The Clearness Index Model for Estimation of Global Solar Radiation in Thailand

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Abstract

The aim of this paper is to present a novel model to estimate monthly global solar radiation in Thailand. The novel model was investigated based upon the regression technique. Meteorological data sets obtained from the ground-based measurement between 1995-2004 at Khon Kaen, Ubon Ratchathani, Nakhon Sawan, Bangkok and Songkhla were used in modeling. The monthly clearness index and normalized monthly sunshine duration were correlated in order to search the regression coefficients using 5 different models i.e. linear, quadratic, linear-logarithmic, logarithmic, and power equations. The MBE, MPE and RMSE were used as the main criteria for selecting the best model for estimation of global solar radiation. Results showed that, the linear equation and power equation were the best fit for Nakhon Sawan whereas the quadratic equation was the best fit for Ubon Ratchathani and Bangkok, while the linear-logarithmic was the best fit for Khon Kaen and Songkhla. Finally, the quadratic equation performed the best fit for all regions compared to other models, as the RMSE was minimum.

Keywords: Clearness Index, Regression, Solar Radiation, Sunshine Duration

1. Introduction

Global solar radiation is the key data for design, development, application and assessment of outdoor solar energy systems. Generally, this data can be obtained accurately from routine ground-based measurement over a particular area. However, the limitation of the measurement is both cost and time consuming. Another means is the use of a model to predict the global solar radiation. Presently several techniques have been presented in modeling solar radiation e.g. forecasting [1] and ANN based modeling [2-3]. However, classical techniques such as regression are still effective. Many results using this technique are presented [4-7]. The model developed by this technique is very useful for simulation and mathematical modeling of such solar energy systems. At present the Meteorological Department has set up solar radiation measurement at 9 main meteorological stations. During the past few years, the Department of Alternative Energy Development and Efficiency (DEDE) has set up a network for measuring global solar radiation. Twenty five stations were set up and installed throughout the country. Results from the collected data by this network are very useful in the prediction of solar radiation in Thailand [8]. It seems to be sufficient, but the number of stations is still limited. To avoid the spatial distribution problem, many researchers have proposed several mathematical models to estimate the global solar radiation from ground-based measurement. The extensive investigations have been conducted and presented [9-12]. Among these models, the sunshine duration was best parameter and is often used to correlate to the global solar radiation.

In Thailand, the estimation of global solar radiation from the number of sunshine hours has been investigated by Kirtikara and Siriprayuk [4]. Most of these models used data sets obtained during the last two decades. Recently, Janjai and Tohsing have proposed a new model for estimating the global solar radiation from sunshine duration in Thailand [10]. In this paper the data set of global solar radiation and sunshine duration between 1995-2004 was used in the analysis for modeling.

2. Data Preparation and Modeling

Prior to analyzing and correlating the clearness index and normalized sunshine duration, the extraterrestrial radiation was firstly computed [13]. In this calculation, the data of location, i.e., latitude and longitude are required. Table 1 shows the geographical locations of five meteorological stations in Thailand. The clearness index, which is the ratio of global solar radiation and extraterrestrial radiation, was then correlated to the normalized sunshine duration (the ratio between the number of sunshine hours and length of the day) based on the regression technique. Five different models as shown in Eq. 1-Eq. 5 were applied to search for the best model. In order to select the best model, the mean bias error (MBE) as shown in Eq. 6, the average absolute percentage error (MPE) as shown in Eq. 7, and the root mean square error (RMSE) as given in Eq. 8., were used as the main criteria. Not only that, the coefficient of determination (r^2) was also used. Finally, contour maps of monthly mean global solar radiation of Thailand were created using Surfer computer software in order to display the spatial distribution of global solar radiation over Thailand. An interval of 0.2 MJ/m^2/day was used to create the contour map.

Table 1 Geographical coordinate of 5 meteorological stations.

Station	Symbol	Latitude (^{o}N)	Longitude (^{o}E)
Khon Kaen	KK	16.28	102.47
Ubon Ratchathani	UB	15.25	104.87
Nakhon Sawan	NSW	15.80	100.02
Bangkok	BK	13.73	100.57
Songkhla	SK	7.20	100.60

Linear Model $K_T = a + bR_s$ (1)

Quadratic $K_T = a + bR_s + cR_s^{\ 2}$ (2)

Linear-Logarithmic $K_T = a + bR_s + c\log R_s$ (3)

Logarithmic $K_T = a + b\log R_s$ (4)

Power $K_T = e^a R_s^{\ b}$ (5)

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(H_i - \hat{H}_i\right) \quad (6)$$

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_i - \hat{H}_i}{H_i}\right)\times 100 \quad (7)$$

$$RMSE = \sqrt{\sum_{i=1}^{n}\left(H_i - \hat{H}_i\right)^2 /(n-k)} \quad (8)$$

where K_T is the monthly clearness index

R_s is the normalized monthly sunshine hours

MBE is the mean bias error

MPE is the average absolute percentage error

$RMSE$ is the root mean square error

a,b,c is the regression coefficient

H_i is the measured global solar radiation

$\hat{H}_i$ is the predicted global solar radiation

n is the number of valid data points

k is the number of parameters estimated in the model.

The goodness of fit was judged by the size of the coefficient of determination. The MBE, MPE, and $RMSE$ were computed as a further check on the stability of the models [12].

3. Results and Discussion

The regression coefficients are shown in Table 2, whereas the errors of each model are displayed in Table 3. Results show that, the linear equation and power equation are the best fit for Nakhon Sawan, whereas the quadratic equation is the best fit for Ubon Ratchathani and Bangkok, while the linear-logarithmic is the best fit for Khon Kaen and Songkhla. Furthermore, the quadratic equation performed the best fit for all regions compared to other models, as the RMSE is at a minimum. Table 2 shows that the r^2 is in the range of 0.819-0.981. Table 3 shows that the MBE is in the range of -0.06-0.47, the MPE is in the range of 5.12-5.49 and the RMSE is in the range of 0.47-1.59. The estimated monthly global solar radiation using the quadratic model for Thailand is shown in Fig. 1-Fig. 12. It is found that the monthly intensity of incident global solar radiation over Thailand is in the range of 14.25-23.76 MJ/m^2/day.

Table 2 Regression coefficients of 5 different models for each station.

Station	Model	a	b	c	r^2
KK	1	0.32	0.45	-	0.98
	2	0.29	0.56	-0.10	0.98
	3	0.34	0.42	0.01	0.98
	4	0.71	0.23	-	0.98
	5	-0.31	0.42	-	0.98
UB	1	0.26	0.49	-	0.88
	2	0.55	-0.66	1.07	0.91
	3	-1.97	0.91	-1.13	0.92
	4	0.69	0.24	-	0.85
	5	-0.32	0.49	-	0.87
NKW	1	0.39	0.27	-	0.83
	2	0.55	-0.66	1.07	0.91
	3	0.29	0.38	-0.06	0.83
	4	0.63	0.14	-	0.82
	5	-0.45	0.27	-	0.82
BK	1	-0.25	0.51	-	0.91
	2	0.43	-0.21	0.71	0.92
	3	-0.26	1.10	-0.29	0.92
	4	0.69	0.24	-	0.89
	5	-0.32	0.49	-	0.90
SK	1	0.25	0.53	-	0.89
	2	-0.05	1.63	-0.96	0.90
	3	1.22	-0.55	0.6	0.90
	4	0.73	0.30	-	0.89
	5	-0.28	0.54	-	0.89

4. Conclusion

This paper investigated a novel model for predicting global solar radiation in Thailand. The meteorological data set between 1995-2004 was analyzed using a regression technique in order to correlate the clearness index and normalized sunshine duration using 5 different models. Results indicate that, the linear and power models are suitable for estimating global solar radiation for Nakhon Sawan, whereas the quadratic model is suitable for Ubon Ratchathani and Bangkok while the linear-

Table 3 The *MBE*, *MPE* and *RMSE* of 5 different models.

Station	Model	*MBE*	*MPE*	*RMSE*
KK	1	0.05	5.13	0.47
	2	-0.01	5.13	0.49
	3	-0.01	5.13	0.49
	4	-0.02	5.12	0.53
	5	-0.02	5.12	0.48
UB	1	-0.04	5.49	1.39
	2	-0.01	5.49	1.22
	3	-0.01	5.49	1.22
	4	-0.06	5.50	1.59
	5	-0.04	5.49	1.49
NKW	1	-0.05	5.33	0.85
	2	0.47	5.21	1.82
	3	-0.05	5.33	0.89
	4	-0.06	5.33	0.89
	5	-0.05	5.33	0.88
BK	1	-0.05	5.49	1.14
	2	-0.05	5.49	1.07
	3	-0.05	5.49	1.08
	4	-0.06	5.49	1.26
	5	-0.05	5.49	1.20
SK	1	0.02	5.33	1.35
	2	0.01	5.32	1.29
	3	0.01	5.32	1.28
	4	0.02	5.32	1.30
	5	0.02	5.32	1.33

logarithmic model is suitable for Khon Kaen and Songkhla. Finally, the quadratic model has the best results for all regions of Thailand. Using the quadratic model, the estimated global solar radiation in Thailand is in the range of 14.25-23.76 MJ/m^2/day. However, these maps are simply indicative of the distribution of solar radiation and can be of limited use for finding out the utilization potential of solar energy.

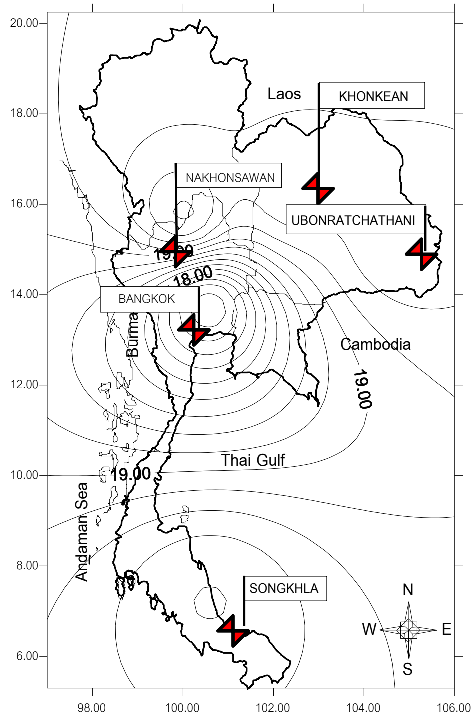

Fig. 1 The contour map of monthly mean global solar radiation in January (MJ/m^2/ day).

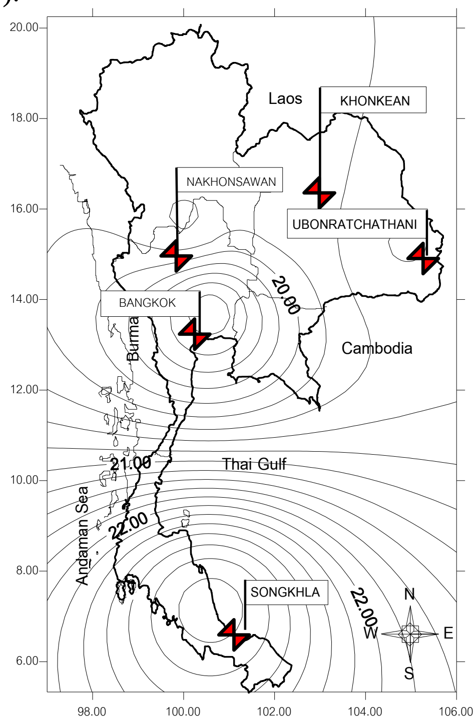

Fig. 2 The contour map of monthly mean global solar radiation in February (MJ/m^2/ day).

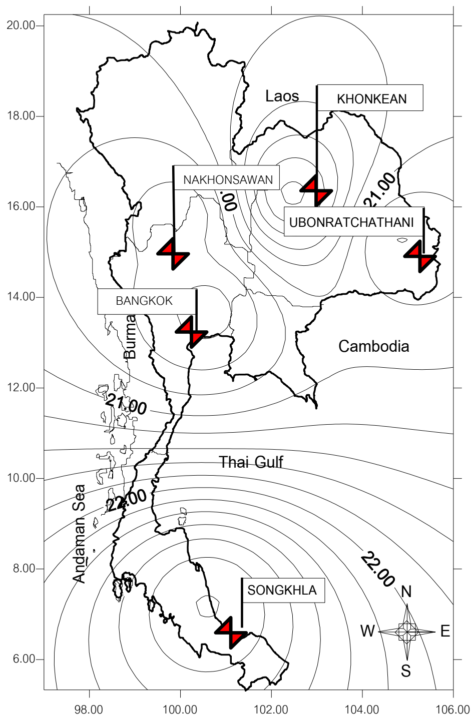

Fig. 3 The contour map of monthly mean global solar radiation in March (MJ/m^2/day).

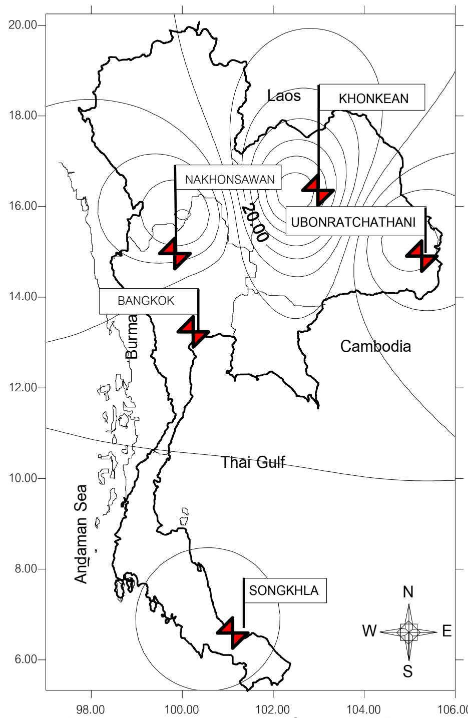

Fig. 5 The contour map of monthly mean global solar radiation in May (MJ/m^2/day).

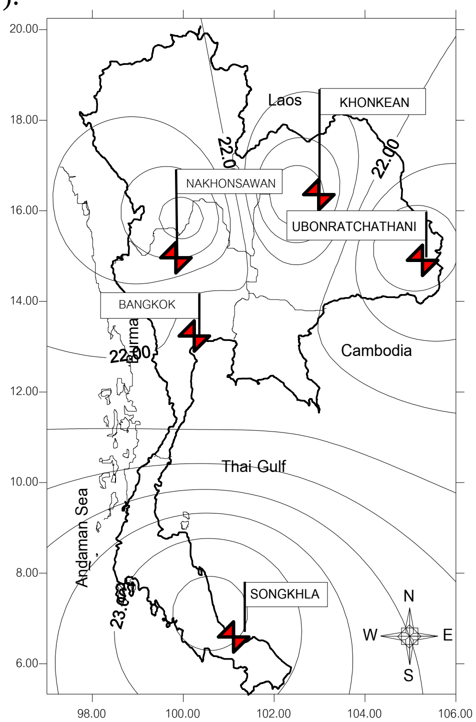

Fig. 4 The contour map of monthly mean global solar radiation in April (MJ/m^2/day).

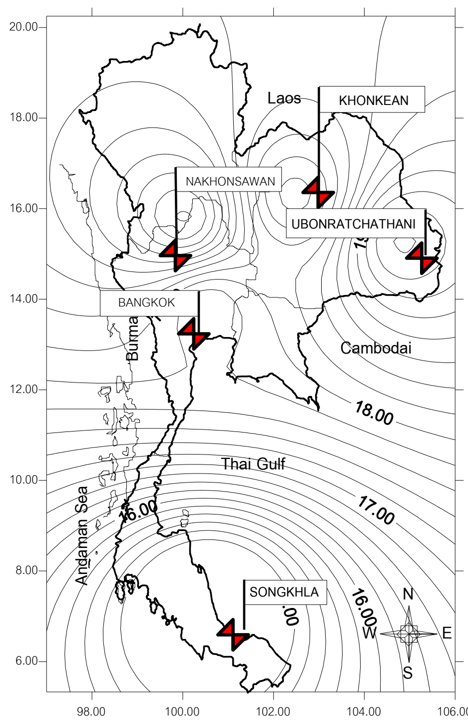

Fig. 6 The contour map of monthly mean global solar radiation in June (MJ/m^2/day).

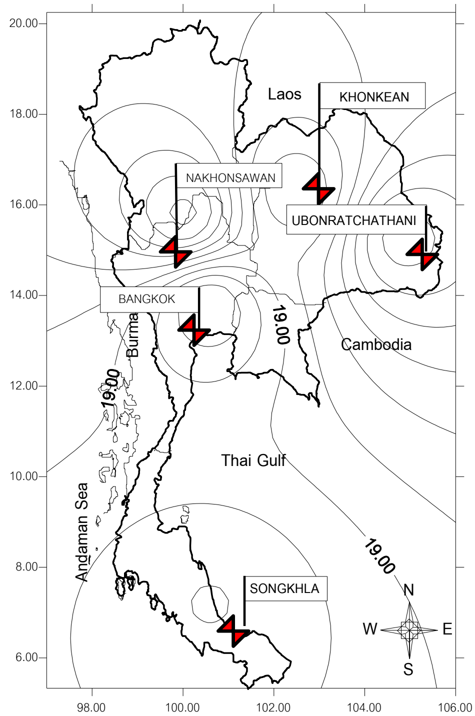

Fig. 7 The contour map of monthly mean global solar radiation in July (MJ/m^2/day).

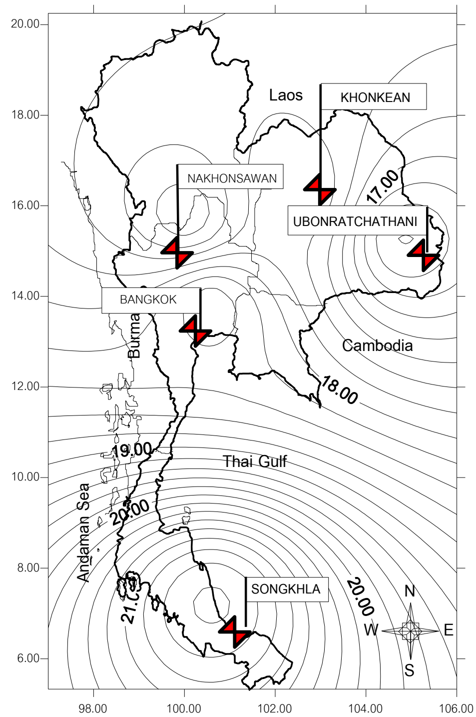

Fig. 8 The contour map of monthly mean global solar radiation in August (MJ/m^2/day).

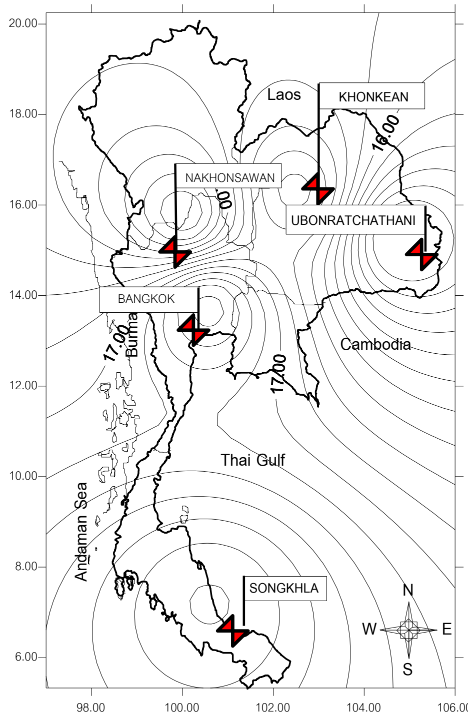

Fig. 9 The contour map of monthly mean global solar radiation in September (MJ/m^2/day).

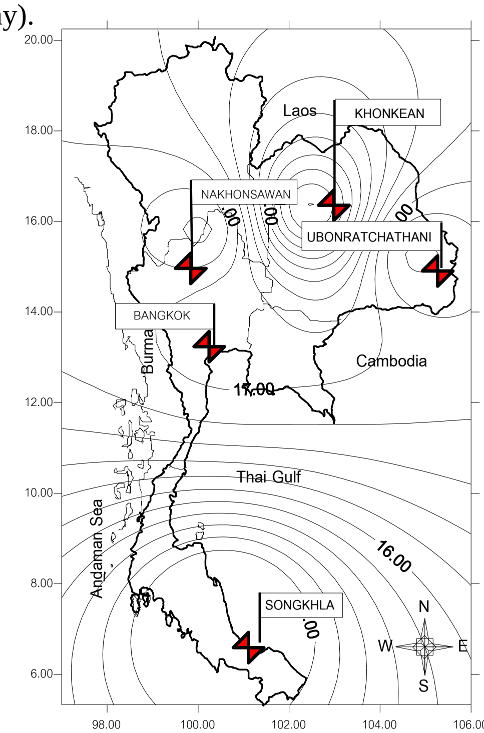

Fig. 10 The contour map of monthly mean global solar radiation in October (MJ/m^2/day).

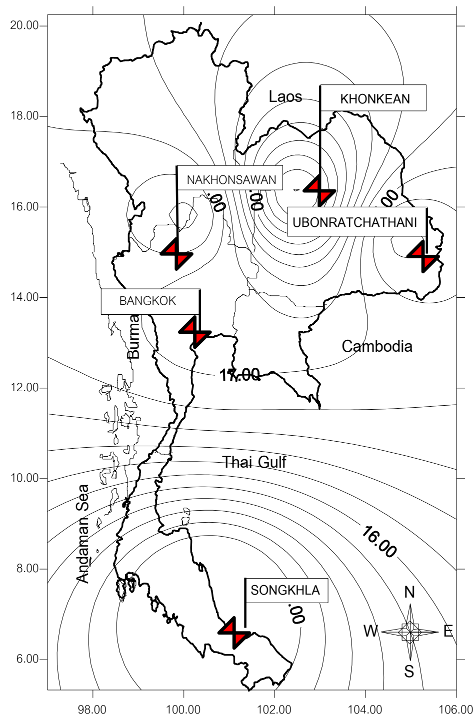

Fig. 11 The contour map of monthly mean global solar radiation in November ($MJ/m^2/day$).

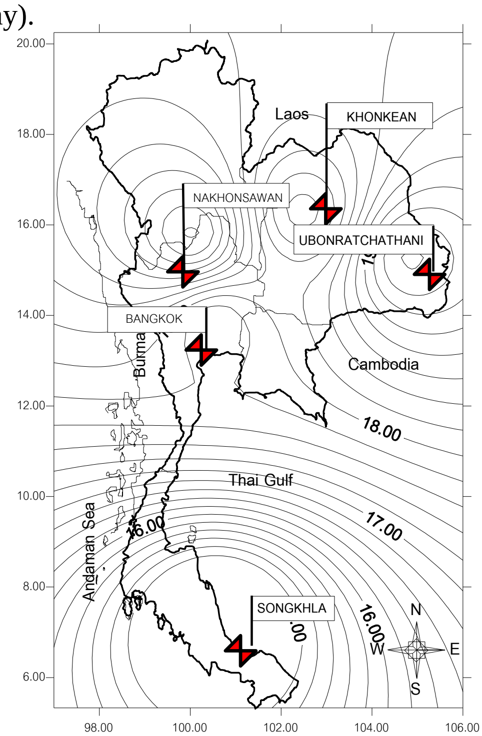

Fig. 12. The contour map of monthly mean global solar radiation in December ($MJ/m^2/day$).

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