Estimation of solar radiation using Angstrom-Prescott model and interpolation of empirical coefficients in Thailand

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Abstract. Angstrom-Prescott model, defined by $H = H_0\left[a + b(\frac{s}{s_0})\right]$, was applied to estimate solar radiation for 11 meteorological stations in Thailand. In this research, the empirical coefficients (a and b) were calculated by using the least square model. Statistical values, i.e., root mean square error (RMSE) and correlation, were analyzed the model ability in estimating solar radiation by compared with the measurement. The empirical coefficients overall Thailand were interpolated by using geographic information system (GIS). This technique can be calculated for estimation of solar radiation in every region in Thailand. In the results, the statistical tests show the ability of Angstrom-Prescott model to estimate solar radiation in Thailand and the least square method is suitable for computing empirical coefficients.

1. Introduction

The consumption of energy from limited natural source, for example, fossil, coal, oil and natural gas had increased and would eventually be depleted. The renewable energy which can be reduce air pollution and global warming emission, such as, solar, wind and water, are increasingly used. In this study, solar energy is focused since it is inexhaustible and clean energy,

The equipment called pyranometer and technique, i.e., the determination by using meteorological satellite data, were essential for measuring solar radiation. The cost of technique and equipment are relatively high, so that most developing country might be faced with lack of the observation data set.

2. Methodology

The empirical method had been originally studied by Angstrom [1] and later developed by Prescott [2]. Many studies show that the solar radiation can be estimated by using meteorological data, i.e. sunshine hour, air temperature [3], precipitation [3], cloud cover data [4]. In this research, the estimation of solar radiation by using sunshine hour data set was focused since it is accessible to collect sunshine duration in Thailand.

The daily solar radiation can be estimated by using Angstrom-Prescott method follows the other parameters, i.e. daily extra-terrestrial solar radiation, empirical coefficients, are calculated.

$$H_i = H_{0i}\left(a + b\left(\frac{s_i}{s_{0i}}\right)\right) \tag{1}$$

$i = 1,2,\ldots,365$ is the 1st day to 365th day.

H_i is daily estimated solar radiation [MJ m^{-2} day^{-1}]. H_{0i} is daily extra-terrestrial radiation [MJ m^{-2} day^{-1}]. s_i is daily sunshine hours [hours] and s_{0i} is daily maximum possible sunshine hours [hours]. a and b are daily empirical coefficients for the square least method. The daily maximum possible hours and daily extra-terrestrial radiation are computed by equation (2) and (3), respectively.

$$s_{0i} = \frac{2}{15}\omega_{si} \tag{2}$$

$$H_{0i} = \frac{24}{\pi} I_{sc}\left[1 + 0.033\cos\left(\frac{360i}{365}\right)\right]\left[\cos(\phi)\cos(\delta_i)\sin(\omega_{si}) + \frac{2\pi\omega_{si}}{360}\sin\phi\sin\delta_i\right] \tag{3}$$

Where ω_{si} is sunset solar hour angle that is calculated by using equation (4). ϕ and δ_i are latitude and solar declination angle, respectively. I_{sc} is solar constant which is defined by the value of 1366.1 W m^{-2} or 118.108 MJ m^{-2} day^{-1}.

$$\omega_{si} = \cos^{-1}[-\tan(\phi)\tan(\delta_i)] \tag{4}$$

There are many methods to estimate empirical coefficients around the world. In the previous study, 4 empirical methods, i.e., FAO, Reitveld, Glover Mc-Culloch and Tiwari & Sangeeta models were selected [5]. It was found that empirical coefficients over Thailand need an improvement to calculate solar radiation estimation correctly. In this study, the new method for calculating empirical coefficients that is the least square model (L.S.) was tested.

Least square model is shown in the following formula which related to observed solar radiation and observed sunshine hours. Where m are number of data.

$$b = \frac{m\Sigma\left(\frac{s}{s_0}\right)\left(\frac{H}{H_0}\right) - \left(\Sigma\left(\frac{s}{s_0}\right)\right)\left(\Sigma\left(\frac{H}{H_0}\right)\right)}{m\Sigma\left(\frac{s}{s_0}\right)^2 - \left(\Sigma\left(\frac{s}{s_0}\right)\right)^2} \tag{5}$$

$$a = \frac{\Sigma\left(\frac{H}{H_0}\right)}{m} - b\frac{\Sigma\left(\frac{s}{s_0}\right)}{m} \tag{6}$$

The statistical tests which are root mean square error (RMSE) and correlation were calculated to validate the model. The absolute zero of root mean square error is ideal [6]. The value of correlation shows estimated solar radiation and measured solar radiation that has no relation (correlation=0) and perfect relation (correlation=1) [7].

$$RMSE = \sqrt{\left(\frac{1}{m}\Sigma(H_{est} - H_{mes})^2\right)} \tag{7}$$

$$correlation = \frac{\Sigma(H_{est}-\bar{H}_e)(H_{mes}-\bar{H}_m)}{\sqrt{\Sigma(H_{est}-\bar{H}_e)^2\,\Sigma(H_{mes}-\bar{H}_m)^2}} \tag{8}$$

After that, empirical coefficients of least square model were interpolated by using Geographic Information System (GIS) in all region in Thailand.

3. Result and Discussion

The average solar radiation and statistical tests were determined as shown in Table 1. The average estimated solar radiation is relatively close to the measured solar radiation. Surat Thani station has the maximum solar radiation because the location effects to the influence of monsoons and the Inter Tropical Convergence Zone (ICTZ). The southwest and northeast monsoon pass over Thailand in May to October and October to November, respectively. The ITCZ movement is impacted by season so it arrives Thailand in May and retreats in October. There is a great amount of cloud and rainfall cover Southern Thailand during this period. It causes less solar radiation in Surat Thani station. Otherwise, Surin station has the minimum solar radiation. The RMSE of solar radiation was about 3 MJ m^{-2} day^{-1}. The value of close-zero RMSE shows the good performance of solar radiation estimation by using Angstrom-Prescott equation in Thailand. The correlation was in the range of 0.6-0.7 implied that the ability of estimated solar radiation has a good relationship with the observation. Moreover, the small correlation in Chiang Mai and Nan station reveals the medium relationship because the collected data sets of the sunshine hours and solar radiation were limited in a few years.

The observed sunshine hours and solar radiation at Bangkok station has been collected since 1995 so that in this study, it was analyzed for 20 years (1995-2014). Meanwhile the geography and climate of Surin Province has low humidity and low precipitation. Therefore, the sunshine hours and solar radiation data are more precisely assembled than other stations.

Table 1. Average solar radiation and statistical tests in Thailand.

Station	Estimated Solar Radiation	Observed Solar Radiation	Statistical Tests	
			RMSE (MJ m^{-2} day^{-1})	Correlation
Chiang Rai	18.209	18.474	3.143	0.679
Chiang Mai	17.801	17.543	3.064	0.590
Nan	17.296	17.049	3.087	0.475
Bangkok	16.517	16.601	2.653	0.785
Phitsanulok	17.447	17.295	2.718	0.634
Nakhon Sawan	18.131	17.932	2.983	0.613
Kon Kaen	18.598	18.124	2.920	0.621
Nakhon Phanom	17.408	17.005	2.795	0.696
Surin	13.950	13.842	2.375	0.939
Surat Thani	19.325	18.842	3.591	0.672
Songkhla	17.589	17.291	3.330	0.628

The estimation of empirical coefficient ‘a’ for Chiang Mai,Chiang Rai, Nan, Bangkok, Phitsanulok, Nakhon Sawan, Kon Kaen, Nakhon Phanom, Surin, Surat Thani and Songkla stations are 0.468, 0.448, 0.525, 0.282, 0.442, 0.452, 0.503, 0.386, 0.385, 0.395 and 0.311, respectively. The ‘b’ coefficient at the same stations are 0.282, 0.313, 0.239, 0.387, 0.275, 0.302, 0.296, 0.398, 0.357, 0.415 and 0.377, respectively.

The estimated empirical coefficients were interpolated for every region in Thailand as shown in Figure 1. The maximum and minimum value of coefficient ‘a’ are 0.487 and 0.338 in northern and southern Thailand, respectively. The higher value of coefficient ‘a’ depends on the location of station where are at higher latitude. In the other hand, the value of coefficient ‘b’ are 0.415 and 0.239 as the maximum and minimum in southern and northern Thailand, respectively. The coefficient of ‘b’ relies on latitude, inversely.

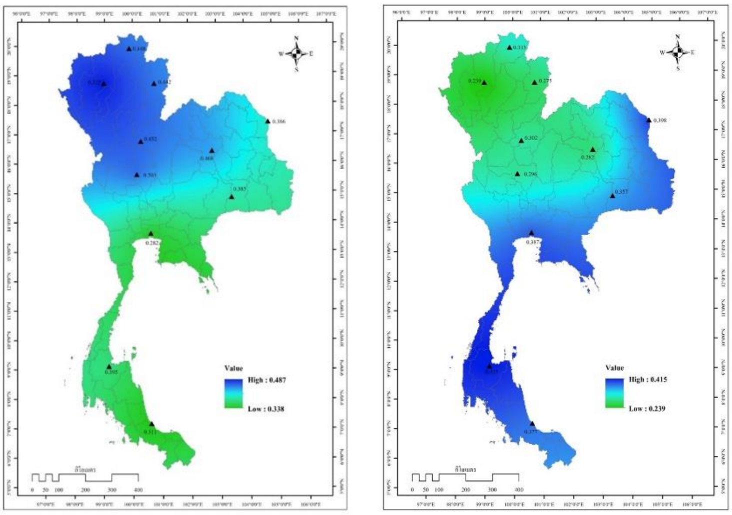

Figure 1. Interpolation of empirical coefficients ‘a’ (left) and ‘b’ (right) in Thailand

Eventually, the solar radiation can be calculated in other region by using sunshine duration data sets and the interpolation of empirical coefficients as shown in figure 2 (left) and the percentage difference between the estimation and observation is presented in figure 2 (right). The maximum solar radiation (red) is 19.5 MJ m^{-2} day^{-1} and the minimum solar radiation (yellow) is 11.5 MJ m^{-2} day^{-1}. In the comparison between the estimation and observation, the highest error is 6.56%. Since the overall percentage difference is lower than 10 %, it is acceptable for estimating solar radiation.

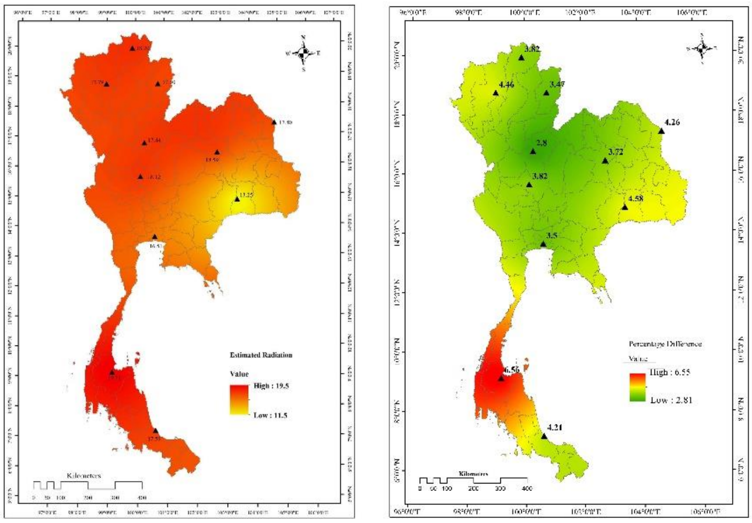

Figure 2. Interpolation of estimated solar radiation(left) and percentage difference(right).

4. Conclusion

It is confirmed by RMSE and correlation that the least square model is suitable to calculate empirical coefficient ‘a’ and ‘b’ over Thailand. Therefore, they provide the estimation of solar radiation more correctly. Moreover, the solar radiation can be calculated by using the interpolating of empirical coefficients over all region in Thailand. This study shows that the data sets of sunshine hours can be used to estimate solar radiation in Thailand.

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