



IMPROVED GLOBAL SOLAR RADIATION CORRELATIONS ON HORIZONTAL SURFACE ON THE EARTH OF NADI, FIJI

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ABSTRACT

Detailed knowledge of solar radiation distribution is highly important for many activities on earth such as agricultural practices, renewable energy installation, climate control and many more. Climatic diversity out of other diversities on earth has made it difficult to use knowledge of solar radiation distribution within a fragmental part of the earth in generalizing the solar radiation distribution on the earth surface. In view of this, this work tested and calibrated seven highly used empirical correlations for global solar radiation on horizontal surface on the earth of Nadi, Fiji. The result confirms that solar radiation is site specific as different correlation coefficients are obtained for this study site. Similarly, the result shows that five models that are based on relative sunshine hour, temperature, and precipitation are good models, while models based on relative humidity are poor models for predicting global solar radiation at Nadi, Fiji. Specifically, based on Mean Percentage Error (MPE), Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE), the Angstrom-page sunshine hour based correlation is the best, while relative humidity based correlation is poor. However, based on correlation coefficient, temperature difference correlation proves to be the best, while relative humidity based correlation proves still the poorest. In the light of the accuracy of the other models except relative humidity based correlation, choices can be made depending on the availability of data, quality of data, ease of computation and many other factors, in the estimation of monthly global solar radiation with satisfactory result. Summarily, Nadi, Fiji is endowed with abundant solar radiation as the entire clearness indexes are within partly overcast and also very close to clear sky in some months.

Keywords: solar radiation, empirical correlations, nadi, solar energy, sunshine.

1. INTRODUCTION

The pursuit of a higher quality of living has always been a major issue for human growth on the planet, particularly in this era of rapid industrialization. Energy availability and security play a vital role in this aspect. Energy sources can either be non-renewable or renewable, but nonrenewable energy has become the primary source of energy over time, owing to lack of methods to harness renewable energy. However, as the climate deteriorates and energy demand rises exponentially, different renewable energy sources are been investigated which has given rise to increasing attention and utilization of solar energy been the cleanest and possibly most promising of all alternative energy sources.

The sun emits energy in the form of radiation but due to the high costs and difficulties in maintaining and calibrating the recording equipment in several locations within the specified region, global solar radiation data are not widely available at many locations throughout the globe [1]. However, alternative approaches such as Artificial Neural Network (ANN) [2]-[7], remote sensing extraction [8]-[13], and empirical models have been established to estimate global solar radiation data.

Empirical models are more widely utilized because of their easily accessible inputs and low processing costs [1], [14]. Muzathik *et al.* [15] calculated solar radiations from specified models using hourly solar radiation data collected at Terengganu, Malaysia between 2004 and 2007. Based on their results, a new model based

on the Kadir Bakirci linear exponential model was developed which was recommended for a horizontal surface in the estimation of monthly mean daily global sun irradiation. In addition, a model for converting horizontal sun global radiation to radiation on a slanted surface was described. Santos *et al.* [16] evaluated the quality of nine models in predicting daily and monthly solar irradiation utilizing only extraterrestrial solar irradiation and two extremes of air temperature as the main data input collected at eight solarimetric stations in Alagoas, Brazil between 2007 and 2009. Hassan *et al.* [17] proposed new ambient-temperature-based models for predicting global solar radiation as alternatives to the frequently used sunshine-based models. They estimated the monthly average daily global solar radiation on a horizontal surface using seventeen novel temperature-based models derived, validated, and compared with three other existing models from literature. It was observed that for global solar radiation at different locations, the local formula for the most accurate new model provides good predictions especially at coastal sites and perform better than the two most accurate sunshine-based models from the literature. Zhao *et al.* [18] developed a new empirical model based on Air Pollution Index (API) data used to change the coefficients of the most widely used Angström–Prescott equation. The linear, exponential and logarithmic models of the newly developed model were validated using daily solar radiation, sunlight hours, and air pollution data from nine meteorological sites in China from 2001 to 2011,



with the logarithmic model performed better with respect to the other models when evaluated by performance indicators of Mean Bias Error (MBE), Mean Absolute Bias Error, (MABE) Mean Percentage Error (MPE), Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE), and Nash–Sutcliffe Equation. Further studies shows that aerosol can play an important role in the estimation especially in highly polluted regions.

Adaramola [19] estimated global solar radiation using common meteorological data in Akure, Nigeria with simple empirical relations. The study showed that Angstrom-Page correlation predicts accurately than other correlation developed in the study. The study shows that temperature only based correlation and precipitation based correlation can be employed with fair accuracy if Angstrom-Page correlation could not be used because of its dependency on sunshine hour data which is difficult to measure with accuracy. Ajayi *et al.* [20] collected data from the Nigeria Meteorological Agency which covered twelve sites spread over six geopolitical zones between 1987 and 2010. They derived a multivariate model which estimates global solar irradiance in terms of maximum daily temperature, daily relative sunshine, latitude, daily average relative humidity, and cosine of day number. With the addition of the highest daily temperature and daily mean relative humidity, their model becomes significantly more responsive to climatic and meteorological variations. Tabari *et al.* [21] examined the validity of twelve solar radiation models as well as their effects on a daily reference of evapotranspiration estimates using the Penman-Monteith FAO-56 technique under cool arid and semi-arid conditions in Iran. The results showed that the average increase in accuracy of the evapotranspiration estimations using the calibrated empirical models, as measured by the decrease in RMSE were 2.8 % for semiarid climates and 6.4% for dry climates. Kirman *et al.* [22] proposed an empirical approach for estimating solar energy based on the Angstrom model. Using several climatic factors such as temperature, mean sunshine duration per hour, wind speed, relative humidity, and rainfall, seven regression equations were built. The findings reveal that the equation with the highest of correlation coefficient, coefficient of determination and the least value of RMSE, MPE, MBPE and MBE provide better results. Quej *et al.* [23] reviewed four current day-of-year-based models and were able to derive a new empirical day-of-year-based model which calculates daily global solar radiation on a horizontal surface for six metrological stations in Mexico. The results revealed that the newly suggested model outweighs the conventional day-of-year-based models in estimating daily solar radiation. Performance of different correlation adopted in southern United States was evaluated by Woli and Paz [24]. It was concluded that out of the sixteen empirical relation, temperature and/or precipitation based models called the Mavromatis model was found to be the best. The piecewise linear regression-based model by Wu *et al* model was found to be the best among the model that

make use of both temperature and precipitation besides being very good due to its separate relationship for low and high radiation levels. This indicates that the suitability of correlation varies with location.

In the foregoing, the quintessential of solar radiation data is well elucidated and substantial works had been done in this regard. Notwithstanding, there is still scarce availability of weather stations with solar radiation data in Nadi, Fiji; hence this paper focuses on using seven selected models that are most commonly used to predict the global solar radiation. This will in no way assist in contributing immensely towards encouraging improved solar energy applications in the area.

2. THE MATERIALS AND METHOD

A. Study Area

Nadi (Figure-1) on latitude of 17.7765°S and longitude of 177.4356°E is Fiji's third largest urban area with a total population of 42,284 inhabitants [25], the economic center and second highly populated area in Fiji and thus was chosen as the study location in this work. Due to its economic importance, its airport is the busiest in the region serving Fiji and neighboring pacific countries thus meteorological data are available at the airport over time. The Fiji meteorological services have also been collecting data in this location making the data readily available.

B. Methods

The data used was collected from Fiji meteorological Centre and the data span from 1981 to 2019 (29 years). The data recorded includes wind direction, wind speed, global solar radiation, sunshine hours, relative humidity, rainfall, minimum temperature, maximum temperature and their corresponding saturation pressures and mean temperature. The Fiji Meteorological Service used pyronometers to record global solar radiation with accuracies higher than $\pm 3\%$. As accuracy of the data recorded is highly important in this study, the data was checked for unreasonable values starting with proper examination of global solar radiation greater than $25.2 \text{ MJm}^{-2}\text{day}^{-1}$ and also gaps within the record are assumed that the pyronometer are not used then.

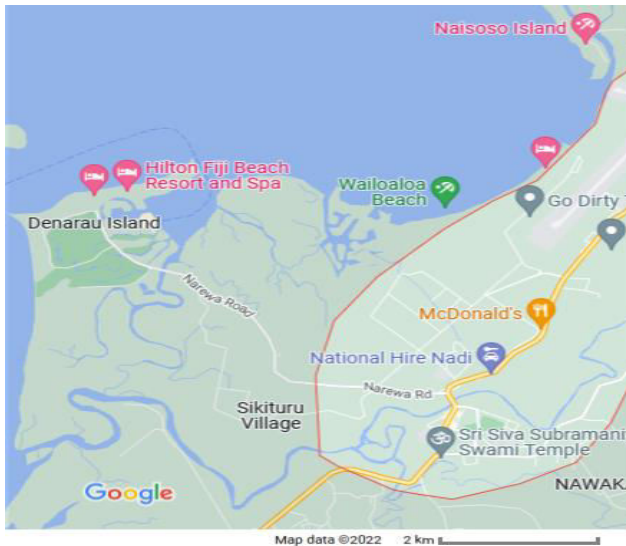


Figure-1. Map of Nadi. <https://www.google.com/maps/@-17.779046,177.4057667,13z?hl=en>

Modelling deals with finding the mathematical relationship between one (univariate) or more (multivariate) dependent variable(s) with one or more independent variable(s). Similarly estimating global solar radiation requires modelling its relationship with one or more meteorological variables/parameters. Specifically, in this study, modeling the ratio of the monthly mean daily global solar radiation (H_m) to the monthly mean daily extraterrestrial solar radiation (H_0) (clearness index $K_t = \frac{H_m}{H_0}$) to one or more other meteorological variables such as ratio of monthly mean daily sunshine hours to monthly mean daily daylight hour, temperature difference (positive difference between maximum temperature and minimum temperature), temperature ratio (minimum temperature to maximum temperature), temperature average (average of minimum and maximum temperature), relative humidity and combination of others. The global solar radiation is site specific because the radiation is absorbed by ozone, oxygen, water vapour, carbon dioxide, nitrogen in the atmosphere and all this varies with geographic location. Besides human activities, nature and many other things affect the amount of solar radiation receive on the earth. Selection of model depends on many factors such as data availability, accuracy, simplicity, maintenance and operation, and many other factors. In this work seven models are selected because they are the most commonly used and usually serve as the representative of other models. The models are listed as indicated equations 1-16.

Model 1:

$$\frac{H_m}{H_0} = a + b \frac{S_m}{S_0} \quad (1)$$

This model is called Angstrom-Page model and it linearly relates the ratio global solar radiation (H_m) and

the extraterrestrial solar radiation (H_0) ($K_t = \frac{H_m}{H_0}$) to the ratio sunshine hour and the daylight hour. Using this relation requires availability of the global solar radiation and sunshine hour from the meteorological records as other could be determined using derived equations. The main interest is the derivation of the constant of this relation which are known to be function of location on the earth.

Model 2:

$$\frac{H_m}{H_0} = a(\Delta T)^{0.5} \quad (2)$$

This model is called Hargreaves and Allen model. It relates clearness index to the square root of temperature difference ($\Delta T^{0.5}$). This can be used in the absence of sunshine hour data. Where ΔT = Maximum temperature - minimum temperature.

Model 3:

$$\frac{H_m}{H_0} = a + b \frac{RH}{100} \quad (3)$$

This model linearly relate clearness index to the relative humidity (RH).

Model 4:

$$\frac{H_m}{H_0} = a + b T_{avg} \quad (4)$$

This model linearly relate clearness index to average temperature ($T_{avg} = \frac{\max temp + \min temp}{2}$).

Model 5:

$$\frac{H_m}{H_0} = a + b(TR) \quad (5)$$

This model relates the clearness index to the temperature ratio ($TR = \frac{\min temp}{\max temp}$).

Model 6:

$$\frac{H_m}{H_0} = a + b(TR) \left(\frac{RH}{100} \right) \quad (6)$$

This model relate clearness index to the product of relative humidity and temperature ratio.

Model 7:

$$\frac{H_m}{H_0} = a + bP \quad (7)$$

This model relate clearness index to the precipitation (P (mm)).

The daily average extraterrestrial global solar radiation H_0 is given as

$$H_0 = \frac{24}{\pi} I_0 \left(1 + 0.033 \cos \frac{2\pi n}{365} \right) * \left(\cos \phi \cos \delta \sin w_s + \frac{2\pi w_s}{360} \sin \phi \sin \delta \right) \quad (8)$$



$$w_s = \arccos(-\tan\phi \tan\delta) \quad (9)$$

$$S_0 = \frac{2}{15} w_s = \frac{2}{15} \arccos(-\tan\phi \tan\delta) \quad (10)$$

Where I_0 is the solar constant, $4.9212 \text{ MJm}^{-2} \text{ day}^{-1}$; ϕ is the latitude of the location (in degree); δ is the solar declination angle (in degree); w_s is the sunset hour angle and n is day of the year. The solar declination angle is determined using Spencer (1971) equation

$$\delta = (0.006918 - 0.399912 \cos\gamma + 0.070257 \sin\gamma - 0.006758 \cos 2\gamma + 0.0009072 \sin 2\gamma - 0.002697 \cos 3\gamma + 0.00148 \sin 3\gamma) \quad (11)$$

$$\gamma = \frac{2\pi}{360} (n - 1) \quad (12)$$

C. Comparison of Correlation Models

The rank of any of the models stated in eqn. 1 to 7 depends on the statistical evaluation criteria. Though there are many evaluation criteria such as MBE, MABE, MAPE, MPE, RMSE. In this work, MPE, MAPE, RMSE and Correlation Coefficient are considered. All these provide information about measure of estimation error, estimation accuracy and how the model perfectly fit the data. The smaller these evaluation criteria except correlation coefficient the better the model. These evaluation criteria are given as follows:

$$MPE = \frac{1}{P} \sum 100 \left(\frac{H_{m-mes} - H_{m-est}}{H_{m-mes}} \right) \quad (13)$$

$$MAPE = \frac{1}{P} \sum 100 \left| \left(\frac{H_{m-mes} - H_{m-est}}{H_{m-mes}} \right) \right| \quad (14)$$

$$RMSE = \left\{ \frac{1}{P} \sum (H_{m-mes} - H_{m-est})^2 \right\}^{0.5} \quad (15)$$

$$R = \frac{\sum (H_{m-est}^i - \bar{H}_{m-est}^i)(H_{m-mes}^i - \bar{H}_{m-mes}^i)}{\sqrt{\sum (H_{m-est}^i - \bar{H}_{m-est}^i)^2 \sum (H_{m-mes}^i - \bar{H}_{m-mes}^i)^2}} \quad (16)$$

Where;

H_{m-est} = estimated value of the global solar radiation.

H_{m-mes} = measured value of the global solar radiation.

P = number of the data.

3. RESULTS AND DISCUSSIONS

Table-1 shows the monthly mean daily extraterrestrial radiation (H_0), monthly mean daily global solar radiation (H_m), monthly mean daily daylight hours (S_0), monthly mean daily sunshine hours (S_m) and their ratios ($K_t = \frac{H_m}{H_0}$ and $K_s = \frac{S_m}{S_0}$). The table shows that the clearness index ($K_t = \frac{H_m}{H_0}$) of Nadi, Fiji range from minimum in the month of February as 0.5028 to maximum in the month of July as 0.5454.

Table-1. Clearness index and the ratio of sunshine hours.

Mon	$H_0(\text{MJm}^{-2}\text{day}^{-1})$	$H_m(\text{MJm}^{-2}\text{day}^{-1})$	$S_0(\text{hr})$	$S_m(\text{hr})$	H_m/H_0	S_m/S_0
JAN	41.3678	21.1394	12.9359	6.9	0.5110	0.5334
FEB	39.9606	20.0912	12.5821	6.5836	0.5028	0.5233
MAR	36.7937	18.7122	12.1026	6.2951	0.5086	0.5201
APR	32.0931	16.7505	11.5889	6.5721	0.5219	0.5671
MAY	27.6248	14.5484	11.1629	6.6671	0.5266	0.5973
JUN	25.3538	13.6546	10.9531	6.7258	0.5386	0.6141
JUL	26.2996	14.3428	11.0516	7.0416	0.5454	0.6372
AUG	30.0526	16.2587	11.4189	7.1580	0.5410	0.6269
SEP	34.8045	18.8011	11.9144	7.0602	0.5402	0.5926
OCT	38.6837	20.9533	12.4269	7.5242	0.5417	0.6055
NOV	40.8343	21.4171	12.8487	7.2681	0.5245	0.5657
DEC	41.5818	21.3160	13.0478	6.9949	0.5126	0.5361

The lowest in the month of February is due to the cloud formation as a result of the rain as this period are the rainiest period in Fiji [26]–[28]. Also the highest in the month of July is due to the fact that this month experience least rainfall as well as the sky clearest month where sunshine hour index ($K_s = \frac{S_m}{S_0}$) is at the highest value of 0.6371[27]. Generally, using the weather condition classification by Igbal [29] which state that clearness

index ≤ 0.4 is heavily overcast, index between 0.4 and 0.6 as partly overcast while index ≥ 0.7 as clear weather, thus it is concluded that the weather of Nadi is partly overcast. Besides, since the clearness index is a measure of the fraction of extraterrestrial radiation that get to a surface on the earth and all the clearness index shown in the table are above the average thus Nadi receives high solar radiation. Similarly, using the sunshine hour classification index by



World Meteorological Organization [30], that states $0 \leq K_s \leq 0.3$ is cloudy, $0.3 \leq K_s \leq 0.7$ is scattered cloudy sky while $0.7 \leq K_s \leq 1$ is fair weather thus, the weather of Nadi is scattered cloudy throughout as all the index fall within this range. This also confirms why Fiji is a tourism based country.

A. Sunshine Hour Based Model

Figure-2 shows the relationship between clearness index and fraction of sunshine hour for both field data and estimated data using the Angstrom-Page linear relation. The correlation coefficient of 0.9229 was obtained indicating perfect correlation between clearness index and fraction of sunshine hour. The constant a in the correlation was obtained for Nadi as 0.3258 which correspond to the fraction of extraterrestrial radiation under a cloudy condition when the intensity of the direct radiation is below the minimum value of about 120 Wm^{-2} . The b in the correlation was estimated to be 0.3476 for Nadi which correspond to the fraction of the normalized global radiation to the fraction of sunshine hour. The $a+b$ of the two site specific constants is equal to 0.66734 which indicate turbidity of the location when $K_s = 0$ and this is a measure of fraction of the global solar radiation when the weather is totally cleared. This value is within the value of 0.8 predicted by Angstrom-Page for low latitude as Nadi is on latitude of 17.7765°S .

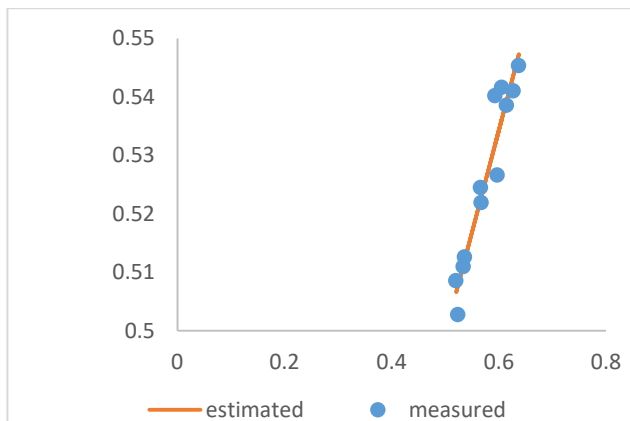


Figure-2. Sunshine hour correlation.

The Figure-3 shows the graph of the measured global radiation (GloSolRad) per month and estimated global radiation (PGloSolRad1) per month by the Angstrom-page model. It can be inferred from this graph that this model is accurate in the estimation of the global solar radiation as only few deviation from the actual values could be observed. The statistical error analysis of this model is discussed below with other models to save space and ease comparison between the model.

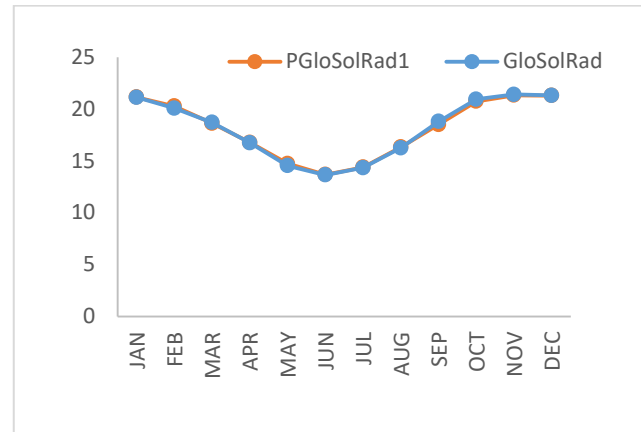


Figure-3. Comparison of sunshine hour estimate with measured global solar radiation.

B. Temperature Difference Based Model

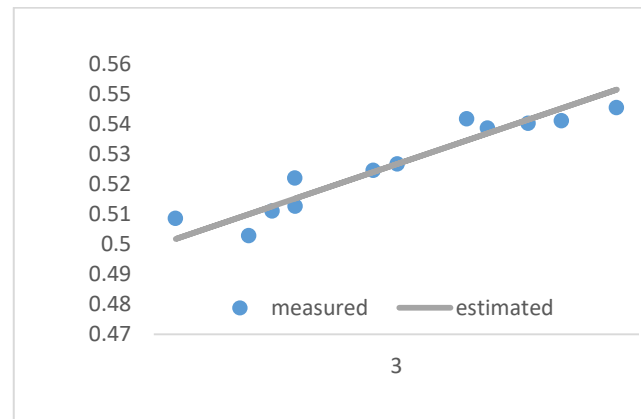


Figure-4. Temperature difference correlation.

Not only because of the unavailability of some meteorological data that lead to developing other correlation, but It is important to test the accuracy of all correlations even if all data needed for a specific model is available. This is because this will proffer the opportunity of selecting the best model for the specific location, proffer the opportunity of explaining some phenomena such as non-correlation in some meteorological parameters and proffer the opportunity of making choices based on ease of computation, cost and many other factors. Besides it proffers the opportunity of combining many parameters so as to obtain better result than when a single parameter is used. In view of this, other models were also considered in this work. Figure-4 shows the relationship between clearness index and temperature difference for both field data and estimated data using the Allen-Hargreaves relation. The coefficient of correlation between the parameter is 0.9999 which may be said to be 1 indicating perfect correlation between the temperature difference and the clearness index. This is so because the rain occurs during the hottest period of the year which indicate what may be termed humid subtropical climate existence at Nadi. The only constant of correlation a , is estimated to be



0.1755 which is closed to the value 0.17 recommended for coastal region by Hargreaves and Samani [31]. This difference in site specific value and the Hargreaves recommended value further buttress the need for the constant to be site specific and moreover not all climate can be classified into the group proposed by Hargreaves and Samani [31].

C. Relative Humidity Based Model

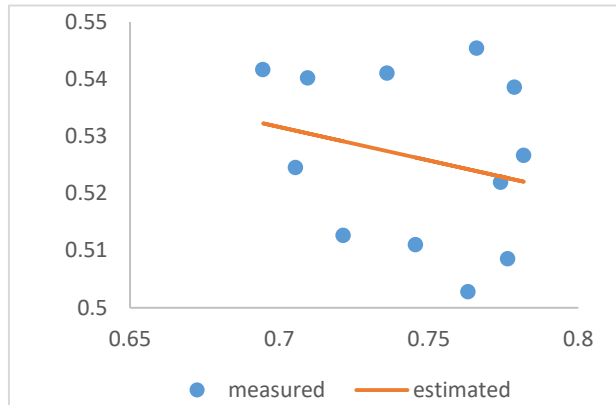


Figure-5. Relative humidity based correlation graph.

Also relative humidity as a meteorological parameter is also used to predict the global solar radiation. This work evaluated the relative humidity based correlation and its result is shown in Figure-5. The correlation coefficient obtained is 0.06544 which indicate poor correlation between the relative humidity and the clearness index. It is so because as stated earlier, the climate of Nadi may be classified as Humid subtropical climate which mean the humidity is always high and thus the contribution of the radiation variation may not be significant to indicate the correlation. Also the negative constant of -0.117 indicate that as the global radiation decrease the relative humidity increase which should be otherwise, provided other things remain constant. The negative means that the relation is poor. In the light of this, the estimated global solar radiation by this relative humidity based model was compared with field measured value as shown in the Figure-6. It is clearly shown that the correlation is not accurate as only about three months of the year approximately coincided with the measured values.

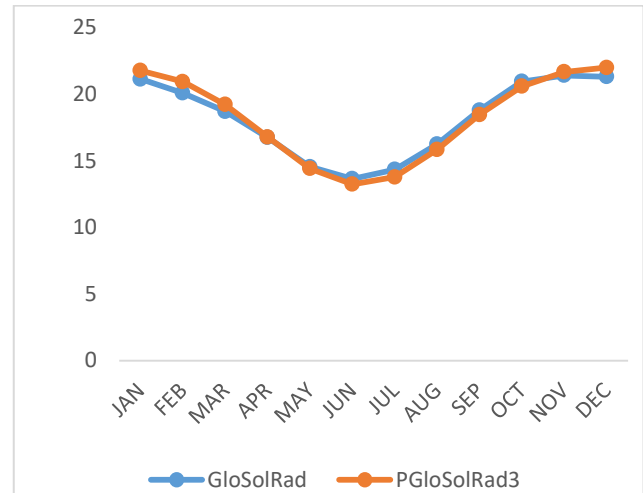


Figure-6. Relative humidity based correlation estimated and measure global solar radiation comparison graph.

D. Average Temperature Based Model

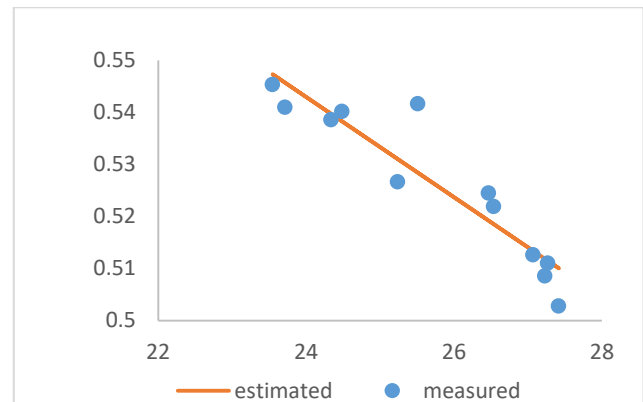


Figure-7. Temperature average correlation graph.

The correlation based on average temperature is shown in Figure-7. This relation produced correlation coefficient of 0.8664 which indicate a good approximation. Since average temperature can hardly be negative for this region [26], [27] thus this correlation indicates that the clearness index cannot be greater than 0.7742 and also if the prevailing average temperature is used in this relation, the clear index will be within the measured region.

E. Temperature Ratio Based Model

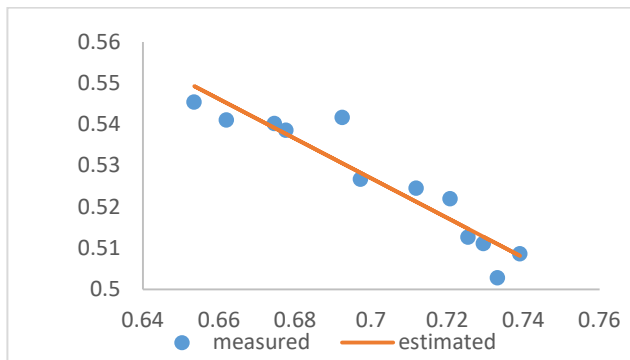


Figure-8. Temperature ratio based correlation graph.

Figure-8 shows the relationship between clearness index and temperature ratio for both field data and estimated data using the temperature ratio based relation. The correlation coefficient of 0.8905 was obtained which shows that this relation can be used for estimating global solar radiation with satisfactory accuracy.

F. Temperature Ratio and Relative Humidity Based Model

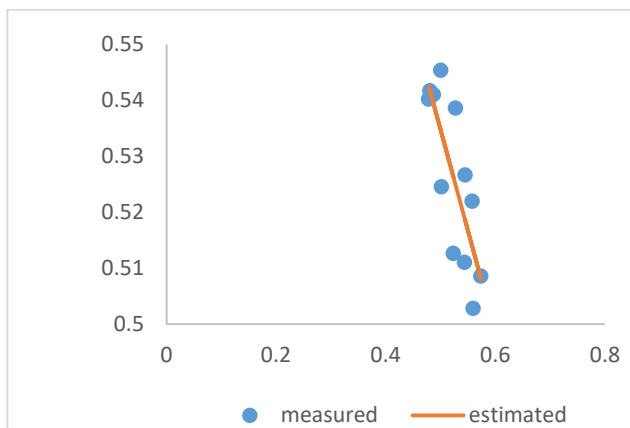


Figure-9. Product of temperature ratio and relative humidity based correlation graph.

Figure-9 shows the relationship between clearness index and the product of relative humidity and temperature ratio for both field data and estimated data using the relative humidity-temperature ratio based relation. The correlation coefficient of 0.6366 was obtained which is lower than the coefficient obtained for only temperature ratio based relation of 0.8905 but higher than the coefficient obtained for relative humidity alone based relation of 0.06544. This shows that combining parameters with hope of producing better result has two sides either generating better relation than both of the initial relations or within the correlation coefficient of the two initial relations. Therefore care must be taken in combining parameters though it may work for some location thus, site specific validation is required.

G. Precipitation Based Model

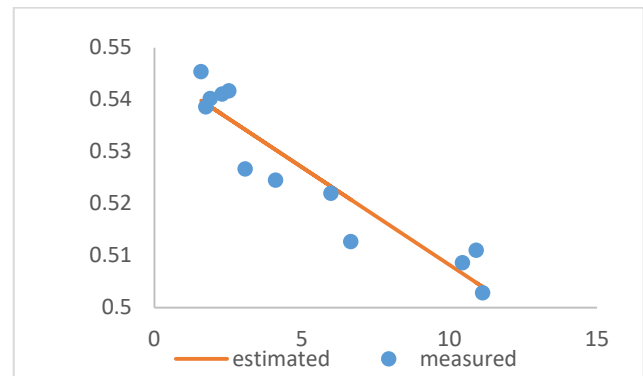


Figure-10. Precipitation based correlation graph.

Figure-10 shows the relationship between clearness index and precipitation for both field data and estimated data using the precipitation based relation. The correlation coefficient of 0.8865 was obtained which shows that precipitation based model can be used for global solar radiation with reasonable accuracy.

H. Comparison of the Estimation

Most of the previous charts show how the models correlate with the data but without comparing the models based on the field measured values and the estimated in all. Though Figure-3 and Figure-5 show this but because Figure-3 was only shown to generally see the behavior of the model while Figure-5 was presented because of its extreme low correlation coefficient. In view of this, the estimated global solar radiation by all these models were compared with field measured value as shown in the Figure-11. This not only provide information on how individual model estimate are closed to the actual value (field measured values) but also ease comparing of all the model with one another estimate. From this figure, it is obvious that model 3 (relative humidity based model), model 6 (product of relative humidity and temperature ratio based model) and partly model 7 (precipitation based model) significantly deviate from the actual values. While other models' estimates are very close to the actual values.

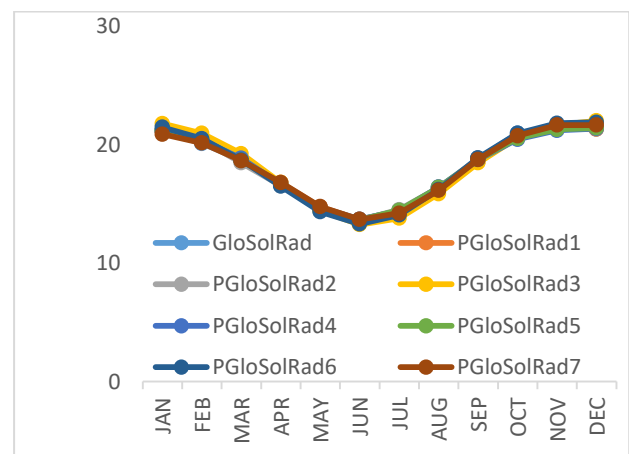


Figure-11. Comparison of the correlation models estimate with measure global solar radiation graph.

**Table-2.** Statistical evaluation criteria analysis for model 1 to model 4.

Model/ Parameter	Model1= S_m/S_0 , $R^2=0.9229$			Model2= $\Delta T^{0.5}$, $R^2=0.9999$			Model3= $RH/100$, $R^2=0.0654$			Model4= T_{avg} , $R^2=0.8664$		
	MPE (%)	MAPE (%)	RMSE (MJ/m ² /day)	MPE (%)	MAPE (%)	RMSE (MJ/m ² /day)	MPE (%)	MAPE (%)	RMSE (MJ/m ² /day)	MPE (%)	MAPE (%)	RMSE (MJ/m ² /day)
JAN	-0.0413	0.0413	0.0002	-0.3064	0.3064	0.0016	-2.9895	2.9895	0.0153	-0.0911	0.0911	0.0005
FEB	-0.9783	0.9783	0.0049	-1.4247	1.4247	0.0072	-4.2693	4.2693	0.0215	-1.4425	1.4425	0.0073
MAR	0.3847	0.3847	0.0020	1.3543	1.3543	0.0069	-2.7742	2.7742	0.0141	-0.6428	0.6428	0.0033
APR	-0.1929	0.1929	0.0010	1.3050	1.3050	0.0068	-0.1971	0.1971	0.0010	0.6556	0.6556	0.0034
MAY	-1.2869	1.2869	0.0068	-0.0057	0.0057	0.0000	0.8701	0.8701	0.0046	-0.8298	0.8298	0.0044
JUN	-0.1293	0.1293	0.0007	0.3213	0.3213	0.0017	2.9979	2.9979	0.0161	-0.2094	0.2094	0.0011
JUL	-0.3542	0.3542	0.0019	-1.1017	1.1017	0.0060	3.9357	3.9357	0.0215	-0.3623	0.3623	0.0020
AUG	-0.4993	0.4993	0.0027	-0.7674	0.7674	0.0042	2.5150	2.5150	0.0136	-0.8673	0.8673	0.0047
SEP	1.5543	1.5543	0.0084	-0.2266	0.2266	0.0012	1.7919	1.7919	0.0097	0.3554	0.3554	0.0019
OCT	0.9925	0.9925	0.0054	1.3251	1.3251	0.0072	1.7345	1.7345	0.0094	2.4499	2.4499	0.0133
NOV	0.3904	0.3904	0.0020	0.1021	0.1021	0.0005	-1.2400	1.2400	0.0065	1.0115	1.0115	0.0053
DEC	0.0910	0.0910	0.0005	-0.4924	0.4924	0.0025	-3.2168	3.2168	0.0165	-0.1491	0.1491	0.0008
Mean	-0.0058	0.5746	0.0040	0.0069	0.7277	0.0047	-0.0701	2.3777	0.0139	-0.0102	0.7556	0.0052

Table-3. Statistical evaluation criteria analysis for model 5 to model 7.

Model/ Parameter	Model5=TR, $R^2=0.8905$			Model6=(TR)(RH/100), $R^2=0.6366$			Model7=P, $R^2=0.8865$		
	MPE (%)	MAPE (%)	RMSE (MJ/m ² /day)	MPE (%)	MAPE (%)	RMSE (MJ/m ² /day)	MPE (%)	MAPE (%)	RMSE (MJ/m ² /day)
JAN	-0.3366	0.3366	0.0017	-1.5272	1.5272	0.0078	1.2195	1.2195	0.0062
FEB	-1.6284	1.6284	0.0082	-2.0706	2.0706	0.0104	-0.2342	0.2342	0.0012
MAR	0.0874	0.0874	0.0004	0.1132	0.1132	0.0006	0.4016	0.4016	0.0020
APR	0.9540	0.9540	0.0050	1.5630	1.5630	0.0082	-0.2579	0.2579	0.0013
MAY	-0.3040	0.3040	0.0016	1.5653	1.5653	0.0082	-1.4318	1.4318	0.0075
JUN	0.1616	0.1616	0.0009	2.5738	2.5738	0.0139	-0.1171	0.1171	0.0006
JUL	-0.7190	0.7190	0.0039	1.9964	1.9964	0.0109	1.0147	1.0147	0.0055
AUG	-0.7772	0.7772	0.0042	0.3162	0.3162	0.0017	0.7154	0.7154	0.0039
SEP	0.1976	0.1976	0.0011	-0.4107	0.4107	0.0022	0.2924	0.2924	0.0016
OCT	2.0475	2.0475	0.0111	0.0121	0.0121	0.0001	0.9928	0.9928	0.0054
NOV	0.6192	0.6192	0.0032	-1.7997	1.7997	0.0094	-1.1097	1.1097	0.0058
DEC	-0.4030	0.4030	0.0021	-2.6589	2.6589	0.0136	-1.5840	1.5840	0.0081
Mean	-0.0084	0.6863	0.0047	-0.0273	1.3839	0.0086	-0.0082	0.7809	0.0048

Tables 2 and 3 show the statistical errors for all the seven models per month of the year and the cumulative error of all the months. MPE range from; 1.5543% to -1.287% with mean value of -0.006%, 1.3251% to -

1.4247% with mean value of 0.0069%, 3.9357% to -4.269% with mean value of -0.07%, 2.4499% to -1.443% with mean of -0.01%, 2.0475% to -1.628% with mean -0.008%, 2.5738% to -2.659% with mean -0.027% and



1.2195% to -1.584% with mean -0.0082% for model 1, model 2, model 3, model 4, model 5, model 6 and model 7 respectively. Based MPE, the best model is model 1, while the least is model 3. In term of MAPE, model 1 is still the best with cumulative value of 0.5746%, while least model is model 3 with cumulative mean of 2.3777%. Considering the actual deviation value, the least RMSE is 0.003983 $MJm^{-2}day^{-1}$ for model 1 while the highest value is 0.0139 $MJm^{-2}day^{-1}$ for model 3. The tables are bird view of the result that gives the model constants, coefficient of correlation, MPE, MAPE and RMSE of all the seven models considered in this study for Nadi, Fiji. The inference that could be made from this table is that the best model could not be decided except it is based on one of the statistics since the ranking of each model varies with these statistics except for model 3 and model 6. Summarily, model 1, model 2, model 4, model 5 and model 7 can be used to estimate global solar radiation at Nadi, Fiji with satisfactory result of MPE less than $\pm 0.01\%$, MAPE less than 0.8% and RMSE less than 0.008 $MJm^{-2}day^{-1}$

4. CONCLUSIONS

In this study, the global solar radiation of Nadi, Fiji was estimated using seven empirical models that are based on common meteorological parameters. The data used for this study was obtained from Fiji Meteorological Centre Services spanned from 1981 to 2019 (29 years) which comprises of daily sunshine hour, precipitation, pressure, minimum temperature, maximum temperature, mean temperature, relative humidity and global solar radiation. The result of this work showed that model 1 (sunshine based), model 2 (temperature difference based), model 4 (average temperature based), model 5 (temperature ratio based) and model 7 (precipitation based model) can be used to estimate solar radiation. The outcome of the study revealed that Nadi, Fiji is endowed with abundant solar radiation as all the clearness index are within partly overcast and also very close to clear sky in some months. The general overview of this work is concisely highlighted in Table-4.

Table-4. Summary of all the models properties for Nadi, Fiji.

Model	a	b	R^2		MPE		MAPE		RMSE	
			Value	Rank	Value	Rank	Value	Rank	Value	Rank
$\frac{H_m}{H_0} = a + b \frac{S_m}{S_0}$	0.3258	0.3476	0.9229	2	-0.006	1	0.5746	1	0.003983	1
$\frac{H_m}{H_0} = a(\Delta T)^{0.5}$	0.1755	0*	0.9999	1	0.0069	2	0.7277	3	0.00469	2
$\frac{H_m}{H_0} = a + b \frac{RH}{100}$	0.6135	-0.117	0.06544	7	-0.07	7	2.3777	7	0.0139	7
$\frac{H_m}{H_0} = a + bT_{avg}$	0.7742	-0.0096	0.8664	5	-0.01	5	0.7556	4	0.0052	5
$\frac{H_m}{H_0} = a + b(TR)$	0.8634	-0.4807	0.8905	3	-0.008	3	0.6863	2	0.0047	3
$\frac{H_m}{H_0} = a + b(TR) \left(\frac{RH}{100} \right)$	0.7154	-0.3614	0.6366	6	-0.027	6	1.3839	6	0.0086	6
$\frac{H_m}{H_0} = a + bP$	0.5458	-0.0038	0.8865	4	-0.0082	4	0.7809	5	0.0048	4

ACKNOWLEDGMENT

We would like to thank Fiji Metrological Centre for providing meteorological data for this study.

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