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Modeling Of Solar Radiation Using Artificial Neural Network for Renewable Energy Application

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Abstract:*For Solar Energy Utilization And Installation Of Any Solar Devices, The Accurate Measurement And Knowledge Of Global Solar Radiation Of A Particular Location Is Very Essential For Effective And Efficient Usage Of Solar Devices In That Particular Area. However, The Number Of Radiation Stations Are Not Many When Compared To The Stations That Collecting Atmospheric Parameters Like Ambient Temperature, Relative Humidity, Rainfall E.T.C., The Modeling Of Global Solar Radiation With An Atmospheric Parameter Using Artificial Neural Networks (ANN) At Subang Selangor Malaysia (Latitude 7on, Longitude 103oe) Was Carried Out In This Study In A Simpler Way. The ANN Was Used To Develop A Model Based On Multi-Layer Perceptron (MLP) Of ANN Which Trained And Tested Using A Period Of Eleven Years (2000-2010) Meteorological Data. The Estimated Result That Generated From The Artificial Neural Network Was Validated Using Mean Bias Error (MBE), Root Mean Square Error (RMSE), And Mean Percentage Error (MPE). Based On Analysis And The Result Obtained From The Proposed Model Using ANN, A Close Agreement Is Obtainedbetween The Measured Values Of Annual Global Solar Radiation And The Predicted Values By The Proposed Model And The Correlation Coefficient Estimated To Be 0.972. The Value Of Mean Bias Error, Root Mean Square Error And Mean Percentage Error Are 0.00422, 0.00312 And -0.0811 Respectively. This Confirms That The Model Can Be Used Successfully For Estimating Global Solar Radiation In The Study Area For Solar Energy Devices Applications.*

Key Words: *Global Solar Radiation, Artificial Neural Networks, Solar Energy, Atmospheric Parameters.*

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I. Introduction

Solar Radiation Is The Energy That Transmitted From Sunlight To The Earth Surface In Form Of Electromagnetic Waves. The Transmission Of Solar Energy At A Definite Rate And Density Is Known As An Electromagnetic Wave, The Initial Cause Of Energy Distressing In The Atmospheric Motion Was Solar Radiation That Mottled To The Earth's Surface And In Atmosphere [1]. A Reliable Conduct Of The Atmospheric Parameters Is By Modeling Of Solar Radiation Using Available Solar Energy Application Parameters In A Place Where There Is No Equipment For Measuring Global Solar Radiation And ,Numerical Models Of The Atmospheric Circulation Is Important For Long-Range Weather Forecasts And For Climatologically Studies [2]. The Rate At Which The Of Solar Energy Radiation Reaching The Earth's Surface, Solar Energy May Then Be Considered As The Potential Energy Source For The Industrial, Commercial And Domestic Purpose [3]. Availability Of The Solar Radiation Usage On The Earth Surface Rest On The Atmospheric Parameters Such As Temperature, Relative Humidity, Rainfall, Wind, Speed And So On [4]. However, The Knowledge Of Global Solar Radiation Is Important In The Prediction Study And Design Of Economic Viability Of A Photovoltaic System Which Uses Solar Energy System Application [5]. Therefore, Manufactures And Designers Of A Photovoltaic System Component For The Purpose Of Worldwide Marketing, The Mean Global Solar Radiation Available In Different And Exact Study Locations Needs To Need Know And Study For Effective Utilization Of Solar Energy. The Measured Data Obtain Is The Best Method To Use, But Due To Non-Availability Of Meteorological Stations That Measure Global Solar Radiation, Most Especially In Remote And Rural Areas Where The Application Of The Photovoltaic System Is Very Imperative, Prediction Of This Data Is Necessary Using Mathematical Modelling. In A Location Where The Measured Values Do Not Exist, The Common Application Has Been Used In Determining This Parameter By Suitable Relations Who Are Empirically Well-Known Using The Measured Data [6, 7].

The Neural Network Is A Software Application That Can Be Used To Predict A Value Of Data Such As Solar Radiation. Artificial Neural Networks (ANNs) Are Information Processing Systems That Are Non-Algorithmic, Non-Digital And Intensely Parallel [8, 9,10]. A Neural Network Learns The Relationship Between The Input And Output Variables Through Studying Previously Recorded Data By A Procedure Called Learning (Or Training). The Neural Network Employed Is A Multi-Layer Feed Forward Perceptron Which Is One Of The Most Commonly Used Neural Network Models That Learn From Examples [11, 12].The Neural Network Can Be Used In Modelling An Equationfor Predicting The Value Of Solar Radiation Where There Is No Equipment To Measure The Solar Parameters Especially In The Rural Areas As A Result Of High Expensive Of The Weather Stationequipment. The Prediction Of The Solar Radiation By Application Neural Network Will Be Useful In Any Utilization Solar Energy Particularly In Design And Manufacture Of Any Solar Devices For High Performance Efficiency**.** Artificial Neural Networks Are Generally Accepted As A Technology Involvement To Encounter Multifaceted And Ill-Defined Problems. They Have Been Used In Different Applications Device, Weather Forecasting, Power System, Robotics, Medicine, Industrialization And Optimization, Signal Processing And Social/Psychological Sciences [13, 14, 15].

II. Materials And Method

2.1 Data Acquisition

The Monthly Mean Daily Data Maximum Temperatures Were Collected From TheMalaysian Meteorological Department (PetalingJaya Station). The Data Cover A Period Of Eleven Years (2000 – 2010) In The Area Of Study (Latitude 7°N, Longitude 103°E). The Meteorological Data That Are Selected For The Analysis Are The Monthly Average Temperature And The Monthly Average Global Solar Radiation. The Study Made Use Of Artificial Neutron Networks As The Study Methodology. An Artificial Neuron Is A Unit That Performs As A Simple Mathematical Operation On Its Inputs And Emulates The Functions Of Biological Neurons And Their Unique Process Learning.

2.2 Development 0f The ANNs For Solar Radiation Models

The Model Development Was Based On Multi- Layer Perceptron (MLP) Of ANN Which Trained And Tested Using A Period Of Eleven Years (2000 – 2010)) Meteorological Data. The ANN Model Is Developed Using Artificial Neural Network Fitting Tool Of MATLAB 2013 Software.

The Data Collected Is Randomly Divided And 60% Was Used For Training, 20% For Testing And 20% For Validation. Testing Data Does Not Have Any Effect On Training. It Provides Independent Measure Of Network Performance During And After Training. The Following Is An Outline Of The Procedure To Use In The Development Of The ANN Model: Input And Target Values Were Normalized, In The Range -1 To 1., Matrix Size Of The Dataset Was Defined, Partition; Create Training, Test And Validation Sub-Datasets, The MLP Neural Network Will Be Created, The MLP Neural Network Will Be Trained, Automatic Architecture Will Be Selected, Output Values Will Be Generated, Un-Normalize The Output Values, The Performance Of The Neural Network Will Be Checked By Comparing The Output Values With Measured Values.

2.3 The Model

The Armstrong-Type Regression Model Equation Has Been Used To Determine Its Applicability For This Work.

The Equation Is Expressed As; $\frac{H}{H_0} = K = a + b1$

Where T Is Mean Ambient Temperature Of The Study Station.

'A' And 'B' Are Constants For A Particular Station Been Considered Which Are Dependent On Latitude And Other Meteorological Parameters.

The Ratio Of Mean Monthly Global Solar Radiation (H) To The Mean Monthly Extraterrestrial Solar Radiation (Ho) I.E Average Clearness Index Was Correlated With Monthly Average Ambient Temperature, Transforming Equation 1 Into Equation 2

Y= Bx + A

Where's Y = 0.0314x - 0.77682

Y Is Equivalent ToH/Ho = K,

X Is Equivalent ToT

A = 0.7768 And B = 0.0314

Where H Is The Global Solar Radiation, Extraterrestrial Solar Radiation, K Is The Clearness Index And T Is Mean Ambient Temperature Of The Study Station.

'A' And 'B' Are Constants For A Particular Station Been Considered Which Are Dependent On Latitude And Other Meteorological Parameters. ANN Predicted Values Of Monthly Average Global Solar Radiation As Well As Average Monthly Clearness Index Were Computed Using Equation 8 And Then Compared With The Measured Values.

2.4 Validation Of Model

The Estimated Results That Will Be Given By The Artificial Neural Network Will Validated Using The Following Errors Analysis; Mean Bias Error (MBE), Root Mean Square Error (RMSE) And Mean Percentage Error (MPE). The Statistical Expressions For The Estimators Are Expressed As Follows:

$$\text{MBE} = \sum_{i=1}^{n} \left(\frac{K_{Tp} - K_{Tm}}{n} \right) \quad 3$$

$$\text{RMSE} = \sum_{i=1}^{n} \left(\frac{K_{Tp} - K_{Tm}}{n} \right)^{1/2} \quad 4$$

$$\text{MPE} = \sum_{i=1}^{n} \left(\frac{k_{Tm-} K_{Tp}}{K_{Tm} / n} \right) \text{X } 1005$$

III. Results And Discussion

3.1 Distribution Of Global Solar Radiation In The Study Area.

Table 1 Shows The Measured Global Solar Radiation (Hm) Of The Study Station. From The Table1, It Is Seen Clearly That The Highest Magnitude Of Solar Radiation Was Received On The Earth Surface In The Year 2004 And The Lowest Magnitude Of Solar Radiation Was Received In The Year 2003 At The Study Area. Also, It Is Observed From The Table That Year 2007, 2008, 2009 And 2010 Have A Close Range Of Magnitude Of Solar Radiation, This Implies That In These Years, At The Area Of Study, Approximately, The Same Values Of Solar Radiation Were Received On The Earth Surface From The Sun. Hence, The Effect Of Solar Radiation Characteristic Will Also Be In Close Range In These Years, Thus, This Could Also Be Attributed To Stable Climate Characteristics In The Study Area. This Is Evidence And Ascertained That The Area Of Study And Its Environs Actually Have High Potential For The Solar Energy Applications, Especially For The Photovoltaic Solar System To Sustain Both Long Term And Less Expensive Power Supply Compared To Conventional Power System Currently Using In The Area.

The Reports Of**Figure2**, Shown That The Minimum Value Of Global Solar Radiation Is 19.86 Mjm-2day-1. It Occurs In The Month Of March. This Result Is Expected Because The Month Of March Is Dry Period In The Study Station, The Southern Part Of The Country. The High Values Of Solar Radiation From **Figure 2** Occur In February To May When Most Part Of The Station Area Experiences High Intensity Of Sunshine.

3.2 Variation Of Annual Mean Ambient Temperature

Global Solar Radiation Depends Upon The Location And Has Many Effects On The Type And Rate Of Chemical Reaction In The Atmosphere. It Affects The Air Convection And Mixing And Thus, The Ambient Temperature Of The Day. However, It Is Observed From **Figure 1** That The Maximum Temperature Obtained In The Months Of April, May And June Is Around Approximately 28^{o}c, While The Minimum Temperature Recorded Is Round 27^{o}c In The Months Of August To December And January. Generally, The Trend Of Temperature Variation Expected To Be Similar To All The Studied Years In The Area, Since The Ambient Temperature Is The Function Of The Global Solar Radiation Reaching The Surface Of The Earth.

It Was Observed From **Table 3** That There Were Consistent Decreases In Mean Values Of Ambient Temperature, Measured Global Solar Radiation, Extraterrestrial Solar Radiation On The Horizontal Surface As Well As The ANN Predicted Global Solar Radiation From July To December And January To February. The Low Values Are Attributed To Rainy Season In The Station When Temperature Is Expected To Be Low. The High Value Of Temperature In The Month Of March, April, May And June Explain While The Great Landmasses Of The Station Hemisphere Are Much Hotter At The Same Latitude, And Low Value In The July To December Confirmed The Reversed Situation. This Indicates That Temperature Of The Atmosphere Is Greatly Influenced By Both The Land And The Sea Areas.

Comparison Of The Results Predicted By The Proposed Model And Measured Values Of Annual Global Solar Radiation Is Presented Graphically In Figure 3. **Figure 3** Displays The Variation Of The Measured Values Of Global Solar Radiation Obtained In The Study Area And Predicted Results Of Global Solar Radiation By The Proposed Model Using ANN With Number Of Years. It Could Be Deduced From This Graphical Analysis That Result Obtained From The Model Has A Closer Agreement With The Measured Values Of Annual Global Solar Radiation In The Study Area. This Confirms That Predictive Value By The Proposed Model Using ANN And Measured Values Are Of The Same Values. Hence, The Model Can Serve As

A Baseline Tool That Will Use In Designing And Sizing Solar Devices Application In SubangArea Of Malaysia And Its Environs For Solar Installers And Users.

3.2.1model Validation

From The Table 2 Validation Of The Results Estimated By The Model Using Error Analysis Gives The Values Of Mean Bias Error (MBE) As 0.00422, Root Mean Square Error (RMSE) As 0.00312 And Mean Percentage Error (MPE) As -0.0811. It Can Be Concluded From The Errors Analysis Results That Low Values Of Both MBE And RMSE Attributes To The Good Performance Of The Proposed Model. It Is Also Important To Note From The Results That The Value Of MPE From The Model Is Less Than 1%. From Table 3, Even When The Model Was Subjected To Further Statistical Analyses; Percentage Error And Coefficient Of Determination, R^2, The Model Stood Out Uniquely, Correlation Coefficient (0.982) Is High For The Studied Area. This Implies That, There Are Statistical Significant Relationships Between The Global Solar Radiation And Ambient Temperature (T) In The Location Considered.

IV. Conclusion

The Development And Implementation Of Many Solar Energy Devices And For Estimates Of Their Performances Require An Accurate Knowledge Of Global Solar Radiation Distribution At A Particular Geographical Location. The Best Way The Amount Of Global Solar Radiation Can Be Determined Is Through Recorded Atmospheric Data At The Actual Location. The Estimation Of Global Solar Radiation For The South Western Region Of Malaysia Was Carried Out In This Work. The Study Basically Using ANN Approaches For Predicting The Global Solar Radiation On Horizontal Surface Reaching The Earth**.** The Results Obtained From The Model Were Validated Using Three Different Error Analysis. Based On The Validation Results, It Therefore, Becomes Clear That The Proposed Model Has Better Agreement In Performance With Measured Values Of Global Solar Radiation In The Study Area. The Model Is Simple And Could Estimate The Global Solar Radiation With Relatively High Accuracy. Therefore, It Is Recommended That The Model Should Be Used, Even When Only Temperature Data Are Available, For Estimation Of Global Solar Radiation In SubangArea Of Malaysia And Other Locations With Similar Solar Characteristics. Finally, The Model Provides A Simple And Low Cost System For Estimating Global Solar Radiation In The Study Area. It Does Not Require Information From Neighboring Stations For Spatial Interpolation And It Does Not Require Expensive Hardware For Data Processing.

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Table 1Meteorological Data Of The Study Location

Year	Month											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2000	15.77	17.19	17.58	17.32	18.20	15.65	16.39	15.78	15.40	17.25	13.94	15.73
2001	14.32	14.66	18.63	16.57	16.73	17.31	16.07	15.75	16.73	16.62	15.24	14.95
2002	15.82	17.12	17.24	16.27	16.24	15.47	14.80	14.31	14.91	15.35	14.36	14.26
2003	12.90	15.51	17.22	15.24	15.89	14.71	14.23	15.55	14.93	15.89	14.26	12.92
2004	15.46	16.07	16.47	Def.	Def.	14.79	13.95	16.94	15.56	14.89	14.37	12.82
2005	15.99	18.17	18.11	16.55	13.92	15.94	15.28	15.87	18.00	15.06	14.16	13.77
2006	15.55	16.43	Def.	15.95	15.51	15.11	14.74	15.51	15.94	17.56	17.33	15.82
2007	15.89	18.39	20.24	19.37	20.15	17.85	16.85	19.04	19.73	17.54	17.15	16.00
2008	17.62	19.41	18.44	17.81	18.66	17.57	16.95	18.05	18.57	19.77	17.42	15.87
2009	16.69	19.26	18.68	20.36	20.28	18.53	18.19	18.49	18.30	18.91	15.97	16.35
Average	17.52	21.47	22.06	Def.	19.20	17.90	17.70	19.83	18.84	19.19	18.21	15.33

Table 2: The Values OfStatistical Indicators For The Error Analysis

R^2	MBE	RMSE	MPE	% Error
97.2	0.00422	0.00312	-0.0811	3.6270

Table 3Meteorological Data OfMeasured And Predicted ANN Solar Radiation, And Maximum Temperature Of Study Area

Month Of The Year	Ho ($MJ/M^2/Month$)	Hm ($MJ/M^2/Month$)	Hp ($MJ/M^2/Month$)	Temp (^Oc)
Jan	284.584	16.93	**17.01**	**27.23**
Feb	138.583	19.63	**18.38**	**27.59**
Mar	179.798	19.86	**19.00**	**27.94**
Apr	139.038	19.18	**18.68**	**27.86**
May	149.603	19.57	**18.70**	**28.57**
Jun	243.685	17.96	**18.06**	**28.16**
Jul	269.253	17.42	**18.68**	**27.85**
Aug	203.910	18.86	**17.54**	**27.90**
Sep	192.056	18.69	**18.01**	**27.61**
Oct	185.346	18.85	**18.18**	**27.35**
Nov	281.763	17.19	**18.70**	**27.05**
Dec	228.756	15.89	**16.84**	**27.70**

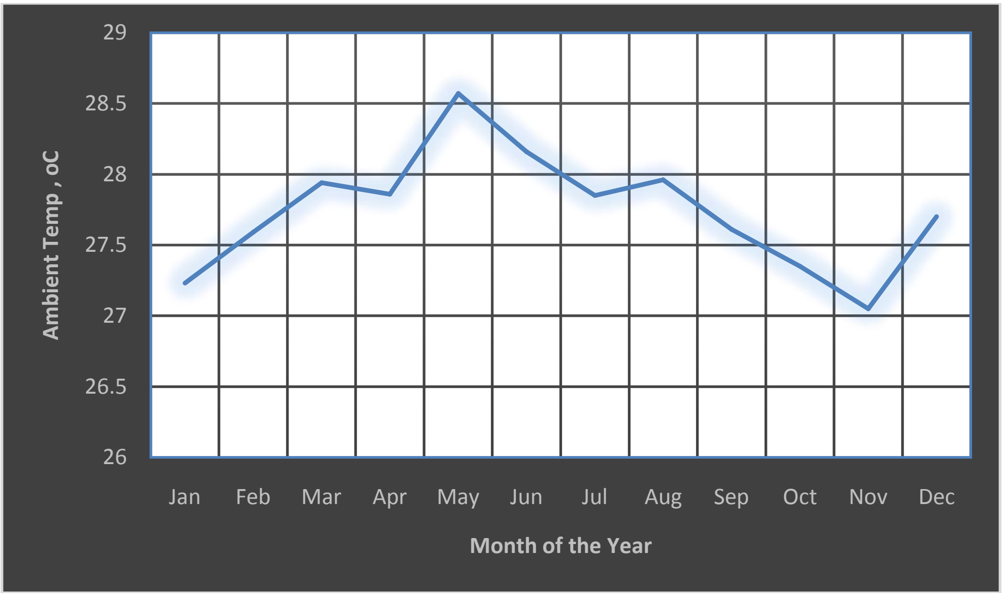

Figure 1: Accumulated Mean Variation of Ambient Temperature Of The Station

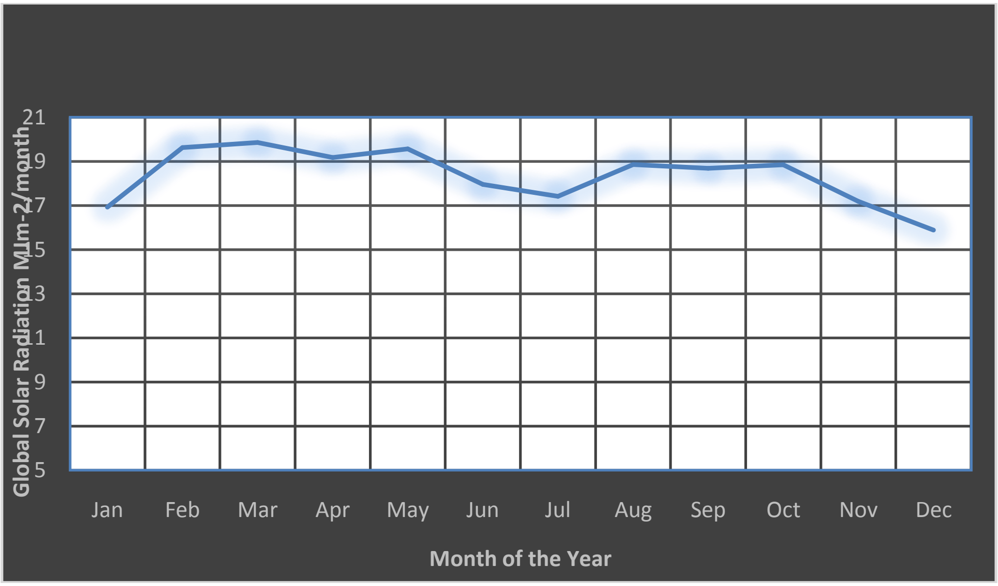

Figure 2: Accumulated Mean Variation of Measured Global Solar Radiation Of The Station

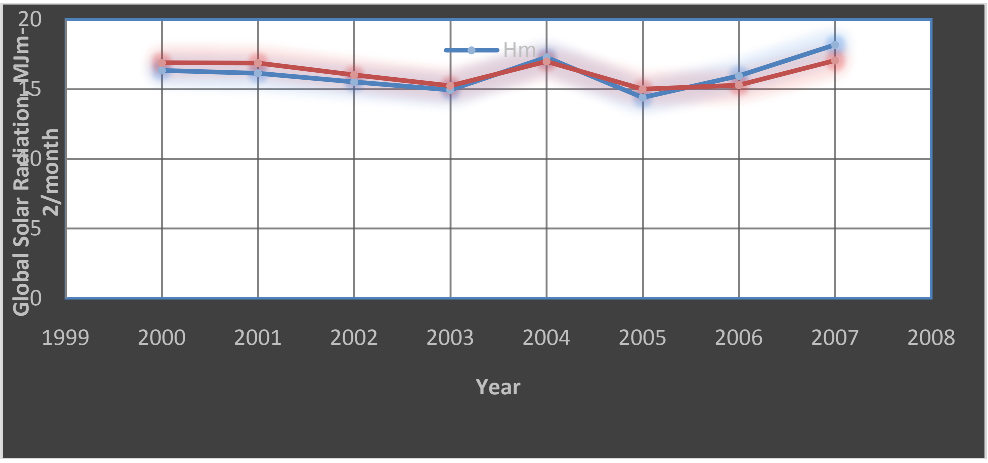

Figure 3: Comparison of Annual Variation Of The MeasuredAnd Predicted Global Solar Radiation Of The Study Station

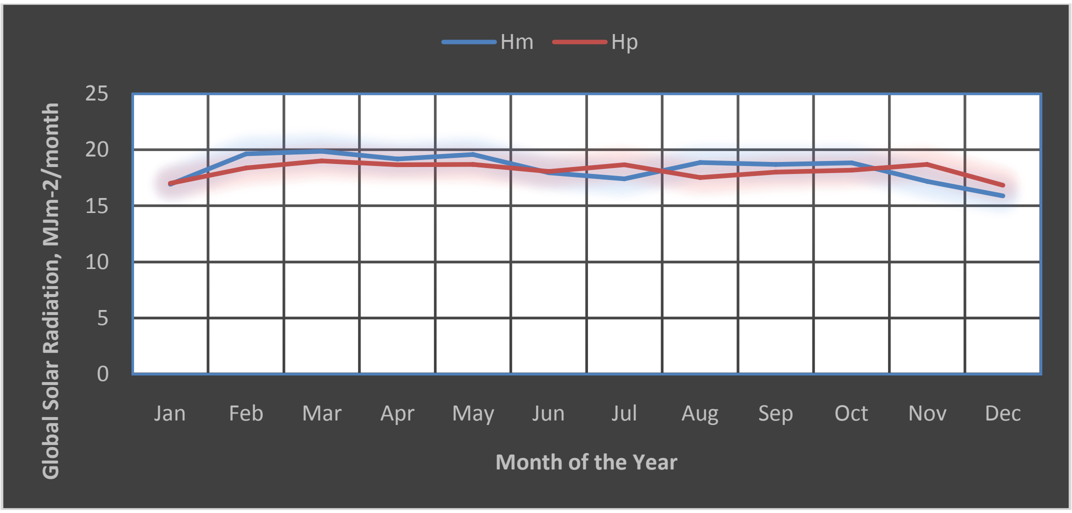

Figure 4: Comparison of Annual Variation of TheMeasured Global Solar Radiation Of The Study Station

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