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Mathematical Modeling for Water Level Prediction in Sirikit Dam

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Abstract

More frequent floods and droughts have occurred in Thailand. The climate change is believed to be a major cause of the amount and fluctuation behaviors of rainfalls. Nan province is the main focus of this research because, unlike other provinces, Nan had experienced frequent floods in the last decade. In addition, rainfalls in Nan directly affect the water level of Sirikit dam which, from the past data, apparently related to floods and droughts in Nan province since the dam was built in 1974. Forest area is believed to be a factor affecting the water level causing from the amount of rainfalls. Due to widespread deforestation in Nan and throughout Thailand, mathematical model on the relationship between forest area, rainfalls and water level in Sirikit dam is developed to predict the water level of Sirikit dam. The models are then validated using Nan's forest data during 1973-2013 period, daily rainfalls from all stations in Nan province during 1970-2013 period and water level in SiriKit dam during 1974 – 2013 period. The parameters in the model are also estimated using the data on the forest area, amount of rainfalls and water level of Sirikit dam.

Keywords: Mathematical Modeling, Flood Prediction, Climate Change, Forest Reduction, Deforestation

1. Introduction

At present in Thailand, more frequent droughts and floods are likely to occur. In the past 30 years, Thailand also had suffered from more than 50 droughts and floods, causing a total estimated loss of more than billion Baht. Climate change is one of the main causes [1]. Meteorological Department of Thailand defines the climate change as a change of average weather such as rainfall temperature and wind [2]. In addition, human activity has now become the main cause of climate change by emitting greenhouse gases to the atmosphere, causing global warming. The effects of rising temperatures on extreme weather events could also cause floods and droughts [3-5]. Increased intensity of floods and droughts brought on by the water level in river resulting from changes in rainfall. In addition, many researchers support that forest area affects the amount of water in the river [6-8]. Since

1961, Thailand has faced the widespread problem of deforestation. Therefore, the forest areas have decreased steadily. About 20% of forested areas were lost [9]. Nan province is the main focus in this research because Nan is one of the five provinces that experienced the most deforestation in 2013, and the forest area decreased more than 5% [10]. In addition, extensive flooding has occurred in Nan province more than 3 times in the past 10 years [11]. Nan River is the major river in Nan province flowing southward to Sirikit dam [12]. As a result, the amount of water flowing to Sirikit dam can refer to the amount of water in Nan River from rainfall in Nan province.

In this research, the purpose of using Mathematic modeling to predict an amount of water flowing into dam due to the changes of forest area and rainfall in Nan province.

2. Materials and Methods

The forest area data in Nan province

Forest area data in Nan province were derived from the Royal Forest Department during the 1973-2013 period [9]. That data were normalized with Nan area to make values available 0-1. Fig.1 shows normalized data of forest area in Nan.

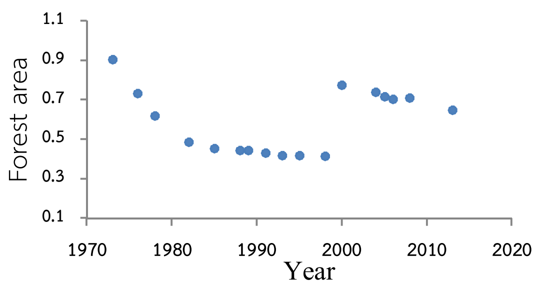

Fig. 1 Normalized data of forest area in Nan during 1973-2013 period

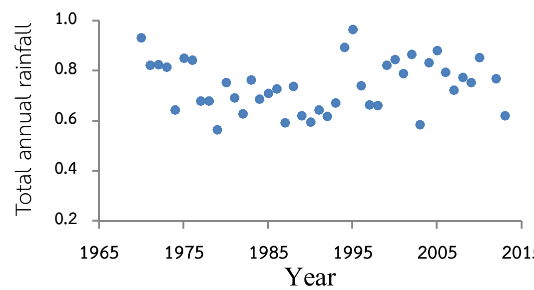

Fig. 2 Total annual rainfall data already normalized during 1970-2013 period

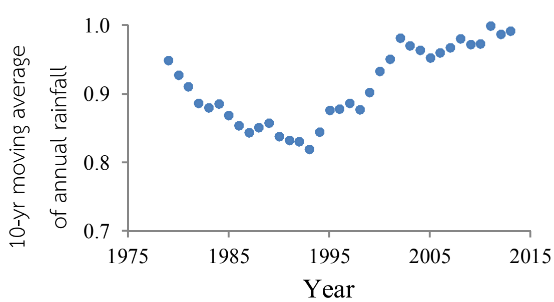

Fig. 3 10-yr moving average of annual rainfall during 1979-2013 period

The rainfall data in Nan

The amount of rainfall data was drawn from Meteorological Department during 1970-2013 period. The total annual rainfall data were normalized with the possible maximum value that shown in Fig. 2. and were calculated to 10-yr moving average, as shown in Fig. 3.

Amount of water flowing into the Sirikit dam

The data of water flowing into the Sirikit dam were derived from Electricity Generating Authority of Thailand during 1974-2013 period [12]. For the investigation of flood and drought condition, the amount of water flowing in the dam was separated into two cases. The first case was the amount of water flowing into the dam within six months that had more rainfall in April, May, June, July, August and September. The second case was the amount of water flowing into the dam within six months that had less rainfall in October, November December, January, February and March. Their data were normalized, as shown in Fig.4 and were calculated to 10-yr moving average that shown in Fig.5.

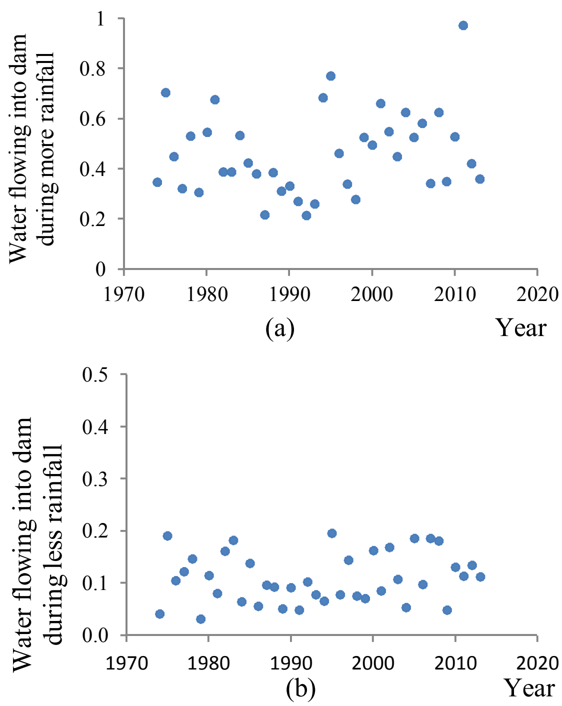

Fig. 4 Normalized data of water flowing in Sirikit dam during 1974-2013 period (a) More rainfall condition and (b) less rainfall condition

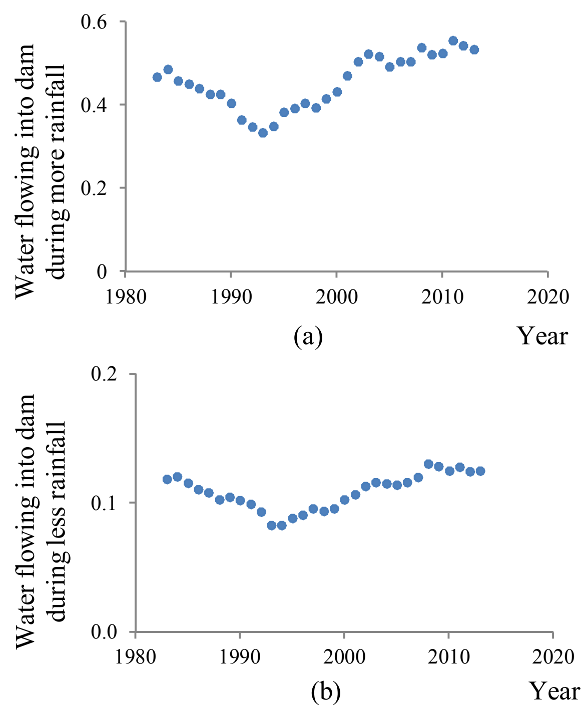

Fig. 5 10-yr moving average of water flowing in Sirikit dam during 1974-2013 period (a) more rainfall condition and (b) less rainfall condition

3. Materials and methods

Forest area model development

Recent studies in northern Thailand and Thailand's forest area change reported that logistic function was appropriate for forest area data [13-14]. In the change of Nan forest area, many researchers believe that it can be explained by logistic function because the maximum of forest area should be more than some values such as Nan province area, and the minimum of forest area should be limited with some values except zero. The equation of logistic function is as follows:

$$\frac{dF}{dt} = aF - bF^2 \quad ; \qquad F(t) = \frac{F_{\min}}{1 + \frac{F_{\min} - F_0}{F_0} e^{-kt}} \tag{1}$$

where F_0 is the forest area with t=0 (year 1973)

$F_{\min}$ is the minimum of forest area

k is constant

For Fig.1, the trend of forest area change in Nan province is not continuous between 1973-1998 period and 2000-2013 period. The data from Northern Thailand forest area and Thailand forest area showed similar result [13-14]. This may be caused by different measurement in correction data. However, we must edit the data using Eq.1. After that the data were validated, the researcher found that Eq.1 was suitable for the forest area data between 1973-1998 period and 2000-2013 period. Then the data was edited as shown in Fig. 6. Logistic function was validated again with Nan forest area data between 1973-2013 period (Fig.7).

Fig. 7 shows the estimated curve with the minimum sum squared error using logistic function with correlation coefficient of 0.9750, and sum squared error of 0.00910 where F_0 = 0.8934, $F_{\min}$ = 0.2850 and k =-0.03974. The validation result showed that logistic function was suitable to explain the change of forest area in Nan province.

Rainfall model development

Fig. 3 shows tendency of moving average of total annual rainfall in Nan province that decreased during 1979-1993 period, and increased during 1993-2013 period. We use the data during 1993-2013 period to develop a model to predict a total of average annual rainfall in ten years' time after 2013. In specific conditions, the tendency of moving average of total annual rainfall in Nan after 2013 increased. Fig.8 shows moving average of total annual rainfall in Nan during 1993-2013 period.

For Fig. 8, it can be seen that data is distributed in a similar exponential function. Then the exponential function was validated with the data of 10-yr moving average of annual rainfall during 1993-2013 period as shown in Fig.9.

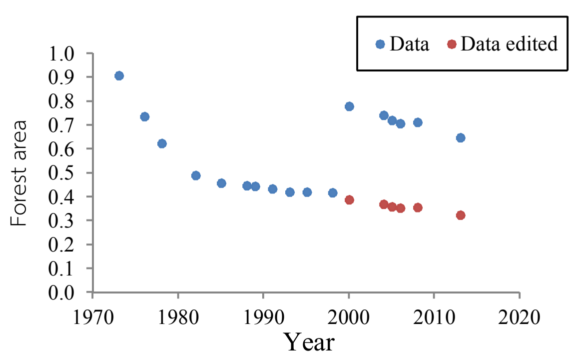

Fig. 6 Editing data of forest area in Nan during 1973-2013 period

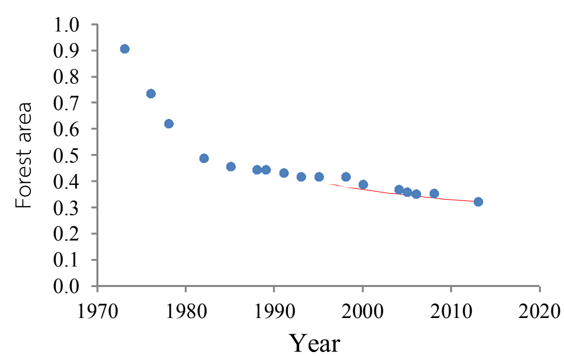

Fig. 7 Model validation on forest area data using logistic function

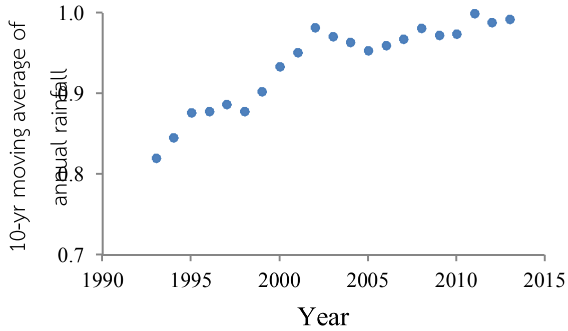

Fig. 8 10-yr moving average of annual rainfall during 1993-2013 period

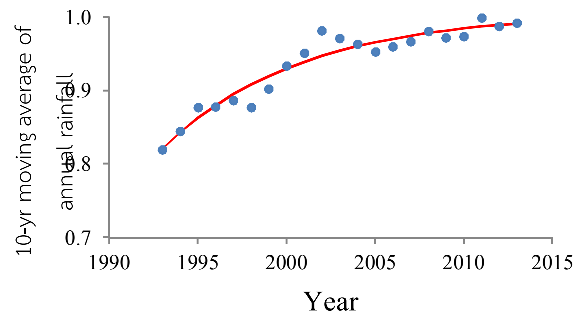

Fig. 9 Model validation on rainfall data using exponential function

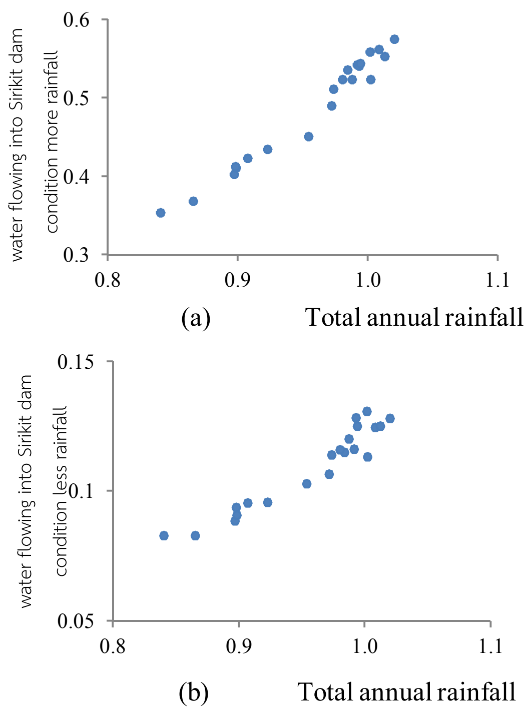

Fig. 10 Relationship between variables (a) water flowing into Sirikit dam under more rainfall condition and total annual rainfall (b) water flowing into Sirikit dam under less rainfall condition and total annual rainfall

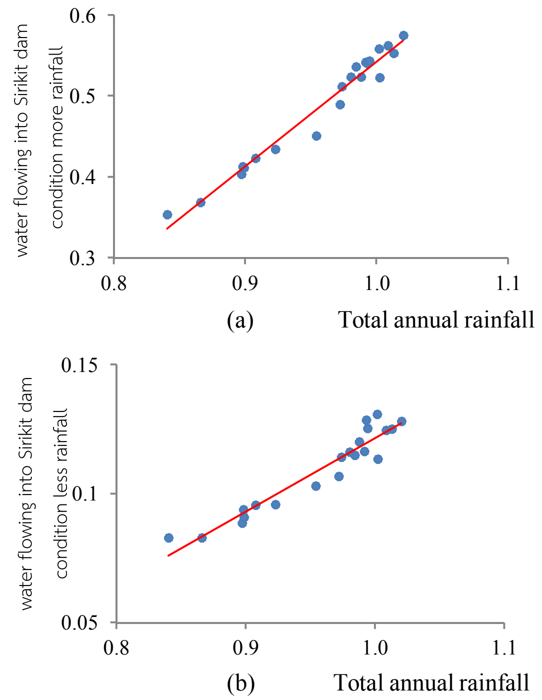

Fig. 11 Model validation by linear function on relationship between variables (a) water flowing into Sirikit dam under more rainfall condition and total annual rainfall (b) water flowing into Sirikit dam under less rainfall condition and total annual rainfall

Fig. 9 shows the best-estimated curve using the exponential function with correlation coefficient of 0.9318 and sum squared error of 0.003843. The statistical value shows that exponential function is appropriate for the data of 10-yr moving average of annual rainfall during 1993-2013 period. The equation result is as follows:

$$R(t) = -0.439e^{-0.1276t} + 1.006 \quad (2)$$

Relationship between water flowing in Sirikit dam and total annual rainfall in Nan

For the relationship between water flowing in Sirikit dam and total annual rainfall in Nan, Pearson's correlation was used to study the relationship between variables shown in Table 1. The result shows that water flowing in Sirikit dam in more and less rainfall condition had a high relationship with total annual rainfall in Nan.

Table 1 Pearson's correlation value between water flowing in Sirikit dam and total annual rainfall in Nan

Pearson's correlation value		
between	water flowing into Sirikit dam under more rainfall condition	water flowing into Sirikit dam under less rainfall condition
Total annual rainfall in Nan province	0.984	0.956

Fig. 10 shows the relationship between water flowing in Sirikit dam and total annual rainfall in Nan. For Fig.10, it can be seen that the data is distributed in a similar linear function. Then the data was validated by a linear function that showed in Fig.11 with the equation below.

$$W = \alpha R + \beta \quad (3)$$

where R is amount of rainfall, W is water flowing into Sirikit dam and α, β are constant.

The parameter results in Table 2 and the statistical values in Table 3 reveals that relationship in high correlation between water flowing into Sirikit dam under more rainfall condition and total annual rainfall, and water flowing into Sirikit dam under less rainfall condition and total annual rainfall can be explained with linear function.

Table 2 Parameter value of relationship between total annual rainfall and water flowing into Sirikit dam

Parameters	Parameter value of relationship between and total annual rainfall and water flowing into Sirikit dam under two specific conditions	
	more rainfall condition	less rainfall condition
α	1.2930	0.2855
β	-0.7446	-0.1582

Table 3 Statistical value of relationship between total annual rainfall and water flowing into Sirikit dam

Statistical value	Statistical value of relationship between and total annual rainfall and water flowing into Sirikit dam under two specific conditions	
	more rainfall condition	less rainfall condition
SSE	0.003046	0.0004324
r	0.9687	0.9140

4. Results and Discussion

Nan's forest area prediction

After the logistic function was validated and found its suitability for the forest area data. We use logistic function as shown in Eq.1 to predict the forest area in Nan province in 2023. Table 4 shows the prediction of Nan's forest area in 2023 decreasing 5.20% from 2013.

Table 4 The prediction of Nan forest area in 2023

Prediction of forest area	
Actual value Year 2013	Prediction value Year 2023
0.3307	0.3135

Table 5 The prediction of annual rainfall in 2023

Annual rainfall prediction	
Actual data Year 2013	Prediction value Year 2023
0.9926	1.0019

Prediction of annual rainfall in Nan

The validating results revealed that exponential function was suitable to explain the rainfall changes in Nan. Then, we use an exponential function (Eq.2) to predict the moving average rainfall in Nan in 2023. Table 5 showed moving average rainfall in Nan in 2023 increasing 0.93% from 2013. However, we use 10 years' time to calculate moving average of rainfall and amount of water flowing into the dam. If we use another number for moving average, the result will be different. The study by Limjirakan *et al*. [15] reported that the average rainfall in Northern Thailand tended to increase, and Chinwanno's study [16] found that in 30 years' time, rainfall will increase in every region of Thailand.

Table 6 The prediction of water flowing into Sirikit dam in 2023

	Prediction of water flowing into Sirikit dam	
	Year 2013 (actual value)	Year 2023 (prediction value)
more rainfall condition	0.5333	0.5508
less rainfall condition	0.1251	0.1278

Prediction of water flowing into Sirikit dam

We use the results from the prediction of annual rainfall to predict the moving average of water flowing into the dam in 2023 with Eq. (3). The prediction in Table 6 showed water flowing into Sirikit dam under more rainfall condition in 2023 increasing 3.28% from 2013, and the water flowing into Sirikit dam under less rainfall condition increasing 2.15% from 2013.

5. Conclusion

In this study, the change of forest area in Nan can be explained by the logistic function with correlation coefficient of 0.9750 and sum squared error of 0.00910. In addition, the forest area model showed that forest area in Nan tended to decrease and be able to predict the forest area in 2023 decreasing from 2013 about 5.20%. For the rainfall changes in Nan, exponential function was suitable for the data with correlation coefficient of 0.9318 and sum squared error of 0.003843. The prediction of annual rainfall under specific conditions continues increasing. It is found that moving average of annual rainfall in 2023 will increase from 2013 about 0.93%. Due to the relationship between variables, there were relationships with high correlation between water flowing into Sirikit dam and total annual rainfall. The relationship can be explained with a linear function. We can also predict water flowing into Sirikit dam due to rainfall changes. The prediction found that moving average of water flowing into dam tended to increase under more rainfall and less rainfall conditions. However, the results can explain only the relationship between the water flowing into Sirikit dam and the annual rainfall in Nan except the forest area in Nan. Therefore, this research will help guide future research into the forest area of Nan.

6. References

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