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Model for Estimation of Global Solar Radiation in Sarawak, Malaysia

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Abstract: The aim of this work was to estimate the obtainable amount of global solar radiation for the development of solar photovoltaic power systems at four locations namely Sri Aman, Sibu, Bintulu and Limbang in Sarawak, Malaysia. For this purpose, three empirical models namely Angstrom type Page model, Hargreaves equation and the Sayigh Universal formula were selected for the assessment of their estimated values. The data of selected locations were acquired from the Malaysian Meteorological Services Regional Office based at Kuching. It is confirmed from the evaluation of results that the selected models overestimated the amount of obtainable global solar radiation when compared with the measured data taken from the nearest station. The models did not perform well in almost all four selected places. This may be due to the weather conditions and geographical location of the area. Therefore, an improved model was formulated based on the recorded meteorological data of available parameters such as bright sunshine hours, relative humidity and maximum temperature. The proposed model established less than 10 and 8 percentage of root mean square error and mean bias error and produced acceptable results as compared to examined models. Therefore it is preferred for the estimation of global solar radiation in the remote places of Sarawak, where the facilities for the measurement of global solar radiation by pyranometers is not available.

Key words: Bright sunshine hours · Empirical models · Global solar radiation · Meteorological parameters · Solar energy systems

INTRODUCTION

Solar energy is a natural green technology resource, environment and nature-friendly, does not produce emissions that contribute greenhouse effect or destroy the ecological balance of the area and occupies one of the most important places among various alternative energy sources [1]. Information of solar radiation data is a pre-requisite for the modeling and design of all solar energy systems. Architects, agriculturalists, air conditioning engineers and energy designers require the familiarity of solar radiation data [2-8], for climatology and pollution studies [9-10] and for many other applications, such as atmospheric energy-balance studies, analysis of the thermal load on buildings, solar energy collecting systems and economic viability of methods [11, 12]. The network of meteorological stations measuring the solar radiation data is sparse in many developing countries and only few stations are well equipped for the measurement of the daily solar radiation on a consistent basis [13]. Measured monthly average values of daily irradiation, are usually the best source of information and provide the starting point for many calculations. The usefulness of long-term monthly averages of daily radiation can be understood from the fact that at a particular location these averages are relatively constant, so that past values can be used to estimate future ones. If the recorded solar radiation data is not available, then there is one possibility to get reasonable estimation of solar radiation by using commonly available meteorological parameters, such as bright sunshine hours, relative humidity, maximum and minimum temperatures and cloud cover of that geographic location [14]. For this purpose, in the past, numerous empirical correlations have been developed in order to estimate the available global solar radiation around the world. Several models are existed, which correlate the global solar radiation to other meteorological parameters such as bright sunshine hours, relative humidity and maximum temperature. The most commonly used parameter for estimating global solar radiation, is bright

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sunshine duration. The sunshine duration can be easily and reliably measured and the data is also widely available in most of places around the globe [15]. The data of sunshine hours and other parameters requires a correlation for estimation of available global solar radiation. It can be carried out by the use of empirical models. Empirical Models were found to be essential and economical tools for transforming the meteorological parameters to calculate the amount of global solar radiation.

The basic and fundamental equation has been used since 1924 is Angstrom-type regression model [16]. Most authors modified that equation for the prediction of solar radiation data. Moreover, others formulated quadratic, linear, logarithmic, power and trigonometric models. In this study, three empirical models were examined for computing global s olar radiation at various places of Sarawak State namely; Sri Aman (1.14°N, 111.3°E), Sibu (2.17°N, 111.64°E), Bintulu (3.13°N, 113.02°E) and Limbang (4.53°N, 115.00°E). The first empirical relationship used for analysis, was proposed by Page, which was based on data of bright sunshine hours and climatic constants. The second equation given by Hargreaves which employed temperature difference (maximum and minimum) and the third formula involved the parameters such as relative humidity, bright sunshine hours, ambient temperature and sun angles was developed by Sayigh. The brief introduction of the selected empirical models is given below:

Angstrom Type Page Model: Page (1964) incorporated the term of extraterrestrial radiation on a horizontal surface for clarification of term clear day radiation used by Angstrom [17]. The model is given as:

$$H = H_o\,[a + b(S)] \qquad (1)$$

Where, H_o is the extraterrestrial radiation on a horizontal surface for the location averaged over the time period in question and a and b are constants depending on location and S is considered as the ratio of monthly average bright sunshine hours $(\bar{n})$ to the day length $(\bar{N})$ hours, of the average day of the month. The monthly average daily extraterrestrial solar irradiance on the horizontal surface was computed by taking the values of a single day (close to monthly mean values) for every month of the year. The value of constants (a) and (b) were developed for various climate types and locations, that can be used in the absence of available constants for any area with similar meteorological conditions [15]. The recommended values for the constants a = 0.28 and b = 0.39 (for tropical forest climate, constant moisture, rainfall throughout the year and for broadleaf evergreen trees) were used for the selected locations.

Hargreaves' Equation: The first idea for the calculation of clearness index from the difference of the mean value of the daily maximum temperatures (T_{max}) and minimum temperatures (T_{min}) was proposed by Hargreaves (1982). The equation is given as [18]:

$$H = \alpha \times H_o\,(T_d)^{0.5} \qquad (2)$$

Where, T_d is the daily temperature difference "maximum minus minimum" (°C). The value of empirical parameter a was initially fixed as 0.17 for arid and semiarid climates. Later, Hargreaves recommended the use of a = 0.16 for interior regions and a = 0.19 for coastal regions [19-21]. The temperature difference becomes less when cloud cover is greater. This is because, the day temperatures remain high and the heat is conserved so that the night temperature is also high, resulting in less temperature range during the day. The temperature difference takes into account the changes in the solar radiation due to proximity to oceans, mountains and the altitude of the location [22]. The data for Hargreaves equation is mostly available at many locations around the world.

Sayigh Universal Formula: The Sayigh Universal formula correlated the global solar radiation (H) with mean maximum temperature T_{max} (°C), mean relative humidity RH (taken as a fraction) and the ratio of sunshine hours to the length of the day [23-29]. It is expressed as:

$$H = k \times K \exp\left[\varphi\left(S - \left(\frac{RH}{15}\right) - \frac{1}{T_{\max}}\right)\right] \qquad (3)$$

$$k = 1.7 - 0.458\varphi \qquad (4)$$

$$a = 0.2/(1+0.1\,\varphi) \qquad (5)$$

k and a are constants, φ is the latitude of the location, (taken in radians for k & H and employed for the calculation in degrees for a and K).

$$K = 1.163\left(a \times \overline{N} + \psi_{ij}\cos\varphi\right) \qquad (6)$$

Where, K is a constant (kWh/m^2/day), while k, α and K are factors which were computed using the respective equations. ψ_{ij} is a humidity factor, i = 1,2,3. The value of 1 is used for RH < 65%, 2 is for RH > 70% and 3 is for 65%

≤ RH ≤ 70%. On the other hand, j = 1, 2,……12, refers to the months of the year. Humidity factor ψ_{ij} was taken from the Figure provided by [29].

Formulated Model: The Sayigh Universal Formula could not be easily implemented because of many variables involved in the model. The Hargreaves equation considered only temperature difference and did not account any climatic factor. The constant or interpolated values were used in Page model, which do not varies according to the environmental conditions. But, the proposed model incorporates the environmental aspects such as temperature and humidity. These factors were considered as changing forces that affect the amount of global radiation received at any particular place. The criteria framed for this approach was based on simplicity, accuracy and availability of input data. It was assumed that the suggested model meets all these requirements. The model is expressed as follows:

$$H = H_o\left[a + \left(T_{\max}/_{RH}\right)(S)\right] \quad (7)$$

Where, a is the location constant depending on geographical site and environmental conditions of the area. The value of a was calculated by collecting the information for the mean ambient temperature, wind speed, cloud cover, rainfall conditions, vegetation types and pollution level of the area as expressed in equation (8)

$$a = \frac{Number\ of\ Parameters}{Sum\ of\ Assigned\ Values} \quad (8)$$

The parameters, their description and associated assigned values are given in Table 1. The assigned values will be chosen from the corresponding ranges of geographical and environmental parameters of the area. The value of a was found to be 0.24 for Sarawak region as per formulated procedure. $T_{\max}$ is the average maximum temperature (°C) and RH is relative humidity taken as whole not in fraction. For example: If the RH is 75%, then

Table 1: Description for the Determination of Location Constant a

S.R. No	Location and Environmental Parameters	Description and Range of Parameters	Assigned Values
1	Mean Ambient Temperature (°C)	1-10	1
		10-20	2
		20-30	3
		30-40	4
		40-50	5
2	Wind Speed (m/s)	< 2	1
		2-4	2
		4-6	3
		6-8	4
		> 8	5
3	Cloud Cover (Oktas)	1	1
		2	2
		3	3
		4	4
		5	5
		6	6
		7	7
		8	8
4	Rainfall Conditions	No or light rainfall	1
		Low rainfall	2
		Rainfall throughout year with long dry season	3
		Rainfall throughout year with short dry season	4
		Rainfall throughout year	5
5	Condition of Vegetation	Desert	1
		Grasses and herbaceous plants	2
		Broadleaf evergreen trees shrub form	3
		Broadleaf deciduous trees	4
		Broadleaf evergreen trees	5
6	Pollution Level (Particulate Matter)	Extremely high	1
		High	2
		Medium	3
		Low	4
		None or Negligible	5

it is taken as 75 in equation (7). In proposed model, the temperature and relative humidity were related with the bright sunshine hours, which take into account the changeable nature of variables that restricts the amount of global solar radiation reaching to the earth's surface.

MATERIALS AND METHODS

Data Acquisition: The data was obtained from Malaysian Meteorological Services, Regional Office Kuching. The facility for measuring the solar radiation data is available at Kuching only in the whole Sarawak State. Since, six years measured global solar radiation data for the year 2005-2009 from Kuching was used for the comparison of estimated results computed from selected models. The 10 years data of sunshine hours, relative humidity, monthly mean, maximum and minimum air temperature from 2000-2009 was used for three stations, namely Sri Aman, Sibu and Bintulu. Only 3 years data from 2007 to 2009 was used for Limbang. The previous data was not available for that location. The daily meteorological variables were the maximum and minimum temperatures and bright sunshine hours and relative humidity.

Single day for each month was selected for representing the entire month for the whole year as suggested by Klein (1977). The 17th of January and July, 16th of February, March and August, 15th of April, May, September and October, 14th November, 11th of June and 10th December were chosen days for this analysis [16]. The selected days gave results close to the monthly mean values for every month of the year, representing that individual month. Then, declination, sunset hour angle, average day length were computed by empirical relationships. After that, the monthly average daily extraterrestrial solar irradiance (H_o) on the horizontal surface was determined by taking the average values of a single day for all months. Three models were examined for the determination of global solar radiation at four sites of Sarawak State. Finally, the results were compared with global solar radiation data which is measured at Kuching, the nearest station with similar meteorological conditions.

Accuracy and Validation: The accuracy of different models and correlations was evaluated by means of two widely used statistical methods, root mean square error (RMSE) and mean bias error (MBE). In general, a low RMSE is desirable, the positive MBE demonstrates that the predicted values overestimated the measured values; whereas, a negative MBE indicates the underestimation of the observed values. The percentage RMSE and MBE of corresponding values were also calculated for the comparison of computed results with measured values [24]. These statistical methods are defined by the following equations [25-26]:

$$RMSE = \sqrt{\sum (y_i - \hat{y}_i)^2 / n} \quad (9)$$

$$MBE = \sum (y_i - \hat{y}_i) / n \quad (10)$$

$$\%RMSE = \frac{RMSE}{\bar{y}} \times 100 \quad (11)$$

$$\%MBE = \frac{MBE}{\bar{y}} \times 100 \quad (12)$$

Where, y_i is the ith calculated value, $\hat{y}_i$ is the ith measured value, $\bar{y}$ is the mean of the measured values and n is the number of valid data points.

RESULTS AND DISCUSSION

The estimated global solar radiation of all four selected locations namely Sri Aman, Sibu, Bintulu and Limbang are shown in Figures 1 to 4. Sayigh Universal Formula predicted nearly 30 MJ/m^2 from the month of April to July in Sri Aman and Sibu as shown in Figures 1 and 2. Hargreaves equation estimated between 23 and 26 MJ/m^2 for the entire year in both places. The results obtained from Angstrom type Page model were 15 to 16MJ/m^2, which were found to be closest values to the measured ones. The Sayigh formula predicted lower solar radiation availability in the months of November and December than Hargreaves equation for Sri Aman and Sibu and from January to March for Limbang. This is because there is less temperature variation in tropical regions. The less variation has a little effect on the estimation of global solar radiation. Sayigh Universal formula estimated higher values of available global solar radiation in dry season from April to September in all locations among the examined models. Whereas, the estimated values of Hargreaves equation were lower than Sayigh Universal formula in dry season and higher in wet season.

As compared to other examined models Angstrom type Page model displayed quite reasonable results in dry as well as wet season for all months at every selected location, because it incorporates the climatic and location coefficients. The obtained results of Angstrom type Page model were between 13 and 18MJ/m^2 in all observed

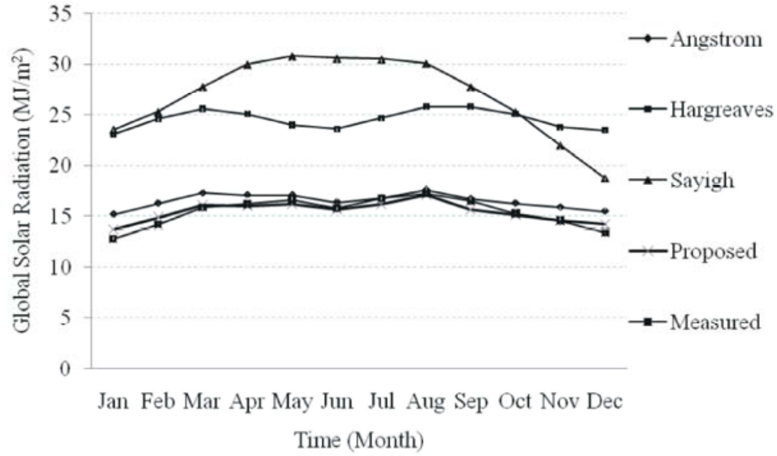

Fig. 1: Values of monthly mean daily global solar radiation verses time at Sri Aman

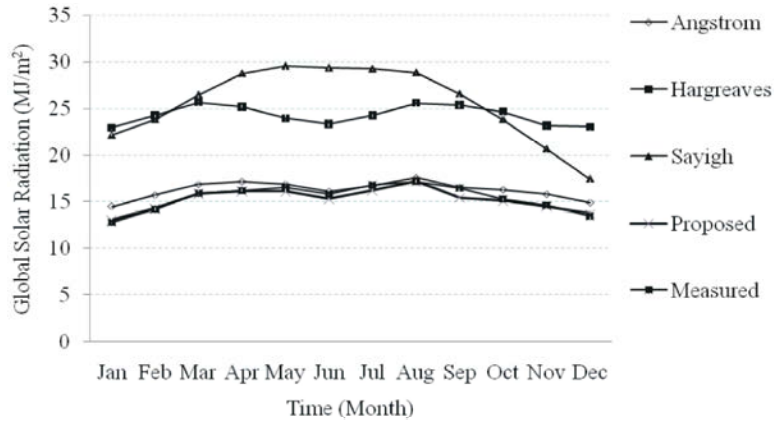

Fig. 2: Values of monthly mean daily global solar radiation verses time at Sibu

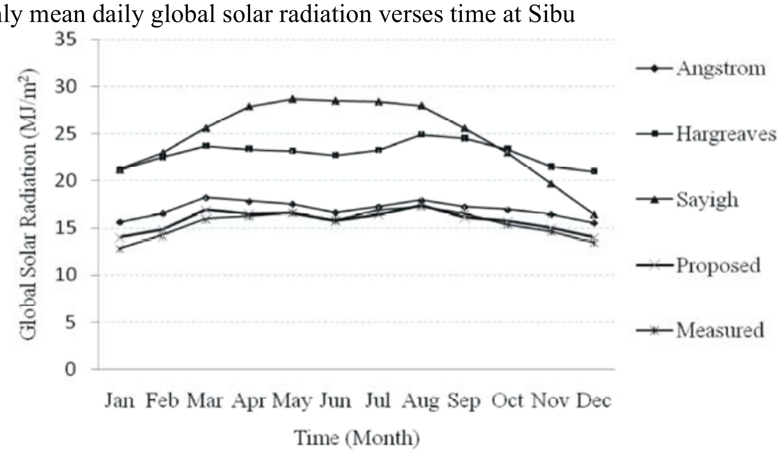

Fig. 3: Values of monthly mean daily global solar radiation verses time at Bintulu

locations. These results were found to be in agreement with measured values of the area. Higher prediction of available solar radiation by Sayigh Universal formula and Hargreaves equation was unjustifiable due to the presence of dense clouds and high humidity. The prediction of Angstrom type Page model was quite acceptable.

The accuracy of calculated data was checked by estimating RMSE and MBE values and their respective percentage error for all models, which are graphically presented in Figures 5 and 6. The analysis of entries confirmed that the Hargreaves and Sayigh models are not feasible for Sarawak climatic conditions due to extremely high RMSE and MBE and their models overestimated the

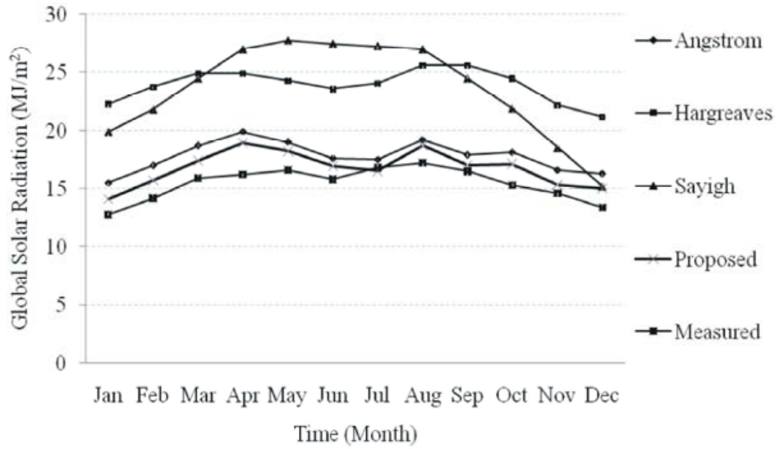

Fig. 4: Values of monthly mean daily global solar radiation verses time at Limbang

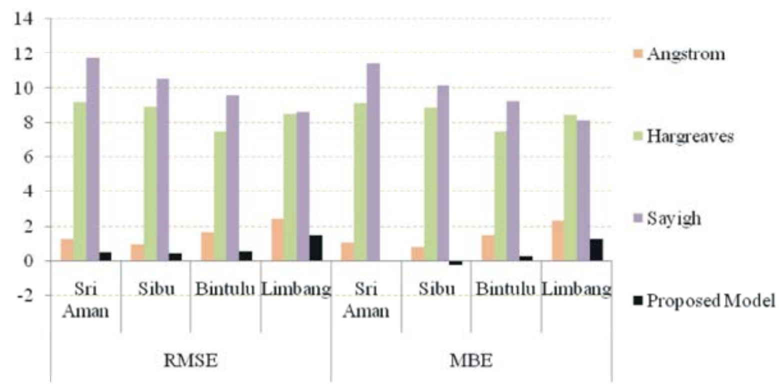

Fig. 5: Comparison of RMSE and MBE in (MJ/m^2) of examined models verses locations

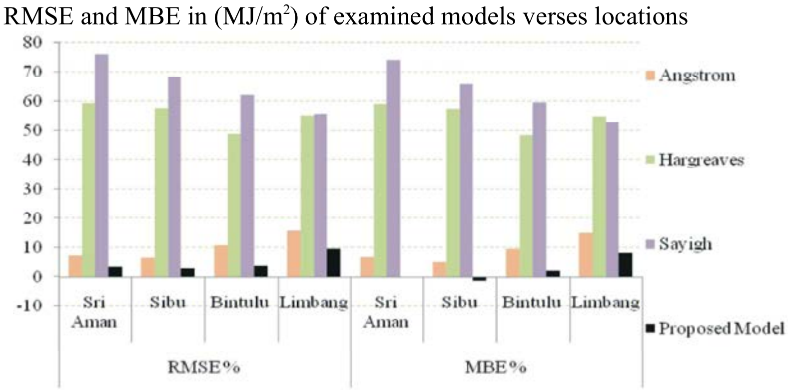

Fig. 6: Comparison of Percentage RMSE and MBE of examined models verses locations

amount of global radiation of the area, whereas, the Angstrom type Page model showed 20 percentage error. The formulated model performs well in the Sarawak scenario and demonstrated less than 10 and 8% of percentage RMSE and MBE respectively. The RMSE and MBE were demonstrated higher at Limbang only, in the proposed model. It is because the long term data was not available in that location and only three years average data was used. At other stations the results were found very close to unity.

It was revealed that the Hargreaves equation demonstrated high values in all months, whereas; The Sayigh's Formula established nearly two times higher values than measured results at nearest location, especially from the month of March to October. Angstrom type Page model exhibited better and reliable results as compared to other models and slightly overestimated the results in the month of January to March and from October to December at all places, except at Limbang where it demonstrated higher values in the whole year.

Usually, the Hargreaves' equation and Sayigh's Universal Formula does not perform well in Sarawak region, it may be due to the high relative humidity factor in the area and less temperature difference. These equations may be valid for dry and temperate climate regions, but not useful in this region. On the other hand, the proposed model showed satisfactory results as compared to reviewed models and its values were found more convincing in all stations of Sarawak State.

CONCLUSIONS

It was found that Hargreaves' equation and Sayigh's Universal Formula overestimated the available amount of global solar radiation and were not suitable estimators for the monthly mean global solar radiation in the region. The Angstrom type Page model produced appropriate results of global solar radiation with a 20 percentage error as compared to the measured data. Moreover, no agreement was found in the obtained results of reviewed models when compared among each other and with measured data taken from the nearest station at Kuching.

The formulated model demonstrated less than 10 and 8 percentage of root mean square error and mean bias error. Therefore it is preferred for the estimation of global solar radiation in the remote places of Sarawak, where the facility for the measurement of global solar radiation by pyranometers is not available.

REFERENCES

1. Jakhrani, A.Q., A.K. Othman, A.R.H. Rigit, S.R. Samo, L.P. Ling and R. Baini, 2010. Evaluation of Incident Solar Radiation on Inclined Plane by Empirical Models at Kuching, Sarawak, Malaysia, presented at the IEEE ICSET 2010, Kandy, Sri Lanka.
2. Muneer, T., S. Younes and S. Munawwar, 2007. Discourses on Solar Radiation Modeling. Renewable and Sustainable Energy Reviews, 11: 551-602.
3. Helen C., 2001. Power Estimating Clear-Sky Beam Irradiation from Sunshine Duration. Solar Energy, 71(4): 217-224.
4. Driesse, A. and D. Thevenard, 2002. Test of Suehrcke's Sunshine-Radiation Relationship using a Global Data Set. Solar Energy, 72(2): 167-175.
5. Li, D.H.W., T.N.T Lam and V.W.C. Chu, 2008. Relationship between the Total Solar Radiation on Tilted Surfaces and the Sunshine Hours in Hong Kong. Solar Energy, 82(12): 1220-1228.
6. Chang, J.M., J.S. Leu, M.C. Shen and B.J. Huang, 2004. A Proposed Modified Efficiency for Thermosyphon Solar Heating Systems. Solar Energy, 76(6): 693-701.
7. Ghosal, M.K., G.N. Tiwari, D.K. Das and K.P. Pandey, 2005. Modeling and Comparative Thermal Performance of Greenhouse Air Collector and Earth Air Heat Exchanger for Heating of Greenhouse. Energy and Buildings, 37(6): 613-621.
8. Tiwari, G.N., H.N. Singh and R. Tripathi, 2003. Present Status of Solar Distillation. Solar Energy, 75(5): 367-373.
9. Gueymard, C. and F. Vignola, 1998. Determination of Atmospheric Turbidity from the Diffuse-Beam Broadband Irradiance Ratio. Solar Energy, 63(3): 135-146.
10. Kharol, S.K., K.V.S. Badarinath, D.G. Kaskaoutis and H.D. Kambezidis, 2007. Impact of Dust Storm Over Indian Region on Ground Reaching Solar Radiation; A Case Study Using Multi-Satellite Data and Ground Measurements. In Proceedings of 3rd International Conference on Solar Radiation and Day Lighting, Indian Institute of Technology Delhi, New Delhi, India, pp: 169-179.
11. Metwally, M.E., 2005. Sunshine and Global Solar Radiation Estimation at Different Sites in Egypt. J. Atmospheric and Solar-Terrestrial Physics, 67: 1342.
12. Robaa, S.M., 2008. Evaluation of Sunshine Duration from Cloud Data in Egypt. Energy, 33: 785-795.
13 Chineke, T.C., 2008. Equations for Estimating Global Solar Radiation in Data Sparse Regions. Renewable Energy, 33(4): 827-831.
14. Suehrcke, H., 2000. On the relationship between duration of Sunshine and Solar Radiation on the Earth's Surface: Angstrom's Equation Revisited. Solar Energy, 68(5): 417-425.
15. Bakirci, K., 2009. Models of Solar Radiation with Hours of Bright Sunshine: A Review. Renewable and Sustainable Energy Reviews, 13: 2580-2588.
16. Klein, S.A., 1977. Calculation of Monthly Average Insolation on Tilted Surfaces, Solar Energy, 19: 325.
17. Page, J.K., 1964. The Estimation of Monthly Mean Values of Daily Total Short Wave Radiation on Vertical and Inclined Surface from Sunshine Records for Latitudes 40N-40S. Proceedings of UN Conference on New Sources of Energy, pp: 378-390.
18. Hargreaves, G.H. and Z.A. Samani, 1982. Estimating Potential Evapo-transpiration. J. Irrg. Drain. Engrg, 108(3): 225-230.

19. Prieto, J.I., J.C.M. Garcia and D. Garcia, 2009, Correlation between Global Solar Irradiation and Air Temperature in Asturias, Spain. Solar Energy, 83: 1076-1085.
20. Hargreaves, G.H., 1994. Simplified Coefficients for Estimating Monthly Solar Radiation in North America and Europe. Departmental Paper, Dept.of Biol. and Irrig. Engrg. Utah State University, Logan, Utah.
21. Chineke, T.C., J.I. Aina and S.S. Jagtap, 1999. Solar radiation Database for Nigeria. Discov Innov., 11: 207-210.
22. Halawa, E.E.H. and Sugiyatno, 2001. Estimation of Global Solar Radiation in the Indonesian Climatic Region. Renewable Energy, 24: 197-206.
23. Sayigh, A.A.M., 1977. Estimation of Total Radiation Intensity-A Universal Formula. In N.A. Mancini and I.F. Quercia, (Eds.) 4th Course on Solar Energy Conversion, 2: ICTP, Trieste, Italy.
24. De Miguel, A., J. Bilbao, R. Aguiar, H. Kambezidis and E. Negro, 2001. Diffuse Solar Irradiation Model Evaluation in the North Mediterranean Belt Area. Solar Energy, 70(2): 143-153.
25. Pandey, C.K. and A.K. Katiyar, 2009. A Note on Diffuse Solar Radiation on a Tilted Surface. Energy, 34: 1764-1769.
26. Efim, G.E. and A.I. Kudish, 2009. The Assessment of Different Models to Predict the Global Solar Radiation on a Surface Tilted to The South. Solar Energy, 83: 377-388.
27. Lof, G.O.G., J.A. Duffie and C.O. Smith, 1966. Engineering Experiment Station Report 21, University of Wisconsin, Madison, World distribution of Solar Radiation.
28. Duffie, J.A. and W.A. Beckman, 2006. Solar Engineering of Thermal Processes. 3rd Edition, John Wiley & Sons Inc.
29. Afriyie, K.O., 1995. International Centre for Theoretical Physics Performance of Sayigh's Universal Formula in the Estimation of Global Solar Radiation in Ghana. International Atomic Energy Agency and United Nations Educational Scientific and Cultural Organization.