TEMPORAL PATTERNS AND FORECAST OF DENGUE INFECTION IN NORTHEASTERN THAILAND

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Abstract. This study aimed to determine temporal patterns and develop a forecasting model for dengue incidence in northeastern Thailand. Reported cases were obtained from the Thailand national surveillance system. The temporal patterns were displayed by plotting monthly rates, the seasonal-trend decomposition procedure based on loess (STL) was performed using R 2.2.1 software, and the trend was assessed using Poisson regression. The forecasting model for dengue incidence was performed in R 2.2.1 and Intercooled Stata 9.2 using the seasonal Autoregressive Integrated Moving Average (ARIMA) model. The model was evaluated by comparing predicted versus actual rates of dengue for 1996 to 2005 and used to forecast monthly rates during January to December 2006. The results reveal that epidemics occurred every two years, with approximately three years per epidemic, and that the next epidemic will take place in 2006 to 2008. It was found that if a month increased, the rate ratio for dengue infection decreased by a factor 0.9919 for overall region and 0.9776 to 0.9984 for individual provinces. The amplitude of the peak, which was evident in June or July, was 11.32 to 88.08 times greater than the rest of the year. The seasonal ARIMA (2, 1, 0) $(0, 1, 1)^{12}$ model was model with the best fit for regionwide data of total dengue incidence whereas the models with the best fit varied by province. The forecasted regional monthly rates during January to December 2006 should range from 0.27 to 17.89 per 100,000 population. The peak for 2006 should be much higher than the peak for 2005. The highest peaks in 2006 should be in Loei, Buri Ram, Surin, Nakhon Phanom, and Ubon Ratchathani provinces.

INTRODUCTION

Dengue is a mosquito-borne infection which in recent years has become a major international public health concern in tropical and subtropical regions around the world. The global burden of dengue has grown dramatically in recent decades and all tropical regions of the world have now become hyperendemic, with all four serotypes circulating simultaneously (WHO/SEARO, 1999; Suwanchaichinda, 2000; Nisalak *et al*, 2003). The factors associated with the worldwide increase in the incidence and distribution of dengue are closely linked to changes in human ecology and behavior (WHO, 1997, 2004; Thomas, 2004). Although case fatality is decreasing, dengue infection is still a great burden on public health of Thailand (Gubler, 2000; Bureau of Epidemiology, 2002; UNDP/World Bank/WHO, 2004). Presently, neither a vaccine nor specific treatment are available. The only solution to prevent the disease is vector control. Thus, well designed and reliable strategies to specify the temporal patterns and a predictive model for the disease

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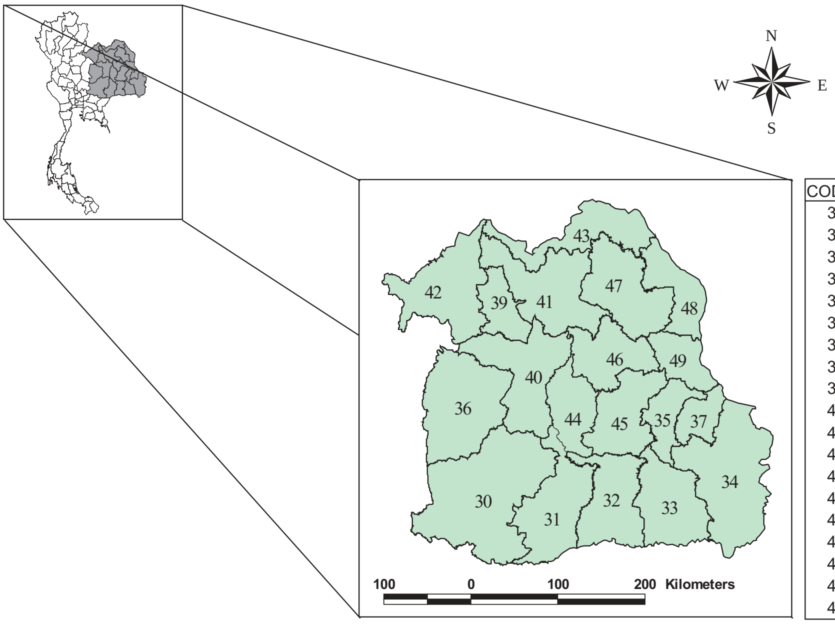
are needed. Most previous research efforts about dengue have focused on the biological, entomological and clinical aspects and risk factors for dengue incidence and epidemics. During the past few decades, research regarding the temporal patterns and the development of forecasting models for dengue have gained in interest, especially in Thailand, where graphical presentation of the data is a major strategy in specifying the temporal patterns of the disease and associated factors, especially in regard to climatic variables, which have been used to model disease epidemics. Findings from the research so far has indicated that the temporal patterns and ability to develop a predictive forecasting model for this disease ocurrence are still doubtful and not reliable (Kanchanapairoj *et al*, 2000; Nagao *et al*, 2003; Muttitanon *et al*, 2005; Thammapalo *et al*, 2005). Our research was carried out in an attempt to determine the temporal patterns of disease using a decomposition procedure and to propose a forecasting model for dengue incidence by taking seasonal variation into account using a seasonal autoregressive integrated moving average model.

MATERIALS AND METHODS

The northeastern part of Thailand occupies approximately 170,226 km^2 or roughly one-third of the country. It is bordered by Lao PDR in the northern part of the region and by Cambodia in the southern part of the region. In 2005, reported census population was 21,297,769 with a population density ranging from 52.13 to 154.69 persons/km^2. The mean annual rainfall ranged between 824.4 mm and 2,306.0 mm, with a relative humidity of 70% to 77%. It is comprised of 19 provinces (Fig 1) and the major source of income is agriculture, especially the cultivation of rice. During the last decades there has been a huge development of infrastructure



CODE	PROVINCE NAME
30	Nakhon Ratchasima
31	Buri Ram
32	Surin
33	Si Sa Ket
34	Ubon Ratchathani
35	Yasothon
36	Chaiyaphum
37	Amnat Charoen
39	Nong Bua Lam Phu
40	Khon Kaen
41	Udon Thani
42	Loei
43	Nong Khai
44	Maha Sarakham
45	Roi Et
46	Kalasin
47	Sakon Nakhon
48	Nakhon Phanom
49	Mukdahan

Fig 1–Northeastern Thailand by province.

and travel in this region with the availability of regional airports, domestic airlines, and several bus routes (Anonymous, 2007).

Reported dengue fever, dengue hemorrhagic fever and dengue shock syndrome (DF, DHF and DSS) cases and midyear population were obtained from the national surveillance database, Bureau of Epidemiology, Ministry of Public Health. Such reported cases were diagnosed by physicians using WHO criteria (WHO, 1997) and reported following national surveillance system guidelines.

Monthly incidence rates for the overall region and for individual provinces were calculated using the midyear population as the denominator. The temporal patterns for total dengue cases, DF and DHF were explored by plotting monthly rates and the seasonal-trend decomposition procedure based on loess (STL) using R 2.2.1 software. In determining trends and seasonal variation, techniques based on locally weighted least squares were employed. The trend was assessed using a Poisson regression model with monthly cases, with population size being the offset term, as the outcome and month as the predictor variable.

Modeling and forecasting of dengue incidence was performed using R 2.2.1 and Intercooled Stata 9.2 using the seasonal Autoregressive Integrated Moving Average (ARIMA) model. In order to identify the best fit model, different models were examined including ACF and partial ACF. Possible seasonal ARIMA models, with seasonal and non-seasonal differencing, were fitted to data series for the overall northeastern region and individual provinces from 1996 to 2003 (the training sets). Then the one-step ahead prediction method was used for each of the remaining data series during 2004 to 2005 (the testing sets). The model diagnostic test was performed by examining the stadardized residuals, residual ACF, p-values for Ljung-Box statistic, the cumulative periodogram for residuals, and the Box–Pierce statistic. A value of $p>0.05$ was considered a good model. The mean errors for actual rates and predicted rates for the good models were calculated. The best model and least mean error were fitted to the data from 1996 to 2005 and monthly dengue incidence rates from January to December 2006 were forecasted.

RESULTS

Temporal patterns of dengue incidence

The median annual incidence rates of total dengue, DHF, and DF in nineteen provinces in northeastern Thailand during 1996 to 2005 were 92.99 (range= 7.70-233.76), 73.85 (range=5.47-197.71), and 19.39 (range=2.23-48.31) per 100,000 population, respectively. Almost all cases had DHF, whereas the rates of DF have been increasing in recent years. Regarding the occurrence of the disease in the region from 1996 to 2005, there were initially three yearly peaks, followed by two small yearly peaks then three yearly peaks and two medium peaks which likely indicated that epidemics of the disease in the overall region were evident every two years, with approximately three year long epidemic periods (Figs 2, 3). For the trends, we found that if a month increased, the rate ratio for dengue infection would be expected to decrease by a factor 0.9919 for the overall region and 0.9776 to 0.9984 for the individual provinces. After removing the long-term trend, the seasonal patterns of dengue incidence showed sharp peaks in June or July, except in 1997 in which the peak was evident in August. The amplitude of the peak was 11.32 to 88.08 times greater than the rest of the same year (Fig 4).

Modeling and forecasting of dengue incidence

For the total dengue incidence in the overall northeastern region, the seasonal ARIMA (2, 1, 0) $(0, 1, 1)^{12}$ model was fitted to data from 1996 to 2003. Employing the ARIMA model, monthly rates during 2004 to 2005 were predicted and compared to actual rates

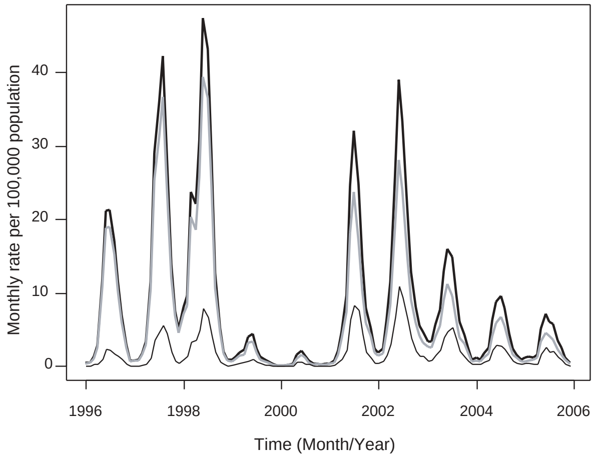


Fig 2–Monthly rates of total dengue (black-thick), DHF (grey), and DF (black-thin) incidence in northeastern Thailand during 1996 to 2005.

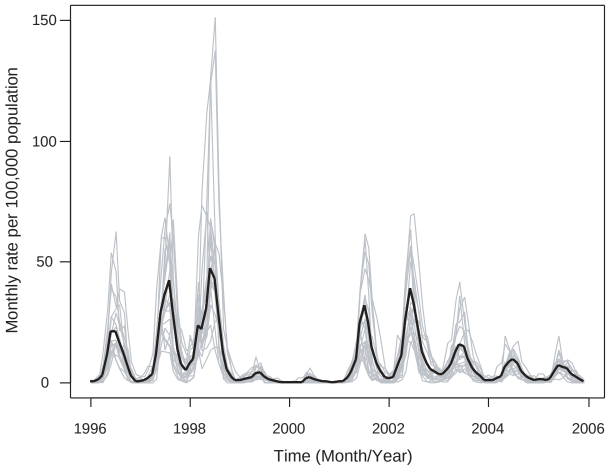


Fig 3–Monthly rates of total dengue incidence in the overall northeastern region (black) and individual provinces (grey) during 1996 to 2005.

during the same period. The model indicated that the predicted rates and the actual rates fit closely (Fig 5) and the mean absolute percentage error (MAPE) was 6.6%. The model was also the best model for forecasting regional monthly rates during January to December 2006. When examining the models for each province in the region, the best seasonal ARIMA model for each individual province was also identified. The best fit models varied for each province. As shown in Table 1, data series for the six provinces best fit the ARIMA (1, 1, 0) (0, 1, 1)^{12} model, five provinces best fit the ARIMA (0, 1, 1) (0, 1, 1)^{12} model and five provinces best fit the ARIMA (0, 1, 0) (0, 1, 1)^{12} model, two provinces best fit the ARIMA (2, 1, 0) (0, 1, 1)^{12} model, and one province best fit the ARIMA (1, 1, 1) (0, 1, 1)^{12} model.

After fitting the best model for the data from 1996 to 2005 and forecasting monthly dengue incidence rates for January to December 2006, it was found that the monthly rates for the northeastern region should range between 0.27 and 17.89 per 100,000 population and the peak in 2006 for the overall region as well as the individual provinces would be much higher than the peak for 2005, except for the Mukdahan Province where the two peaks would be equal (Figs 6, 7). The highest peak was seen in the Loei Province (33.07 per 100,000 population), followed by Buri Ram, Surin, Nakhon Phanom, and Ubon Ratchathani (26.84, 25.74, 24.29, and 23.05 per 100,000 population), respectively (Table 2).

DISCUSSION

From 1996 to 2005, there were initially three yearly peaks, followed by two small yearly peaks then three yearly peaks and two medium peaks which indicates the disease epidemic occurred every two years, with approximately three year epidemic periods. This is similar to the countrywide pattern and is thought to reflect host-pathogen population dynamics (Bureau of Epidemiology, 2002; Nisalak *et al*, 2003; Cummings *et al*, 2004), and that the next epidemic will be observed in 2006 to 2008. The annual rates during the epidemic periods for nearly all the provinces were higher than the control target set by the Ministry of Public Health (50 per 100,000 popoulation) (Suwanchaichinda, 2000; Julaserikul, 2002; Usaha *et al*, 2004). This indicates that efforts for disease control, which

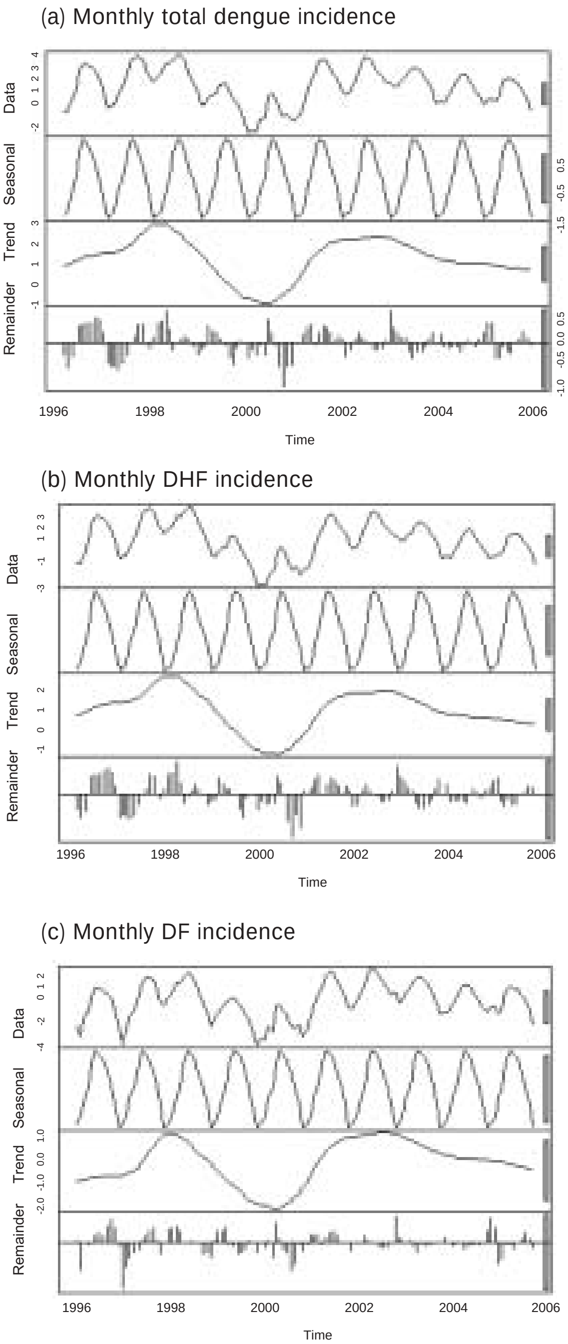


Fig 4–The trend, seasonal and residual (remainder) components derived from the STL decomposition of monthly total dengue incidence for the overall northeastern region (Data), log10 scale during 1996 to 2005; (a) monthly total dengue incidence; (b) monthly DHF incidence; and (c) monthly DF incidence.

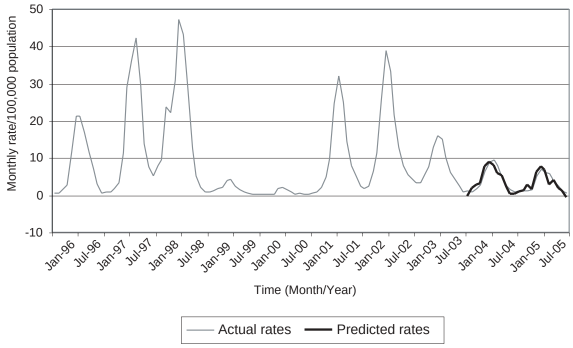


Fig 5–Monthly rates of total dengue incidence for the overall northeastern region. Grey: actual rates during 1996 to 2005; Black: predicted rates during 2004 to 2005 after fitting an ARIMA (2, 1, 0) (0, 1, 1)^{12} model to data during 1996 to 2003.

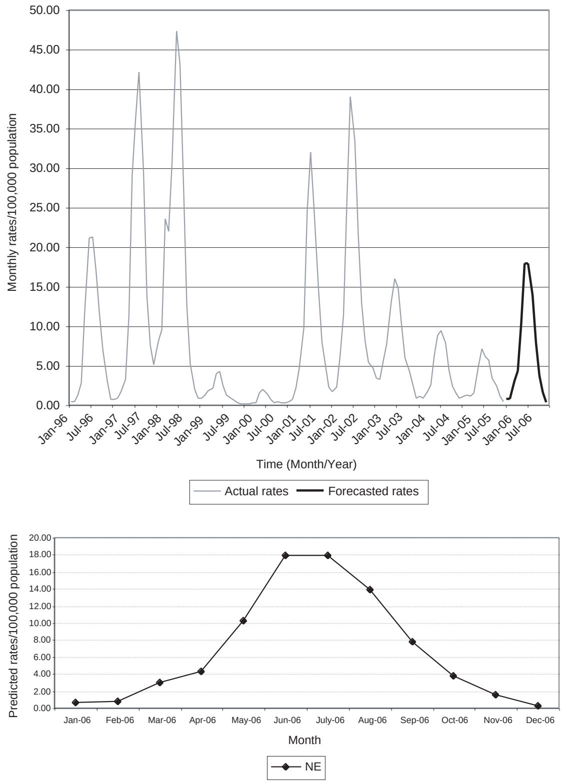


Fig 6–Forecasted monthly total dengue incidence for the overall northeastern region after fitting an ARIMA (2, 1, 0) (0, 1, 1)^{12} model to data for 1996 to 2005. Top: actual rates (grey) and forecasted rates (black) during 1996 to 2006; Bottom: forecasted rates for 2006.

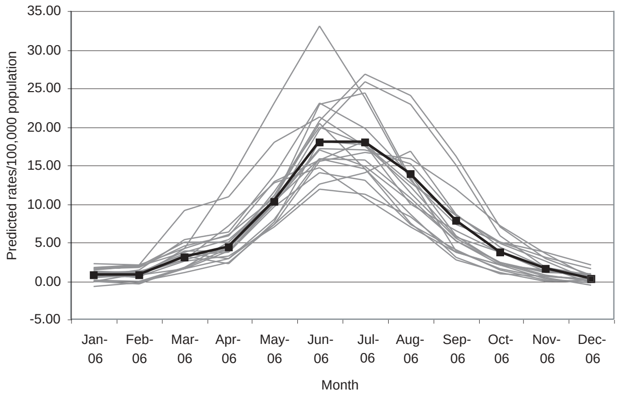


Fig 7–Forecasted monthly total dengue incidence for the overall northeastern region (black) and individual provinces (grey) during January to December 2006.

rely on vector control, have not met desirable outcomes and this goal has been difficult to achieve for most provinces in the region (Thavara *et al*, 2006). This may correlate with the predominant dengue serotypes which change from time to time and place to place (Anantapreecha *et al*, 2004). Moreover, epidemics may be due to the spread of a new or rare virus serotype in areas with limited immune protection against that serotype (herd immunity) (Mutttitanon *et al*, 2005). A sharp seasonal peak is usually observed in June or July, which may be attributed to patterns of vector occurrence and the high rates of dengue transmission in May and June (Strickman and Kittiyapong, 2003).

Table 1
Differences between actual and predicted monthly rates for total dengue incidence for the overall northeastern region and individual provinces.

Province	Best fitted model (Seasonal ARIMA)	Average monthly rate/100,000 population		
		Actual rates	Predicted rates	Actual-predicted rates
Nakhon Ratchasima	$(1, 1, 0) (0, 1, 1)^{12}$	4.63	4.35	0.28
Buri Ram	$(0, 1, 1) (0, 1, 1)^{12}$	4.58	4.23	0.34
Surin	$(2, 1, 0) (0, 1, 1)^{12}$	3.61	3.56	0.04
Si Sa Ket	$(1, 1, 0) (0, 1, 1)^{12}$	4.00	4.05	-0.06
Ubon Ratchathani	$(0, 1, 0) (0, 1, 1)^{12}$	3.93	3.74	0.19
Yasothon	$(1, 1, 1) (0, 1, 1)^{12}$	2.30	2.31	-0.01
Chaiyaphum	$(0, 1, 0) (0, 1, 1)^{12}$	3.63	3.21	0.43
Amnat Charoen	$(0, 1, 0) (0, 1, 1)^{12}$	3.19	2.93	0.26
Nong Bua Lam Phu	$(0, 1, 1) (0, 1, 1)^{12}$	2.13	2.04	0.09
Khon Kaen	$(1, 1, 0) (0, 1, 1)^{12}$	3.19	2.72	0.47
Udon Thani	$(0, 1, 1) (0, 1, 1)^{12}$	2.07	1.74	0.33
Loei	$(0, 1, 1) (0, 1, 1)^{12}$	3.35	3.28	0.07
Nong Khai	$(1, 1, 0) (0, 1, 1)^{12}$	2.76	2.75	0.01
Maha Sarakham	$(0, 1, 0) (0, 1, 1)^{12}$	1.94	1.29	0.65
Roi Et	$(0, 1, 0) (0, 1, 1)^{12}$	4.17	4.16	0.00
Kalasin	$(1, 1, 0) (0, 1, 1)^{12}$	3.75	3.50	0.25
Sakon Nakhon	$(0, 1, 1) (0, 1, 1)^{12}$	4.01	3.86	0.15
Nakhon Phanom	$(2, 1, 0) (0, 1, 1)^{12}$	1.77	1.83	-0.06
Mukdahan	$(1, 1, 0) (0, 1, 1)^{12}$	3.92	3.86	0.06
Northeastern region	$(2, 1, 0) (0, 1, 1)^{12}$	3.53	3.31	0.22

Table 2
Forecasted rates of total dengue incidence for the overall northeastern region and the individual provinces duning January to December 2006.

Province	Forecasted rates/100,000 population											
	Jan-06	Feb-06	Mar-06	Apr-06	May-06	Jun-06	Jul-06	Aug-06	Sept-06	Oct-06	Nov-06	Dec-06
Nakhon Ratchasima	0.06	-0.03	1.08	2.30	7.31	15.49	16.56	15.89	11.95	7.10	3.49	0.46
Buri Ram	1.39	1.84	5.00	4.97	11.12	20.73	26.84	24.02	16.15	7.00	2.81	0.77
Surin	0.75	0.84	3.82	3.79	9.98	19.63	25.74	22.91	15.03	5.88	1.70	-0.29
Si Sa Ket	1.55	1.67	4.45	5.86	12.85	15.65	18.07	11.33	5.50	2.37	1.14	0.84
Ubon Ratchathani	0.53	1.38	5.31	6.28	13.71	23.05	19.83	13.69	5.79	2.24	0.53	0.10
Yasothon	0.49	0.66	3.32	3.67	9.54	14.07	12.97	7.22	3.98	1.47	0.04	-0.28
Chaiyaphum	-0.05	0.84	3.20	2.20	7.59	18.11	17.59	12.73	8.43	4.77	2.57	0.15
Amnat Charoen	0.87	0.48	4.16	5.94	10.74	20.44	14.57	7.45	2.79	1.08	-0.07	0.09
Nong Bua Lam Phu	1.68	2.04	9.16	10.95	18.01	21.26	17.46	12.21	5.73	3.73	1.15	0.59
Khon Kaen	1.63	1.82	3.61	5.39	10.34	17.05	16.89	15.16	8.46	5.07	2.95	1.59
Udon Thani	0.60	0.60	2.53	3.26	6.93	11.95	11.25	8.28	3.66	1.98	1.29	0.65
Loei	2.16	2.11	4.21	12.67	23.11	33.07	23.68	13.11	7.23	5.00	3.64	2.06
Nong Khai	1.12	1.29	2.78	7.19	12.78	14.75	10.81	6.91	3.61	2.05	1.46	0.76
Maha Sarakham	1.22	1.12	3.59	2.86	7.22	12.57	13.95	16.83	8.66	4.35	1.76	0.76
Roi Et	0.99	0.79	1.55	2.84	8.03	15.85	15.69	10.80	5.14	2.12	0.20	-0.18
Kalasin	-0.71	-0.33	1.51	3.85	10.11	16.98	14.85	10.26	5.10	2.32	0.76	-0.04
Sakon Nakhon	0.00	-0.03	1.78	4.24	10.27	15.88	14.53	8.60	3.05	0.96	0.59	0.17
Nakhon Phanom	-0.12	-0.37	1.70	5.01	10.34	22.88	24.29	13.28	3.82	1.48	0.45	-0.56
Mukdahan	1.25	0.83	2.63	4.17	11.52	19.86	17.69	9.88	6.55	3.65	1.65	0.33
Northeastern region	0.67	0.77	3.01	4.34	10.32	17.88	17.89	13.89	7.83	3.72	1.50	0.27

This study identified the best seasonal ARIMA model for each data series. The model was found to be effective in forecasting monthly rates of dengue incidence. The results of the model indicate higher forecasted rates of dengue for 2006 compared to 2005, especially in four provinces located along the Thai-Lao PDR and Thai-Cambodia border areas. This may be correlated with the predominant dengue serotypes, spread of a new virus serotype in those areas or travel of people, both within and across countries.

In conclusion, epidemics of dengue infection in northeastern Thailand by modeling are forecast to occur every two years, lasting approximately three years per epidemic periods, and the next epidemic should occur from 2006 to 2008. It was found that if a month increased, the rate ratio for dengue infection would be expected to decrease by a factor 0.9919 for the overall region and 0.9776 to 0.9984 for each individual province. The seasonal patterns for dengue incidence showed a sharp peak in June or July, of which the amplitude of the peak was 11.32 to 88.08 times greater than the baseline throughout the year. This study identified the best fitted seasonal ARIMA model of each data series and the model was found to be effective in forecasting monthly rates of dengue incidence.

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REFERENCES

Anantapreecha S, Chanama S, A-nuegoonpipat A, *et al*. I. Annual changes of predominant dengue virus serotypes in six regional hospitals in Thailand from 1999 to 2002. *Dengue Bull* 2004; 28: 1-6.

Anonymous.Geographic of Thailand. Northeastern region. (In Thai). [Cited 2007 Mar 4]. Available from: URL: http://www.geocities.com/jea_pat/

Bureau of Epidemiology. Annual epidemiological surveillance report 2002 (In Thai). [Cited 2006 Nov 17]. Available from: URL: http://epid.moph.go.th/

Cummings DA, Irizarry RA, Huang NE, *et al*. Travelling waves in the occurrence of dengue haemorrhagic fever in Thailand. *Nature* 2004; 427: 344-7.

Gubler DJ. Epidemic dengue/dengue haemorragic fever: an emerging global public health problem a challenge for the 21st century. In: Suwanchaichinda C, ed. Proceedings the first international conference on dengue and dengue haemorrhagic fever, Thailand. Nonthaburi: Ministry of Public Health, 2000.

Julaserikul S, ed. Mannual of community participatory learning for dengue haemorrhagic fever control. Nonthaburi: Goods and Inventories Post, 2002. (In Thai).

Kanchanapairoj K, McNeil D, Thammapalo S. Climatic factors influencing the incidence of Dengue Haemorrhagic Fever in southern Thailand. *Songklanakarin Med J* 2000;18: 77-83.

Mutttitanon W, Kongthong P, Kongkanon C, Yoksan S, Gonzalez JP, Babazan P. Spatial and temporal dynamics of dengue haemorrhagic fever epidemics (Nakhon Pathom province, Thailand, 1997-2001). [Cited 2005 Sep 14]. Available from: URL: http://www.gisdevelopment.net/application/health/planning/healthp0010pf.html

Nagao Y, Thavara U, Chitnumsup P, Tawatsin A, Chansang C, Campball-Lendrum D. Climatic and social risk factors for Aedes infestation in rural Thailand. *Trop Med Int Health* 2003; 8: 650-9.

Nisalak A, Endy TP, Nimmannitaya S, *et al*. Serotype-specific dengue virus circulation and dengue disease in Bangkok, Thailand from 1973 to 1999. *Am J Trop Med Hyg* 2003; 68: 191-202.

Strickman D, Kittiyapong P. Dengue and its vectors in Thailand: calculated transmission risk from total pupal counts of *Aedes aegypti* and association of wing-length measurements with aspects of the larval habitat. *Am J Trop Med Hyg* 2003; 68: 209-17.

Suwanchaichinda C, ed. Proceedings the first international conference on dengue and dengue haemorrhagic fever, Thailand. Nonthaburi: Ministry of Public Health, 2000.

Thammapalo S, Chongsuwiwatwong V, McNeil D, Geater A. The climatic factors influencing the occurrence of dengue hemorrhagic fever in Thailand. *Southeast Asian J Trop Med Public Health* 2005; 36: 191-6.

Thavara U, Siriyasatien P, Tawatsin A, *et al*. Double infection of heteroserotypes of dengue viruses in field populations of *Aedes aegypti* and *Aedes albopictus* (Diptera:Culicidae) and serological features of dengue viruses found in patients in southern Thailand. *Southeast Asian*

J Trop Med Public Health 2006; 37: 468-76.

Thomas PM. Dengue: The risk to developed and developing countries (Online). [Cited 2004 Oct 8]. Available from: URL: http://www.nap.edut/openbook/0309051363/html

UNDP/World Bank/WHO. Strategic direction for research (Online). [Cited 2004 Jul 20]. Available from: URL: http://www.who.int/tdr/diseases/dengue/strategy.htm

Usaha J, Sensatien S, Panthana S. Evaluation of the dengue prevention and control programs in commemmoration of the Sixth-Cycle (72nd) Birthday Anniversary of His Majesty the King of Thailand in December 1999 during 1999-2000. Nonthaburi: Goods and Inventories Post, 2004. (In Thai).

WHO/SEARO. Regional guidelines on dengue/DHF prevention and control. New Delhi: Regional Publication, 1999.

World Health Organization. Dengue haemorrhagic fever: diagnosis, treatment, and control. 2nd ed. Geneva: WHO, 1997.

World Health Organization. Dengue and dengue haemorrhagic fever. [Cited 2004 Sep 10]. Available from: URL: http://www.who.int/mediacentre/factsheets2fs1172en/