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A General Solar Radiation Estimation Model Using Ground Measured Meteorological Data in Sarawak, Malaysia

S.Bandy, W.A. Wan Zainal
Department of Electrical and Electronic Engineering, Faculty of Engineering, UNIMAS.
senioritabandy@gmail.com

***Abstract*— Daily solar radiation is main fundamental for most of physical and living processes on the Earth's surface as it plays role in the local and global energy budget. The data at specific location is quite indispensable for many solar energy related researches but not all places are equipped with such measured data collection. Solar radiation models based on meteorological parameters can serve as substitute to measured illuminance and irradiation data. This study is aimed to estimate the missing or incomplete data of solar radiation at meteorological stations in Sarawak using commonly measured meteorological data and selecting optimal models. Using the measured maximum and minimum air temperature differences, ΔT, relative humidity, RH and cloud factor, CF covering the years from 2010 to 2015, existing model are calibrated and new model is developed. The solar radiation is estimated by applying linear regression of ΔT, RH and multiple regression method (MRM). The result of calculation then is compared with the existing temperature-based model namely Hargreaves-Samani model and Bristow-Campbell model using statistical performance. The result shows that over short and long term, MRM perform the best by giving small RMSE and MBE of close to 0%. Linear ΔT and RH gave considerable results of MBE less than 10% but vary in term of RMSE. BC model performance is quite similar to the performance of linear ΔT- K_T model. The application of MRM model to the measured data is the best in predicting solar radiation data.**

***Index Terms*—Air Temperature; Clearness Index; Cloud Factor; Relative Humidity; Solar Radiation Estimation;**

I. INTRODUCTION

A solar resource is a significantly large source and continuously delivered by the sun to the Earth surface for many physical, chemical and biological processes [1], [2]. There are several applications for the resource, for instance: electricity generation, photochemical, solar propulsion, solar desalination, and room temperate control. An accurate knowledge on the solar radiation at particular geographical locations is vital for many research and application fields such as architectures, agronomy, industry, hydrology, agriculture, environment, meteorology, oceanology and ecology [3]–[7]. Availability of long-term solar data is pre-requisite for modeling and design of optimized and operational projects in various application fields

The best solar data at a specific place is continuously measured accurately over the long term. Measured monthly average value of solar radiation are usually the best information obtained and able to provide a starting point for many calculations [8]. However, reliable long-term data availability in developing country is very scarce and often limited due to the absence of measurement and instrument errors or failure [9]. Such problem has led to a major distortion in progressing of solar field. Thus various methods have been uncovered to estimate the solar radiation, using commonly available meteorological parameters with reasonable accuracy.

Numerous empirical correlation between solar radiation and commonly measured meteorological data is developed around the world [10], [11]. The most common parameter that has been used to estimate the radiation is sunshine durations which are measured by using Campbell-Stokes sunshine recorder. Angstrom proposed the classic basic prediction model in 1924 [12], [13]. The linear equation of the model is as shown in (1), where H, H_o , S and S_o are solar radiation, extraterrestrial radiation, sunshine hour and maximum possible sunshine hour respectively. Meanwhile *a* and *b* are coefficient of the linear equation.

Katiyar has reviewed that there are 40 models that has been developed by different authors [11]. There are various values of empirical coefficient being reported. The coefficient values are subjected to region of study and its climatic conditions throughout the year.

$$\frac{H}{H_O} = a + b\frac{S}{S_O} \qquad (1)$$

Despite the prediction using sunshine based model provide more precise estimation, the availability of the data is similar to the solar radiation data. As an alternative, researchers have been using meteorological parameters that are readily available for a long term. One of common approach that has been used to predict solar radiation is from the product of extraterrestrial solar radiation and atmospheric transmissivity coefficient. Some solar radiation estimation model are based ambient air temperature [14], [15], cloudiness [16] or relative humidity [17].

The most commonly used temperature based model estimation are Hargreaves-Samani Model [18] and Bristow Campbell model [15]. Since the establishment of the two models, many studies regarding the temperature based models have been carried out to improve the performances in data predictions, which were reviewed extensively by Liu et al [19]. Hargreaves-Samani solar radiation model is widely applied in evatranspiration application [20]. The model is based on the differences of maximum and minimum air temperature. The parameter is used by many previous researchers to indicate general cloudiness indications [21]–[30].

The presence of cloud cover can decrease the maximum air temperature because of low solar radiation intensity and increases the minimum temperature due to downward emission and long wave radiation reflection by the cloud [31]. Other important parameters such as relative humidity, wind speed, elevation and precipitation have the properties to reduce the transmissivity of solar radiation. However, those mentioned meteorological parameters are not included in model estimation as the effects are fairly constants over a month period [32]. On the contrary, [7], [19], [22], [23], [25], [27], [33]–[44] recommend to include the meteorological parameters in prediction model. Despite the inaccuracy generated, the advantage of solar radiation estimation is greater due to availability of temperature data for long term and wider areas [45]–[48].

In Sarawak, Malaysia, there are no extensive studies on this solar radiation estimation model. The previous study by A.Q Jakhrani [8, 13–15] uses sunshine based solar radiation model to estimate the solar insolation that is available in Sarawak and proposed a new model by adding few parameters to reduce the prediction error. The model incorporates the environmental factor such as temperature and relative humidity. The model equation is expressed as in (2) where T_{max}, RH , and a are maximum air temperature, relative humidity, and location constant respectively. The assigned constant a by the author is 0.24. The performance of the model prediction showed satisfactory results [33]. The author uses the environmental data of 2005-2009 which obtained from local weather stations [8]. However, in the recent, 2010 onwards, surface data measurement by meteorological stations in Sarawak shows that there is no measurement on sunshine duration. Furthermore, it is appeared that there is huge missing or defective gap of time series measurement of solar radiation data (envisaged in Table 2). Assumption of sunshine duration value, without actual measurement, during prediction of solar radiation using (2 would generate inaccuracy. Therefore, as an alternative temperature-based solar radiation model is used to predict the missing or defective solar radiation data.

$$H = H_O \left[a + \frac{T_{max}}{RH} \times \frac{S}{S_O} \right] \quad (2)$$

In the study, Sarawak meteorological data of 2010-2015 are used. The intention of this research are to (i) calibrate and validate existing temperature based solar radiation models; (ii) develop generalized model based on surface measures data obtained from Department of Meteorological Malaysia; and (iii) compare the developed model from existing methods.

II. DATA AND METHOD

A. Data Set

The daily meteorological data of Sarawak stations is used for the purpose of this research study. There are seven weather stations that available in Sarawak, envisaged inTable 1. The types of data being used for six years (2010-2015), obtained from Department of Meteorological Malaysia are maximum and minimum air temperature, relative humidity, and solar radiation. The measurement period of the data sets by the weather stations is as shown in Table 2. There is a complete measurement data for air temperature, cloud factor and relative humidity for a six year period obtained from the Department of Meteorological Malaysia. However, the measured solar radiation data set is found to be missing or incomplete and defective during this period. The defective data of solar radiation obtained from the weather stations are recorded as the value of -1.1. The occurrence of such readings is due to the defects in the measuring tools. Therefore, for analysis purpose the defective values are neglected and considered to be incomplete measurement for the period. Missing data estimation approach is used for the missing or incomplete solar radiation data.

Table 1
Weather Stations in Sarawak

Stations	Latitude	Longitude
Bintulu	3.1713˚N	113.0419˚E
Kapit	1.9951˚N	112.9331˚E
Kuching	1.6077˚N	110.3785˚E
Limbang	4.775˚N	115.0081˚E
Miri	4.3995˚N	113.9914˚E
Sibu	2.2873˚N	111.8305˚E
Sri Aman	1.237˚N	111.4621˚E

Table 2
Measured Data Sets Period by Department of Meteorological Malaysia

Stations	Max and Min Air Temperature (˚C)	Relative Humidity (%)	Cloud Factor (Octa)	Solar Radiation (MJ/day)
Bintulu		2010-2015		16 Nov - 2015
Kapit		2010-2015		14 Feb 2014 - 2015
Kuching		2010-2015		July 2010 - 2014
Limbang		2010-2015		July 2013 - Sept 2014
Miri		2010-2015		2011-2015
Sibu		2010-2015		July 2013 - 2015
Sri Aman		2010-2015		July 2013 - 2015

B. Missing Solar Radiation Data Estimation Approach

The missing solar radiation data is imputable depending on the techniques used (e.g. multiple imputation, mean substitution, interpolation and regression imputation). For this study, linear regression and multiple linear regression method, MRM, are used to estimate the missing data. Linear regression model will provide general relation of global solar radiation, GSR, (known as dependent variable of this study) to the meteorological parameters (or independent variable) used to predict the missing solar radiation data. The differences of linear regression and multiple linear regression approaches is linear regressions uses one parameter to determine GSR. While MRM uses more than one independent variables. Various authors [33], [52]–[56] suggested that to improve model prediction of GSR, independent parameter can be coupled up with more meteorological parameters. The differences of maximum and minimum air temperature, ΔT, relative humidity, RH and CF are used as independent variable to determine the value of GSR. Hence, the imputations of the missing data by using the two methods enable further analysis of the solar radiation available in Sarawak.

The GSR estimation is started by determining extraterrestrial radiation, H_O [57] at each of meteorological stations in Sarawak. The value of H_O is computed by using (3) [57], where I_{SC} is solar constant ($1367\ W/m^2$), E_O is eccentricity coefficient, δ is earth declination, ϕ is latitude and ω_S sunrise hour.

$$H_O = \frac{24}{\pi} \times I_{SC} E_O \times (\sin\delta \times \sin\phi)\left[\frac{\pi\omega_S}{180} - \tan\omega_S\right] \quad (3)$$

Table 3 presents empirical models that are used to estimate GSR at seven different meteorological stations in Sarawak. Model 1 and 2 are developed from linear relations of each of ΔT and RH with respect to GSR. Meanwhile model 3 is developed from multiple linear regression method and uses ΔT, RH and CF simultaneously to determine GSR. Lastly, model 4 and 5 are air temperature based model which are widely implemented and have been established. The two models are used to compare the outcomes predicted by model 1-3. Each of the models has its own empirical coefficients that can be calibrated depending on the sites data provided.

Table 3: Empirical Models Used In Study.

No.	Model		
1	Linear ΔT	$GSR = a_1\Delta T + b_1$	This study
2	Linear RH	$GSR = a_2 RH + b_2$	This study
3	Multiple Linear Regression (MRM)	$GSR = a_3 + b_3\Delta T + c_3 RH + d_3 CF$	This study
4	Hargreaves -Samani	$GSR = a_4 H_O (T_{max} - T_{min})^{0.5}$	[14], [18]
5	Bristow-Campbell	$GSR = a_5\,(1 - e^{-b_5 \Delta T^{c5}}) H_O$	[15]

C. *Statistical Parameters for Model Validation*

The outcomes of each model are validated using the statistical parameters such as Mean Bias Error (MBE), Mean Percentage Error (MPE), and Root Mean Square Error (RMSE). MBE in (4) will exhibit overall trend of a model in long term whether the data generated is overestimated or underestimated, where *n* is the number of observations, $GSR_{i,calc}$ and $GSR_{i,meas}$ are calculated and measured values of i^{th} event. The closer the value of MBE to zero, the model tends to perform with agreeable result. While MPE as in is (5) average percentage error of two data set. RMSE in (6) is used to measure the difference between estimated data with actual data. The smaller the value indicates better performance of the data in short term.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(GSR_{i,\,calc} - GSR_{i,\,meas}) \quad (4)$$

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{GSR_{i,calc} - GSR_{i,meas}}{GSR_{i,meas}}\right) \times 100\% \quad (5)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(GSR_{i,calc} - GSR_{i,meas}\right)^2} \quad (6)$$

The percentage of MBE and RMSE are used to compute percentage error being generated over short and long term. The two tests are defined as the percentage of MBE or RMSE (can be viewed in (7) and (8)) from average measured solar radiation data, $\overline{GSR}$.

$$\%MBE = \frac{MBE}{\overline{\overline{GSR}}} \times 100\% \quad (7)$$

$$\%RMSE = \frac{RMSE}{\overline{\overline{GSR}}} \times 100\% \quad (8)$$

III. Results and Discussion

A. *Localized Solar Radiation Models*

The empirical coefficients of model 1-5 for all the seven stations are vary as claimed by [5], [22], [41], [58]–[65] and are summarized as in Table 4. Coefficient of model 1 is in positive value. The temperature differences, ΔT has properties that can increase the value of GSR estimated as the range between minimum and maximum temperature is high. While the negative value of coefficient of model 2 indicated that RH has reduction properties to the value of GSR predicted. Both of coefficients b of the model 1 and 2 are the intercepts of the model linear relations.

The changes of ΔT are affected by short and long wave radiation of incoming solar radiation which undergoes dimming or brightening effect within a day. Within a day, the maximum daily temperature is mainly affected by the short wave radiation, while, the minimum daily temperature is affected by the long-wave radiation [18], [67]. The variation in ΔT has a complex relation with the cloud cover development, precipitation, water vapor feedback and albedo. Sarawak has high RH which has the properties to reduce the estimated GSR. The existence of a high concentration of water vapor in the atmosphere can reduce the intensity of GSR by diffusing and scattering the incoming solar radiation. The concentration of the water vapor in the atmosphere is induced by the evaporation and transpiration of water from the farm or hydrological landscapes as the temperature during the day increases. Then the temperature drops as the evaporated water condensed into the cloud that reflecting the incoming solar radiation [68], [69].

The coefficients of model 3 are also being summarized in Table 4. Kapit and Sibu stations are using two types of meteorological parameters. At Kapit, the RH is absence in the model 3 while at Sibu station is CF. The absence of the parameters is marked with ‘X’. The absences of the two parameters are due to generation of Pearson distribution analysis value, P-value that is more than 0.15. To model a strong predictive property of a model, the P-value of each parameter should be less than 0.15. Whilst, the value of coefficient of model 4 are fixed to 0.16 for interior areas and 0.19 for coastal areas as suggested by [18], [66]. For model 5, the value of coefficient indicates the maximum clear sky characteristic that can be achieved at each of the seven stations. The coefficients are varied from 0.2 until 0.5, where the maximum clear sky of 0.5 is at Limbang station. At Kuching station, the maximum clear sky can be achieved is 0.2. Coefficient indicates how soon the maximum clear sky can be achieved as ΔT increases. From the values computed, the maximum clear sky is increasing slowly as the ΔT increases. This is perhaps due to the humid condition of

Sarawak. It is adequate to set the value of to default value of 2.4 [15].

Table 4
Empirical Coefficient of Solar Radiation Model

Model No.	1		2		3				4	5		
Station	a_1	b_1	a_2	b_2	a_3	b_3	c_3	d_3	a_4	a_5	b_5	c_5
Bintulu	5.2E-3	0.2985	-5.1E-3	0.79	1.68	-0.02	-0.01	-0.05	0.16	0.3	-4.3E-4	2.4
Kapit	5.7E-2	2.8E-2	-2.7E-2	2.85	1.28	0.04	-0.01	**X**	0.16	0.4	-2.0E-3	2.4
Kuching	5.6E-2	2.0E-3	-1.7E-2	1.88	0.78	0.04	-0.01	0.01	0.16	0.2	-2.1E-3	2.4
Limbang	6.5E-2	-2.0E-4	-1.7E-2	1.92	1.60	0.04	-0.01	-0.06	0.16	0.5	-4.9E-5	2.4
Miri	4.5E-2	7.9E-2	-2.0E-2	2.16	1.99	0.04	-0.01	-0.13	0.16	0.4	-2.3E-3	2.4
Sibu	4.6E-2	4.9E-2	-1.3E-2	1.52	1.10	0.04	**X**	-0.14	0.16	0.3	-1.9E-3	2.4
Sri Aman	4.8E-2	3.7E-2	-1.8E-2	2.02	0.48	0.04	-0.01	0.01	0.16	0.4	-4.627	2.4

X= Inapplicable parameter

B.Model Performances

The predicted values of GSR by using models in Table 3 are compared with the measured GSR. The closeness of the predicted and measured GSR is defined by using statistical parameters as in Section **Error! Reference source not found. Error! Reference source not found.**.

Table 4 shows the performances of the empirical models at each of meteorological stations in Sarawak. Model 3 at each of the station are in bold fonts and it is indicates that the model perform the best. Model 3 is developed to increase the accuracy of the two linear relation models by considering three meteorological parameters at once. The results of %MBE shows that Sri Aman is overestimated GSR for 0.12% in long run. The other sites provide 0% of bias error which indicates good performance over a long run. The model 3 performs the best at Bintulu site with MPE of 6.43% and 9.5% of %RMSE while the worst is at Sibu with MPE of 25.06% and %RMSE of 21.88%.

Model 1 is underestimated GSR at Limbang (7.18%), Miri (3.98%), Kuching (0.3%), and Bintulu (0.06%). Meanwhile at Sibu, Sri Aman and Kapit sites are overestimated by 1.84%, 0.09%, and 0.04% respectively. The MBE of the linear relation shows that it has trends that predict GSR with less bias error in long term, where the %MBE at all stations are not exceed 10%. At Bintulu site the linear model estimated GSR that is close to the actual measured data by 7.76% of %MPE and %RMSE of 11.3%. The MPE value of model 1 at Kapit site is 32.57% with %RMSE of 16.59% (907.45 W/m^2). Model 1 performs the worst at Sibu with %RMSE of 24.41% and MPE of 31.46%.

Model 2 prediction shows that the GSR are underestimated at five sites: Limbang (7.18%), Miri (3.65%), Sri Aman (0.51%), Kuching (0.5%), Kapit (0.17%) and Sibu (0.13%). While at Bintulu and Sibu are overestimated by 0.78% and 0.13% respectively. It performs the best at Bintulu with MPE of 7.11% and RMSE of 10.5% (339.77 W/m^2). The predicted value by the model is the closest to the actual measured value compared to the other site. But comparing with the performances of model 1 at Bintulu, model 2 gives smaller RMSE. The highest value of MPE is at Kapit site with 34.38% however, the site's RMSE is 17.58%, which is second smallest compared to the other site. The performance of model 2 does not perform well at Sibu site as it generates 25.05% of RMSE.

The trends of predicted GSR value by model 4 underestimates GSR value by 0.6% at Bintulu and 0.65% at Sibu sites. Meanwhile it overestimates the value by 3.33% at Kapit, by 2.09% at Limbang, by 1.55% at Sri Aman, by 0.84% at Miri and by 0.5% at Kuching. In term of MPE, the percentage errors that being generated in Kapit site is the highest among the other sites, which is 35.68%. While, at Bintulu site has 7.64% of MPE that is the smallest. The differences of predicted value are the closest to the mean measured value compared to the other sites. Meanwhile the RMSE value at Bintulu site indicates that the model 4 performs the best with value of 11.3% (365.96 W/m^2). This model took consideration of atmospheric transmittance in the equations.

The values of GSR predicted by this model 5 are higher compared to the other models used in this study. Overall trend of data at long run or MBE shows that this model overestimated the data at Bintulu (27.6% or 895.22 W/m^2), Kuching (7.42% or 311.43 W/m^2), Sibu (3.7% or 148.70 W/m^2), and Sri Aman (0.98% or 35.35 W/m^2) stations. While at Miri (-13.5% or -643.582 W/m^2), Kapit (-11.9% or -612.49 W/m^2), and Limbang (-10.8% or -579.65 W/m^2) stations are underestimated. The prediction of GSR by model 5 at the long run can generate error up to MPE of 33.67% which occurred at Sri Aman site. The lowest error that is generated by model 5 is at Kuching (MPE of 15.75%). The range of mean error of this model estimation is considered high, and the range is between 15% and 34%. The results show that the data predicted at Sri Aman site is closest to the actual data by 17.3% or 903.03 W/m^2. This model performs worst at Bintulu site since the differences of the predicted data and actual data is 32.4% (1051.13 W/m^2). This model may seem to look very simple but in term of accuracy are not suitable for the estimation of solar radiation especially at high humidity area [33].

Consistent with findings by Irwanto [53], the performances of model 5 produces high MBE and RMSE for prediction of GSR in Perlis. A study by [33] in Sarawak also found out that model 5 cannot perform well. The recommended model coefficient by the author [18] is 0.16 for the interior region and 0.19 for the coastal area. But in this model, geographical profiles of sites are not taken into consideration. Since geographical characteristic of Sarawak consist of complex terrain, model 5 prediction of solar radiation is unstable and will contributes to high error prediction.

When comparing all of tested model at each station, model 3 performs the best compared to the other four models. The data generated by it shows that it is neither overestimated nor underestimated. The MBE of the model at the seven sites is as close to zero. Meanwhile its RMSE indicates that the performances of model 3 are the smallest. Model 1 and 2 also can perform with agreeable results at each sites of Sarawak by generating second smallest percentage of RMSE. But the two linear relations are not taking consideration of other factor such as cloud factor in predicting the value of GSR.

Table 4
Statistical Performances of Solar Radiation Models.

Station	**Model No.**	**Statistical Parameters**				
		MBE		**MPE**	**RMSE**	
		(%)	$\left(W/m^2\right)$	**(%)**	**(%)**	$\left(W/m^2\right)$
Bintulu	1	-0.06	-1.79	7.76	11.3	366.49
	2	0.78	25.46	7.11	10.5	339.77
	3	**0.0**	**0.437**	**6.43**	**9.5**	**307.45**
	4	-0.6	-18.9	7.64	11.3	365.96
	5	27.6	895.22	30.96	32.4	1051.13
Kapit	1	0.04	2.43	32.57	16.59	907.45
	2	-0.17	-9.40	34.38	17.58	962.31
	3	**0.002**	**0.09**	**30.23**	**15.08**	**825.49**
	4	3.33	182.30	35.68	18.95	1037.15
	5	-12.0	-657.91	36.31	22.1	1211.67
Kuching	1	-0.3	-14.49	14.70	16.12	690.35
	2	-0.5	-21.09	20.33	19.53	836.45
	3	**0.0**	**0.5**	**12.5**	**13.78**	**590.1**
	4	0.5	21.24	19.03	19.98	855.69
	5	7.5	320.20	22.75	19.92	853.45
Miri	1	-3.98	-197.79	26.07	21.29	1058.65
	2	-3.65	-181.35	25.88	21.14	1051.33
	3	**0.01**	**0.45**	**23.95**	**19.09**	**948.97**
	4	0.84	41.64	30.06	22.35	1111.33
	5	-13.5	-671.22	28.64	26.06	1295.76
Limbang	1	-7.18	-382.17	16.08	17.90	953.14
	2	-7.18	-382.17	14.77	17.90	953.14
	3	**0.00**	**0.00**	**12.89**	**13.68**	**728.65**
	4	2.09	111.17	23.03	22.85	1217.17
	5	-8.90	-473.98	17.81	20.33	1082.70
Sibu	1	0.08	3.74	25.03	21.75	997.43
	2	0.13	5.92	30.65	25.05	1149.13
	3	**0.00**	**0.00**	**25.06**	**21.88**	**1003.46**
	4	-0.67	-30.80	30.80	23.88	1093.10
	5	3.74	171.10	29.56	23.27	1065.50
Sri	1	0.09	4.36	27.19	15.51	746.78
Aman	2	-0.51	-24.36	30.99	18.46	888.91
	3	**0.12**	**5.63**	**24.79**	**14.18**	**682.45**
	4	1.55	74.46	30.95	18.62	896.54
	5	0.98	47.15	31.41	17.28	832.02

Model 1, 4, and 5 are the model that using only the temperature differences, ΔT in the estimation of GSR. But when predicting, there are various factor that dampen the temperature range, ΔT. It is either existence of high water molecules, aerosol, or dust particles in the atmosphere. Even though the prediction model of model 2 is slightly off compared to the model 1, it is an important parameter which allows understanding the effects of RH on the GSR. Sarawak is well known to have high RH that is range between 85-90% throughout the year and heavy cloud cover at average of 7 Octas daily. The two factors thus are known as the factor that reduces the ΔT.

IV. Conclusion

The GSR estimation models are using the recent (2010-2015) meteorological data from seven local weather stations are calibrated to estimate the missing solar radiation data. The calibrated models are localized specifically to the location of meteorological stations in Sarawak. Model 5 demonstrates unstable prediction as it either overestimate or underestimates the solar radiation with a high percentage of error, thus it is unsuitable in the GSR estimation. Model 4 performs moderately depending on the temperature differences and coefficients at different locations. The two linear relation models, model 1 and 2, are complimentary to each other and perform satisfactory at the seven meteorological stations. However, the errors generated by the linear models can be reduced by the application of model 3. The model uses temperature differences, relative humidity and cloud factor in the estimation. For long term, model 3 estimation is stable as it does not underestimate or overestimate the value of GSR. Moreover, the RMSE of model 3 are the smallest among the entire tested model which indicates good performances for short term prediction. Other independent variables such as daily transmittance can be used to further minimize the error produced. The estimation of the solar radiation is intended to fill the missing gap of the six years data. However, validation using long term and reliably measured data is needed to validate the existing models and hence can be applied to the wider application.

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