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Research Article

Geospatial Merging of Ground Measurements with Satellite Data to Exploit Solar Energy Potentials in Kano, Nigeria

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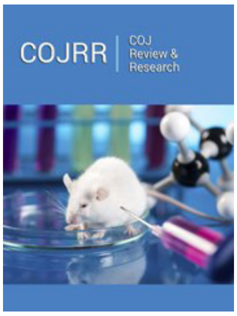

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Abstract

This study applied geospatial techniques to merge ground-measured solar radiation data with satellite-derived solar radiation data to assess solar energy potentials in Kano state of Northwestern Nigeria. Inverse Distance Weighted (IDW) interpolation was used to map the ground-measured and the satellite solar radiation data. The ground measurements of solar radiation were obtained from the Nigerian Meteorological Agency (NIMET) and the satellite solar radiation data were obtained from National Aeronautics and Space Administration Surface Meteorology and Solar Energy (NASA SSE). The solar radiation data is in kilowatt hour per meter square per day (kWh/m^2/day). The ground-measured solar radiation data was merged with the satellite-derived solar radiation data to produce calibrated maps of solar radiation in the area. The calibration method was validated using the Mean Bias Error (MBE), Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE). The validation process of the merging method obtained average MBE values of -0.45%, RMSE of 0.46%, and MAE of 0.57%. These values indicate a good performance of the merging method used in this study.

Keywords: Solar radiation; Solar energy; Satellite data; Ground measurement

Introduction

Solar energy is one of the most sustainable renewable sources of energy on the Earth's surface. It can be generated through a direct method using the Photovoltaic (PV) technology which converts sunlight into electricity; or using indirect method referred to as Concentrating Solar Power (CSP) where the sunlight is used to generate heat which is used to drive a turbine which powers a generator that provides electricity [1].Hermann, Miketa and Fichaux (2014) found that there are abundant different levels of solar energy potentials which can be harnessed in large parts of the African continent using PV or CSP technologies. However, there is general scarcity of information on renewable energies such as solar radiation in Africa [2]. Consequently, the level of solar energy development and utilization as an alternative source of power is very low resulting to millions of Africans lacking access to electricity. Several methods are used to derive solar energy information in a given area or region. Conventionally, solar radiation data is acquired through ground-based measurements in meteorological stations. Lealea and Tchinda et al. [3] estimated diffuse solar radiation in Cameroun using ground measurements. However, very few of such stations are available to provide comprehensive solar radiation data of the desired locations in Northwestern Nigeria.

An alternative method which has been developed to model solar radiation based on available meteorological data has been experimented with by various researchers. For example, Angela, Taddeo and James et al. [4] used Artificial Neural Network to predict global solar radiation in Kampala; Hussein et al. [5] used mathematical model to estimate global solar radiation in Egypt; Ogbaka and Silikwa [6] used various climatic parameters to estimate solar radiation in different parts of Nigeria. Another alternative approach to solar radiation modelling is the application of geospatial techniques to analyze satellite data. The use of satellite data as an alternative method to derive solar energy information was demonstrated by Bois et al. [7], Journée, Müller and Bertrand [8], Basir et al. [9], Janjai [10] and Yushchenko et al. [11]. However, Journee and Bertrand [12] and Basir, Aziz, Ahmad and Wahid [9] established that merging of ground measurements with satellite data has been used by researchers to effectively estimate solar radiation in different parts of the world. The merging methods have been used to provide reliable high-resolution maps of global solar radiation [8] because they compensate for errors inherent to the satellite data with accurate ground measurement [13]. However, the benefit of merging ground-based data with satellite data to derive solar radiation information has not been exploited in Northwestern Nigeria. Therefore, this study applied geospatial techniques to merge ground-measured solar radiation with satellite data to assess solar energy potentials in Northwestern Nigeria.

Materials and Method

Types and sources of data

The study used both ground measurements of solar radiation obtained from the Nigerian Meteorological Agency (NIMET) and satellite solar radiation data obtained from National Aeronautics and Space Administration Surface Meteorology and Solar Energy (NASA SSE). The solar radiation data is in kilowatt hour per meter square per day (kWh/m^2/day).

Merging of satellite with ground-measured solar radiation data

Merging of satellite data with ground measurements requires two different sets of stations referred to as the calibration and the validation stations as demonstrated by Flores and Baldasano [14], Vazquez et al. [15] and Pettazzi and Salsón [16]. This study used both ground measurements of mean daily solar radiation obtained from the Nigerian Meteorological Agency (NIMET) and satellite solar radiation data obtained from NASA SSE. To merge the ground-measured solar radiation data with the corresponding satellite data, the following steps were adopted:

i. Firstly, the satellite insolation (S) at every station was divided by the corresponding ground insolation (G) at that station to obtain a factor (X)

ii. then, the factor was multiplied by the satellite solar radiation values to obtain the calibrated solar radiation values (S*X),

iii. The calibrated solar radiation values were then used to produce the map.

The Inverse Distance Weighted (IDW) interpolation was used to generate the solar radiation map of solar energy potentials in Kano (Figure 1). This was achieved using the Spatial Analyst tool in ArcGIS environment.

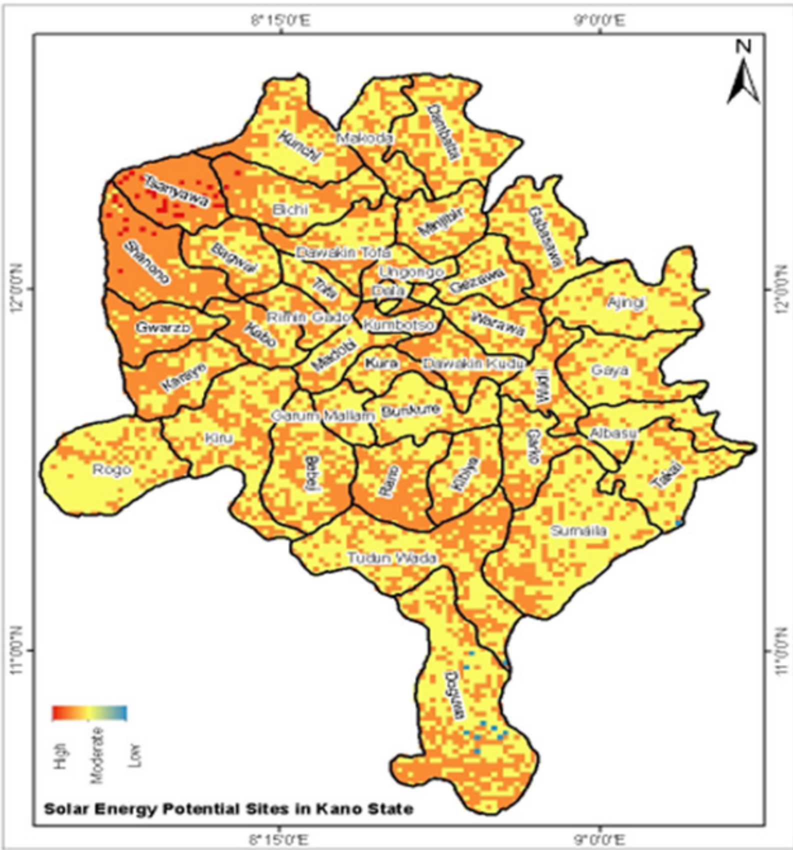

Figure 1: Solar energy potential sites in kano state.

Validation of satellite solar radiation with ground-based measurements

Several statistical tests are used to validate satellite-derived solar radiation with ground-based measurements. This study used Mean Bias Error (MBE), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE) because they are the most commonly used statistical measures to investigate the accuracy of the estimation of global solar radiation as shown in studies by Journée and Bertrand [12], Journée et al. [8], Okundamiya and Nzeako [17], Antonanzas-Torres et al. [18], Pettazzi and Salsón [16], Chai and Draxler [19].

Result and Discussion

Analysis of solar radiation in kano state based on multiple sources of data

Table 1 presents solar radiation data obtained from three sources which are ground measurement (Measured), satellite data (NASA SSE) and merging of ground with satellite data (Calibrated). Observation of the Table shows some level of similarity between the three sources of solar radiation data in the area. It can be observed from the Table that the maximum solar radiation values were recorded in the months of March, April and May by all the three sources; while minimum solar radiation values were recorded in the months of December, January and August based on the three sources of solar radiation data. Based on the measured, satellite and calibrated insolation data as shown in Table 1, the maximum insolation values (ranging from 6.60- 7.11kW/m^2/day) in Kano were observed between the months of March and May. On the other hand, the minimum solar radiation values (ranging from 4.93-5.63kW/m^2/day) were observed in the months of August, December and January as shown in Table 1. The minimum radiation values observed in Kano during the months of August correspond to the rainy season when radiation level is generally lower than for the dry season [20]. The minimum radiation values can also be attributed to the maximum albedo experienced in Kano during this period. This is because the period of maximum albedo, which is characterized by the peak of cloud activity in Kano is found in the month of August [21]. Also, a similar trend of minimum solar radiation in Kano as observed by this study was confirmed by the findings of Ezenekwe, Ezemonye and Emeribe [22], which revealed that radiation values in Kano start with lowest values in January and gradually increase to highest peak in April. Also, the findings of this study are supported by the results of Isikwue et al. [21] which showed that in Kano, high solar radiation values were obtained between February and June with the maximum attained in March and minimum attained in August.

Table 1: Monthly mean daily values of global solar radiation in kano (kWh/m^2/day).

Month	Measured	NASA SSE	Calibrated
Jan	5.63	5.49	5.35
Feb	6.7	6.33	5.98
Mar	6.99	6.79	6.6
Apr	6.81	6.96	7.11
May	6.68	6.76	6.84
Jun	6.48	6.42	6.36
Jul	5.65	5.81	5.97
Aug	5.48	5.41	5.34
Sep	5.78	5.67	5.56
Oct	6.27	5.9	5.56
Nov	6.06	5.72	5.4
Dec	5.64	5.27	4.93

Validation of satellite-derived solar radiation with ground-based measurements

Ground-measured and satellite-derived solar radiation data have some differences resulting from their different sources of acquisition. Ground stations record solar radiation at point locations while satellites record solar radiation over an area or theme. This study used statistics (Table 2) to measure the level of differences between the satellite and the ground data. The results were compared with those of previous studies found in the literature. It can also be observed from Table 2 that the annual average MBE value of -0.45% obtained in the validation process is lower than the average MBE value of -0.78% obtained by Osinowo et al. [23] for Sudan savannah. This suggests that the result of the validation process used in this study is better. Likewise, the results of the validation process confirm the findings of Journée et al. [8] which observed that merging both ground and satellite solar radiation data into a single estimate further improves the results by reducing the MBE value very close to zero. In addition, it can be seen from Table 2 that a low annual average MAE value of 0.57% was obtained, which is another indication of good agreement between the measured and calibrated solar radiation data. Also, the low annual average RMSE value of 0.46% obtained in this study is desirable as recommended by Iqbal [24]. The RMSE value of 0.46% is another confirmation of the reliability of the calibration method used in this study, in view of the fact that it is greatly lower than the average RMSE value of 1.28% obtained by Osinowo et al. [25] for selected locations (Kano, Sokoto, Bauchi and Yola) in Sudan savannah.

Table 2: Temporal validation of the calibrated solar radiation data.

Month	MBE (%)	MAE (%)	RMSE (%)
Jan	0.28	0.28	0.26
Feb	-0.08	0.22	0.23
March	-0.47	0.47	0.45
Apr	-0.71	0.71	0.67
May	-0.65	0.65	0.48
Jun	0.059	0.22	0.19
Jul	-0.71	0.71	0.58
Aug	-0.66	0.67	0.44
Sep	-1.15	1.15	0.88
Oct	-1.08	1.08	0.83
Nov	-0.23	0.42	0.41
Dec	0.07	0.2	0.1
Annual Average	-0.45	0.57	0.45

Conclusion

This study merged satellite-derived solar radiation data with ground-measured solar radiation data for the analysis of solar energy potentials in the study area. The calibration method was validated using statistics. An average MBE value of -0.45%, RMSE of 0.46%, and MAE of 0.57% were obtained. These values indicate a good performance of the merging method used in this study.

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