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A Mathematical Model to Predict a Coastal Erosion: Case Study Chalathat Beach, Songkhla, Thailand

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***Abstract*—Geographical condition in the south of Thailand stretches along both sides of the sea, causing coastal erosion problems. Especially at Chalathat Beach of Songkhla Province, problems caused by erosion are caused by many reasons. However, the rate of erosion is increasing every year. This research combines primary and secondary data to analyze coastal erosion trends using geographic measurement techniques using Google Earth Pro and Linear Regression to obtain a coastal erosion rate forecasting model that can forecast the area caused by the erosion of the coast of Chalathat Beach Songkhla Province in the next ten years. In 2032, the area of Chalathat Beach will be eroded by approximately 213,448.8232 square meters. This model can be applied to assess coastal erosion in the area nearby. In addition, this research is helping environmental agencies in coastal erosion assessments where they can assess the damage caused by coastal erosion and used for editing plans for long-term coastal erosion solutions.**

***Index Terms*—Coastal erosion, Mathematical Model, Linear Regression, Songkhla**

I. Introduction

Geography of Thailand It is a peninsula that is part of the Indo-Pacific region. It is shaped like an ancient ax. Also known as the "Golden Axe", it has an axe handle, which is geographically referred to as Malaya Peninsula or Malay. The sea is divided into two sides, the Gulf of Thailand and the Andaman Sea. It has a total distance of 3,148.23 kilometers along the coast, with details as follows: The total coastal length is 2,055.18 kilometers, located in the South China Sea, the pacific ocean. The Gulf of Thailand's characteristics can be divided into two parts according to the region of Thailand.

- The Eastern Gulf of Thailand, including the coastal area from the midpoint between the mouth of the Tha Chin River and the Chao Phraya River to the east to the border of Cambodia. Ban Hat Lek, Trat Province, or from Trat, Chanthaburi, Rayong, Chonburi, Chachoengsao, Samut Prakan, and Bangkok. The southwest monsoon influences this coastline from March to August.
- The western Gulf of Thailand starts from the midpoint of the Chao Phraya River and the Tha Chin River to the west and goes south to the border of Malaysia. At the mouth of the Su-ngai Kolok River, Narathiwat Province or from Samut Sakhon, Samut Songkhram, Phetchaburi, Prachuap Khiri Khan, Chumphon, Surat Thani, Nakhon Si Thammarat, Songkhla, Pattani, and Narathiwat, it is the coast that is influenced by the northeast monsoon winds blowing to shore during November to February.

The Andaman coast stretches for 1,093.14 kilometers, connecting the provinces of Phuket, Nga Province, Krabi, and Phang Nga across six provinces, including Ranong and Krabi. It is defined by glacial landforms such as tidal flats 0.5–4 meters above sea level and rivers flowing through soft soils. Moreover, upstream up the mountain, a considerable amount of sediment deposited along the sea coast was transported out into the river's mouth because of most of Thailand's vast coastal scenery.

Most are mangrove forest areas, such as the upper Gulf of Thailand, where waves, wind, high tides, and currents sweep offshore sediments to build along the coast. The little sediments build, causing coastal areas to be used as shrimp farming and community living habitats. The problem of Thailand coastal erosion is now recognized as urgently needed. Because it affects more than 12 million people living in coastal areas, the coastal areas still suffer from the severity of the rapidly changing climate. The coastline in Southern Thailand still suffers from continual erosion [1], [2]. The monsoons and storms that are more intense yearly make the sea waves more volatile, directly affecting the coast of Thailand. Many areas face severe coastal erosion. Twenty-three coastal provinces were eroded together for a distance of more than 830 kilometers, or 26 percent of the coastal area. This occurred

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similar to Nepal. Land degradation, particularly soil erosion, is currently a major challenge for Nepal. With a high rate of population growth, subsistence-based rural economy, and increasingly intense rainfall events in the monsoon season [3].

Furthermore, the coastal erosion affects many aspects of the economy, including the tourism industry, agriculture, aquaculture, and coastal fisheries, which can create jobs and incomes for communities. It also significantly impacts ecosystems and natural resources, including mangrove forests, coral reefs, and seagrass. The survey found that the coastline of the Gulf of Thailand is the most eroded, with a distance of more than 730 kilometers, while the Andaman Sea is more than 100 kilometers, divided into 44 critical areas in 19 provinces, a distance of 169 kilometers, and 146 urgent areas. The distance is eroded by about 399 kilometers in 21 provinces.

II. Literature Review

A study on coastal changes in the region surrounding the Gulf of Pattani intends to categorize the coastal geomorphology units there. Outline the history of coastal development and research changes to the coast. It was a survey study conducted between 1969 and 2002 using topographic maps, soil maps, and aerial pictures. Investigations using satellite images and the outdoors ArcView and MapInfo are used to process data, map it, and present the results as research reports. The findings revealed that the Gulf of Pattani area is made up of five geomorphic units associated with sea action: sand beach, sand ridge, old and recent lagoon, tidal flat, and A total of 507.90 square kilometers, or 59.3 % of the study area, make up the old tidal flat. The coastline had eroded an area of 3.342 square kilometers, the landfill an area of 8.385 square kilometers, and the net change increased to 5.043 square kilometers between 1969 and 2002. The growth of land is about 0.153 square kilometers yearly on average. A more significant net change rate between 1986 and 2002 is more than between 1969 and 1986. This is because the material from the dredging of the Pattani River Estuary in 1996 and 1997 was placed there, leading to the construction of a groin dam near the point of Laem Pho. Ban Talo, Samilae, and Bang Tawa are among places that have significant erosion. Rip rap and sea barriers are used for coastal protection, which can help limit the amount of erosion. However, it results in more erosion in the neighborhood. Because the shore is a geomorphic region with high dynamics, it requires ongoing research and monitoring to offer reliable information for effective coastal land use planning and coastal preservation [4].

Department of Marine and Coastal Resources reports [5] showed the survey and follow-up on the coastal erosion situation in Muang district, Songkhla province, 19.45 km long coastline. A balanced sandy beach characterizes the coastal area with a distance of approximately 9.14 km and an estuary area of 0.24 km. The four areas affected by coastal erosion are Chalathat Beach, which has little coastal erosion. The distance is about 0.10 kilometers south of chalathat Beach. The beach has been restored by transferring sand, causing waves to erode the beach with a vertical cross-section. The height is about 10 - 60 cm—a distance of 0.65 km. Kao Seng community has severe coastal erosion. The distance is about 0.15 km long because there is a coastal breakwater when the waves collide with a coastal breakwater. The impact caused high waves to cross the coastal breakwater. The line behind the breakwater was severely eroded. However, the breakwater caused coastal erosion at the end of the dam. The villagers then placed sandbags temporarily to protect their residences and mosques. Baan Chai Talay, Village Moo. 7, Khao Rup Chang Subdistrict, has severe coastal erosion. At the end of the project, the impact that caused the pines to fall, a distance of 0.13 km long, was the end of the coastal erosion protection wall project, which tends to be more severe. The structure was found to prevent coastal erosion, a distance of 9.04 km, including the placement of synthetic fiber bags containing sand, coastal breakwater upright, concrete wall, and offshore breakwaters.

Research is still being done, but it has been determined that the issue and reason for the collapse of Chalathat beach were the intrusive constructions on the sandy beach, which are particularly prone to human poaching. Since 2001, a sewage pump pond has been built at Ban Kao Seng beach as a result of this. However, it got worse as more breakwaters were built, which is entirely compatible with coastal engineering theory—and resolving old issues, whether by filling the beach with silt and sand or stone reclamation, by laying sandbags. To lessen the harm, they are only resolving issues at their source. Chalathat beach was not corrected and restored under academic standards.

There are several ways to predict coastal erosion. We can calculate it using linear regression if we have historical data. In order to give meaningful interrelationships on the spatial and temporal dynamics of shoreline alterations, it has a research integrated remote sensing, Geographic Information Systems (GIS), and modeling methodologies [6]. Another research combined Remote Sensing, Geographical Information System (GIS), Linear Regression Rate (LRR), and End Point Rate (EPR) approaches to analyze long-term coastal erosion over the whole Karnataka coast. The Digital Shoreline Analysis System (DSAS) program has been used to analyze 26 years (1990 to 2016) of erosion using Landsat photos [7]. A machine learning algorithm based on supervised learning is linear regression. It executes a regression operation. Regression uses independent variables to model a goal prediction value. It is mostly used to determine how variables and forecasting relate to one another. Regression models vary according to the number of independent variables they use and the type of relationship they take into account between the dependent and independent variables.

III. Research Method

This research collected both primary and secondary data on coastal erosion. Secondary data was obtained by collecting erosion data before each period for approximately ten years in 1966, 1974, 1989, 1995, 2001, 2012, and 2013. In addition, for 2017 and 2022, the primary data collection, the researcher entered the data storage area by himself. The exact method is as follows.

A. Research Area

There is a road along the seashore. There is a northeast monsoon wind. In the rainy season, the rainfall of Songkhla Province is quite good. The average annual rainfall is approximately 2,093.8 millimeters, and approximately 159 days of rainfall occur. The rainiest month is November. The average rainfall was about 582.6 millimeters, and rain was about 23 days. The highest rainfall in 24 hours was 329.4 millimeters.

B. Data Collection

Data gathering is a crucial component of regression analysis. Regression analysis can only be as accurate as the data it references. There are three fundamental ways to get data: a planned experiment, an observational study, and a retrospective study using historical data [8]. This research used historical data, and it is to collect additional information from what was done from 1966 to 2013. The former area was Chalathat Beach, Muang District, Songkhla Province, with 4,300 meters along the beach.

C. Devices

Measuring equipment and tools and the analysis of the data is as follows: 1) Geographic locator (GPS) brand Garmin model etrex H; 2) Mobile phone model Huawei y9s; 3) Table data management program Microsoft office excel 365; 4) Geographic information system program Google Earth Pro; and 5) Tide table of the year 2017 and 2021.

D. Process

- The research explores the area of Chalathat Beach, Mueang District, Songkhla Province, to study the area's condition. Moreover, the research studies physical of the beach environment and changing conditions of the Chalathat beach that have changed all the time
- The researcher determines the date and time of the highest sea level rise by collecting data from different coordinates. In this study, data were collected in the Grid Coordinates system, Universal Tra Mercator (UTM), using a geographic coordinate device (GPS) from the data from the tidal table of Songkhla Province. A study showed that the tidal impacts the coast erosion [9]. Courtesy of the Southern Eastern Meteorological Center To be used to determine the date and time of the highest tide level to collect data. The season of Chalathat beach is changing; the researcher planned to collect coastal coordinate data twice. The 1^{st} time in 2017, on 15 March 2017, from 06.30 a.m. to 11:00 a.m. The 2^{nd} time in 2021, dated 10 January 2021 from 7:00 a.m. to 10.30 a.m. See Fig. 1.
- The research collects the coordinates of Chalathat Beach during the highest tide according to the specified date using a geographic locator device, walks ten steps further, and collects another coordinate to create a beach line of Chalathat Beach on the specified date and time. There are processes for collecting data as follows: 1) Determine the location of the sea and the sandy beach, in another word the area where the clear wave reaches the highest part of the beach to store the coordinates of the location "Mermaid Statue" to "Wat Khao Kao Saen"; and 2) the coordinates of the road line. See Fig. 2.

Fig. 1. Chalathat Beach

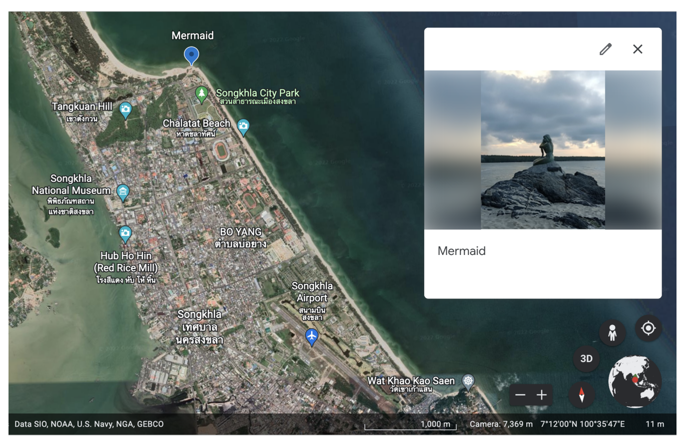

Fig. 2. Google Earth Pro shows Chalathat Beach from Mermaid Statue to Wat Khao Kao Saen

IV. Results and Discussion

This study focused on the eroded areas of the coastline at Chalathat Beach, Songkhla Province, by converting the Chalathat Beach area from aerial photographs at Chalathat Beach in 1966, 1974, 1989, 1995, 2001, and 2012. The Chalathat beach coordinates were obtained from collecting data with a Geographic Coordinate Machine (GPS) [10]. The authors added the data in 2017 and 2022, then analyzed all data

TABLE I
CHALATHAT BEACH AREA

Year	Years Accumulated	Chalathat Beach area (m^2)
1966	0	456,676.05
1974	8	422,259.12
1989	23	428,978.09
1995	29	355,954.07
2001	35	321,948.70
2002	36	328,802.39
2012	46	265,375.90
2013	47	256,008.31
2017	51	280,108.00
2022	56	273,667.00

TABLE II
MULTIPLE REGRESSION RESULTS

R Square	0.898336849
Adjusted R Square	0.885628955
Standard Error	25106.70487
Observations	10

with the Geographic Information System using the program Google Earth Pro to calculate the area of Chalathat Beach. The researcher cleaned the data with a spreadsheet program to verify the correctness, then created a pin showing beach points every ten steps with Google Earth Pro. Every point data were calculated to the area (polygon) each year. Then, the area data of each year is overlapped to find the area of erosion each year. After that, the eroded area was taken for an erosion model.

A. Results

The collected data was used to calculate the beach area from the import of Google Earth Pro, overlaid with road data built parallel to Chalathat Beach. All data were divided into ten periods, calculating the years accumulated for each period. To calculate the beach area that changes per year (m^2/year) and then divided by the length of Chalathat Beach (4300 meters) to calculate the rate of change of Chalathat Beach in square meters/year. See "Table. I"

TABLE III
ANOVA

	Regression	Residual	Total
df	1	8	9
SS	4.456E+10	5042773034	4.9603E+10
MS	4.456E+10	630346629	
F	70.6912455		
Significance F	3.05E-05		

TABLE IV
REGRESSION ANALYSIS RESULTS

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	465269.8	16989.9728	27.3849642	3.41E-09
XVar1	-3815.47	453.800685	-8.4078086	3.05E-05

An R Square (R^2) value is 0.89833685 or 89.83 percent indicates that the number of years increase (x) affects the Chalathat beach area (y), Standard Error is 25106.70487, Observations are 10 periods, and Significance F is less than 0.05, indicating that the model is well predictable.

B. Equations

The relationship between a scalar answer and one or more explanatory variables can be modeled linearly using the technique of regression. "Table. IV" shows the Coefficients value of Intercept, 465269.8, and X variable 1 (XVar1) is -3815.47. The important part is the replacement of Coefficients values that can be used to construct the linear regression equation as follows:

$$y = bx + a \tag{1}$$

For the above data, y is the area of Chalathat Beach and x is the cumulative number of years added. Therefore, the new equation shows below:

$$y = (XVar1) * x + Intercept \tag{2}$$

So,

$$y = -3815.4693 * x + 465269.797 \tag{3}$$

It can be seen that the values in the resulting equation are negative. If calculated, this will show that the area of Chalathat Beach will gradually decrease as the accumulated year's increase. From the above equation, it can be estimated that the Chalathat Beach area in the next ten years. When the cumulative number of years ($x = 66$) is substituted into the equation, the area of Chalathat Beach (y) is 213,448.8232 square meters. "Fig. 3" shows the relationship between number of years accumulated and Chalathat Beach area (m^2).

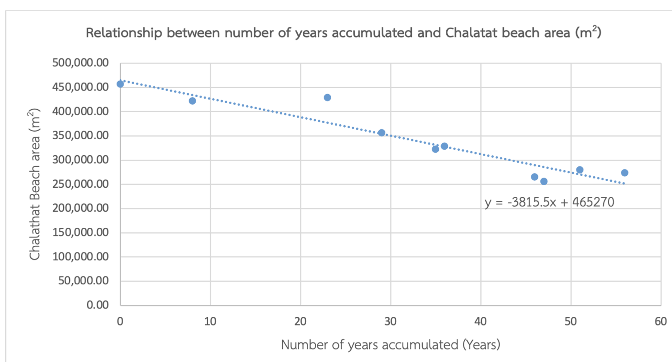

Fig. 3. Relationship between number of years accumulated and Chalathat beach area (m^2)

It can be seen that as the number of years accumulates, the more the beach area decreases. It can be written as an equation as (3).

"Table. V" shows the beach area measured from Google Earth Pro and from the calculation with the equation (3) to find

TABLE V
CHALATHAT BEACH AREA DIFFERENCE

Year	Year	Chalathat Beach area		
	Accumulated	***From Google***	***From equation***	***Difference***
1966	0	456,676.05	465,269.797	8,593.75
1974	8	422,259.12	434,746.0426	12,486.92
1989	23	428,978.09	377,514.0031	-51,464.09
1995	29	331.054.08	354,621.1873	-1,332.88
2001	35	321,948.70	331,728.3715	9,779.67
2002	36	328,802.39	327,912.9022	-889.49
2012	46	265,375.90	289,758.2092	24,382.31
2013	47	256,008.31	285,942.7399	29,934.43
2017	51	280,108.00	270,680.8627	-9,427.14
2022	56	273,667.00	251,603.5162	-22,063.48
2035	66	-	213,448.8232	-

TABLE VI
CHANGING AREA AND RATE OF CHANGE

Years	***Number of years***	***Changing area*** (m^2)	***Rate of change***[a]
1966-1974	8	-4,302.11625	-1.00
1974-1989	15	447.9313333	0.10
1989-1995	6	-12,170.67	-2.83
1995-2001	6	-5,667.561667	-1.32
2001-2002	1	6,853.69	1.59
2002-2012	10	-6,342.649	-1.48
2012-2013	1	-9,367.59	-2.18
2013-2017	4	6,024.9225	1.40
2017- 2022	5	-1,288.2	-0.30

[a]meter/year

areas of the beach that have been eroded. The area difference show in the Difference column in "Table. V".

C. Evaluation

"Table. VI" shows the area of Chalathat Beach for nine periods. The area of change and rate Chalathat Beach changes. Most of them were negative, which means the beach area was eroded. The slightest periods have positive values, meaning the beach area has increased deposition. During 2001-2002, the highest deposition was 6,853.69 square meters/year; the deposition rate was 1.59 meters/year. During that time, the year with the most eroded areas was 1989-1995, with an area of 12,170.67 square meters/year, with an erosion rate of 2.83 meters/year.

For Thailand, there are ways to solve coastal erosion problems. Natural methods of prevention and remedy use engineering methods and an integrated approach. The details are as follows:

- 1) natural methods of prevention and remedy, including the restoration and conservation of mangrove forests, beach forests, sea grass resources, and coral reefs to reduce the intensity of waves that hit the shore—are considered a way to prevent erosion by imitating nature. However, it takes time to build stability and strength for the coast. Chalathat Coast has cement pipes to reduce the impact of offshore waves, and used as a spawning ground for fish, and is the habitat of coral.
- 2) Engineering method. It uses engineering structures to trap sand sediment and dissipate wave energy. Alternatively, build more sandy beaches to protect and maintain coastal conditions using academic principles, studies, and analyses that cover all dimensions, such as breakwater, revetment, sand nourishment, and dune nourishment. Chalathat coast, sandbags are placed on the beach when the monsoon season arrives; See Fig. 4 however, it cannot solve the problem sustainably.

Fig. 4. Sandbags placed on Chalathat Beach

- 3) Using a combination method: Using natural and engineering methods together, such as implementing coastal erosion prevention in Scathing Phra District. Using wave breaks by embroidering bamboo as a wall reduces the intensity of the waves. There is more precipitation and deposition. Therefore, mangrove trees were planted behind the bamboo embroidery line. It was found that the mangrove trees were growing well to restore the natural mangrove forest. Chalathat coastal beach has sand extracted from the sea to fill the beach area to solve the problem of coastal erosion temporarily. See Fig. 5

Fig. 5. Sand extracted process to fill the beach

V. Conclusion

This research studies the change in the Chalathat area and beach line in 1966, 1974, 1989, 1995, 2001, 2012, 2013, 2017, and 2022. The data was used to compare the change in the Chalathat Beach area. It was found that over time, the area of Chalathat Beach had changed, the area had decreased, or the area had been eroded more. The erosion rate is based on the linear regression equation as (3). This model can predict the Chalathat Beach area in the next ten years (2032). Chalathat Beach will be eroded by about 213,448.8232 square meters. Therefore, relevant units have devised measures to protect the Chalathat beach line by various methods, such as aligning sandbags in a line. This research helps provide advice for environmental agencies in the assessment of coastal erosion. They can assess the damage caused by coastal erosion and use this model to plan long-term coastal erosion solutions.

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