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Impact of Meteorological Parameters on Global Solar Radiation (GSR) at Nepalgunj Airport, Nepal

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Abstract

Global solar radiation (GSR), is the main source of heat that powers the energy between the geosphere and the atmosphere, is the total of the direct and diffused shortwave solar radiation that reaches the earth's surface. The target of the present report is to analyze the GSR from the data of Nepalgunj airport, Nepal in 2020. In addition, to analyze the effect of rainfall, relative humidity, maximum temperature, and minimum temperature to the GSR. The data on a horizontal surface for Nepalgunj airport, Nepal in 2020 were collected from the Department of Hydrology and Meteorology, Government of Nepal. The Angstrom-Prescott, Tiwari, and Sangeeta models were used to calculate the GSR theoretically on a horizontal surface with the help of the estimated sunshine hour. The yearly average value of GSR for the year 2020 was 18.73 $MJ/m^2/day$. The measured GSR on a horizontal surface was found maximum in April which was 27.64 $MJ/m^2/day$ and minimum in August which was 6.38 $MJ/m^2/day$ The minimum amount of GSR found in August may be due to the high amount of rainfall of 10.51 mm in August. Talking about the seasonal variation, the Spring season receives the maximum amount of GSR i.e. 24.75 $MJ/m^2/day$ and the minimum amount is in winter i.e. 9.13 $MJ/m^2/day$. Here, the summer season belongs to June, July, and August, and the minimum amount of solar radiation was found in August. During that month a high amount of rainfall was observed, and minimum amount of average temperature was observed. On studying the graph of variation of GSR with various meteorological parameters well-accepted relations were found. A direct relation is found between GSR and average maximum temperature, minimum temperature, rainfall, and relative humidity.

Keywords**:** *Solar energy, meteorological parameter, global solar radiation (GSR)*

1. Introduction

All living things on Earth require energy to survive; otherwise, our cosmos would be nothing more than a frozen rock. The primary energy source on the surface of the world is electromagnetic radiation, or radiant energy, which the planet receives from the sun. Solar energy controls all of the energy sources found on the globe's surface, whether they are renewable, non-renewable, or the final source (Elekalachi et al. 2016).

One of the cheapest and fastest-growing power sources in the world is solar energy, which may be exploited primarily through photovoltaic and solar thermal capture technologies. 86% of all homes had access to power, according to the Nepal Power Authority's (NEA) report for the 2019–2020 fiscal year. The total amount of electricity produced by the power plants was 3021 GWh, 18.57% more than in the fiscal year (FY) 2018–2019, The main energy sources in Nepal include coal, hydroelectricity, biomass, natural gas, and petroleum products. Of the population, 78% have access to grid-connected energy, while 82% cook using solid fuels like coal, wood, and dung. Most home uses account for ninety-five percent (95%) of biomass, which has a negative environmental impact. The second most common energy fuel in Nepal is petroleum, which is imported and non-renewable (Shrestha, Thapa, and Gautam 2019a). Hence, solar energy can be considered one of the best, easily accessible, and renewable types of energy sources for Nepal. Human health and the environment are directly impacted by fossil fuels. They are also pricey. Numerous issues plague large hydropower projects, including sedimentation, landslides, and harm to vegetation, aquatic life, and ecology. Cultural difficulties and rehabilitation are two examples of societal obstacles. Therefore, solar electricity, which is inexpensive, widely accessible, and ecologically beneficial, can be a good alternative energy source that can be deployed anywhere. *https://kathmandupost.com/money/2019/06/04/955-percent-of-nepalis-have-an-electricity-connection-report-says*. Before putting in solar devices, it is important to have a precise understanding of the site's location and weather conditions. Meteorological forecasts, photovoltaic and agricultural studies, atmospheric energy balance studies, and building thermal load analyses should all be accessible and dependable for the design and performance assessment of solar technology (Kumar, Aggarwal, and Sharma 2013).

The energy density of incoming solar radiation (extraterrestrial solar radiation) is influenced by other metrological and geological elements. Latitude, sunshine duration, solar declination, precipitation, relative humidity (RH), air pressure, air temperature, solar zenith angle, and earth atmosphere are some of these variables. In this context, the total of the direct, diffused, and reflected radiation is known as the GSR (Iqbal 2012). GSR can be calculated using a variety of models; however, the model to be employed in a given area depends on the availability and applicability of meteorological information. Few studies have been conducted on the calculation of GSR in Nepal because there are few meteorological stations and incomplete data on climatic parameters. Using the Angstrom-Prescott model, (Adhikari, Bhattarai, and Gurung 2013) calculated the GSR for Biratnagar, Kathmandu, Pokhara, and Jumla, which are located at 72, 1350, 800, and 2850 meters above sea level, respectively. Jumla, located at a higher altitude with clearer skies and fewer aerosols, recorded highest GSR of 25.21 MJ/m^2/day, while Biratnagar, with more cloudy days, had lowest at 7.508 MJ/m^2/day, found excellent agreement between the estimated and measured values of GSR. the GSR using models based on temperature and RH.

They found that while there is an inverse link between RH and GSR, there is a direct relationship between temperature and GSR. Additionally, they found a high link between the estimated and observed values (Adhikari, Gurung, and Bhattarai 2014). Here, we use the empirical model to estimate the global solar radiation by estimating the sunshine hour data. In addition to the GSR and the sunshine hour, we study the impact of meteorological parameters on global solar radiation and evaluate its performance in Nepalgunj Airport, Banke, Nepal.

The information of the GSR is of particular significance in reliable evaluation of the solar energy potential in a given locality (Nwokolo and Ogbulezie 2018). Utilizing solar energy requires accurate information about global solar radiation (GSR), which is critical for designers and manufacturers of solar energy systems and equipment (Gouda et al. 2020). It is also an essential physical quantity for agricultural management and designing infrastructures (Iiyama 2024). The study of the impact of meteorological parameters on GSR at Nepalgunj Airport, Nepal, highlights several research gaps. Nepalgunj, located in the subtropical region of Nepal, experiences unique climatic conditions influenced by seasonal monsoons, temperature fluctuations, varying levels of humidity, and rainfall. However, there is limited research analyzing how these factors influence GSR at a localized scale. Existing studies primarily focus on global or regional trends, often neglecting the specific meteorological dynamics of Nepalgunj. This gap is critical, as understanding the relationship between meteorological parameters and GSR could optimize solar energy utilization and contribute to sustainable development in Nepal.

2. Materials and methodology

The data of daily global solar radiation, maximum and minimum temperature, rainfall, and RH on a horizontal surface for Nepalgunj airport, Nepal in 2020 were collected from the archives of the Department of Hydrology and Meteorology, Government of Nepal (DHM/GoN), were fitted by using origin software, and excel.

2.1. Study area

Nepalgunj is situated at 28°05' North latitude and 81°36' East longitude at an elevation of 150 m from sea level. It is a sub-metropolitan city of Banke district included within Lumbini Province. It is the fourth largest city in terms of population with 1,28,952 as a population of 2017 and second in terms of population density of 1616.84 per km^2. The climate is classified as warm and temperate. The summers here have a good deal of rainfall, while the winters have very little. The average annual temperature is 23.37°C with precipitation here around 1172.8 mm. The basis for the estimation of TSR for the places with similar features can be provided through the overall climatic and geographical features of Nepalgunj.

2.2 Theoretical detail

The Angstrom-Prescott, Tiwari, and Sangeeta models (Kumar et al. 2013) are used to calculate the GSR theoretically on a horizontal surface with the help of the estimated sunshine hour of the year 2020 in Nepalgunj Airport. The model is given by:

$$\frac{H}{Ho} = a + b\left(\frac{n}{N}\right)$$

Where, H is the Monthly average daily GSR on the horizontal surface, H_0 is the Monthly average daily extraterrestrial radiation, n is the monthly average daily number of hours of bright sunshine, N is the average daily number of possible sunshine, and a and b are the regression constant. Vasel and Iakovidis 2017 in their paper have presented a regression equation which is based on the monthly daily temperature. Equation (2) was used to estimate the sunshine hour data of Nepalgunj Airport.

$$n = 4.352 + 0.232T$$

Where n is the sunshine hour and T is the average daily mean temperature.

The extraterrestrial solar radiation (Ho) on a horizontal surface is given by (Lee, Rahim, and Al-Turki 2013) as follows;

$$Ho = \frac{24}{\pi} * IscEo[(\frac{\pi}{180})\omega s(Sin\delta Sin\emptyset) + (Cos\emptyset Cos\delta Sin\omega s)]$$

Where Isc and E_0 are the solar constant and eccentricity correction factor, which is given as,

$$Isc = \frac{1367*3600}{10^6} \quad \text{MJ/m}^2\text{/day}$$

$$Eo = 1 + 0.33Cos\frac{360\,Nd}{365}$$

Where, Nd is the day of the year, Julian days (1^{st} January, Nd = 1 and 31^{st} December, Nd=365). ωs is the hour angle, $\emptyset$ being the latitude of the site and δ is the solar declination which can be calculated as,

$$\omega s = arcCos(-tan\emptyset tan\delta)$$

$$\delta = 23.45[\frac{360(Nd + 284)}{365}]$$

The maximum possible sunshine hours or day length can be calculated as,

$$N = \frac{2}{15}arcCos(-tan\emptyset tan\delta)$$

$$= \frac{2}{15} \omega s$$

The regression coefficients a and b are calculated by using Sangeeta and Tiwari model [10, 15],

$$a = -0.110 + 0.235 cos\emptyset + 0.323 \frac{n}{N}$$

$$b = 1.449 - 0.553 cos\emptyset - 0.694 \frac{n}{N}$$

Where, $\emptyset$ is the latitude of the location

To predict the accuracy of the model and to know how the calculated GSR (Hc) varies with measured GSR (Hm) following statistical test is done.

$$RMSE = \left[\sum_{i=1}^{n} \frac{(Hic - Him)^2}{N}\right]^{\frac{1}{2}}$$

Where n is the number of data, i.e., several months, Him is the i^{th} measured value, Hic is the i^{th} calculated value and N is the number of observations. Root Mean Square Error (RMSE) measures how much error is obtained between the calculated and the measured data set. Also tells us how the calculated GSR deviates from the measured GSR.

$$MBE = \frac{\sum_{i=1}^{n}(Hic - Him)}{N}$$

Mean bias error (MBE) is an indication of the average deviation of calculated values from the measured values.

$$MPE = \frac{\sum_{i=1}^{n} \frac{(Him - Hic)}{Him} * 100}{N}$$

Mean percentage error (MPE) is the computed average of the percentage of errors by which the calculated value of a model differs from the measurement values of the quantity being predicted.

$$MAE = \frac{\sum_{i=1}^{n} |(Hic - Him)|}{N}$$

Mean absolute error (MAE) measures how far calculated values are away from the measured values. Hence, another statistical parameter like the coefficient of regression (R), and coefficient of determination (R^2) is also calculated.

3. Results and discussion

In this chapter, we study the variation of maximum and minimum air temperature, RH, and rainfall on GSR. CMP3 pyranometer is used to measure GSR and becomes the backbone for the study to be carried out. Also, we study the daily variation, monthly variation, and seasonal variation of GSR of Nepalgunj Airport Nepal of the year 2020 A.D.

3.1 Seasonal variation of GSR

The seasonal variation of GSR shown in figure 1 reveals it was maximum in spring, i.e., 24.75 $MJ/m^2/day$ and minimum in winter season, i.e., 9.13 $MJ/m^2/day$ but always it is not possible to find minimum GSR in summer. It is because of the high wind velocity and number of cloudy days, unexpectedly high amount of rainfall in summer reduces GSR. So, it can be made clear that the value of solar energy can be utilized to promote solar applications.

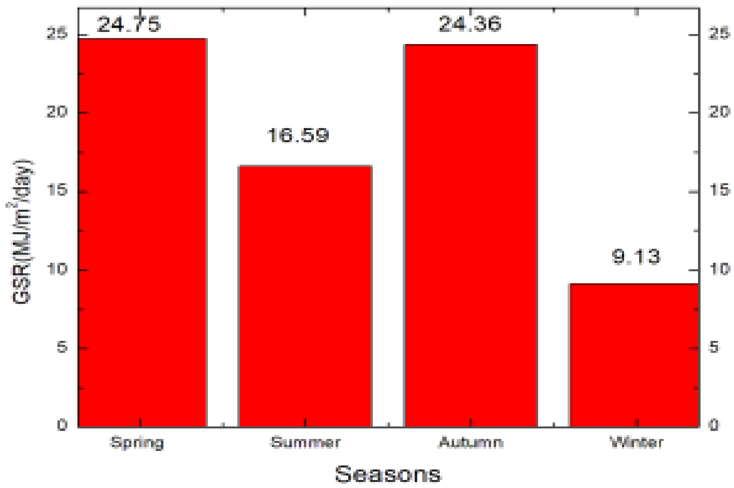

Fig.1: Seasonal variation of GSR.

3.2 Monthly variation of GSR

The monthly variation of GSR is displayed in figure 2, indicates the minimum and maximum values of monthly GSR. The low value of GSR was found in January, August, and December. It may be due to cloudy skies and rainy circumstances (average rainfall 3.62 mm per day). This is not always true but the main thing is in winter it is obvious to all that GSR is low compared to summer and the maximum value of GSR found in April, June and September is 27.64 $MJ/m^2/day$, 25.78 $MJ/m^2/day$, 27.01 $MJ/m^2/day$.

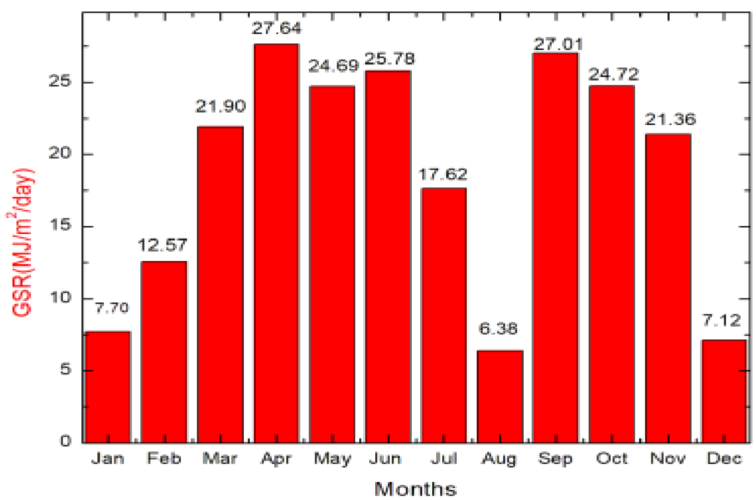

Fig.2: Monthly variation of GSR.

3.3 Daily Variation of GSR

The different meteorological parameters which include rainfall, maximum and minimum temperature, and RH adversely affect GSR. The main aim of studying the daily variation is to know the status of GSR at that place. The daily variation of GSR at Nepalgunj airport, Nepal in the year 2020 A.D. Figure 3 illustrates that the value of GSR is continuously increasing and was found at a maximum of 22.35 $MJ/m^2/day$ in March.

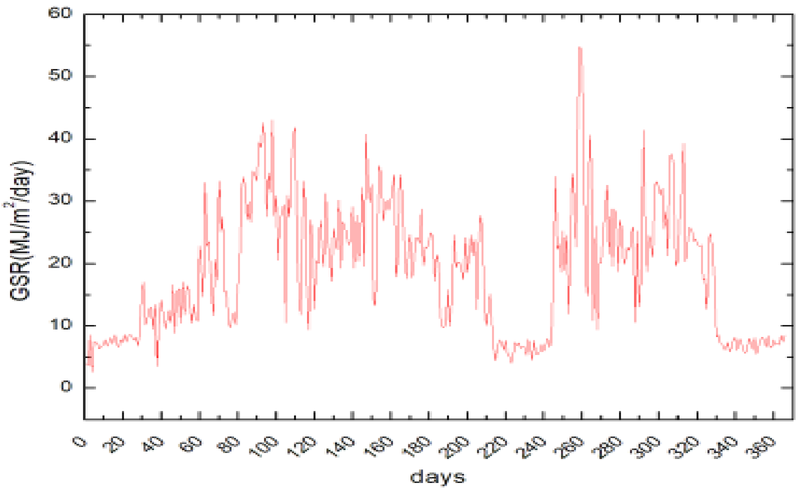

Fig. 3: Daily variation of GSR.

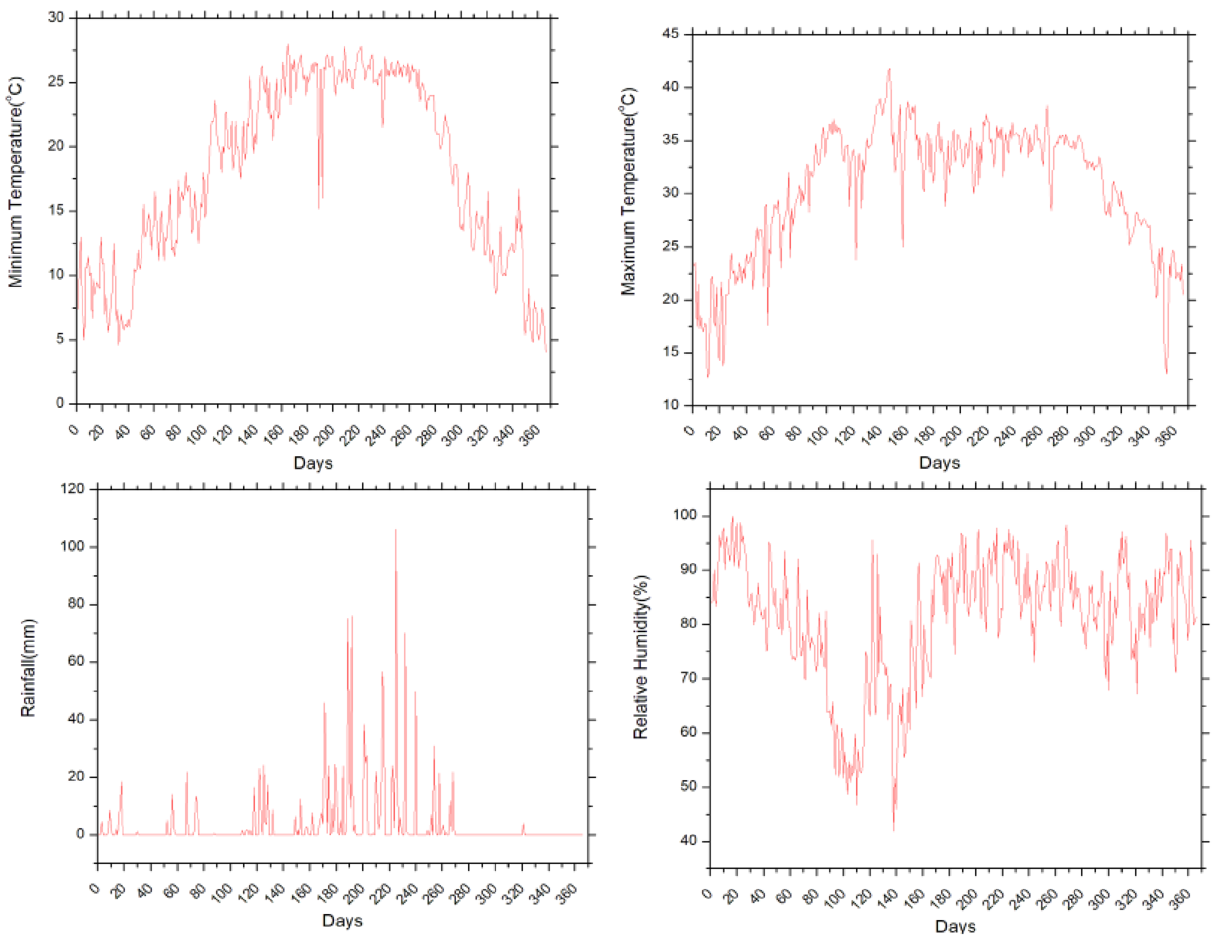

Fig 4: Daily variations of maximum temperature, minimum temperature, RH and rainfall.

This is because it is the end of the winter season, and the fog and moist formation process decreases which influences the increase of GSR. After reaching the peak, the GSR decreases and was found to be a minimum of 9.35$MJ/m^2/day$ in August, it was due to the rainy season and there was high rainfall and RH was also maximum. Yearly 18.73$MJ/m^2/day$ of GSR was found in the year 2020.The maximum value of GSR suggests that there is a high potential for solar farming at that place. Furthermore, the variations in maximum temperature, minimum temperature, RH, and rainfall are shown in figure 4 below.

3.5 Daily variation of GSR with average maximum temperature

Air Temperature is one of the meteorological parameters which directly affect the GSR. As temperature increases, GSR also increases and vice versa. The daily variation of GSR with average maximum temperature is presented in figure 5.

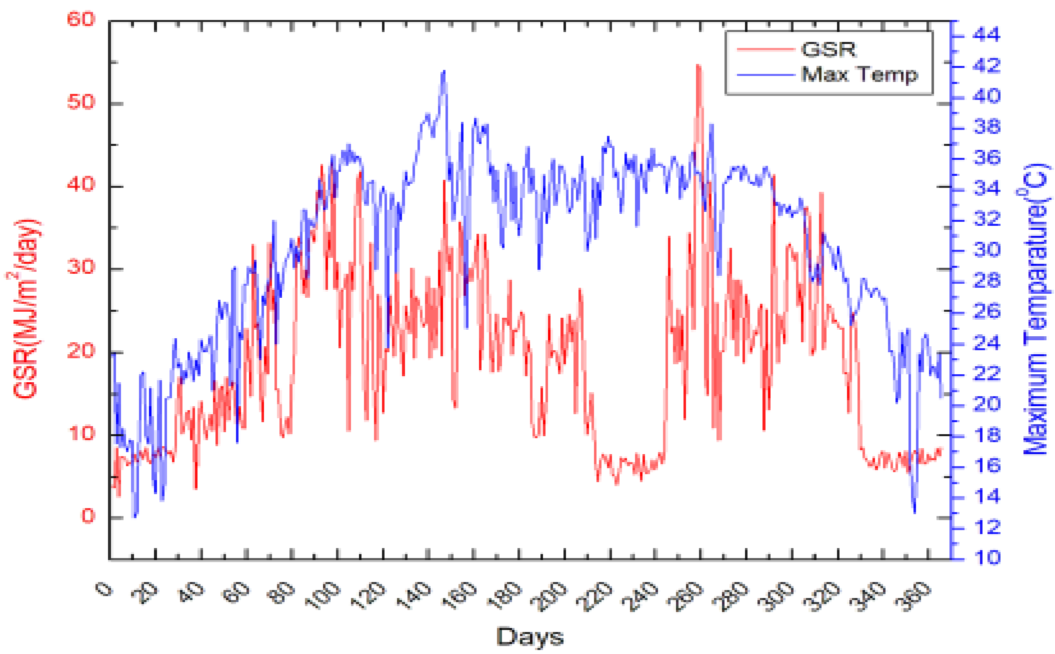

Fig. 5: Daily variation of GSR with average maximum temperature.

The above figure shows that there was strong agreement between measure GSR and maximum temperature, it indicates that temperature varies from day to day and season to season due to the rotation of the earth. In the above figure at first, both temperature and GSR increases become maximum and both decrease sharply due to the cloudy days, high relative humidity, and a high frequency of rainfall in July, August, and September.

3.6 Daily variation of GSR with average Rainfall

Rainfall is an important factor that can affect the GSR. There was an inverse relation between GSR and rainfall. As rainfall increases GSR decreases and vice versa. Figure 6 demonstrates he high amount of rainfall can affect air temperature as well as the GSR of that place.

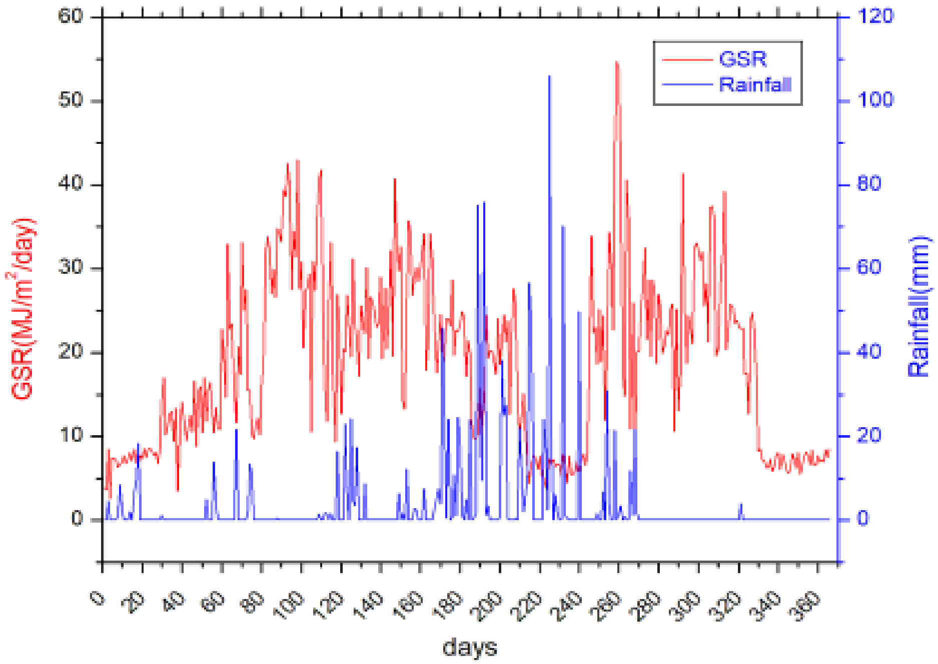

Fig.6: Daily variation of GSR with average rainfall

From the above graph, we can say that in starting of the month i.e. from January there is low rainfall, and GSR is found to increase after a certain month the number of rainfalls increases rapidly i.e. in the rainy season average of 9.68 mm of rainfall in three months July, August September. In the graph at the point of maximum rainfall, GSR cannot be seen since rainfall requires clouds in the sky, and in the presence of clouds GSR is blocked and scattered and the horizontal level of the ground cannot receive the expected amount during the rainfall which is indicated by the graph. In Nepalgunj airport, Nepal maximum of 10.51 mm of rainfall is found in Aug, and in the same month minimum GSR of 16.55 $MJ/m^2/day$ is found. So, Nepalgunj Airport, Nepal is a place where a high amount of rainfall is found in the rainy season of the year 2020 A.D. which is suitable for agriculture production and also equally important for solar energy farming.

3.7 Monthly variation of GSR with relative humidity (RH)

The inverse relation is found between GSR and RH i.e. more is the relative humidity less GSR is found and vice versa. RH is defined as the amount of water vapor present in air expressed as a percentage of the amount needed for saturation at the same temperature (Shrestha, Thapa, and Gautam 2019).The GSR is scattering due to the presence of water in the air and the expected amount of GSR cannot be found on the ground. The monthly variation of GSR and RH is shown in figure 7.

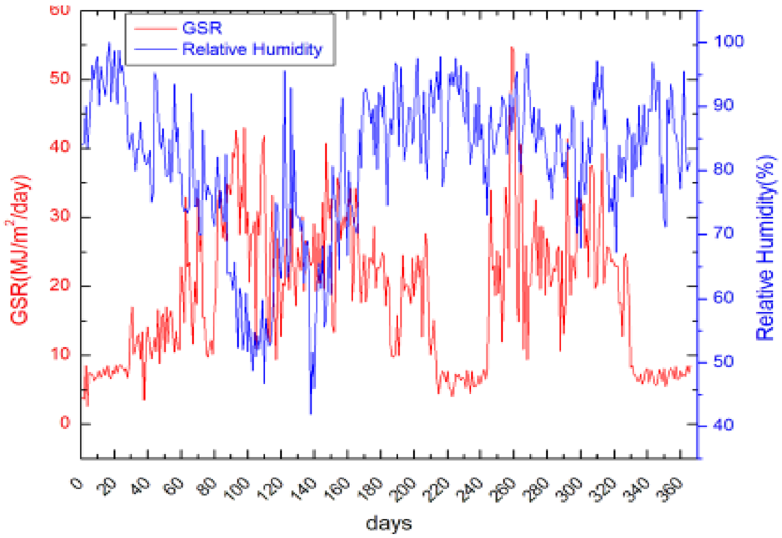

Fig. 7: Monthly variation of GSR with relative humidity

There is strong agreement between the inverse relation between GSR and RH. Low RH is found due to the dryness and presence of moisture. A minimum of 66.86% of RH is found in March and April i.e. in the winter season and a maximum of 92.86% of RH is found in December and June i.e. in the summer season. In summer there is the presence of lots of water vapor and the water in the air acts as a disturbance for GSR that falls on the ground which decreases the amount of GSR that has to befall on the surface and there is no possibility of very low humidity at that place which is a favorable environment for tourist. The future energy harvesting project along with its effect on vegetation can be made.

3.8 Daily variation of GSR with Minimum temperature

Minimum temperature is one meteorological parameter that directly affects the GSR.As temperature increases, GSR also increases and vice versa. The figure 8 gives information about the daily variation of GSR with average minimum temperature in Nepalgunj.

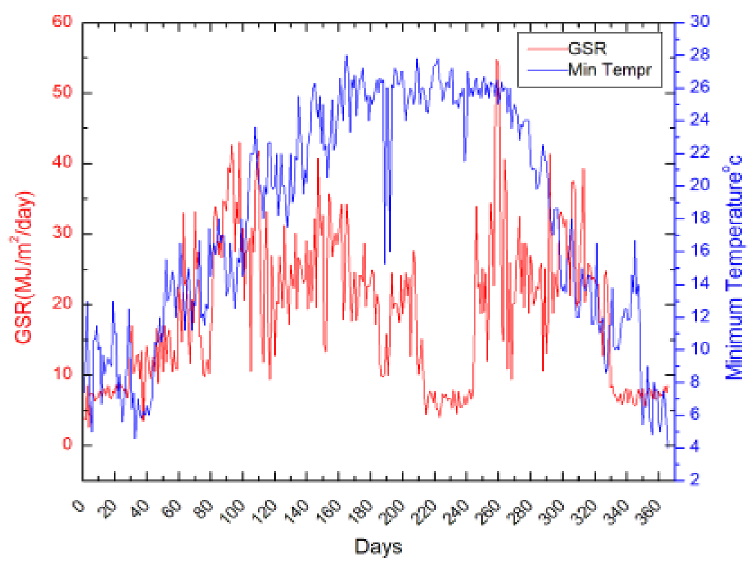

Fig. 8: Daily variation of GSR with Minimum Temperature

The above figure shows that there is strong agreement between measure GSR and minimum temperature, it indicates that temperature varies from day to day and season to season due to the rotation of the earth. In the above figure at first, temperature and GSR increases become maximum and both decrease sharply due to the cloudy days and high relative humidity.

4. Conclusion

The measured GSR and other meteorological parameters were studied by using origin 6.10 software and Microsoft Excel. The GSR of the year in 2020 at Nepalgunj Airport, Nepal was measured at the horizontal surface using a CMP3 pyranometer. The yearly average value of GSR for the year 2020 is 18.73 $MJ/m^2/day$. The measured and calculated value of GSR confirms that Nepalgunj airport, Nepal is a place where the high potential of solar radiation is observed, and which is sufficient to promote solar energy technology at the terrain of Nepalgunj and similar geographical locations of Nepal. The measured GSR on a horizontal surface was found to be maximum in April and minimum in August, it may be due to the high amount of rainfall in August. On studying the graph of variation of GSR with various meteorological parameters well-accepted relations were found. A direct relation is found between GSR and average maximum temperature, minimum temperature, rainfall, and relative humidity similarly, an inverse relation is found between GSR and rainfall and relative Humidity. This is all due to the variation in the zenith angle, atmospheric conditions, and revolution of the earth which cause seasonal variations. Hence all this finding supports solving the energy crisis problem, of harvesting solar energy and also help to inform internal as well as an external tourist about Nepalgunj Airport, Nepal.

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Conflict of interest

The authors report that there are no conflicts of interest.

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