Forecasting Rabies in Dogs in Thailand: Time Series Analysis

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Abstract

Background: Rabies is a dangerous infectious disease spread from dogs to humans by bites from rabid dogs. There is a lack of studies investigating trends of rabies in dogs in Thailand. The objectives of this study were to investigate trends in rabies in dogs in Thailand and use this to develop a model to predict the number of dogs with rabies in Thailand.

Methods: The number of dogs with rabies between 2013 and 2017 were retrieved from the rabies surveillance report system of the Bureau of Disease Control and Veterinary Services in Thailand. Time series analysis using Holt-Winter and Box-Jenkins methods were performed to create a predictive model. Akaike information criterion (AIC) and Root Mean Square Error (RMSE) were used to choose an appropriated model for predicting the number of dogs with rabies in Thailand in 2018.

Results: During 2013-2017 there was a significant increase in the number of rabid dogs in northeastern Thailand. Using the Seasonal Autoregressive Integrated Moving Average (SARIMA $(1, 1, 0)$ $(0, 1, 1)_{12}$) predictive model, the number of rabid dogs in Thailand was predicted to be highest in December 2018.

Conclusion: The number of dogs with rabies in Thailand is increasing and the SARIMA predictive model was the most suitable for forecasting the number of rabid dogs that might be found in Thailand at national and regional levels.

Keywords: Forecasting, Rabies dogs, Modelling, Time series

Introduction

Rabies is a contagious disease that is spread from animals to humans and is an important problem in public health surveillance systems worldwide because it kills around 59,000 people each year (Centers for Disease Control and Prevention, 2015). Dogs spread this disease from one dog to another and are also responsible for 99% of rabies cases in humans (World Health Organization, 2018). Bites from infected dogs are the main cause of rabies in humans, causing up to 95% of cases. In each year, there are more than one million people bitten by dogs (The Thai Red Cross Society, 2018) and 99 percent of rabies patients were bitten by dogs (World Health Organization, 2018).

During 2010 to 2014, Asia accounted for 59.6% of global deaths due to rabies (Ahmad, Musa, & Jin, 2018). The number of annual human deaths in Bhutan due to rabies is estimated to be 1.5 per 100,000 population (Tenzin et al., 2011; Ahmad et al., 2018). In addition, the number of animal bite cases rose by 20,000 every year from 2011 to 2015 in India (Kulkarni, 2016). For Thailand, 17 patients died from the disease in 2018 (Bureau of Epidemiology, 2018; Biovalys, 2019). The rabies vaccination coverage rate in dogs in Thailand is quite low at 14.18 % (Sagarasearanee & Chanruang, 2017).

The Ministry of Public Health in Thailand found a positive correlation between the number of rabies deaths and the number of animals that are detected to have rabies (r = 0.952 and P-value < 0.001)(Department of Disease Control, 2014). Furthermore, a previous study found that the number of animal rabies cases had a negative relationship with the amount of rabies vaccination coverage (r = -0.71) (Wongphruksasoong & Khemmapat, 2016).

Time series approach is usually used to analyze a series of data points that depend on time order. In addition, the approach is also popular to handle data that might consist of trend, seasonality and cycle. Thus, time series analysis might be suitable to create a predictive model for rabies in dogs because an occurrence of the disease is more likely to related with weather seasons (Hengtrakool, Thongratsakul, Leelehapongsathorn, & Poolkhet, 2017).

However, there is a lack of information about trends and predictive models of rabies in dogs. The present study aimed to explore the trend of rabies in dogs and to develop an appropriate time series model for predicting the number of dogs with rabies in Thailand. It is expected that this model might prove useful for planning interventions and controlling rabies in dogs.

Methods and Materials

Data and statistical analysis

The rabies data set was the diagnostic results from dogs' head samples that were examined in the laboratory from 2013 to 2017. The dataset was retrieved from the rabies surveillance report system at the Bureau of Animal Disease Control and Prevention, Bureau of Disease Control and Veterinary Services in Thailand.

Rabies information in dogs by year and month were described by median minimum and maximum. Ratios between number of dogs with rabies and number of people (RRP) in both region and health provider region were calculated and plotted onto regional maps of Thailand.

To conduct time series modelling, the data were from 1 January 2013 to 31 December 2017(60 months) was used to create the time series model using Holt-Winter, ARIMA (Autoregressive Integrated Moving Average) and SARIMA methods. The most suitable model was selected by considering the lowest AIC and RMSE. Moreover, The suitable model must have following conditions: residuals are uncorrelated, residuals are normally distributed, and stationarity. The Ljung-Box test statistic was used to check for independence of residuals. Shapiro-Wilk test was also used to exam the normality of residuals. Augmented Dickey-Fuller (ADF) test was used to test the stationarity. Data exploration and data cleaning were performed using summ and tab1 functions in epiDisplay package on RStudio program (Chongsuvivatwong, 2018; RStudio, 2018). Time series analyses were conducted in R and RStudio programs with forecast and tseries packages (R Core Team, 2018; RStudio, 2018; Hyndman et al., 2019; Trapletti, Hornik, & LeBaron, 2019).

Results

The number of dogs with rabies in Thailand increased from 2013 to 2017 with the highest yearly number of dogs with rabies (59 dogs) in 2017. (Figure 1 and Table 1). Table 1 shows that February and November were the months that had the highest number of dogs with rabies (median 39 dogs) in the last five years.

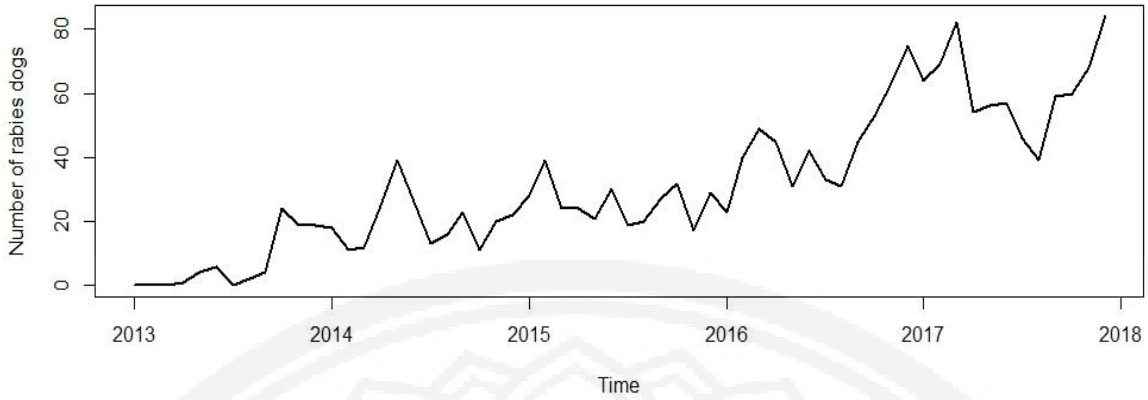

Figure 1 Trend of detection of rabies in dogs in Thailand 2013 to 2017

Table 1 Rabies disease detection in dogs by year and month during 2013 to 2017

	Variable	Median (min, max)
Year	2013	3 (0, 24)
	2014	19 (11, 39)
	2015	25.5 (17, 39)
	2016	43.5 (23, 75)
	2017	59.5 (39, 84)
Month	January	23 (0, 64)
	February	39 (0, 69)
	March	24 (0, 82)
	April	25 (1, 54)
	May	31 (4, 56)
	June	30 (6, 57)
	July	19 (0, 46)
	August	20 (2, 39)
	September	27 (4, 59)
	October	32 (11, 60)
	November	39 (0, 69)
	December	29 (19, 84)

The number of dogs with rabies per 100,000 persons (RRP) were calculated for all regions and plotted onto Thailand regional maps. People in the study area are at high risk of rabies disease if the RRP is high. Figure 2 reveals that Northeastern Thailand had the highest risk of the disease in dogs with 15.96 dogs with rabies per 100,000 persons in 2017.

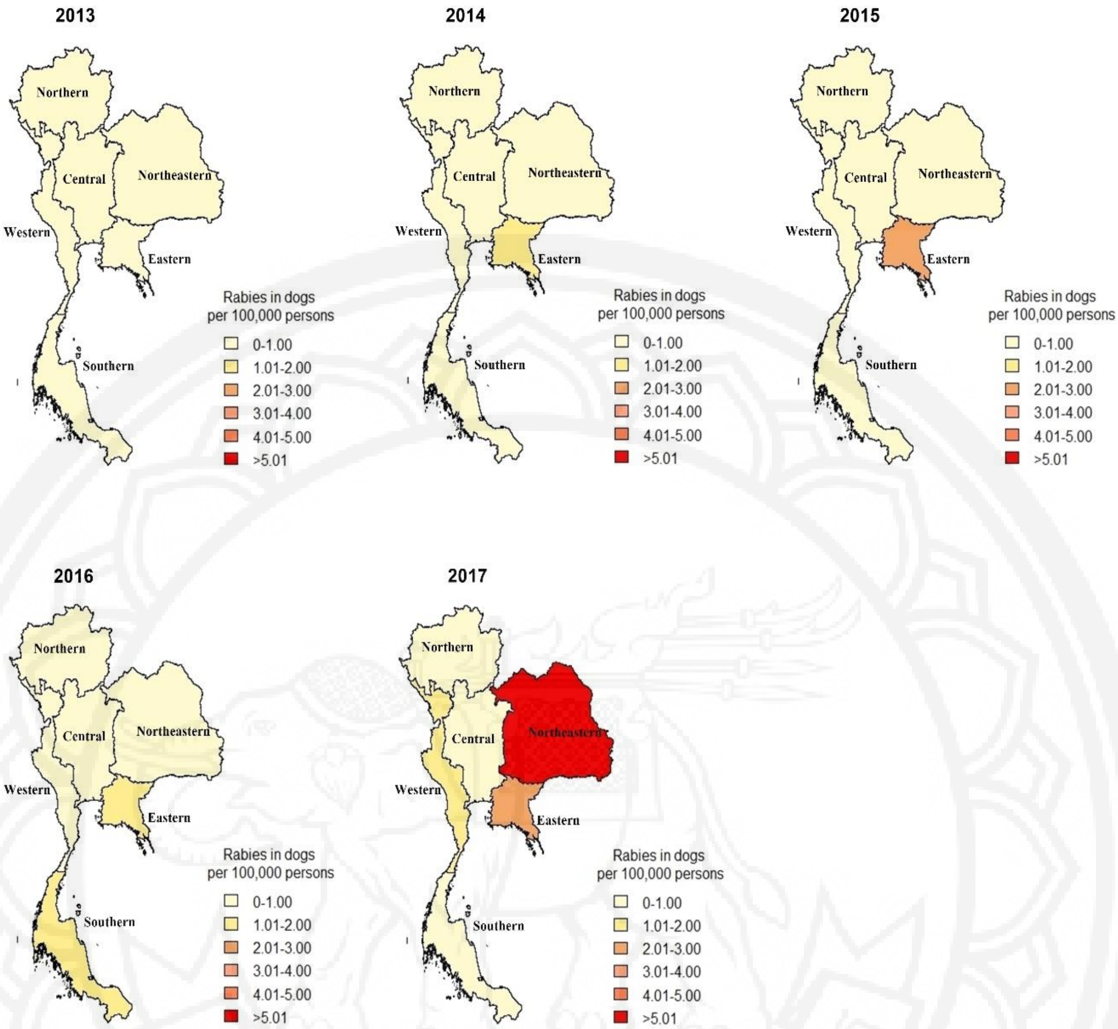

Figure 2 The number of rabies disease detected in dogs per 100,000 persons by region between 2013 and 2017

The Ministry of Public Health in Thailand has separated health service management into 13 health service areas (including special area Bangkok) as shown in Figure 3. When considering the number of dogs with rabies per 100,000 persons by health service area, there were no significant differences between health service areas. However, health service areas no. 10 and no. 6 had the highest RRP (ratio is 2.28 and 2.30, respectively) in 2016 and area no. 10 had the highest risk of rabies in dogs (3.28 per 100,000 persons) in 2017.

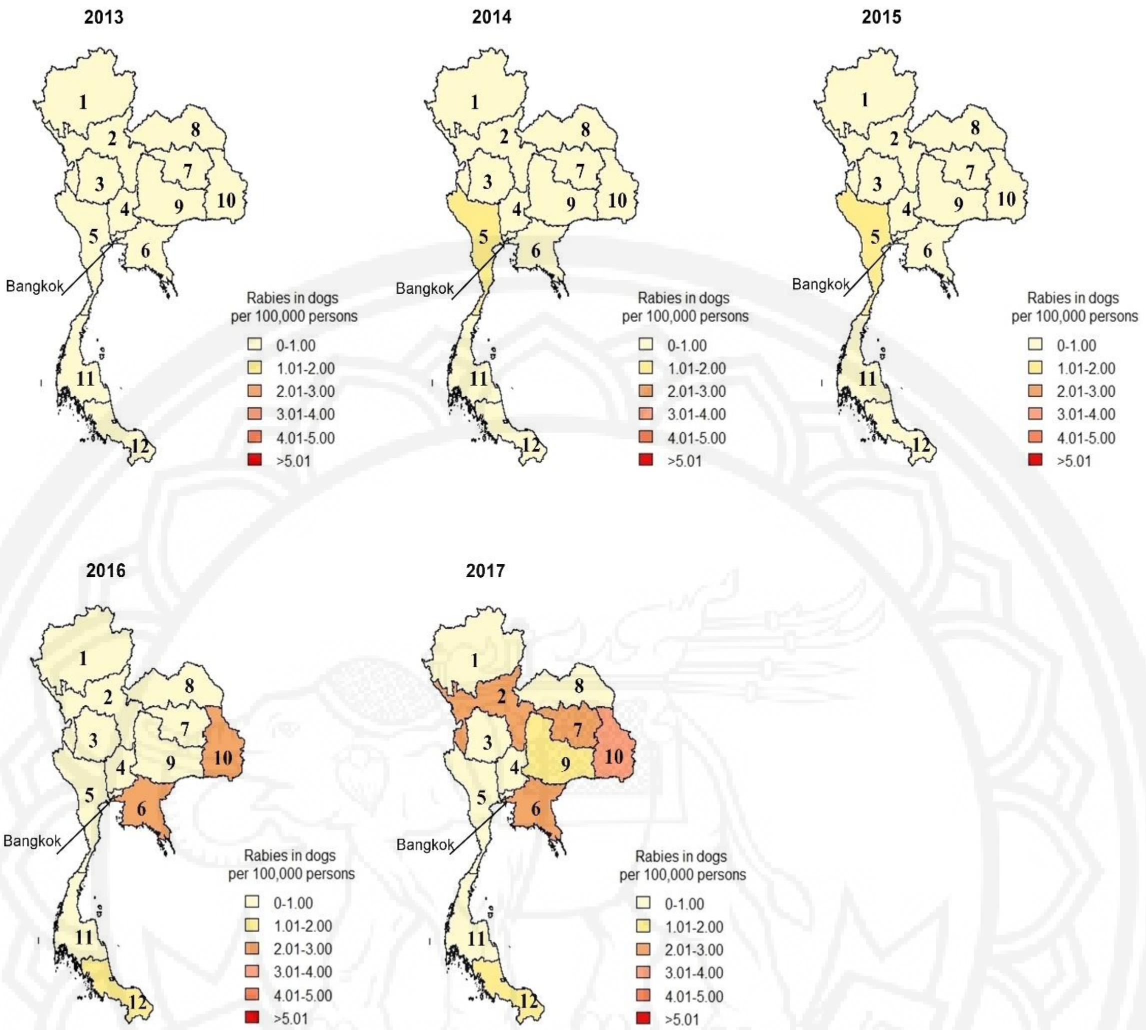

Figure 3 The number of rabies disease detected in dogs per 100,000 persons by health service area 2013 to 2017

Table 2 displays the list of time series models considered for predicting the number of dogs with rabies in Thailand. The models were created by Holt-Winter and Box-Jenkins method. SARIMA (1, 1, 0) $(0, 1, 1)_{12}$ model was chosen as the most suitable model with the lowest AIC and RMSE values (364.24 and 9.30, respectively) when the residuals of the model were independent of each other (p-value of Ljung-Box test = 0.71), were normally distributed (p-value of Shapiro-Wilk test = 0.06), and stationarity (p-value of ADF test = 0.01). The equation of the model is as follows:

$$\hat{y}_t = y_{t-12} + y_{t-1} - y_{t-13} - 0.2576y_{t-1} + 0.2576y_{t-13} + 0.2576y_{t-2} - 0.2576y_{t-14} + \varepsilon_t - 0.5138\varepsilon_{t-12}$$

Where $\hat{y}$ is the predicted value of y in the model, y_t is the observed data (number of rabies in dogs) at time t and ε_t is a residual value at time t. Fitted values from above model had a similar pattern with actual data (Figure 4).

Table 3 reveals the predicted values for next 12 months of rabid dogs based on SARIMA $(1, 1, 0)(0, 1, 1)_{12}$. It can be seen that the number of rabid dogs from laboratory examination was forecasted to be highest in December 2018 (100.8 dogs with 95% confidence interval (CI) 41.6 to 160 dogs).

Table 2 Forecasting model of rabies in dogs in Thailand, year 2013 to 2017

Model	AIC	RMSE	P-value of Ljung-Box test	P-value of Shapiro-Wilk test	P-value of ADF test
Holt-winter	NA	10.22			
SARIMA$(0, 1, 2)(1, 0, 0)_{12}$	440.11	9.25	0.88	0.56	0.02
SARIMA$(1, 1, 0)(0, 1, 1)_{12}$	**364.24**	**9.30**	**0.71**	**0.06**	**0.01**
SARIMA$(1, 1, 0)(1, 1, 1)_{12}$	366.14	9.14	0.70	0.05	0.01
SARIMA$(1, 1, 0)(1, 0, 1)_{12}$	442.24	9.43	0.70	0.48	0.01
SARIMA$(1, 1, 0)(1, 1, 0)_{12}$	365.93	9.63	0.74	0.17	0.01
SARIMA$(1, 1, 0)(1, 0, 0)_{12}$	440.26	9.44	0.70	0.48	0.01
SARIMA$(1, 1, 0)(0, 1, 0)_{12}$	370.65	10.58	0.80	0.04	0.01
SARIMA$(0, 1, 1)(0, 1, 1)_{12}$	362.62	9.12	0.60	0.04	0.01
SARIMA$(0, 1, 1)(1, 1, 1)_{12}$	364.52	8.95	0.60	0.04	0.01
SARIMA$(0, 1, 1)(1, 0, 1)_{12}$	441.31	9.35	0.92	0.70	0.01
SARIMA$(0, 1, 1)(1, 1, 0)_{12}$	364.33	9.45	0.59	0.10	0.01
SARIMA$(0, 1, 1)(0, 1, 0)_{12}$	369.26	10.41	0.58	0.01	0.01

NA: Not applicable

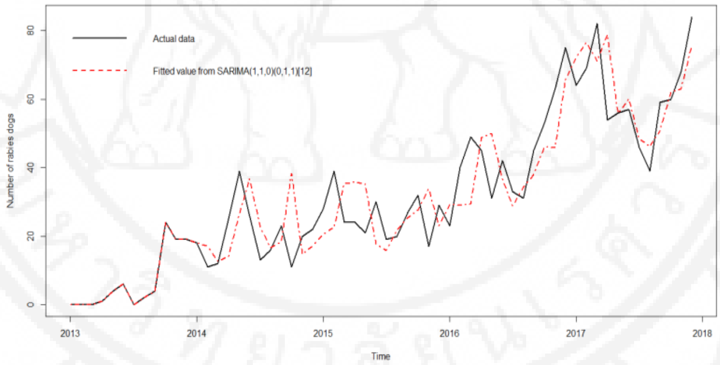

Figure 4 Comparison of the actual number of rabies in dogs with fitted values from the SARIMA model in Thailand 2013 to 2017

Table 3 Predicted values for the next 12 months of rabies in Thai dogs between January 2018 and December 2018

Month	Predicted values	95% CI	
		Lower	Upper
January 2018	76.1	55.0	97.2
February 2018	84.2	58.0	110.5
March 2018	90.8	59.5	122.1
April 2018	77.2	41.7	112.6
May 2018	75.4	36.2	114.7
June 2018	79.0	36.4	121.7
July 2018	68.6	22.8	114.5

Table 3 (Cont.)

Month	Predicted values	95% CI	
		Lower	Upper
August 2018	65.2	16.4	114.0
September 2018	80.0	28.4	131.6
October 2018	83.3	29.0	137.6
November 2018	88.2	31.4	145.0
December 2018	100.8	41.6	160.0

Table 4 displays the most suitable predicting models created using Box-Jenkins method for fitting diseased dogs in each region and health service area in Thailand. It was found that the SARIMA model was suitable for data from all areas except Northeastern, Eastern, health service area no.3 and health service area no.8. (Table 4).

Table 4 Selected models of rabies in dogs in Thailand by region and health service area.

Area		Model	Fit	
			RMSE	AIC
Regions	Northern	SARIMA(1, 1, 0) $(0, 1, 0)_{12}$	1.82	215.16
	Northeastern	ARIMA(0, 1, 1)	4.15	306.17
	Central	SARIMA(0, 1, 1) $(1, 1, 0)_{12}$	1.89	214.36
	Eastern	ARIMA(0, 1, 2)	3.85	334.28
	Western	SARIMA(0, 1, 1) $(0, 1, 1)_{12}$	1.18	173.33
	Southern	SARIMA(0, 1, 1) $(1, 1, 1)_{12}$	2.66	271.28
Heath Regional	1	SARIMA(1, 1, 0) $(0, 1, 1)_{12}$	1.83	211.27
	2	SARIMA(1, 1, 0) $(1, 1, 1)_{12}$	0.61	119.74
	3	ARIMA(0, 0, 1)	0.20	-15.80
	4	SARIMA(1, 1, 0) $(0, 1, 1)_{12}$	1.41	202.75
	5	SARIMA(0, 1, 1) $(1, 1, 0)_{12}$	1.23	191.15
	6	SARIMA(0, 1, 1) $(1, 1, 0)_{12}$	3.87	282.74
	7	SARIMA(1, 1, 0) $(0, 1, 0)_{12}$	1.06	179.32
	8	ARIMA(1, 1, 2)	3.06	264.12
	9	SARIMA(1, 1, 0) $(0, 1, 1)_{12}$	1.86	216.17
	10	SARIMA(0, 1, 1) $(0, 0, 1)_{12}$	4.24	345.21
	11	SARIMA(0, 1, 1) $(1, 1, 1)_{12}$	0.68	136.65
	12	SARIMA(0, 1, 1) $(1, 1, 1)_{12}$	1.97	240.63
	Bangkok	SARIMA(0, 1, 1) $(1, 1, 1)_{12}$	3.02	277.67

Discussion

This research investigated the time series for rabies prediction in dogs in Thailand using the Holt-Winter exponential smoothing method, and the ARIMA and SARIMA models. After comparing the forecast models from those methods, it was found that The SARIMA (1, 1, 0) $(0, 1, 1)_{12}$ model was the most suitable for rabies prediction in dogs in Thailand. The predicted values of the model looked similar pattern with actual data and indicated that rabies in dogs will increase in March and will peak in December 2018 (100.8 rabid dogs, 95% CI 41.6 to 160 rabid dogs). Additionally, this method also fitted with most regions and health service areas in Thailand.

Our results are consistent with Hengtrakool et al. (2017) who performed a time series analysis of rabies in Thailand during 2015 to 2016 using a decomposition method. They reported that the occurrence of rabies in dogs correlates with seasons as most cases of rabies were usually found in February (Hengtrakool et al., 2017). According to results from this study, the highest surveillance of disease occurred during February and November every year. This is similar to the study of Ernst and Fabrega (1989) that performed a time series of rabies control in Chile from 1950 to 1986. Ernst's study showed that rabies tended to increase in November and December of every year, and that the outbreak cycle usually repeats every five years.

The SARIMA model that we used in this study proved the most suitable for predicting rabies in dogs in Thailand at regional and health service area levels. Other study from Latin America indicated that canine rabies had seasonality occurred in spring and late winter, and showed results from SARIMA models that ARIMA(0, 1, 1), SARIMA(1, 0, 1)$(0, 1, 1)_{12}$ and SARIMA(1, 1, 1)$(0, 1, 1)_{12}$ were adequate models for canine rabies in Bolivia, Argentina and Paraguay, respectively (Scortti, Cattan, & Canals, 1997). However, two studies from China reported using ARIMA models to estimate human rabies in China. Ping and coworkers reported ARIMA (2, 1, 1)$(2, 0, 0)_{12}$ as the best predictive model (Ping et al., 2018) and the Rabies Surveillance Center in Chenghua District of Chengdu City reported that ARIMA (1, 0, 0)$(1, 1, 0)_{12}$ could be useful for predicting the case number of rabies (Jing & Qiang, 2016).

The map of the number of rabies disease detected in dogs per 100,000 persons in all regions and health service areas in Thailand were created for depicting the risk of outbreaks in Thailand. Lee et al. (2018) conducted a similar geographic study of rabies in Vietnam to understand the relationship between geographic patterns and new risk areas in each period. This study from Vietnam found that rabies in human was at its highest point in February and July (Lee et al., 2018). In addition, Guo et al. (2013) investigated the spread of rabies in humans in China from 2005 to 2011 and found that human rabies was distributed in geographical clusters (Guo et al., 2013). Moreover, a study of the epidemiologic trends of rabies in domestic animals in southern Thailand between 1994 to 2008 found that Thailand had long been a country highly endemic for rabies and rabies was still endemic in its dog population (Thiptara, Atwill, Kongkaew, & Chomel, 2011).

The current study analyzed only the number of rabies infections in dogs. It is likely that the inclusion if other factors such as average temperature and density of dog populations in each area, vaccination rates, and rabies prevention campaigns would improve the predictability of the model.

Conclusion

The highest proportion of rabid dogs were detected in February and November every year. The northeastern region and health service area 10 of Thailand had the highest proportion of dog with rabies in 2017. SARIMA (1, 1, 0) $(0, 1, 1)_{12}$ Model is recommended to forecast rabid dogs in Thailand. Moreover, the model indicated that highest number of rabid dogs was found in December 2018 about 100.8 dogs, 95% CI 41.6 to 160 dogs). The SARIMA model was also appropriate with most regional levels and health service areas.

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