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RESEARCH ARTICLE

STATIC EVALUATION OF THE GLOBAL SOLAR POTENTIAL IN THE REGION OF KARA (TOGO) BY EMPIRICAL MODELS.

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Abstract

In this work, we propose different empirical models for the estimation of daily global solar radiation on a horizontal plane in the region of Kara in Togo. The performance of the models is evaluated on the basis of statistical indicators such as: the correlation coefficient (R) and the Root Mean Square Error (RMSE). It appears that the Angstrom-Preseott linear model is the most efficient for the site. For this model, the values of R and RMSE are 0.9256 and 0.046, respectively. It can therefore be used to estimate the solar potential of the region of Kara.

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Introduction:-

Energy plays a vital role in the current societies, accelerate economic development (Samadianfard and al., 2019). In particular, solar energy occupies the most important position among the various renewable energy sources (Tikyaa and al., 2019). From the time immemorial, solar energy has remained the most reliable source of energy that has the capacity to sustain and maintain all the activities and processes that support life for plants, animals and other materials on earth (Nwokolo and Ogbulezie, 2018).

Thus, knowledge of global solar radiation is of particular importance. It implies the imperative need to finely estimate the solar potential on the basis of astronomical and meteorological data. However, because of the cost implication, maintenance and expertise involved in ground measurement of solar radiation data, several models were proposed across the world that can estimate global solar radiation without considering the cost of the instrument needed (Etuk, and al., 2016).

Therefore, empirical models are developed. These models are intended to quantify the best solar radiation on any site and at any time. Thus, these models estimate the values of solar global radiation for a region of interest from more readily available meteorological, climatological and geographical parameters (Besharat et al., 2016), such as the duration of sunshine.

Indeed, the region of Kara has a very favorable climate for the use of solar energy, especially solar photovoltaic (the rate of sunshine is around 2700h/year (K. Amegassivi, 2012)). However, the distribution of the radiation remains poorly known. This study aims to determine, among three (03) selected empirical models in the literature (linear,

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logarithmic and exponential), which are the most adapted to the estimation of the daily global solar radiation on a horizontal plane on the site of Kara.

Materials and Methods:-

There is a relationship between the clarity index (ratio of daily global solar radiation to extraterrestrial daily global radiation measured on a horizontal plane) and a daily insolation fraction calculated from direct light measured by report to a normal plan. Thus, several models have been developed in this direction. In this article, Angstrom-PreScott linear (Angstrom, 1924), Ampratwum-Dorvlo logarithmic (Ampratwum and Dorvlo, 1999) and Almorox-Hontoria exponential (Almorox and Hontoria, 2004) models are considered. After a physical overview of the site, data and performance indicators selected for model validation are presented.

General Characteristics of the Site

Located in the northern part of Togo (400 km north of the capital Lomé), the regional area of Kara is made up of seven (07) districts covering an area of 11738km², nearly 21% of the national territory. With a population of 769940 inhabitants at the last general census of population and housing in 2010, the Kara region is the fourth most populous region of the five administrative regions of Togo (see Figure 1).

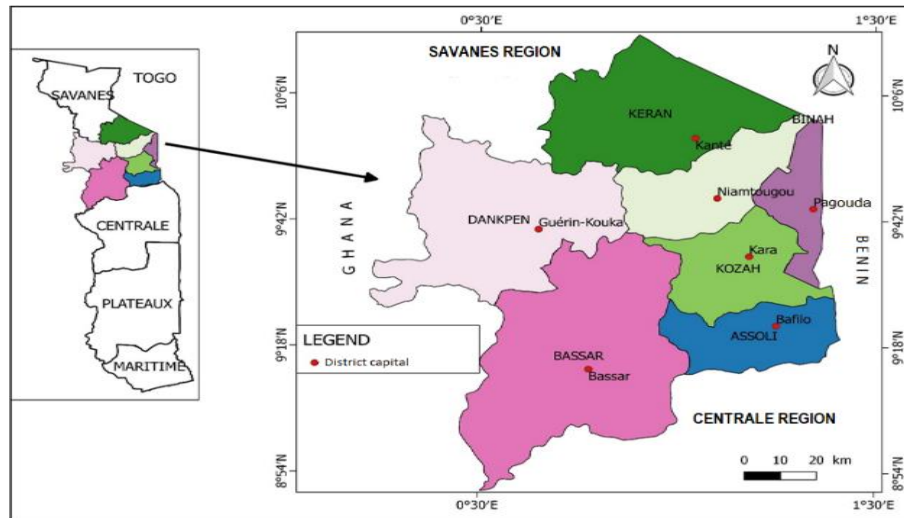


Figure 1:-Location of the Study Area

The geographical coordinates are 9°40'0" N and 0°55'0" E in DMS (Degrees, Minutes and Seconds) or 9.66667 and 0.916667 (in decimal degrees). The altitude above sea level is 291m. It houses a unique meteorological station where average temperature, humidity, dew point, pressure and visibility are measured.

Collection of data

This study concerns the region of Kara in Togo. The radiation data used in this context are provided by MINES ParisTech/Armines (France). Those selected for the modeling range from January 1st to December 31st, 2005. The base includes: global solar radiation measured on a horizontal plane, global extraterrestrial solar radiation on the horizontal plane, duration of sunshine and the maximum duration of measured sunshine.

Presentation of models

Three models are used:

the linear model (A. Angstrom, 1924), expressed by the relation (1)

$$\frac{G}{G_0} = a + b \left(\frac{S}{S_0} \right) \quad (1)$$

the logarithmic (Ampratwum and A. Dorvlo, 1999), expressed by relation (2)

$$\frac{G}{G_0} = a + b * \log\left(\frac{S}{S_0}\right) \quad (2)$$

the exponential model (Almorox and C. Hontoria, 2004), expressed by the relation (3) $\frac{G}{G_0} = a + b * \exp\left(\frac{S}{S_0}\right)$

(3)

where a and b are empirical coefficients to be estimated.

S is the duration of sunshine (h) and S_0 is the maximum duration of measured sunshine (h), proportional to ω as following:

$$S_0 = \frac{2}{15} \omega \quad (4)$$

G is the global solar radiation measured on the horizontal plane ($\text{Wh.m}^{-2}.\text{d}^{-1}$) and G_0 is extraterrestrial global solar radiation on the horizontal plane ($\text{Wh.m}^{-2}.\text{d}^{-1}$), given by equation (5)

$$G_0 = \frac{24}{\pi} I_0 \left(1 + 0.33 \cos \frac{360n}{365} \right) \left(\cos \lambda \cos \delta \sin \omega + \frac{2\pi}{360} \omega \sin \lambda \sin \delta \right) \quad (5)$$

where

1. $I_0 = 1367 \text{ W.m}^{-2}$ is the solar constant;
2. n is day of the year;
3. λ is latitude of the place;
4. δ is the declination given by relation (6):

$$\delta = 23,45 \left[\sin \frac{360(284 + n)}{365} \right] \quad (6)$$

ω is the hour angle related to λ and δ through equation (7)

$$\omega = \cos^{-1}(-\tan \lambda \tan \delta) \quad (7)$$

Model Performance Indicators

For the validation of the model, the recourse is made to two (02) popular and widely used statistical indicators which are:

the correlation coefficient (R), given by formula (8), it measures how much the predicted values are closer to the real values; clearly, a correlation coefficient value closer to unity implies a better prediction;

$$R = \left[\frac{\sum_{i=1}^N (G_{mes}(i) - \bar{G}_{mes}(i)) G_{mes}(i)}{\sqrt{\sum_{i=1}^N (G_{mes}(i) - \bar{G}_{mes}(i))^2 \sum_{i=1}^N (G_{est}(i) - \bar{G}_{est}(i))^2}} \right] \quad (8)$$

the Root Mean Square Error (RMSE), estimated by formula (9); it identifies the precision comparing the difference between the values obtained during the estimation and those of the measured data, it always has a positive value;

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (G_{mes}(i) - G_{est}(i))^2 \right]^{1/2} \quad (9)$$

where

1. N: number of examples used in the training or test database;
2. G_{mes} : measured solar radiation ($\text{Wh.m}^{-2}.\text{d}^{-1}$);
3. G_{est} : solar radiation estimated by the model ($\text{Wh.m}^{-2}.\text{d}^{-1}$);
4. \bar{G}_{mes} : average value of the measured solar radiation ($\text{Wh.m}^{-2}.\text{d}^{-1}$);
5. \bar{G}_{est} : average value of the estimated solar radiation ($\text{Wh.m}^{-2}.\text{d}^{-1}$);

Results achieved:-

The first step is to check if there is a linear relationship between the clarity index and the insolation fraction observed, according to the different models. The following figures are obtained:

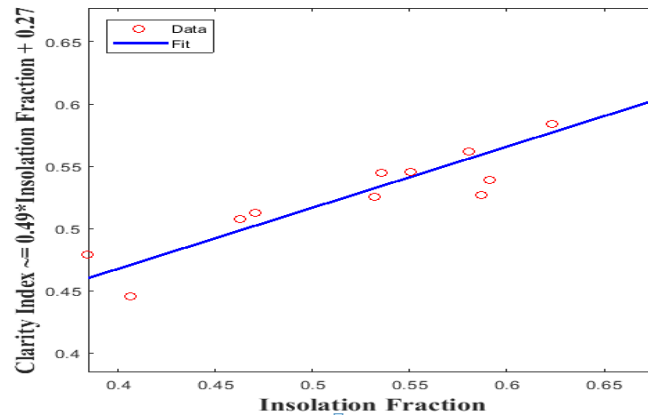


Figure 2:-Regression Curve of Linear Model

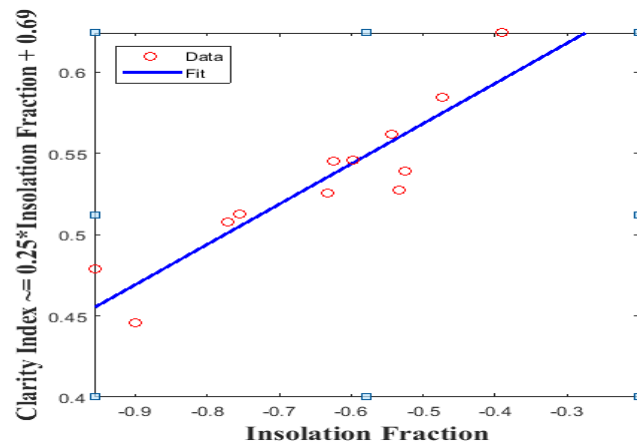


Figure 3:-Regression Curve of The Logarithmic Model

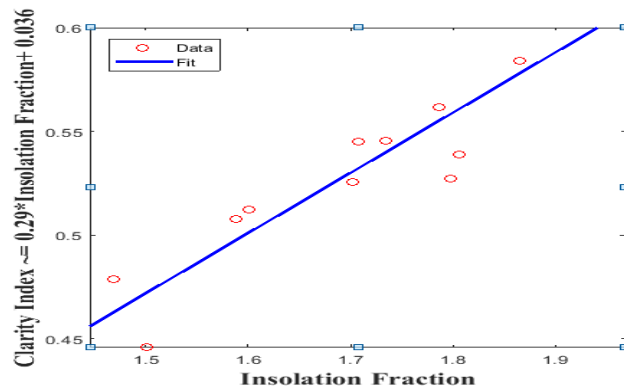


Figure 4:- Regression Curve of the Exponential Model

After analysing Figure 4, 5 and 6, we notice that there is a linear relationship between the solar radiation and the insolation fraction. The coefficients a and b as well as the coefficients R and RMSE are listed in the table (2)

Table 1:-Summary table of statistical indicators according to the model

Model	Equation	correlation coefficient (R)	Root Mean Square Error (RMSE)
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Linear	$\frac{G}{G_0} = 0.27 + 0.49 \frac{S}{S_0}$	0.9255791	0.046
Logarithmic	$\frac{G}{G_0} = 0.69 + 0.25 * \log\left(\frac{S}{S_0}\right)$	0.9144457	0.66
Exponential	$\frac{G}{G_0} = 0.036 + 0.29 * \exp\left(\frac{S}{S_0}\right)$	0.9295757	0.71

To validate the model, we compared the average values of the measured radiation with the estimated values by these models. Figure 7 shows the evolution of monthly average global solar radiation compared to those estimated by the three (03) models.

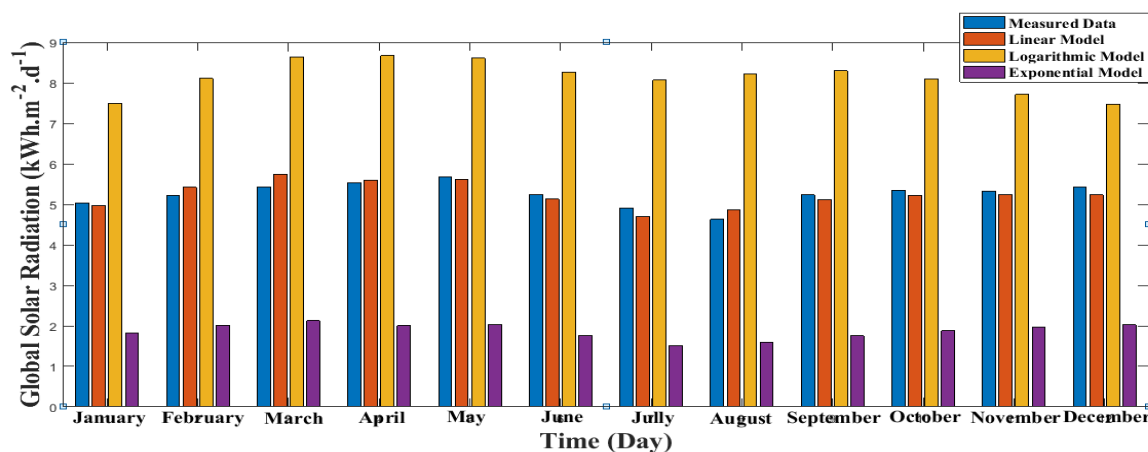


Figure 5:-Histogram Showing Measured and Estimated Radiation in Kara

Discussion:-

Empirical relationships for the estimation of global solar radiation are proposed for the region of Kara, using solar radiation data collected on the MINES ParisTech/Armines (France) website. Statistical indicators R and RMSE of the different models are summarized in table 2.

The analysis of this table allows a better appreciation of linear and exponential models. The exponential model has a larger RMSE. Also Figures 7 reveals that the linear model is suitable for the Kara region. This gives an average daily solar radiation value of G_{mean} (measured) = 4.7366 kWh.m⁻².d⁻¹ by performing a weighted average of the radiation as a function of frequency and G_{mean} (estimated) = 4.7303 kWh.m⁻².d⁻¹ for the Angstrom-Prescott linear model with a relative error of 0.133%. It implies a slight underestimation of 0.0063 kWh.m⁻².d⁻¹.

Conclusion:-

In this work, different models (linear, logarithmic and exponential) are simulated in order to choose the most efficient and this on the basis of performance indicators R and RMSE. The present work allowed us to compare the values measured and those estimated by the three (03) models.

It

follows that the most suitable model for estimating global solar radiation for the region Kara is the Angstrom-Prescott linear model. Indeed, the average global radiation found by applying the latter is 4.7303 kWh.m⁻².d⁻¹ whereas that of the data measured by MINES ParisTech / Armines (France) [12] is 4.7366 kWh.m⁻².d⁻¹.

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