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Comparative study of the monthly global solar radiation estimation data in Jakarta

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Abstract. The objective of this paper is to get the most suitable model of monthly global solar radiation estimation in Jakarta which performs better than the others model. In this study, measured data of solar radiation were utilized to be compared with the empirical models from the literature and a new based-temperature model, to estimate the monthly intensities of global solar radiation in Jakarta, Indonesia (Latittude: 6.13º S, Longitude: 106.8º E). Global solar radiations were measured for two complete years, and the estimation of monthly solar radiation were calulated by four empirical models and also one linear regression model. The accuracy of the models was then analyzed in terms of some statistical indicators such as Mean Bias Error (MBE) and Root Mean Square Error (RMSE). The statistical analysis of result revealed that the empirical models have not the same accuracy, and it is concluded that there are the models that can be preferred for the estimation of monthly global solar radiation in Jakarta, Indonesia. The obtained results indicate that Allen is performing better than the others by obtaining maximum MBE of 0.52 and maximum RMSE of 1.82 . It also can be said that Allen is the most suitable model for estimating a monthly global solar radiation in Jakarta, Indonesia.

1. Introduction

Solar energy is the renewable radiation energy of the sun and it is fast becoming an alternative to other conventional sources of energy [1].There are several factors that affect the production of solar irradiance energy, such as the solar elevation. The amount of solar irradiance also varies depending on the time of the day and the season. The altitude of an areas also affect the amount value of solar irradiance. It has been found that solar irradiance increases by up to 4% for every 300 m increase in altitude [2]. Clouds also have a big impact on the amount of solar irradiance reaching the surface of earth. On average, clouds absorb or scatter about 20% of the incoming solar radiation.

Indonesia has several areas with a really great solar energy potential, especially those that located along equator line. Despite the potential of solar energy resources, the availability of its data is still limited. Regarding to that condition, there's been several studies to learn more about this solar radiation and to develop a new empirical models in order to estimate the amount of solar irradiance especially for the location that has limited measured data, such as at 1992, Graham L. Morrison from UNSW Sydney along side Sudjito create new model based on ambient temperature at 3 cities, Denpasar, Jakarta, and Kupang[3]. This empirical models are being used to estimate and predict the value of solar radiation using different meteorological data such as heat, sun duration period, and so on. Heat is one of the commonest indicators of solar energy radiation[4]. Therefore, temperature is a meterological indicator which can be used to quantify the size of solar radiation at a given location[5].

This study aims at using temperature data measured in Jakarta for a period of two years (2014-2015), as an independent variable to be calculated by four empirical models and one linear regression new models based on Javier Almorox research. The result from those models then being compared and analyzed statistically to know which one is the most suitable model to estimate the monthly solar radiation in Jakarta, Indonesia(Latittude: 6.13º S, Longitude: 106.8º E). The statistical analysis is performed to assess the accuracy of the proposed models by ranking the models with a purpose of finding the most suitable model.

2. Materials and methods

2.1. Characteristics of location under study

Jakarta is the capital city of Inonesia which located in DKI Jakrta province, with population 10187595 and 661.52 km^2area respectively. This city is located at 6.13º S latitude and 106.8º E longitude. Jakarta has an average monthly temperature varies from 24º C - 34º C approximately (**Table 1**). Jakarta is the largest city in Indonesia and classified as the industrial city. The region experiences a warm climate with a larger amount of rainfall in summer due to warm-wet flow from the tropics than in winter.

2.2. Instrumentation and data collection

The measurements were carried out for a period of two years (Januari, 2014-December 2015) to asses the solar radiation potential. The measured data then being calculated statistically to show which month reach the highest value of global solar radiation intensities. The measured data is shown on table 2 below. It can be observed that at 2014, the months August-Octobers show a high solar energy potential in terms of global solar radiation with September being the month where the mean global solar radiation reaches a maximum value of 16.62 MJ/m^2-day. While the minimum global solar radiation is observed in January and February due to the fact that in that moment is rainy season. The average minimum value of 7.21 MJ/m^2-day is observed in the month of January. For 2015, it can be observed that September reaches the highest value of average monthly global radiation of 15.49 MJ/m^2-day, while February is observed as the lowest value of monthly global solar radiation with value of 9.60 MJ/m^2-day.

Meteorological data comprising of maximum and minimum temperatures measured in Jakarta for two years period (2014-2015) were obtained from Indonesia Meterological Agency (BMKG). These maximum and minimum temperatures data of the study area were used as the materials to calculate the estimated monthly global solar radiation values by five empirical models.

Table. 1. Jakarta's Average Temperature.

Month	2014 Average Temperature		2015 Average Temperature	
	Tmin	Tmax	Tmin	Tmax
January	24.65	29.3	25.14	30.76
February	24.71	29.91	24.85	29.77
March	25.56	31.33	25.69	31.34
April	26.52	33.06	26.25	32.23
May	26.78	32.8	26.46	32.71
June	26.56	32.22	26.16	32.33
July	25.62	32.14	25.82	32.35
August	25.8	32.79	25.3	32.24
September	26.55	32.87	25.46	32.58
October	27.06	33.76	27.02	33.22

IOP Conf. Series: Earth and Environmental Science **105** (2018) 012111 doi:10.1088/1755-1315/105/1/012111

November	27.04	33.4	26.95	33.04
December	26.21	32.48	26.11	32.15

Table 2. Summary of statistical measured data.

2014												
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Des
Statistics												
Mean	7.21	9.87	11.41	13.21	11.15	10.63	11.89	13.85	16.62	14.35	12.27	12.78
Median	7.31	10.42	11.13	12.45	10.65	10.27	11.25	13.39	15.44	13.03	11.50	12.33
Skewness	2.08	1.44	1.39	1.23	1.26	1.23	1.20	1.00	0.92	1.05	1.24	1.25
2015												
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Des
Statistics												
Mean	10.76	9.60	12.60	12.26	12.46	12.21	13.07	15.32	15.49	15.48	12.66	12.65
Median	8.48	8.62	11.44	12.23	11.19	11.50	12.74	15.35	16.05	14.44	11.98	12.88
Skewness	1.60	1.74	1.37	-0.18	1.14	1.10	1.02	0.87	0.85	0.92	1.10	1.01

3. Empirical models

The monthly global solar radiation models are based on empirical correlations and depends on the most common meteorological parameters including cloud cover, ambient temperature, relative humidity, and also sunshine duration, which is the most widely used meteorological parameter to estimate monthly global solar radiation[6]. There are several methods to estimate and predict a monthly solar radiation, however since the temperature data available more in Indonesia's meteorological station, so the empirical correlations that was being used in this study is the temperature-based models. Temperature-based models for estimating global solar radiation utilize the direct affects of atmospheric transmissivity. These models assume that a high or low transmissitivity is due to an increase or decrease in air temperature. In this study, the estimation of the monthly global solar radiation calculated based on the temperature data measurement that available from BMKG shown in figure 1.

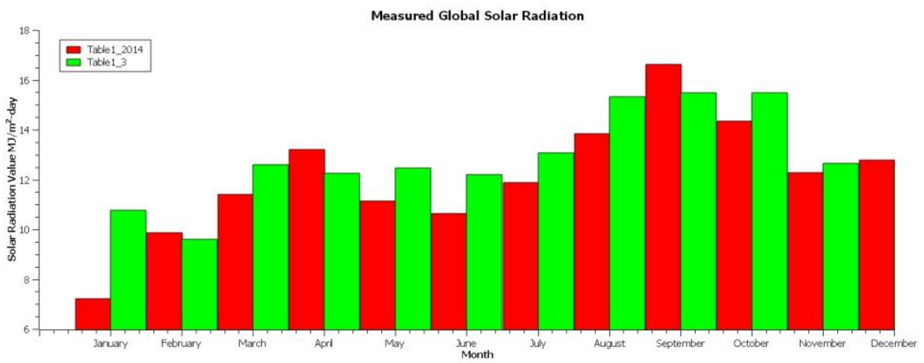

Figure 1. Measured Global Solar Radiation 2014 and 2015.

3.1. Model 1

Annadele et. al. proposed the estimation of solar radiation based on maximum and miniumum temperatures by take account the effect of decreased altitude and atmospheric thickness on global solar radiation by the suggestion of a correction factor. The model suggested by Annadele et. al. [7] :

$$G_D = A(1 + 2.7x10^{-5}Z)(T_{max} - T_{min})^{0.5}G_H \tag{1}$$

IOP Conf. Series: Earth and Environmental Science **105** (2018) 012111 doi:10.1088/1755-1315/105/1/012111

A is an empirical coefficient and the recommend value is 0.1072 in Jakarta. Z is the elevation in meter, $T_{max}$and $T_{min}$is the maximum and minimum of temperature in Celcius degree. Then $G_H$is extraterrestrial radiation which is a function of latitude and day of the year.

3.2 Model 2

Allen proposed a model of global solar radiation based on maximum and minimum temperature [8], as in:

$$G_D = A(T_{max} - T_{min})^B G_H \tag{2}$$

A and B are empirical coefficient, which the value in Jakarta for A is proposed to be 0.07768, while for B is to be 0.905. Z is the elevation in meter, $T_{max}$and $T_{min}$is the maximum and minimum of temperature in Celcius degree and also $G_H$is extraterrestrial radiation which is a function of latitude and day of the year[8].

3.3. Model 3

Bristow and Campbell proposed a simple model to estimate global solar radiation which is assumed to be exponential function of temperature difference as in [9]:

$$\mathrm{G_D = A[1 - \exp(-B\Delta T^B)\, G_H]} \tag{3}$$

$$B = 0.036\exp(-0.154\ \Delta\mathrm{T}) \tag{4}$$

A and C are empirical coeffecient which the value for A is 0.4895, and for C is to be 2.35.

3.4. Model 4

Hargreaves and Samani were the first to suggest that incident radiation could be evaluated from the difference between daily maximum and daily minimum temperature. The equation introduced by Hargreaves and Samani [10] :

$$\mathrm{H_c = H_o\ x\ [Kr\ x\ (T_{max} - T_{min})^{\frac{1}{2}}]} \tag{5}$$

where, Hc is the estimated solar radiation, Ho is the extraterrestrial solar radiation, Tmax is the maximum daily temperature, Tmin is the minimum daily temperature and Kr is an empirical coefficient that can be obtained by :

$$\mathrm{Kr = A(T_{max} - T_{min})^2 + B(T_{max} - T_{min}) + C} \tag{6}$$

Kr is a function of the daily temperature range where, A; B; C are empirical coefficient

3.5. Model 5

A correlation analysis between variables provided by the meteorological station (daily maximum temperature and dailiy minimum temperature) and the extraterrestrial solar radiation (calculated for the model's application site) was performed. The general equation for new based-temperature model by linear regression :

$$\mathrm{H_c = AT_{max} + BT_{min} + CH_o + D} \tag{7}$$

Values for A is 0.62, B is -0.46, C is 0.42 and D is -7.07

4. Result and discussion

Four empirical models from literature and also one new based-temperature models by Jaview Almorox that was developed than being evaluated from its statistical point of view. The resulting values of monthly global solar radiation are presented in figure 2 and figure 3 below.

IOP Conf. Series: Earth and Environmental Science **105** (2018) 012111 doi:10.1088/1755-1315/105/1/012111

To evaluate the calculation result from the developed models above, the performance of those three models than being examined and analyzed by statistical test such as Mean Biass Error (MBE) and also Root Mean Square Error (RMSE). These two statistical indicators are being calculated by :

$$MBE = \frac{1}{K}\Sigma(\mathrm{G_p} - G_m) \quad (8)$$

$$RMSE = \sqrt{\frac{1}{K}\Sigma\left(\mathrm{G_p} - G_m\right)^2} \quad (9)$$

K is the total number of observations, $\mathrm{G_p}$ is the value of calculated global solar radiation, while G_m is the value of measured global solar radiation. The estimation value of monthly global solar radiation was being calculated based on temperature data measurement in Jakarta, Indonesia. From the figure 4 above we can see that that the value from all the models is still quite far from the measured data, but we can conclude that model proposed by Allen is the closest amongst two others models. Also from the table 3 below we can see that the model which proposed by Allen has the lowest value of MBE and RMSE. This result indicates a good fitting and the closest from the measured values.

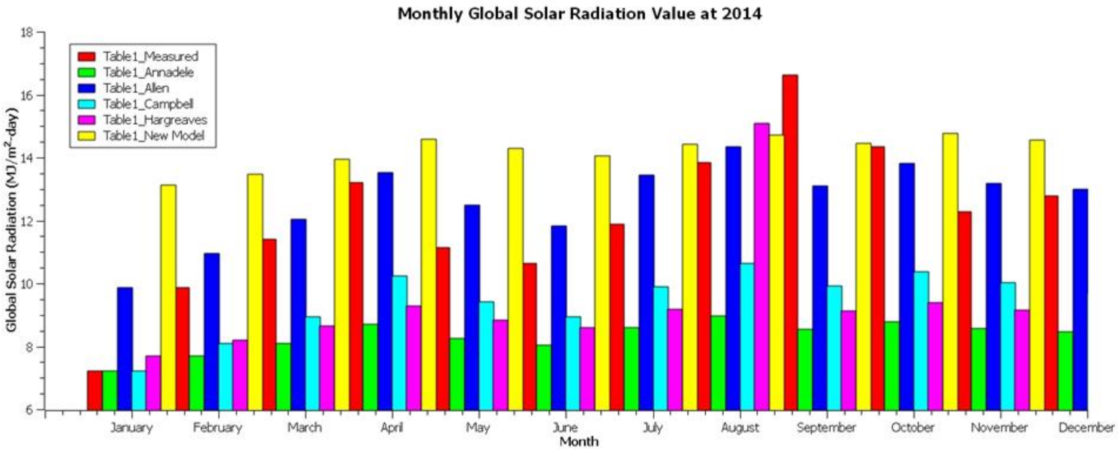

Figure 2. Monthly Global Solar Radiation Value at 2014 (measured and estimated).

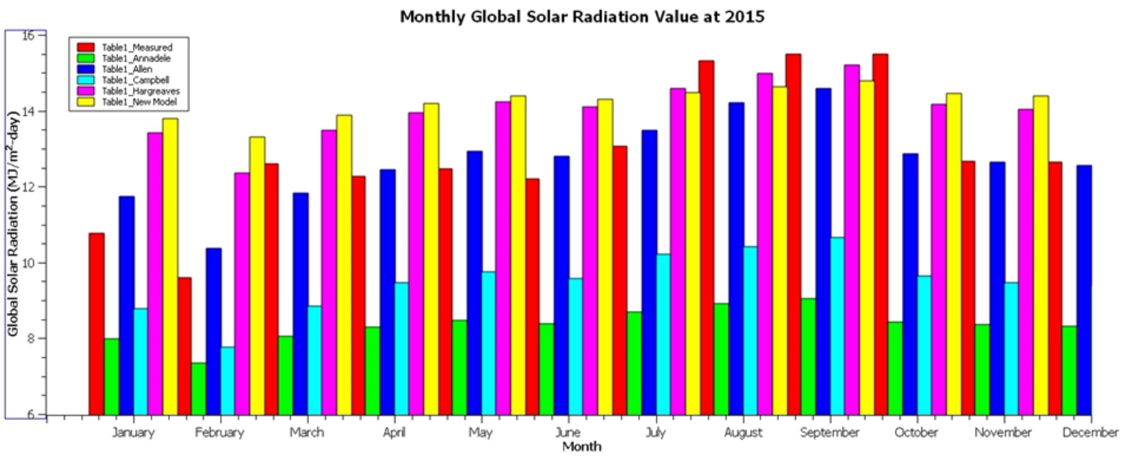

Figure 3. Monthly Global Solar Radiation Value at 2015 (measured and estimated).

Table 3. Statistical analysis of estimated solar global solar radiation.

			2014		
Models	Annadele	Allen	Campbell	Hargreaves	New Models
MBE	-3.774679276	0.52641898	-2.65418611	1.026145924	1.603394227
RMSE	13.07587258	1.82356884	9.19437039	3.554673753	5.55432053
			2015		
Models	Annadele	Allen	Campbell	Hargreaves	New Models
MBE	-4.524548075	-0.174433298	-3.382436419	5.686296492	1.526279762
RMSE	15.67349429	0.604254669	11.71710346	19.69790886	5.28718819

5. Conclusion

Solar energy is one of the resources that has a huge potential to fulfilling the demands of energy because of energy crisis, as the renewable energy. The estimation of monthly global solar radiation in Jakarta, Indonesia has been calculated by several empirical models from the literatures and one new based-temperature model. The calculation results from all models then being compared with the measured data and later being analyzed and assessed by the statistical methods. The best model regarding the lowest MBE and RMSE is Allen which provides the best performance for estimating global solar radiation and it can be said the most suitable model that can be used to estimate another areas in Indonesia.

6. Acknowledgments

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