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Daily Maximum Rainfall Forecast Affected by Tropical Cyclones using Grey Theory

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Abstract

This research aims to develop a model for forecasting daily maximum rainfall caused by tropical cyclones over Northeastern Thailand during August and September 2022 and 2023. In the past, the ARIMA or ARIMAX method to forecast rainfall was used in research. It is a short-term rainfall prediction. In this research, the Grey Theory was applied as it is an approach that manages limited and discrete data for long-term forecasting. The Grey Theory has never been used to forecast rainfall that is affected by tropical cyclones in Northeastern Thailand. The Grey model GM(1,1) was analyzed with the highest daily cumulative rainfall data during the August and September tropical cyclones of the years 2018–2021, from the weather stations in Northeastern Thailand in 17 provinces. The results showed that in August 2022 and 2023, only Nong Bua Lamphu province had a highest daily rainfall forecast of over 100 mm, while the other provinces had values of less than 70 mm. For September 2022 and 2023, there were five provinces with the highest daily rainfall forecast of over 100 mm. The average of mean absolute percentage error (MAPE) of the maximum rainfall forecast model in August and September is approximately 20 percent; therefore, the model can be applied in real scenarios.

Keywords: Grey Theory; Tropical Cyclones; Daily Maximum Rainfall.

1. Introduction

A tropical cyclone is a storm that causes strong winds and flash floods and may also cause damage to homes and agricultural crops. Tropical cyclones that affect Thailand are mostly formed in the North Pacific Ocean (western part), the South China Sea, and the Bay of Bengal. In addition, global warming, which occurs when the Earth is unable to normally radiate the heat received from solar radiation back into space, contributes to climate change. When the Earth's climate has changed, its average temperature is then higher, resulting in an increase in glacial melting at the poles and a greater volume of water flowing into the rivers and seas that will affect life on Earth. Thailand usually experiences about 3–4 storms each year. They mainly affect Northeastern Thailand from August to September every year, with violent storms and thunderstorms destroying and damaging houses and farms. Heavy rainfall can cause floods and landslides. Therefore, it is necessary to be prepared in order to prevent or mitigate the likely damage that will occur, most of which will occur in communities located in flood-prone areas.

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Based on the data report of the next 80-year rainfall forecast in Northeastern Thailand, rainfall intensity shows a tendency to increase (Figure 1). It can be seen that Northeastern Thailand is prone to experiencing more severe flooding as it is more likely to experience heavy rainfall in a short period of time, instead of having fairly widespread rainfall throughout the rainy season like in the past. Thailand is typically affected by a tropical depression with an average of 3–4 storms per year. As for tropical cyclones in Thailand, they usually occur in the rainy season from May through October. They could be tropical cyclones that are formed in the Indian Ocean, or the Pacific Ocean and the South China Sea. However, almost all of them are tropical cyclones that occur in the Pacific Ocean or in the South China Sea. They move through Northeastern Thailand from July to September every year. According to past data, it was found that August and September each year are the periods when storms often occur, resulting in large accumulated rainfall.

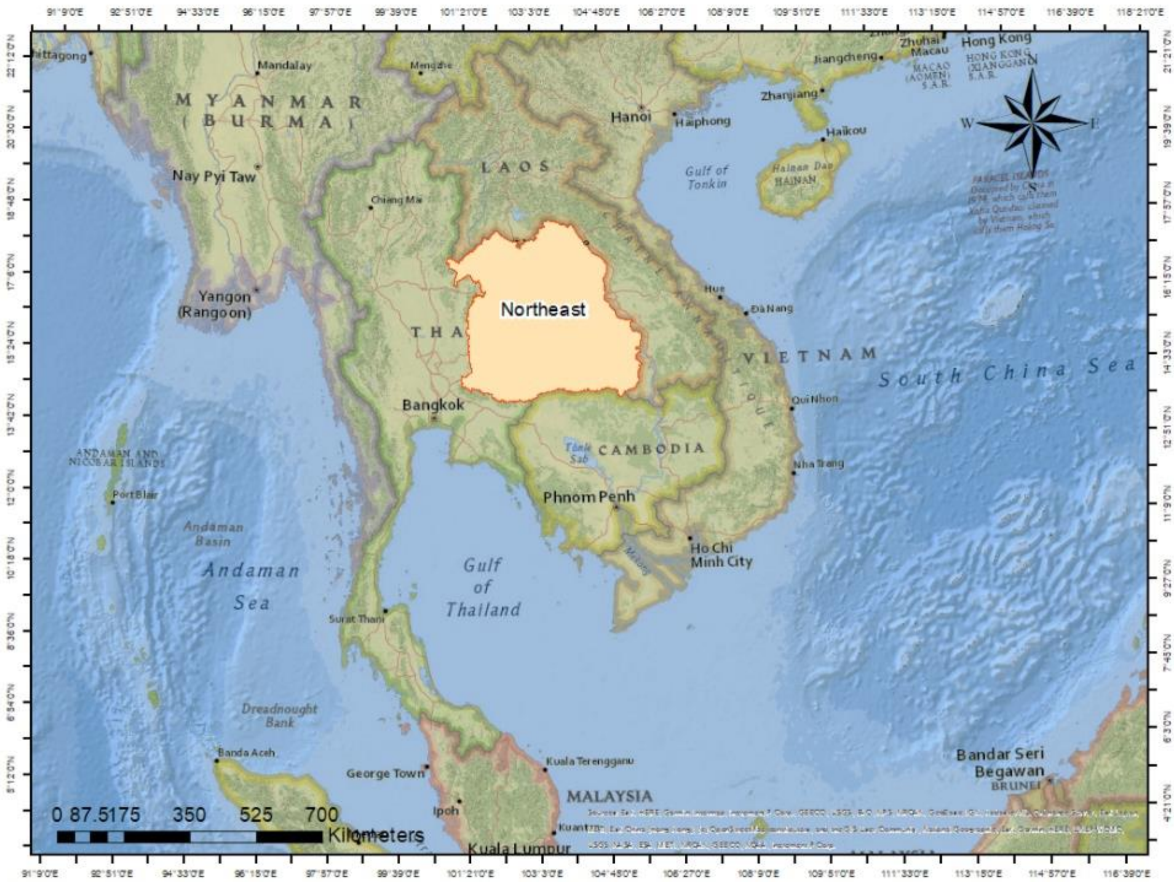


Figure 1. The Northeastern region of Thailand

There are many researchers who have studied rainfall forecasting using an ARIMA model, such as Geetha and Nasira [1], Rahman et al. [2], Bhardwaj and Duhoon [3], Wu et al. [4], and Masum et al. [5]. Additionally, there are researchers who have studied rainfall forecasting using an ARIMAX model with other variables related to rainfall to assist in modeling such as Islam and Imteaz [6], Amelia et al. [7], and Musa et al. [8].

In addition to the ARIMA and ARIMAX models, there is also the Grey forecasting model, a time series forecasting method developed from the Grey System Theory which was invented by Julong Deng in 1982. The Grey model can be applied to uncertain systems and small data for analysis. The model can handle disordered raw data better by converting it to sequential data using a differential equation. The Grey model has been developed and applied across many fields such as medicine (Kuniya [9], Saxena [10], Chutiman et al. [11]), agriculture (Busababodhin and Chiangpradit [12]), environment and water allocation (Shi [13], Shao et al. [14], Shirisha [15]), ecology (Chen and Wang [16]), meteorology (Salookolaei [17]), and engineering (Zhou et al. [18], Wang et al. [19], Wu et al. [20], Shaheen et al. [21], Liu and Wu [22]).

Therefore, the researcher would like to present the Grey Theory to develop a model for forecasting daily maximum rainfall affected by tropical cyclones in Northeastern Thailand during August and September so that relevant agencies can use it as a guideline for planning water management in the region efficiently.

2. Domain of Experiment and Methodology

2.1. Domain of Experiment

The experiment data in this research were selected from the highest cumulative daily rainfall during tropical cyclones from the local meteorological stations which observe rainfall in each of 17 provinces in Northeastern Thailand, in August and September. The period of tropical cyclones over Northeastern Thailand is shown in Table 1.

Table 1. Tropical cyclones over Northeastern Thailand in August and September

Year	Storm Name	The date of the storm in August	The date of the storm in September
2018	BEBINCA (1816)	16 – 18	
	MANGKHUT (1822)		17 - 19
2019	PODUL (1912)	29 -31	
	KAJIKI (1914)		3 – 5
2020	SINLAKU (2003)	2 – 4	
	NOUL (2011)		18 – 20
2021	OMAIS (2112)	27-30	
	CONSON (2113)		12 - 14
	DIANMU (2115)		24 - 26

2.2. Methodology

The daily maximum rainfall data during tropical cyclones occurring in August and September from 2018 to 2021 are used for building a GM(1,1) model. The daily maximum rainfall in August for each station and in September for each station will be analyzed to forecast the daily maximum rainfall for August and September in 2022 and 2023.

The steps for creating a GM(1,1) model are as follows:

Step 1: Define a sequence for the original data

$$x^{(0)} = \{x^{(0)}(1), x^{(0)}(2),..., x^{(0)}(n)\} \quad (1)$$

Step 2: Calculate the original cumulative sum and set it as a new variable

$$x^{(1)} = \{x^{(1)}(1), x^{(1)}(2),..., x^{(1)}(n)\}, \quad (2)$$

where $x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i)$ and $k = 1,2,..., n$.

$x^{(1)}(k)$ is the cumulative sum of the original data, or substituted with 1-AGO (Accumulated Generating Operation of $x^{(0)}(k)$).

Step 3: Compute the background value by using the sequence of middle values and derivatives of the sequence.

The differential equation of the model GM(1,1) is

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b \quad (3)$$

The result of taking the derivative of the function, $x^{(0)}(k) + az^{(1)}(k) = b$, where *a* and *b* are the model parameters, *a* is the developing coefficient and *b* is the Grey input.

Estimate both parameters with the Least Square Method:

$$[a, b]^T = (B^T B)^{-1} B^T Y_n \quad (4)$$

where $Y_n = [x^{(0)}(2), x^{(0)}(3),..., x^{(0)}(n)]$ and $B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix}$.

From the above equation, the background value can be calculated as follows:

$$z^{(1)}(k+1) = \frac{1}{2}\left(x^{(1)}(k) + x^{(1)}(k+1)\right), \text{ and } k = 1,2,..., n-1 \quad (5)$$

Step 4: Estimate the forecast value of the GM(1,1) model

Find the forecast value of the GM(1,1) model from

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{b}{a}\right) e^{-ak} \frac{b}{a}. \tag{6}$$

The new equation can be adjusted:

$$\hat{x}^{(1)}(k+1) = x^{(1)}(k) - x^{(1)}(k) = (1 - e^{a}) \left(x^{(0)}(1) - \frac{b}{a}\right) e^{-ak}, \text{ and } k = 1,2,\ldots, n-1. \tag{7}$$

2.3. Forecasting Performance

Mean absolute percentage error (MAPE) was used to measure the forecast accuracy:

$$MAPE = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{y_t - \hat{y}_t}{y_t} \right| \times 100, \tag{8}$$

where y_t represents the actual value of the data at time t, $\hat{y}_t$ represents the predicted value of the data at time t and n represents the total amount of data.

The procedures for processing this research are shown in Figure 2.

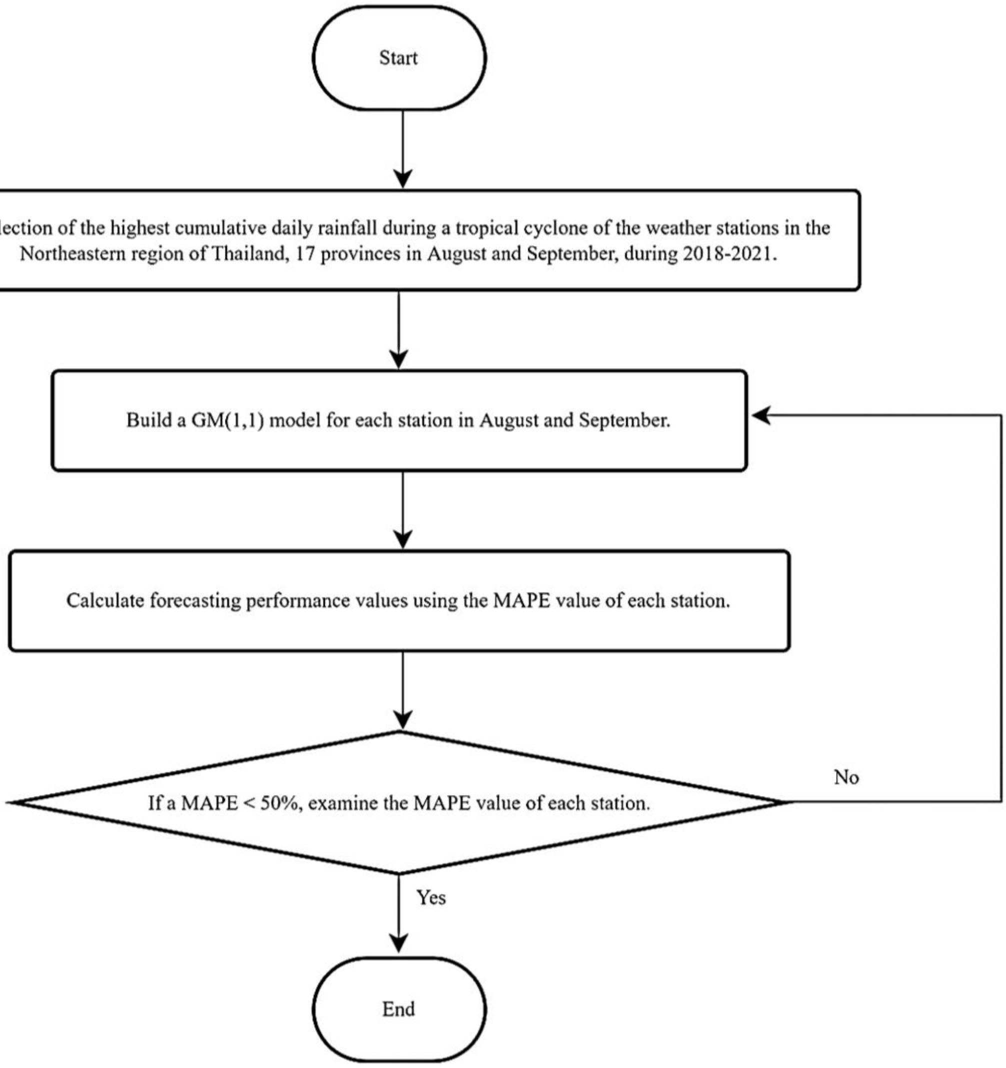


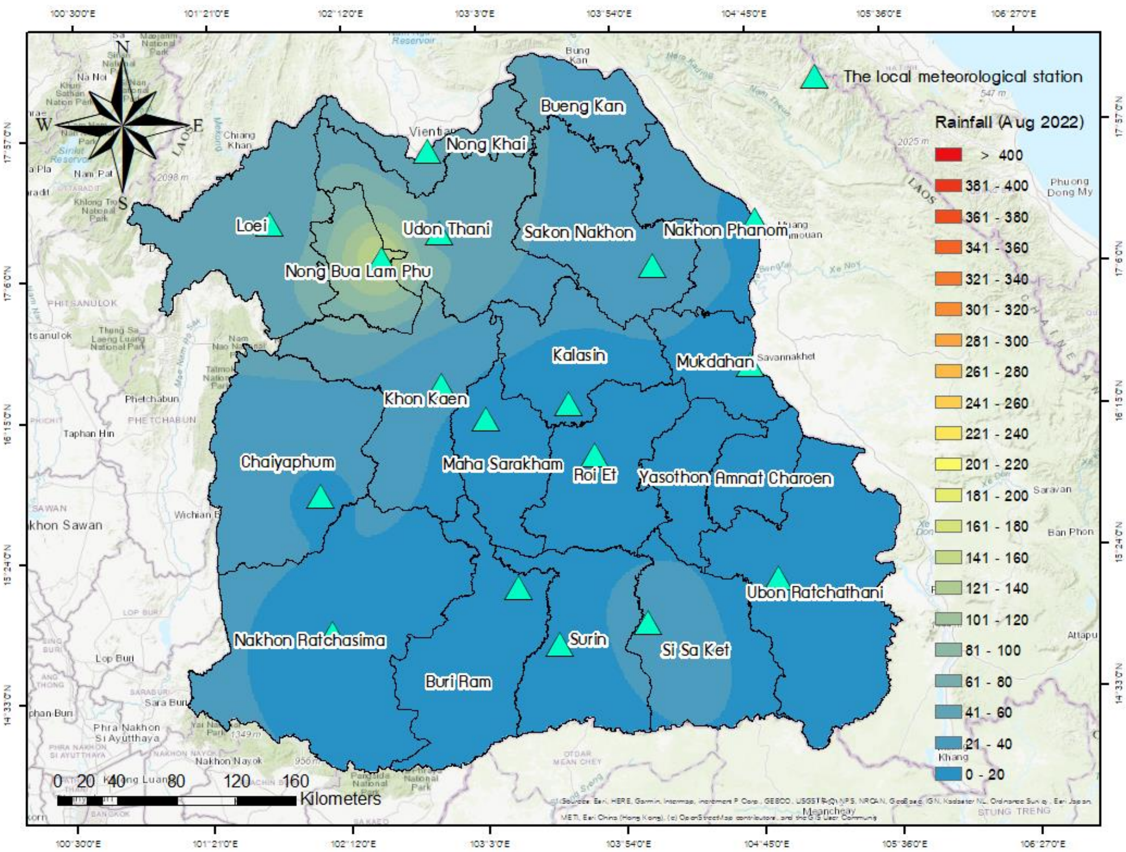
Figure 2. The procedures of the research methodology

3. Results and Discussion

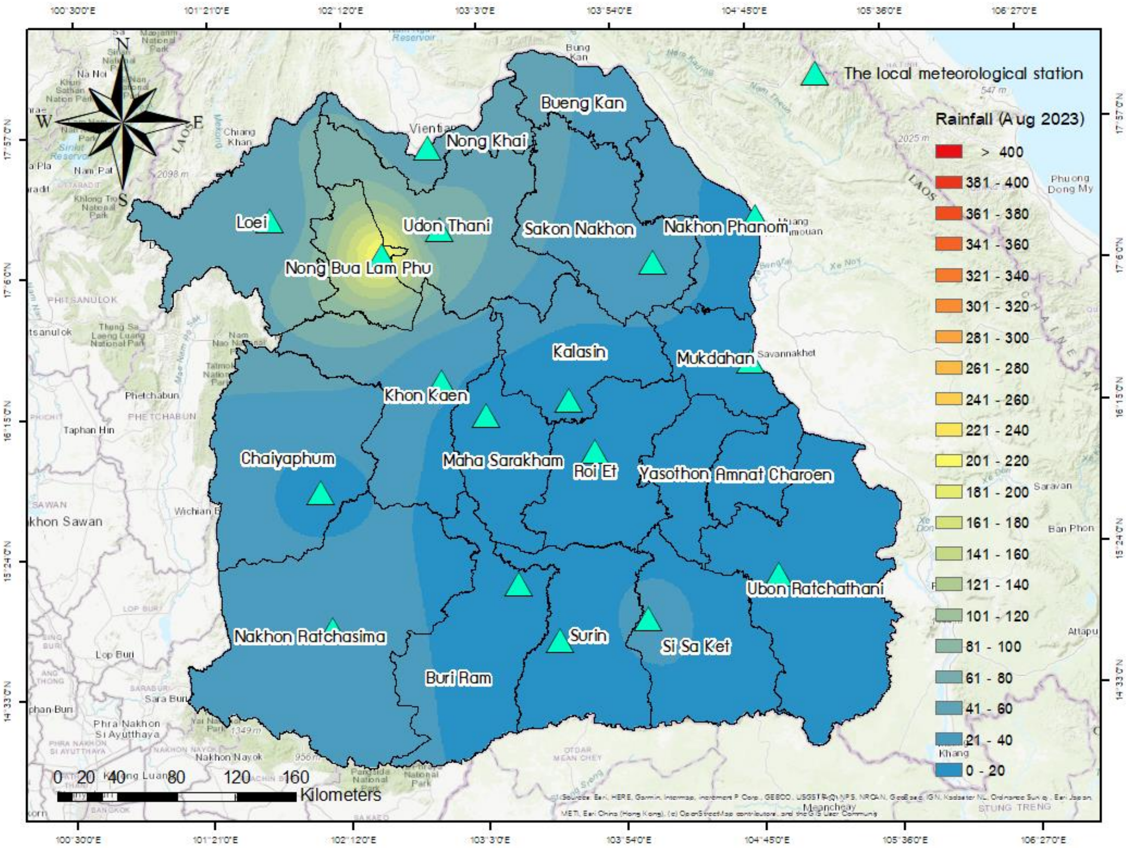
The results from the Grey model to forecast the highest cumulative daily rainfall in August and September 2022 and 2023 and the MAPE of the maximum rainfall forecast model are shown in Table 2. The forecast values of the highest cumulative daily rainfall for August 2022 and 2023 were used to create a contour graph using the GIS Kriging interpolation in the Geographic Information System (GIS) as shown in Figures 3 and 4.

Table 2. The highest daily cumulative rainfall forecast for August and September 2022–2023

Province	The highest daily cumulative rainfall forecast for August		MAPE (%) for August	The highest daily cumulative rainfall forecast for September		MAPE (%) for September
	2022	2023		2022	2023	
Ubon Ratchathani	15.23	9.76	7.39	197.32	217.18	19.91
Si Sa Ket	29.32	25.02	10.39	121.31	115.86	23.66
Nakhon Ratchasima	15.73	37.29	49.55	189.92	349.17	15.60
Surin	9.50	5.87	22.91	46.56	35.46	32.71
Buriram	6.94	3.08	30.80	80.35	83.79	42.36
Nong Khai	42.04	41.55	38.76	**9.58**	**4.81**	17.22
Loei	46.86	42.79	19.29	189.68	475.62	13.16
Udon Thani	56.48	64.59	32.59	15.89	15.25	18.34
Sakon Nakhon	30.10	28.10	5.48	17.36	12.60	0.45
Nakhon Phanom	16.96	11.55	0.92	22.09	13.78	6.94
Nong Bua Lamphu	**142.79**	**195.89**	46.95	12.29	8.67	11.91
Khon Kaen	28.01	22.03	13.95	75.87	98.26	42.19
Mukdahan	9.10	3.41	6.15	38.48	32.23	7.53
Maha Sarakham	2.70	0.64	22.62	58.16	61.68	44.28
Kalasin	**1.87**	**0.39**	26.13	98.86	112.47	12.79
Chaiyaphum	18.25	13.01	28.03	**357.96**	**961.72**	32.65
Roi Et	3.89	0.92	19.57	51.27	47.59	10.13
Average of MAPE			**22.44**	**Average of MAPE**		**20.70**

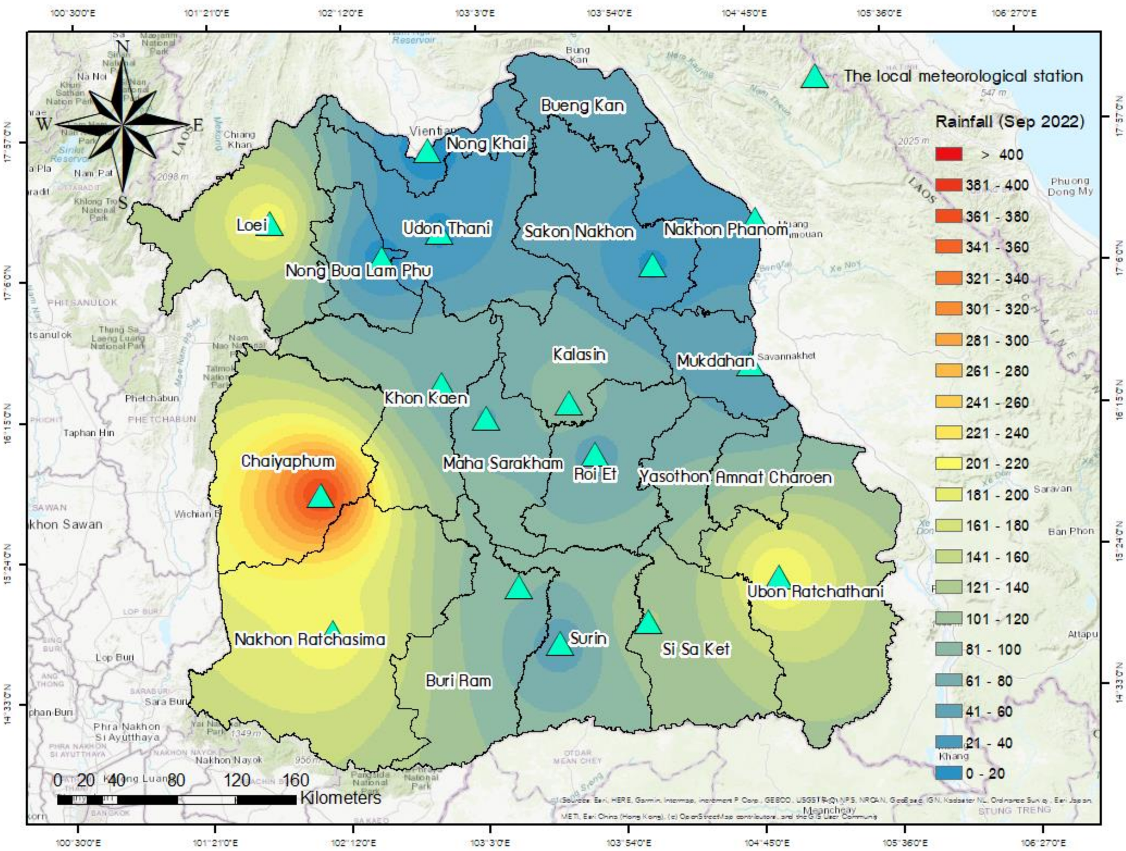


(a)

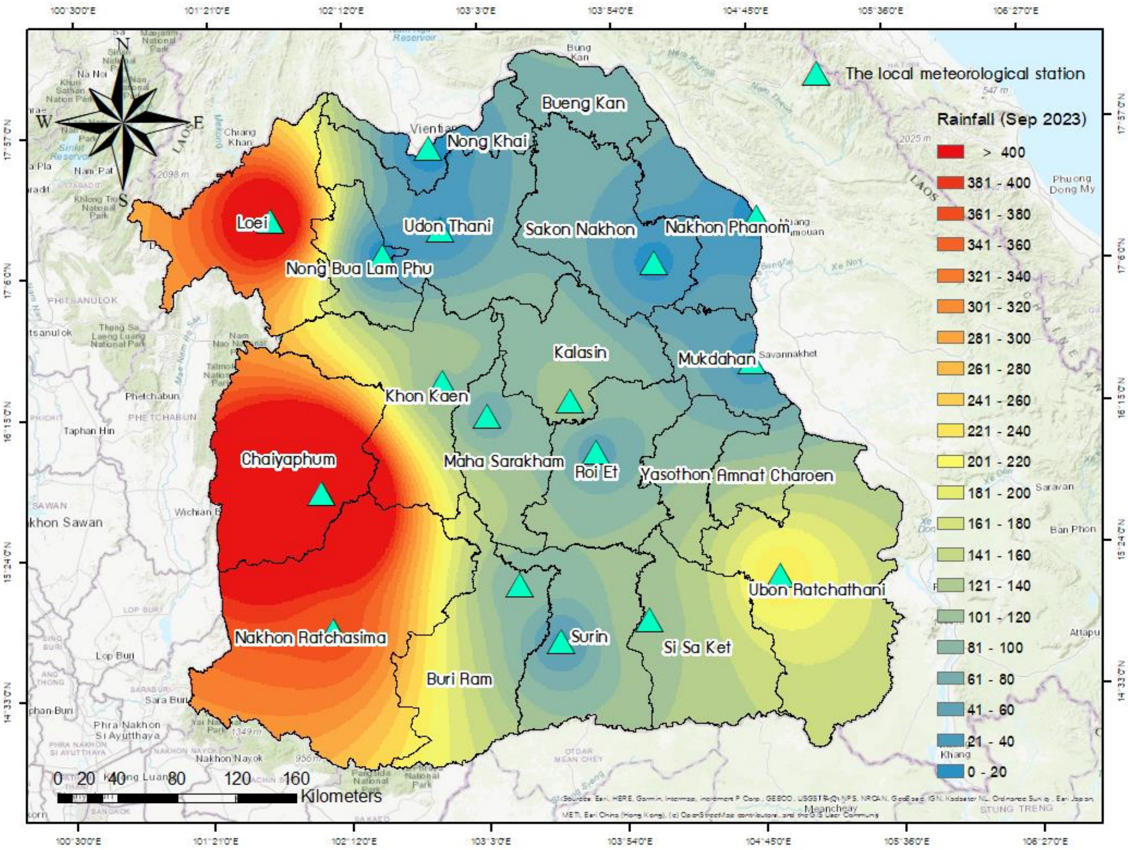


(b)

Figure 3. The highest cumulative daily rainfall modeled for August (a) 2022 (b) 2023



(a)



(b)

Figure 4. The highest cumulative daily rainfall modeled for September (a) 2022 (b) 2023

4. Conclusion

According to the use of Grey theory to develop a model for forecasting daily maximum rainfall affected by tropical cyclones in Northeastern Thailand during August and September in 2022 and 2023, using the daily maximum rainfall data during tropical cyclones occurring in August and September from 2018 to 2021 for building a GM(1,1) model, the results showed that in August 2022 and 2023, Nong Bua Lamphu has the highest daily rainfall forecast, followed by Udon Thani, Loei, and Nong Khai, respectively. They are provinces in upper Northeastern Thailand. However, in September 2022, it was found that Chaiyaphum had the highest daily rainfall forecast, followed by Ubon Ratchathani, Nakhon Ratchasima, and Loei, respectively. In September 2023, the study found that Chaiyaphum still has the highest daily rainfall forecast, followed by Loei, Nakhon Ratchasima, and Ubon Ratchathani, respectively. In addition, it was found that the daily maximum rainfall forecast in September is higher than in August, which is in accordance with the historical statistics of tropical cyclones occurring in Northeastern Thailand, leading to higher daily rainfall in September than in August. The percentage error in forecasting the daily maximum rainfall in August and September is approximately 20%. Therefore, this model can be used in forecasting rainfall and for relevant agencies to use as a guideline for planning water management in Northeastern Thailand efficiently. In future research, more than one variable affecting rainfall during a tropical cyclone period, such as relative humidity, wind speed, wind direction, and temperature, may be studied together with the Grey Theory for a more realistic model.

5. Declarations

5.1. Author Contributions

Conceptualization, N.C., P.G., B.K. and M.C.; methodology, M.C.; software, M.C.; validation, P.G. and B.K.; formal analysis, M.C.; investigation, B.K. and M.C.; resources, C.C. and P.G.; data curation, C.C., P.G. and P.B.; writing - original draft preparation, N.C.; writing - review and editing, P.G.; visualization, P.B.; corresponding author, P.G.; project administration, N.C.; funding acquisition, N.C. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

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5.4. Acknowledgements

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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