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New model to estimate daily global solar radiation over Nigeria

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ABSTRACT

This study focussed on developing an appropriate model for estimating daily global solar radiation for any location in Nigeria. Data for the study were obtained from the Nigeria Meteorological Agency, covering 12 sites, spread across the six geopolitical zones, for a period between 1987 and 2010. Various statistical methods were employed to determine the performance and accuracy of the model. A multivariate model that expresses global solar irradiance in terms of location latitude, daily relative sunshine, maximum daily temperature, daily average relative humidity, and cosine of day number was developed. The inclusion of the maximum daily temperature and daily mean relative humidity makes the model much more sensitive to climatic and weather changes. Also, the seasonal fluctuations of the humid tropical region are also well captured in the model. The analysis showed a good agreement between the measured data and computed results. Thus the model can be used to predict the global solar irradiance over Nigeria with minimum error. Further to this, the global solar radiation intensity values produced by this approach can be used in the design and estimation of the performance of solar applications.

Introduction

Over the years energy availability has proved to be a pivotal element to the development of any nation. The challenge of improving existing energy generation modules and also developing new ones has always been a major phenomenon across the globe. The issues of sustainable development as it concerns energy generation and distribution is also a subject of intense debate [1]. This is because the widely used energy generation modules across several countries are those of fossil fuel and nuclear power origin. These sources have been proven to be harmful to both the environment and humans. The present energy shift is basically towards encouraging utilization of renewable energy (RE) resources for power generation. This is due to the fact that they are environmentally friendly, widely available, easily applicable and non toxic [2,3]. One of the major sources of RE is the Solar energy.

Solar energy occupies one of the most significant positions among the various potential alternative energy sources [4]. A precise knowledge of the solar radiation profile at a particular geographical location is of vital importance for the development and performance estimation of most solar energy devices [4]. However, for many developing countries solar radiation measurements are not easily obtainable due to inability to afford the required measuring equipment and poor operating techniques used on the available ones. In Nigeria, barely few stations collect solar radiation data on a regular basis [5].

Moreover, the utilization of solar energy resources for power generation in a given location requires the first step of resource assessment. This is necessary in order to have adequate information on the solar radiation intensity at such location [6,7]. Thus the information on the global solar radiation of different local sites is usually globally required [8–12]. Such knowledge will aid solar energy product marketing and also enhance the development of solar applications [12,13]. It is also required for the determination of the global distribution of thermal load on buildings and to carryout analysis and design of solar-energy collecting systems [10]. Other important areas of application include its use in the development of crop growth models and also to carryout designs of irrigation systems [10].

Therefore since the shift in energy utilization for sustainable growth and development is towards renewable energy such as solar electricity. It is therefore imperative that accurate and precise data is used in the design of various solar power systems. However, solar radiation data obtained through direct measurements are not always readily available for different places across the world. Therefore, various estimation procedures have been developed to evaluate global solar radiation which is the integral of solar irradiance over a time period. This is by way of modelling.

Modelling global solar radiation: previous studies and the case for present work

There have been numerous researches into the estimation of the global solar radiation incident on a horizontal surface. An initial empirical correlation was proposed by Angstrom [14], which

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correlated global solar radiation with the ratio of sunshine duration. The Angstrom correlation was adjusted by Prescott [15] and Page [16], and their modifications are being used widely to estimate global irradiance [17].

A study of the world profile of solar radiation was carried out by Lof et al. [18] and attempts at finding common models applicable anywhere in the world are still in progress [19]. More so, attempts at developing models in large domains such as Europe [20] and wet tropical countries [21] have been the focus of some investigators. In addition, the accuracy of the Angstrom correlation and its several derivatives for predicting solar radiation over an entire country has been examined in many countries. Such countries include Canada [22,23] and Australia [24]; South Asian countries such as Sri Lanka [25], India [26] and Pakistan [27]; Caribbean countries such as Guatemala [28], the West Indies [29] and Venezuela [30]. Research has also been undertaken in Middle East countries like Kuwait [31], Iraq [32] and Turkey [33,34]. In South East Asia, studies have been done in Hong Kong [35], Macau [36], Thailand [37], Malaysia [38], Singapore [39], Vietnam [40] and China [41]. On the African continent, countries such as Egypt [42,43], Nigeria [44], Sudan [45] and Lesotho [46] have also modified the correlation.

Moreover, different models exist that correlates different meteorological parameters to evaluate the global solar irradiance (H) of a place. Some of these include those that evaluate H from the correlation of parameters such as maximum and minimum temperatures, amount of cloud cover, extraterrestrial radiation, relative humidity, latitude, elevation, soil temperature, precipitation, evaporation and number of rainy days, [8,10–12,47–60], also parameters such as sunshine duration, maximum air temperature, altitude and location of the place in relation to water surfaces, the solar declination angle, mean daily vapor pressure and mean daily sea level pressure, mean cloudiness, mean precipitation and mean evaporation [47–55] have also been used in creating models.

The model that correlates the global solar radiation to the relative sunshine hours commonly called the Angstrom–Prescott model is given by Eq. (1):

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

where K_T = clearness index, H_o = extraterrestrial solar radiation, $\bar{n}$ = the monthly average sunshine hours, N = monthly average sunshine duration or day length, a and b are correlation coefficients (or constants). The ratio $\frac{\bar{n}}{N}$ is called the relative sunshine.

Basically, major argument against Eq. (1) or its modifications has been the fact that it is location dependent [8,9,61]. However, it is reported in Ertekin and Yaldiz [62] and Jin et al. [8] that Eq. (1) type models give better accuracy than others and that it is convenient to apply.

For the case of Nigeria, some literatures exists that reported global solar radiation models of the Angstrom–Prescott and other model types. Some of the Angstrom–Prescott type models include the ones of Fagbenle [63]. He developed quadratic models to estimate global solar radiation for Benin City, Samaru and Ibadan, three locations in Nigeria. Akpabio and Etuk [9] developed a linear Angstrom–Prescott type model for Onne, Nigeria while Udo [61] presented a quadratic model for daily data spread over a two year period for Ilorin, Nigeria. In addition, Akpabio et al. [61] presented a modification to the Angstrom–Prescott model using a quadratic model to estimate for Onne, Nigeria. Augustine et al. [77] also created several regression models for 4 cities in southern Nigeria, using location dependent equations for each of the cities, their predictor variables were clearness index, relative sunshine, maximum temperature, cloudiness index, and relative humidity. Also Olayinka [78] estimated global and diffuse solar radiation for 4 selected cities in Nigeria with the same predictor variables as [77] using regression analysis, but the models were also site dependent. Yohanna et al. [74] also created an Angstrom–Prescott type model for Makurdi, Nigeria, the model is also location dependent.

Worthy of note however is the fact that, apart from Fagbenle [63] that estimated for the nation, other few existing reports estimated for specific local sites. However, it is reported that as at 2001, about 25% of the 774 local government areas of Nigeria were not connected to the national electricity grid and as at 2010, more than 80% of these areas were still not connected [64]. Therefore, since employing solar for power generation will be beneficial to these localities, modelling global solar radiation provides a way out to the unavailability of information regarding measured solar radiation in the country. Thus, a national estimation model developed from data for as many sites as are available is a plus.

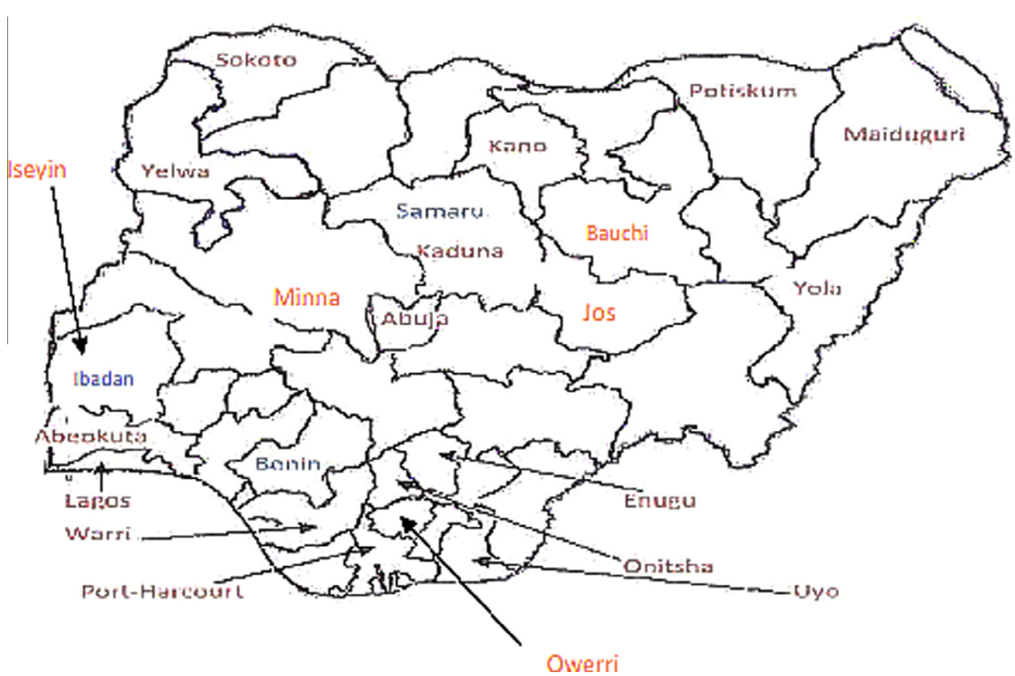

Fig. 1. Map of Nigeria showing the meteorological locations employed in the study. Samaru, Benin and Ibadan are sites employed by Fagbenle [63].