Incorporating the Use of Time Series Remote Sensing Data to Assess the Vulnerability of the Thai Coast to Climate Change Induced Coastal Hazards

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Abstract

The climate change has the direct and indirect effects on natural negative changing such as disasters, animal and forestry reduction and habitat loss. Coastal changes including accretion and erosion are also affected by climate change which tend to intensify. Samut Prakan and Chachoengsao are two of the coastal provinces in Thailand having high economic and population growth which lead to the increment of coastal land use and the destruction of coastal resources. In addition, the characteristics of muddy coasts in Samut Prakan and Chachoengsao are susceptible to sediment movements. These cause severe coastal erosion in Samut Prakan and Chachoengsao. This project aims to provide the data of coastal erosion/accretion in Samut Prakan and Chachoengsao, over 40 kilometres long, from 2017 to 2020. The rates of coastal changes would be generated and calculated by Digital Shoreline Analysis System (DSAS) v.5, the extension of ArcMap, based on the statistical concept of a linear regression. In addition, the image processing uses PlanetScope satellite imagery and the Normalised Difference Water Index (NDWI), spatial analysis function in ArcGIS, in water extraction process. The result shows that 40.33% of the study area are eroded while 59.67% are accreted. In addition, each part of study areas has different rates of shoreline changes depending on the diversity of coastal impacts and protections. Coastal protections including hard-engineered structures, soft protection

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structures and shoreline protection from nature, especially mangroves, as well as climate change are the main concerns of shoreline changes in this project analysis. The coastal protections play the vital role in preventing shoreline erosion from offshore factors, such as the intensify of winds, waves and marine disasters, and onshore factors, such as land subsidence and coastal land use. Furthermore, the result also infers that the order of coastal protection placement has the potential influences on preventing the shoreline from erosion as well as sedimentation increment of muddy coasts.

Key words: "Thailand", "Coastal Erosion", "Remote Sensing", "DSAS", and "NDWI"

1. Introduction

Around one-third (15-40%) of world's population live in coastal areas [1]; therefore, a large number of people impacted by coastal problems. Due to an increasing human population, there is a higher demand on using coastal resources as evidenced by the expansion of communities, number of residents and construction near coastal areas. This leads to various coastal hazards, especially coastal erosion [2]. There are two main coastal characteristics in Thailand including: (1) sandy coast (most coasts) and (2) muddy coast (along the inner upper Gulf of Thailand) [3]. It seems that the muddy coast would have higher rate of coastal accretion and erosion due to its characteristics than the sandy coast. Furthermore, the muddy coast is also mainly involved in both ecosystem and economy growth in Thailand [3]. Samut Prakan and Chachoengsao are muddy coastal provinces which have received significant effects from coastal erosion; therefore, Samut Prakan and Chachoengsao are the focus of this research.

The coastal management mostly depends on the measurement and prediction of shoreline changes; therefore, DSAS - Digital Shoreline Analysis System, the extension of analysis tools in ArcGIS, has been widely used in calculating and processing the coastal changes [4]. In addition, the high-resolution satellite imagery could be used to improve the analysis regarding the accuracy in pixels [4]. Therefore, using DSAS with high-resolution imagery could provide high credibility in the analysis of coastline changes

1.1 Aim and Objectives

The aim of this research is to assess the vulnerability of the Thai coast to climate change induced coastal hazard by using time-series remote sensing data. The result would be illustrated in maps showing the rate of shoreline changes using the PlanetScope satellite imagery from 2017 to 2020. This will be achieved through the following objectives: (1) the image processing with ArcGIS Pro and ArcMap software, (2) the image calculation by the Normalised Difference Water Index (NDWI), spatial analysis function in ArcGIS Pro, and Digital Shoreline Analysis System (DSAS) v.5, an extension of ArcMap, as well as (3) the qualitative ground validation. In addition, the causes and effects in accordance with the result will also be discussed.

2. Literature Review

2.1 Study Area

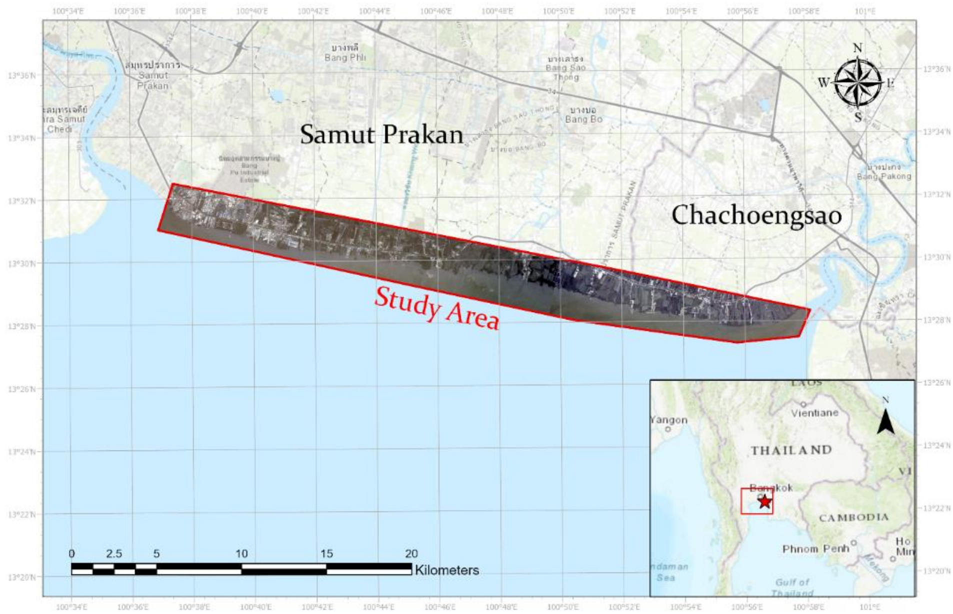


Figure 1 Coastal areas of Samut Prakan and Chachoengsao provinces in the inner upper Gulf of Thailand shown by PlanetScope imagery in 2020.

According to [5], Samut Prakan and Chachoengsao (Figure 1) have long muddy coastal area, more than 40 km., as well as receive the severe effect on coastal erosion in the past. According to the study of [3] by using 30-m-resolution LANDSAT satellite imagery, between 1989 and 2010 (20 years), the coasts in some areas of the two provinces have been eroded over 660 m. or around 33 m. per year.

2.2 Coastal erosion factors

According to [3], the height of offshore wave is approximately 2.4 m with 7.7 s. period. The direction of waves is from south and south-west as well as the mean high-water level is 1.4 m above mean sea level. Furthermore, the beach slope of study area was less than 1:300 as well as the study area has been protected by; (1) hard coastal protection structure (low-crested revetment and sand-filled geocontainer or sand sausages) and (2) soft breakwaters (bamboo fencing) since 2010 [3]. Consequently, there are one factor causing natural forces, winds and waves, as well as the other factor protecting that forces which are coastal protection structures.

2.3 Remote Sensing

In recent decades, remote sensing is one of the most useful technique in analysing large area data in terms of area classification and monitoring the changes over time [6]. To model and calculate complex data, geographic information systems (GIS) also considered as one of the effective analysis tools from the acquired Remote Sensing data (e.g. aerial photograph and satellite images) [6]. The erosion rate normally has been computed and analysed to observe and monitor the sediment movement and natural process related to the unique of each area [6]. The remote sensing approaches used in this project compose of the Normalised Difference Water Index (NDWI) and Digital Shoreline Analysis System (DSAS).

2.3.1 The Normalised Difference Water Index - NDWI

Water resource and coastal managements has been developed and effective by using remote sensing outcomes and analysis [7]. The data from satellite imagery could extract the land and water area by using computation of single band and multi band method [8]. However, the multi-band method seems to outweigh to detect the difference between open-water and land area. Each involved band within multi-band imagery is distinct on detecting specific area [7]. The NDWI was proposed in 1996 by McFeeters [8]. The index composition/equation uses the difference signature between visible and near infrared (NIR) wavelength. By this calculation, the reflection water features are enhanced while the land and vegetation are decreased except the build-up land due to the mixed noise [7]. The equation would be shown as follows;

$$NDWI = \frac{Green\ wavelength - NIR\ wavelength}{Green\ wavelength + NIR\ wavelength} \quad \text{Eq. 1}$$

While Green wavelength could be reflected significantly by water, NIR wavelength would be absorbed significantly by water. Moreover, NIR wavelength could be reflected significantly by vegetation and soil features

2.3.2 Digital Shoreline Analysis System - DSAS

Remote sensing data by using satellite imagery has been widely use to analyse the shoreline changes related to time-series [2]. In addition, the DSAS software start developing in early 1990s which try to help calculating the coastal rate of change by providing statistics outcomes for a time series [4]. DSAS, the extension of analysis tools in ArcGIS, has been widely used in calculating and processing the coastal changes [4]. The process consumes short amount of time while providing high effective outcome to understand the coastal process in specific areas [2].

The changes over time of coastal erosion and accretion in large area could be measured and analysed by extracting/digitising shoreline from satellite imagery [6].

3. Methodology

3.1 Satellite Datasets

The satellite imagery in the process using PlanetScope imagery cover the study area, over 40 km. long. The specification and information of PlanetScope and its satellite imagery are provided as shown in Table 1

Table 1 PlanetScope characteristics including satellite numbers, bands and resolutions [8]

Number of Satellites	Band	Spatial Resolution	Temporal Resolution
Approx. 170	Band 1 (blue) 455-515 nm Band 2 (green) 500-590 nm Band 3 (red) 590-670 nm Band 4 (near infrared) 780-860 nm	3.7 m.	Daily

Planet is the operational satellite imagery company which launched a group of PlanetScope, named flocks. This composes of 170 small cubic satellites, known as ‘doves’, which have dimensions 10 cm × 10 cm × 30 cm. [9].

The period of satellite imagery using in the study is on March of 2017, 2018 and 2020 which aim to mitigate the monsoon wind factor in accordance with the literature review. In addition, the coordinate system using for this satellite imagery is WGS 1984 UTM Zone 47N which has already been automatically set as the default of the PlanetScope satellite imagery in this area.

3.2 Image Processing

This project using ArcGIS Pro for preparing data as well as ArcMap 10.6.1 with DSAS v.5 extension in coastal erosion/accretion calculating process. The summary process would be shown in Figure 2

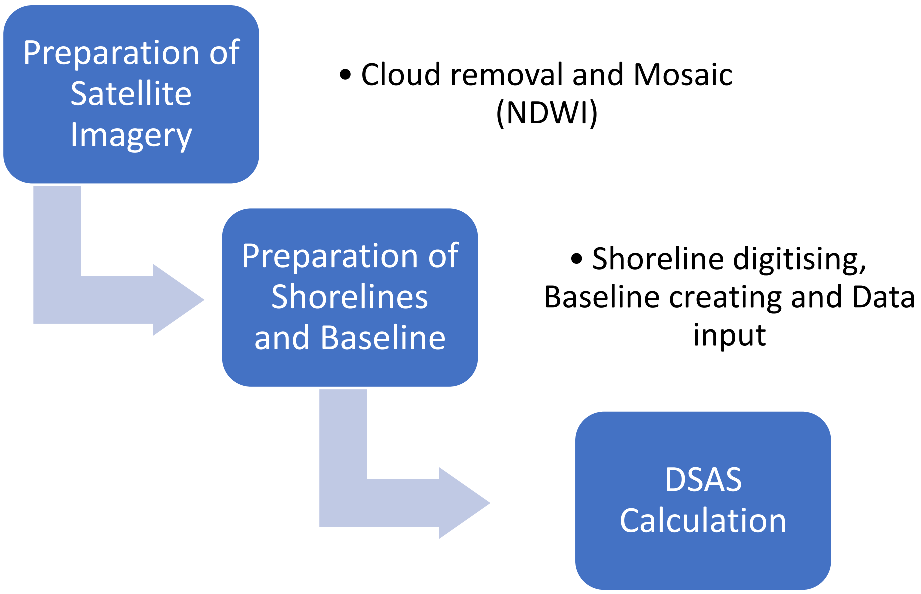
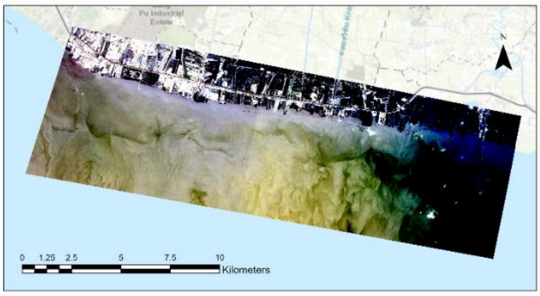
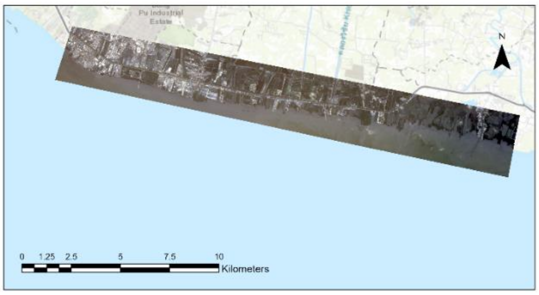


Figure 2 A Workflow Diagram of image processing by using ArcGIS pro, ArcMap and DSAS v.5, the extension of ArcMap before producing outcomes.

The acquired imagery has large areas on water covered by clouds (Figure 3); therefore, the polygon feature is created to use in clipping clouds which would benefit the mosaic process.



(a)



(b)

Figure 3 The PlanetScope satellite imagery (a) with cloud (original) and (b) without cloud.

The advantage of NDWI is that the extracted water is distinctive when comparing vegetation and soil features with open water. On the other hand, the contrast between water and built-up land by using MNDWI is distinguishing [8]. In addition, the coastline of study areas composes of mangroves, mud, soft and hard coastal protection structures as well as open water. From these factors, it seems that NDWI is more suitable for this study area than MNDWI. Therefore, NDWI was used in the mosaic calculation.

This means that the digitising process would have more precise and accuracy because the uncertainty from human error would be lessen (Figure 4).

Figure 4 Digitising process using PlanetScope satellite imagery in 2017.

After digitising coastlines in 2017, 2018 and 2020, all data were merged (Figure 5), and then created buffer. The buffer distance would be used as the range between baseline and shoreline so the distance should base on previous erosion rate from 1989 to 2010 which was around 33 metres/year. The period of the PlanetScope satellite imagery in this project is 4 year; therefore, the erosion would be approximately 132. Consequently, setting baseline range at 150 metres is reasonable. After that, the 3 objectIDs of created buffer would be merged (Figure 6).

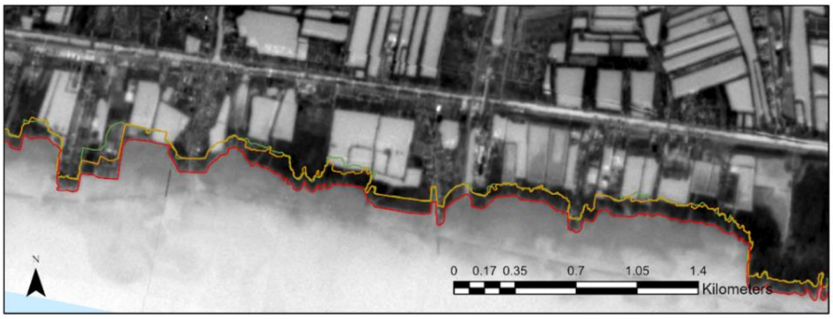


Figure 5. The coastlines in 2017, 2018 and 2020.

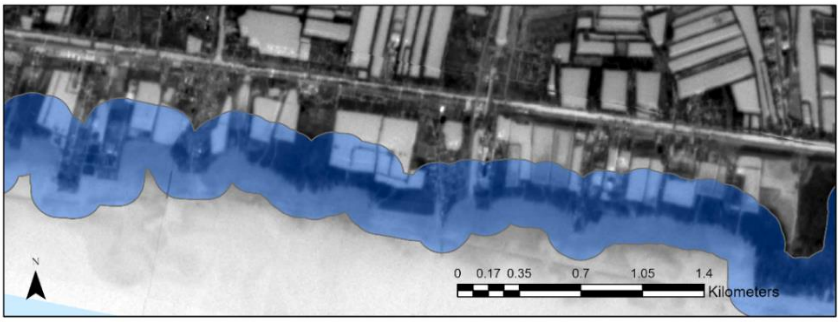


Figure 6. A buffer from the coastlines using for the baseline creation

The merge shoreline would be used as shorelines while the buffer range (upper/land side) would be used as a baseline (Figure 7).

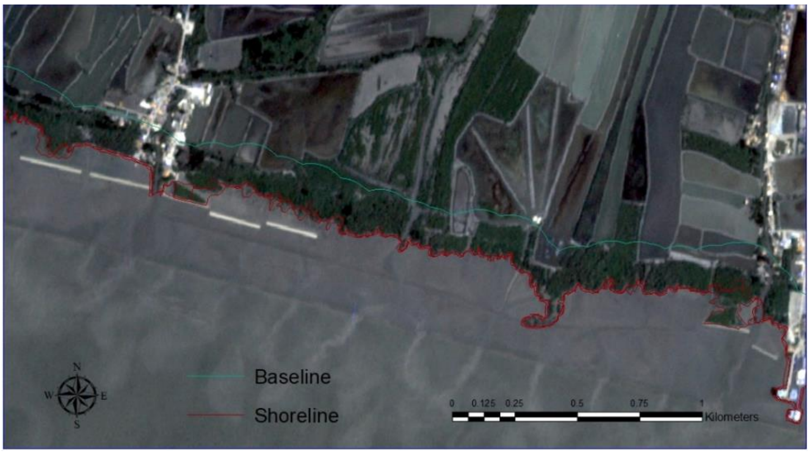


Figure 7. Baseline and shorelines using in DSAS calculation process.

The new feature class of attribute table would be created by following the DSAS v.5 extension requirement as shown Table 2.

Table.2. Attribute table of shoreline and baseline including field names and data types.

Shoreline		**Baseline**	
Field Name	Data Type	Field Name	Data Type
OBJECTID	Object ID	OBJECTID	Object ID
SHAPE	Geometry	SHAPE	Geometry
Shape_length	Double	ID	Long Integer
DSAS_date	Text	Group	Long Integer
DSAS_uncy	Double	Search_distance	Short Integer
		Type	Short Integer

The personal geodatabase, known as .mdb file, was created for computation in the DSAS process by using data from baseline and shoreline in file geodatabase, known as .gdb file. If there are the attribute tables/fields missed from creating feature class, the Attribute Automator could be used to add that fields.

The baseline, shoreline parameters setting would be added as shown in Table 3.

Table 3. Baseline and shoreline parameters.

Baseline Parameters		**Shoreline Parameters**	
Baseline Layer	Baseline	Shoreline Layer	Shoreline
Baseline ID Field	ID	Shoreline ID Field	DSAS_date
Baseline Group Field	Group_	Shoreline Uncertainty Field	DSAS_uncy
Baseline Search Distance	Search Distance	Default Data Uncertainty	10
Baseline Orientation	Right	Seaward Intersect	
Baseline placement	Onshore	Log File Output	Extended
Log File Output	Extended		

The uncertainty of digital pixels from PlanetScope is equal to 3.7 metres (Table 3). Furthermore, the digitising process potentially has human error. Therefore, the uncertainty in the Transect process should be 10 metres.

The baseline orientation (Table 3.) could be illustrated as shown in Figure 8.

Figure 8. Baseline orientation using in attribute table.

After setting default parameters, the transect has already to be created by using Cast Transect and input data as shown in Table 4.

Table 4. The maximum distance using in Cast Transect.

Maximum Search Distance	
From Baseline	450
Transect Spacing	30
Smoothing Distance	1200

The transect lines generated from Table 4 could cover coastlines in most of the study area (Figure 9).

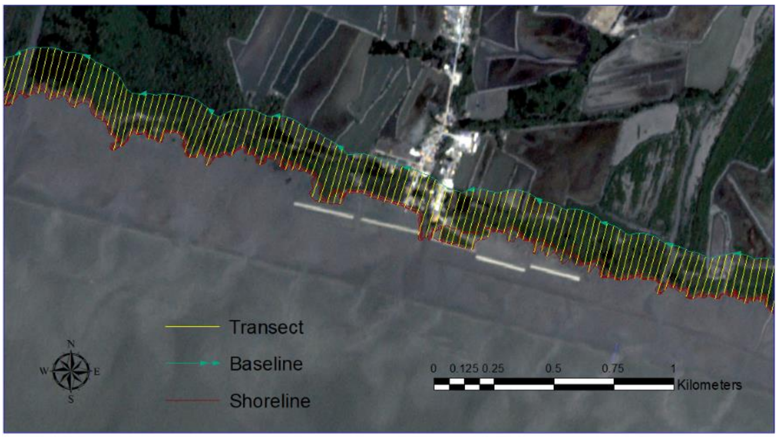


Figure 9. Transect lines between baseline and shorelines.

After that, the transect lines would be used to calculate SCE, NMS, EPR, LRR and WLR with 99% confidence interval due to the uncertainty setting from Table 3. Furthermore, the results from transect calculation could display SCE or NMS in distances as well as EPR, LRR or WLR in rate per year by selecting on the DSAS data visualisation. In this study, the LRR would be used as the calculation method due to the suitability and high credibility of statistical concept as illustrated in the literature review.

The erosion/accretion rate would be categorised into 6 levels; (1) very high erosion (30-40 metres/year), (2) High erosion (15-30 metres/year), (3) moderate erosion (0-15 metres/year), (4) moderate accretion (0-15 metres/year), (5) high accretion (15-30 metres/year) and (6) very high accretion (30-40 metres/year).

4. Result and Discussion

4.1 Result

4.1.1 The DSAS data summary

After DSAS calculation, the DSAS extension would produce the DSAS data summary which provide results of coastal changes including distances (minimum, average and maximum) in metre and metre/year as well as percentages and numbers of transect in both negative and positive values. The important calculating outcomes would be shown in Table 5.

4.1.2 DSAS result analysing

When the study area observed, there were four main human activities to protect the study area; (1) Off-shore coastal protection structures – breakwaters, (2) Coastal protection along the shore – seawalls and revetments, (3) Soft coastal protection structures – bamboo fencing and (4) mangrove planting projects. The protections of the above factors are different along each coastal part of the study areas; therefore, the study area distribution would be significantly useful and effective in analysis.

As following the DSAS (Figure 10), to explain the study thoroughly, the study areas would be separated into four parts including: (1) study area A covering the west area which has no breakwaters, (2) study area B covering the middle-west area which has breakwaters, (3) study area C covering the middle-east area which has breakwaters and (4) study area D covering the East area which has no breakwaters.

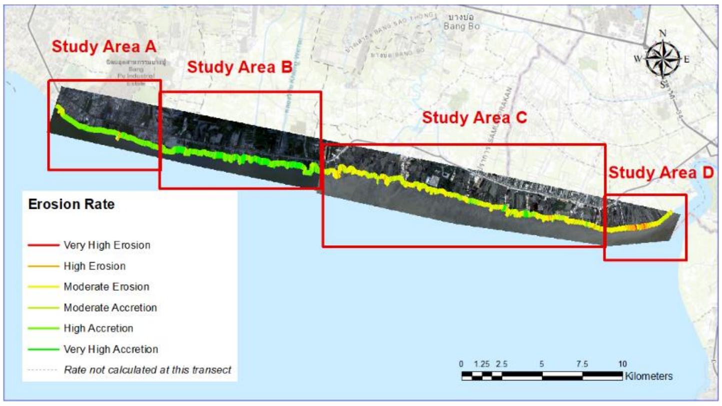


Figure 10. The map showing the 4 study areas in result analyzing.

Table 5. DSAS summary transect data of the shoreline changing from 2017 to 2020.

	Average distance/rate	Minimum distance	Maximum distance	Percent of all transects that have a negative distance/rate	Average of all negative distances/rates	Percent of all transects that have a positive distance/rate	Average of all positive distances/rates
DISTANCE: SCE (Shoreline Change Envelope, m)	51	0.35	499.06				
DISTANCE: NSM (Net Shoreline Movement, m)	27.18			27.18%	-23.18	58.11%	63.49
RATE: EPR (End Point Rate, m/yr)	8.91			41.89%	-7.6	58.11%	20.8
RATE: LRR (Linear Regression Rate, m/yr)	9.82			40.33%	-7.58	59.67%	21.57
RATE: WLR (Weighted Linear Regression, m/yr)	9.82			40.33%	-7.58	59.67%	21.57

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4.1.3 Study Area A

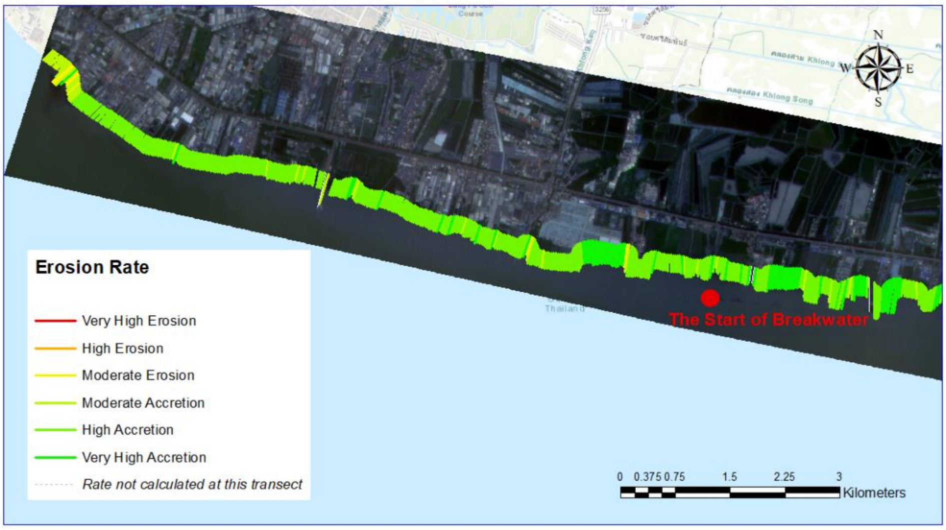

Figure 11. Study Area A – West area without outer coastal protections.

The result from Figure 11 shows that the coastal areas, in study area A, are noticeably increased in the high and very high accretion rates, principally; however, there are some part on the left having a moderate erosion rate. Furthermore, the coastal structures in the study area A, from qualitative ground validation, mainly compose of revetments and seawalls on-shore, while dense mangroves and bamboos fencing off-shore. By these evidences, it could be assumed that the integrated coastal protections in this area could manage the coastal problem.

4.1.4 Study Area B

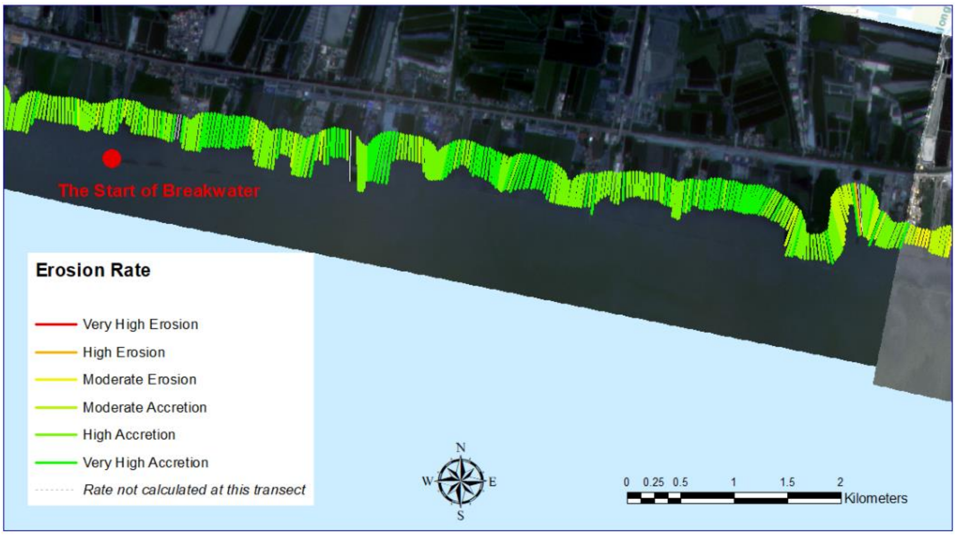

Figure 12. Study Area B – West area with outer coastal protection.

The coastal changes in the study area B are quite similar to the study area A which means that most of the coastal areas have increased since 2017; however, some parts of shoreline on the East have slightly been eroded in the moderate accretion rate (Figure 12).

4.1.5 Study Area C

Figure 13. Study Area C – East area with outer coastal protection.

The coastal changes in the study area C are mostly erosion which is in moderate erosion rate (Figure 13). Although the coastal structure types in the study area C are similar to the study area B which compose of breakwaters, revetments, seawalls, mangroves and bamboo fencing, the arrangement of coastal protection is different. In this area, the hard-coastal protection structures are located outside covering the mangrove areas inside. On the other hand, the study area A and B have mangroves and bamboo fencing outside, excluding breakwaters.

This could be assumed that coastal protections from nature, bamboo fencing and especially mangroves, could not only prevent the shoreline erosion, but it is also able to preserve and collect muddy sediment to help increasing coastal areas. In contrast, the hard-engineered structures could merely reduce the rate of coastal erosion in the muddy coastal areas.

4.1.6 Study Area D

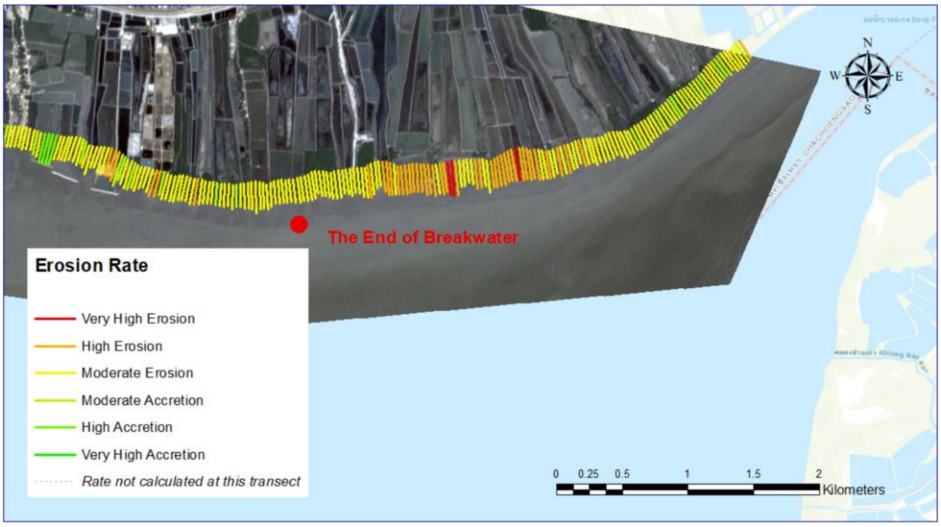

Figure 14. Study Area D - East area without outer coastal protection.

Since there are no additional ground truth data in this area, the analysis would only be based on the DSAS result (Figure 14), satellite imagery analysis and assumed data from nearby areas. Study area D has the most erosion rate among the 4 areas which approximately 30% are in high and very high erosion rate, while around 60% are in moderate erosion rate. This is probably because this area located at the end of the breakwaters; therefore, the natural force action could erode directly to the shorelines. Moreover, the muddy sediments in this area potentially move to nearby areas due to the coastal protection side-effect with regard to the sediment movement based on literature review.

4.2 Summary

In this chapter, overall, the coastal protection structures, both soft and hard, as well as the mangrove planting projects seem to mitigate the severity of coastal erosion in Samut Prakan and Chachoengsao efficiently and effectively, especially in Samut Prakan. 59.67% of the study areas increase, and the erosion rates of around 40% are reduced. Nonetheless, approximately 40% of all study areas still have coastal erosion problems, mostly with the moderate erosion rate or 0-15 metres/year. In addition, around 5% of the erosion areas have erosion rate within high and very high erosion range or within 15-30 and 30-40 metres/year, respectively. This means that the coastal management of Thailand is still deficient and has some limitations in some areas. According to the literature review, the function of breakwater could only protect the specific area in front of the structures, while the nearby coasts would not be protected. Therefore, the rate of erosion in study area D tend to be noticeably higher from this presumption, reasonably.

The placement of coastal protections is also necessary in terms of the protection capability. The study areas compose of similar coastal protections (breakwaters, revetments, seawalls, mangroves and bamboo fencing); however, the order of placement is different. Study area A and B use mangroves as the first coastal protection, excluding breakwaters, while study area C use revetments and seawalls. The placement of coastal protections in study area A and B seem significantly better than study area C. In other words, in study area A and B, coastal areas are increased; while, in study area C, coastal areas are still eroded. These could be assumed that mangroves are the most suitable coastal protections using in muddy coasts located as the first protection. In addition, breakwaters could mitigate the coastal erosion in sensitive areas as following the result of the study area D.

5. Conclusions

This project aims to find Thai muddy coastal hazard related to climate changes by using remote sensing time-series. The overview information has been provided in the literature review including causes and effects of climate change on coastal areas, general Thai coastal information, muddy coast description as well as shoreline change factors including monsoon winds and coastal protection structures. In the literature review, it can be seen that the rate of erosion/accretion in Samut Prakan and Chachoengsao, muddy coastal provinces, has been significantly changed by; (1) the unique characteristics of muddy coasts (2) natural force changing and (3) human activities. In addition, the climate changes seem to intersify the changes of natural forces, especially winds and waves, which have the direct impact on coastline changes. Although coastal protection structures have been created to reduce the increase of natural forces influenced by climate changes, there would be some side-effects with regard to each type of coastal protection structures as well as the placement.

The main motivations of finding the coastal erosion/accretion rate in the study area from 2017 to 2020 is because Samut Prakan and Chachoengsao have a unique coastal type as well as faced the severe coastal erosion due to the climate change. In addition, the result of this project could be compared with the previous study in the same area of [3]. This could improve the analysis of coastal change under the complicated factors and circumstances since the study area in Thailand has more coastal change factors in recent years. The result of this project could also be used in creating the coastal protection structures which would be used to protect the coastlines in the similar area types same as this study area.

The result of this project shows that 40.33% of coastal area have been eroded while 59.67% has been accreted from 2017 to 2020. The average of accretion is 21.57 metres/year, whereas the erosion average is 7.58 metres/year; however, there are 5% of eroded areas having the erosion rate greater than 30 metres/year. The previous research from [3] showed that the muddy coast erosion rate, in one part of study areas, was approximately 33 metres/year before establishing the coastal protection structures in 2010. This means that coastal protection structures constructed in study areas could solve the coastal erosion problems; however, the erosion rates are still high in some areas. In addition, when considering the placement of coastal protections, the areas depending on a large number of mangroves as the first prevention have significant increment of coastal area. On the other hand, the erosion of shoreline using hard-engineered structures, such as revetment and seawall, as the first protection would only decrease.

In conclusion, in this study area, using remote sensing, time-series, analysing how severe the climate change have direct influence on the coastal hazard is complex because there are various factors causing coastal changes including protection and erosion sides. Climate changes are still the major factors of coastal erosion problem which could not be completely solved and inevitable. Although the human-made coastal protections could protect the target shores, the nearby coastal areas would still receive the side-effects on erosion increasing. In addition, the placement of coastal protections seems to have a significant influence on preventing and preserving coastal areas. Mangroves which are the coastal protection from nature seem to have benefits in preserving and collecting the muddy sediments outweighing the man-made engineered structures.

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