Analysis of global solar radiation, satellite frequency for the city of juliaca

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Abstract. The path towards a greener economy is leading the world energy scenario to an increasing use of renewable energy sources such as solar, however, in order to make better use of this type of energy, it is necessary to keep the data updated regarding to the amount of solar radiation that falls on each area of our planet. The research aimed to obtain satellite data and compare it with the measurement by the ground station and establish the degree of reliability by the satellite. The mean standard error (RMSE), the mean error (MBE), the determination coefficient ($R2$) and the correlation coefficient (r) were used to evaluate the data obtained from the satellite. The data obtained from NSRDB was determined to have a higher correlation than that from POWER, for which the global solar radiation data correction equation for the city of Juliaca was obtained. These analyzed data presented values from 4.1 to 6.6kwh / m ^ 2 monthly and annual average of 5.43kwh / m ^ 2, concluding that the data obtained from NSRDB with respect to the station data have a linear correlation of 0.852 for clear skies and cloudy and 0.952 for clear skies.

Keyword : renewable energy, solar energy, radiation, satellite

1. Introduction

It is well known that energy from the sun and thus solar radiation is one of the most important outdoor climatic conditions besides air temperature, precipitation, humidity, wind speed, and plays important roles in different fields, such as agriculture, energy and architecture (Yang et al, 2020), in that sense, solar radiation is attracting attention in the field of water treatment and recently several applications involving sulphate radicals and sunlight have been reported (Solis et al, 2020).

However, the energy structure is still dominated by coal, oil, natural gas and other fossil fuels worldwide. However, the massive exploitation and use of conventional fossil energy aggravates the problem of energy scarcity and causes serious environmental pollution, which is why recently a series of actions have been carried out with the aim of increasing the rate of use of renewable energies as a better solution to the energy problem (Xu et al, 2020) within which stands out solar energy which has a number of advantages over fossil fuels (Heng et al, 2020), some of these being its wide dissemination and availability (Tregambi et al, 2020).

Recently, the use of solar energy has focused on solar photovoltaic power generation, solar thermal utilisation and integral solar photovoltaic utilisation (Xu et al, 2012), a situation that has led to an increase in the use of solar energy as a primary energy source in recent years, with the installed photovoltaic capacity worldwide exceeding the most optimistic expectations year after year (Righini et al, 2014). This infinite energy provided by the sun through photovoltaic devices, which can directly convert solar energy into electricity, has triggered extensive research (Zhao et al, 2020).

Solar energy deployments require a decade-long series of high-quality solar irradiance data for technical (planning, design and layout) and financial aspects of the project (Fernández-Peruchena et al, 2018). However, because of the intraday and interannual variability of solar irradiance and solar resource assessment must consider time series, rather than considering only climatological averages so that data to be considered reliable must include at least time series of direct normal irradiance and global irradiance or global array plane irradiance (Sengupta et al., 2017).

Long-term time series of solar radiation components at the Earth's surface can be modelled by many methodologies based on satellite imagery or numerical reanalysis of the meteorological model (Polo et al, 2020), some based on relative humidity (Adeala et al, 2015; Kolebaje et al, 2016; Muhammad & Darma, 2014), others

based on cloud cover in the sky (Okundamiya, et al, 2016), sun-based (Gairaa & Bakelli, 2013), extreme temperatures (Fan et al., 2018; Jamil et al., 2020), artificial neural networks (Elsheikh et al., 2019; Rodriguez et al, 2018), statistical adjustment dependents (Jamil & Akhtar, 2017; Paredes & Pereira, 2019) and satellite image processing (Cornejo-Bueno et al, 2019; Mazorra et al, 2019) is why it is of utmost importance to be able to have up-to-date solar radiation records.

According to several investigations, Peru is considered an ideal place to initiate renewable energy projects (Camayo, et al, 2019) that include the sustainable use of solar energy, especially in the city of Juliaca, which has high radiation values. In this context and taking into account the high importance of keeping updated data related to the amount of solar radiation in the area of Juliaca, it has been considered important to carry out this work whose objective was to obtain satellite data and compare it with that measured by the ground station and establish the degree of reliability of the satellite.

2. Methodology

Study area

The research was carried out in the city of Juliaca, which is located in the province of San Roman in the department of Puno, in southeastern Peru (Figure 01). This city is located at an altitude of 3824 m.a.s.l. It occupies part of the high plateau of Toropampa, in the basin of the Coata river, Ayabaca section, developing between the Zapatiana, de la Cruz and Huaynaroque hills. It is an important economic centre in the Puno region. The main climatic characteristics of the city of Juliaca are rainfall, winds, low temperatures in the winter season and in the summer season with clear, partly cloudy and cloudy skies and high levels of solar radiation.

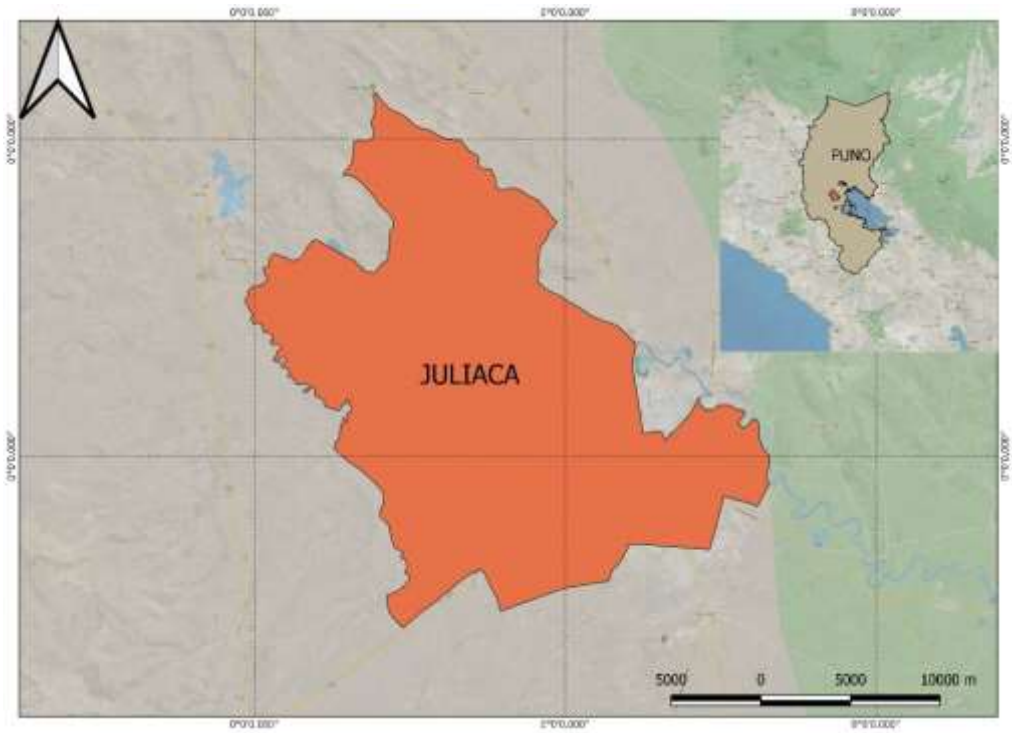


Figure 01: Map of the study area (own elaboration)

Collection of Surface solar radiation data

The data used were measured by the DAVIS Vantage PRO2.0 Plus weather station (Figure 02a) using a solar radiation sensor (Pyranometer) (Figure 02 b) (Dejmal, Hudec, Kolar, & Novotny, 2017; Eraso-Checa, Jiménez, Escobar, & Insuasty, 2018) at 1-hour intervals in units of w/m2.



Figure 02: Equipment used for solar radiation data collection (Photographs by authors)

The sensor consists of a high-precision silicon photodiode, located inside a plastic casing that provides a path for air currents to cool the interior by convection, minimising the heating of the sensor, which has a measurement range of [0-1800] with a resolution of 1w/m,2 in 1min intervals with an accuracy of ±5%. Regarding the weather station, it is installed in an area free of shadows and obstacles in the general classrooms of the National University of Juliaca at the coordinate's latitude -15.4890, longitude -70.1515 and an altitude of 3.825 masl.

Obtaining satellite data

Global solar radiation data in the horizontal plane for the coordinates of -15.4890 (latitude) and -70.1518 (longitude) were generated from the NASA website (POWER Data Access Viewer) in units of kwh/m2 /day which are stored daily (Debnath et al, 2019). The web-based mapping application POWER Data Access Viewer (DAV) contains geospatially enabled solar, meteorological and cloud-related parameters formulated to assess and design renewable energy systems (Stackhouse et al., 2018).

The National Solar Radiation Database, NSRDB, is a widely used public solar resource dataset that has been developed and updated for more than 20 years to reflect advances in solar radiation measurement and modelling. The most recent version of the NSRDB uses 30-minute satellite products at 4×4 km resolution covering the period 1998-2018 (Habte et al., 2017).

Statistical analysis

To evaluate the satellite data, the average standard error or root mean square error (RMSE) was used, which provides information on the short-term performance and is a measure of the variation of the satellite values around the measured data per weather station, the mean error (MBE), also called bias or deviation, was also used, which is an indication of the mean deviation of the satellite-derived values from the corresponding station-measured data, on the other hand, the coefficient of determination ($RR2$) was also calculated to estimate the performance of the satellite data and finally, the correlation coefficient (r) used to measure the linear relationship between the station-measured values with respect to the satellite-derived values was calculated (Blal et al., 2020). The equations used are given below:

$$RMSE = \left[\frac{\sum_{i=1}^{n}(R_{mi} - R_{si})^2}{n}\right]^{1/2}$$

$$MBE = \frac{\sum_{i=1}^{n}(R_{mi} - R_{si})}{n}$$

$$R^2 = \frac{[\sum_{i=1}^{n}(R_{mi} - \bar{R}_{mi})(R_{si} - \bar{R}_{si})]^2}{[\sum_{i=1}^{n}(R_{mi} - \bar{R}_{mi})^2][\sum_{i=1}^{n}(R_{si} - \bar{R}_{si})^2]}$$

$$r = \sqrt{R^2}$$

Where:
R_{mi} = Measured by the weather station
R_{si} = Satellite data
$\bar{R}_{mi}$= Average of the data measured by the meteorological station
$\bar{R}_{si}$= Average of the satellite data
n = Total number of observations
In order to correct the satellite data, the linear regression equation of the NSRDB data and station for the city of Juliaca was considered, obtaining:

$$Ra = 0.762 \times Rs + 0.448$$

Where:
$Ra =$ Adjusted global solar radiation for the city of Juliaca
$Rs =$ Global solar radiation obtained from NSRDB

3. Results

The analysis of data obtained from POWER and NSRDB compared with the measurements by the ground station for the year 2018 was carried out, considering 362 data, and the daily global solar radiation was considered in units of kwh/ m^2/day which is shown in figure 03, where it is observed that the data from the station present a greater dispersion for the days included in the months of January, February, November and December, months in which the rains and cloudy skies are present in greater numbers compared with the clear skies.

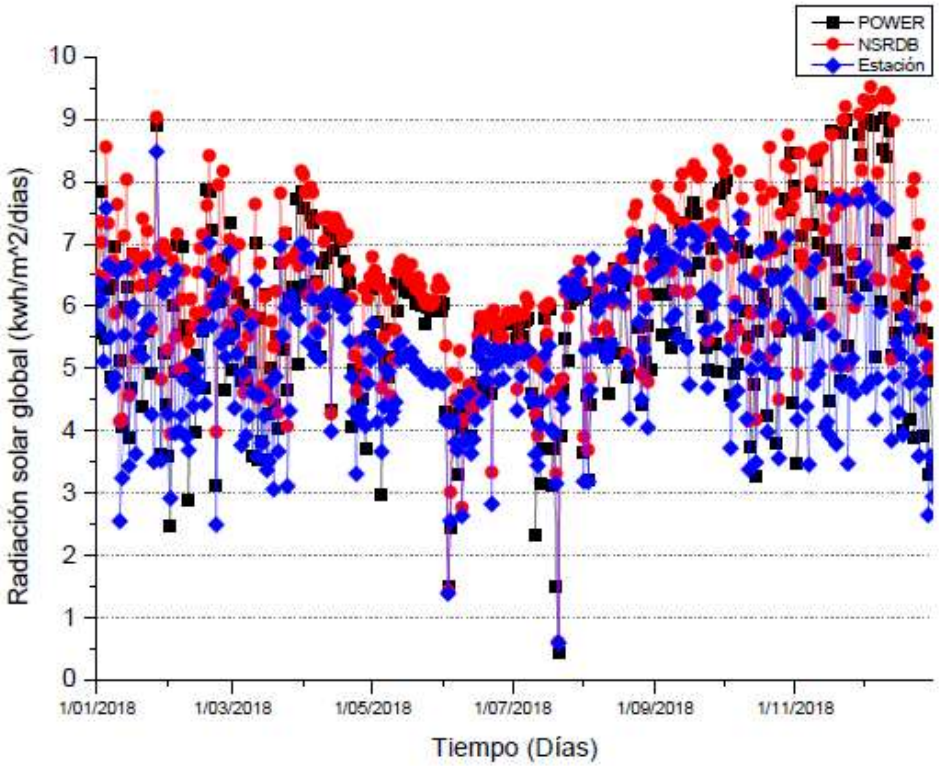


Figure 03: Overall solar radiation of the station, NSRDB and POWER (own elaboration)

The corresponding statistical analysis was carried out by calculating the correlation coefficient between the data indicated in table 01, obtaining that the relationship between POWER and station is r=0.733, which indicates that only 73.3% of the total data has a linear relationship, these values are due in part to the influence of the sky characteristic of the city of Juliaca.

On the other hand, the relationship between the NSRDB and the station yielded a value of r=0.824, which indicates that 82.4% of the total data have a linear relationship. This result is greater than the one obtained when calculating the relationship with POWER, which is why it was considered for the analysis of global solar

radiation for the city of Juliaca. With respect to the average values in units of kwh/m^2/day, these were: station 5.274, POWER 5.778 and NSRB 6.389,

The data biases presented are: for POWER and Station 0.930, NSRDB and Station 0.751 indicating that the data compared between Station and NSRDB have a higher bias.

Table 01: Comparison statistic

Data	MBE	RMSE	R^2	r
Station – Power	0.930	1.168	0.537	0.733
Station -NSRDB	0.751	1.347	0.679	0.824

Own elaboration

Figure 04 represents the data obtained between 01 and 23 July, dates in which the level of cloudiness was lower and rainfall was scarce, while figure 05 represents the data dispersion analysis using the linear correlation coefficient.

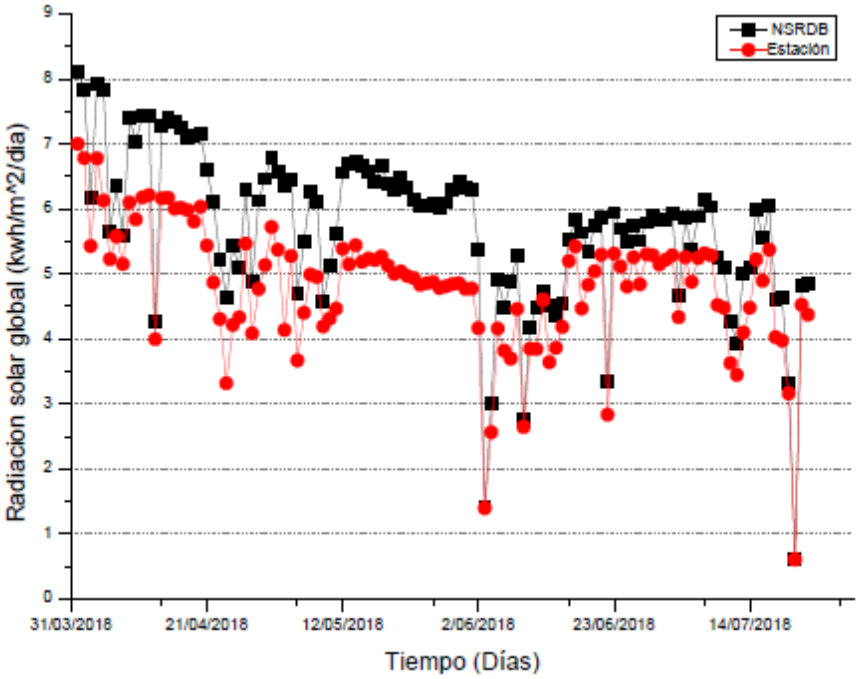


Figure 04: Global radiation recorded between 01 – 23 July (own elaboration)

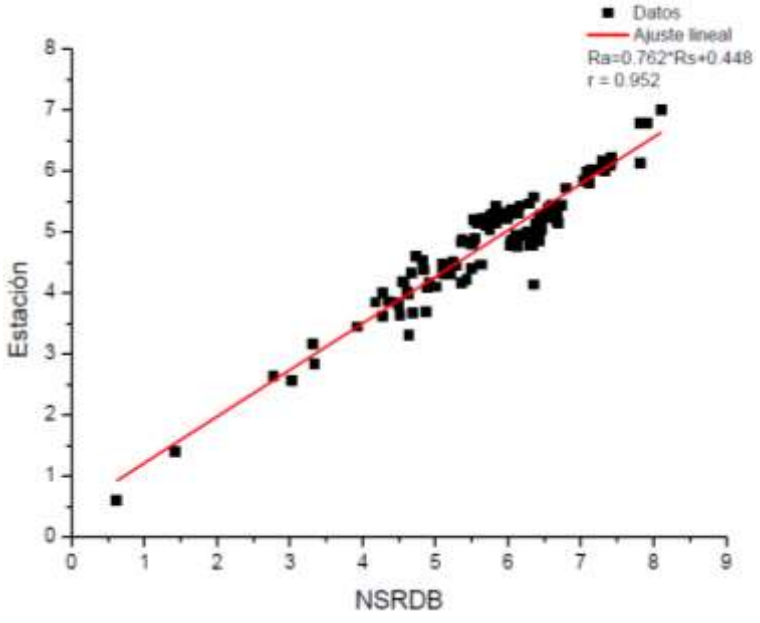


Figure 05: Dispersion of NSRDB and station (own elaboration)

For the period 1998 to 2018 data was obtained from the NSDB taking into consideration the coordinates of -15.4890 (latitude) and -70.1518 (longitude) for the city of Juliaca with maximum values of 7.222kwh/m^2/day, minimum of 1.100kwh/m^2/day and an average of 5.352kwh/m^2/day, which is shown in Figure 06.

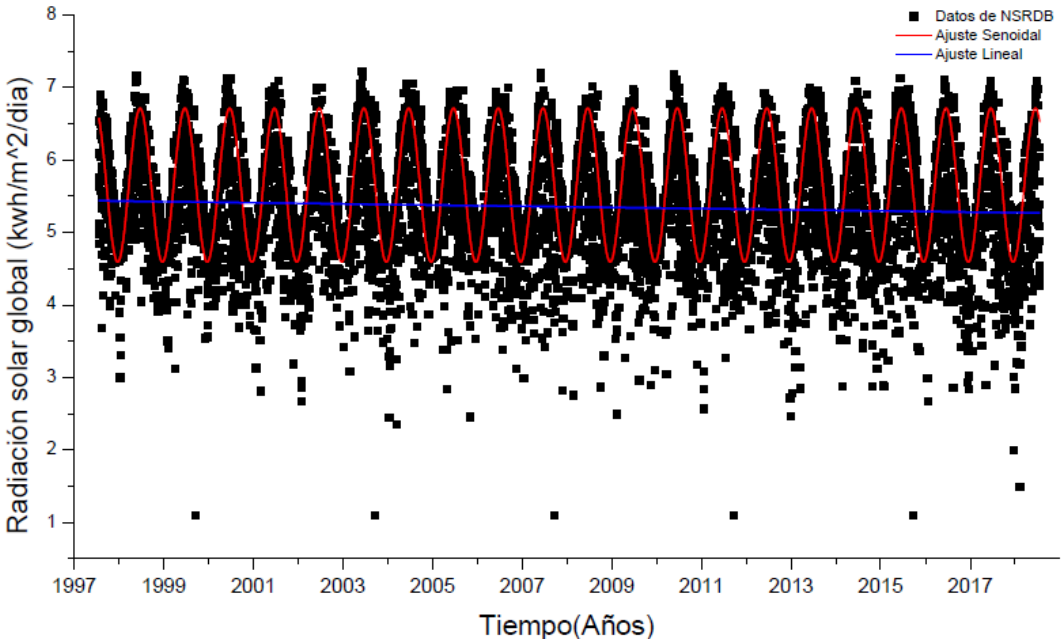


Figure 06: Global solar radiation period 1998 – 2018 obtained from NSRDB

On the other hand, the monthly data for the last three years available in NSRDB were also analysed and are detailed in table 02.

Table 02: Solar radiation

	2018				2017				2016			
Month	Rad.	Prom.	Max	Min	Rad.	Prom.	Max	Min	Rad.	Prom.	Max	Min
1	166.486	5.370	7.232	3.512	172.304	5.558	7.232	2.569	194.234	6.266	7.549	4.199
2	143.582	5.128	6.762	3.359	160.081	5.717	7.418	3.698	147.626	5.091	7.283	0.448
3	151.661	4.892	6.574	3.455	156.640	5.053	6.605	3.256	191.019	6.162	7.076	3.620
4	160.143	5.338	6.525	3.606	153.961	5.132	6.172	3.464	153.289	5.110	5.990	3.191
5	156.578	5.051	5.524	3.825	138.279	4.461	5.660	2.550	160.788	5.187	5.546	4.241
6	123.593	4.119	5.143	1.433	140.759	4.692	5.162	3.189	143.182	4.773	5.274	2.724
7	137.055	4.421	5.468	0.818	157.427	5.078	5.392	3.941	152.814	4.929	5.470	2.346
8	152.453	4.918	6.158	3.163	173.714	5.604	6.240	3.579	169.385	5.464	6.425	4.106
9	180.116	6.004	6.827	4.516	162.516	5.417	7.035	3.277	181.071	6.036	6.859	4.295
10	172.150	5.553	7.011	3.520	198.597	6.406	7.409	2.608	184.074	5.938	7.332	4.103
11	178.523	5.951	7.360	4.087	196.643	6.555	7.694	3.906	199.001	6.633	7.719	4.815
12	181.739	5.863	7.601	4.164	182.362	5.883	7.456	2.948	186.965	6.031	7.440	3.997
		5.22				5.46				5.63		

Own elaboration

Finally, radiation values were plotted for the period from 2010 to 2018 (Figure 07)

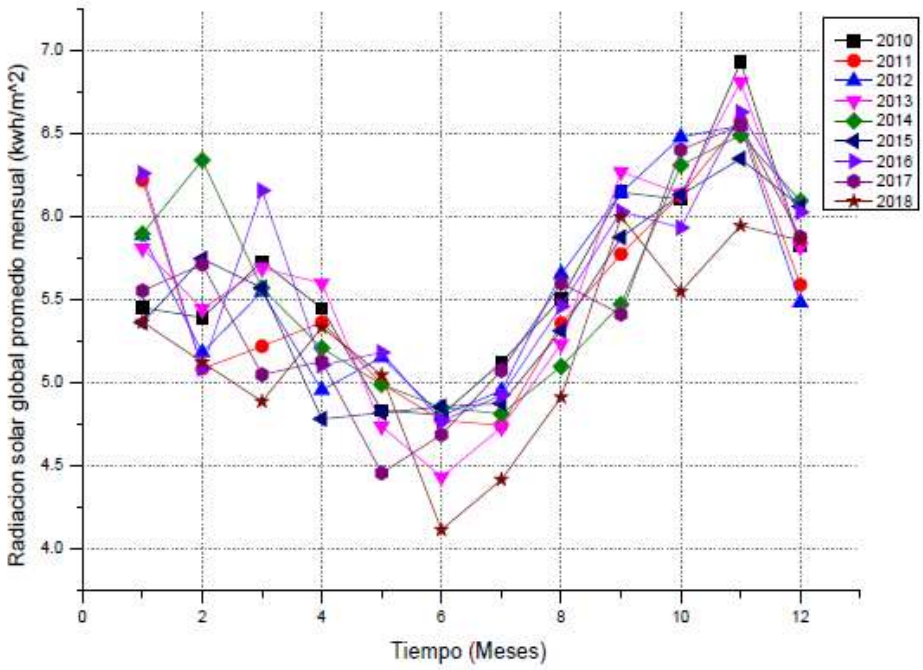


Figure 07: Solar radiation values between the years 2010 and 2018 (own elaboration)

4. Discussion of results

From the data represented in Figure 04, an overestimation of global solar radiation is observed for the data obtained from NSRDB compared to the station, these results agree with the works of Antón et al (2010), Nolasco et al (2018) and Polo et al (2020) who state in their research that data obtained from satellites overestimate solar radiation values by 17-40%, mainly due to the climatic characteristics of the location. To illustrate this variability, only some recent validation results are provided below, e.g., in India, SARAH-E satellite-based estimates resulted in a 10-20% overestimation of the incoming solar radiation at the surface (Riihelä, 2018), on the other hand, in Chile, a nearly unbiased hourly GHI with a 20% RMSD was estimated using GOES satellite imagery (Molina et al., 2017) while in Morocco, the HelioClim-3 database reported 8% MBD and 20% RMSD for DNI estimates (Merrouni et al., 2017).

Taking into account the above, we proceeded to carry out the data dispersion analysis using the linear correlation coefficient, determining a value of r equal to 0.952, which indicates that 95.2% of the total data for cloudless skies and rainfall have a linear relationship, as shown in figure 05.

Figure 06 shows a sinusoidal behaviour of the solar radiation data for the period 1998-2018, which coincides with the data obtained by Jiménez et al. (2016), for data from five meteorological stations belonging to the Obispo Colombres Agroindustrial Experimental Station in the province of Tucumán, Argentina, and also agrees with the results obtained by Calbo et al (2017), who conducted their research in the northeastern region of the Iberian Peninsula, and with Qin et al (2020), for data from 29 CERN stations over mainland China.

From the analysis of the monthly data for the last three years available in NSRDB, applying the linear correction equation, it is evident that the average values are in the range of 4.1 to 6.6 kwh/m^2/month which are in agreement with the works of Huillca & Taipe (2015) and the annual average is 5.43kwh/m^2. On the other hand, figure 07 shows that the minimum values occur in the winter season and the maximum values occur in the summer season, these values are influenced by factors such as the distance from the sun to the earth, thus demonstrating that the behaviour of the monthly average values is seasonal and cyclical of the monthly average global solar radiation values, coinciding with the data obtained by Marchetti et al (2016) for the areas of Murcia, Valencia, Palma de Mallorca, Barcelona and Rome with respect to the seasonal variation of the data.

With respect to the cyclical and seasonal behaviour of the solar radiation data observed in figure 07, the highest data were obtained in the summer season, unlike the results of the monitoring carried out by Herrera (2017), who determined for the city of Ayacucho that the highest intensity values occurred in spring with oscillating values between 973 w/m2 and 979 w/m2 due to the clear sky, and the lowest solar radiation values in autumn due to the presence of cloud cover; Although it is true that the seasons do not coincide with the results obtained,

it was possible to corroborate that the influence of cloudiness in the sky is an important factor in measuring the values of incident solar radiation on the earth.

The annual average values obtained for the years 2016, 2017 and 2018 (table 02) are considered cost-effective values for solar thermal and solar electricity generation applications as described by Camayo-Lapa et al (2019).

5. Conclusions

From the data obtained it is concluded that there is a linear correlation of 0.824 for the NSRDB database for clear and cloudy skies for the year 2018 while for clear skies without rain it was 0.952, indicating that the data is closer for clear skies.

The equation has been obtained to perform the correction of satellite data from the NSRDB database of global solar radiation for even horizontal plane, using an interval of clear days of the year 2018, which served to perform the data analysis for the period of years 2010-2018.

The data determined in relation to global radiation averages in the range of 4.1 to 6.1 kwh/m^2 for the years 2016 to 2018 and annual average of 5.43kwh/m^2 agreeing with the data obtained in previous research for the region of Puno.

Finally, the information generated from this research will serve as a basis for raising awareness among regional, local and sectoral authorities to consider the domestic and industrial use of solar energy as a source of energy in their plans and programmes and to meet the goals of the national strategic plan for 2021 to consider a 56% share of renewable energy in the gross domestic supply of the energy matrix by 2021.

Funding

Self-financing

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