Statistical Modeling for Riverbank Erosion

Marushme Awang

A Thesis Submitted in Partial Fulfillment of the Requirement for the

Degree of Master of Science in Research Methodology

Prince of Songkla University

2022

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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

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บทคัดย่อ

การกัดเซาะตลิ่งของแม่น้ำเป็นภัยธรรมชาติต่อผู้ที่อาศัยอยู่บริเวณตลิ่งของแม่น้ำ การแตกตัวของตลิ่งแม่น้ำเกิดขึ้นจากการไหลของน้ำในแม่น้ำเกิดการพัดพาตะกอน มีการกัดเซาะพื้นที่หนึ่งไปทับถมอีกพื้นที่หนึ่งทำให้เกิดการเปลี่ยนแปลงรูปแบบของแม่น้ำ งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษารูปแบบการกัดเซาะของแม่น้ำเทพา ตำบลเทพา อำเภอเทพา จังหวัดสงขลา ใช้ข้อมูลที่แปลงภาพถ่ายดาวเทียมจาก Google Earth เป็นข้อมูลเชิงตัวเลข ของ ปี 2003 2011 2015 2017 และ 2018 โดยวิเคราะห์การเปลี่ยนแปลงของแต่ละปีเทียบกับปี 2003 ใช้ตัวแบบ Cubic Spline วิเคราะห์รูปแบบการเปลี่ยนแปลงของแม่น้ำพบว่า มีการเปลี่ยนแปลงของแม่น้ำโดยที่มีการขยับของตลิ่งทั้งทางซ้ายและขวาไปทางทิศตะวันตกอย่างสม่ำเสมอจากปี 2003 ถึงปี 2018 แสดงว่ามีการกัดเซาะตลิ่งแม่น้ำทางด้านซ้ายสำหรับตลิ่งฝั่งขวามีการทับถมตะกอน อาจเกิดจากสาเหตุการพัดพาตะกอนจากพื้นที่หนึ่งไปทับถมอีกพื้นที่หนึ่ง

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ABSTRACT

River erosion is a critical process that cause a lot of terrain changes and affects people who live on the river or live nearby the river areas. This study analyzed the erosion pattern of Thepha river in years 2003, 2011, 2015, 2017 and 2018. The data obtained from satellite images in Google Earth covering latitude 6.824138^{o}-6.827198^{o} N and longitude 100.972019^{o}-100.973211^{o} E of 570 points along each bank. Cubic spline model was used to fit the change of each year compared to 2003 for left and right bank. The results show that there is movement of river bank line to west.

Acknowledgements

I would like to express great appreciation to my supervisor, Asst. Prof. Dr. Somporn Chuai-Aree, my co-advisor, Asst. Prof. Dr. Rhysa McNeil, Department of Mathematics and Computer Science and Emeritus Prof. Dr. Don McNeil, Macquarie University, Australia, for their invaluable quidance and cooperation throughout the study.

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Marushme Awang

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Chapter 1

Introduction

1.1 Background and rationale

Erosion is a critical process for land and watershed managers to understand, as sediment is the world's leading surface water pollutant (Lal, 2001). Excessive erosion results in significant topsoil losses, leading to declines in agricultural productivity (Peng *et al*., 2011) and water erosion is an erosion that can affect geographic changes (Bene, 2007).

The community at risk areas should be provided with useful information about land degradation. Erosion is a key social factor that is important in deciding options for controlling soil losses. Therefore, understanding the Community's knowledge and their perception and factors that influence their land management practices are of paramount importance for promoting sustainable land use in the study area (Ofgeha, 2017). Soil erosion studies have gained great prominence because of the potential threat it has to land resource and crop productivity and this in association with inappropriate land management practices is one of the main factors causing degradation.

Water erosion is the detachment and removal of soil material from water (Neidhold *et al*., 2005; Pimentel, 2006). The process may be natural or accelerated by human activity. The rate of erosion may be slow to rapid, depending on the soil, the local landscape, and weather conditions. Soil erosion can occur in many ways, water, rainfall or river and all this cause can produce a change of topography (Tomoshige *et al*., 2014; Zhou *et al*., 2014). Erosion that can cause a lot of terrain changes and affect people who live on the river or live in nearby the river areas is river erosion (Aher *et al*., 2012). If the flowing of river has run, it will cause erosion and sediment transported by water flow (Galin and Poulin, 2005; Xing *et al*., 2011). The rate of outer bank erosion and of inner bank deposition and, hence, in ensuring a reliable and robust simulation of platform meander migration (Frascati and Lanzoni, 2013). Moreover, if the flowing of the river has turned it will cause faster erosion (Dietsch *et al*., 2014).

River erosion is a naturally occurring process that affects river shape (Guite and Bora, 2016). In the agricultural field, river erosion refers to the disappearance of a field's topsoil by the physical forces of water. River erosion can be a slow process that continues relatively unnoticed or can occur at an alarming rate, causing serious loss of topsoil. The condition of erosion continues shifting of river course and erosion introduce vulnerable conditions on physical as well as the social environment (Ghosh *et al*., 2018; Abidin *et al*., 2017). Overall, the condition of the erosion victims is very poor and challenging. Erosion causes changes in the topography and the landscape will certainly have an effect. Erosion may occur over a long period of time. Hence, there should be warnings or information for preventing damage that may occur in the future. Therefore, this study in order to solve and analyze erosion will be summarized by reading satellite images from Google Earth which has a comparison with the past that converts to numerical data by image processing method.

Past river erosion problems; contemporary societies live on a cultivated planet where agriculture covers around 38% of the land surface (Borrelli *et al*., 2020). In the study area, soil erosion affects not only the cultivated land but also sedimentation of the river (Nguyen and Pham, 2018). The biodiversity of rivers is seriously affected by erosion (Mondal and Tripathy, 2020).

1.2 Objective

To analyze the erosion pattern of river flow using statistical modeling and image processing technique.

1.3 Expected outcome

This research differentiates between current satellite image changes from previous ones which will give basic information. Part of it might be useful information for communities in the study area.

1.4 Literature reviews

The interest of this research is a change of river using image processing, mathematical and statistical methods. In this session review of related literature shall be presented as follows.

1.4.1 Image processing

Patil *et al*. (2012) has studied land use and land cover change and developed a model for image classification tool for land use / land cover analysis. The author conducted a comparative study of maximum likelihood and minimum distance method using data from satellite imagery from Landsat (The Landsat Program is a series of Earth-observing satellite missions). Digital data was converted from the image by reading color shades values. The primary colors are red, green and blue. Digital data was done by selecting pixel shades. Red shades represent (r=255, g=0, b=0) replace buildings, yellow (r=210, g=180, b=140) represents barren areas, blue (r=0, g=0, b=255) represents wet and green areas (r=0, g=255, b=0) represents vegetation areas. These will be compared twice to indicate whether the color values were increased or decreased. The value of these images then be converted into digital data and be compared by 2 methods are Maximum Likelihood Classification (MLC) and Minimum Distance Classification (MDC).

1.4.2 River change and land use change

Bene (2007) conducted a real-time erosion by using shallow water simulation. In this study the researcher applied the model in computer graphics to take the information from the geographic of the huge area by minimizing its size and simulating it in a form of a computer animation application, this would allow the researcher of controlling it.

This simulator has simulated water flow from high to low of landscape, soil eroded of terrain, sediment transports along with the water flow, including soil smoothed the shallow water equation. The result of this experiment is the terrain changes after running this equation.

Aher *et al*. (2012) conducted a study on the change of Pravara River in India. The author tried to find out the direction the river flow from the past to the present and also to forecast the trends in future changes. In this study, the information was taken from satellites twice. The First was Topo sheet in 1974 and second was cut from Google Earth in 2006 in the area of Pravara River. The positions of the two images were on the same spot by latitude and longitude. After that they overlapped these two images to observe the changes that occurred on the river during year 1974 to 2006. As a result, the river was divided into sections throughout the area. They measured distance of two rivers. Both sides of the river of 2 images were then measured. The location of each river was divided into sections and then distance of both sides of river bank were measured. This was done the same to the left side river bank line from 2006 and 1974. By doing this, the researchers got data to analyze the next river change.

Austin *et al*. (2017) has studied the disappearance of forests in the reserve area of Indonesia. In this study, the researcher used photo information from Landsat which recorded the image in years 1995, 2000, 2005, 2010 and 2015. From here, the maps of the landscape were made by reading from color analysis, the result was shown the missing of forest areas and the increased of palm oil garden.

Ghost and Sahu (2018) conducted a case study on the problem of river bank failure and the condition of the erosion victims in Dhulia, West Bengal, India and found continuous shifting of river course and erosion caused vulnerable conditions on the physical and social environment. This research conducted the satellite image cutting from Google Earth 7 times. There were 1984, 1990, 1995, 2000, 2005, 2010 and 2015. All bank lines of the respective years have been directly digitized from Google Earth. The bank lines have been lapped with the Remote Sensing (RS stand for reads data from satellite images) and Geographic Information System (GIS) techniques to measure the rate of erosion and deposition.

Kim (2016) was creating the research about land use changes, especially of deforestation and forest degradation in the past 20 years in Lombok Island using satellite imageries.

The data from Landsat satellite imageries which medium scale Landsat multiple scanner (MSS), Landsat thematic mapper (TM), and enhanced thematic mapper collection (ETMC) satellite imageries were used for this study. Landsat time-series data from 1990 to 2010 with 5-year intervals were selected for extracting information on land use and land cover changes on Lombok Island.

Guo *et al*. (2020) study the regularity of sediment transport and sedimentation during floods in the lower Yellow River, China. The problem of this research foresees flood season that expected erosion faster than any other time and this season is an important moment resulting in a change of the terrain. The study area of this research is part of a river in China which has an approximate length of 800 km during 1960-2006. This study compared the denseness of sludge from water flow to examine the rate of change of the river. The result of this research showed the intenseness of sediment effective change of river.

Pitchford (2014) was studied streambank erosion in the topic of modelling streambank erosion potential using maximum entropy in a central Appalachian watershed. The study area is Cacapon River Watershed, West Virginia. This research has modeled the rate of erosion with variables related to erosion. Major environmental variables controlling these processes were streambank slope, soil characteristics, bank. Data were used to create environmental three layers to represent features associated with streambank erosion potential (SEP). They are min, max and mean. The methodology of this study, the map was created from the logistic model output to represent three levels of SEP. And this conducted a one-way Analysis of Variance (ANOVA) to test the

strength of our classification scheme, using normally distributed migration rates (m/year) as the dependent variable. A significant ANOVA was followed with a Tukey's Honest Significant Difference (HSD) post hoc test to compare migration rates between low, moderate, and high SEP.

Chapter 2

Methodology

This chapter describes the methodology consisting of study area, data acquisition, method for converting the satellite image into digital data by image processing, and statistical methods.

2.1 Study area

This study analyses river changes of Thepha River in Songkhla province, southern of Thailand. The selected locations of this area are shown in Figure 2.1
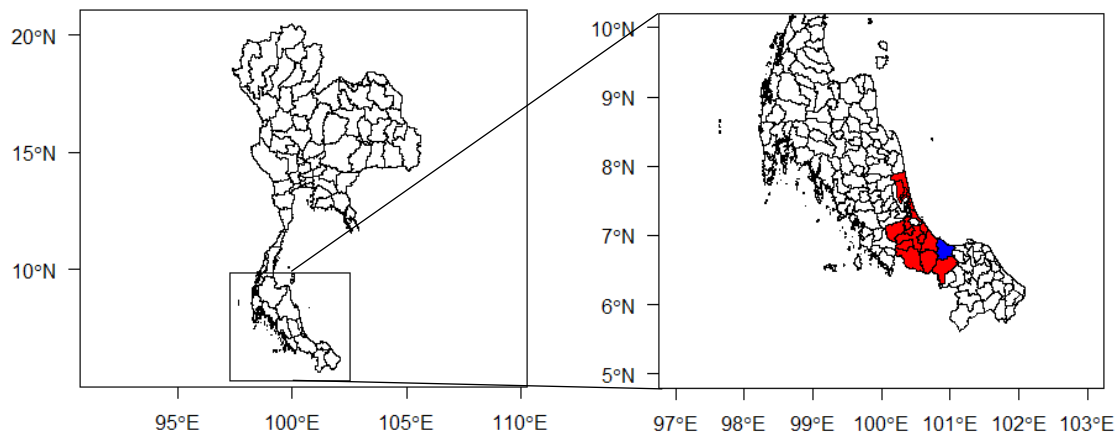
Figure 2.1 Map of study area

Figure 2.1 red color in the map is Songkhla province, blue color is Thepha subdistrict in Songkhla in which Thepha river flows. Many communities live on the river bank which is at risk of erosion when the river ebbs and flows. This study chose a stretch of Thepha river in a rectangular area located at the following corners: 6.824638 N latitude and 100.972019 E longitude, 6.824638 N latitude and 100.973611 E longitude, 6.827198 N

latitude and 100.973611 E longitude and 6.827198 N latitude and 100.972019 E longitude. The dimensions of the rectangle are approximately 174×283 meters.

2.2 Satellite image

Google Earth is a satellite photo program that can view satellite imagery data over the world that renders a 3D representation of Earth based primarily on satellite imagery. It can also provide satellite image data in the past. The satellite image can be used in image processing to convert from image into digital data. Google Earth can be zoomed to enlarge images on the map to the desirable resolution.

Five images of Thepa river over the previous 5 years were downloaded on certain date as follows: 27th May 2003, 3rd September 2011, 23th March 2015, 14th March 2017 and 21th April 2018. These are shown in Figure 2.2.

a) 27th May 2003

b) 3rd September 2011

c) 23th March 2015

d) 14th March 2017

e) 21th April 2018

Figure 2.2 Satellite image from Google Earth

2.3 Analysis

In this research we analyze the changes to Thepa river from satellite images. The images were downloaded from Google Earth, then converted into digital data. The analysis will be described in two main topics as follows.

2.3.1 RGB color

The images incorporate three colors: red, green and blue (RGB). An RGB image is an image consisting of fixed values of color contents for each pixel. These are the primary colors of visible light and is how computers and televisions display images on their screens. RGB colors often appear brighter and more vivid specifically because the light is being projected directly into the eyes of the viewer (Nishad *et al.,* 2013). The RGB color space is used throughout computer graphics. Red, green and blue are three primary additive colors: each color normally ranges from 0 to 255 that is R= {0, 1, 2 ….. 255}, G= {0, 1, 2 ….. 255} and B= {0, 1, 2 ….. 255}(Prabhakar *et al.*, 2017). An RGB image is a blend of three different color layers (RGB).

$$p = \sqrt{(255 - r)^2 + (0 - g)^2 + (0 - b)^2} \qquad (2.1)$$

The algorithm that we used to read these images will be converted to numerical data when the program found the red color value with the formula (2.1)

where *p* is the final shade value, *r* is the red color value, *g* is the green color value and *b* is the blue color value.

2.3.2 Image processing and data acquisitions

In the procedure of image processing to analyze the changing of river banks we have to distinguish between river and land since the edge of the river is important. From Figure 2.3 we have trouble distinguishing water from soil. Since the color separation of image processing found many places that contain water, we could not find the border of the river. Consequently, the image was modified by changing the color of the water in the river to be different from other areas. These images can be edited so that the river will be seen more clearly shown in Figure 2.3.

a) Year 2003
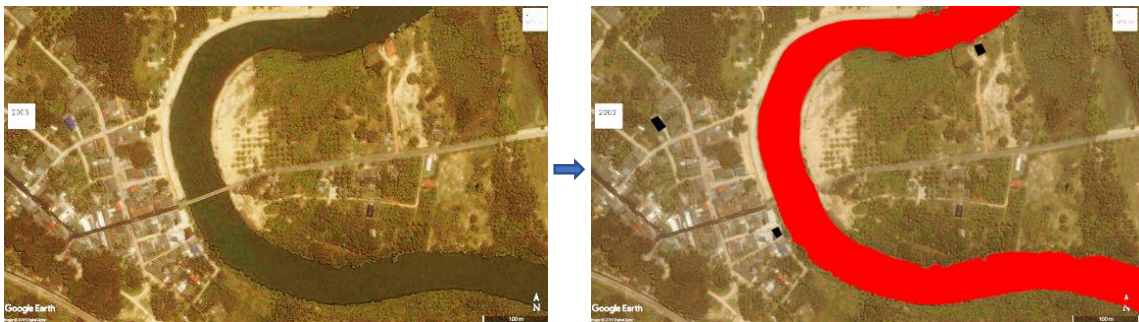
b) Year 2011
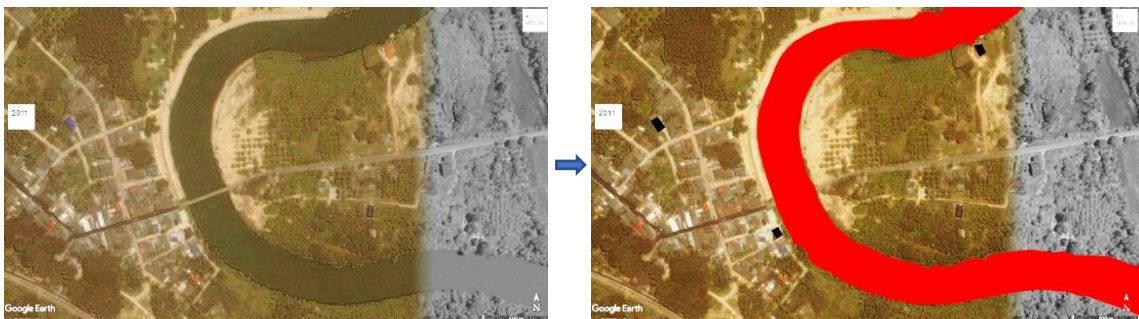
c) Year 2015

d) Year 2017

e) Year 2018

Figure 2.3 Red color of river

Satellite images were taken from Google Earth at different time points. Therefore, there is a chance that an error occurred in the downloaded images of the same location. In Figure 2.4, 4 reference points are shown for all images. Point **a** is an intersection in Thepha Municipality at 6.826014 N latitude and 100.9713 E longitude. Point **b** is an intersection in Thepha Municipality at 6.824828 N latitude and 100.9716 E longitude, point **c** locates

three intersections in the district of Thepha at 6.825783 N latitude and 100.9753 E longitude, and point **d** locates Thepha railway station at 6.823967 N latitude and 100.9704 E longitude. Finally, by overlapping all the pictures with all 4 reference points on the same spot we arrive at Figure 2.4.
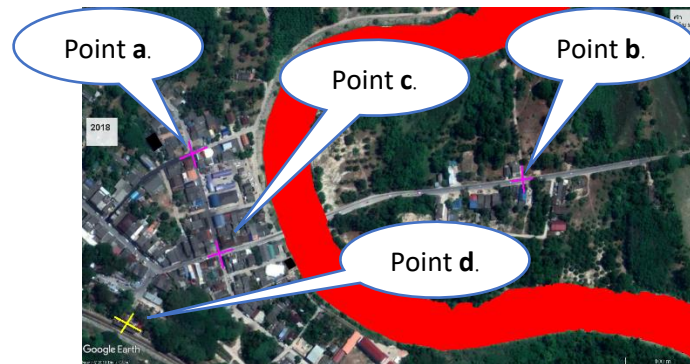
Figure 2.4 Reference points on same spot

The data for the image was collected using the image processing method. This process involves coloring those pictures in order to distinguish water from soil. The Lazarus program was used to change the images to numerical data. This research has selected the areas as shown in Figure 2.5. The image inside this rectangle will be converted into digital data to analyze by statistical methods.

Figure 2.5 The area of converting from image into digital data

From Figure 2.5 the image in the blue rectangular divides the grids of the image. The position of the pixel in the data starts from i, j where i increases according to columns which can go up to 350, then j increases according to rows which can go up to 570. The number of ranked pairs can be explained by Figure 2.6.

1,1	1,2	1,3	...	1,350
2,1	2,2	2,3	...	2,350
3,1	3,2	3,3	...	3,350
⋮	⋮	⋮	⋱	⋮
570,1	570,2	570,3	...	570,350

Figure 2.6 Grids of image

Figure 2.7 The difference grids color

For the grids of image shown in Figure 2.6 we compared the image in the rectangle frame of Figure 2.5, the grid with red color value, the latitude and longitude were recorded for anal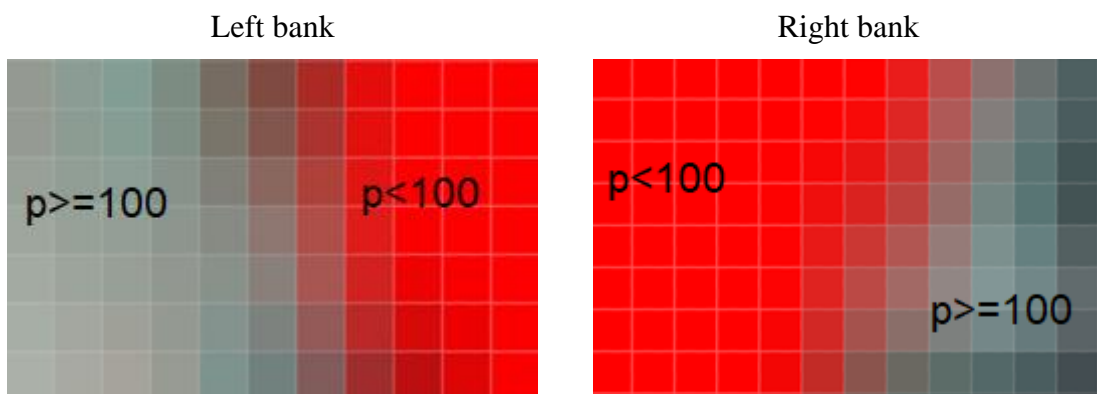ysis. In the process of reading color values in each grid were checked one by one of pixel. Starting from grid 1 until grid 350, if the colour shade is less than 100, which is the color value of the experimented the closest red color, it will collect latitude and, longitude of left bank Figure 2.7 (left) and right bank Figure 2.7 (right). Table 2.1 shown the variables of this study.

Table 2.1 Data dictionary of images

Variable	Data type	Description
i	Integer	Number of rows
latL	Integer	Latitude location of left bank
longL	Integer	Longitude location of left bank
latR	Integer	Latitude location of right bank
longR	Integer	Longitude location of right bank
year	Categorical	Year of image recording; 2003, 2011, 2015, 2017 and 2018

2.3.3 The difference of Longitude

Table 2.1, year is the group data. There are 4 variables, the vector of Latitude location of left bank, the vector of Longitude location of left bank, the vector of Latitude location of right bank and the vector of Longitude location of right bank.

The difference value of longitude for the left bank and right bank was calculated for every year compared to year 2003. There are four differences in longitude between 2003 and 2011, 2003 and 2015, 2003 and 2017, and 2003 and 2018. For example, the difference value of longitude from 2003 to 2011 as shown in table 2.2-2.4.

Table 2.2 Example of data in year 2003

id	LatL	LongL	LatR	LongR
1	6.825841642	100.9721646	6.825841642	100.972697
2	6.825846133	100.9721646	6.825846133	100.972697
3	6.825850624	100.9721692	6.825850624	100.972697
⋮	⋮	⋮	⋮	⋮

Table 2.3 Example of data in year 2011

id	LatL	LongL	LatR	LongR
1	6.825841642	100.9721555	6.825841642	100.9727106
2	6.825846133	100.9721555	6.825846133	100.9727106
3	6.825850624	100.9721555	6.825850624	100.9727106
⋮	⋮	⋮	⋮	⋮

Table 2.4 The difference value of longitude in 2003 and 2011

id	LatL	LongL	LatR	LongR
1	6.825841642	-0.0000091	6.825841642	0.000014
2	6.825846133	-0.0000091	6.825846133	0.000014
3	6.825850624	-0.0000137	6.825850624	0.000014
⋮	⋮	⋮	⋮	⋮

Table 2.4 showed the example of the difference value of left bank and right bank from 2003 to 2011. The calculation of the difference of 3 more pairs, 2003-2015, 2003-2017 and 2003-2018 were the same for both left and right bank.

2.3.4 Conversion the data from degree into meter

The geography degree unit can be converted into meters (Wieczorek *et al*., 2004). The distance in meters was used to analyze the movement of river banks in easterly. It is

110396.22 meters for 1 degree, which was obtained by comparing the triangles and distance between 1 degree of latitude and longitude, which is the same interval. In this research, the change in the border of the river is the difference compared between 2003 and other years in degree. Conversion from degree longitude to meter is multiplication of 110396.22 meters to the difference. Table 2.5, the difference value of longitude in meters is as follows.

Table 2.5 The difference in longitude values in meters between 2003 and 2011.

id	LatL	LongL(meter)	LatR	LongR(meter)
1	6.825841642	-1.00461	6.825841642	1.501389
2	6.825846133	-1.00461	6.825846133	1.501389
3	6.825850624	-1.51243	6.825850624	1.501389
⋮	⋮	⋮	⋮	⋮

2.3.5 Statistical methods

We investigate the change of river in year 2011, 2015, 2017 and 2018 compared to year 2003 by taking the difference using pair t-test.

Paired t-test

Paired t test can be used when two groups under comparison are dependent on each other (Kim, 2015), the formula as follows

$$t = \frac{\overline{d} - \mu}{\frac{s}{\sqrt{n}}}$$
(2.2)

where $\bar{d}$ is mean of the difference in meters of year 2011, 2015, 2017 and 2018 related to 2003. μ is the mean different of 0, s is standard deviation of the difference value and n is sample size of 570. The confidence interval at 95% of the mean difference as following

$$\bar{d} = t_{0.05,df}\frac{s}{\sqrt{n}}, df = n-1 \tag{2.3}$$

Simple linear regression function

Linear regression model was used to examine the trend of the change. The model takes the form

$$y = \beta_0 + \beta_1 x_1 + \varepsilon \tag{2.4}$$

where y is difference of distance in meters from 2003 to 2011, 2015, 2017 and 2018, x_i are Latitude, β_i are slope of difference in each year and ε is error.

Cubic spline function

The cubic spline function is widely used for smoothing data in various fields of study such as interactive computer graphics, real-time digital signal processing and satellite-based time series data (Wongsai *et al.,* 2017). This cubic spline function was used to examine the pattern of the changes of river.

A cubic spline with n knots where $x_1 < x_2 < x_3 < \ldots < x_n$ is any function $s(x)$ with continuous second derivatives comprising piecewise cubic polynomials between and beyond the knots. Denoting by x_+ the function taking the value x for $x > 0$ and 0 elsewhere, $s(x)$ may be written as (McNeil *et al.*, 2011)

$$s(x) = d_0 + d_1 x + d_2 x^2 + d_3 x^3 + \sum_{i=1}^{n} c_i (x - x_i)_+^3 \tag{2.5}$$

Since $s(x)$ is linear for $x < x_1$ if d_2 and d_3 are both 0, this requires that the cubic and quadratic terms in $s(x)$ must also disappear for $x < x_n$, so to be a natural spline the $n+4$ coefficients in the cubic spline as following two equations (McNeil *et al*., 2011)

$$d_2 = 0, \sum_{i=1}^{n} c_i = 0, \tag{2.6}$$

$$d_3 = 0, \sum_{i=1}^{n} x_i c_i = 0. \tag{2.7}$$

The appropriate model is a cubic spline with specific boundary conditions that ensure smooth periodicity (Wongsai *et al*., 2017) and the formula for a cubic spline function is

$$s(x) = d_0 + d_1 x + \sum_{i=1}^{n} c_i (x - x_i)_+^3 \tag{2.8}$$

where x is latitude, due to research on changes in the area. Changes in the river is edge along the latitude. The cubic spline function with degree 3 can be rewritten as

$$s(x) = d_0 + d_1 x + \sum_{i=1}^{n-3} c_i \left[(x - x_i)_+^3 - e(x - x_{n-2})_+^3 + g(x - x_{n-1})_+^3 - h(x - x_n)_+^3 \right] \tag{2.9}$$

where

$$e = \frac{(x_n - x_i)(x_{n-1} - x_i)}{(x_{n-1} - x_{n-2})(x_n - x_{n-2})}, g = \frac{(x_{x-2} - x_i)(x_n - x_i)}{(x_{n-1} - x_{n-2})(x_n - x_{n-1})}, h = \frac{(x_{x-2} - x_i)(x_{n-1} - x_i)}{(x_n - x_{n-2})(x_n - x_{n-1})} \tag{2.10}$$

All graphical and statistical analysis were analyzed using R program.

Chapter 3

Results

This chapter reported the results of analyzing the change of Thepha river change in year 2011, 2015, 2017 and 2018 comparing to year 2003. This also demonstrated the movement of riverside.

3.1 The change of river

The graphical displayed the riverside of each bank in year 2003, 2011, 2015, 2017 and 2018 as shown in Figure 3.1.

a)   b)
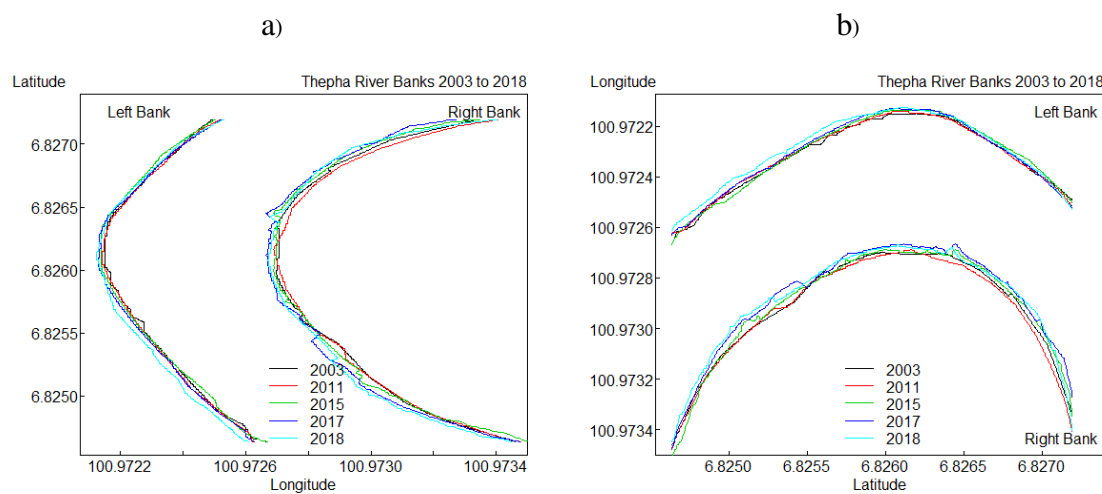
Figure 3.1 Thepha river banks of each year

The figure 3.1 showed the border of river in five times of image. Black line, red line, green line, blue line and blue sky line represented year 2003, 2011, 2015, 2017 and 2018 respectively. Figure 3.1(a), both of river bank was plotting from digital data which converted by image processing method. the direction of flow started from below to top of figure 3.1(a). The direction of water in this study area started form south to north if considered with a compass. We rotated the direction with 90 degrees. From the north to the east, pointing up to observed erosion that has an eastward direction, Figure 3.1

(b). The rotation of longitude and latitude used similar swap axis in scene coordinates. Rotation of scale could be easier to see the change of the river line of both in figure 3.2 and table 3.1 following.

3.2 The changing of river for each year comparing to 2003
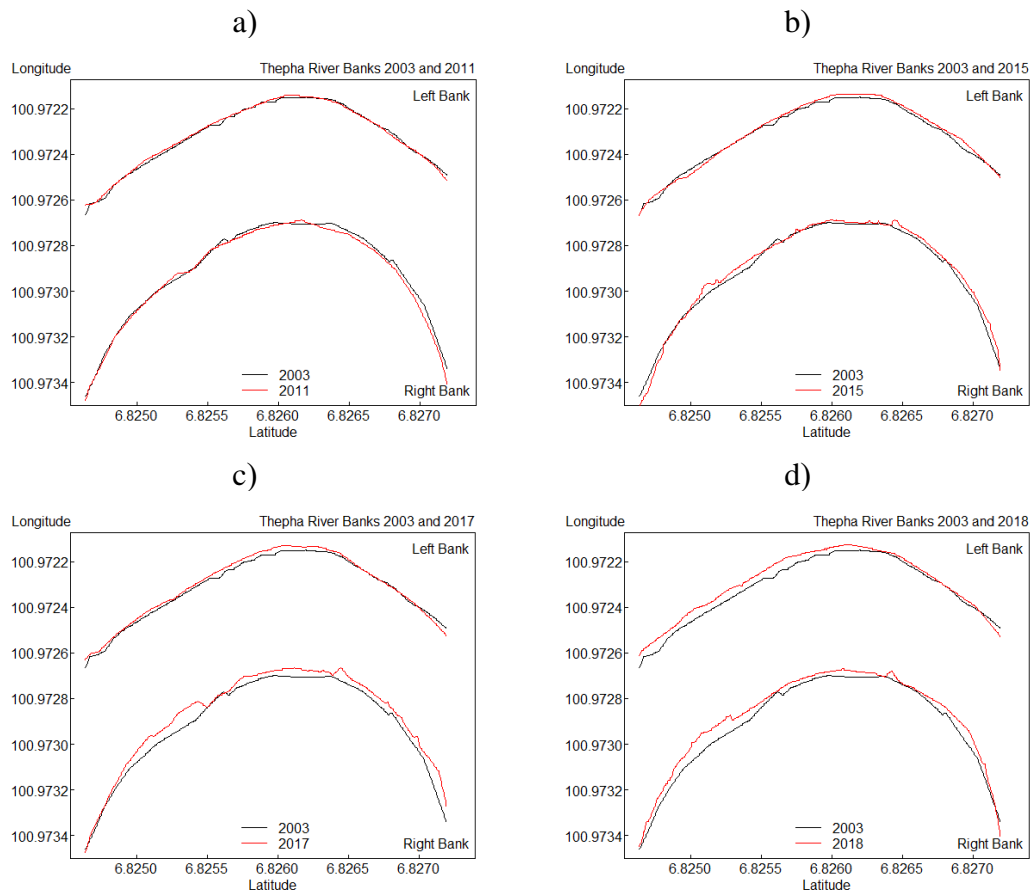

Figure 3.2 Comparisons of each year with 2003

Table 3.1 Erosion or deposition along the lines of graph.

Red line	Upper	Lower
Left	Erosion	Deposition
Right	Deposition	Erosion

The figure 3.2 shows that the left banks of year 2011 was little different from 2003. The right banks the river bank lines in 2017 and 2018 were clearly difference from 2003. The explanation direction of change in left bank and right bank was explained in table 3.1. The red line above or below the black line of figure 3.2 indicated the river erosion or deposition. If red line above black line of left bank, it means river erosion. But for the right bank means river deposition. If red line below black line of left bank, it means river deposition. But for right bank means river erosion

The analysis of the difference of each year with 2003 using paired t-test was shown in Figure 3.3

3.3 The changing of Left-Right bank
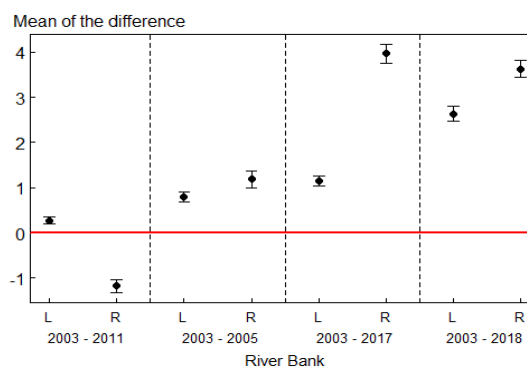
Figure 3.3 The 95% confidence interval of the mean difference

Figure 3.3 shows the 95% confidence interval of the mean difference in distance. The red line is the mean difference equal to zero. The difference in river border between the years 2011, 2015, 2017 and 2018 compared to the year 2003 was noticeable on both the left and right sides.

In the natural process of erosion, when water flows crash the barrier that erodes the spot, causing the opposite part to be deposited. Next, we used simple linear regression to see the change of the difference, as shown in figure 3.4.
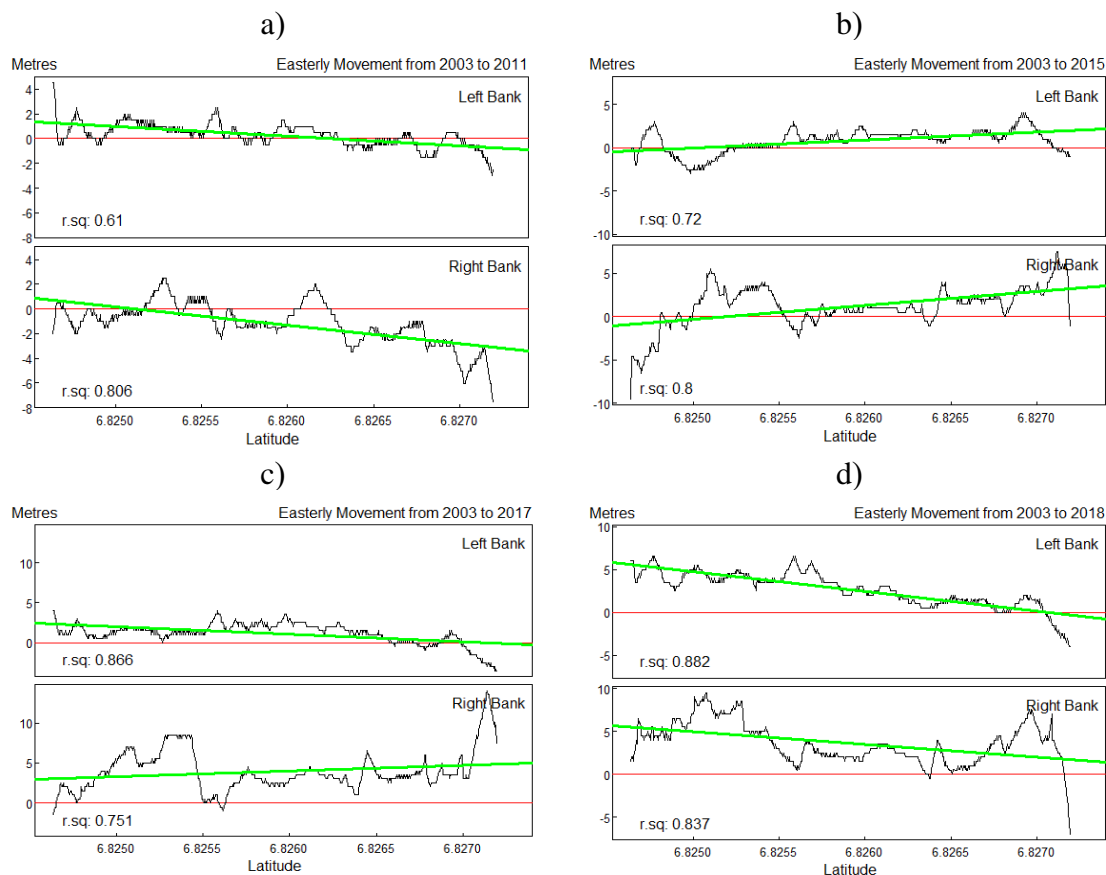
Figure 3.4 Easterly movement of Thepha river banks in linear model

Figure 3.4 shows easterly movement of river bank line from east to west of Thepha river with the negative fitted line from 2003 to 2011 and 2003 to 2018. The difference of comparing in meters (y axis) compared by latitude points (x axis). The changed of 2003 to 2015 and 2017 for both river banks were positive. The river sides were shifting from west to east. he green line that is farther from the red line explains that there was a change at that latitude. If slope of line more than zero it will shift the river form east to west, if slope of both of line less than zero it will shift the river from west to east. Figure 3.4 (a); left bank was erosion before latitude 6.826 and after that point were deposition, in right bank were deposition before latitude 6.825 and after that point were erosion. Figure 3.4 (b); it has an intersection of zero around latitude 6.825 in both banks and a slope greater than zero in both banks too. The meaning of the left bank after latitude

6.825 is erosion, and the meaning of the right bank after latitude 6.825 is deposition. However, when the distance between the comparative years is increased, we will see more changes. Figure 3.4 shows the bank line of the river shifting from east to west along both banks.

The natural changes of the river are not obvious in nature. Some areas could be erosion or deposition, and the changing of the left bank and right bank are not the same. Next, we use a cubic spline to investigate the pattern of the change of both the right and left banks of the river.

3.4 Cubic spline

Suitable number of knots (Equation 2.5) for smoothing the spline curve would result in summarize the results of bank line changing in each latitude.
For this research, we used spline 12 knots because it is a suitable number for dividing both of the river line spline from the beginning location to the end

a)   b)

c)   d)
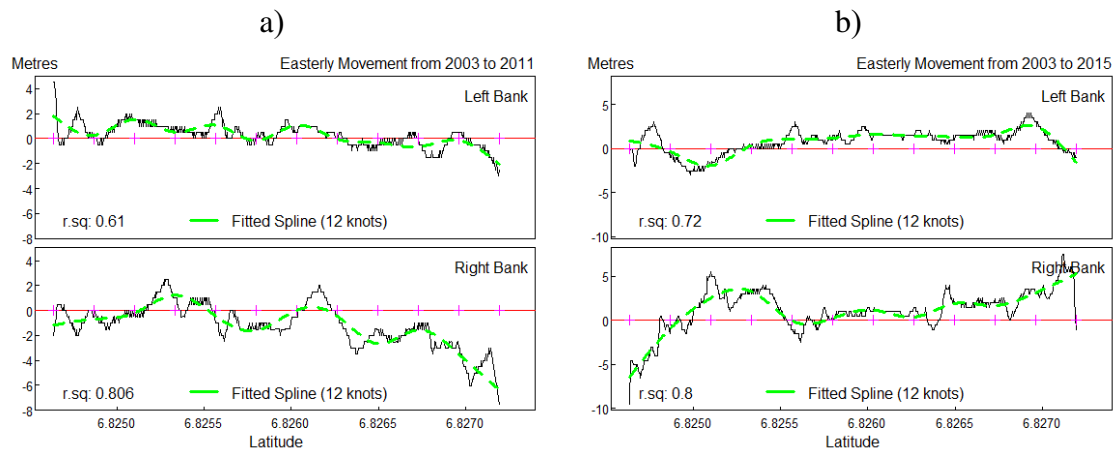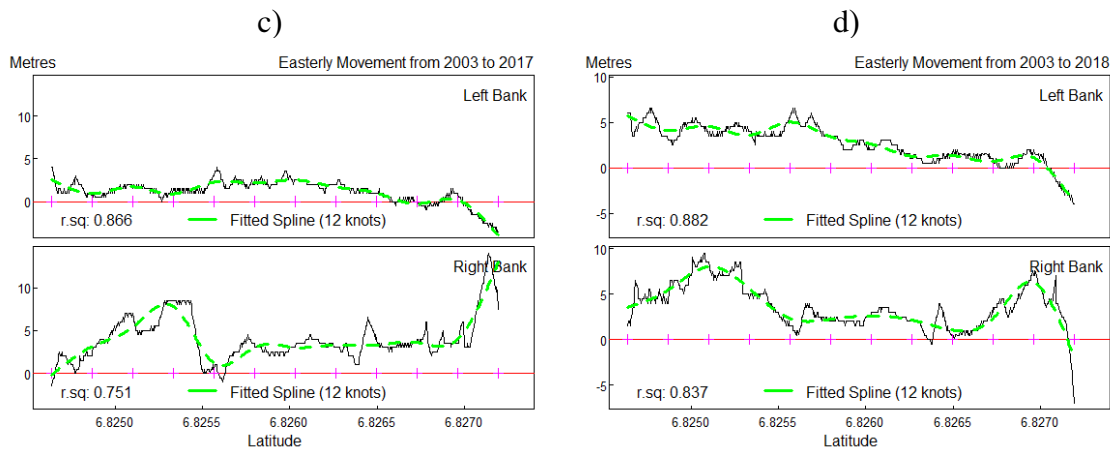
Figure 3.5 Easterly movement of Thepha river banks

From the results, we have seen that the Thepha river has changed from 2003 until 2018 from the statistical examination. This solution compares changes from several years to confirm the change. It consists of 2003-2011, 2003-2015, 2003-2017, and 2003-2018. Changes from 2003-2018 have a distance of many years when compared to 2003-2011. Figure 3.6 added a note to this section to consider the change as followed.
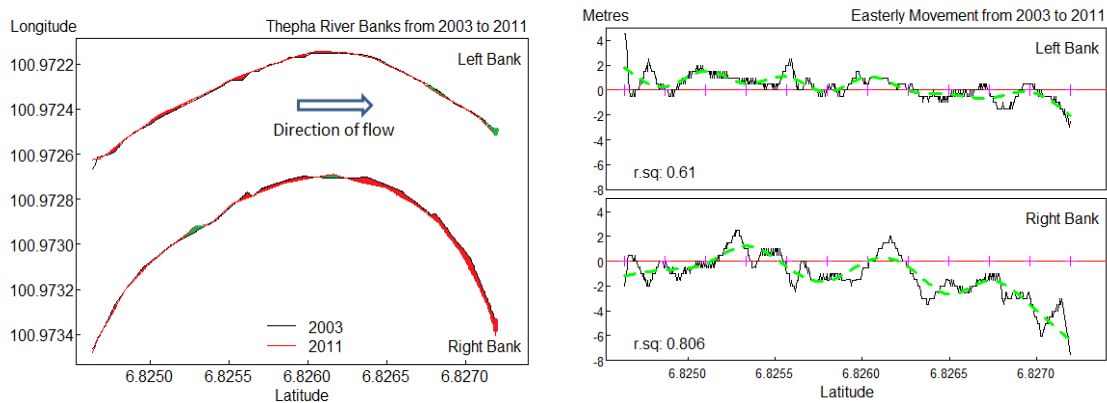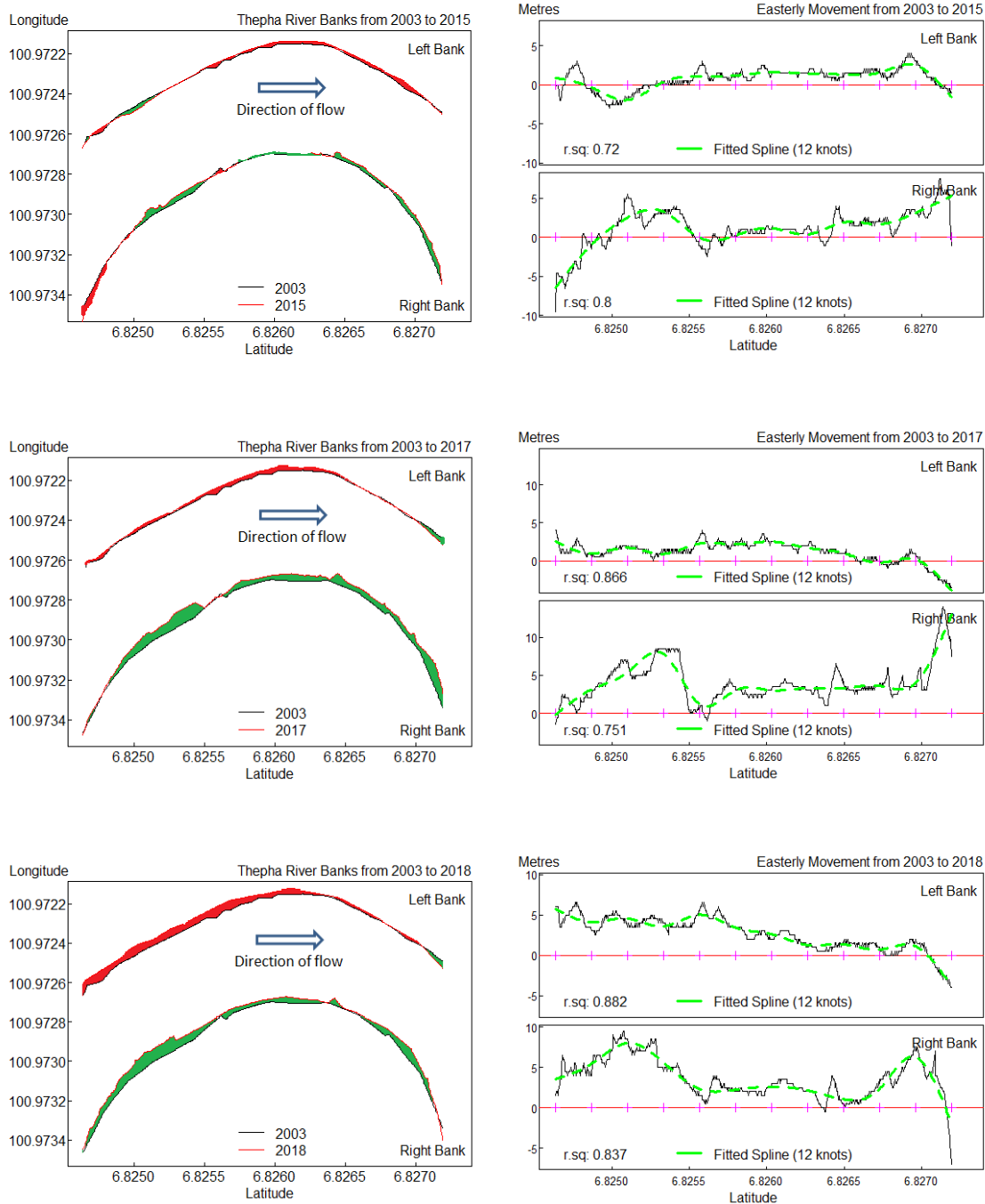
Figure 3.6 Easterly movement of Thepha river banks in each year

The figure 3.6 explained that changing of river in each year which images they are 8 pairs. In the case of natural river erosion at the left bank or right, the results are not the

same when compared with the easterly movement graph (right of figure 3.6). For left bank when the spline less than zero that mean is deposition but in the opposite; when the spline more than zero that mean is erosion.

The Thepha river bank from 2003 to 2011 (top figure) was eroded on both the left and right bank. There were some places where sediment was deposited, but there was little sediment deposited. Most of the areas experiencing erosion are after 6.806 latitude until the end of this study area. This erosion might be contrary to general erosion when comparing to other years. Thepha river bank from 2003 to 2015, 2003 to 2017 and 2003 to 2018 have erosion especially 2003 to 2018. The results shown that the river bank line had moved from east to west both left and right banks. In left bank had eroded and right bank had deposited.

Figure 3.7 Erosion from 2003 to 2018

Figure 3.7 explains that from 2003 to 2018, the left bank was eroded, with the highest being around 3 meters, and this is longitudinal from 6.825 latitude until 6.8265, a distance of approximately 15 meters. On the right bank, approximately 7 meters were deposited, starting from the beginning longitude point until 6.8255 latitude. From 2003 to 2018, this point did not change.

Chapter 4

Conclusion and Discussion

This chapter described the conclusion and discussion limitations, suggestions for future studies.

4.1 Conclusion and discussion

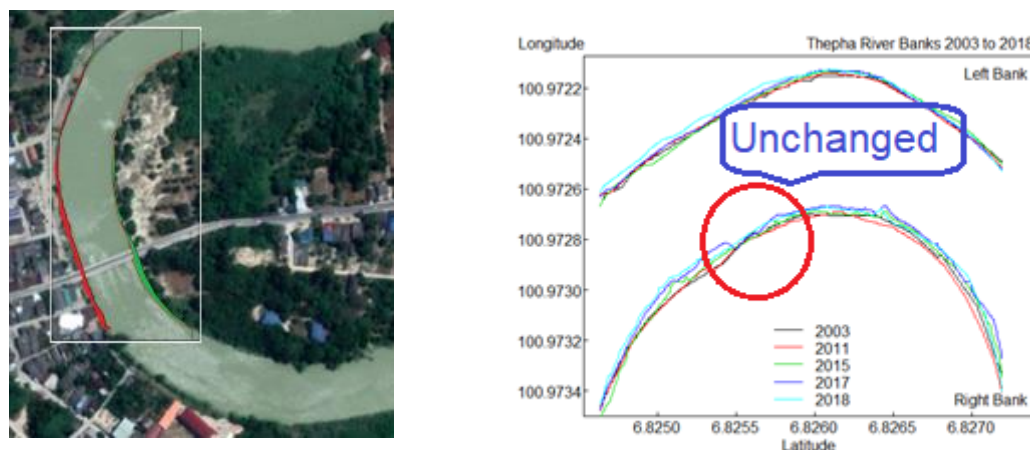This study investigated the change of the Thepa river using the data from satellite images of Google Earth by conversing into digital data. The river has changed from 2003 to 2018, where the left bank was eroded and the right bank was deposited. The changing river bank showed most of the areas of brae erosion or deposition. The curve of the river bank has different changes in different areas. Most of the area of the left bank was eroded, and most of the area of the right bank was deposited. Some points without erosion resulted in there being no change in that area. In this study area, the river left bank already has a sieve of stone to prevent erosion but most of the stone grate is decayed. The rocks were partially moved away by the water flow and there may be some that are not eroded from 2003 to 2018.

This may be caused by tree roots in the area because throughout the river on the right bank, at some points, there are trees along the banks. The river banks with tree are a factor that affects erosion (Duro *et al*., 2020). The plants or biofilm could be saved from the disappearance of the soil (Duro *et al*., 2020). These might be erosion prevention guidelines. The left bank of the study area used to have a stone grate, but the grate has decayed, and most of the rocks were blown away by the water flow. Only a few stones were left on the banks of the river.

The heavy erosion areas are the areas most affected by water flow and that combined with sediment intensity. This intense sediment effectiveness change in the river (Guo *et al.,* 2020; Rabbi *et al.,* 2013). Water movement and water flow in rivers affect sediment transport (Nasrollahi *et al*., 2020; Zhang *et al*., 2020), and the opposite will cause

deposition. The cause of erosion is also due to the sloping soil profile depth with the watershed soils (Achasov, 2019). The slope of river banks affects the erosion rate (Kheiralla *et al*., 2015). In the study area; most of the location was a slope of sand in both banks. These might be caused by change as well.

The direction of flow from west to north can be discussed curve of the river having erosion cause. The direction of flow affects erosion as well. If that eroded in the river bank, on the opposite side of the bank will deposition (Joan *et al*., 2008; Sainath *et al*., 2012). The left bank of the river was eroded by water flow. The sediment had moved by water from the left bank to the right bank. Deposited sediment of the right bank might be sediment transportation from other areas. Erosion or deposition will depend on the context of the curvature of the river. The curve of water flows affects the crash of the river bank. The point that crashing river flow is the erosion point and the point that does not collide is the deposition point. The result; left bank was erosion and sediment transport from left to deposition in the right bank. However; this shows that Thepha river from latitude around 6.825 to 6.827 had moved from east to west.

4.2 Limitations and suggestions

This study used a small area of the Thepha River located in the community. Further study could investigate the bigger area and include all the natural circumstances of the area, such as planting areas and fishing areas.

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Appendix (1)

CERTIFICATE

— OF PARTICIPATION —

Institute for Scientific and Engineering Research

International Conference on Mathematics and Statistics (ICMS-21)

28th January 2021, Phuket, Thailand

This is to certify that **Marushme Awang**

of Prince of songkla university, Thailand has done his/her excellence in presenting the

research paper titled "Statistical Modeling for River Flow and Bank Erosion"

on 28th January 2021 at Phuket, Thailand.

Dr. Chi-Yuang San
Director

George Mathew
Program Manager

Statistical Modeling for River Flow and Bank Erosion

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Abstract— River erosion is a critical process which cause a lot of terrain changes and affect people who live on the river or live in nearby the river areas. This study analyzed the erosion pattern of Thepha river in year 2003, 2011, 2015, 2017 and 2018. The data obtained from satellite image in Google Earth covering latitude 6.824138o-6.827198o N and longitude 100.972019o-100.973211o E of 570 points along each bank. Linear regression model was used to investigate the trend of change compare to 2003 for left and right bank. The results show that there is movement of river bank line to west.

Index Terms— Erosion, Deposition, Satellite image, linear regression, latitude and longitude

I. INTRODUCTION

Erosion is a critical process for land and watershed managers to understand, as sediment is the world's leading surface water pollutant[1]. Excessive erosion results in significant topsoil losses, leading to declines in agricultural productivity[2] and water erosion is an erosion that can affect geographic changes. Water erosion is the detachment and removal of soil material from water[3,4]. The process may be natural or accelerated by human activity. The rate of erosion may be slow to rapid, depending on the soil, the local landscape, and weather conditions. Soil erosion can occur in many ways, water, rainfall or river and all this cause can produce a change of topography[5,6]. Erosion that can cause a lot of terrain changes and affect people who live on the river or live in nearby the river areas is river erosion [7].

River erosion is a naturally occurring process that effects of river shape [8]. In agricultural field, river erosion refers to the disappearance of a field's topsoil by the physical forces of water. River erosion can be a slow process that continues relatively unnoticed or can occur at an alarming rate, causing serious loss of topsoil. The condition of erosion continues shifting of river course and erosion introduce vulnerable conditions on physical as well as social environment[9,10]. Overall the condition of the erosion victims is very poor and challenging. Erosion causes changes in the topography and the landscape will certainly have an effect. Erosion may occur over a long period of time. Hence, there should be warning or information for preventing damage that may occur in the future.

Several studies investigate the river erosion rates based on satellite image. The data was converted from image into digital data using image processing technique by reading color shaded values of red, green and blue (RGB)[11,12]. In this study, we read satellite image from Google Earth of Thepha River in Songkhla province, Thailand in year 2003, 2011, 2015, 2017 and 2018, and converts the image to numerical data, and investigate the erosion rate of the river using statistical modeling.

II. STUDY AREA

The area study is Thepha River in Songkhla province, southern Thailand as shown in figure 1
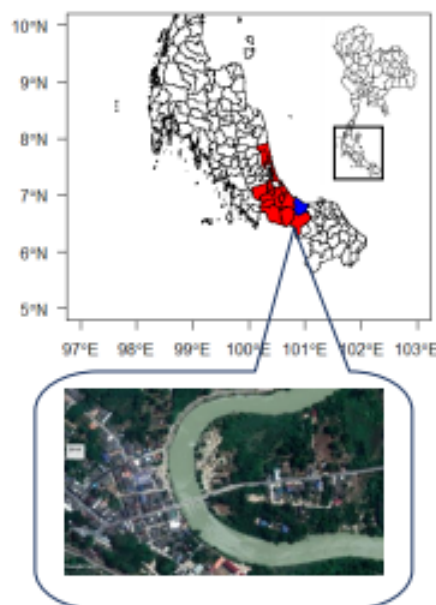

Figure 1: Study area

Statistical Modeling for River Flow and Bank Erosion

Figure 1, red color is Songkhla province, blue color is Thepha subdistrict in Songkhla province where the communities live on the river bank which is the turn of river flow and risk of erosion area. The selected area covers latitude 6.824138°-6.827198° N and longitude 100.972019°-100.973211° E. The total area of the image covers 350×570 pixels.

III. DATA ACQUISITION

We recorded satellite images of Thepa river from google earth of year 2003, 2011, 2015, 2017 and 2018 with certain date of satellite photo. There are 27th May 2003, 3rd September 2011, 23th March 2015, 14th March 2017 and 21th April 2018. Then the satellite images were distinguished between river and land using incorporation of three colors, red, green and blue (RGB) before analysis. RGB colors often appear brighter and more vivid specifically because the light is being projected directly into the eyes of the viewer [12]. Red, green and blue are three primary additive colors: each color normally ranges from 0 to 255 that is R= {0, 1, 2 ..... 255}, G= {0, 1, 2 ..... 255} and B= {0, 1, 2 ..... 255}[13]. Appertain extraction of RGB color; an RGB image is a blend of three different color layer (red, green and blue). The algorithm to read the images and convert it to numerical data when the program found the red color follows the formula (1)

$$p = \sqrt{(255-r)^2 + (0-g)^2 + (0-b)^2} \quad (1)$$

where, p is shades value, r is red color value, g is green color value and b is blue color value.

IV. METHODOLOGY

First we investigate the change of river in year 2011, 2015, 2017 and 2018 compared to year 2003 by taking the difference using pair t-test. Then using linear regression model to see the trend of the change. The model takes the form

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + K + \beta_n x_n + \varepsilon \quad (2)$$

where y is dependent variable, x_i are independent variable, β_i are parameter and ε is error.

All analyses and graphical displays were carried out using R (R Core Team, 2018).

V. RESULTS

The data was plot to show each river banks in year 2003, 2011, 2015, 2017 and 2018 in figure 2.
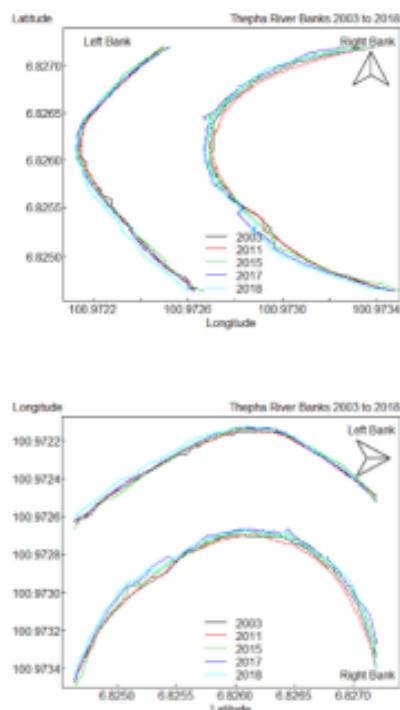
Figure 2. Thepha river banks of each years

Figure 2(top panel), both river banks have shown no direction change which cause erosion and deposition. To observe the changing of river banks more clearly we rotated the direction with 90 degree to the right. From the north to the east pointing up to observed erosion that has eastward direction Figure 2 (bottom panel).

Next we plot the river changing of each year compared to 2003 separately as shown in figure 3.
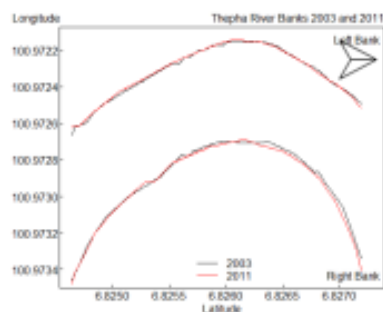
Statistical Modeling for River Flow and Bank Erosion
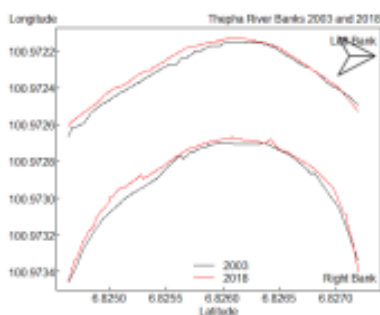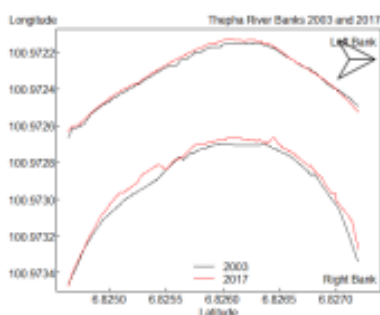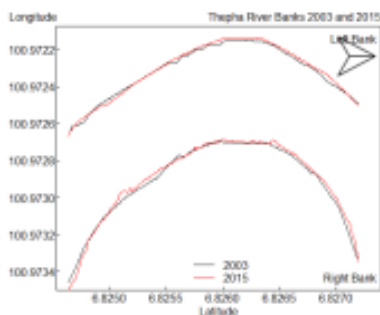
Figure 3. Thapa river changes compare to 2003

Figure 3 shown that the river bank lines in 2017 and 2018 are clearly difference from 2003 especially the right bank. Next we takes the difference of each year with 2003 and analyzed the changes using pair t-test. The results are shown in Figure 4.
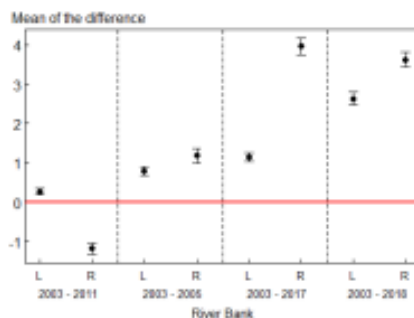
Figure 4. 95% confidence interval of the difference

Figure 4 shows that mean of the difference of distance that was shifting of river lines, the red line of graph is the comparison of year that does not difference. In this graph showed that the river border comparison of every year difference either on the left and right sides.
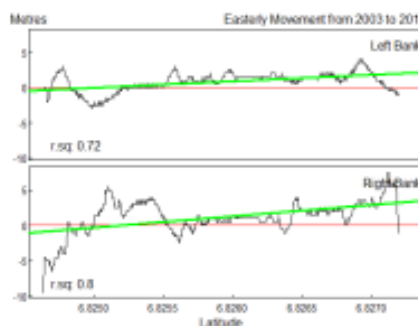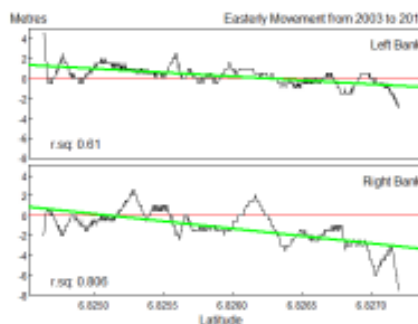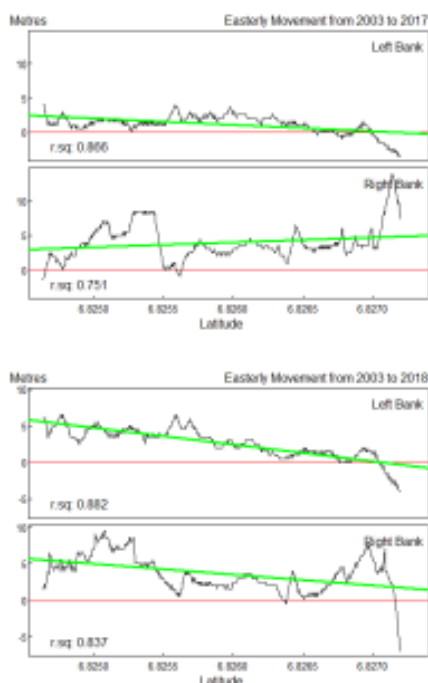
Figure 5. easterly movement of Thepha river banks

Figure 5 showed easterly movement of river bank line from east to west of Thepha river with the negative fitted line from 2003 to 2011 and 2003 to 2018. The changed of 2003 to 2015 and 2017 for both river banks were positive. The river sides were shifting from west to east.

VI. CONCLUSION AND LIMITATION

The results of this research indicate that both of river sides were moved to west. There was erosion on the left bank and deposition of the right bank. The changes of the river were fluctuated; the spline model should be used for further investigation. It will be more informative to analyze the higher resolution of the satellite image.

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Appendix (2)

Algorithm for converting from image into digital data

In the methods of converting from satellite image into digital data were used Lazarus program. For this study was used object-oriented programming principles (OOP) which included multiple functions for processing. In this article discusses some of the important command in Lazarus as follows.

New color plot for research areas

```
For j := 1 to number of image height grids do
      For i :=1 to number of image width grids do
            if delta[i+x0,j+y0]=0 then
                  if diff[prev,i,j]<>0 then
                        image1.Picture.Bitmap.Canvas.Pixels[i+x0,j+y0]:=clgreen;
                  else
                        image1.Picture.Bitmap.Canvas.Pixels[i+x0,j+y0]:=clHighlight;
                  end;
            end;
      end;
```

Set value for water and soil

```
p := 100;

wim :=image1.Picture.Bitmap.Width;

him:=image1.Picture.Bitmap.Height;

delta:=nil;

setlength(delta,wim,him);

strdata :='i j';

for j:=0 to number of image height grids-1 do

begin

        for i:=0 to number of image width grids-1 do

     begin

                r:=red(image1.Picture.Bitmap.Canvas.Pixels[i,j]);

                g:=green(image1.Picture.Bitmap.Canvas.Pixels[i,j]);

        b:=blue(image1.Picture.Bitmap.Canvas.Pixels[i,j]);

                if sqrt(power(255-r,2)+power(255-g,2)+power(0-b,2))<=p then

                     strdata:=strdata+inttostr(i)+' '+inttostr(j);

          end;

         end;

   end;
```

Set left bank and right bank of river

```
for j:=y0 to number of image height grids-1 do
begin
     for i:=x0 to number of image width grids-1 do
     begin
          r:=red(image1.Picture.Bitmap.Canvas.Pixels[i,j]);

          g:=green(image1.Picture.Bitmap.Canvas.Pixels[i,j]);

         b:=blue(image1.Picture.Bitmap.Canvas.Pixels[i,j]);

         if sqrt(power(255-r,2)+power(0-g,2)+power(0-b,2))<=p then

          begin

               delta[i,j]:=1; garea[i,j]:=3;

               image1.Picture.Bitmap.Canvas.Pixels[i,j]:=clblue;

           end else
          begin

               delta[i,j]:=0; garea[i,j]:=2;

               image1.Picture.Bitmap.Canvas.Pixels[i,j]:=clOlive;

           end;
     end;
 end;
```

Digest water and ground and set new value for ground

```
for j:=y0 to number of image height grids-1 do
begin
    for i:=x0 to number of image width grids-1 do
    begin
                image1.Picture.Bitmap.Canvas.Pixels[i,j]:=clGray;
                if ( delta[i,j]=1 )then break;
            garea[i,j]:=1;
        end;
end;
for j:=y0 to number of image height grids-1 do
begin
    for i:=x0 to number of image width grids-1 do
    begin
                bleft[i,j]:=0;
                bright[i,j]:=0;
        end;
end;
```

Digest ground left area and right area from river and set value

```
for j:=y0 to number of image height grids-1 do
begin
    for i:=x0 to number of image width grids-1 do
    begin
            if garea[i,j]<>1 then
             begin
                 bleft[i,j]:=i; break;
           end;
       end;
end;
for j:=y0 to number of image height grids-1 do
begin
    for i:=x0 to number of image width grids-1 do
    begin
               if garea[i,j]<>2 then
               begin
               bright[i,j]:=i;
               ji[j]:=i; break;
           end;
    end;
```

Appendix (3)

Command in r

This research was used r program for analyze easterly movement of Thepha river banks to finding the models of this study, conclusion of models and so on. The command in r comprise of 4 parts are set the data, river matching Google Earth of Thepha river banks, easterly increase in bank location and summary the results as follows.

Set the data

```
#Read file
setwd("C:\\Users\\ac\\Documents\\editing\\ThesisResearch\\datav4")
dd03<-read.csv("d2003.csv",sep=",",header=T)
dd11<-read.csv("d2011.csv",sep=",",header=T)
dd15<-read.csv("d2015.csv",sep=",",header=T)
dd17<-read.csv("d2017.csv",sep=",",header=T)
dd18<-read.csv("d2018.csv",sep=",",header=T)
#---------------------------------------------end---------------------------------------------
library(nlme)
library(epiDisplay)
#Subset only left bank line
ddL03<-subset(dd03,dd03$bleft>0)
ddnL03<-ddL03[,c(3:7)]
ddL11<-subset(dd11,dd11$bleft>0)
ddnL11<-ddL11[,c(3:7)]
ddL15<-subset(dd15,dd15$bleft>0)
ddnL15<-ddL15[,c(3:7)]
ddL17<-subset(dd17,dd17$bleft>0)
ddnL17<-ddL17[,c(3:7)]
ddL18<-subset(dd18,dd18$bleft>0)
ddnL18<-ddL18[,c(3:7)]
#---------------------------------------------end---------------------------------------------
```

```
#Subset only left bank line

ddR03<-subset(dd03,dd03$bright>0)

ddnR03<-ddR03[,c(3:7)]

ddnR03$id<-seq(1:570)

ddR11<-subset(dd11,dd11$bright>0)

ddnR11<-ddR11[,c(3:7)]

ddnR11$id<-seq(1:570)

ddR15<-subset(dd15,dd15$bright>0)

ddnR15<-ddR15[,c(3:7)]

ddnR15$id<-seq(1:570)

ddR17<-subset(dd17,dd17$bright>0)

ddnR17<-ddR17[,c(3:7)]

ddnR17$id<-seq(1:570)

ddR18<-subset(dd18,dd18$bright>0)

ddnR18<-ddR18[,c(3:7)]

ddnR18$id<-seq(1:570)

#-----------------------------------------------end-----------------------------------------------

#Merge column of left and right banks into 1 file

nams <- c("xL","yL","ngrid","latL","lonL","xR","yR","ngridR","latR","lonR")

ddn03<-cbind(ddnL03,ddnR03)

names(ddn03)[1:10] <- nams

ddn03$yr <- 2003

ddn11<-cbind(ddnL11,ddnR11)

names(ddn11)[1:10] <- nams

ddn11$yr <- 2011

ddn15<-cbind(ddnL15,ddnR15)

names(ddn15)[1:10] <- nams

ddn15$yr <- 2015

ddn17<-cbind(ddnL17,ddnR17)

names(ddn17)[1:10] <- nams
```

```
ddn17$yr <- 2017

ddn18<-cbind(ddnL18,ddnR18)

names(ddn18)[1:10] <- nams

ddn18$yr <- 2018
```

#---end---

```
#Merge row of year into 1 file
dAll <- rbind(ddn03,ddn11,ddn15,ddn17,ddn18)
```

#---end---

```
#Change variable
d1 <- subset(dAll,yr==2003)

d2 <- subset(dAll,yr==2011)

d3 <- subset(dAll,yr==2015)

d4 <- subset(dAll,yr==2017)

d5 <- subset(dAll,yr==2018)
```

#---end---

```
#Set lat and long to meters using to summary the model
d1$latL<-110396.22*(d1$latL-d1$latL[1])

d1$latR<-110396.22*(d1$latR-d1$latR[1])

d2$latL<-110396.22*(d2$latL-d2$latL[1])

d2$latR<-110396.22*(d2$latR-d2$latR[1])

d3$latL<-110396.22*(d3$latL-d3$latL[1])

d3$latR<-110396.22*(d3$latR-d3$latR[1])

d4$latL<-110396.22*(d4$latL-d4$latL[1])

d4$latR<-110396.22*(d4$latR-d4$latR[1])

d5$latL<-110396.22*(d5$latL-d5$latL[1])

d5$latR<-110396.22*(d5$latR-d5$latR[1])
```

#---end---

River matching Google Earth of Thepha river banks

```
# Figure; River matching Google Earth map in of Thepha River Banks: 2003

windows(8,10)
```

```r
par(las=1,oma=c(0,0,0,0),mar=c(3,3.5,2.5,1),mgp=c(1.1,0.1,0),tcl=0.2)

xlm <- c(min(d1$lonL,d2$lonL),max(d1$lonR,d2$lonR))

ylm <- c(min(d1$latL,d2$latL),max(d1$latR,d2$latR)+0.0001)

plot(d1$lonR,d1$latR[570:1],type="l",xlim=xlm,ylim=ylm,xlab="Longitude",ylab="")

mtext(side=3,line=0.2,adj=-0.18,"Latitude")

mtext(side=3,line=0.2,adj=1,"Thepha River Banks: 2003")

points(d1$lonL,d1$latL[570:1],type="l")

legend("topleft",bty="n",leg="Left Bank")

legend("topright",bty="n",leg="Right Bank")

#--------------------------------------------------end--------------------------------------------------

# Figure; River matching Google Earth map in of Thepha River Banks: 2011

windows(8,10)

par(las=1,oma=c(0,0,0,0),mar=c(3,3.5,2.5,1),mgp=c(1.1,0.1,0),tcl=0.2)

xlm <- c(min(d1$lonL,d2$lonL),max(d1$lonR,d2$lonR))

ylm <- c(min(d1$latL,d2$latL),max(d1$latR,d2$latR)+0.0001)

plot(d1$lonR,d1$latR[570:1],type="l",xlim=xlm,ylim=ylm,xlab="Longitude",ylab="")

mtext(side=3,line=0.2,adj=-0.18,"Latitude")

mtext(side=3,line=0.2,adj=1,"Thepha River Banks: 2011")

points(d1$lonL,d1$latL[570:1],type="l")

legend("topleft",bty="n",leg="Left Bank")

legend("topright",bty="n",leg="Right Bank")

#--------------------------------------------------end--------------------------------------------------

# Figure; River matching Google Earth map in of Thepha River Banks: 2015

windows(7,10)

par(las=1,oma=c(0,0,0,0),mar=c(3,3.5,2.5,1),mgp=c(1.1,0.1,0),tcl=0.2)

xlm <- c(min(d3$lonL,d3$lonL),max(d3$lonR,d3$lonR))

ylm <- c(min(d3$latL,d3$latL),max(d3$latR,d3$latR)+0.0001)

plot(d3$lonR,d3$latR[570:1],type="l",xlim=xlm,ylim=ylm,xlab="Longitude",ylab="")

mtext(side=3,line=0.2,adj=-0.1,"Latitude")

mtext(side=3,line=0.2,adj=1,"Thepha River Banks: 2015")
```

```
points(d3$lonL,d3$latL[570:1],type="l")

legend("topleft",bty="n",leg="Left Bank")

legend("topright",bty="n",leg="Right Bank")

#-----------------------------------------------end-----------------------------------------------

# Figure; River matching Google Earth map in of Thepha River Banks: 2017

windows(7,10)

par(las=1,oma=c(0,0,0,0),mar=c(3,3.5,2.5,1),mgp=c(1.1,0.1,0),tcl=0.2)

xlm <- c(min(d4$lonL,d4$lonL),max(d4$lonR,d4$lonR))

ylm <- c(min(d4$latL,d4$latL),max(d4$latR,d4$latR)+0.0001)

plot(d4$lonR,d4$latR[570:1],type="l",xlim=xlm,ylim=ylm,xlab="Longitude",ylab="")

mtext(side=3,line=0.2,adj=-0.1,"Latitude")

mtext(side=3,line=0.2,adj=1,"Thepha River Banks: 2017")

points(d4$lonL,d4$latL[570:1],type="l")

legend("topleft",bty="n",leg="Left Bank")

legend("topright",bty="n",leg="Right Bank")

#-----------------------------------------------end-----------------------------------------------

# Figure; River matching Google Earth map in of Thepha River Banks: 2018

windows(7,10)

par(las=1,oma=c(0,0,0,0),mar=c(3,3.5,2.5,1),mgp=c(1.1,0.1,0),tcl=0.2)

xlm <- c(min(d5$lonL,d5$lonL),max(d5$lonR,d5$lonR))

ylm <- c(min(d5$latL,d5$latL),max(d5$latR,d5$latR)+0.0001)

plot(d5$lonR,d5$latR[570:1],type="l",xlim=xlm,ylim=ylm,xlab="Longitude",ylab="")

mtext(side=3,line=0.2,adj=-0.1,"Latitude")

mtext(side=3,line=0.2,adj=1,"Thepha River Banks: 2018")

points(d5$lonL,d5$latL[570:1],type="l")

legend("topleft",bty="n",leg="Left Bank")

legend("topright",bty="n",leg="Right Bank")

#-----------------------------------------------end-----------------------------------------------

# Figure; All riverside each year

windows(5,4)
```

```
par(las=1,oma=c(0,0,0,0),mar=c(3,4.5,2.5,1),mgp=c(1.1,0.1,0),tcl=0.2)

plot(d1$lonL,d1$latL[570:1],type="l",xlim=xlm,ylim=ylm,xlab="Longitude",ylab="")

mtext(side=3,line=0.2,adj=-0.17,"Latitude")

mtext(side=3,line=0.2,adj=1,"Thepha River Banks 2003 to 2018")

points(d1$lonR,d1$latR[570:1],type="l")

legend("topleft",bty="n",leg="Left Bank")

legend("topright",bty="n",leg="Right Bank")

points(d2$lonL,d2$latL[570:1],type="l",col=2)

points(d2$lonR,d2$latR[570:1],type="l",col=2)

points(d3$lonL,d3$latL[570:1],type="l",col=3)

points(d3$lonR,d3$latR[570:1],type="l",col=3)

points(d4$lonL,d4$latL[570:1],type="l",col=4)

points(d4$lonR,d4$latR[570:1],type="l",col=4)

points(d5$lonL,d5$latL[570:1],type="l",col=5)

points(d5$lonR,d5$latR[570:1],type="l",col=5)

legend("bottom",bty="n",lwd=1,col=c(1,2,3,4,5),leg=c(2003,2011,2015,2017,2018))

#--------------------------------------------------end--------------------------------------------------

# Figure; All riverside each year rotated by 90 degrees

windows(5,4)

par(las=1,oma=c(0,0,0,0),mar=c(3,4.5,2.5,1),mgp=c(1.1,0.1,0),tcl=0.2)

plot(d1$latL,d1$lonL[570:1],ylim=xlm[c(2,1)],xlim=ylm,type="l",xlab="Latitude",ylab="")

mtext(side=3,line=0.2,adj=-0.17,"Longitude")

mtext(side=3,line=0.2,adj=1,"Thepha River Banks 2003 to 2018")

points(d1$latR,d1$lonR[570:1],type="l")

legend("topright",bty="n",leg="Left Bank")

legend("bottomright",bty="n",leg="Right Bank")

points(d2$latL,d2$lonL[570:1],type="l",col=2)

points(d2$latR,d2$lonR[570:1],type="l",col=2)

points(d3$latL,d3$lonL[570:1],type="l",col=3)

points(d3$latR,d3$lonR[570:1],type="l",col=3)
```

```r
points(d4$latL,d4$lonL[570:1],type="l",col=4)

points(d4$latR,d4$lonR[570:1],type="l",col=4)

points(d5$latL,d5$lonL[570:1],type="l",col=5)

points(d5$latR,d5$lonR[570:1],type="l",col=5)

legend("bottom",bty="n",lwd=1,col=c(1,2,3,4,5),leg=c(2003,2011,2015,2017,2018))

#----------------------------------------------end----------------------------------------------

# Figure; comparison between 2003 and 2011 rotated by 90 degrees
windows(5,4)

par(las=1,oma=c(0,0,0,0),mar=c(3,4.5,2.5,1),mgp=c(1.1,0.1,0),tcl=0.2)

plot(d1$latL,d1$lonL[570:1],ylim=xlm[c(2,1)],xlim=ylm,type="l",xlab="Latitude",ylab="")

mtext(side=3,line=0.2,adj=-0.17,"Longitude")

mtext(side=3,line=0.2,adj=1,"Thepha River Banks 2003 and 2011")

points(d1$latR,d1$lonR[570:1],type="l")

legend("topright",bty="n",leg="Left Bank")

legend("bottomright",bty="n",leg="Right Bank")

points(d2$latL,d2$lonL[570:1],type="l",col=2)

points(d2$latR,d2$lonR[570:1],type="l",col=2)

legend("bottom",bty="n",lwd=1,col=c(1,2),leg=c(2003,2011))

#----------------------------------------------end----------------------------------------------

# Figure; comparison between 2003 and 2015 rotated by 90 degrees
windows(5,4)

par(las=1,oma=c(0,0,0,0),mar=c(3,4.5,2.5,1),mgp=c(1.1,0.1,0),tcl=0.2)

plot(d1$latL,d1$lonL[570:1],ylim=xlm[c(2,1)],xlim=ylm,type="l",xlab="Latitude",ylab="")

mtext(side=3,line=0.2,adj=-0.17,"Longitude")

mtext(side=3,line=0.2,adj=1,"Thepha River Banks 2003 and 2015")

points(d1$latR,d1$lonR[570:1],type="l")

legend("topright",bty="n",leg="Left Bank")

legend("bottomright",bty="n",leg="Right Bank")

points(d3$latL,d3$lonL[570:1],type="l",col=2)

points(d3$latR,d3$lonR[570:1],type="l",col=2)
```

```
legend("bottom",bty="n",lwd=1,col=c(1,2),leg=c(2003,2015))

#------------------------------------------------end------------------------------------------------

# Figure; comparison between 2003 and 2017 rotated by 90 degrees

windows(5,4)

par(las=1,oma=c(0,0,0,0),mar=c(3,4.5,2.5,1),mgp=c(1.1,0.1,0),tcl=0.2)

plot(d1$latL,d1$lonL[570:1],ylim=xlm[c(2,1)],xlim=ylm,type="l",xlab="Latitude",ylab="")

mtext(side=3,line=0.2,adj=-0.17,"Longitude")

mtext(side=3,line=0.2,adj=1,"Thepha River Banks 2003 and 2017")

points(d1$latR,d1$lonR[570:1],type="l")

legend("topright",bty="n",leg="Left Bank")

legend("bottomright",bty="n",leg="Right Bank")

points(d4$latL,d4$lonL[570:1],type="l",col=2)

points(d4$latR,d4$lonR[570:1],type="l",col=2)

legend("bottom",bty="n",lwd=1,col=c(1,2),leg=c(2003,2017))

#------------------------------------------------end------------------------------------------------

# Figure; comparison between 2003 and 2018 rotated by 90 degrees

windows(5,4)

par(las=1,oma=c(0,0,0,0),mar=c(3,4.5,2.5,1),mgp=c(1.1,0.1,0),tcl=0.2)

plot(d1$latL,d1$lonL[570:1],ylim=xlm[c(2,1)],xlim=ylm,type="l",xlab="Latitude",ylab="")

mtext(side=3,line=0.2,adj=-0.17,"Longitude")

mtext(side=3,line=0.2,adj=1,"Thepha River Banks 2003 and 2018")

points(d1$latR,d1$lonR[570:1],type="l")

legend("topright",bty="n",leg="Left Bank")

legend("bottomright",bty="n",leg="Right Bank")

points(d5$latL,d5$lonL[570:1],type="l",col=2)

points(d5$latR,d5$lonR[570:1],type="l",col=2)

legend("bottom",bty="n",lwd=1,col=c(1,2),leg=c(2003,2018))

#------------------------------------------------end------------------------------------------------
```

Easterly increase of bank location

```
# Figure; Easterly increases in bank locations: 2003-2011

windows(6,4.5)

par(mfrow=c(2,1),las=1,oma=c(2,2,2,1),mar=c(0.5,0,0,0),mgp=c(1.1,0.1,0),tcl=0.2)

d2.lonLInc <- 110396.22*(d1$lonL[570:1]-d2$lonL[570:1])

d2.lonRInc <- 110396.22*(d1$lonR[570:1]-d2$lonR[570:1])

ylm1 <- c(min(d2.lonLInc,d2.lonRInc),max(d2.lonLInc,d2.lonRInc))

plot(d1$latL,d2.lonLInc,type="n",xlim=ylm,ylim=ylm1,xaxt="n",xlab="",ylab="",cex.axis=0.8)

abline(h=0,col=2)

points(d1$latL,d2.lonLInc,type="l")

mtext(side=3,line=0.2,adj=-0.05,"Metres")

titl <- "Easterly Movement from 2003 to 2011"

mtext(side=3,line=0.2,adj=1,titl)

legend("topright",bty="n",leg="Left Bank")

# fit natural cubic spline to Easterly increases at successive latitudes

d1$lonLInc1 <- d2.lonLInc

str(d1)

yyl <- d1[,c(13,5)]                    # y and x coordinates

names(yyl) <- c("y","x")

x <- yyl$x

kn <- quantile(x,prob=c(0,0.5,1:29,29.5,30)/30)# 33 spline knots

kn <- quantile(x,prob=c(0:29)/29)      # 30 spline knots

kn <- quantile(x,prob=c(0:15)/15)      # 16 spline knots

p <- length(kn)

h <- kn[p]-kn[p-1]

for (j in c(1:(p-2))) {

  sj <- ifelse(x>kn[j],(x-kn[j])^3,0)

  sj <- sj-((kn[p]-kn[j])/h)*ifelse(x>kn[p-1],(x-kn[p-1])^3,0)

  sj <- sj+((kn[p-1]-kn[j])/h)*ifelse(x>kn[p],(x-kn[p])^3,0)

  yyl[,(j+2)] <- sj
```

```
  names(yyl)[j+2] <- paste("s",j,sep="")

}

mod1l <- lm(data=yyl,y~.)

rsq <- summary(mod1l)$adj.r.sq

fv <- mod1l$fitted.values

points(kn,0*kn,pch=3,col=6)

legend("bottomleft",bty="n",leg=paste("r.sq:",round(rsq,3)))

lg <- paste("Fitted Spline (",p," knots)",sep="")

legend("bottom",bty="n",leg=lg,lwd=3,col="green")

zzzl <- gls(y ~ ., data = yyl,corr = corAR1(0.95), method = "ML")

points(d1$latL,zzzl$fitted,type="l",col="green",lwd=3,lty="dashed")

#--------------Left bank---------------#

plot(d1$latR,d2.lonRInc,type="n",xlim=ylm,ylim=ylm1,xlab="Latitude",ylab="",cex.axis=0.8)

abline(h=0,col=2)

points(d1$latR,d2.lonRInc,type="l")

legend("topright",bty="n",leg="Right Bank")

at1 <- mean(d1$latL)

axis(outer=T,side=1,at=at1,lab="Latitude",padj=0.8,tcl=0)

d1$lonRInc1 <- d2.lonRInc

yyr <- d1[,c(14,5)]                    # y and x coordinates

names(yyr) <- c("y","x")

x <- yyr$x

for (j in c(1:(p-2))) {

  sj <- ifelse(x>kn[j],(x-kn[j])^3,0)

  sj <- sj-((kn[p]-kn[j])/h)*ifelse(x>kn[p-1],(x-kn[p-1])^3,0)

  sj <- sj+((kn[p-1]-kn[j])/h)*ifelse(x>kn[p],(x-kn[p])^3,0)

  yyr[,(j+2)] <- sj

  names(yyr)[j+2] <- paste("s",j,sep="")

}

mod1r <- lm(data=yyr,y~.)
```

```
rsq <- summary(mod1r)$adj.r.sq

fv <- mod1r$fitted.values

points(kn,0*kn,pch=3,col=6)

legend("bottomleft",bty="n",leg=paste("r.sq:",round(rsq,3)))

zzzr <- gls(y ~ ., data = yyr,corr = corAR1(0.95), method = "ML")

points(d1$latR,zzzr$fitted,type="l",col="green",lwd=3,lty="dashed")

#------------right bank-------------------------#

mod1l <- lm(data=yyl,y~.,corr = corAR1(0.95))

mod1r <- lm(data=yyr,y~.,corr = corAR1(0.95))

zl <- gls(y ~ ., data = yyl, method = "ML")

zr <- gls(y ~ ., data = yyr, method = "ML")

zzzl <- gls(y ~ ., data = yyl,corr = corAR1(0.95), method = "ML")

zzzr <- gls(y ~ ., data = yyr,corr = corAR1(0.95), method = "ML")


par(mfrow=c(2,1),las=1,oma=c(2,2,2,1),mar=c(0.5,0,0,0),mgp=c(1.1,0.1,0),tcl=0.2)

acf(residuals(zzzl,type = "n",xlim=ylm,ylim=ylm1,xaxt="n",xlab="",ylab="",cex.axis=0.8))

mtext(side=3,line=0.2,adj=-0.05,"ACF")

mtext(side=3,line=0.2,adj=1,"The correlations from 2003 to 2011")

legend("topright",bty="n",leg="Left Bank")

acf(residuals(zzzr,type = "n",xlim=ylm,ylim=ylm1,xlab="Latitude",ylab="",cex.axis=0.8))

legend("topright",bty="n",leg="Right Bank")

axis(outer=T,side=1,at=at1,lab="lag",padj=0.8,tcl=0)

summary(zl)

summary(zzzl)

summary(zr)

summary(zzzr)

anova(zl,zzzl)

anova(zr,zzzr)

#--------------------------------------------end-----------------------------------------------

# Figure; Easterly increases in bank locations: 2003-2018
```

```
par(mfrow=c(2,1),las=1,oma=c(2,2,2,1),mar=c(0.5,0,0,0),mgp=c(1.1,0.1,0),tcl=0.2)

d5.lonLInc <- 110396.22*(d1$lonL[570:1]-d5$lonL[570:1])

d5.lonRInc <- 110396.22*(d1$lonR[570:1]-d5$lonR[570:1])

ylm1 <- c(min(d5.lonLInc,d5.lonRInc),max(d5.lonLInc,d5.lonRInc))

plot(d1$latL,d5.lonLInc,type="n",xlim=ylm,ylim=ylm1,xaxt="n",xlab="",ylab="",cex.axis=0.8)

abline(h=0,col=2)

points(d1$latL,d5.lonLInc,type="l")

mtext(side=3,line=0.2,adj=-0.05,"Metres")

titl <- "Easterly Movement from 2003 to 2018"

mtext(side=3,line=0.2,adj=1,titl)

legend("topright",bty="n",leg="Left Bank")

# fit natural cubic spline to Easterly increases at successive latitudes

d1$lonLInc1 <- d5.lonLInc

str(d1)

yyl <- d1[,c(13,5)]                    # y and x coordinates

names(yyl) <- c("y","x")

x <- yyl$x

kn <- quantile(x,prob=c(0,0.5,1:29,29.5,30)/30)# 33 spline knots

kn <- quantile(x,prob=c(0:29)/29)      # 30 spline knots

kn <- quantile(x,prob=c(0:15)/15)      # 16 spline knots

p <- length(kn)

h <- kn[p]-kn[p-1]

for (j in c(1:(p-2))) {

  sj <- ifelse(x>kn[j],(x-kn[j])^3,0)

  sj <- sj-((kn[p]-kn[j])/h)*ifelse(x>kn[p-1],(x-kn[p-1])^3,0)

  sj <- sj+((kn[p-1]-kn[j])/h)*ifelse(x>kn[p],(x-kn[p])^3,0)

  yyl[,(j+2)] <- sj

  names(yyl)[j+2] <- paste("s",j,sep="")

}

mod1l <- lm(data=yyl,y~.)
```

```
rsq <- summary(mod1l)$adj.r.sq

fv <- mod1l$fitted.values

points(kn,0*kn,pch=3,col=6)

legend("bottomleft",bty="n",leg=paste("r.sq:",round(rsq,3)))

lg <- paste("Fitted Spline (",p," knots)",sep="")

legend("bottom",bty="n",leg=lg,lwd=3,col="green")

zzzl <- gls(y ~ ., data = yyl,corr = corAR1(0.95), method = "ML")

points(d1$latL,zzzl$fitted,type="l",col="green",lwd=3,lty="dashed")

#--------------Left bank---------------#

plot(d1$latR,d5.lonRInc,type="n",xlim=ylm,ylim=ylm1,xlab="Latitude",ylab="",cex.axis=0.8)

abline(h=0,col=2)

points(d1$latR,d5.lonRInc,type="l")

legend("topright",bty="n",leg="Right Bank")

at1 <- mean(d1$latL)

axis(outer=T,side=1,at=at1,lab="Latitude",padj=0.8,tcl=0)

d1$lonRInc1 <- d5.lonRInc

yyr <- d1[,c(14,5)]                     # y and x coordinates

names(yyr) <- c("y","x")

x <- yyr$x

for (j in c(1:(p-2))) {

  sj <- ifelse(x>kn[j],(x-kn[j])^3,0)

  sj <- sj-((kn[p]-kn[j])/h)*ifelse(x>kn[p-1],(x-kn[p-1])^3,0)

  sj <- sj+((kn[p-1]-kn[j])/h)*ifelse(x>kn[p],(x-kn[p])^3,0)

  yyr[,(j+2)] <- sj

  names(yyr)[j+2] <- paste("s",j,sep="")

}

mod1r <- lm(data=yyr,y~.)

rsq <- summary(mod1r)$adj.r.sq

fv <- mod1r$fitted.values

points(kn,0*kn,pch=3,col=6)
```

```
legend("bottomleft",bty="n",leg=paste("r.sq:",round(rsq,3)))

zzzr <- gls(y ~ ., data = yyr,corr = corAR1(0.95), method = "ML")

points(d1$latR,zzzr$fitted,type="l",col="green",lwd=3,lty="dashed")

#------------right bank------------------------#

zl <- gls(y ~ ., data = yyl, method = "ML")

zr <- gls(y ~ ., data = yyr, method = "ML")

zzzl <- gls(y ~ ., data = yyl,corr = corAR1(0.95), method = "ML")

zzzr <- gls(y ~ ., data = yyr,corr = corAR1(0.95), method = "ML")

par(mfrow=c(2,1),las=1,oma=c(2,2,2,1),mar=c(0.5,0,0,0),mgp=c(1.1,0.1,0),tcl=0.2)

acf(residuals(zzzl,type = "n",xlim=ylm,ylim=ylm1,xaxt="n",xlab="",ylab="",cex.axis=0.8))

mtext(side=3,line=0.2,adj=-0.05,"ACF")

mtext(side=3,line=0.2,adj=1,"The correlations from 2003 to 2018")

legend("topright",bty="n",leg="Left Bank")

acf(residuals(zzzr,type = "n",xlim=ylm,ylim=ylm1,xlab="Latitude",ylab="",cex.axis=0.8))

legend("topright",bty="n",leg="Right Bank")

axis(outer=T,side=1,at=at1,lab="lag",padj=0.8,tcl=0)

summary(zl)

summary(zr)

summary(zzzl)

summary(zzzr)

anova(zl,zzzl)

anova(zr,zzzr)

#------------------------------------------------end-----------------------------------------------
```

Summary the results

```
#Summary fitted value
summary(zzz$fitted)
points(kn,rep(0,16))
View(d1)
d1[d1$latL<kn[1],]$id
```

d1[d1$latL<kn[3]&d1$latL>kn[2],]$id# to see length of each knots

summary(zzzl$fitted[1:1*38]) # to see the summarise of the number

#--end--

#Summary fitted value in each location of left bank

summary(zzzl$fitted[min(d1[d1$latL<kn[2],]$id):max(d1[d1$latL<kn[2],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[2],]$id)+1:max(d1[d1$latL<kn[3],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[3],]$id)+1:max(d1[d1$latL<kn[4],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[4],]$id)+1:max(d1[d1$latL<kn[5],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[5],]$id)+1:max(d1[d1$latL<kn[6],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[6],]$id)+1:max(d1[d1$latL<kn[7],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[7],]$id)+1:max(d1[d1$latL<kn[8],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[8],]$id)+1:max(d1[d1$latL<kn[9],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[9],]$id)+1:max(d1[d1$latL<kn[10],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[10],]$id)+1:max(d1[d1$latL<kn[11],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[11],]$id)+1:max(d1[d1$latL<kn[12],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[12],]$id)+1:max(d1[d1$latL<kn[13],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[13],]$id)+1:max(d1[d1$latL<kn[14],]$id)])

summary(zzzl$fitted[max(d1[d1$latL<kn[14],]$id)+1:max(d1[d1$latL<kn[15],]$id)])

#--end--

#Summary fitted value in each location of right bank

summary(zzzr$fitted[min(d1[d1$latL<kn[2],]$id):max(d1[d1$latL<kn[2],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[2],]$id)+1:max(d1[d1$latL<kn[3],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[3],]$id)+1:max(d1[d1$latL<kn[4],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[4],]$id)+1:max(d1[d1$latL<kn[5],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[5],]$id)+1:max(d1[d1$latL<kn[6],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[6],]$id)+1:max(d1[d1$latL<kn[7],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[7],]$id)+1:max(d1[d1$latL<kn[8],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[8],]$id)+1:max(d1[d1$latL<kn[9],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[9],]$id)+1:max(d1[d1$latL<kn[10],]$id)])

```
summary(zzzr$fitted[max(d1[d1$latL<kn[10],]$id)+1:max(d1[d1$latL<kn[11],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[11],]$id)+1:max(d1[d1$latL<kn[12],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[12],]$id)+1:max(d1[d1$latL<kn[13],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[13],]$id)+1:max(d1[d1$latL<kn[14],]$id)])

summary(zzzr$fitted[max(d1[d1$latL<kn[14],]$id)+1:max(d1[d1$latL<kn[15],]$id)])

#-------------------------------------------------end-----------------------------------------------

#To see interval of latitude in each location
c(d1$latL[min(d1[d1$latL<kn[2],]$id)],d1$latL[max(d1[d1$latL<kn[2],]$id)])

c(d1$latL[max(d1[d1$latL<kn[2],]$id)],d1$latL[max(d1[d1$latL<kn[3],]$id)])

c(d1$latL[max(d1[d1$latL<kn[3],]$id)],d1$latL[max(d1[d1$latL<kn[4],]$id)])

c(d1$latL[max(d1[d1$latL<kn[4],]$id)],d1$latL[max(d1[d1$latL<kn[5],]$id)])

c(d1$latL[max(d1[d1$latL<kn[5],]$id)],d1$latL[max(d1[d1$latL<kn[6],]$id)])

c(d1$latL[max(d1[d1$latL<kn[6],]$id)],d1$latL[max(d1[d1$latL<kn[7],]$id)])

c(d1$latL[max(d1[d1$latL<kn[7],]$id)],d1$latL[max(d1[d1$latL<kn[8],]$id)])

c(d1$latL[max(d1[d1$latL<kn[8],]$id)],d1$latL[max(d1[d1$latL<kn[9],]$id)])

c(d1$latL[max(d1[d1$latL<kn[9],]$id)],d1$latL[max(d1[d1$latL<kn[10],]$id)])

c(d1$latL[max(d1[d1$latL<kn[10],]$id)],d1$latL[max(d1[d1$latL<kn[11],]$id)])

c(d1$latL[max(d1[d1$latL<kn[11],]$id)],d1$latL[max(d1[d1$latL<kn[12],]$id)])

c(d1$latL[max(d1[d1$latL<kn[12],]$id)],d1$latL[max(d1[d1$latL<kn[13],]$id)])

c(d1$latL[max(d1[d1$latL<kn[13],]$id)],d1$latL[max(d1[d1$latL<kn[14],]$id)])

c(d1$latL[max(d1[d1$latL<kn[14],]$id)],d1$latL[max(d1[d1$latL<kn[15],]$id)])

c(d1$latL[max(d1[d1$latL<kn[15],]$id)],d1$latL[max(d1[d1$latL<kn[16],]$id)])

#-------------------------------------------------end-----------------------------------------------

# Merge fitted value of each location in left bank
data_box1l <- cbind(zzzl$fitted[min(d1[d1$latL<kn[2],]$id):

max(d1[d1$latL<kn[2],]$id)],1)

data_box2l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[2],]$id):

max(d1[d1$latL<kn[3],]$id)],2)

data_box3l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[3],]$id):
```

```
max(d1[d1$latL<kn[4],]$id)],3)

data_box4l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[4],]$id):

max(d1[d1$latL<kn[5],]$id)],4)

data_box5l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[5],]$id):

max(d1[d1$latL<kn[6],]$id)],5)

data_box6l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[6],]$id):

max(d1[d1$latL<kn[7],]$id)],6)

data_box7l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[7],]$id):

max(d1[d1$latL<kn[8],]$id)],7)

data_box8l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[8],]$id):

max(d1[d1$latL<kn[9],]$id)],8)

data_box9l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[9],]$id):

max(d1[d1$latL<kn[10],]$id)],9)

data_box10l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[10],]$id):

max(d1[d1$latL<kn[11],]$id)],10)

data_box11l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[11],]$id):

max(d1[d1$latL<kn[12],]$id)],11)

data_box12l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[12],]$id):

max(d1[d1$latL<kn[13],]$id)],12)

data_box13l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[13],]$id):

max(d1[d1$latL<kn[14],]$id)],13)

data_box14l <- cbind (zzzl$fitted[max(d1[d1$latL<kn[14],]$id):

max(d1[d1$latL<kn[15],]$id)],14)

data_boxl <- rbind(data_box1l,data_box2l,data_box3l,data_box4l,data_box5l,data_box6l,

        data_box7l,data_box8l,data_box9l,data_box10l,data_box11l,data_box12l,

    data_box13l,data_box14l)

data_boxl <- data.frame(data_boxl)

data_boxl$X2 <- factor(data_boxl$X2)

#--------------------------------------------------end----------------------------------------------


# Merge fitted value of each location in right bank
```

```
data_box1r <- cbind (zzzr$fitted[min(d1[d1$latL<kn[2],]$id):

max(d1[d1$latL<kn[2],]$id)],1)

data_box2r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[2],]$id):

max(d1[d1$latL<kn[3],]$id)],2)

data_box3r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[3],]$id):

max(d1[d1$latL<kn[4],]$id)],3)

data_box4r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[4],]$id):

max(d1[d1$latL<kn[5],]$id)],4)

data_box5r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[5],]$id):

max(d1[d1$latL<kn[6],]$id)],5)

data_box6r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[6],]$id):

max(d1[d1$latL<kn[7],]$id)],6)

data_box7r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[7],]$id):

max(d1[d1$latL<kn[8],]$id)],7)

data_box8r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[8],]$id):

max(d1[d1$latL<kn[9],]$id)],8)

data_box9r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[9],]$id):

max(d1[d1$latL<kn[10],]$id)],9)

data_box10r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[10],]$id):

max(d1[d1$latL<kn[11],]$id)],10)

data_box11r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[11],]$id):

max(d1[d1$latL<kn[12],]$id)],11)

data_box12r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[12],]$id):

max(d1[d1$latL<kn[13],]$id)],12)

data_box13r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[13],]$id):

max(d1[d1$latL<kn[14],]$id)],13)

data_box14r <- cbind (zzzr$fitted[max(d1[d1$latL<kn[14],]$id):

max(d1[d1$latL<kn[15],]$id)],14)

data_boxr <- rbind(data_box1r,data_box2r,data_box3r,data_box4r,data_box5r,data_box6r,

            data_box7r,data_box8r,data_box9r,data_box10r,data_box11r,data_box12r,
```

```
            data_box13r,data_box14r)

data_boxr <- data.frame(data_boxr)

data_boxr$X2 <- factor(data_boxr$X2)

#-------------------------------------------------end-----------------------------------------------


#Boxplot of fitted value of location and river banks

windows(8,7)


par(mfrow=c(2,1),las=1,oma=c(2,2,2,1),mar=c(0.5,0,0,0),mgp=c(1.1,0.1,0),tcl=0.2)

boxplot(data=data_boxl,X1~X2,xaxt="n",xlab="",ylab="")

mtext(side=3,line=0.2,adj=-0.05,"Metres",cex = 1.2)

titl <- "Easterly Movement of  splines interval from 2003 to 2017"

mtext(side=3,line=0.1,adj=0.7,titl,cex = 1.6)

legend("bottomleft",bty="n",leg="Left Bank",cex = 1.5)

boxplot(data=data_boxr,X1~X2)

legend("bottomright",bty="n",leg="Right Bank",cex = 1.5)

axis(outer=T,side=1,at=at1,lab="Interval",padj=0.8,tcl=0,cex.axis = 1.8)

#-------------------------------------------------end-----------------------------------------------
```

VITAE

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Education Attainment

Degree	Name of Institution	Year of Graduation
Bachelor of Science (Applied Mathematics)	Prince of Songkla University	2016

List of Publication and Proceedings

Proceedings:

Awang, M., Chuai-Aree, S. and McNeil, R. (2021, January). Statistical modeling for river flow and bank erosion. Paper presented at the 21th International Conference on Mathematics and Statistics, Phuket, Thailand.