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ABSTRACT

The present study aims to determine the analysis of available satellite-derived data (https://power.larc.nasa.gov) of solar radiation and meteorological parameters (temperature and relative humidity) at the National Aeronautics and Space Administration (NASA) for three main places, namely – Gopeshwar (30.40ºN, 79.31ºE), Nainital (29.38ºN, 79.46ºE) and Pithoragarh (29.58º N, 80.21ºE) of Uttarakhand. The seasonal average data of solar radiation and meteorological parameters recorded for a period of six years (2013-2018) are utilised in the present investigation. Three statistical treatments (standard deviation, kurtosis and skewness) were performed to check the accuracy of data. A trend analysis of the maximum and minimum seasonal average data of global solar radiation, temperature and relative humidity. The highest global solar radiation recorded as 11.23 kWh/m^2 (autumn) for the Nainital location and the lowest global solar radiation recorded as 4.80 kWh/m^2 (winter) for Gopeshwar location. The results show increases in trends and anomalous behavior that may be considered as a result of the effect of climate change and climate variability. Investigation of data indicated that Nainital location obtains an ample amount of global solar radiation, indicating the strong potential for the use of solar energy. Through this type of study we observe the climatic conditions for any particular site.

Keywords: *Solar radiation, Climate change, statistical parameters, meteorological parameters.*

INTRODUCTION

On the earth, sunlight is cleaned over earth's atmosphere which is the main energy source of the earth's surface environment and is observable as sunshine when the sun is beyond the horizon. When the solar radiation is not blocked through clouds, it is skilled as sunshine, a combination of bright light and radiant heat, if it is blocked by clouds or reflects in edible other objects, it is skilled as diffused light [1]. The sun produces electromagnetic radiation through the maximum of the electromagnetic spectrum. The invisible radiation is also emitted gamma rays, x-rays, ultraviolet, visible light, infrared, and radio waves [2]. Radio waves are also emitted by gases and stars in space. Infrared light emitted through our skin and objects with heat. In space, infrared light helps us plan the dust among stars. Infrared radiation from the sun is absorbed and concludes the atmospheric molecules like-water vapor, carbon dioxide, and ozone [3]. Solar radiation is an enormous consequence to worldwide climate transform and human actions (agricultural production, medical sector, solar power generation, etc.) [4-6]. The spatial and sequential distributions of the clear-sky conditions offer an significant suggestion for evaluating the impact of natural inconsistency and human activities on climate change. The changes in solar radiation have intense outcomes on the earth's surface temperature, water cycle and the environment [7-9] The concentration of solar radiation at a given location depends on the consequent latitude, geography, season, time and atmospheric conditions [10-12]. The astronomical aspects determine how much solar radiation reaches the top of the atmosphere, and are also the main factors for the daily and seasonal variations in solar radiation. The atmospheric conditions conclude the advance changes, and clouds are the main driving factor of atmospheric conditions [6, 13]. Solar radiation data is critical to the design and operation of solar energy utilization systems, a large number of models have been proposed and developed to estimate solar radiation and meteorological parameters in the previous years. Estimations of the hourly, monthly, annually, and seasonally average solar radiation data for a large number of locations are presented by many researchers [14-22]. There are several formulae which relate to solar radiation to other climatic parameters

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such as sunshine hours, relative humidity, temperature etc. The most commonly used parameter for estimating solar radiation is sunshine duration which is easily and reliably measured data and widely available. As well as statistical parameters (standard deviation, kurtosis, correlation coefficient, skewness and errors) also shows the good agreement of solar radiation data for a particular site. In the present study, three parameters (standard deviation, kurtosis and skewness) are used to calculate the approximately good accuracy of global solar radiation and meteorological data. The satellite-derived data is collected from the National Aeronautics and Space Administration (NASA) organization “Prediction of Worldwide Energy Resource" (POWER). This organization gives global coverage on 1o latitude by1 longitude grid. Satellite-derived NASA (https://power.larc.nasa.gov) is used in the present investigation. The (POWER) project was introduced to progress upon the current renewable energy data set and to make new data sets from new satellite systems. The POWER projects target three user groups viz., Sustainable Buildings, Renewable Energy, and Agro climatology. Sustained Building record is calculated to provide industry-friendly parameters for the buildings community, to contain parameters in multi-year monthly averages. The database in this study includes 6 years of data from 2013 to 2018. An investigation is carried out for the global solar radiation, temperature, and relative humidity data for three locations of Uttarakhand (Gopeshwar, Nainital, and Pithoragarh), India. In the present paper, we analyze the seasonal variations of global solar radiation and meteorological parameters for three selected sites in Uttarakhand the satellite derived data has been used in the present observations. The organization of this paper is as follows. A brief description of the study sites is presented in section 2.1 and detailed statistical parameters are performed in section 2.2 followed by the results and discussion (section 3). A summary and conclusions are presented in section 4.

MATERIAL AND METHODOLOGY

Description of study sites: The study is based on the meteorological parameters (temperature and relative humidity) and global solar radiation data, mainly three sites (Gopeshwar, Nainital, and Pithoragarh) are selected for this current investigation of Uttarakhand in Himalayan region. The detailed information of the sites are shown in Fig. 1.

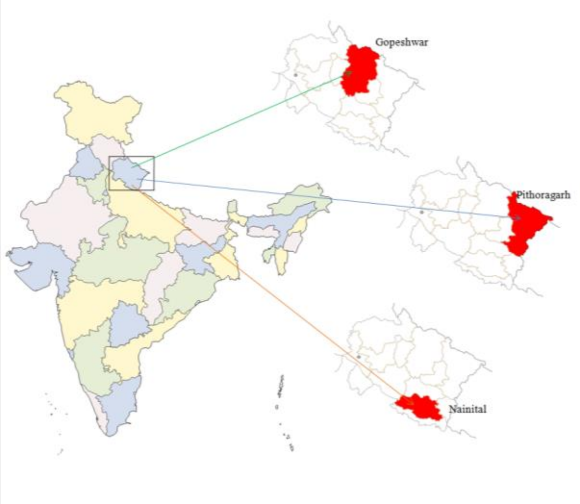

Fig. 1: Location of the study sites in Uttarakhand state, India.

Gopeshwar is a township in the Garhwal hills and a municipal boarding inside the Chamoli district and located at 1,550 m (5,090 ft.) above the sea level. The lat-long of Gopeshwar is 30.40°N-79.31°E. Gopeshwar is able to captivate any tourist with its mystical charm and pristine beauty. There are several snow-capped hills and peaks observable from Gopeshwar [23]. Nainital is situated at an altitude of 2,084 meters (6,837ft) above the sea level and the latitude and longitude of Nainital are 29.38°N and 79.46°E respectively [24]. Nainital is a little dry in winter and very rainy during summer due to the Indian South-west monsoon system[25]. Pithoragarh is the biggest prepared semi-urban to urban town and village cluster in the hills of Uttarakhand [26]. The latitude and longitude are 29.58° N and 80.21°E respectively. Pithoragarh district has extreme variation in temperature due to large variations in altitude [27]. In the present investigation, the study is carried out by seasonal average satellite derived data of global radiation, temperature, and relative humidity for three locations of Uttarakhand in Himalayan region, India during the period of 6 years (2013 to 2018) are used for the current analysis. The seasonal months are characterized by winter (December and January), spring (February and March), summer (April to June), monsoon (July to September), and autumn (October and November) in this paper [28].

Statistical Performance: Statistical factors are used to ensure the accuracy of data and verify its reliability. The statistical parameters, standard deviation (SD), skewness (SKEW), and kurtosis (KURT) are used to verify the performance of global solar radiation, temperature, and relative humidity data [29]. SD used to quantify the amount of variation or spreading of agreed data values. A low SD describes that the data points tend to be nearby to the mean (expected value) of the set; however a high SD specifies that the data points are spread out over a broader range of values. The calculation formulas are as follows:

$$SD=\sqrt{\frac{\sum(x-\bar{x})^2}{(n-1)}}, \quad \ldots(1)$$

where, x is the sample mean average, $\underline{x}$ is the mean value of the observation and n is the number of observations [30].

SKEW is a quantity of symmetry, additionally accurately, lack of symmetry, or data set of symmetry, if it looks the same to the left and right of the middle point. SKEW is zero for the ordinary distribution, and any symmetric data should have Skewness near to zero. Skewness can be positive as well as negative. Negative values for the skewness indicates data that the left skewed left and positive values for the skewness indicate data that the right skewed.

$$SKEW=\frac{n}{(n-1)(n-2)}\sum\left(\frac{x_j-\bar{x}}{s}\right)^3, \quad \ldots(2)$$

where, x_j is the j^{th} value of the observation and s is the standard deviation [31].

KURT is a statistical amount used to define the degree of peakedness which clusters in the tails on the peak of a frequency distribution. The peak is the tallest portion of the distribution, and the tails are the ends of the distribution. [32, 33].

$$KURT=\left\{\frac{n(n+1)}{(n-1)(n-2)(n-3)}\sum\left(\frac{x_j-\bar{x}}{s}\right)^4\right\}-\frac{3(n-1)^2}{(n-2)(n-3)}. \quad \ldots(3)$$

Where, x_j is the j^{th} value of the observation and s is the standard deviation [34].

RESULTS AND DISCUSSION

Study of temperature: The seasonal average study of temperature has been performed in Fig. 2 for three locations (Gopeshwar, Nainital, Pithoragarh) of the study. In Gopeshwar, the maximum seasonal average data of temperature recorded as 17.62ºC (summer) in the year of 2016 and summer starts from April to June it is hot in comparison to other seasons. and the maximum amount of temperature also found in the Monsoon season for all the selected years in the study and in the month of July to September (monsoon season) received the heaviest rainfall. The climate is extremely cool during the months of December to January (winter season). During the winter season weather is cool and the temperature is falling down up to the freezing point so that the minimum temperature recorded as 3.45ºC (winter season) in the year of 2013. The data values also show the minimum temperature in the spring season. After the spring season the amount of temperature is in increasing order up to monsoon season after that the data values start to decrease which depends on their weather and atmospheric conditions. In summer and monsoon seasons there is no more difference between the data values, it shows very less distribution between them it can be seen from the given figure. Similarly for Nainital, the highest and lowest amount of temperature recorded are 30.59 ºC (2017) and 12.81 ºC (2013) in the summer and winter season respectively with the large altitude in the winter season is extremely cool because of snowfalls. Thus, for the third location Pithoragarh, the maximum temperature recorded is 18.95ºC for summer season in the year of 2016 while, the minimum amount of temperature recorded as 4.99 ºC in winter season which is extremely minimum temperature in the year of 2013 and is freezing cold with snow at higher altitude. When the temperature is between 7 degree to 20 degree, and during the winter season the days are quite chilly and have an average temperature of 4 degree to 8 degree. Now if compare the temperature among three selected locations Nainital show the highest amount of temperature and the lowest is recorded for Gopeshwar according to their latitude and longitude.

Table 1 presents the results of statistical parameters of temperature for Gopeshwar, Nainital, and Pithoragarh locations. The maximum and minimum SD noticed for the Gopeshwar site are 1.45ºC (spring) and 0.29ºC

(Monsoon) respectively. Similarly, for the Nainital location the high and low values of SD are 7.82ºC (autumn) and 0.65ºC (Monsoon) respectively. Thus the highest amount of SD is 1.45ºC (spring), while the lowest amount is 0.35ºC (monsoon seasons) for Pithoragarh location. For the Gopeshwar site skewness is negative in summer and autumn season, so the skewness is left skewed and for the remaining season skewness value is positive, than which is right skewed. In the same way for Nainital the skewness value is negative in summer and spring season, so the data values show the underestimation, for the remaining seasons skewness is positive which shows the overestimation. All the selected locations show the kurtosis values are less than 3 in all the seasons. So that the curve is known as platykurtic because of distribution with negative excess.

Table 1: Statistical parameters of temperature for the selected sites of the study.

S.N.	Seasons	Gopeshwar			Nainital			Pithoragarh		
		SD	SKEW	KURT	SD	SKEW	KURT	SD	SKEW	KURT
1	Winter	1.175	0.916	-0.074	0.87	0.438	-1.503	1.151	0.38	-0.566
2	Spring	1.451	-0.611	-1.635	1.559	-0.477	-1.554	1.454	-0.392	-1.896
3	Summer	0.974	0.599	0.043	1.325	-0.191	-0.101	1.044	0.762	1.557
4	Monsoon	0.293	0.276	0.307	0.653	0.194	-0.334	0.35	-0.158	-1.341
5	Autumn	0.878	-0.539	-0.534	7.828	0.59	2.985	0.871	-0.692	-0.425

Table 2: Statistical parameters of relative humidity for the selected sites in the present study.

S.N.	Seasons	Gopeshwar			Nainital			Pithoragarh		
		SD	SKEW	KURT	SD	SKEW	KURT	SD	SKEW	KURT
1	Winter	10.1	-1.152	0.786	8.249	0.171	-0.959	9.493	-0.584	-0.659
2	Spring	12.772	0.17	-1.358	12.676	0.362	-1.922	13.284	0.242	-1.616
3	Summer	9.379	0.116	-0.137	8.576	0.42	0.679	10.158	0.207	0.657
4	Monsoon	3.833	-0.791	1.41	6.28	-0.722	0.937	3.866	-0.866	0.822
5	Autumn	8.449	-0.399	0.806	10.158	0.789	-0.272	8.026	0.102	0.503

Table 3: Statistical parameters of global solar radiation for the selected locations.

S.N.	Seasons	Gopeshwar			Nainital			Pithoragarh		
		SD	SKEW	KURT	SD	SKEW	KURT	SD	SKEW	KURT
1	Winter	0.157	0.869	1.251	0.19	-0.117	1.041	0.149	0.625	1.953
2	Spring	0.129	0.572	-0.843	0.155	0.212	-1.314	0.121	0.405	-0.995
3	Summer	0.187	0.061	-0.318	0.194	0.157	-0.178	0.200	0.114	-0.271
4	Monsoon	0.137	-0.323	0.257	0.092	-0.875	1.798	0.114	-0.562	1.155
5	Autumn	0.189	0.286	-0.768	9.886	1.601	3.933	0.240	0.271	-0.032

Study of relative humidity: The variation of seasonal average data of relative humidity has been showing in Fig. 3 for these three locations of the study. The maximum amount of relative humidity recorded for Gopeshwar, Nainital and Pithoragarh are 90.99%, 86.40% and 89.67% respectively for the same monsoon season and in the same year 2013. Because of the relative humidity is high during monsoon season, generally exceeding 70% on the average. Since it is in the monsoon period, rainfall mostly occurred in the month of July to September, while temperature in these months is nearly high which makes the presence of water vapor quite high. July and August are often called humid months. While the minimum relative humidity for Gopeshwar and Pithoragarh locations are 32.90% and 32.83% respectively in the same year 2016 and same winter season. Thus the lowest amount found for Nainital is

29.57% in spring season (2018). For the reason that the winter air contains less water, so the relative humidity is lower in the winter season. But actually relative humidity depends on the places, some places will have higher relative humidity in the winter, some not like that Nainital in which the minimum relative humidity is not shown in winter season while it is shown in summer season because of the Nainital have some very humid months, and slightly dry months in the opposite season. According to the graph of relative humidity for three locations, maximum values of relative humidity are shown in the monsoon season and minimum values are shown in the winter season.

The statistical factors of relative humidity for the three locations (Gopeshwar, Nainital, and Pithoragarh) are characterized in the given Table 2. In spring season, Gopeshwar and Nainital have the largest value of SD which is calculated are 12.77% and 12.68% respectively, thus the highest value for Pithoragarh was found 13.29% in the spring season. Similarly, the lowest SD of Gopeshwar, Nainital, and Pithoragarh are 3.83%, 6.28%, 3.87% respectively for the same monsoon season. Now, the skewness value is positive in the spring and summer season for Gopeshwar site which shows the distribution is right skewed and let season show the skew is left skewed. Skewness is positive in Nainital for all the seasons excluding monsoon season so i.e. defined as the right tail is longer and the distribution is said to be right skewed. Therefore, skewness is negative in the winter and monsoon season and the data values show the distribution is left skewed and for the remaining seasons skewness is positive and right skewed. Kurtosis is less than 3 for all the selected locations than the curve is showing a flat distribution of data values of relative humidity.

Study of global solar radiation: The graphical demonstration is shown in Fig. 4. The highest points of global solar radiation data recorded are 7.89, 9.86 and 9.23 kWh/m^2 for Gopeshwar, Nainital and Pithoragarh locations respectively for the same season (Monsoon) and same in the year (2018). minimum radiation is 4.63 kWh/m^2 (winter) in 2013. For the reason that the dry seasons months are March-July have high solar energy potential in terms of global solar radiation and long sunshine duration with mostly clear skies led to the high availability of solar energy in these months. Conversely, the low amount (4.64 kWh/m^2) of solar radiation was found for Gopeshwar in the winter season (2013). The minimum global solar radiation data observed during the winter season is the heavy fog and precipitation that usually occur during the season so that the minimum amount recorded. For Nainital and Pithoragarh the minimum values for global solar radiation are found 6.16 kWh/m^2 and 5.76 kWh/m^2 respectively for the same season (winter season) and same in the year (2018). Therefore the maximum and minimum global solar radiation is present in the monsoon and winter seasons respectively.

Now the statistical indicators (SD, KURT, and SKEW) for global solar radiation data are shown in the given Table 3. The highest values of SD for Gopeshwar, Nainital, and Pithoragarh are 0.189 kWh/m^2, 9.886 kWh/m^2 and 0.240 kWh/m^2 respectively and all these values are in the autumn season. The minimum deviation recorded for Gopeshwar location is 0.129 kWh/m^2 (spring season). Furthermore the minimum SD for Pithoragarh and Nainital sites are 0.092 kWh/m^2 and 0.114 kWh/m^2 respectively both are the same in the monsoon season. Skewness is negative for the Gopeshwar and Pithoragarh location in the monsoon season which show the left skewed while the remaining seasons show positive values for the location i.e. show the distribution is right skewed. The data points of kurtosis are less than 3 in every season and for each and every one the locations, if kurtosis is greater than 3 than the curve is give an idea about the leptokurtic, and shows the high variation in global radiation distribution, whereas the less than 3 values of kurtosis are showing the less variance and flat distribution of global solar radiation, and that type of curve is called the platykurtic.

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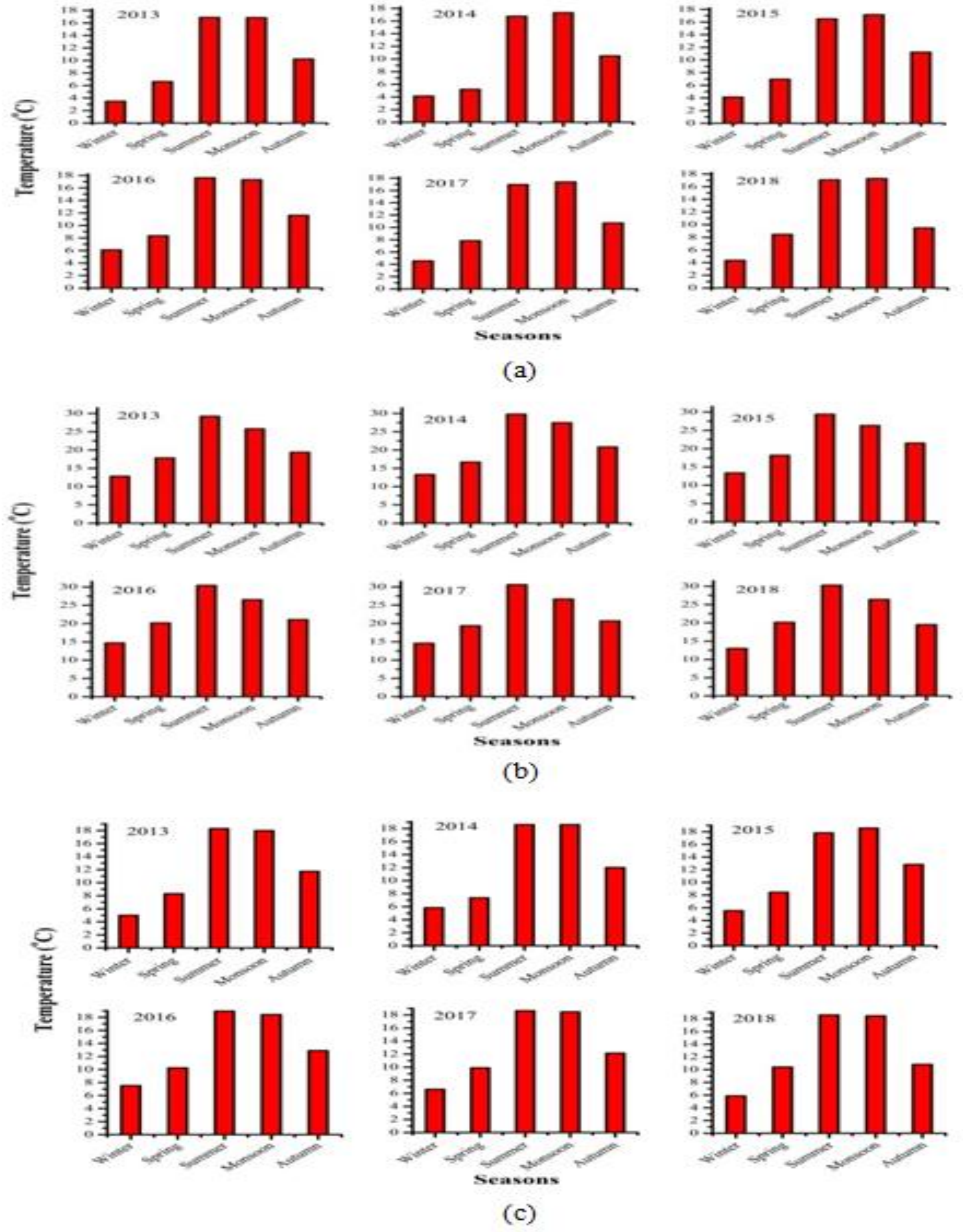


Fig. 2. Seasonal variation of temperature for the (a) Gopeshwar, (b) Nainital and (c) Pithoragarh sites.

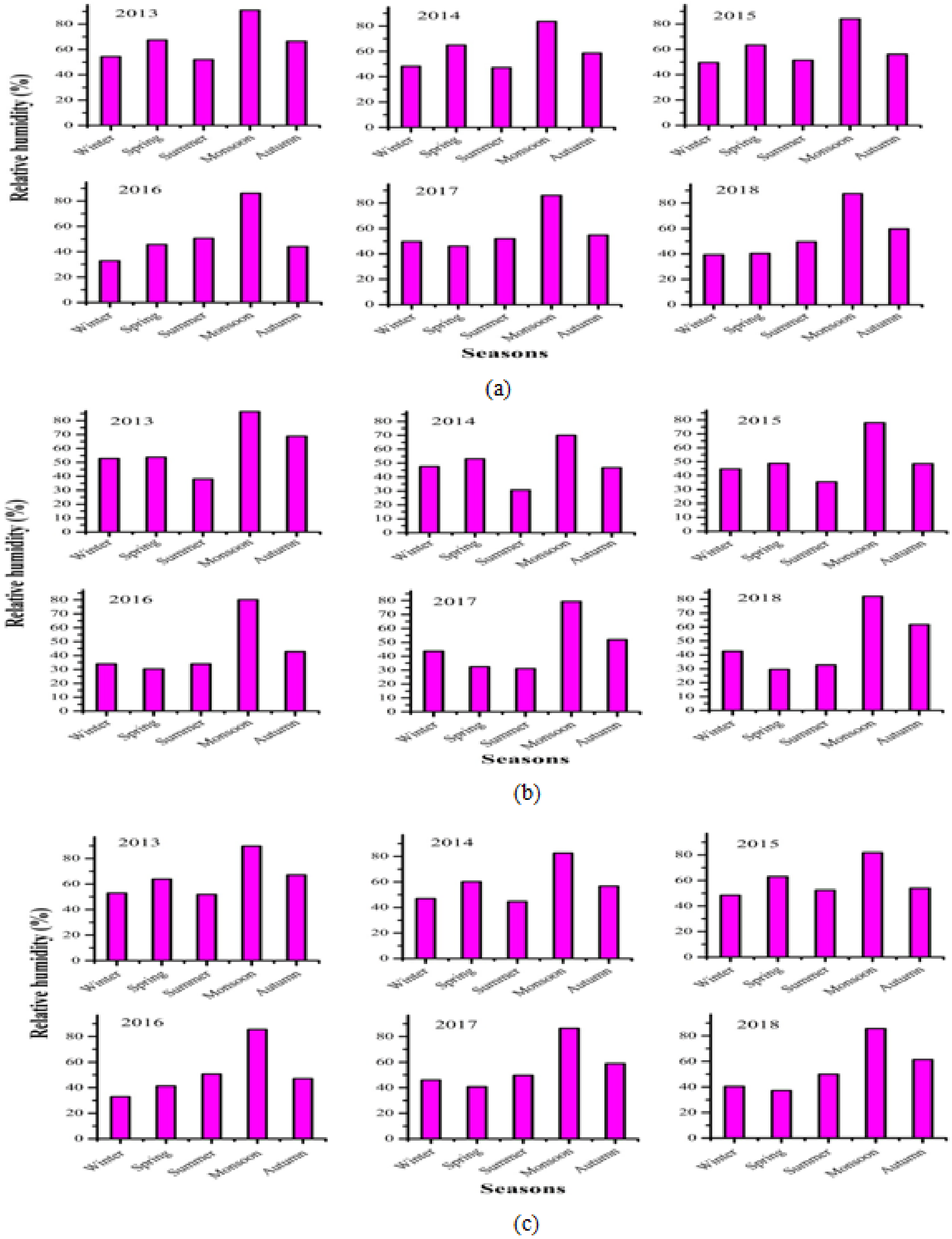
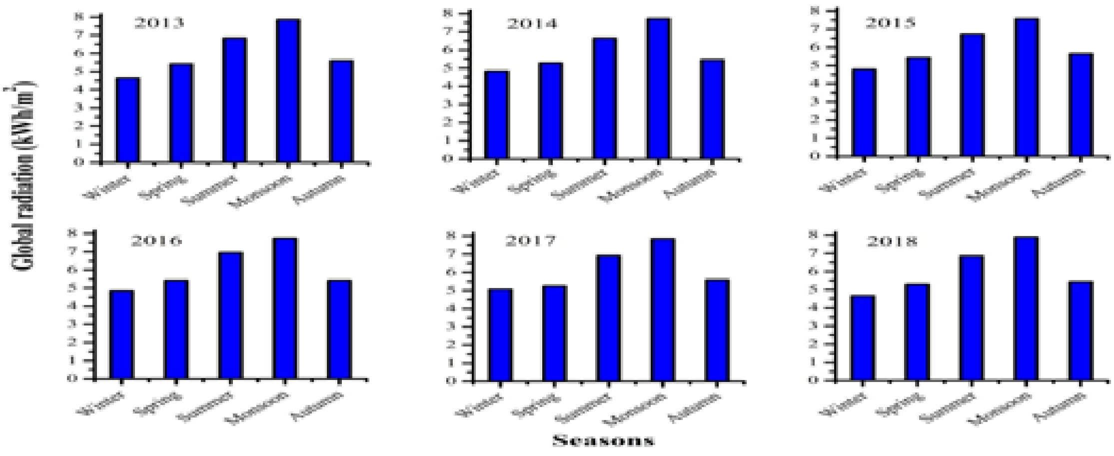
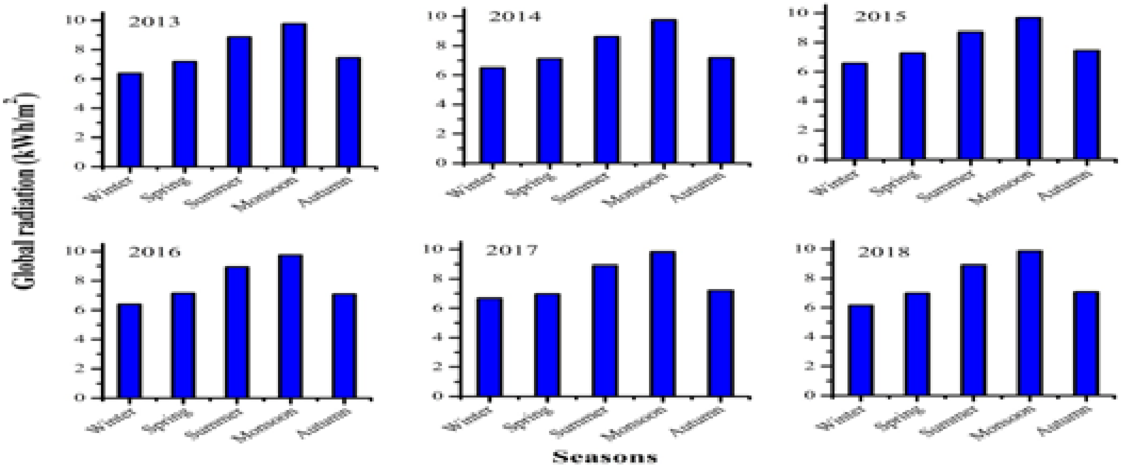


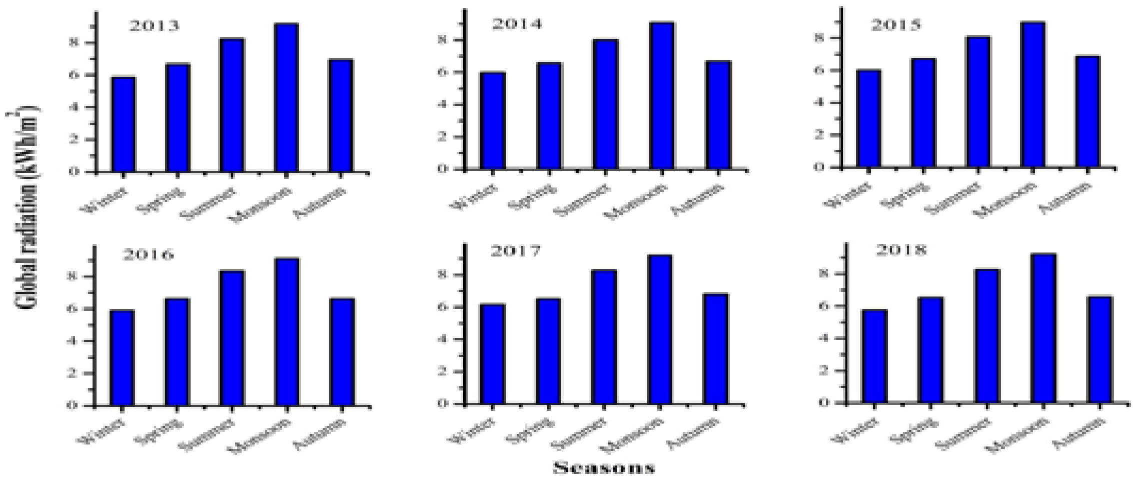
Fig. 3. Seasonal variation of Relative humidity for the (a) Gopeshwar, (b) Nainital and (c) Pithoragarh sites.



(a)



(b)



(c)

Fig. 4. Seasonal variation of global solar radiation for the (a) Gopeshwar, (b) Nainital and (c) Pithoragarh sites.

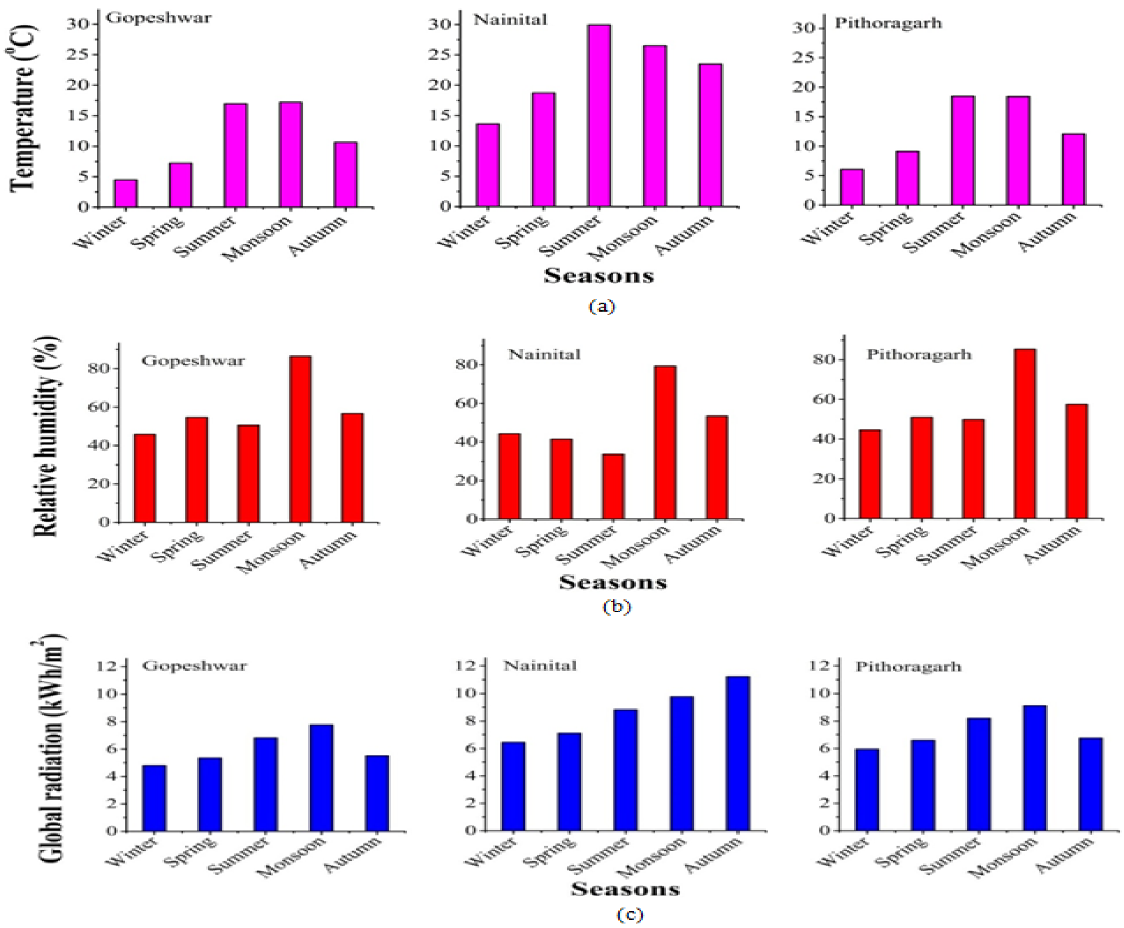


Fig. 5: Average seasonal variation of temperature, relative humidity and global solar radiation for the selected sites Gopeshwar, Nainital and Pithoragarh.

SUMMARY AND CONCLUSION

The database in this study includes 6 years of data from 2013-2018 and investigation is carried out for the global radiation, temperature, and relative humidity at three locations of Uttarakhand (Gopeshwar, Nainital, and Pithoragarh). The seasonal variation of global solar radiation and meteorological indicators in the Himalaya region of Uttarakhand show a very good agreement with statistical performance. Concluded that the highest amount of temperature was found in the summer season for Nainital site while the lowest amount found in winter season for Gopeshwar location. The maximum amount of relative humidity recorded for Gopeshwar location in monsoon season and the minimum was found (summer season) for Nainital. The highest and lowest amount of global solar radiation recorded in autumn and winter season for Nainital and Gopeshwar location respectively. Nainital location presents a good amount of global solar radiation in comparison to other two sites which show very essential results of data values. As well as the other locations (Gopeshwar and Pithoragarh) also the good conformity of the data and it can be verified by the Fig. 5. Latitude and altitude are important factors affecting the clear-sky solar radiation are quantitatively analyzed, while the effects of other air molecules on the clear-sky solar radiation are not involved. The factors make a more comprehensive quantitative analysis of solar radiation. The statistical parameters namely, standard deviation (SD), skewness (SKEW), and kurtosis (KURT) are used to verify the reliability, accuracy and performance of the data. If we compare among all the selected sites the statistical presentation shows the minimum deviation (global solar radiation) for Nainital which gives the more accurate results in comparison to other locations.The data analysis is very helpful for the simple analysis of hourly, monthly, annually, and seasonal variation of solar radiation and meteorological parameters for any testing sites with several time periods and to check and install the solar systems. In the near future, plan to analyze ground-based and satellite data of solar radiation, aerosols and other atmospheric data for estimating the different types of models and to install the solar photovoltaic systems for any site by using different meteorological parameters. Through this study we observed that weather conditions for any particular site and on the behalf of this study put the solar photovoltaic systems for any specific location.

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