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(RESEARCH ARTICLE)

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Evaluation of some linear regression models for the prediction for daily global solar radiation in the village of Koyli Alpha, district of Linguere, Louga region, Senegal

Badara Mbow *, Serigne Ndiangue Leye, Papa Lat Tabara Sow and Senghane Mbodji

Research Team in Renewable Energies, Materials and Lasers, Department of Physics, Alioune DIOP University, Bambey, Senegal.

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Abstract

In this paper, we compare three models in order to determinate the daily mean monthly of global solar radiation using climate conditions of a Koyli Alpha, which is a village located in the district of Ferlo zone, North of Senegal. The first model used the temperature, the model 2 depends on the sunshine duration and the model 3 is related on the sunshine duration and the relative humidity. These models are calculated using both the regression coefficients and the meteorological data recorded from the set-up weather station in Widou village. This village is located about 20 km from the village of Koyli Alpha. Both villages have neighboring geographical characteristics and are not far apart. The best model for the estimation of the monthly mean daily global solar radiation on horizontal surface in Koyli Alpha is determined. Hence, it was observed that the highest predicted values, measured in April, year 2017, are 5,456.26 Wh/m²/day for the model 1, 5,521.80 Wh/m²/day for model 2 and 5,450.67 Wh/m²/day for the model 3. The first model is better than models 2 and 3 because it has the highest values of the coefficient of determination (R^2), NSE, SDFE and the lowest values of MRE and RMSE. Among these three linear regression models, the first model using ambient temperature is the most accurate model for the site of Koyli Alpha because it is justified by the statistical parameters used in this paper.

Keywords: Relative humidity; Regression linear; Temperature; Monthly mean daily global solar radiation; Sunshine

1. Introduction

The population of the world increases with a high load energy demand and whose supply is assured in a big part by fossil energy resources. Among these fossil resources, fuel plays a main role. However, fossil fuel reserves decrease and their uses caused negative impacts. They are responsible of many environment drawbacks, which are the greenhouse emission, high temperature and acid rain. The increase of oil price has prompted policymakers and researchers to turn to alternative energies sources to low energy costs and reduce the emission of greenhouse gases [1].

In Africa, despite of the high use of fossils energy, many countries try to solve the lack of electric power for satisfying needs of the population and particularly rural areas gases [2]. Hence, in order to answer to these environmental problems, we use renewable energy sources which produce zero or a very little amount of carbon dioxide or other chemical pollutants gases [3]. In Africa, we have several sources of the renewable energy as solar photovoltaic, geothermal, hydroelectric, biomass, Concentrating Solar Power (CSP) and the wind energy resources. The Maghreb countries have an interesting solar deposit and particularly the sunshine exceeds 3000 hours per year in Algeria. It is noted that the annual average daily sunshine in the city of Adrar is between 5 and 7 kWh/m²/day [4]. The work of A. Sadio et al., happened in Senegal, showed an average daily radiation equal to 5.8 kWh/m²/day, this potential had

* Corresponding author: Badara Mbow

encouraged the state of Senegal to build solar power plants in Bokhol, Malicounda, Mekhe and Merina and to promote the use of solar energy in remote areas [5].

Solar radiation varies with many the latitude, the longitude and the declination angle etc. In Adrar, Algeria, authors showed a minimal and maximal values of monthly mean daily solar radiation equaled to 5.5 kWh/m^2 /day and 7.5 kWh/m^2 /day in March and October, respectively [6]. Al-Ghamdia et al., worked with experimental data of Al-Baha city, over twelve months in 2014 in order to determinate monthly mean daily solar radiation on a horizontal surface [7]. They have shown the huge solar potential in Al-Baha city. This town receives in May and in January a maximum and minimum values of solar radiation approximately estimated to 6.5 kWh/m^2/day and to 3 kWh/m^2/day, respectively. Indeed, sizing and installation solar require more data to optimize the systems operating. In some areas, lack of meteorological data and weather station become a serious problem which must be resolved by using several techniques. The linear regression methods can solve the lack of solar radiation data in some localities because they allowed to estimate theirs annual, monthly, daily values of solar radiation. Various models based on geographic coordinates are utilized for predicting the solar radiation of a site. Hence, Muzathik et al., worked with the method of Angstrom in order to estimate the monthly average daily global radiation in Kula Terengganu site, in Malaysia gases [8]. In our study, we are looking to determine an accurate model for the estimation of the daily mean monthly global solar radiation on a horizontal surface in Koyli Alpha, Senegal. The set-up weather station installed in Widou, allowed to record hourly data during three years, from august 2015 to august 2018. These data are the wind speed, the relative humidity, the ambient temperature and the solar radiation. In this work, we use three among the linear regression models in order to establish the correlation between the measured data obtained from the weather station of Widou and the predicted data. Finally, we will complete our study with a comparison between these three models. In fact, this paper testes the performance of three models based on different statistical parameters Nash–Sutcliffe model efficiency coefficient (NSE), Mean Relative Error (MRE), Standard Deviation Fractional Error (SDFE), Root Mean Square Error (RMSE) and compares them with the observed data of Widou meteorology station. The document treats at first, the methodology and meteorological data from Widou weather station, secondly presents three linear regression models used for evaluating the most accurate model and finally shows the results and the discussions.

2. Material and methods

2.1. Presentation of Study site

Our study is happened in the village of Koyli Alpha, which is located in 15.8956° west longitude and 15.1189° north latitude, in Mboula area, district of Yang-Yang, Department of Linguere, region of Louga, Senegal. The most of the population in this area is active in breeding and agriculture. Koyli Alpha village is situated in the Great Green Wall, particularly in Ferlo zone. Great Green Wall Project realized the building of many boreholes of water supplied by diesel generators and polarized 7 villages with a population around 1,700 inhabitants. In, the water table is too far away with the depths greater than 150 meters leading to a permanent lack of water which is not always resolved. The boreholes of water in Ferlo zone operate on diesel fuel through 40 000 Voltage Ampere generator set using approximately 60 liters for the operating times of 15 hours per day in summer or 40 liters during 8 hours per day in the winter season. In order to solve the environmental and the energetics troubles, we will focus our choice on photovoltaic solar energy thanks to the significant local and the national solar potential. Thereby, we present the location of Koyli Alpha, village.

Figure 1 Localization of Koyli Alpha, Village in Senegal

2.2. Meteorological data from weather station of WIDOU

The Data are the main entrances which define the geographical location of a study site. Koyli Alpha is near to the Widou site and have almost the same geographical coordinates. The Campbell Scientific BSW200 station is installed in Widou in Ferlo. In this study, we used meteorological data from the Widou weather station, part of the Campbell Scientific BSW 200 series. The station is installed inside a waterproof enclosure containing an acquisition unit. The station consists of a 5W solar panel, a 12-volt battery installed inside the enclosure, a CD containing the PC 200W software, a CD containing a copy of the program running to collect data from the BWS 200 station, a computer, and several sensors. These sensors are the CS 215 temperature and relative humidity sensor, the Wind Sentry anemometer, the ARG 100 rain gauge, the CS 300 global radiation sensor, and the CS 100 barometer. These communication methods use a direct connection to a computer or remote modem communication to transmit data over the public telephone network or mobile network. Direct communication with a computer allows for a direct connection between a computer's serial port and the CR 200X control panel's RS 232 port over a distance of less than 15 meters. This station also has a communication line and additional lightning protection devices to protect the station. Thus, for distances greater than 15 m, it uses communication interfaces, namely the RS 485 protocol with an MD 485 interface or the CR 216X central unit with a built-in radio device. In other words, the Modem is a point-to-point CS-SRM communications kit with modems connected together via a telephone cable over short distances. It can achieve communication distances of up to 25 km. Multipoint communication, in turn, allows multiple weather stations to communicate via the same data bus. Evapotranspiration is calculated on an hourly or daily basis and depends on meteorological data, ambient temperature, relative humidity, wind speed and solar radiation. It also depends on latitude, longitude, and altitude. The weather station is programmed to the Greenwich Meridian (0° East) to obtain good results. However, this assumption is not entirely accurate because data changes depend on the meteorological and geographical conditions of the localities. Data representativeness refers to the location for which the sensors have consistent values relative to their location. In other words, this BWS 200 station is also used to measure the actual parameters of a site in order to determine the difference between the actual parameters and those recorded by a station in a regional meteorological network. The CR 200X controller used with the BWS 200 station includes a data acquisition program in non-volatile flash memory, and the program remains active even when the battery is disconnected. The clock settings (date and time) are also saved in the event of a power outage [9]. Figure 2 shows the Widou weather station in Ferlo.

Figure 2 Widou weather station in Ferlo

Meteorological data are obtained from Widou weather station about different sensors. Meteorological data were downloaded by a microcomputer and we collected from 25 August 2015 to 25 August 2018 corresponding to 36 months.

It allows to record hourly data during three years. These data are the wind speed, the relative humidity, the ambient temperature and the solar radiation.

The figure 3 shows the monthly solar radiation variation in 2017.

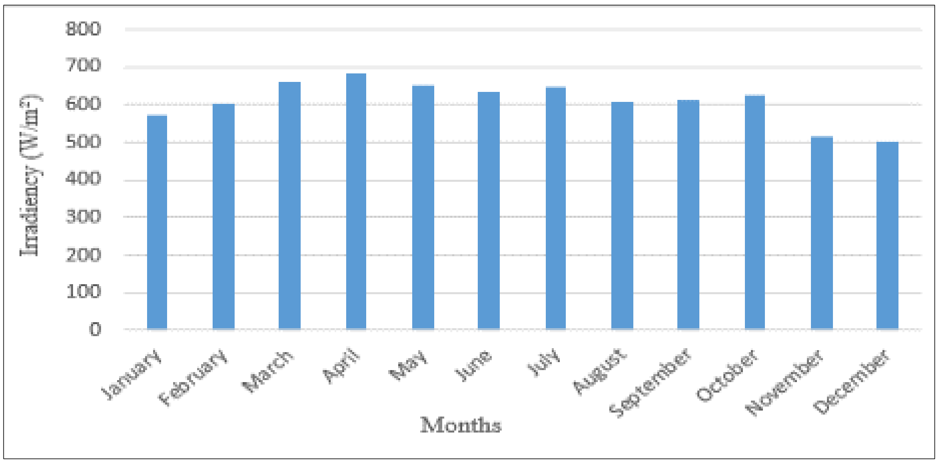

Figure 3 Monthly solar radiation variation of the 2017 year

Analysis of the figure 3 shows that values vary between a maximum solar radiation (683.6 W/m^2) and a minimum solar radiation (501.86 W/m^2). The important difference between some months can be explained by a lack of sunshine during the night, the days without sunrise of the rain season. The best solar radiation is noted during March, Avril, June and May and lowest solar radiation are observed in November, December, January, and February.

In figure 4, the variation of wind speed during twelve months in 2017 year is drawn.

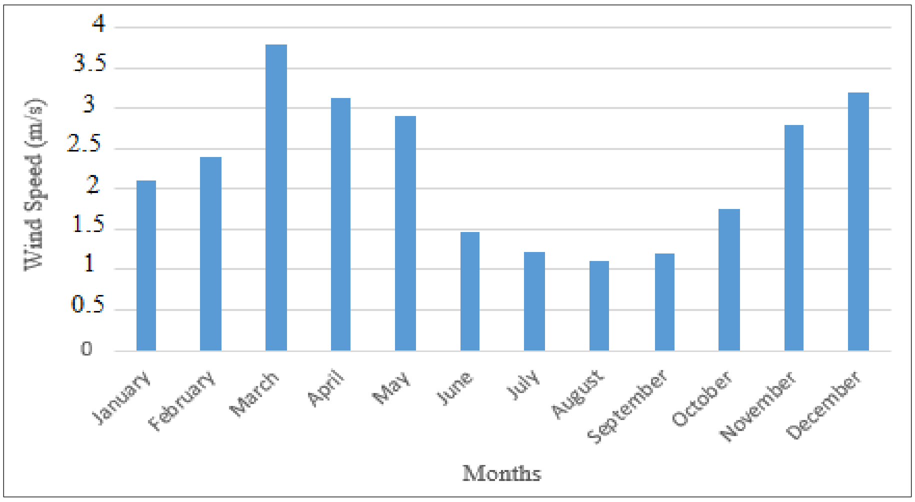

Figure 4 Monthly wind speed variation of the 2017 year

Figure 4 shows the potential of wind speed collected from the Widou meteorological station. This study of the wind speed variation involves the 12 months of the year 2017. We notice that, these data vary between a maximum value (3.8 m/s) and a minimum value (1.11 m/s). These values are lightly different and less than to the wind's speed values evaluated, in the Ngoundiane site, which revealed that for three years 2013, 2014 and 2015, the annual average speeds varied from 2.9 to 5.4 m/s [10]. Ould Bilal et al., also showed in their article, that significant wind power 95 and 72 W/m^2 are recorded on Potou and Kayar sites in Senegal [11].

Figure 5 presents relative humidity on twelve months in 2017.

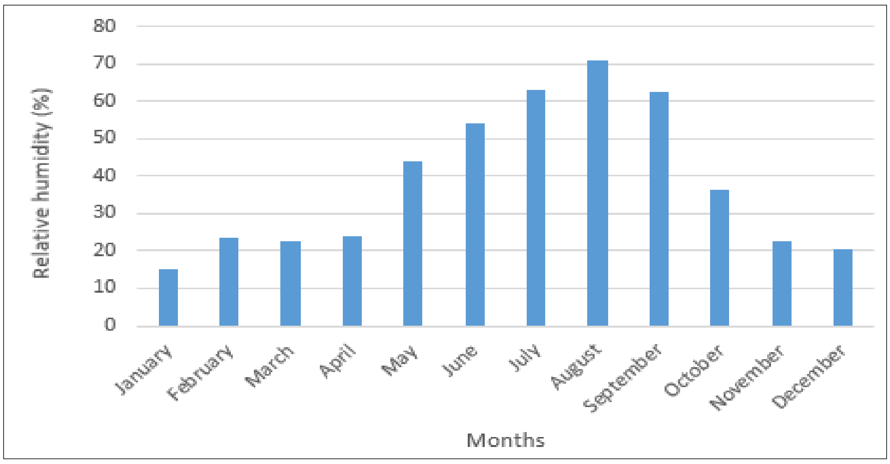

Figure 5 Monthly relative humidity variation of the 2017 year

It is known that the relative humidity is a good meteorological parameter for predicting the solar radiation of a site. It is noted that the high values of relative humidity are recorded in June, July, August, September and the low values are set in the months of November, December and January. The maximum and minimum values are equaled to 15 % and 71% in January and August, respectively.

Figure 6 involves the variation of the monthly ambient temperature during twelve months of the 2017 year

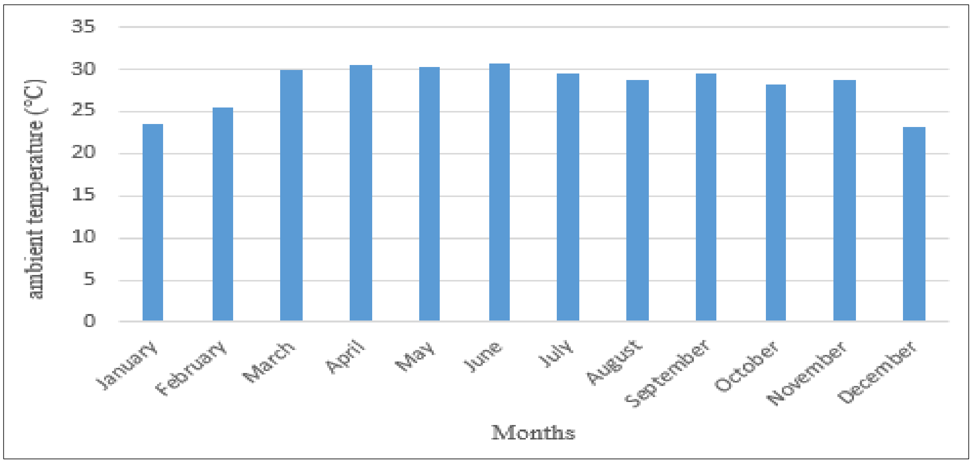

Figure 6 Monthly ambient temperature variation of the 2017 year

In figure 6, the ambient temperatures values vary between 23.12°C and 30.7°C. The highest temperatures are noted in March, April, June and November and lowest temperatures are observed in January, February and August. The temperature, an important input for the realization and sizing of PV systems, is already used in various studies. Leye et al., showed the negative influence of temperature in performance of solar panel [12] while Chander et al., also studied the impact of temperature on performance of series and parallel connected mono-crystalline silicon solar cells with cell temperature in a range of 25 and 60°C [13]. Results concluded that the efficiency of solar cell and solar panel decrease with the cell temperature because of the decrease and increasing of the open circuit voltage and short-circuit current respectively.

2.3. Linear regression methods for the evaluation of daily global solar radiation in Koyli alpha Village

In order to predict the solar radiation data of Koyli Alpha village, we use the linear regression methods to show the correlation between values measured given by the weather station of Widou and values estimated from these available data. We then choose three models to estimate the daily mean global solar radiation. The objective of our study is to determine the most efficient model among these three following models.

The first one, corresponding to model 1, is proposed by [14]. It is given by equation (1) presented below:

$$KT = \frac{G}{G_0} = a + b \cdot T_r + c \cdot T_{max} \quad \text{.........} \quad (1)$$

$$T_r = \frac{T_{min}}{T_{max}} \quad \text{..............} \quad (2)$$

Where T_r means the ratio of temperature, KT is corresponding to the clearness index, G defines the monthly mean daily global solar radiation. a, b and c are empirical coefficients.

T_{max} and T_{min} are maximum and minimum temperatures, respectively and G_0 means is equal to the average daily extraterrestrial radiation.

The daily extraterrestrial radiation G_0 is given by following equation [15]:

$$G_0 = \frac{24 \cdot K_S}{\pi}\left[1 + 0.003\cos\left(\frac{360 \cdot d}{365}\right)\right]\left[\cos\delta \cdot \cos W_s \cdot \cos\phi + \frac{\pi \cdot W_s}{180} \cdot \sin\delta \cdot \sin\phi\right] \quad \text{........}(3)$$

Where K_S equaled to 1367 W/m^2 is a solar constant [16]. d: means is day number counted from 1 to 365, ϕ : means latitude of Koyli Alpha, δ: means corresponds to the declination angle and is given as [17]:

$$\delta = 23.45 \cdot \sin\left(360 \cdot \frac{284 + d}{365}\right) \quad \text{...........} \quad (4)$$

W_s is the sunset hour expressed as:

$$W_s = \cos^{-1}[-\tan\delta \cdot \tan\phi] \quad \text{...........}(5)$$

The second model correlates global solar radiation and sunshine duration. It is studied by [18], [19], [20], and [21]. We applicated its for January to December during the 2017 year. This model is expressed by equation (6):

$$K_T = \frac{G}{G_0} = a + b \cdot \frac{S}{S_0} \quad \text{.................}(6)$$

S means the day length, S_0 means the maximum sunshine duration.

The maximum possible sunshine duration $S_0$was calculated by the following equation (7) as shown in [22]:

$$S_0 = \frac{2 . W_S}{15} \quad \text{.............} \ (7)$$

The third model which we used for the period of the month of January of the 2017 year is related to the sunshine duration and the relative humidity. It is written using equation (8) as:

$$K_T = \frac{G}{G_0} = a + b \cdot \frac{S}{S_0} + c \cdot RH \quad \text{............}(8)$$

In this section, we present five statistical parameters that allow to show the best model among them proposed in this paper. The performance of these models was defined by the Nash–Sutcliffe model efficiency coefficient (NSE), which is a statistical indicator proposed as shown in [23], the Mean Relative Error (MRE), the Standard Deviation Fractional Error (SDFE), the Root Mean Square Error (RMSE) and the coefficient of determination (R^2). These indicators are mainly employed for the adjustment of solar radiation data in Koyli Alpha, village. Among these statistical parameters developed in this paper, Kerkouche et al. used these coefficients of determination (R^2) and Root Mean Square Error (RMSE) for finding the best model solar radiation prediction in Bouzareah [24].

The simulation on Microsoft Excel 2007 software of these three models allows to find empirical constants which are discussed in the table 1. At a 95% confidence level, are obtained their empirical constants by regression analysis on proposed models. A stochastic analysis was performed on the estimation models using twelve months of the year 2017 (January to December).

The results of the analysis are illustrated in Table 1, Table 2 and Figures 7, 8, 9 and 10.

3. Results and discussion

At first, we present in results, the empirical coefficients obtained from the simulation.

The Results are showed in table 1.

Table 1 Empirical coefficients obtained from three models

Coefficients	Model 1	Model 2	Model 3
a	855.52	1,337.1	1,537.25
b	-37.63	-616.94	-1,900.04
c	43.43	0	45.47

Empirical coefficients illustrated in table 1 allowed to rewrite the three models as follows equations:

Model 1:

$$K_T = \frac{G}{G_0} = 855.52 - 37.63 \cdot T_r + 43.43 \cdot T_{max} \quad \text{……….} \ (9)$$

Model 2:

$$K_T = \frac{G}{G_0} = 1{,}337.1 - 616.94 \cdot \frac{S}{S_0} \quad \text{……}(10)$$

Model 3:

$$K_T = \frac{G}{G_0} = 1{,}537.25 - 1{,}900.04 \cdot \frac{S}{S_0} + 45.47 \cdot RH \quad \text{………..} \ (11)$$

The results from these models (estimated values) are represented by the following figures.

Figure 7 represents the solar radiation estimated from model 1.

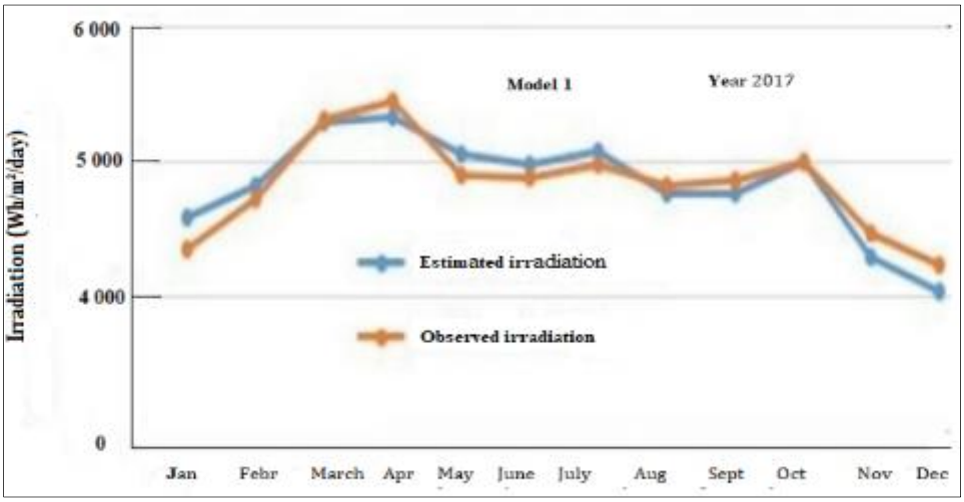

Figure 7 Comparison between solar radiation values obtained from weather station of WIDOU and estimated from model 1

Figure 7 compares estimated and predicted values of annual average monthly solar irradiation. The model 1 presents predicted irradiation values that vary between a minimum of 4,232.29 $Wh/m^2/day$ in December and a maximum of 5,456.26 $Wh/m^2/day$ in April 2017. For the months of February, March, April, June, July, August, September, and

October, the irradiation values collected from the Widou station (observed) are in perfect agreement with the values obtained from model 1. We note that the estimated and observed irradiation values differ significantly between the months of January, May, November, and December.

Figure 8 represents the irradiation estimated from model 2.

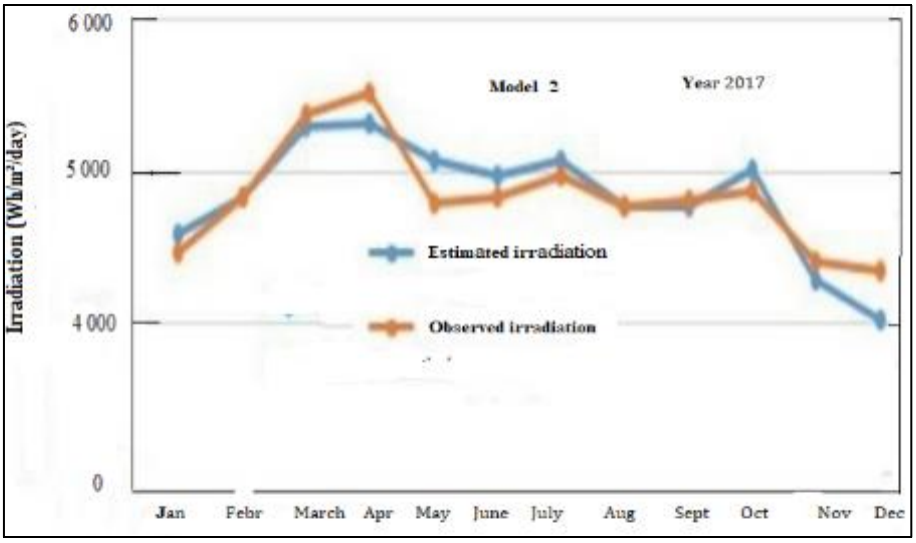

Figure 8 Comparison between solar radiation values obtained from weather station of WIDOU and estimated from the model 2

In the model 2, we observed a minimum estimated irradiation value of 4,343.29 Wh/m^2/day in December and a maximum value of 5,521.80 Wh/m^2/day in April 2017. We observed that in January, February, March, June, July, August, September, October, and November, the irradiation values collected from the Widou station (observed) were close to the estimated irradiation values predicted from model 2. Indeed, in April, May, and December, we observed significant differences between the compared irradiation values from the Widou station and the model 2.

Figure 9 represents the irradiation estimated from the model 3.

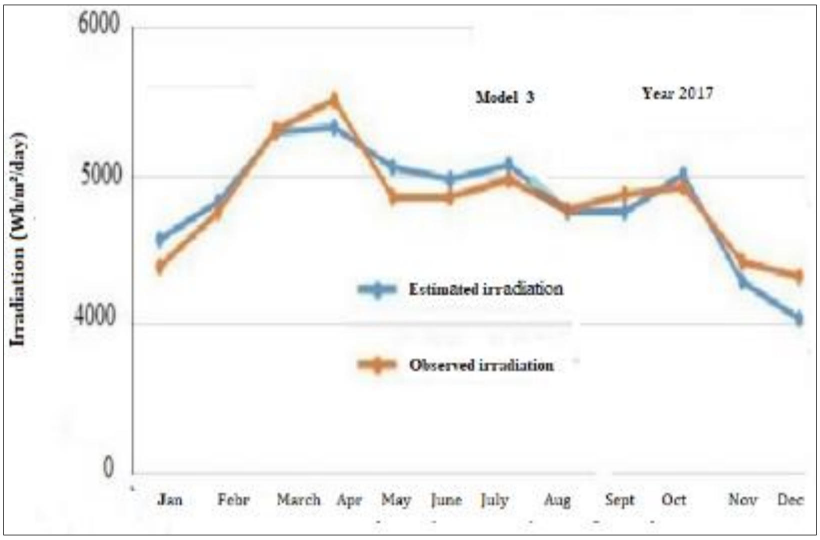

Figure 9 Comparison between solar radiation values obtained from weather station of WIDOU and estimated from model 3

The model 3 predicts minimum irradiation values of 4,223.39 Wh/m^2/day and maximum irradiation values of 5,450.67 Wh/m^2/day in December and April 2017, respectively. A comparative study between the irradiation estimated by model 3 and the observed irradiation reveals a significant similarity between the latter in February, March, June, July, August, September, October, and November, while in January, April, May, and December, the compared predicted and observed irradiation values show significant differences.

Figure 10 shows the comparison of the estimated values of monthly mean daily global solar radiation obtained by the three previous models. It shows also, the measured values obtained from the weather station of Widou for the twelve months in 2017 year. Indeed, irradiation values obtained by the proposed models have a good agreement with the values measured during the months of the year 2017.

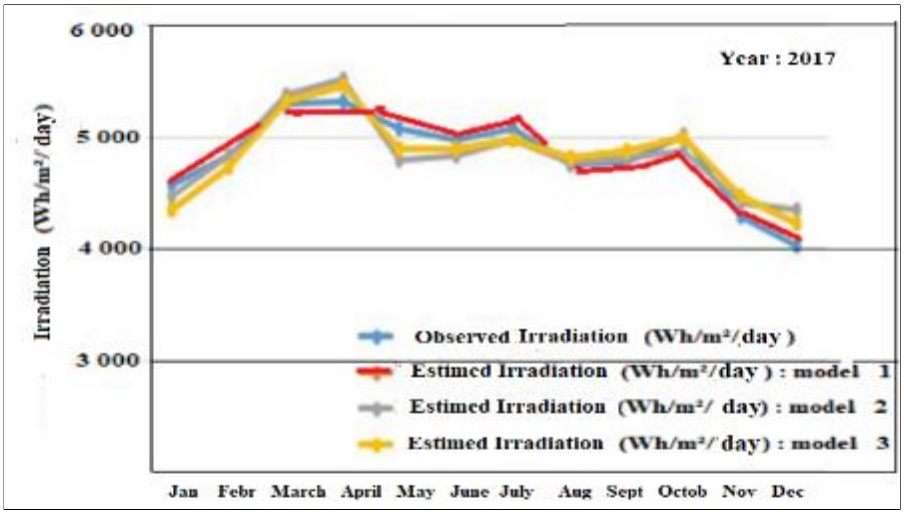

Figure 10 Comparison between estimated values obtained by using the three models and the measured values obtained from weather station of WIDOU

The model 1 gives estimated values of solar radiation which vary between 4,232.29 Wh/m^2/day, the minimum radiation, in December and the maximum radiation which is 5,456.26 Wh/m^2/day noted in April, 2017 year. Also, the model 2 gives predicted values which vary from the minimum radiation value that is 4,343.29 Wh/m^2/day noted in December, 2017 year to the maximum radiation value which corresponds to 5,521.80 Wh/m^2/day in April of the year 2017. Regarding the estimated values of global solar radiation given by the model 3, we noted in December and April in year 2017 give the minimum and maximum values which are 4,223.39 Wh/m^2/day and 5,450.67 Wh/m^2/day respectively. As for the measured values obtained from weather station of Widou, we noted that they vary from 5,424.56 Wh/m^2/day (maximum radiation) in April to 4,027.39 Wh/m^2/day (minimum radiation) in December, year 2017. Annual mean monthly global solar radiation on a horizontal surface in Koyli Alpha was obtained from Widou weather station. The table 2 has elaborated the fact where the results of the error and performance analysis have been highlighted.

Their Results are presented in table 2

Table 2 Statistical parameters obtained from three models

Errors and analysis performance	Model 1	Model 2	Model 3
R^2	0.87	0.82	0.83
NSE	0.87	0.82	0.84
SDFE	103.95	100.84	101.94
MRE	0.025	0.057	0.052
RMSE	134.24	158.8	150.25

In this study, we observed that the coefficient of determination (R^2) and the NSE for all three models are between the range of 0.82 to 0.87 at the site of Koyli Alpha. It reflects a good agreement between the predicted and measured values of solar irradiance. These models are accurate for the evaluation of the global radiation. Hence, we noted that Okundamiya et al. found in its study a best coefficient of determination equal to 0.988 in Abuja, Nigeria [25] while AL-Naimi et al. showed some prediction errors of monthly mean daily global solar radiation for nine models. Among these nine models, artificial neural network (ANN) model, is used as the model for the training stage and which found the best coefficient of determination equal to 0.9967 in Baghdad, Iraq [26]. For others statistical parameters as MRE and RMSE, we noted a variation between models proposed. The values of MRE are 0.025, 0.057, 0.052 in quite close to zero, in the models 1, 2 and 3, respectively. The low values of MRE and RMSE and the high values of NSE, SDFE and R^2 show the suitability of the model 1 to detriment of the others models mentioned. From errors and performance indicators, we can conclude that the model 1 using temperature responds favorably to those statistical parameters unlike the model 2 using sunshine and model 3 involving ambient temperature and relative humidity. So, the best model which can be used for the modelling of the solar radiation in Koyli Alpha village, is the model 1 that uses the ambient temperature. According to performance analysis criteria, it is followed by models 3 and 2, respectively.

4. Conclusion

This This paper evaluates monthly average daily global solar radiation using three regression linear models. These values are compared with observed data from Widou meteorology weather station. This study determined among these three models, the most accurate model for the estimation of monthly average daily global solar radiation on a horizontal surface in the village of Koyli Alpha in the Ferlo zone in Senegal. These models used many inputs which are the solar radiation, the sunshine duration, the temperature and the relative humidity simulated. Statistical parameters allow to evaluate the best model and we have seen that the model 1 which uses the temperature, has the highest values of the coefficient of determination and NSE estimated to (0.87 and 0.87) against (0.82 and 0.82) and (0.83 and 0.84) for the model 2 linked to the sunshine and the model 3 related to the sunshine and the relative humidity, respectively.

Compliance with ethical standards

Statement of conflict of interest

No conflict of interest to be disclosed.

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