Comparison of Ground-Based Global Horizontal Irradiance and Direct Normal Irradiance with Satellite-Based SUNY Model

Adnan Ayaz [1], Faraz Ahmad [2,*] ID, Mohammad Abdul Aziz Irfan [1] ID, Zabdur Rehman [2,*], Krzysztof Rajski [3] ID and Jan Danielewicz [3,*]

[1] Mechanical Engineering Department, University of Engineering and Technology Peshawar, Peshawar 25120, Pakistan; adnanayaz@uetpeshawar.edu.pk (A.A.); mairfan@uetpeshawar.edu.pk (M.A.A.I.)

[2] Department of Mechanical Engineering, Aerospace and Aviation Campus Kamra, Air University Islamabad, Kamra 43570, Pakistan

[3] Faculty of Environmental Engineering, Wrocław University of Science and Technology, PL50377 Wrocław, Poland; krzysztof.rajski@pwr.edu.pl

[*] Correspondence: faraz.ahmad0460@gmail.com (F.A.); zabd@aack.au.edu.pk (Z.R.); jan.danielewicz@pwr.edu.pl (J.D.)

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Abstract: Since the fossil reserves are depleting day by day, the trend of modern energy sector is going towards renewable energy. The demand of solar power plants is therefore at the peak nowadays across the globe. However, the construction of these plants is extremely dependent on feasibility study to estimate the real solar potential before installing it in any region. To evaluate the solar energy potential of Peshawar region in Pakistan, Ground-based global horizontal irradiance (GHI) and direct normal irradiance (DNI) were compared with satellite-based model SUNY. Ground measurements were done at the University of Engineering and Technology Peshawar (UET Peshawar) with the help of pyranometer and shadowband irradiometer. Comparison of the data showed that there was a maximum difference of 42.90% in ground and satellite-based GHI in the month of December. Minimum difference in GHI was found for the month of March that was −3.83%. Moreover, ground-based GHI was overestimated in the month of February, March, and April, while in rest of the months, satellite values of GHI exceeded the ground measurements. Similarly, maximum difference of 55.86% was found in the month of November between ground and satellite-based DNI while minimum difference of −3.34% was seen in DNI in the month of March between the two data. Furthermore, satellite-based DNI was underestimated in the months of February, March, and April while in rest of the months it was overestimated compared to ground measurements. In addition to this, correlation of ground and satellite-based GHI and DNI showed R^2 value of 0.8852 and 0.4139, respectively. The results of this study revealed that the difference between ground measurements and satellite values was considerable and hence real time measurements are necessary to properly estimate solar energy resource in the country.

Keywords: global horizontal irradiance; direct normal irradiance; satellite based SUNY model; combined uncertainty

1. Introduction

Utilization of energy has become a vital part of our life and its demand is increasing day by day [1]. Like most of the countries across the globe, Pakistan is also facing a serious issue of energy crisis for past few decades and the problem is getting severe with the passage of time [2]. At the moment, most of the energy demands are met by utilizing fossil fuels like coal, oil, and gas. However, these fossil fuels are rapidly depleting and they will disappear completely in the coming years. Moreover, consumption of fossil fuels strongly affects natural environment by releasing greenhouse gases into the atmosphere. There is a dire need to shift from conventional energy resources to renewable resources of energy. Solar energy is considered to be one of the vital resources of renewable energy [3].

In the past few decades, numerous studies have been conducted to assess the solar energy resource potential and increasing its efficiency using different techniques [4]. For example, Gueymard et al. [5] conducted a study to assess solar energy resource in United States of America with respect to spatial and temporal variation. Data were taken mostly from SUNY model of National Solar Radiation Database (NSRDB) for a time span between 1998 and 2005. A similar kind of research was conducted by Zell et al. [6] in Saudi Arabia in which a solar energy monitoring program was devised by King Abdullah City for Atomic and Renewable Energy (KACARE). The annual average GHI variated from 5700 Wh/m^2 to 6700 Wh/m^2. Same study mentioned that performance of PV might be degraded because of higher temperature which is almost 30 °C on average at various locations of Saudi Arabia. Similarly, a study was carried out by Al Yahya and Irfan [7] which presented discussion on the new solar atlas of Saudi Arabia. This solar atlas consisted of 41 stations which were capable of delivering solar data across the various regions of the country. This study was part of the Renewable Resource Monitoring and Mapping (RRMM) program. Through RRMM, they found that direct normal irradiance (DNI) of the country ranged from 5000 Wh/m^2/day which was recorded in winter to 9000 Wh/m^2/day in summer.

Moreover, Alnaser et al. [8] presented a study in which they presented the data of Solar Radiation Atlas for the Arab World. For a period of 10 years in Arab world, the highest annual mean global solar irradiance was calculated to be 6.7 kWh/m^2/day Nouakchott, Mauritania and 6.6 kWh/m^2/day in Tamenraset, Algeria. However, the minimum mean global irradiance was calculated in Mosul, Iraq which was 4.1 kWh/m^2/day. Similarly, Bachour and Perez [9] analyzed ground-based GHI at Doha International Airport in the time span between 2008 and 2012 which revealed that average daily GHI was 5.61 kWh/m^2/day which in other words becomes 2048 kWh/m^2/year. In addition to this, a maximum monthly average was calculated to be 6.97 kWh/m^2/day for the month of June.

Satellite-based DNI is affected by several parameters out of which the most critical and important factor is aerosol optical depth (AOD) [10]. Aerosols are very crucial for calculation of solar energy resource and play a critical role to estimate surface irradiance from the available satellite-based solar irradiance. A study in Thailand revealed that in majority of the cases, 10 to 15% of total depletion of solar energy by all atmospheric particles occurred due to aerosols [10]. Moreover, it has been found that 5% of the total depletion of solar energy from aerosols occurs due to scattering of solar energy from continental aerosols. Similarly, a research in India was done to incorporate aerosols dataset to get an accurate satellite model for computing DNI [11]. It was noted that the fine aerosol particles could be removed from atmosphere in monsoon season. It was also noticed that due to wind, aerosols also moved from one location to another, hence creating uncertainty in the estimation of DNI. In addition to this, a study compared eight clear sky broadband models [12]. This study concluded that turbidity plays a very important and crucial role to estimate the irradiance received. This study also stated that the important factors that are considered for clearest atmospheric conditions are aerosol loads, water vapor component, and least turbidity. To account for such issues in analyzing the solar irradiance, Mueller et al. [13] devised a satellite-based model called The SOLIS clear-sky module. While making this model, ozone, water vapors, and aerosols were taken into the account. Results obtained from this model were compared with ground-based measurements.

Satellite-based data are acquired on the basis of forecasting techniques. Some satellite-based forecasting techniques use position of clouds to estimate solar energy over a particular location. A study showed that motion vectors were used to predict the upcoming position of the clouds over particular location of the ground and it was noted that they provided fine forecasting accuracy of almost 6 h. Predictions from cloud pose several problems to properly forecast solar irradiance [14]. Therefore, comparison of satellite-based solar data and ground-based measured solar data has been of much importance to many researchers across the globe. Vignola et al. [15] conducted a study at Kimberly, Idaho in which satellite-based solar data and ground-based solar data were analyzed to validate the satellite-based solar model. It was found that mean bias error for satellite-based global irradiance was 5%

and it was 2% for beam irradiance. Similarly, Blanksby et al. [16] conducted a research in Australia to check the accuracy of satellite-based solar model. It was noted that for lesser values of GHI, satellite-based data were overestimated compared to the ground-based data. However, for greater values of GHI, satellite-based data were either overestimated or underestimated compared to the ground-based data.

A study in Brazil compared satellite-based solar irradiance with ground-based measurements [17]. Irradiance was analyzed on the basis of monthly average daily mean values. Comparison of this satellite-based data and ground measurements showed a global root mean square error of 13% for all data points. To estimate the satellite-based direct normal irradiance in the tropical environment of Thailand, a method was devised by Janjai [18] where the satellite selected for this study was MTSAT-1R. First, data of this satellite were used to estimate the global horizontal irradiance and then satellite-based diffused fraction model was devised to estimate the diffuse solar irradiance. Based on global horizontal irradiance and diffuse irradiance, direct normal irradiance was estimated. A similar kind of research was conducted to verify the values of direct normal irradiance of SUNY which is a satellite-based model with the ground-based values in various locations of California [19]. The study focused on finding variation in both the data and also to find accuracy in SUNY model. Mean bias error was noted in the range of −6.39% to 14.21% and correlation coefficient was 0.90 to 0.95 for direct normal irradiance.

Perez et al. [20] compared the satellite-based data taken from GOES 8 with the data which was interpolated and extrapolated with respect to 12 ground-based measurement stations located in New York and Massachusetts in America. A satellite-based model was devised by Janjai et al. [21] to calculate global solar irradiance in tropical areas of Thailand. This study shows that tropical areas in Thailand have high aerosols load. Ambient temperature and relative humidity were used to predict absorption of solar rays due to water vapors in atmosphere. This model also explained how to relate visibility with depletion due to aerosols load. Monthly average hourly global irradiance calculated from both the satellite-based model and ground-based measurements was quite matching with each other by having a root mean square difference of 10% only. An experiment was conducted in the summer months of the year 1977 in United States to check whether ground-based solar irradiance could be obtained through estimation from geostationary satellites [22]. When satellite-based daily insolation was compared to ground-based pyranometers data, the standard error was calculated to be 10% of the mean data. Furthermore, three pyranometers stations were installed at three different locations of Canada which were Ottawa, Toronto, and Montreal [23]. Measurements done at these stations in the summer and spring duration of the year 1978 concluded that on the average, there measurements had 9% variation compared with satellite-based model for daily insolation data in cloudy conditions.

A lot of studies were conducted on ground-based data and satellite-based data [24–29]. Some of studies done in the past showed that there were various errors associated with satellite-based models and that is why there was a difference between solar data obtained from satellite models and ground measurements [30–32]. One such study in Northeastern US showed that there was relative root mean square error of 23% between satellite model (based on data of GOES-8) and 8 years on site measured hourly irradiance [30]. Pixel-to-irradiance conversion error in satellite model was calculated to be 12–13%. Another analysis was done to find long run variation in broadband solar irradiance at surface [31]. Data analyzed were based on three-hourly duration for a time of 18 years. Satellite data of this research were taken from ISCCP (International Satellite Cloud Climatology Project). The data taken were validated with the data based on two years, obtained from Meteosat. Validation of the data showed that when volcanic aerosols were not and were included, annual average of DNI was reduced by 16% while annual average of GHI was reduced by less than 2.2%. Cebecauer and Suri [32] developed a new model based on the data obtained from Meteosat MSG (Meteosat Second Generation). This improved model had the capability to better predict variation and improve accuracy in GHI and DNI, when there were high vapor contents and aerosols load.

Keeping in view the depletion of fossil fuels, the establishment of solar power plants is need of the hour for any country across the globe. However, their construction must be emphasized in order to overcome energy crises in the country. Feasibility study is one of the important phases in establishment of solar power plants. There is a need to estimate the solar energy potential at a particular site in order to have a clear overview to identify if the site is a good choice for the installation of any solar power plant. To identify the best site for the installation of solar power plants, solar energy resource assessment plays a vital role which can be done using various equipment like pyranometer and phyreliometer. These equipment are used to measure ground-based solar energy resource at any location where establishment of solar power plant is desired. Therefore, ground stations are very important to measure the actual solar energy received with the help of these equipment. Besides ground measurements, there are various satellite models in use these days which show an estimation of solar energy potential and they can be widely used to guess the solar energy resource [33]. Problem associated with satellite models is that they are not accurate and there is significant variation between ground measurements and satellite modeled data. Therefore, satellite-based solar data are often compared to ground-based measurements to find the amount of variation between the two [33]. Comparison of ground measurements and satellite modeled solar data provides a clear insight to decide whether or not solar power plants can be established on the basis of satellite modeled data.

Keeping in view of the previous studies, it was clear that in in some cases ground-based GHI and DNI were more accurate than satellite data. To accurately study the difference in results, an experimental study was performed in the current research, which will enable researchers to accurately use solar data in the applications of solar energy. In the present study, ground-based global horizontal irradiance (GHI), and direct normal irradiance (DNI) were measured and compared with satellite modeled data. Ground-based measurements were done at UET Peshawar by using its weather station. Weather station at UET Peshawar consists of various devices among which pyranometer and shadowband irradiometer are used to measure solar irradiance. Satellite-based solar energy was taken from a model called SUNY.

2. Materials and Methods

2.1. Equipment

Various equipment used in this study are part of the established weather station at University of Engineering and Technology (UET) Peshawar. Weather station at UET Peshawar was installed by World Bank under its program called Energy Sector Management Assistance Program (ESMAP). This project of World Bank aimed to map renewable energy resources in Pakistan. Several other weather stations were also established at different locations of Pakistan. Currently, weather station is maintained by UET Peshawar. Figure 1 shows weather station located at UET Peshawar.

Figure 1. Weather Station established at UET Peshawar.

This weather station consists of various equipment which were used in this study. Some of the equipment used in this study are discussed as follows.

2.1.1. Pyranometer

Pyranometer is used to measure solar irradiance received at a surface and there are various types of pyranometers available in the market with different technologies and specifications. However, pyranometers used in this study came from well-known manufacturer called Kipp and Zonen (Delft, The Netherlands) whose model is Kipp & Zonen CMP10. This pyranometer was used to collect global horizontal irradiance (GHI) received at UET Peshawar. Figure 2 shows pyranometer installed at UET Peshawar and its specifications are given in Table 1.

Figure 2. Kipp & Zonen CMP10 pyranometer installed at UET Peshawar.

Table 1. Specifications of Kipp & Zonen CMP10 pyranometer.

Properties	Values
Spectral range (50% Points)	285 to 2800 nm
Sensitivity	7 to 14 μV/W/m^2
Response Time	<5 s
Zero offset A	<7 W/m^2
Zero offset B	<2 W/m^2
Directional response (up to 80° with 1000 W/m^2 beam)	<10 W/m^2
Temperature dependence of sensitivity (-10 °C to +40 °C)	<1%
Operational temperature range	-40 °C to +80 °C
Maximum solar irradiance	4000 W/m^2

2.1.2. Rotating Shadowband Irradiometer (RSI)

Rotating shadowband irradiometer (RSI) is used to measure global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal irradiance (DHI). RSI installed at UET Peshawar came from Concentrating Solar Power Services (CSPS) which is called CSPS Twin-RSI. It has two radiation detectors made from silicon located in the middle of a spherical shaped shadowband. The two radiations sensors called LI-200 came from LI-COR Inc. (Lincoln, NE, USA). When shadowband is below the sensor in rest position, the sensor measures GHI. Shadowband moves after some time and it comes in the path to block DNI. When DNI is blocked, the sensor measures DHI. When GHI and DHI both are known, DNI can easily be calculated. Figure 3 shows RSI installed at UET Peshawar. Specifications of CSPS Twin-RSI are given in Table 2.

Figure 3. CSPC Twin-RSI installed at UET Peshawar.

Table 2. Specifications of Twin-RSI.

Temperature range	-30 to $+65\,^{\circ}$C
Humidity	0 to 100% Rh
Dimensions	$500 \times 100 \times 200$ mm
Weight	2.1 kg
Power demand	<1 W at average
Output signal	$\approx$90 µA per 1000 W/m^2
Response time	10 µs

2.1.3. Data Logger

Data logger is used for data acquisition which come from various components of weather station like pyranometer and RSI. Data which are collected by various components of weather station are stored in data logger and then extracted by connecting it with a computer. Data can also be transferred remotely. The data obtained from data logger contained missing and redundant values. Therefore, two types of quality controlled (QC) tests were performed to make the data ready to use. First, automatic QC tests were performed to identify the missing values, time shift, consistency of data by comparing the redundant values, and the data were compared with maximum and minimum irradiance values. Then, the visual QC tests were performed for flagging the data. A more detailed description of these tests can be found in [34,35].

Data logger used in UET Peshawar's weather station is a product of Campbell Scientific Inc. and its model is CR1000. This data logger is very good for extreme conditions and remote environments. Figure 4 shows the data logger which is part of the weather station located at UET Peshawar.

2.2. Location of UET Peshawar

University of Engineering and Technology is located at Peshawar region of Pakistan having latitude of 34.0017° N and longitude of 71.4854° E. Data used in this study were taken from Weather station established at UET Peshawar. Then, these data were filtered through QC tests discussed in the data logger section.

Figure 4. CR1000 data logger installed at UET Peshawar's weather station.

2.3. Methodology Adopted

In this part of the study, satellite-based GHI and DNI are compared with ground measurements for year 2017. As mentioned earlier, ground-based data were taken from weather station established at UET Peshawar.

Ground-based GHI and DNI were measured by pyranometer and Twin-RSI which both are already explained previously. These DNI and GHI were collected from data logger and were further analyzed. Data were available for the whole year 2017 except for the first 16 days of January and the last 19 days of December. Data were received at weather station after each 10 min duration. Available DNI and GHI for each month were processed on the basis of daily total monthly mean. When all the data were processed on the basis of daily total monthly mean, one data point was obtained for each month. In this way, 12 data points were available for the 12 months of 2017.

Satellite model chosen for analysis was SUNY (https://nsrdb.nrel.gov/international-datasets, accessed on 10 February 2021). National Renewable Energy Laboratory (NREL) made National Solar Radiation Database (NSRDB) which developed a model called SUNY. SUNY provides satellite-based data for South Asian countries mostly. SUNY has temporal and spatial resolution of 1 h and 10×10 km respectively. DNI and GHI from SUNY model are available after one hour duration. These satellite-based DNI and GHI available from SUNY were analyzed on the basis of daily total monthly mean averaged over 15 years i.e., from 2000 to 2014. Hourly data were summed up to measure the daily total for all 15 years. Then, daily total was further processed to measure daily total averaged over these 15 years and then finally monthly mean of daily total averaged over 15 years was measured. In this way, daily total monthly mean averaged over 15 years for DNI and GHI was calculated on the basis of SUNY satellite model data. For each month, one data point was obtained.

3. Results and Discussions

Satellite-modeled GHI and DNI were compared with ground measurements. Results were plotted and are discussed below.

Table 3 and Figure 5 show the comparison of satellite and ground-based GHI. Ground measurements showed that highest ground-based GHI was 6415 Wh/m^2 and lowest ground-based GHI was 1605 Wh/m^2. Similarly, highest and lowest GHI measured by satellite model were for the months of June and December, respectively. Moreover, GHI showed by satellite model for the month of June was 7177 Wh/m^2 and for the month of December was 2811 Wh/m^2. Comparison of both the data showed a clear trend and the highest difference of 42.90% in GHI was found for the month of December. In other words, satellite-based GHI was overestimated by a value of 1206 Wh/m^2. Similarly, the lowest

difference in GHI was noted in the month of March, which was -3.83%. Satellite-based GHI in the month of March was underestimated by a value of -181 Wh/m^2. The average difference in GHI was noted to be 556 Wh/m^2 which means that on average, satellite-based GHI was overestimated by a value of 556 Wh/m^2 for each month. Satellite-based GHI was greater for all the months except February, March, and April where ground measurements exceeded satellite values.
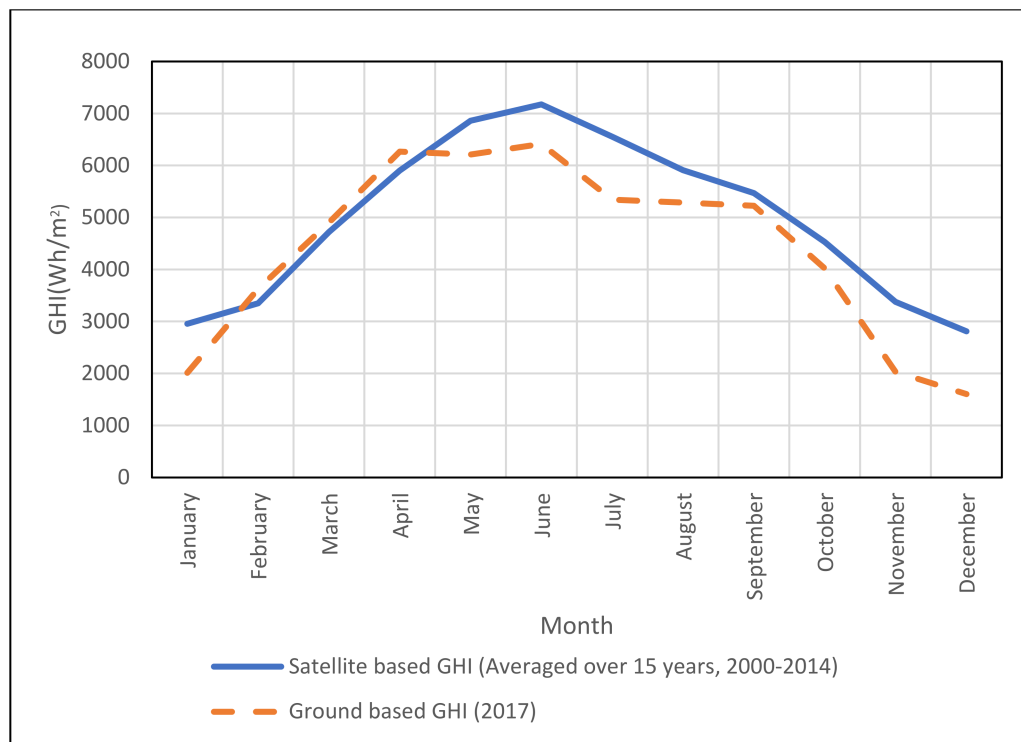

Figure 5. Comparison of ground-based GHI with satellite-based GHI.

Table 3. Comparison of ground-based GHI with satellite-based GHI.

Month	Satellite Value (Wh/m^2)	Ground Value (Wh/m^2)	Difference (Satellite-Ground) (Wh/m^2)	Percent Difference {(Sat-Ground)/Sat}s $\times$ 100
January	2955	2013	942	31.87%
February	3350	3627	-277	-8.26%
March	4721	4902	-181	-3.83%
April	5901	6267	-366	-6.20%
May	6861	6210	651	9.48%
June	7177	6415	762	10.61%
July	6553	5341	1212	18.49%
August	5909	5286	623	10.54%
September	5468	5226	242	4.42%
October	4530	4020	510	11.25%
November	3378	2032	1346	39.84%
December	2811	1605	1206	42.90%

The correlation of satellite-based GHI with ground-based GHI has been developed and shown in Figure 6 where each data point represents a month. There is a substantial positive correlation between satellite and ground-based GHI. The value of R^2 for the correlation is 0.8852 which shows that there is high correlation between these two.
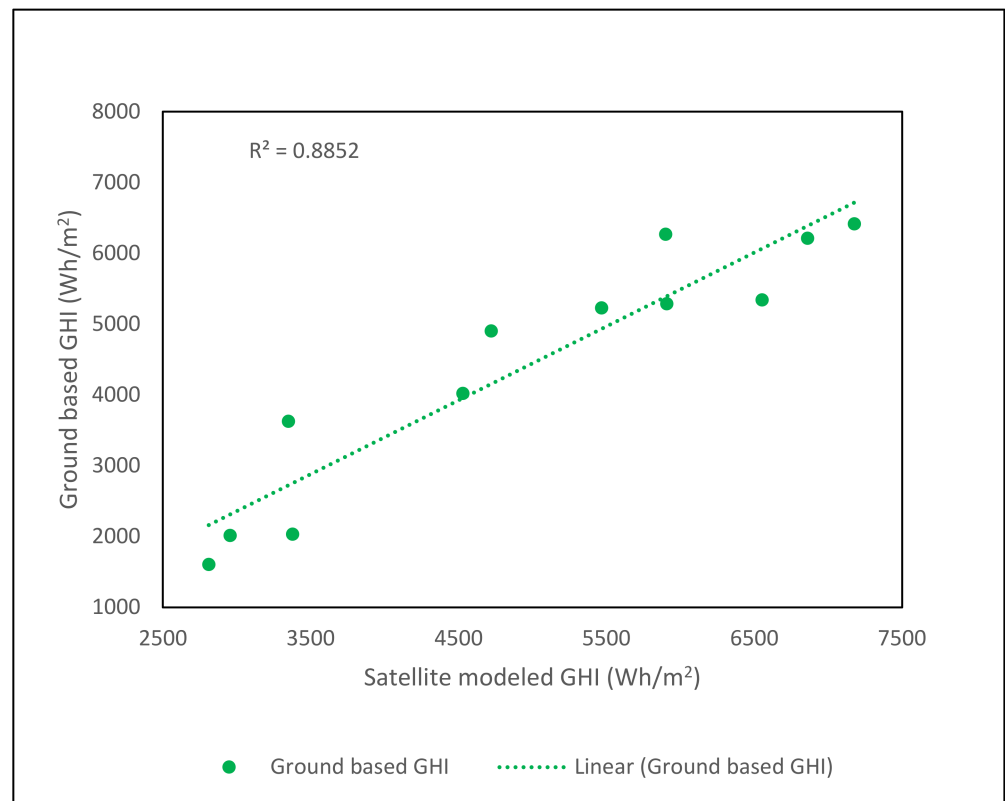
Figure 6. Correlation of satellite modeled GHI with ground-based GHI.

The comparison of ground-based monthly DNI with satellite-based DNI is given in Table 4 and Figure 7 which show that highest and lowest ground DNI were recorded in the months of April and January, respectively. It has been found that ground-based DNI in April was 5884 Wh/m^2 and it was 1718 Wh/m^2 in January. On the other hand, highest and lowest satellite-based DNI were seen in the months of May and February respectively. Satellite-based DNI in May was 6095 Wh/m^2 and it was 3240 Wh/m^2 in February. When satellite modeled and ground measured DNI were compared, satellite-based DNI overestimated ground measurements for all the months except February, March, and April. Maximum difference in DNI was found in the month of November which was 55.86%. Satellite-based DNI in November was overestimated by a value of 2348 Wh/m^2. On the other hand, minimum difference was noted in the month of March which was −3.34%. In March, satellite-based DNI was underestimated by a value of −140 Wh/m^2. Average difference in DNI between both data was 983 Wh/m^2 which means that on the average, for each month, satellite modeled DNI overestimated ground measurements by a value of 983 Wh/m^2. Ground measurements showed lower values of DNI in comparison with satellite modeled value for all months except February, March and April where ground measurements exceeded satellite-based values of DNI.
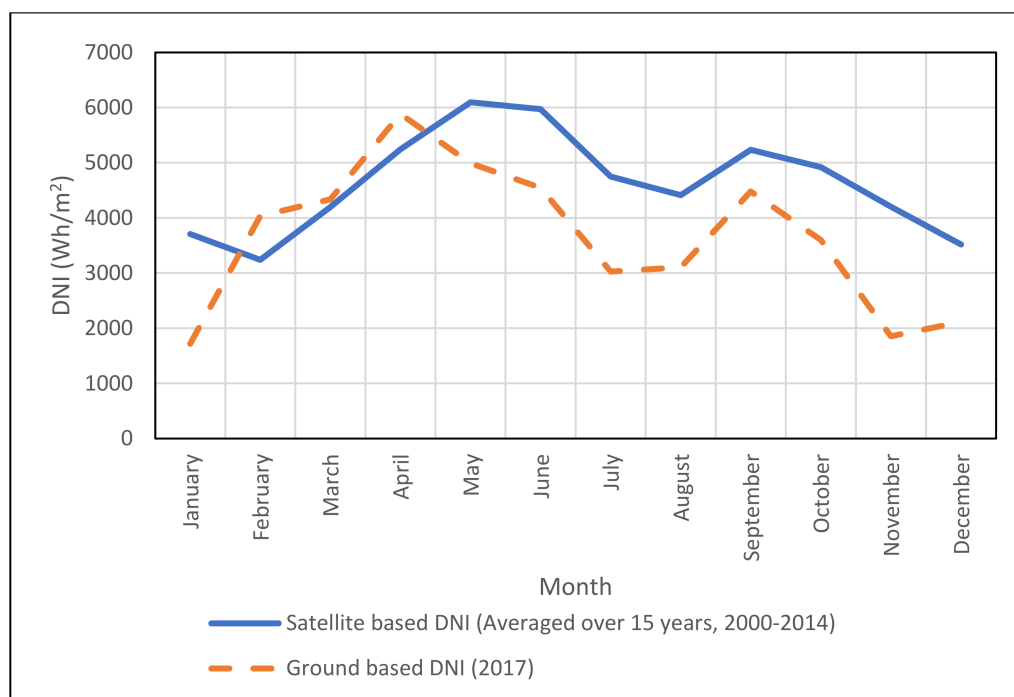
Figure 7. Comparison of ground-based monthly DNI with satellite-based DNI.

Table 4. Comparison of ground-based monthly DNI with satellite-based DNI.

Month	Satellite Value (Wh/m^2)	Ground Value (Wh/m^2)	Difference (Satellite-Ground) (Wh/m^2)	Percent Difference {(Sat-Ground)/Sat}s × 100
January	3706	1718	1988	53.64%
February	3240	4034	−794	−24.50%
March	4196	4336	−140	−3.34%
April	5243	5884	−641	−12.22%
May	6095	4989	1106	18.15%
June	5969	4545	1424	23.86%
July	4747	3027	1720	36.23%
August	4412	3103	1309	29.67%
September	5233	4478	755	14.43%
October	4920	3599	1321	26.85%
November	4203	1855	2348	55.86%
December	3517	2112	1405	39.95%

The correlation between satellite-modeled DNI and ground-based DNI has been developed which is shown in Figure 8 where each data point represents a month. There exists a moderate positive correlation between satellite and ground-based DNI having R^2 of 0.4139. Moreover, Table 5 shows uncertainties in ground measurements as well as satellite modeled GHI and DNI. Uncertainties in equipment were taken from CMP6/CMP10/CMP11/CMP21-Campbell Scientific (Logan, UT, USA) and Rotating Shadowband Irradiometer CSPS Twin-RSI of CSP Services Inc. (Cologne, Germany). Hourly uncertainties of SUNY model were 9.6% for GHI and 15.9% for DNI which were taken from (A Review of Measured/Modeled Solar Resource Uncertainty). Uncertainties in GHI and DNI of Shadowband irradiometer are <2% for annual sum. Daily uncertainties in GHI and DNI of Kipp and Zonen CMP10 pyranometer are <2%. On the basis of these values, in our study, we have assumed that our calculations have 2% uncertainty. Combined uncertainty of both the ground measurements and satellite model is 11.6% for GHI while maximum difference in GHI was found to be 42.90%. Difference in satellite and ground-based GHI exceeded from combined uncertainty which means the difference was significant and it needed to be taken into the account for calculations of solar

data in Peshawar. Moreover, combined uncertainty in DNI of satellite model and ground measurements is 17.9% whereas maximum difference in both the data of DNI is 55.86%. Maximum difference in DNI exceeds the combined uncertainty which means that the difference is significant and both the data have considerable variation.
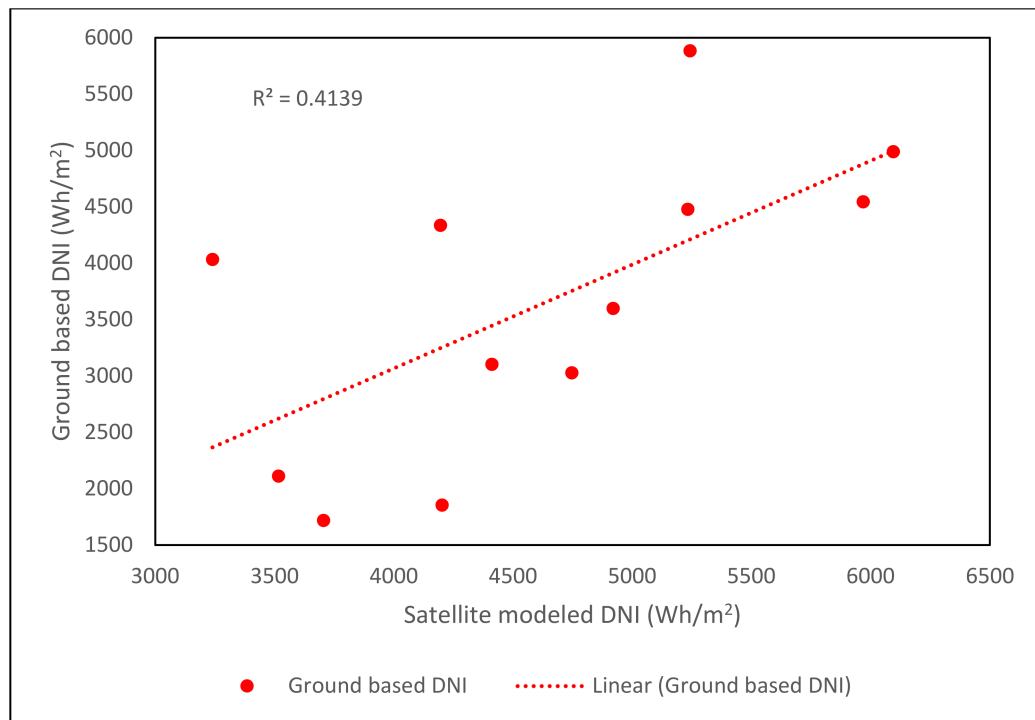

Figure 8. Correlation of satellite-modeled DNI with ground-based DNI.

Table 5. Comparison of uncertainties and maximum differences in GHI and DNI.

Property	Equipment Uncertainty (%)	SUNY Uncertainty (%)	Combined Uncertainty (%)	Maximum Difference (%)
GHI	2	9.6	11.6	42.9
DNI	2	15.9	17.9	55.86

From Table 5, it is evident that maximum difference in GHI and DNI is way greater than combined uncertainty, so there is significant difference which is worth considering in analysis.

Some of the reasons for variation between satellite and ground-based GHI and DNI in literature are [5,8,9]:

- Presence of aerosols in atmosphere;
- Presence of various gases in atmosphere;
- Presence of water vapors in air;
- Poor estimation of satellite model;
- Presence of mountains in vicinity;
- Shading of trees in the surrounding;
- Satellite confuses between clouds and snow.

4. Conclusions

The assessment of solar energy potential in a certain region is a basic step in establishing solar plants in that region. There is solar data available from satellite-based models. However, it is affected by some factors and should be validated using ground-based data. Therefore, there is a need of solar energy measurements based on ground-based data which can be obtained using different equipment like pyranometer and rotating shadow-

band irradiometer. To evaluate the solar energy potential of Peshawar region in Pakistan, ground-based global horizontal irradiance (GHI) and direct normal irradiance (DNI) were compared with satellite-based model SUNY. Ground measurements were done at (University of Engineering and Technology) UET Peshawar with the help of pyranometer and shadowband irradiometer.

This study concluded that there was significant difference between satellite and ground-based GHI and DNI. In the months of February, March, and April, ground-based GHI and DNI were overestimated compared to satellite-based GHI and DNI. In rest of the months, satellite-based GHI and DNI were greater than ground-based GHI and DNI. Maximum and minimum difference of 42.90% and -3.83% between satellite and ground-based GHI was found in the month of December and March respectively. For DNI, maximum and minimum difference of 55.86% and -3.34% between satellite and ground-based data was found in the month of November and March respectively. The percentage combined uncertainties between satellite and ground-based GHI and DNI were 11.6% and 17.9%. The maximum percent differences were more compared to the combined uncertainties of ground equipment and satellite model. Therefore, the difference was considerable and it is concluded that this difference needs to be taken into account when solar energy resource is assessed in Peshawar. Moreover, correlation of ground and satellite-based GHI and DNI showed squared correlation coefficient R^2 of 0.8852 and 0.4139 respectively.

Moreover, this study recommends that there should be more ground measurement stations across the country to properly assess the solar resource of the country. The difference between ground measurements and satellite values was considerable and hence real-time measurements are necessary to properly estimate solar energy resource in the country. For establishment of any solar energy program in Pakistan and especially in Peshawar, it is not recommended to rely entirely on satellite modeled data, but rather realistic ground measurements are needed. Satellite modeled data can only provide estimation of solar energy resource but not the exact amount of irradiance received at particular location. This study also recommends the researchers and university students to further research in assessment of solar energy resource in various locations of the country.

Furthermore, the data available for ground-based measurements were only for one year (2017) which is a limitation of this study. The study would be far better if the time series was longer enough. Therefore, the authors suggest it as a future recommendation that such studies should be conducted in different locations of the country with a longer time series of data.

Nomenclature

PV	Photovoltaic
UET	University of Engineering and Technology
GHI	Global Horizontal Irradiance
DNI	Direct Normal Irradiance
SUNY	State University of New York
NSRDB	National Solar Radiation Database
RSI	Rotating Shadowband Irradiometer

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