International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2019): 7.583

Estimating the Solar Energy Potential over Indonesia Region Using Daily Sunshine Duration

Yesi C U Sianturi[1]

[1]Applied Climate Information Service Centre, Indonesian Agency for Meteorology Climatology and Geophysics, Indonesia
yesi.ulina[at]bmkg.go.id

Abstract: ***Attempts to map the solar energy potential in Indonesia were often limited by the lack of ground observation of solar radiation. In this study, the Angström-Prescott linear regression models were developed for Indonesia region, to estimate daily solar radiation using the daily sunshine duration data. The intercept values of all models range from 0.27 – 0.49, and the small range of coefficients indicates the homogeneous climatic condition over the Indonesia region. The estimated daily solar radiation from the constructed models fitted the observed daily solar radiation with acceptable accuracy. The selected model was then used to estimate solar radiation over the Indonesia region, using the daily sunshine duration data from 153 meteorological stations in Indonesia. The annual average of daily solar radiation in 2018 over the Indonesia region ranged from 3.0 – 5.6 kWh/m2, and the highest potential is observed over the southern part of Indonesia, particularly in Bali and Nusa Tenggara islands.***

Keywords: Solar radiation, Renewable energy, Sunshine duration, Solar energy

1. Introduction

Solar energy potential is a key information in designing and developing solar power plants. Despite its importance, the solar radiation observation network is relatively sparse compared to the observation network of other climate parameters, as maintaining a proper and calibrated measurement of solar radiation often requires high cost. Different approaches had been used to estimate solar radiation data in various regions, utilizing a more accessible and readily available data that are phsyically related to the incoming solar radiation. In some cases, remote sensing observation and weather models output are used to estimate solar radiation on the earth surface, however, its spatial and temporal coverage are often too sparse and thus leads to decreased accuracy [1] – [3]. Another approach is to construct site-specific emipirical model to estimate daily solar radiation using other ground-observed climate parameters, and in many cases, the empirical model often provides better approximation of solar radiation values despite its simplicity.

One of the most widely applied empirical model is the one proposed by Angström [4], in the form of linear relationship between the relative daily solar radiation and the relative daily sunshine duration. The relative daily solar radiation equals to the fraction of the observed daily solar radiation over the daily solar radiation on a cloudless day. The relative daily sunshine duration, on the other hand, is the fraction of the observed daily sunshine duration over the day length. Hence, the most challenging part of the formula is to determine the value of daily solar radiation on a cloudless day. Prescott [5] overcame this problem by using the value of solar radiation at the top of the atmosphere as an approximation of the clear-sky solar radiation, and the formula is later known as the Angström–Prescott method. In its applications, many modifications were introduced to the simple form of Angström–Prescott formula. Some studies added multiple climate parameters, such as daily sunshine duration, cloud cover, temperature, relative humidity, and precipitation, to construct multiple regression models [6] – [8]. Other studies employed different degrees of regression models to increase the accuracy of the original model [6][9] – [11]. Yet, those modified models need longer calculation than the simple linear model and often do not provide significant increases in the accuracy, compared to the original model that uses daily sunshine duration only. In this study, empirical models to estimate daily solar radiation using daily sunshine duration data only will be constructed for Indonesia region, and a map of solar energy potential will be produced using the model to give initial information regarding solar energy potential over Indonesia region.

2. Materials and Methods

In 2017, a set of instruments called the Automatic Solar Radiation Station (ASRS) that records instantaneous values of solar irradiance were installed over 15 locations in Indonesia by the Indonesian Agency for Meteorology, Climatology, and Geophysics. Each ASRS instrument comprises three pyranometers and one pyrheliometer to measure four parameters – the global horizontal irradiance (GHI), diffuse horizontal irradiance (DHI), reflected irradiance, and direct normal irradiance (DNI). The quantity that reflects the energy input to a solar panel is the global horizontal irradiance (GHI), which is the accumulation of the direct and diffuse components of solar irradiance. One year period of data from the ASRS observation network (January – December 2018) will be used to develop empirical models to estimate daily solar radiation, and a six-month data of daily solar radiation (January – June 2019) will be used to evaluate the models. However, due to data availability, the data from 2 out of the 15 stations – ASRS Tilongkabila and ASRS Seram Bagian Barat – are excluded from further analysis.

The Angström–Prescott formula can be written as:

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2019): 7.583

$$H/H_0 = a + b(n/N) \quad (1)$$

The term H/H_o is known as the clearness index that ranges from 0 to 1, which indicates the atmospheric clearness on a given day. The value of 0 can be associated with full cloud cover condition, while the maximum value indicates a completely clear atmosphere for the whole day. The independent variables are the observed daily sunshine duration (n) and the maximum possible daily sunshine duration (N), or also known as the day length. Both regression coefficients, a and b, depict the characteristic of atmospheric transmission in that particular region. The first coefficient, a, indicates the transmitted solar radiation on a completely opaque atmosphere, while b exhibits the rate of increase in the atmospheric transmissivity given the increases in n/N term (or atmospheric opacity). The sum of both coefficients represents the total transmissivity in clear days. The parameter H and H_o denote the daily solar radiation and daily extraterestrial solar radiation, or the solar radiation at the top of the atmosphere, respectively. The quantity Ho can be calculated using equations below [12]:

$$S_o = \frac{24}{\pi} I_{sc}\left(1 + 0.033\cos\frac{360D}{365}\right)\left(\cos\varphi\cos\delta\sin\omega_s + \frac{2\pi\omega_s}{360}\sin\varphi\sin\delta\right) \quad (2)$$

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \quad (3)$$

$$\delta = 23.45\left(360\frac{284 + D}{365}\right) \quad (4)$$

Table 1: The ASRS observation network used in this study

Station Name	Station ID	Latitude	Longitude
ASRS Bogor	STA6001	-6.5	106.7
ASRS Banjarbaru	STA6002	-3.4	114.8
ASRS Mempawah	STA6003	0.0	109.1
ASRS Aceh	STA6004	5.4	95.5
ASRS Sampali	STA6005	3.6	98.7
ASRS Padang	STA6006	-0.5	100.2
ASRS Jambi	STA6007	-1.6	103.4
ASRS Palembang	STA6008	-2.9	104.7
ASRS Bengkulu	STA6009	-3.8	102.3
ASRS Mlati	STA6010	-7.7	110.3
ASRS Malang	STA6011	-7.9	112.5
ASRS Jembrana	STA6012	-8.3	114.6
ASRS Minahasa	STA6013	1.4	124.8

From the equations above, it can be seen that the daily solar radiation at the top of the atmosphere (S_o) is a function of the solar constant (I_{sc}), the day of the year (D), the latitude of the station (ϕ), solar declination (δ), and solar hour angle (ω_s). In this study, the value of the solar constant, or the radiation received perpendicularly at the top of the atmosphere at the average distance between earth and the sun, is set to 1367 W/m^2.

The daily sunshine duration data is obtained from the Indonesian Agency for Meteorology, Climatology, and Geophysics, for the 18 months period (January 2018 – June 2019). The daily sunshine duration is observed using campbell stokes, where the total hour of bright sunshine period is recorded as burnt marks in the campbell stokes paper. Daily sunshine duration data from the corresponding 13 ASRS stations will be used to construct 13 empirical models. The empirical models will be evaluated using several statistical metrics, which are the Pearson correlation coefficient (r), root mean square error (RMSE), mean percentage error (MPE), and student t-test. The student t-test will be used to assess whether the estimates are statistically different with the observed radiation. The model that shows better performance and does not give statistically different estimates with the observed radiation (based on the student t-test results) will be used to calculate the average of daily solar radiation in 2018 over Indonesia region, using daily sunshine duration data from all 153 meteorological stations in Indonesia.

3. Results and Discussions

The coefficients of the models constructed using 2018 data and its statistical evaluation results (against the observed solar radiation in the same location) are listed in Table 2. Other than estimates from model number 1, 7, and 8 most of the estimates exhibit good relationship (high correlation coefficients) with the observed daily solar radiation. The intercept value of all 13 models ranges from 0.27 – 0.49, however the value range for the slope is comparably larger (0 – 0.45). The small range of coefficients implies that the relationship between daily solar radiation and daily sunshine duration is relatively homogeneous in most locations. However, estimates from models with low b value, as shown by model 1 and 8, tend to have low correlation with the observed radiation (0.3 and 0.0, respectively.)

Table 2: Statistical evaluation of the 13 empirical models against the observed daily solar radiation in 2018

Model	Coefficients		Evaluation		
	a	b	r	RMSE	MPE
1	0.42	0.16	0.32	1043.4	6.8
2	0.42	0.05	0.85	597.3	10.5
3	0.29	0.42	0.85	523.7	1.6
4	0.27	0.39	0.91	997.1	19.5
5	0.32	0.35	0.78	895.4	28.5
6	0.25	0.45	0.91	1219.9	26.0
7	0.36	0.25	0.40	1409.3	63.4
8	0.49	0.00	0.00	1483.1	67.6
9	0.29	0.40	0.84	1311.0	87.4
10	0.29	0.38	0.66	1565.7	-3.9
11	0.29	0.41	0.76	856.9	17.2
12	0.33	0.32	0.74	728.8	25.8
13	0.26	0.43	0.89	914.9	26.5

All the 13 models that were developed using 2018 data is then used to estimate the daily solar radiation for a six month period (January – June 2019) in all 13 ASRS stations, in order to evaluate the performance of each model in different regions. The student t-test is used to examine whether the estimates are statistically different with the measured solar radiation and the p-value of all models is summarized in Table 3. The p-value higher than 0.05

indicates that there was no statistically significant difference between the estimates and the measured daily solar radiation. Several models that have the least statistically significant difference with the observed daily solar radiation is then evaluated further, to choose the model that best represent the relationship between the daily sunshine duration and daily solar radiation over Indonesia region.

The models that are chosen are models number (3), (5), (9), and (11) – or later addressed as EQ3, EQ5, EQ9, and EQ11 – as the four models do not show statistically different estimates in almost all locations, except in Mempawah station. Statistical evaluations, using the daily solar radiation data in 2019, were done to the four models and the results are presented in Figure 1. From Figure 1, it can be seen that EQ9 slightly outperforms EQ3, EQ5, and EQ11 in most stations by showing lower overall bias. The time series of the observed daily solar radiation in 2019 and the estimates generated using EQ9 is presented in Figure 2. From Figure 2, it can be seen that he model can predict daily solar radiation with sufficient accuracy, yet some extreme values, particularly the extreme low, were not always captured by the model. The daily solar radiation for all 153 meteorological stations in Indonesia is then calculated using the daily sunshine duration in 2018 and the annual average of daily solar radiation are interpolated to the whole Indonesia region using the inverse distance weighing (IDW) method in Figure 3.

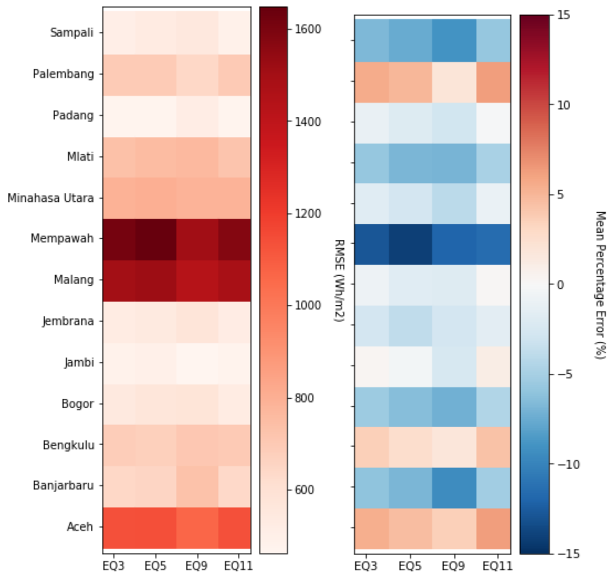

Figure 1: The root mean square error (RMSE) and mean percentage error (MPE) of model 3, 5, 9, and 11 in estimating daily solar radiation in 2019 over all 13 locations. Blue pixel in MPE plot implies underestimation, whereas the red pixel implies overestimation.

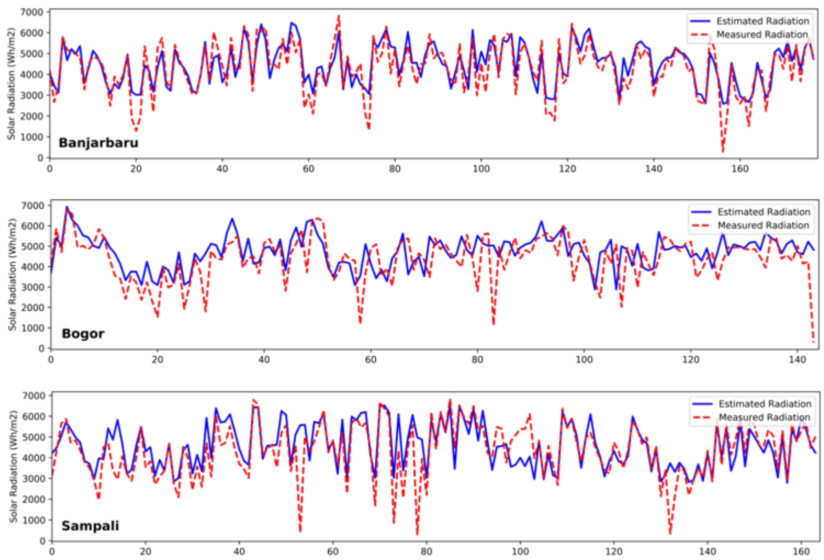

Figure 2: The time series of the calculated and observed solar radiation in Banjarbaru, Bogor, Sampali, and Jembrana stations using (0.29 + 0.40 N/N_o) or EQ9

Table 3: The p-values of the 13 empirical models

No.	Equation	p-values												
		Aceh	Banjarbaru	Bengkulu	Bogor	Jambi	Jembrana	Malang	Mempawah	Minahasa Utara	Mlati	Padang	Palembang	Sampali
1	0.42 + 0.16 N/No	0.282	0.000	0.229	0.000	0.000	0.308	0.097	0.003	0.003	0.006	0.011	0.001	0.000
2	0.42 + 0.05 N/No	0.043	0.003	0.160	0.271	0.191	0.019	0.304	0.252	0.522	0.866	0.880	0.193	0.028
3	0.29 + 0.42 N/No	0.231	0.179	0.576	0.120	0.916	0.429	0.722	0.002	0.588	0.189	0.664	0.229	0.109
4	0.27 + 0.39 N/No	0.002	0.781	0.030	0.731	0.105	0.378	0.223	0.200	0.310	0.835	0.223	0.003	0.941
5	0.32 + 0.35 N/No	0.314	0.052	0.676	0.061	0.539	0.547	0.677	0.004	0.391	0.153	0.512	0.616	0.040
6	0.25 + 0.45 N/No	0.004	0.709	0.054	0.891	0.118	0.707	0.357	0.061	0.373	0.969	0.314	0.002	0.994
7	0.36 + 0.25 N/No	0.381	0.007	0.730	0.029	0.194	0.911	0.724	0.028	0.227	0.148	0.401	0.616	0.010
8	0.49 + 0.002 N/No	0.050	0.000	0.068	0.000	0.000	0.645	0.055	0.068	0.000	0.002	0.001	0.000	0.000
9	0.29 + 0.40 N/No	0.094	0.304	0.338	0.261	0.796	0.742	0.967	0.009	0.847	0.346	0.965	0.122	0.212
10	0.29 + 0.38 N/No	0.030	0.483	0.171	0.505	0.521	0.877	0.650	0.039	0.864	0.579	0.716	0.057	0.382
11	0.29 + 0.41 N/No	0.151	0.235	0.449	0.179	0.941	0.574	0.874	0.004	0.712	0.258	0.809	0.170	0.154
12	0.33 + 0.32 N/No	0.269	0.040	0.612	0.066	0.499	0.718	0.768	0.010	0.396	0.181	0.552	0.720	0.037
13	0.26 + 0.43 N/No	0.006	0.874	0.065	0.996	0.162	0.702	0.389	0.064	0.443	0.909	0.365	0.005	0.879

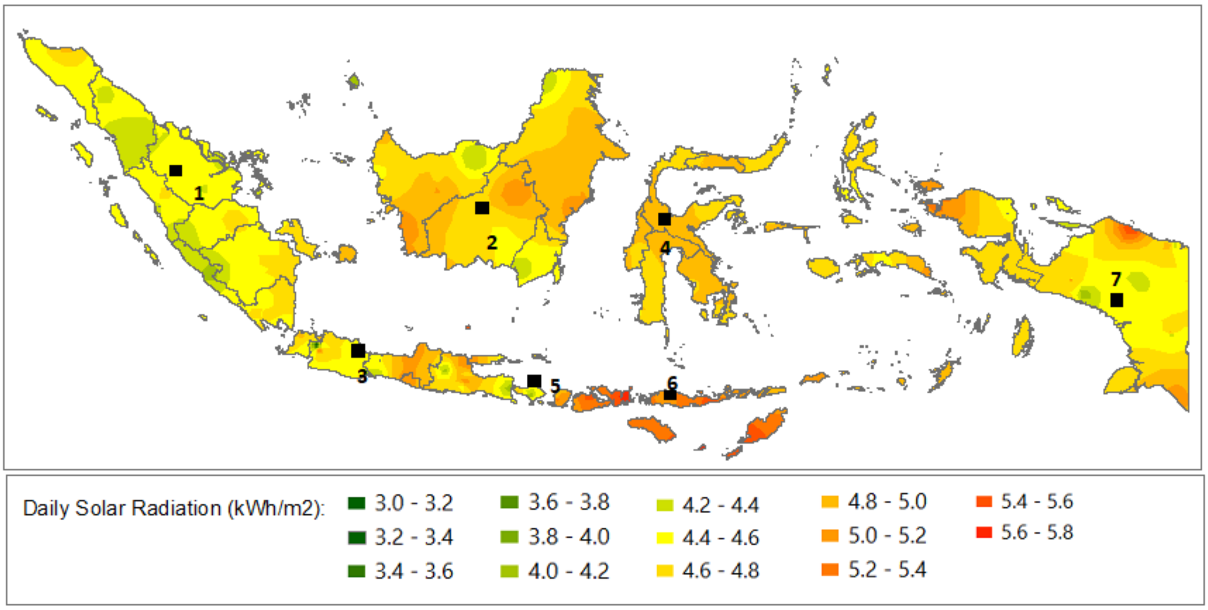

Figure 3: The annual average of daily solar radiation over Indonesia in 2018. The big islands are: (1) Sumatra; (2) Kalimantan; (3) Java; (4) Sulawesi: (5) Bali; (6) Nusa Tenggara; (7) Papua.

The average value of daily solar radiation over Indonesia region ranged from 3.0 kWh/m^2 to 5.6 kWh/m^2 in 2018, which are comparable to the values of daily solar radiation over Indonesia region calculated in previous studies [13 – 15] (Morrison, 1992; Rumbayan, 2012). The southern part of Indonesia has larger solar energy potential in general. The daily solar radiation over Nusa Tenggara islands ranges from 5.0 kWh/m^2 to 5.6 kWh/m^2, whereas the daily solar radiation over West Papua region reaches 5.2 kWh/m^2 to 5.6 kWh/m^2. Lower daily solar radiation values are shown in the western coast of Sumatra (4.0 – 4.6 kWh/m^2), as the region is known to be dominated by highland. The eastern part of Indonesia typically gets more solar radiation than the western part, as the eastern part is also relatively drier than the western region, hence less cloud forms throughout the year. This difference between the east and west region is also documented in a few previous studies. Morisson [13] used the clearness index data to model the solar radiation data and there was a significant difference of diffuse solar radiation values between the western and eastern part of Indonesia. Winarso [16] used secondary data to map the solar energy potential over Indonesia and the same tendency was apparent in the results.

It should be noted that the coefficients of the model depict atmospheric transmissivity and as atmospheric transmissivity depends on the existence of clouds, the best coefficient values might also differ from season to season, as was shown in Rumbayan (2012). Nevertheless, the map produced above provides initial information that can be used further to plan the development of solar energy plants over Indonesia region. It should also be noted that the solar radiation estimated in this study is the theoretical potential of solar energy, and the actual energy input might differ based on instrument specifications or the condition of the immediate surrounding of the solar panel.

4. Conclusions

The Angström–Prescott formula had been used to generate empirical models to estimate daily solar radiation over Indonesia region and statistical evaluations are used to evaluate the suitability of the models. Daily solar radiation estimates from all models generally show good fit with the observed daily solar radiation, however, the evaluation results in a few stations (particularly in Mempawah) show that the models that use daily sunshine duration only is less skillful to estimate the daily solar radiation in this location. Further evaluation gives 0.29 + 0.40 N/No as the model that best represents the relationship between daily sunshine duration and daily solar radiation in most locations. This formula is then used to estimate the solar energy potential over Indonesia region, using the daily sunshine duration in 2018. The southern region of Indonesia, including Bali and Nusa Tenggara islands, has the largest potential of solar energy, whilst the solar energy potential on Sumatra west coast is generally smaller than other regions.

References

[1] Boilley, A., and L. Wald, “Comparison between meteorological re-analyses from ERA-Interim and MERRA and measurements of daily solar irradiation at surface,” Renewable Energy, 75, pp. 135-143, 2015.
[2] Zhang, X., S. Liang, G. Wang, Y. Yao, B. Jiang, and J. Cheng, “Evaluation of the Reanalysis Surface Incident Shortwave Radiation Products from NCEP, ECMWF, GSFC, and JMA Using Satellite and Surface Observations,” Remote Sensing, 8, pp. 225, 2016.
[3] Tahir Z, Ali M, Ahmad S, Asim M, Hayat N, Azhar M et al., “Evaluation of Solar Radiation from MERRA, MERRA2, ERA-Interim and CFSR Reanalysis Datasets Against Surface Observations for Multan, Pakistan,” EuroSun. International Solar Energy Society, 2018.
[4] Angström, A, “Solar and terrestrial radiation,” Q. J. R. Meteorol. Soc. 50, pp. 121 – 125, 1924.
[5] Prescott, J.A., “Evaporation from a water surface in relation to solar radiation,” Trans. Roy. Soc. S. Aust., 46, pp. 114-118, 1940.
[6] Almorox, J. & Hontoria, C., “Global solar radiation estimation using sunshine duration in Spain,” Energy Conversion and Management, 45(9-10), pp. 1529-1535, 2004.
[7] Besharat, F., A. Dehghan, and A. Faghih, “Empirical models for estimating global solar radiation: A review and case study,” Renewable and Sustainable Energy Reviews, 21, pp. 798-821, 2013.
[8] Ekici, C., and I. Teke, “Total Global Solar Radiation Estimation with Relative Humidity and Air Temperature Extremes in Ireland and Holland,” Geoscientific Instrumentation, Methods and Data Systems Discussions, pp. 1-24, 2017.
[9] Trnka, M., Z. Žalud, J. Eitzinger, and M. Dubrovský, “Global solar radiation in Central European lowlands estimated by various empirical formulae,” Agricultural and Forest Meteorology, 131, pp. 54-76, 2005.
[10] Bakirci, K., “Correlations for estimation of daily global solar radiation with hours of bright sunshine in Turkey,” Energy, 34, pp. 485-501, 2009.
[11] Meenal, R. and Selvakumar, A.I., “Estimation of global solar radiation using sunshine duration and temperature in Chennai,” In 2016 International Conference on Emerging Trends in Engineering, Technology and Science (ICETETS), pp. 1-6, 2016.
[12] Duffie, J., and W. Beckman, Solar Engineering of Thermal Processes. Wiley, Somerset, 2013.
[13] Morrison, G. and Sudjito, “Solar radiation data for indonesia. Solar Energy,” 49 (1), pp. 65-76, 1992.
[14] Septiadi, D., Nanlohy, P., Souissa, M. and Rumlawang, F.Y., “Proyeksi potensi energi surya sebagai energi terbarukan (Studi wilayah Ambon dan sekitarnya), “Jurnal Meteorologi Dan Geofisika, 10(1), 2009.
[15] Rumbayan, M., Abudureyimu, A. and Nagasaka, K., “Mapping of solar energy potential in Indonesia using artificial neural network and geographical information system,” Renewable and Sustainable Energy Reviews, 16(3), pp. 1437-1449, 2012.
[16] Winarso, P.A., “Indonesia Solar Power Study Using Secondary Data,” Journal of Climatology & Weather Forecasting, 05(01), 2017