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# Development of a model for ground measured and satellite-derived GSR data

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## Abstract

*The precise knowledge about the solar radiation falling on a surface per unit time is prerequisite for effective design and application of solar technology. Acquiring Global Solar Radiation (GSR) data is not always easy owing to many militating factors such as insufficient funding, lack of skilled personnel and poor maintenance culture. Ground-measured GSR is one of the possible ways of obtaining GSR data, but satellite-measured GSR data is the most available source for any location of interest. The research therefore is aimed at establishing a mathematical model that will predict the ground measured GSR from the available satellite measured GSR using regression analysis. From results, the two data sources showed good agreement with a regression plot of 80%. The performance of the model was tested using statistical metrics. MAE of 0.4004, MBE of 0.0217 and a MSE of 0.2522 were recorded. Hence, the developed model can be adopted for regions that have similar climatic condition as the study area to predict the desired solar insolation from the available solar insolation.*

**Keywords:** Renewable-Solar Energy, Global Solar Radiation (GSR), Ground measured GSR, Satellite measured GSR and Pyranometer.

## Introduction

Economic development is largely connected to energy development[1,2]. In this 21st century, adequate generation and supply of electricity is required for human growth and development in virtually all spheres of life. It was reported that over 2 billion people who constitute about 16% of the world's population are living without electricity[3-5], out of which about 70% domiciled in Africa[6]. As the world's population increases, so also does the demand for energy. The quest to supplying adequate energy to the populace is therefore a global issue with emphasis on the developing parts of the world[7].

For developing countries to meet up with their electricity demand, it is estimated that about 1000 MW is required per million people. For instance, it is estimated that Nigeria as a developing country would require about 195,000 MW generation of electricity to meet up with her current electricity demands for about 195 million people[8]. Currently, about 87.5% of the total power generation in the country is from gas-thermal power source, while the remaining 12.5% is generated from hydropower source[9]. The total installed capacity of all the power stations including the Independent Power Projects (IPP) and the National Integrated Power Projects (NIPP) is about 12,522 MW[5,10]. However, only about 4,000 MW is transmitted owing to several militating factors[9,10]. It is therefore imperative to note that the country experiences a severe loss when comparing the total installed capacity to the generated and transmitted capacity through the national grid[4]. Hence, extending the grid to accommodate every citizen is financially and structurally not credible as this might lead to more loss of the transmitted power. This inadequacy of power supply has therefore caused a drag-back on her productivity, socio-economic growth and development as major commercial operators and companies are folding up or relocating to neighboring countries where their electricity demand can be met[11,12]. Thus, the provision of clean, cheap, sustainable and sufficient electricity is therefore a serious global concern[13].

Solar energy is fundamental to the realisation of other forms of energy. Every form of life on Earth has a tie with solar energy[14]. The energy reaches the Earth through radiation, which is the largest known source of energy that flows into the global ecosystem[15]. Without reference to the reflected and the absorbed portion of the energy in the atmosphere, about 100,000 TW of the energy is received on the Earth's surface[16], which is about 6,000-fold the contemporary global energy consumption that is estimated to be 13.7 TW[17].

Solar energy is clean, abundant, easily accessed, sustainable and inexhaustible. The substitution of solar energy applications for other forms of unclean energy sources has huge potentials to mitigate global warming and purify the atmosphere from green-house gases. But the availability of solar energy resources is unpredictable and varies with time and locations. More so, the development of an effective solar technology relies on the precision of the measured GSR which is location dependent. Therefore, there is need for researchers to provide possible means of obtaining GSR data in order to develop solar energy resources for energy sustainability[13].

**Review of related work:** Energy poverty is a major barrier to modern economy. Presently, a good percentage of the world's energy supplies are generated from fossil fuels, which are non-renewable resources[18]. Fossil fuels exist as solid, liquid and gas which include coal, crude oil and natural gas respectively. Mining, drilling, refining and usage of fossils have many devastating consequences like, land degradation, ocean acidification, atmospheric pollution, global warming, deforestation, depletion of the ozone layer, erosion and flood among others[19]. Solar, wind, tidal, hydro, biomass and geothermal are examples of renewable energy sources.

Renewable energy sources, unlike the non-renewable energy sources, are free and inexhaustible; they require no fuel and greenhouse gases are not emitted at any time in use. Hydropower is one of the oldest means of generating electricity and involves the use of dam. Nevertheless, construction and maintenance of dams require much time; it involves huge capital investment; the expanse of land used may not serve other important purpose; the temperature of damned water may also alter weather activities; aquatic weeds often develop in dams and over flown dams often lead to annual flooding which claim lives and properties.

Solar energy is the largest and the primary source of energy in the global ecosystem. Almost all forms of energy take its source from the sun[20]. Energy of the sun is spread out basically in form of heat and light. Knowing the actual amount of this energy present at the point of application is a requirement[21]. The amount of the energy reaching the surface of the Earth per second is so enormous that converting a little fragment of it into useful work will make up for the world's total annual energy need[16,17,22-24]. Solar radiation varies from one geographical location to another. It is reliant on meteorological parameters such as cloud, evaporation rate, relative humidity, precipitation, air temperature, sunshine duration, extra-terrestrial solar radiation, and albedo of the area under examination among others. The recommended solar constant by the World Meteorological Organisation is $1367 Wm^{-2}$ [25], while the American Society for Testing and Materials gives a more recent solar constant value to be $1366\ Wm^{-2}$ [26-29].

**Review of GSR Identification Techniques:** Three main methods are identified globally for the observation of GSR. These include ground measurement, empirical (mathematical) modelling and satellite remote sensing[30]. Ground measurement of GSR is achieved using a Pyranometer which involves copious capital and expertise[31,32]. According to literature, the most reliable method for obtaining GSR data is by ground measurement[21,33-36]. In order to establish a creditable solar system design, adequate data must be obtained from a multiple of well-structured network of solar radiation monitoring stations.

According to researchers, satellite-derived data is the most abundant data source of GSR. But when used, the data often lead to overestimation of solar resources[37-39]. Different empirical models for estimating GSR from available meteorological data have been developed, but most of these models have failed to provide accurate estimation and they are location dependent[40,41]. In a bid to mitigate the different intolerable errors, the combination of different methods is therefore employed often to validate one another[41-44]. Generalization and validation of ground measured solar irradiance with other sources is only valid for a distance of about 50km away from the observation point[45-49].

Cano *et al*. have established the fact that satellite-derived data is the main source of GSR data for developing regions and for locations where solar sensors cannot easily be installed (such as sea, ocean, and etcetera). The researchers therefore concluded that satellite-derived GSR data can be used to design solar applications because of its ability to provide a comprehensive report of the meso-climatic variations of the GSR over the land[50]. Lysko compared estimated and ground measured solar radiation data in his study[29]. The author attributed errors recorded from ground measured data to uncertainties in shading of the measuring instruments, while the errors recorded from empirical model were attributed to the complex nature of the climate, temporal and spatial variations. The researcher noted the fact that there is poor correlation between estimated and ground based GSR data, which could be corrected by considering a large set of reference sites. In the same vein, Olomiyesan and Oyedum conducted a study which compares ground-measured, satellite-derived and estimated GSR data in Nigeria using twenty years corresponding data[51]. The study revealed a notable disparity between ground-measured and satellite-derived data. It was therefore concluded that there was a poor correlation between satellites derived GSR and ground measured GSR while a good correlation exists between the ground-measured and the estimated GSR data for the different locations considered.

Aderinto observed the disparities between the weather parameters collected from automatic weather observing stations and those collected from manual observing stations[52]. This has been blamed on lack of skilled staff and poor motivation for staff. Apart from the financial implication of the installation and maintenance of solar sensors, issues of shading and missing data were also attributable to ground-measured data. Vernay *et al*. revealed that the problems of variability encountered with solar irradiation data is as a result of different temporal coverage and spatial resolution[53]. Therefore, the uses of database whose features are well known and calibrated with the local measurements are recommended[54]. Ernst *et al*. examined the impact of two solar irradiance data sources on the calculation of the yearly yield and performance ratio of photovoltaic modules for five locations in different climatic regions of Australia. Overestimation was recorded for satellite-based data compared to the ground-based data which is attributed to the average number of cloudy days. In a bid to make up for the overestimation, a correction linear model was developed for better precision[55]. In view of this assertion, there is more need to validate the more available and free satellite-derived GSR data for present and future use[41]. Hence, this study is aimed at establishing the correlation between ground-measured solar radiation data with the satellite-derived solar radiation data in order to establish a regression relationship that will help to validate the two data sources.

## Methodology

Figure-1 describes the series of scientific procedures taken from the beginning of the study to the end, which include data acquisition stage, data filtering stage, data pre-processing stage and data processing stage that gave rise to the result.

**Data Acquisition and Description:** In this paper, two datasets have been used for the development of the model. Li-200SA Pyranometer was used to measure GSR at five-minute integration time for a period of three years (December 2015 to November 2018) at the Photovoltaic research station located in the Federal University of Technology, Minna (Latitude $9.66^0$ N and Longitude $6.53^0$E). A corresponding three-year satellite-measured data were downloaded from the National Aeronautics and Space Agency (NASA) base station and the distribution of the two data sets is presented in Figure-3.

**Data Acquisition Device:** Li-200SA Pyranometer is designed to measure GSR on the field under a clear and open daylight conditions as shown in Figure-2 [56]. It uses a silicon photovoltaic sensor with a maximum error of about ±5% under a natural daylight condition. The sensitivity of LI-200SA is basically 90μA per $1000Wm^{-2}$, its response time is 10μs, while its temperature tolerance ranges between -40 to 65°C, which is comparable to the world class known thermopile-type Pyranometer[49].

As shown in Figure-2, the landscape of the measurement site is considerably flat and unpaved. It is free from shading by any natural or artificial structure. The measurement was carried out in the day time. The Pyranometer senses the intensity of the solar radiation which is recorded by a data logger. The recorded data is later downloaded from the data logger into a laptop computer.

**Data Filtering / Data Pre-Processing:** Filtering of the datasets were done so as to eliminate the hours of no sunshine records. The two datasets are on daily average in $kW\text{-}hr/m^2/day$ and were processed. As part of the pre-processing exercise, it was ensured that the two datasets have equal length of sunshine days and sunshine hours for the three years that was considered.

**Data Processing method:** Regression analysis is used as the method for data processing. Regression analysis is a statistical tool which describes the study of connection between dependent and independent variables[57]. The tool thus helps researchers to establish the underlying relationship between variables and to validate if the independent variables are good enough to predict/ forecast the dependent variables. The dependent variable in this research is the ground-measured GSR, while the independent variable is the satellite-derived GSR.

## Results and discussion

Solar energy is sufficient to provide the Earth with all the required energy if properly harnessed. In order to achieve this goal, there is increasing need to research and explore solar energy technologies[13]. In this work, ground-measured GSR data was correlated with satellite-measured GSR data by considering 10 hours of sunshine duration. Three-year corresponding GSR data was used, out of which about 70% of the data was used for developing a linear model and about 30% was used to test the performance of the model. Figure-4 shows the relationship between the ground and corresponding satellite-measured data sets during the period.

It could be observed that the two graphs depict similar trends despite the differences in their numerical magnitudes and associated militating factors. Accordingly, a credible fit was established between the data sets, given a regression plot of approximately 80% accuracy. The derived equation is of the form;

$$G_{Ir} = \alpha \times S_{Ir} + \beta \qquad (1)$$

Where: $G_{Ir}$ is the ground-measured GSR, $S_{Ir}$ is the satellite-measured GSR data, α and β are regression coefficients with values of 0.8797 and 0.3595 respectively. The developed model was used to predict ground-measured GSR from corresponding satellite-measured GSR using a new set of data which accounted for about 30% of the original data set. A Mean Absolute Error (MAE) of 0.4004 with a Mean Bias Error (MBE) of 0.0217 and a Mean Squared Error (MSE) of 0.2522 were recorded. Form the various statistical analysis, it is therefore acknowledged that the model is valid. Figure-5 explains the relationship between the ground-measured, satellite-measured and the predicted insolation over some selected months.

From the graphical presentation in Figure-4, it could be deduced that the predicted values of the solar insolation are closer to the ground-measured solar insolation values compared to the satellite-measured solar insolation.

## Conclusion

It is evident that there is a difference between the values of a ground-measured and a satellite-measured GSR. Ground-measured GSR data are adjudged the best sources of GSR data. But ground-measured GSR data are often characterized by shading, missing data, invalid data and are scarce. While the satellite-measured GSR are always available for different locations, but are often faced with spatial distance between the sensor and the surface, and sparse cases of invalid data.

However, the study affirms that there is a good relationship between the two sets of measured data and the two data sets can be used to complement each other. Hence, the established model can be adopted in regions that have similar weather conditions as the study area to predict the desired solar insolation from the available solar insolation.

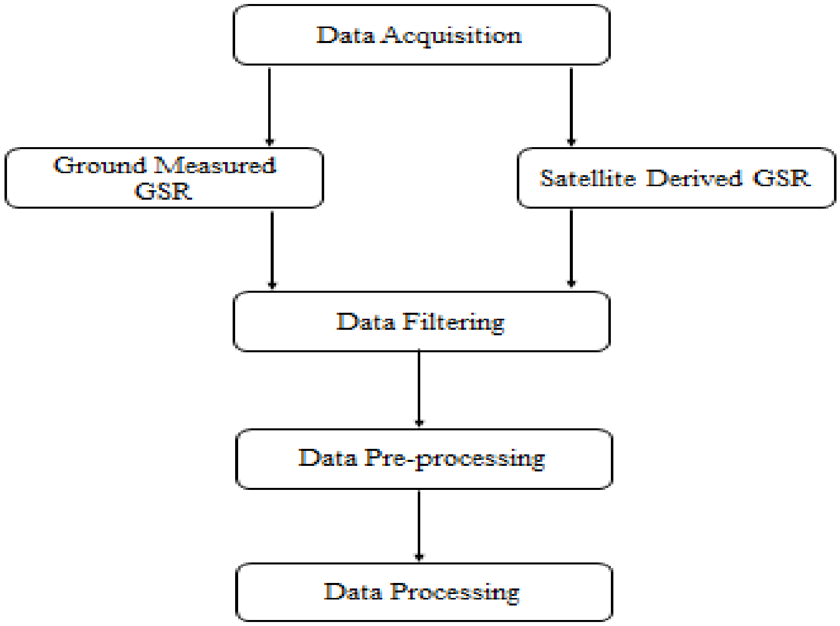


**Figure-1:** Block Diagram of the Research Process.

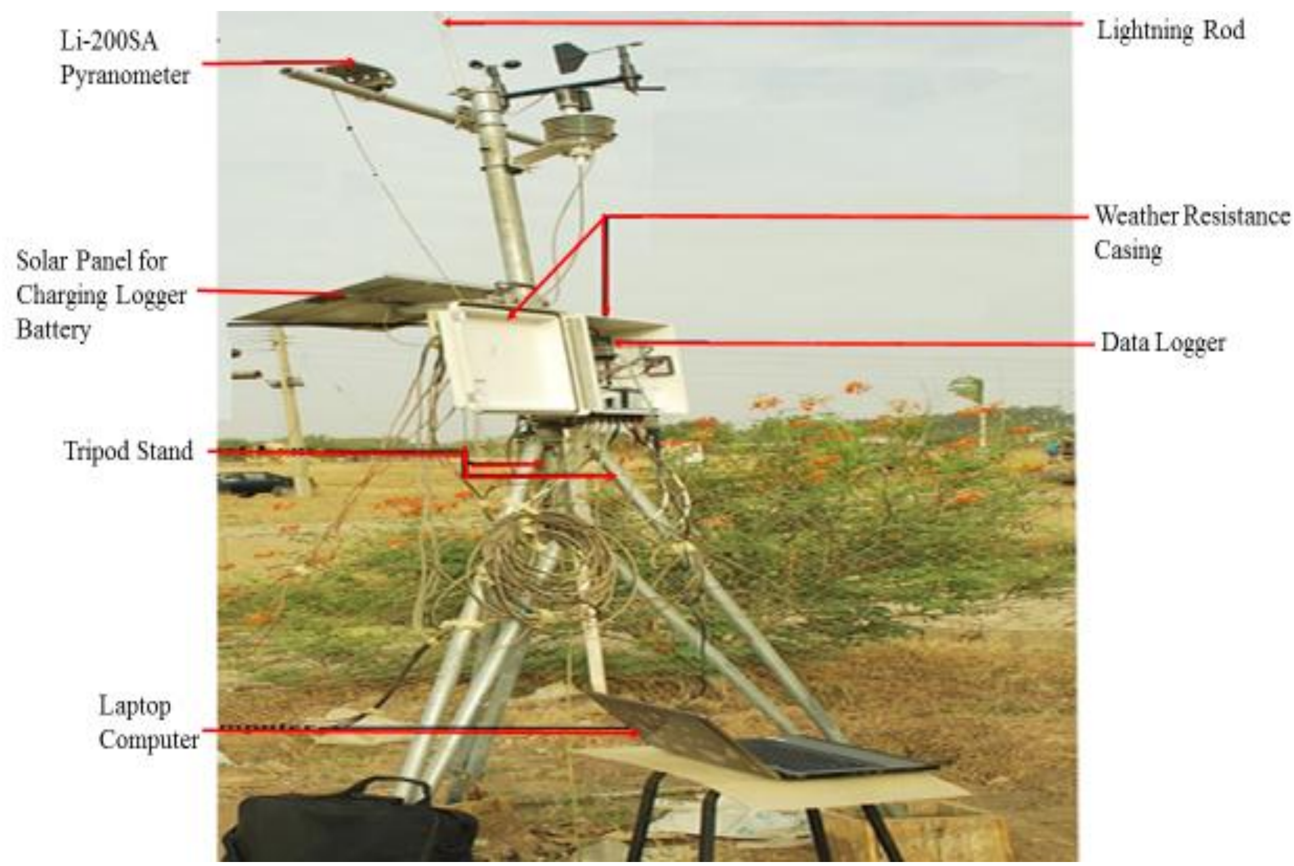


**Figure-2:** Photovoltaic Research Station, Federal University of Technology, Minna.

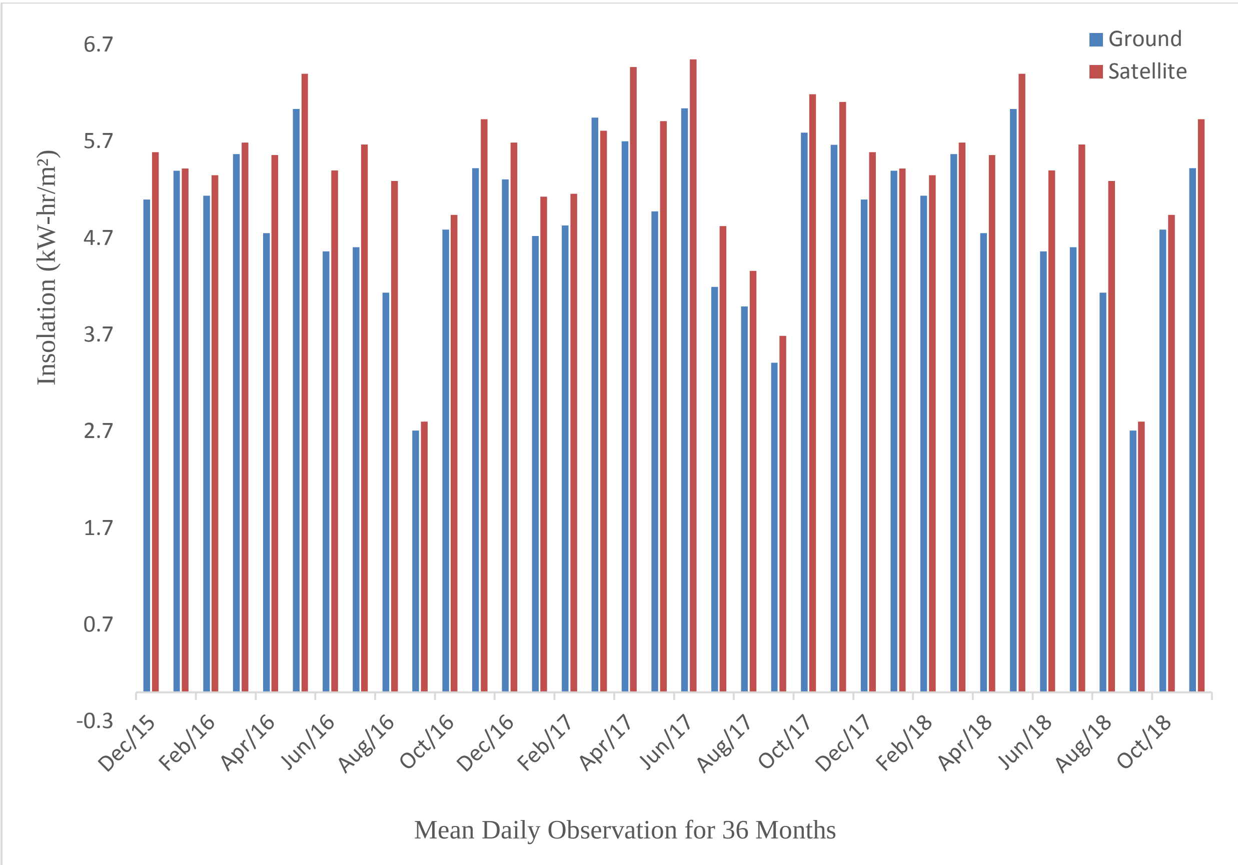


**Figure-3:** Monthly Observation of GSR from December 2015 to November 2018.

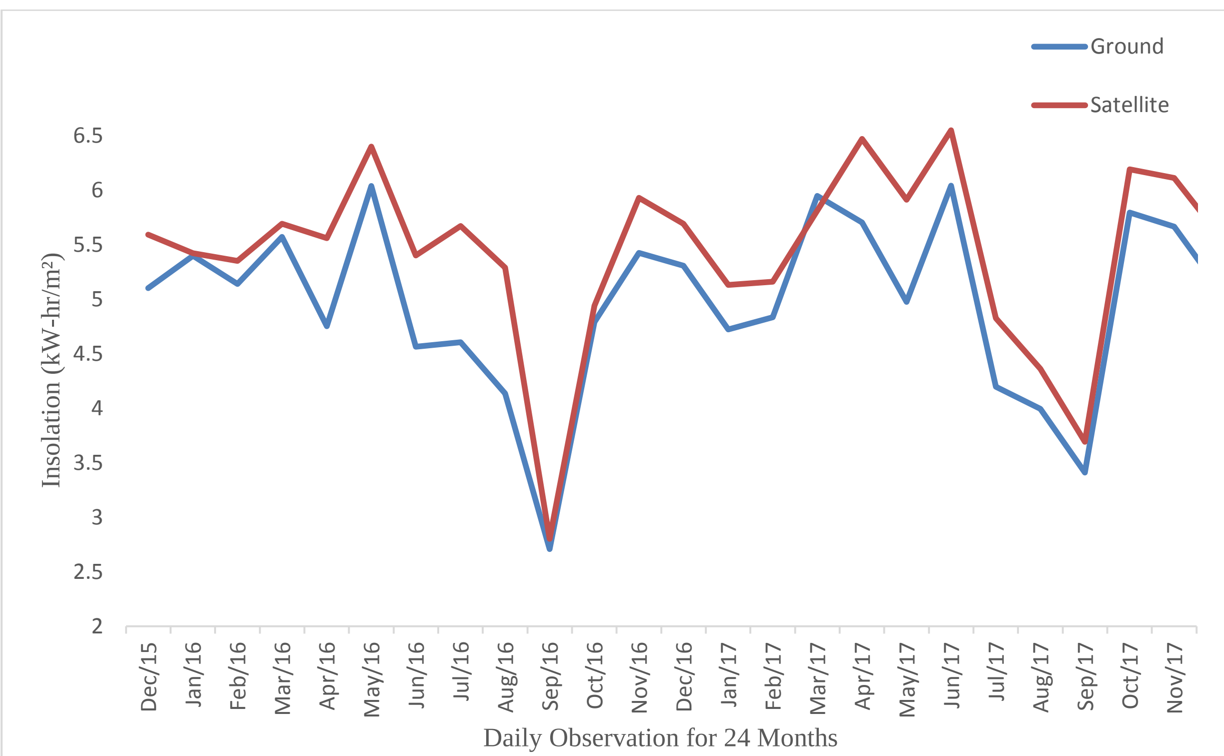


**Figure-4:** Variation of Ground-Measured and Satellite-Measured GSR over Months.

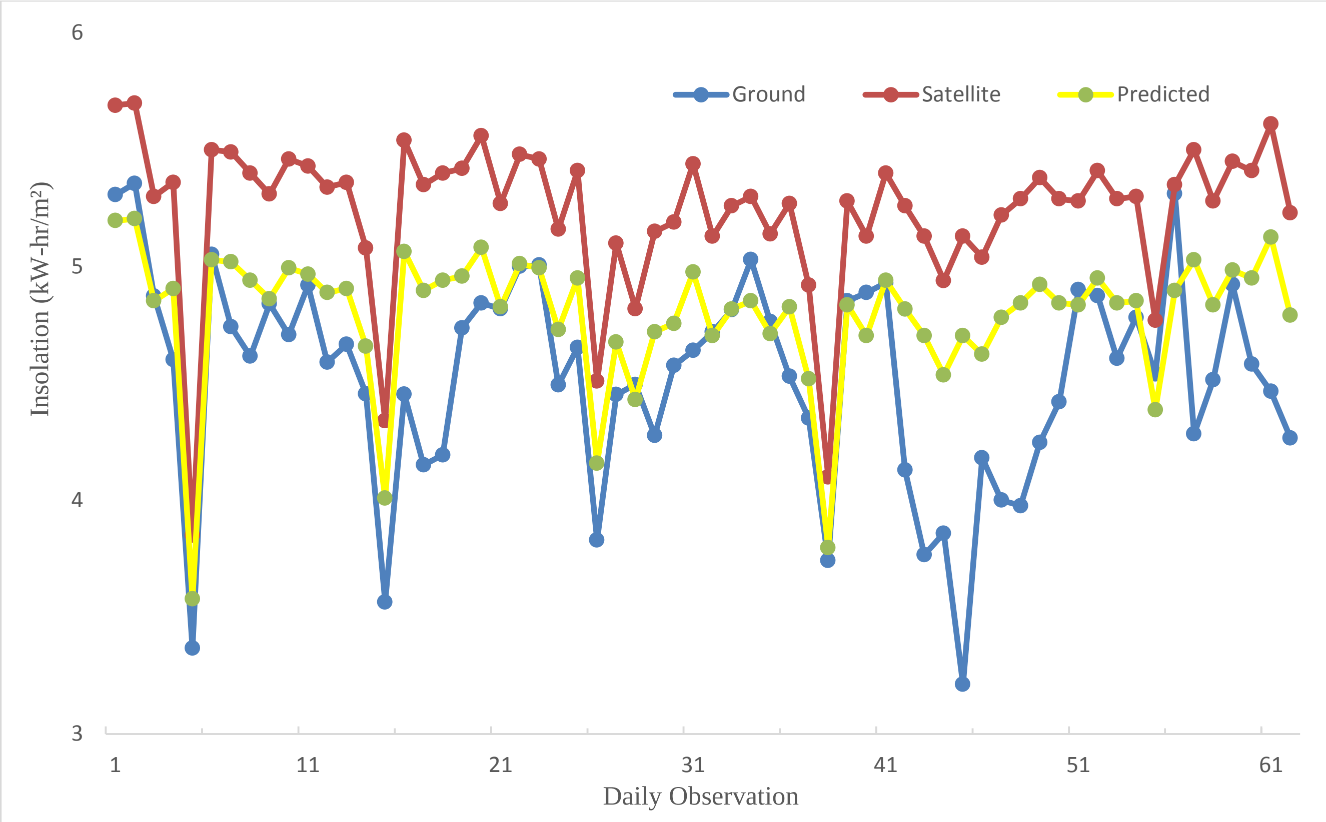


**Figure-5:** Relationship between Measured and Predicted Solar insolution.

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