

Solar Radiation Estimation from the Measurement of Sunshine Hours over Southern Coastal Region, Bangladesh

Shuvankar Podder¹, Md. Minarul Islam²

¹Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

²Department of Electrical and Electronic Engineering, Shahjalal University of Science and Technology, Sylhet, Bangladesh

Email address:

podder.shuvankar@gmail.com (S. Podder), minarbuett@gmail.com (Md. M. Islam)

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Abstract: In this study, the global solar radiation over the southern coastal region of Bangladesh is estimated from the duration of relative sunshine hours. Five models are considered to estimate the solar irradiance. These models are modified form of classical Angstrom – Prescott regression equation. A quadratic logarithmic model, relating the relative solar radiation and the relative sunshine hours is proposed for southern coastal region of Bangladesh. NASA Surface Meteorology and Solar Energy (SSE) have record of solar radiation data all over the world, measured from satellite. As Bangladesh Meteorological Department or any other organization has no record of measured solar radiation data for the considered locations, the estimated solar irradiance from the proposed regression model is compared with the data recorded by NASA SSE. Also t – statistics is applied to the estimated results to determine whether or not they are statistically significant at a particular confidence level.

Keywords: Solar Radiation, Sunshine Hours, Coastal Region, Nonlinear Relation, Hybrid

1. Introduction

According to renewable energy policy 2009, the Government of Bangladesh is committed to facilitate both private and public sector investments in renewable energy projects to substitute indigenous non-renewable energy supplies and scale up contributions existing renewable energy based electricity production. The policy envisions that 5% of the total energy production will have to be achieved by 2015 and 10% by 2020 using renewable resources. There is a good scope for solar, wind, biomass and mini-hydro power generation in Bangladesh. Among these solar and wind possess most potential for electricity generation [1].

The reliability of electric power encourages hybridization of two or more renewable energy systems because of its intermittent nature. Solar-wind hybrid system is an universal one. Bangladesh Power Development Board (BPDB) has launched 7.5 MW off-grid solar-wind hybrid systems in Hatiya Island, Noakhali. BPDB has planned to install 1 MW off-grid solar-diesel based hybrid plant in Kutubdia Island and a 500 kW photovoltaic plant at Sandwip. 8 MW grid-connected and 2 kW off-grid photovoltaic plants are ongoing projects at Rangamati and Noakhali, respectively. BPDB has

also lined up installation of MW range wind power station at Cox's Bazar [1]

Adequate assessment of renewable resource data are essentials for planning and designing renewable energy based power systems. At present, solar radiation data are available from (1) Renewable Energy Research Centre (RERC), Dhaka University; it has recorded long-term hourly solar irradiance of Dhaka city with Eppley Precision Pyrometer. (2) Bangladesh Meteorological Department (BMD); it has 35 sunshine recording stations [2] situated generally in towns and cities. BMD has no record of solar radiation on the abovementioned solar projects areas. Solar radiation reaching the earth's surface depends upon climatic conditions. Thus a mathematical model can be developed relating climatic factors with solar radiation. A number of studies [3-4] have computed solar radiation from observation of cloud cover. Other studies [5-8] have estimated solar radiation from sunshine hours. BMD has record of daily bright sunshine hours at the abovementioned places.

Some studies have correlated sunshine hours and solar radiation over some major cities in Bangladesh [9-10]. But no attempt has yet been made to estimate solar radiation of the places in Bangladesh where the prospect of solar-wind hybrid system has promising potential. In this paper, five

models relating solar radiation and relative sunshine hours have been analyzed and solar radiation is predicted at Rangamati, Sandwip, Noakhali, Kutubdia and Cox's Bazar. Results are compared with the data reported by NASA Surface Meteorology and Solar Energy (SSE) [11] on that places.

2. Experimental Data

Solar radiation arriving on the horizontal earth surface and duration of bright sunshine hours are two main experimental data in this study. Data of sunshine hours for the years 1983 to 2013 have been collected from BMD. As solar radiation data is not available at BMD, they have been collected from NASA SSE. In this paper, the target locations for analyzing solar radiation are Rangamati, Sandwip, Noakhali, Kutubdia and Cox's Bazar. The geographical parameters of those five locations are shown in Table 1. The relative sunshine hours of five places are shown in Table 2.

Table 1. Geographical parameters.

Stations	Latitude	Longitude	Elevation
Rangamati	22.63	92.2	14
Sandwip	22.48	91.48	7
Noakhali	22.70	91.10	12
Kutubdia	21.82	91.86	50
Cox's Bazar	21.58	92.02	3

Table 2. Relative sunshine hours.

Month	Ranga-mati	Sand-wip	Noak-hali	Kutub-dia	Cox's Bazar
January	0.6635	0.6826	0.6225	0.7362	0.7998
February	0.6906	0.6758	0.6626	0.7370	0.7880
March	0.6361	0.6490	0.6324	0.6962	0.7255
April	0.6050	0.6181	0.5929	0.6379	0.6814
May	0.4679	0.4789	0.4804	0.5270	0.5358
June	0.3194	0.3513	0.2821	0.3156	0.2929
July	0.2815	0.3270	0.2657	0.2886	0.2710
August	0.3609	0.3739	0.3486	0.3514	0.3355
September	0.4227	0.4239	0.3935	0.4711	0.4665
October	0.5545	0.5725	0.5584	0.6031	0.6292
November	0.6527	0.6890	0.6598	0.7252	0.7560
December	0.6677	0.6780	0.6478	0.7556	0.7620

3. Methodology

According to World Meteorological Organization (WMO) the sunshine duration is defined as the period during which the direct solar irradiance exceed a threshold value of 120 W/m²-day or 2.88 KWh/m²-day [12]. Solar radiation of a certain period is proportional to sunshine duration. Different models describing solar radiation and sunshine hours are paraphrased here.

3.1. Angstrom Model

The relation between solar radiation and sunshine duration was first proposed by Angstrom in 1924. The original Angstrom equation is given by [13]

$$\frac{\bar{H}}{\bar{H}_c} = a + b \frac{\bar{n}}{\bar{N}} \quad (1)$$

Where \bar{H} = monthly average daily global radiation (Wh/m²/day), \bar{H}_c = monthly average clear sky daily global radiation for the location, \bar{n} = monthly average daily maximum bright sunshine duration in hours, \bar{N} = actual sunshine duration in a day in hours, and a, b are empirical coefficients. These coefficients are location specific.

A basic difficulty in this model is to determine \bar{H}_c , clear sky radiation. To avoid this difficulty a modified model was presented by Prescott [14] in 1940.

3.2. Angstrom-Prescott Model

Popularly known Angstrom-Prescott model is given by

$$\frac{\bar{H}}{\bar{H}_0} = a + b \frac{\bar{n}}{\bar{N}} \quad (2)$$

where, $\bar{H}, \bar{n}, \bar{N}, a, b$ are same as equation (1) and \bar{H}_0 = monthly average daily extraterrestrial radiation at the specific location. The ratio of solar radiation at the surface of the Earth (H) to extraterrestrial radiation (H_0), that is, H/H_0 , is called the clearness Index and the ratio n/N is referred to as the cloudless index.

Monthly average daily extraterrestrial radiation is calculated from following equation:

$$H_0 = \frac{24}{\pi} G_{sc} \left(1 + \cos \frac{360n}{365} \right) \left(\cos \phi \cos \delta \sin \omega_s + \frac{\pi \omega_s}{180^\circ} \sin \phi \sin \delta \right) \quad (3)$$

where,

G_{sc} = the solar constant = 1.367 kW/m²

n = the day of a year (a number between 1 to 365, starting from 1st January)

ϕ = the latitude in degree

δ = the solar declination in degree

ω_s = the sunset hour angle in degree.

The solar declination is calculated according to the following equation:

$$\delta = 23.45^\circ \sin \left(360^\circ \frac{284+n}{365} \right) \quad (4)$$

The sunset hour angle is calculated using the following equation:

$$\cos \omega_s = -\tan \phi \tan \delta \quad (5)$$

The average H_0 for the month is calculated as follows:

$$H_{0,avg} = \frac{\sum_{n=1}^N H_0}{N} \quad (6)$$

where,

$H_{0,avg}$ = the average extraterrestrial horizontal radiation for the month in kWh/m²/day

N = the number of days in the month

The maximum possible sunshine duration N in hours for a horizontal surface is given by:

$$N = \frac{2}{15} \omega_s \quad (7)$$

3.3. Akinoglu and Ecevit Model

Akinoglu BG et al [15] constructed a quadratic relation between H/H_o and n/N from modified Angstrom model. According to Akinoglu BG et al:

$$\frac{\bar{H}}{H_o} = a + b \frac{\bar{n}}{N} + c \left(\frac{\bar{n}}{N}\right)^2 \quad (8)$$

3.4. Newland Model

Newland et al [16] separated global solar irradiance into its components for the southern coastal region Macau, China. He showed that a non linear relation between (n/N) and (H/H_o) gives better prediction of global irradiance. His proposed relation is

$$\frac{\bar{H}}{H_o} = a + b \frac{\bar{n}}{N} + c \log \left(\frac{\bar{n}}{N}\right) \quad (9)$$

3.5. Ampratwum and Dorvlo Model

Ampratwum et al [17] studied five stations in Oman and proposed a logarithmic relationship between (n/N) and (H/H_o) . His proposed model is

$$\frac{\bar{H}}{H_o} = a + b \log \left(\frac{\bar{n}}{N}\right) \quad (10)$$

3.6. Proposed Model

In this paper, another non-linear model is proposed. The proposed model relating (H/H_o) and (n/N) is

$$\frac{\bar{H}}{H_o} = a + b \log \left(\frac{\bar{n}}{N}\right) + c \log \left(\frac{\bar{n}}{N}\right)^2 \quad (11)$$

The coefficients a, b, c of different models are calculated by least square regression. Five models considered for estimating global solar irradiance on five southern coastal region of Bangladesh are tabulated in Table 3. MATLAB simulation is used in determining regression coefficient.

Table 3. Considered models.

Models	Regression Equations
Angstrom-Prescott	$\frac{\bar{H}}{H_c} = a + b \frac{\bar{n}}{N}$
Akinoglu and Ecevit	$\frac{\bar{H}}{H_o} = a + b \frac{\bar{n}}{N} + c \left(\frac{\bar{n}}{N}\right)^2$
Ampratwum and Dorvlo	$\frac{\bar{H}}{H_o} = a + b \log \left(\frac{\bar{n}}{N}\right)$
Newland	$\frac{\bar{H}}{H_o} = a + b \frac{\bar{n}}{N} + c \log \left(\frac{\bar{n}}{N}\right)$
Proposed Model	$\frac{\bar{H}}{H_o} = a + b \log \left(\frac{\bar{n}}{N}\right) + c \log \left(\frac{\bar{n}}{N}\right)^2$

4. Model Performance

Stone [18] concluded that the t-statistics test might be taken as a statistical indicator for the evaluation and comparison of solar models. The smaller the value of t , the better is the model's performance. If the calculated value of t -

stat is less than a critical value t_c , then it can be concluded that estimation is significant to $(n-1)$ degree of freedom at the $(1-\alpha)$ confidence level. Stone recommend that t-statistics may be used in conjunction with Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) to access the relative model performance. The mostly used statistical indicator MBE, RMSE and MAPE are defined as

$$MBE = (\sum_{i=1}^{n=12} (H_{ic} - H_{im}))/n \quad (12)$$

$$MAPE = (\sum_{i=1}^{n=12} |H_{ic} - H_{im}|)/n \quad (13)$$

$$RMSE = \{(\sum_{i=1}^{n=12} (H_{ic} - H_{im})^2)/n\}^{1/2} \quad (14)$$

$$r = \frac{\sum_{i=1}^{n=12} (H_{ic} - \bar{H}_c)(H_{im} - \bar{H}_m)}{\sqrt{(\sum_{i=1}^{n=12} (H_{ic} - \bar{H}_c)^2)(\sum_{i=1}^{n=12} (H_{im} - \bar{H}_m)^2)}} \quad (15)$$

where, H_{ic} , and H_{im} are the estimated and measured monthly average global solar radiation for the i^{th} month. The average of the deviations $E (= H_{ic} - H_{im})$ is MBE and gives information about the long-term performance of the correlations. MAPE is a measure of the goodness of each correlation, while RMSE measures the short-term prediction quality of the correlations [19].

5. Result and Discussion

As shown in Table 1, the five study regions are geographically close to one another and they are mainly southern coastal belt of Bangladesh. Therefore, a general relation between solar radiation and sunshine hours can be developed for these places.

The regression coefficients of five models for the considered locations are shown in Table 4. The physical significance of the regression coefficients ' a ' and ' b ' is that ' a ' is a measure of the overall atmospheric transmission for total cloud conditions ($n/N=0$), and is a function of the type and the thickness of the cloud cover, while ' b ' and ' c ' are the rate of increase of (H/H_o) with (n/N) . The sum $(a+b)$ denotes the overall atmospheric transmission under clear sky conditions.

Statistical evaluations of five models are summarized in Table 5. It is seen that the regional correlation has minimum error in all models. MBE, RMSE and MAPE are lowest in "Akinoglu and Ecevit" model for all locations. Also value of r is highest in "Akinoglu and Ecevit"-model for all locations indicate that this model best fit the sunshine hour data with solar radiation. The value of t -stat lies far below the critical value t_c (at $\alpha=0.01$) indicating correlation models performance is statistically significant at 99% level of significance.

The proposed model in this paper shows statistically good performance. The value of t -stat for all locations in this model is lower than linear and logarithmic models. This indicates that proposed model is better in estimating solar

radiation than that proposed by Angstrom and Ampratwum et al.

Table 4. Regression coefficients in different models.

	Model	a	b	c	a+b+c
Rangamati	Angstrom-Prescott	0.1733	0.6619		0.8352
	Akinoglu & Ecevit	0.4166	-0.4181	1.0930	1.0915
	Ampratwum & Dorvlo	0.7299	0.3041		1.034
	Newland	-0.6133	1.5878	-0.4370	0.5375
	Proposed	0.9107	0.8560	0.3508	2.1175
Sandwip	Angstrom-Prescott	0.1305	0.6898		0.8203
	Akinoglu & Ecevit	0.3240	-0.1174	0.7807	0.9873
	Ampratwum & Dorvlo	0.7249	0.3401		1.0650
	Newland	-0.4791	1.3937	-0.3517	0.5629
	Proposed	0.8689	0.8155	0.3309	2.0153
Noakhali	Angstrom-Prescott	0.1757	0.6457		0.8214
	Akinoglu & Ecevit	0.3952	-0.3909	1.0983	1.1026
	Ampratwum & Dorvlo	0.7083	0.2815		0.9898
	Newland	-0.6030	1.5796	-0.4186	0.5580
	Proposed	0.9061	0.8490	0.3372	2.0923
Kutubdia	Angstrom-Prescott	0.1423	0.6750		0.8173
	Akinoglu & Ecevit	0.2578	0.1845	0.4647	0.9070
	Ampratwum & Dorvlo	0.7293	0.3291		1.0584
	Newland	-0.2779	1.1545	-0.2390	0.6376
	Proposed	0.8472	0.7483	0.2835	1.8790
Cox's Bazar	Angstrom-Prescott	0.1730	0.5868		0.7598
	Akinoglu & Ecevit	0.2792	0.1299	0.4245	0.8336
	Ampratwum & Dorvlo	0.6889	0.2861		0.9750
	Newland	-0.1898	0.9957	-0.2048	0.6011
	Proposed	0.7819	0.6459	0.2413	1.6691

The estimated annual radiations on considered locations along with measured radiation are shown in Table 6.

A general relation relating relative sunshine hours (n/N) and relative solar radiation (H/H_o) has been developed according to proposed model for these southern coastal regions. To determine the coefficients of general relation, least square regression has been used combining all the data of five locations. The proposed general correlation equation for southern coastal region is

$$\frac{H}{H_o} = 0.8111 + 0.6301 \log\left(\frac{n}{N}\right) + 0.2157 \log\left(\frac{n}{N}\right)^2 \quad (16)$$

To validate the proposed general correlation, the estimated solar radiation for considered five locations along with measured radiation has been shown in figure 1 to 5. From those figures it is evident that the predicted radiations according to equation (16) are sufficiently close to that measured by NASA SSE.

Table 5. Statistics of five models.

	Model	r	MBE	RMSE	MAPE	t-stat	t _c
Rangamati	Angstrom-Prescott	0.9595	0.0108	0.1855	0.0334	0.1933	
	Akinoglu and Ecevit	0.9770	0.0061	0.1243	0.0019	0.1642	
	Ampratwum and Dorvlo	0.9226	0.0163	0.2611	0.0208	0.2076	3.106
	Newland	0.9751	0.0065	0.1322	0.0221	0.1639	
	Proposed	0.9729	0.0067	0.1399	0.0234	0.1587	
Sandwip	Angstrom-Prescott	0.9676	0.0069	0.1527	0.0283	0.1502	
	Akinoglu and Ecevit	0.9692	0.0036	0.1351	0.0233	0.0875	
	Ampratwum and Dorvlo	0.9534	0.0110	0.1959	0.0377	0.1858	3.106
	Newland	0.9686	0.0042	0.1383	0.0242	0.1000	
	Proposed	0.9678	0.0047	0.1416	0.0251	0.1102	
Noakhali	Angstrom-Prescott	0.9516	0.0158	0.2151	0.0016	0.2443	
	Akinoglu and Ecevit	0.9676	0.0098	0.1575	0.0012	0.2068	
	Ampratwum and Dorvlo	0.9155	0.0209	0.2863	0.0026	0.2425	3.106
	Newland	0.9676	0.0114	0.1617	0.0014	0.2354	
	Proposed	0.9670	0.0119	0.1668	0.0289	0.2378	
Kutubdia	Angstrom-Prescott	0.9763	-0.0035	0.1591	0.0288	0.0726	
	Akinoglu and Ecevit	0.9859	-0.007	0.1359	0.0228	0.1732	
	Ampratwum and Dorvlo	0.9458	0.0047	0.2469	0.0461	0.0630	3.106
	Newland	0.9869	-0.007	0.1366	0.0235	0.1768	
	Proposed	0.9854	-0.006	0.1387	0.0250	0.1578	
Cox's Bazar	Angstrom-Prescott	0.9771	0.0015	0.1534	0.0288	0.0330	3.106

Model	r	MBE	RMSE	MAPE	t-stat	t_c
Akinoglu and Ecevit	0.9849	-0.004	0.1256	0.0196	0.0965	
Ampratwum and Dorylo	0.9443	0.0098	0.2542	0.0511	0.1276	
Newland	0.9841	-0.002	0.1276	0.0207	0.0578	
Proposed	0.9827	-0.002	0.1321	0.0229	0.0418	

Table 6. Comparison of estimated and measured radiation

Stations	Models	Annual Estimated Radiation	Annual Measured Radiation
Rangamati	Angstrom-Prescott	4.7266	4.72
	Akinoglu and Ecevit	4.7220	
	Ampratwum and Dorylo	4.7321	
	Newland	4.7224	
	Proposed	4.7225	
Sandwip	Angstrom-Prescott	4.5642	4.56
	Akinoglu and Ecevit	4.5619	
	Ampratwum and Dorylo	4.5693	
	Newland	4.5625	
	Proposed	4.5630	
Noakhali	Angstrom-Prescott	4.5741	4.56
	Akinoglu and Ecevit	4.5681	
	Ampratwum and Dorylo	4.5792	
	Newland	4.5698	
	Proposed	4.5703	
Kutubdia	Angstrom-Prescott	4.7707	4.77
	Akinoglu and Ecevit	4.7669	
	Ampratwum and Dorylo	4.7789	
	Newland	4.7669	
	Proposed	4.7677	
Cox's Bazar	Angstrom-Prescott	4.6915	4.69
	Akinoglu and Ecevit	4.6863	
	Ampratwum and Dorylo	4.6998	
	Newland	4.6878	
	Proposed	4.6883	

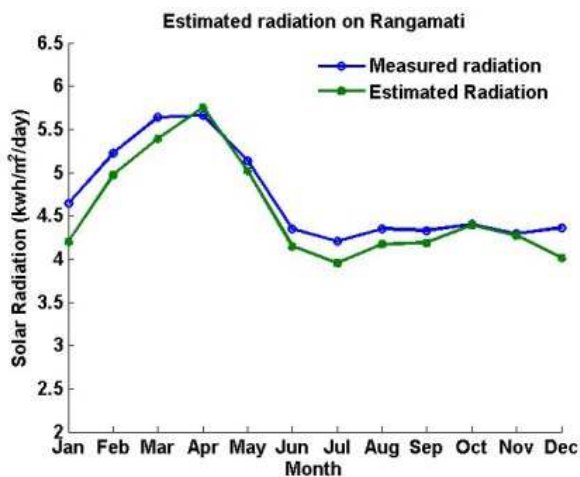


Figure 1. Estimated and measured radiation on Rangamati.

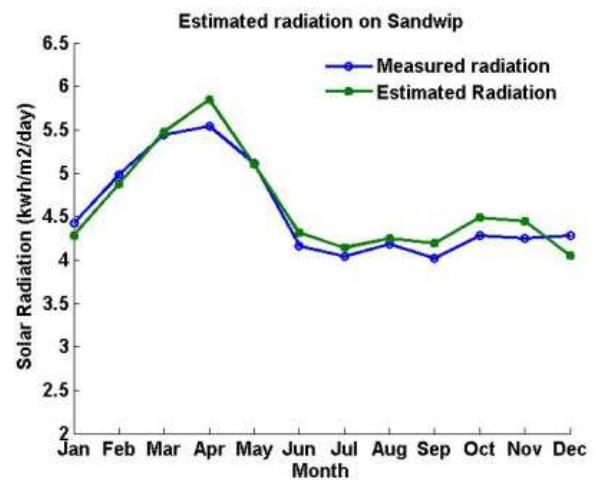


Figure 2. Estimated and measured radiation on Sandwip.

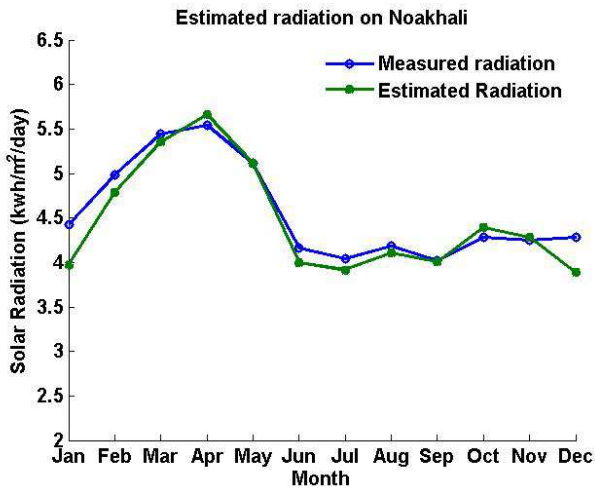


Figure 3. Estimated and measured radiation on Noakhali.

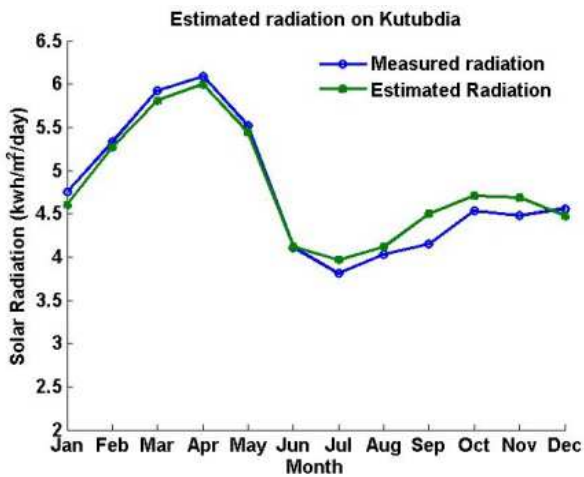


Figure 4. Estimated and measured radiation on Kutubdia.

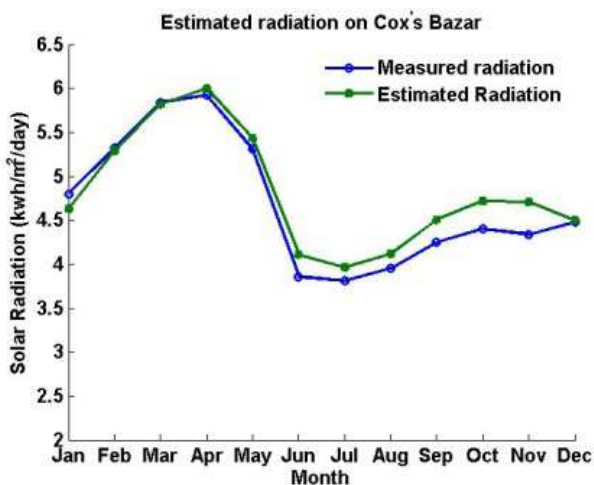


Figure 5. Estimated and measured radiation on Cox's Bazar.

The accuracy of the estimated radiation according to equation (16) has also been determined by statistical means. The MBE, RMSE, MAPE and t-stat for estimated radiation according to proposed equation has been shown in Table 7. It

is found from Table 7 that the values of t-stat are far below from t_c at 99% confidence level. This indicates that the general correlation is statistically significant.

Table 7. Statistics of proposed equation.

Stations	r	MBE	RMSE	MAPE	t-stat	t_c ($\alpha=0.01$)
Rangamati	0.972	-0.106	0.171	0.030	2.638	3.106
Sandwip	0.961	0.062	0.164	0.032	1.358	3.106
Noakhali	0.960	-0.102	0.199	0.023	1.991	3.106
Kutubdia	0.984	0.033	0.155	0.028	0.719	3.106
Cox's Bazar	0.979	0.126	0.198	0.037	2.752	3.106

In this paper, correlation between relative sunshine hour and solar radiation has been developed for southern coastal region of Bangladesh. Using this correlation, global solar radiation on any southern coastal region of Bangladesh can be estimated from relative sunshine hours. To determine the correctness of proposed relation, solar radiation has been estimated on another southern coastal region Patenga, Chittagong. Patenga is situated at 22.7° latitude and 91.8° longitudes.

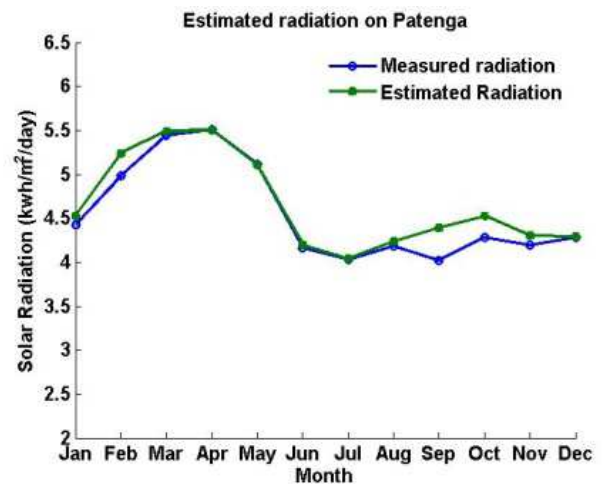


Figure 6. Estimated and measured radiation on Patenga.

Table 8. Radiation on Patenga.

Month	n/N	H_0	H_{measured}	$H_{\text{estimated}}$
January	0.7246	7.1764	4.4207	4.5251
February	0.7345	8.2196	4.9811	5.2379
March	0.6491	9.4823	5.4428	5.4914
April	0.5696	10.4854	5.5048	5.5032
May	0.4809	10.9736	5.1137	5.1079
June	0.3311	11.0921	4.1595	4.1955
July	0.3054	10.9962	4.0356	4.0380
August	0.3724	10.6154	4.1825	4.2380
September	0.4549	9.7876	4.0227	4.3914
October	0.5751	8.5646	4.2823	4.5271
November	0.6648	7.2901	4.2493	4.3000
December	0.7215	6.8279	4.2811	4.2910
Average			4.5563	4.6539

Table 9. Statistics of estimated radiation on Patenga.

Station	<i>r</i>	MBE	RMSE	MAPE	t-stat	<i>t_c</i> ($\alpha=0.01$)
Patenga	0.9749	0.1024	0.1558	0.0238	2.8905	3.106

The estimated solar radiation on Patenga according to equation (16) along with measured solar radiation has been shown in figure 6. The relative sunshine hours, measured solar radiation and estimated solar radiation over the year on Patengahas been shown in Table 8. The statistical parameters MBE, RMSE, MAPE and t-stat for estimated solar radiation according to proposed correlation on Patengahas been shown in Table 9. It is found that estimated global solar radiation is statistically satisfied.

6. Conclusion

In this analysis, five models relating global solar radiation and relative sunshine hours have been considered for predicting the global solar radiation pattern over the southern coastal region of Bangladesh. The level of performance of five models has been studied by statistical measures. The t-statistics have been applied to test the significance of applicability of these models.

A nonlinear logarithmic model has been proposed for estimating the global solar radiation from sunshine hour data. Statistical tests show that proposed model gives fairly good result and can be applied to southern coastal areas of Bangladesh. Few articles correlate the global solar radiation with sunshine ours over Bangladesh. But developing a nonlinear model for estimating solar radiation over southern coastal region of Bangladesh is quiet new. This work emphasis on this region considering the potential of generating electricity from hybrid solar-wind based renewable energy system. The accuracy of prediction can be further developed by considering the fog density, cloud cover and atmospheric scattering effect.

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