation rate deductions in 2014. The values applied in this research were 3 percent and 6 percent for government bonds and minimum loan rate (MLR), respectively (Bank of Thailand, 2014, 2016). Moreover, the erosion rate in years 1 and 2 refers to the rate in Scenario 0 (the do-nothing scenario). The benefits are the different advantages brought by each adaptation option as compared to Scenario 0 (Table 5).

Table 6 shows that, at Laem Mae Phim beach (Kram subdistrict, Rayong Province), Scenario 1 (current adaptation option with stone sea wall) and Scenario 3 (potential adaptation option with artificial reef) should probably be selected for implementation. The stone sea wall option has the highest NPV (518.31 and 354.88 million bahts for 3 percent and 6 percent discount rate, respectively), while the artificial reef option brings the greatest B/C ratio (7.10 and 5.47 for 3 percent and 6 percent discount rate, respectively). At Ban Ko Fai beach (Khanap Nak subdistrict, Nakorn Si Thammarat Province), Scenario 3 (potential adaptation option: hard structural option (artificial reef)) may be optimal as it has the highest NPV (470.27 and 325.98 million bahts), B/C ratio, (7.22 and 5.57), and IRR (48.52 percent). In contrast, Scenario 2 (beach nourishment option) should be avoided. It not only has a negative NPV (-113.32 and -88.45 million bahts), but also a B/C ratio of less than 1 (around 0.5), illustrating that the cost of the option exceeds the benefit. In the final study area, Pak Meng beach (Mai Fat subdistrict, Trang Province), Scenario 1 (wave attenuation dome accompanied with beach nourishment option) is the most suitable method of initiating adaptation activities in the area. High NPVs of between 109.93 and 185.74

million bahts, coupled with high B/C ratio (2.00-2.59) are the key factors recommending this option. Moreover, the negative NPVs (-232.95) and IRR (-55.35 percent) affirm that the beach nourishment option (Scenario 2), in the absence of integration with other measures, is insufficient for areas with high erosion rates, such as Pak Meng beach and Ban Ko Fai beach.

The NPV, B/C ratio, and IRR values at a 6 percent discount rate for the three study areas were recalculated with sensitivity analysis in terms of ±20 percent variations in cost and benefit. At Laem Mae Phim beach, with a +20 percent variation in costs and a -20 percent variation in benefits (the worst-case scenario), Scenarios 1 and 3 are promising, with high NPV (244.74 million bahts) and B/C ratio (3.65). Moreover, in Ban Ko Fai beach, Scenario 3 (featuring the reef) is also recommended due to its high NPV (232.23 million bahts), B/C ratio (3.71), and IRR (32.24 percent), even in the worst case. In contrast, Scenarios 1 and 2 result in negative NPVs (-73.13 million bahts and -140.77 million bahts, respectively). Furthermore, at Pak Meng beach, Scenario 1 is optimal due to its high NPV (43.80 million bahts) and B/C ratio (1.33). Here, Scenarios 2 and 3 are to be avoided due to their negative NPVs of -268.88 and -9.01 million bahts, respectively.

Table 5 Value of Scenario 0: Do-Nothing Scenario

Study area	Sand loss (Million bahts)	Forced people migration (Million bahts)	Tourism revenue (Million bahts)
Mae Phim beach	37.50	27.60	540.90
Ban Ko Fai beach	17.55	84.39	152.30
Pak Meng beach	17.34	23.58	237.17

Table 6 Summary of NPV, B/C Ratio and IRR of the three study area and various scenarios

Provinces/ Beaches	Scenario number								
	1			2			3		
	NPV	B/C	IRR	NPV	B/C	IRR	NPV	B/C	IRR
Mae Phim beach (Kram subdistrict, Rayong province)	518.31 and 354.88 million bahts	6.00 and 4.62	40.28%	330.57 and 237.21 million bahts	3.48 and 3.36	80.65%	264.08 and 182.87m illion bahts	7.10 and 5.47	47.68%
Ban Ko Fai beach (Khanap Nak subdistrict, Nakorn Si Thammarat province)	152.53 and 47.43 million bahts	1.52 and 1.17	8.03%	-113.32 and -88.45mill ion bahts	0.51 and 0.49	-47.65%	470.27 and 325.98 million bahts	7.22 and 5.57	48.52%
Pak Meng beach (Mai Fat subdistrict, Trang province)	185.74 and 109.93 million bahts	2.59 and 2.00	16.60%	-232.95 and -180.20 million bahts	0.44 and 0.42	-55.35%	111.86 and 52.31 million bahts	1.83 and 1.41	10.69%

Discussion

In regards to discussions, the researcher assessed the coastal erosion management plans contained in Thailand's 11th National Economic and Social Development Plan (2010–2014) (National Economic and Social Development Board, 2011) in comparison to the proposed adaptation options set out in this paper. In the plan, coastal and beach erosion is acknowledged as an environmental problem that must be addressed with proper management. The management measures and options on natural resources and the environment toward sustainability are introduced in Chapter 8 and Strategy 5.1.5 Chapter 8 of the plan, which aims to establish a management system and guidelines for marine and coastal resources. Mangrove reforestation, coral reef rehabilitation, and sea grass and seaweed conservation were introduced for the purposes of coastal management. Improvement of construction standards in both residential and industrial areas, as well as coastal infrastructure, was also introduced. Construction standards and coastal infrastructure must be improved by addressing the effects of oceanographic changes and coastal erosion. Moreover, it is necessary to plan long-term responses to rising sea levels to reduce damage to coastal urban areas. Nevertheless, the plan introduces no explicit measures for managing coastal erosion, especially sandy beaches. It also fails to recognize the importance of methods for evaluating the economic impact of the adaptation options. The plan still has no measure to management about migration regarding to the database gap.

From real situations/circumstances of the 3 study areas (the field studies data) shown in Table 6, high erosion rate are occurred in all study areas especially in Ban Ko Fai beach (3-4 meters per year). Moreover, there are high tourism/economic activities in the areas (except Ban Ko Fai beach due to destroyed beach and infrastructure). Nevertheless, in comparison with adaptation options suggested/recommended in the CBA results, it is quite different. Stone sea wall and artificial reef are suggested to be promoted in Mae Phim beach. Artificial reef is also the choice supported in the area of Ban Ko Fai beach. In addition, wave attenuation dome accompanied with beach nourishment option is proper for initiation of adaptation activities in Pak Meng beach. However, in the real world, there are still using the current adaptation option mentioned in Table 7 (stone sea wall for Mae Phim beach, concrete/stone sea wall and breakwater for Ban Ko Fai beach and wave attenuation dome, beach nourishment and disperse concrete sea wall for Pak Meng beach) and also no initiative for conducting new adaptation option.

Table 7 Real situations/circumstances in the 3 study areas.

Study Area / Aspect	Mae Phim beach	Ban Ko Fai beach	Pak Meng beach
Socioeconomic aspect	High tourism/economic activities (hotels, restaurants and shops) and dispersed accommodation outside the beach	No tourism/economic activities due to destroyed beach (only fishery) and low/dispersed accommodation outside the beach	High tourism/economic activities (hotels, restaurants ,shops and tourist port) and dispersed accommodation outside the beach
Beach erosion aspect	High erosion rate (1-2 meters per year)	Very high erosion rate (3-4 meters per year)	High erosion rate (2-3 meters per year)
Adaptation aspect	Stone sea wall nearby restaurants and hotels	Concrete/stone sea wall and breakwater with obvious evidence (destroyed road and narrow beach)	Wave attenuation dome, beach nourishment and disperse concrete sea wall

Sandy beaches form a transition zone between land and sea and are also dynamic systems that change over time (complex adaptive systems). Thus, the introduction of hard structural adaptation options (e.g., jetties, groins, breakwaters, and seawalls) could hamper the natural functioning of these systems. In the sandy beach system, there is a natural balancing process of sediment transport during the monsoon and dry seasons. Erosion occurs during the monsoon season, and accretion occurs in the dry season. This natural process could restore the eroded beach areas in a few years, returning them to dynamic equilibrium as shown at Samila beach, Songkhla Province. However, hard structural options could interrupt this process and also change the directions of wave and longshore sediment transport. These structures cause the deposition of sediment on the updrift side and lead to erosion on the downdrift side (Faculty of Economics, Prince of Songkhla University, 2011). Evidence of problems caused by hard structure adaptations is already apparent along the coast of the Gulf of Thailand. Hard-structural adaptation options in sandy beach areas should be applied with a keen awareness of the aforementioned impacts and consideration of the natural system and process of sediment transport. Furthermore, these structures also block the inland migration of coastal wetlands, leading to the loss of wetland areas and ecosystems.

This paper suggests that adaptation option with hard structures should be conducted with carefulness and the seawall proposed for the beach should be applied partly not fully along the length of sandy beach areas such as hotel, shop, restaurant and infrastructure (as current application in Mae Phim beach). In long term, the structures should be removed from the beach (due to obsolescence) whilst beach nourishment could be applied for short-term solutions. This is state of the art and no single adaptation option or structural type could be applied for all beaches. The use of setbacks should be promoted although there is no consistent methodology for calculating sea-level rise in erosion rate and setback determination (Stanford Law School, 2015) as showed in Introduction Section (Table 1). Furthermore, science/evidence-based planning for sea-level rise, participation of local governments and communities and also laws/policies for proper utilizations of sandy beach areas should be promoted and integrated in the adaptation-option planning and process (Faculty of Economics, Prince of Songkhla University, 2011; Stanford Law School, 2015). Nevertheless, removing of hard structures could lead to higher cost for CBA or project analysis and change the results. Benefits from hard structures could be decreased particularly in socioeconomic aspects (forced people migration and tourism revenue). In this study, stone seawall in Mae Phim beach could lead to 13.85 and 11.76 million bahts per year for benefits in terms of decrease in forced people migration and increase in tourism revenue respectively.

Conclusions

In summary, Scenario 2 is inappropriate for application as an adaptation option to sandy beaches with a high degree of erosion (e.g., Ban Ko Fai and Pak Meng beaches). Other options that are likely to be suitable include seawalls, wave attenuation domes with beach nourishment, and artificial reefs. At Laem Mae Phim beach, the beach nourishment option (Scenario 2) is likely to be applied in isolation due to the relatively low rate of erosion. However, a stone seawall is optimal as this option has the highest NPV (518.31 and 354.88 million bahts). The results of the sensitivity analysis with variations in both cost and benefit of about 20 percent do not alter these recommendations. Nevertheless, Scenarios 2 and 3 must be avoided due to the negative NPVs previously mentioned.

The results of our estimations could fill this gap in terms of determining high-risk beaches or provinces. This may lead to a national-scale database accompanied by further in-depth area-specific research on the correlation between beach erosion and forced human migration, including behavioral studies on the erosion–migration process. The researchers hope this database will benefit the policy-making process in relation to the long-term early warning system and the beach management plan (including city planning) for Thailand. Further studies should apply more complex and related models that can analyze the direct impacts of beach erosion or SLR on tourism flow. Moreover, the erosion rate of a specified beach at the local scale can be estimated by the application of MEPBAY (Model of Equilibrium of Bay Beaches).

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