Original Research Article

Analysis of Solar Radiations: Direct, Diffused and Global over Varanasi, Uttar Pradesh

ABSTRACT

The paper presents the seasonal solar radiations over Varanasi (25° 20' N, 83° 00' E 81.1m altitude) in Eastern Uttar Pradesh (UP) in India. An investigation on solar radiation over Varanasi station, India is carried out by using the five years (2010-2014) recorded direct, diffused, and global radiations data obtained from the radiation unit installed by India Meteorological Department (IMD) at Banaras Hindu University (BHU) campus. Analyses of winter (December, January, February), summer (March, April, May), monsoon (June. July, August, September), and post monsoon (October, November) shows that diffused solar radiation is maximum (~1.42 W/m^2) during monsoon season in 2012 at 12:00 IST and global solar radiation is maximum (~2.9 W/m^2) during summer season in 2012 at 13:00 IST. The results of solar radiation are further analyzed with that of the Aerosols Optical Depth over Varanasi. The increase in diffused radiation are well correlated (R= 0.67) with higher values of aerosols optical depth over the region.

Key words: *solar radiation, scattering, diffusion, temperature, AOD.*

1. INTRODUCTION

Solar radiation is the most important part of Earth-Sun relationship. It is the main driving force of the atmospheric circulation. Passing through the atmosphere, solar radiation gets attenuated due to scattering, diffusion absorption, and reflection by atmospheric composition (Sen, 2008). However, there are various atmospheric conditions that cause solar radiation to be perturbed and its intensity as well as, its character change. Presence of aerosols, turbidity and transparency, air mass, atmospheric water vapor content, distributions of cloud cover, etc. causes major changes in the incoming solar radiation properties, and develops conditions through which the amount of solar radiation varies on spatial as well as temporal scales. Solar radiation is the primary energy source the earth's surface (Duffie, and Beckman 1974), and ultimately controls the life and ecosystems, by playing with the hydrological cycle, weather and climate, surface energy budget, the diurnal/ seasonal thermal regime, and the health of biota, including flora and fauna. Studies accomplished so far have identified that the solar radiation is not a stable quantity, rather it significantly vary on decadal time scale due to various long-term as well as short-term causes, e.g. sunspot cycle (Kodera et al., 2002,) natural or anthropogenic pollution, cloud cover (Shupe et al., 2004), cloud microphysical properties (Stephen et al., 1990).

On the basis of long term studies done with a view of solar dimming or brightening (Shi et al.,2008) concept have shown that solar radiation is decreasing from 1960s to1980s, which recovered afterwards. Solar radiation shows variability from one region to another region, mainly caused due to changes in cloud optical depth (Wielicki et al., 1996), cloud cover and soil properties (Dai et al., 2002), as well as aerosols number concentration. Studies show that the cause of increase in aerosol concentration in the atmosphere is found to be more pronounced in developing and densely-populated countries, such as India, and it is comparatively low in cases of developed part of the globe, where air quality regulations are stricter. Although, the importance of changes in solar radiation is directly or indirectly affecting the day-to-day life of the human being (Norval et al., 2011), studies on solar radiation is scanty over many parts of the globe, including Indian region. Striking reduction in solar radiation are found over India which is related with the increased particle density, caused by industrial pollution, vehicular pollution, biomass burning and soil-dust mixing in the atmosphere. The decrease in solar radiation over India was found to be almost doubled during cloudy days than the clear-sky conditions. The decrease rate, however, is different for various regions and seasons.

Studies also revealed that solar radiations are not constant but changes spatially and seasonally. These changes are mostly natural due to rotation and revolution of the earth, but role of intermittent natural (e.g. volcanoes, dust storms) (Lean et al., 1997) or man-made (e.g. land use land cover change, agriculture residue burning) (Hansen and Lacis, 1990) processes over specific region can not be ruled out. Many locations around the world have already reported a widespread decreasing trend in global solar radiation (Ohmura and Lang, 1989; Li, 1998; Russak, 1990; Liepert, 2002; Liu *et al*., 2004, Stanhill and Cohen, 2001, Liang and Xia, 2005, Abakumova, 1996, Aksoy, 1997, Gilgen and Wild, 1998). For India also, the decreasing trend is reported by Ramanathan *et al*., (2005). After 1990, however, some evidences have been found to show an increasing trend (Wild *et al*., 2005, Pinker *et al*., 2005), but they are for specific regions only. The major sources of these trends have been related to the change in aerosols, clouds, or both, for the region of concern, where aerosols got more attention (Ramanathan *et al*., 2001). The study by Kumari *et al*. (2007) have reported that monthly mean global solar radiation over India is decreasing at the rate of about 0.86 W/m^2 per year for the period 1981–2004. The rapid industrialization and urbanization in India, after 1990, with its increased socio-economics, has caused tremendous increase in energy demand, leading to increase in the emission of pollutants and aerosols. The atmospheric pollution, in general, has significantly increased since 1990s (Guttikunda *et al*., 2003,). Further, high level of pollutants in the Indo-Gangetic plain is reported by many authors, who related this increased aerosol concentration due to land use changes, biomass burning, vehicular pollution, etc.

Although, global radiation has been studied in detail for many parts of the world, the diffuse and direct components of solar radiation has not been studied in general, due to general unavailability of data. Global observations, however, have shown a decreased diffused radiation for Germany (Liepert, 1997), Ireland (Stanhill, 1998) and parts of China (Liang and

Xia, 2005). Theoretically, the clear sky is effective for transmitting more of the solar beam, corresponding to more direct solar radiation, while a cloudy and/ or dusty sky is effective for more diffusion of solar light, corresponding to more diffused radiation at the surface

2. METHODOLOGY

2.1 SOLAR RADIATION (SR)

The solar radiation data for the year 2010-2014 has been obtained from Ozone Unit, Varanasi, which is run by IMD. The radiation data was taken by Thermoelectric Pyranometer, an automatic instrument at each second on a planer surface, and it is designed to measure solar radiance flux density (W/m²). The details of instrument have been given in section 3. All the solar radiation data has been checked manually, for consistency and they are categorized in to monthly basis. After initial quality check, the data is processed and the 10 minute data is added for each hour for final processing. 12 hour daytime data, extending from 0600 hours till 1800 hours (IST) has been considered to infer the diurnal information. The yearly variation of diurnal information is obtained by averaging all the days. Yearly average and summation of radiation data is developed from daily variation. Data was further divided into four seasons for seasonal study, namely winter (December, January, February), summer (March, April, May), monsoon (June, July, August and September), and post monsoon (October and November).

2.2 AEROSOL OPTICAL DEPTH (AOD).

In order to assess the particulate loading at IGPs for the monitoring period, Moderate resolution Imaging Spectrophotometer (MODIS) data on board Terra satellite were analyzed for Aerosol Optical Depth at 550 nm (AOD_{550}). We have used the level 2.0 collection version 5.1 Aerosol Optical Depth at 550 nm wavelength is extracted from MODIS satellite Terra platform for the study period (Payra et al., 2015; Kang et al., 2016).

3. STUDY AREA AND INSTRUMENTATION DETAILS.

Varanasi (25° 20' N, 83° 00' E 81.1m altitude) is one of the ancient and holy cities of the world. Due to its inherited population, and due to great number of floating population on daily basis, the city is one of the densely populated locations in Central Indo-Gangetic Plains (IGP). Since the soil of IGP is highly fertile, agriculture is one of the major occupations of this region and, hence, solar radiation is one of the most important atmospheric inputs for this region. For the location, average temperature and average precipitation, during winter and summer, remains around 22°C temperature, 15 mm precipitation and 33°C temperature, 340 mm precipitation, respectively.

The radiation data for the Varanasi has been obtained from a radiation table installed by IMD at the roof top of a 15 meter building, and it runs under the Ozone Unit set up. The place of the table is devoid of any hindrance from all the directions. The solar radiation data measured under all sky conditions have been collected from this radiation table comprised of direct, diffused, and global solar radiation. The data available for the year between 2010-2014 was taken by Thermoelectric Pyrometer on a planer surface, and it is designed to measure solar radiance flux density (W/m²) from the hemisphere within a wavelength range 300 nm to 3000 nm wavelength range. The absolute accuracy of the instrument is

±0.3%, but the accuracy of the present instruments about ±1%. For this instrument, there is no response obtained when the Sun is at horizon. The radiation data obtained using automatic logger at each second is collected as average of the radiation at each minute. This minute data is, then, added for each 10 minute intervals for collection of long term record.

4. RESULTS AND DISCUSSION

Global solar radiation can be defined as addition of direct and diffused component of solar radiation. The solar radiation consist mainly of two componet: direct and diffused componet. Diffused radiation comes from all the directions, while direct radiation follows the path of sun throughout the day. The transmission of radiation through the atmosphere is affected by aerosol, water vapor, gases and clouds. In an ideal scenario, the global radiation informs about the widespread available radiation in the atmosphere. When there are more number of light diffusing agents in the atmosphere, the diffused radiation shall be more. If the diffusing agent is also an effective absorging agent, the direct radiation will be less.

Seasonally averaged diurnal global, diffused and direct solar radiation, as obtained for five years of data, are shown in Figure 1 (a: winter, b: summer, c: monsoon and d: post-monsoon).

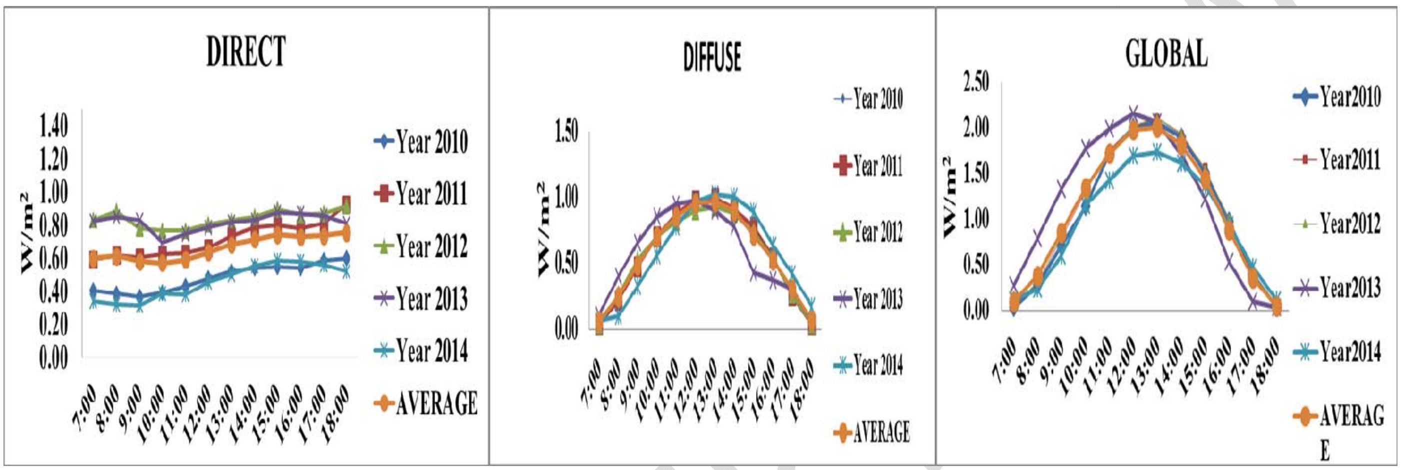
4.1 ANNUAL VARIATION OF SOLAR RADIATION

The figure 1 a shows that diffused and global solar radiation is very low during the sunrise and sunset time and it is showing a usual bell-shaped diurnal distribution, however, the direct radiation is varying according to solar activity. For the 2010-2014 data, winter season global solar radiation is found to be maximum (2.15 W/m^2) at 12 IST during 2013 and minimum (0.02 W/m^2) at 7 IST during 2013, respectively. Direct solar radaiation was maximum (0.87 W/m^2) at 8 IST during 2013 and minimum was 0.31 W/m^2 at 19 IST in 2014. The diffused solar radiation maximum was found to be 1.02 W/m^2 at 13 IST in 2014 and minimum was 0.03 W/m^2 at 7 IST in 2011.

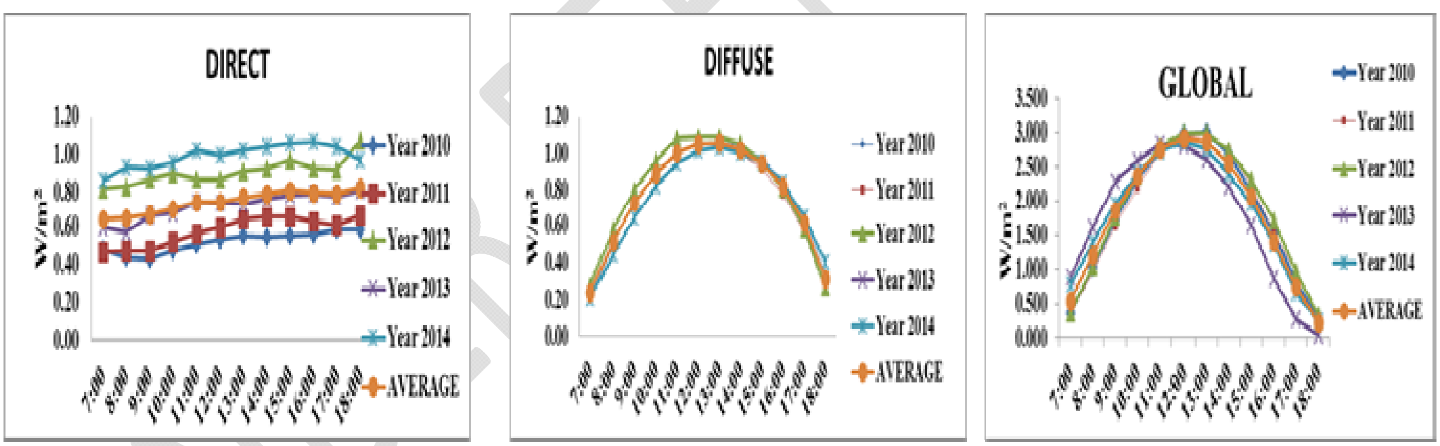
Figure 1(b) represent the direct, diffused and global solar radiation over Varanasi, during summer season. Figure 1 b shows that the maximum global solar radation was found to be 2.9 W/m^2 at 12 IST in 2010 and minimum was 0.23 W/m^2 at 18 IST in 2014. Maximum diffused solar radiation was found to be 1.00 W/m^2 at 12 IST. in 2013 and minimum was 0.20 W/m^2 at 17 IST. in 2014. Maximum direct solar radiation was found to be 1.07 W/m^2 at 16 IST in 2014 and minimum was 0.43 W/m^2 at 9 IST in 2010. In comparision of direct and diffused radiation, the diffused radiation was more in summer season. In 2011 there was more number of light diffusing agent (dust partical and aerosols) in the medium, so, the diffused radiation was more in comparision to direct. Dust particles work for absorbing radiation causing a low in the direct radiation.

Fig.1(c) shows such relationship from the five years (2010-2014) during the monsoon season. The maximum global solar radiation was found to be 2.57 W/m^2 at 11 IST.in 2014 and minimum was 0.07 W/m^2 at 18 IST. in 2014. The maximum direct solar radiation was found to be 0.84 W/m^2 at 15 IST in 2011 and minimum was 0.34 W/m^2 at 10 IST in 2013. Maximum diffused solar radiation was found to be 1.42 W/m^2 at 12 IST in 2012 and minimum was 0.29 W/m^2 at 18 IST in 2011.

Fig.1(d) shows a fairly smooth relationship yearly global, direct and diffused solar radiation for each of five years. Fig. shows that the maximum global solar radiation during the post monsoon season was found to be 2.23 W/m² at 13 IST in 2012 and minimum was 0.04 W/m² at 7 IST in 2012. The maximum direct radiation was found to be 1.16 W/m² at 15 IST in 2011 and minimum was 0.25 W/m² at 8 IST in 2014. Maximum diffused solar radiation was found to be 1.12 W/m²at 12 IST in 2010 and minimum was 0.05 W/m² at 18 IST in 2011.



(a)



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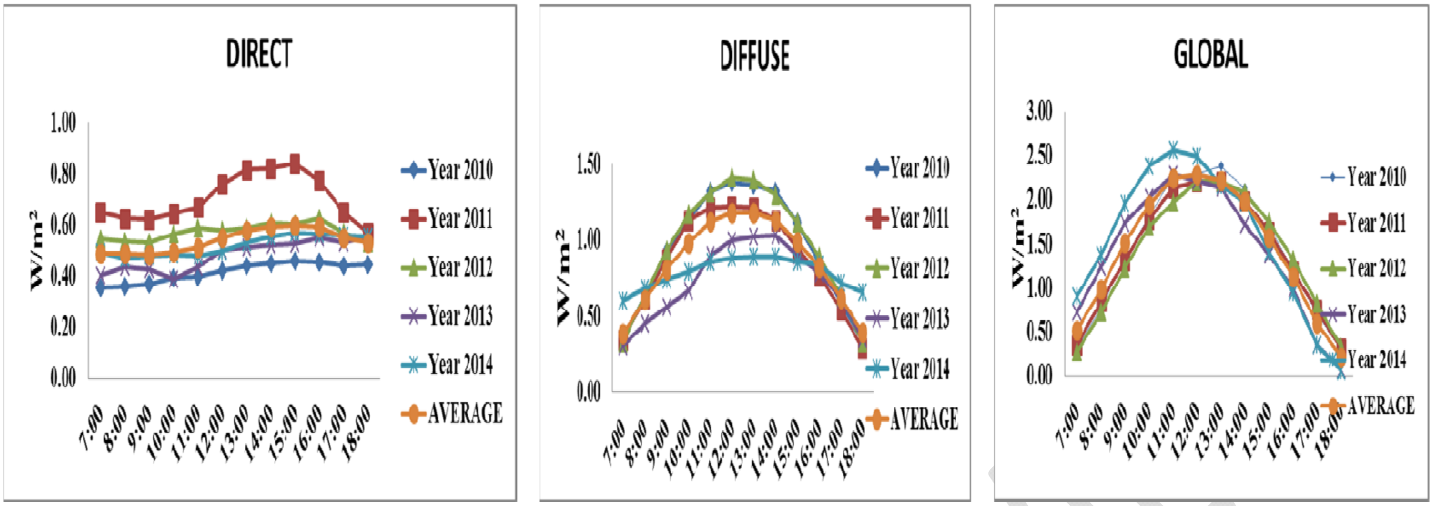

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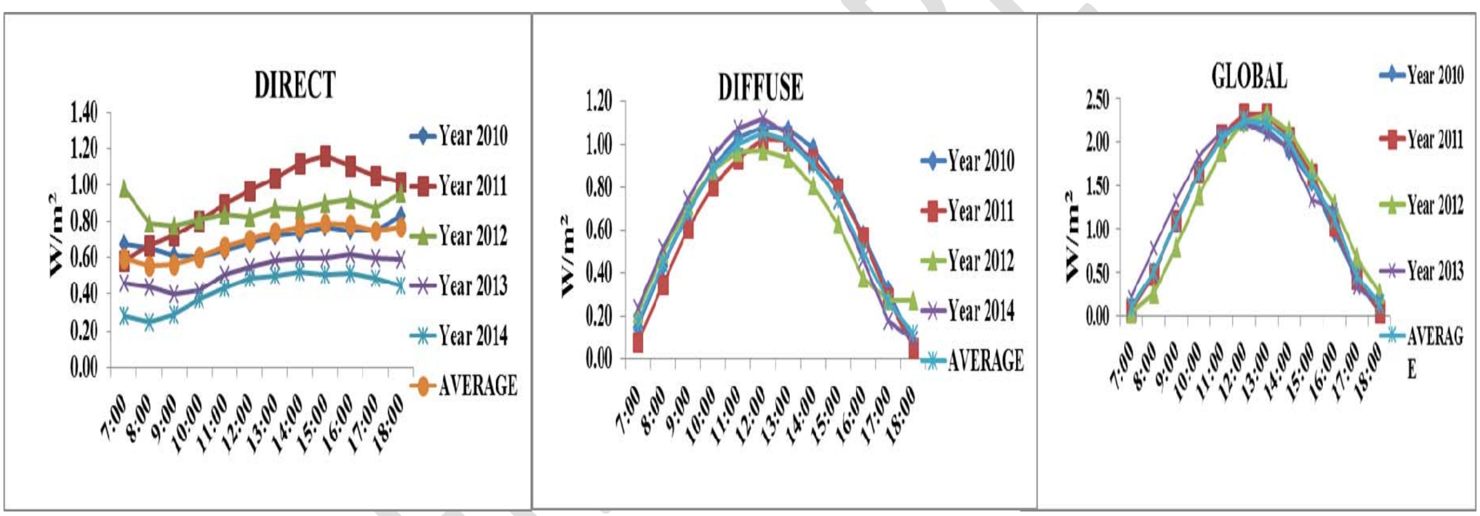
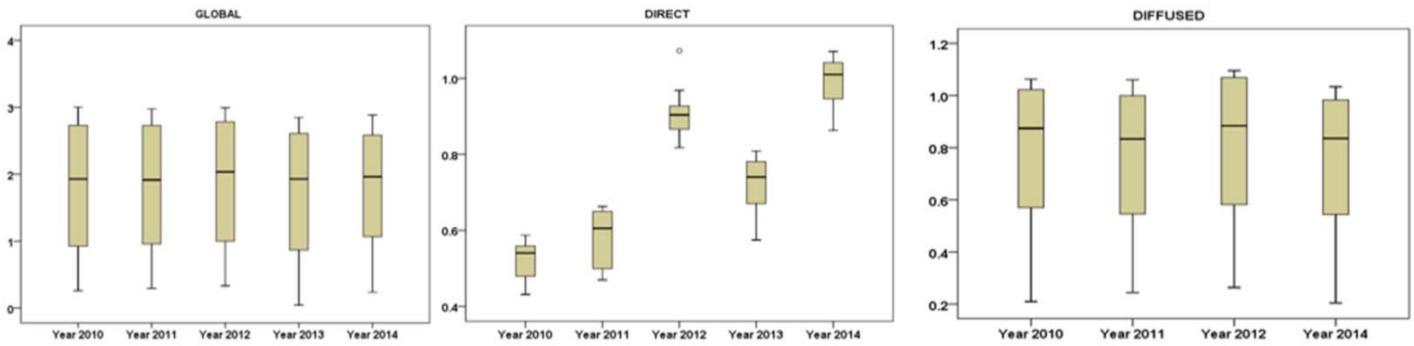
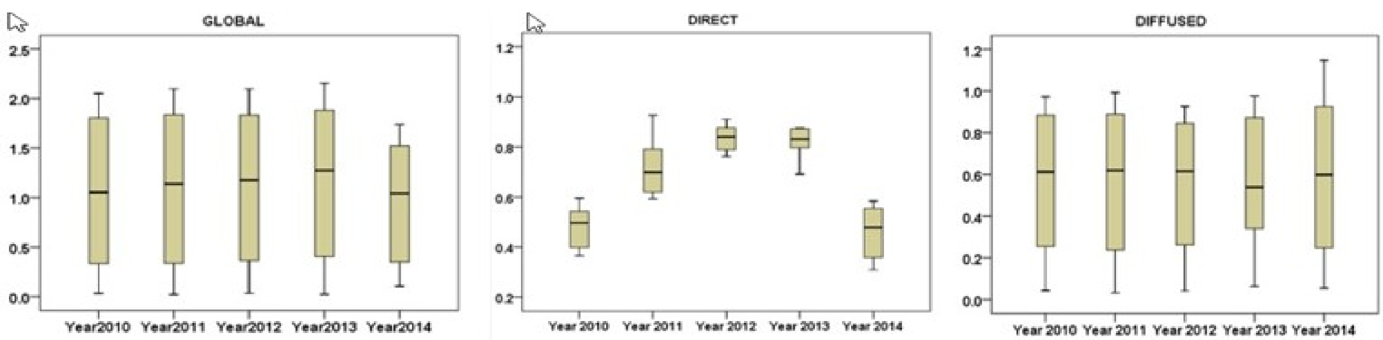


(d)

Fig1: Yearly variation of solar radiation for winter, summer, monsoon and post monsoon season respectively.



(a)



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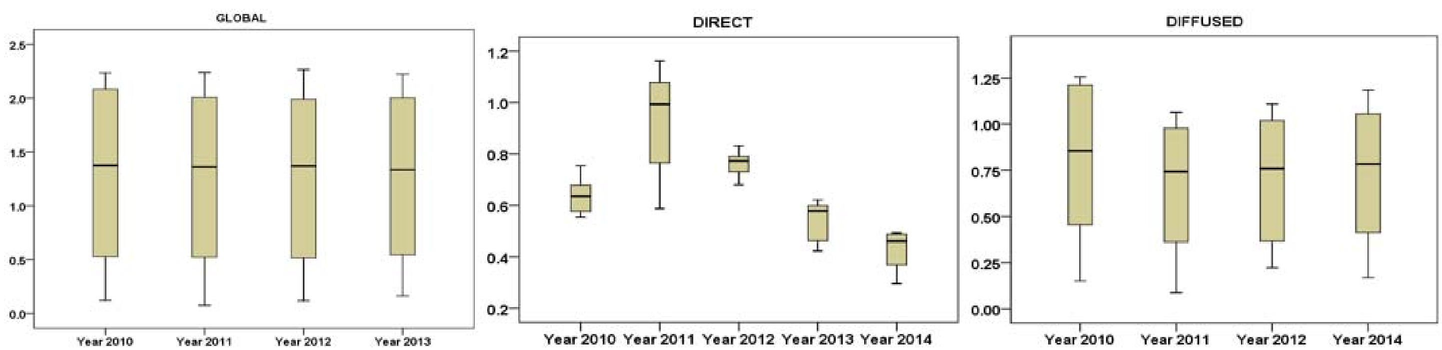

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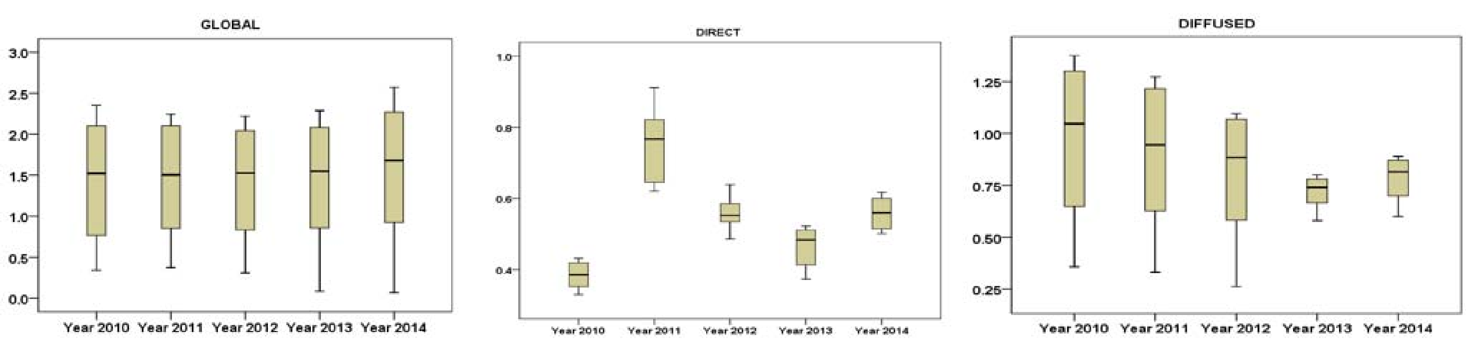

(d)

Fig.2(a-d) Open- high- low plot for winter, summer, monsoon and post monsoon season respectively (Note: Y axis represent the solar radiation W/m²).

Fig. 2 shows a relationship between direct, diffused and global solar radiation. The global solar radiation was found to be increasing. Fig 2(b) shows that the maximum global solar radiation during summer season is observed during 2010 due to fewer amounts of water vapor, soot particle and burning of fossil fuel present in the atmosphere. The boxes marks the 25 and 75% quartile while whisker gives the maximum and minimum value. In winter and summer season diffused solar radiation was less than the direct and global. Fig. [2(a)] shows that less particle or scattering agent present in the atmoshpere, so, the diffused radiation was less in winter season. In summer and monsoon season diffused solar radiation was high as comparasion to direct radiation [Fig.2(b-c)]. Diffused radiation is formed by scattering of the direct beam by particle in the atmoshper diffuse solar radiation that shows higher value in summer and monsoon season due to increased turbidity and cloudiness during this period. Cloudiness is having the gretest influence on diffused radiation in monsoon season. During July month (rainy season), sunshine hours are found to be less at Varanasi. In general, during summer months, the diffused component of radiation increases and the direct component decreases, however, an increase in diffused radiation in winter when precipitation is generally low, was a result of increased optical density pattern from the particles from extensive burning of fossil fuels in the region (Codato et al., 2008).

Table1. The Observed Solar Radiation for Annual, winter, summer, monsoon and post- monsoon Seasons averaged for the Period 2010 – 2014 over Varanasi.

Seasons	Global (W/m^2) / yr	Direct (W/m^2)/ yr	Diffuse (W/m^2)/yr	Temperature (^oC)	Rainfall (mm)
Winter	1.15	0.76	0.60	17	98.2
Summer	1.89	0.86	0.87	30	41.4
Monsoon	1.43	0.54	0.89	31	683.4
Post-Monsoon	1.17	0.68	0.64	26	99.8
Annual	1.41	0.72	0.75	26	922.8

Figure 3 shows the annual averaged diffused radiation and aerosol optical depth with increasing trend of diffuse radiation data for the period of study. The annual averaged daily diffuse solar radiation is observed to be the highest for the month of June, 2013 (0.78 $W/m^2/day$). The annual average daily aerosol optical depth is found to be highest during September, 2013 (0.67) while it is lowest (0.52) during October, 2014. The trends in annual means of diffused radiation and aerosol optical depth have also been analyzed in the study (Figure 3 and Table 1). The linear trends for diffuse radiation during the period 2010 – 2014 over Varanasi are found to be increasing.

Table2. The maximum and minimum temperature over Varanasi from 2010-2014.

Sr. N.	YEAR	TEMPERATURE (□C) (Annual Average)		TEMPRETURE IN SUMMER SEASON (□C)	
		MAX	MIN	MAX	MIN
1	2010	32.70	21	45	21

2	2011	31.46	20	45	16
3	2012	31.84	21	46	19
4	2013	31.16	20	45	18
5	2014	32.61	21	47	18

Annual maximum and minimun air temperature during 2010-2014 are shown in Table 2. The annual average maximum temperature show decreasing treand with a negetive slope of -0.048. The solar radiation affect the Tmax more than Tmin (Wild et al., 2005). During the 2010 to 2014 , the change in Tmax for summer season, however, increased from 45 to 47 □c. higher aerosol optical depth value as well as change in cloud properties contribute to this difference (Kumari et al,. 2007). To validate, this we further analysed the relationship (if any) between aerosol optical depth and solar radiation over varansi during study period.

5.2 RELATION BETWEEN AOD AND SOLAR RADIATION

The AOD observations (2010-2014) from MODIS statelite data have been analysed in explaining the trends in global radiation over Varanasi. Solar irradiance is known to be correlated with cloud cover and bright sunshine duration. The most probable causes of trends in solar radiation is a change in the amount of cloud cover (Stanhill and Cohen, 2001).

Fig 4 represents the annual variation of diffuse radiation and aerosol optical depth. It is seen that there is an increasing trend in aerosol optical depth with diffuse solar radiation with higher values during 2013. Since increase in the cloud amount decreases direct solar radiation and augments diffuse sky radiation (Chacko et al., 1968; Desikan et al., 1969; Mani and Chacko, 1973), we choose 2013 to conduct further analysis to find relation between diffuse solar radiation and aerosol optical depth.

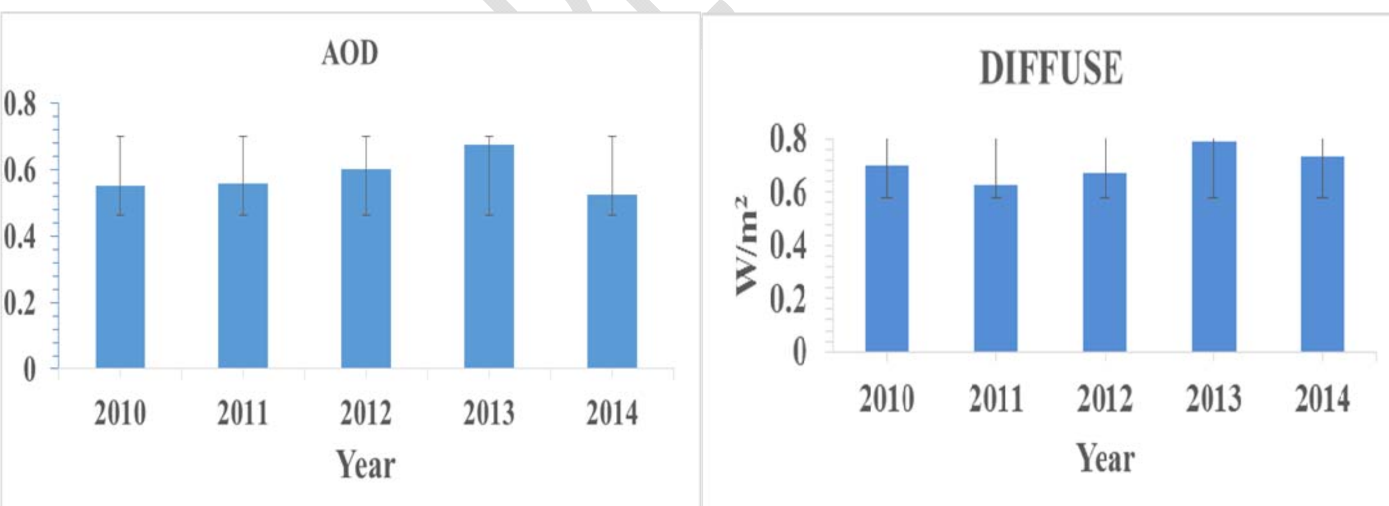

Fig. 3: Annual variation of Diffused radiation and AOD.

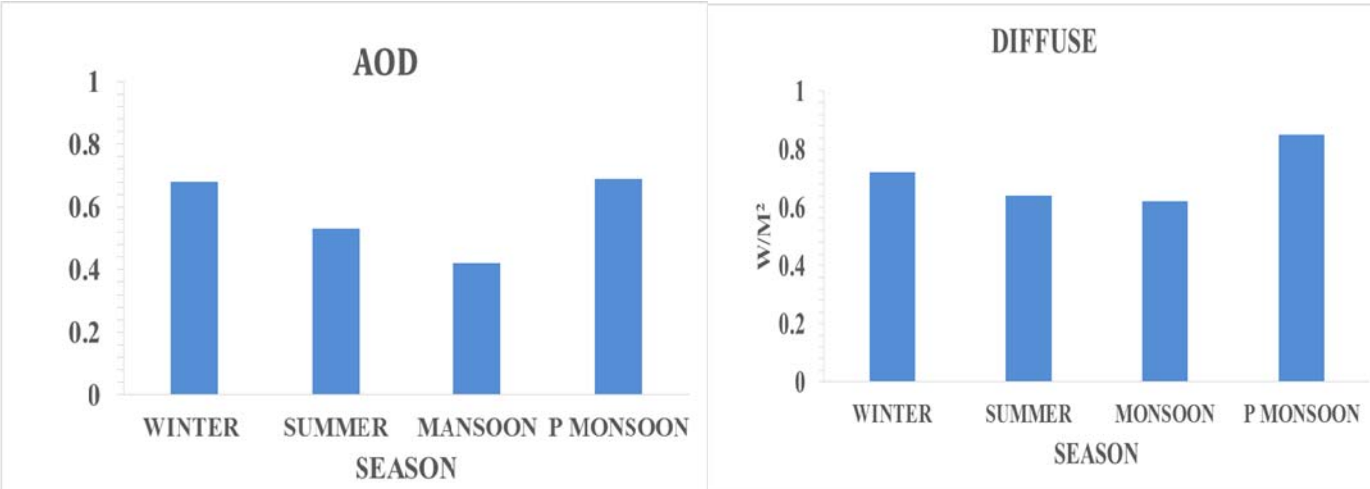

Fig. 4: Seasonal variation of Diffused Radiation with AOD.

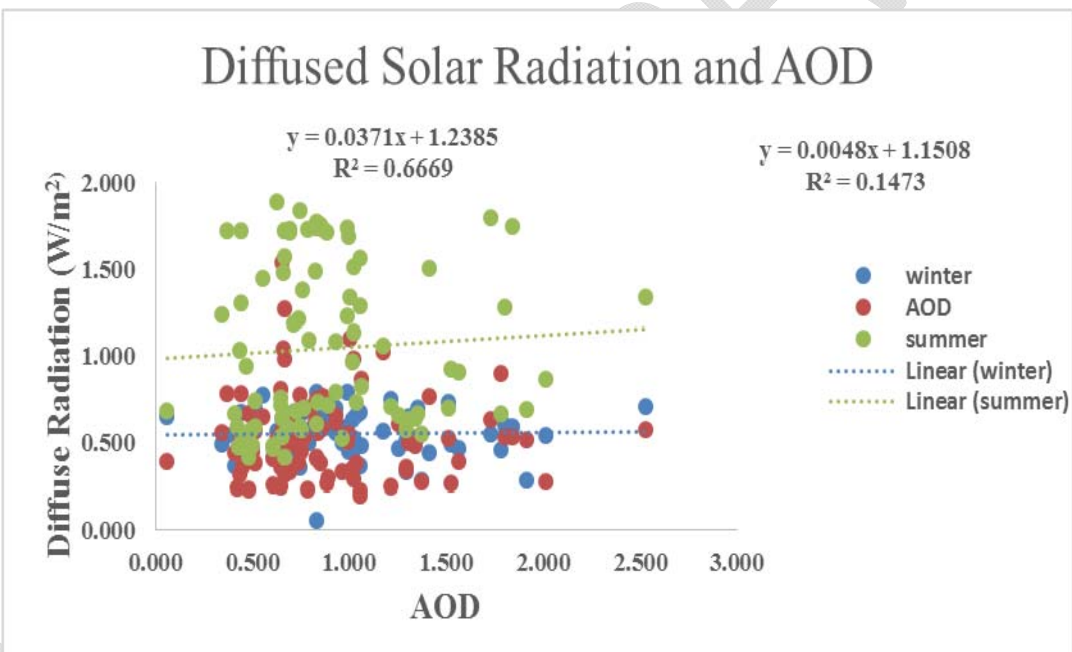

Fig. 5 Interrelation between Diffused Solar Radiation and AOD (550 nm) .

Relationship between Difffused solar radiation and AOD is shown in fig.5 which indicate increasing trend due to increasing in the AOD with a positive slope of 0.0371. The correlation between AOD and diffused solar radiation is found to be more 0.67 during summer over Varanasi than that of winter. Due to the high population growth, increasing urbanisation, industrilisation, the AOD over the IGPs is found to increase, and diffused solar radiation also increas because of diffused solar radiation component are influence by an increament or decrement of AOD.

6. CONCLUSIONS

Entire solar radiation at Varanasi in the Eastern UP region of IGP depends on the variation of direct, global and diffuse component of solar radiation throughout the year. The direct, global and diffuse radiation incidence on the surface has been analyzed over Varanasi. The solar radiation depends upon the topography as well as local weather condition that control the available solar radiation.

The results obtained in the study showed an increasing trend in diffused solar radiation pattern for Varanasi. The decrease in sunshine duration was concomitant with the decrease in global solar irradiance. It is concluded that the solar radiation varies with season. The total solar radiation was higher in the summer season than in winter, monsoon and post monsoon. The annual average of diffuse solar radiation observed over Varanasi for the period 2010-2014 is found to be 0.75 W/m^2 per year while during winter, summer, monsoon and post-monsoon seasons it is 0.60, 0.87, 0.89 and 0.64 W/m^2 per year, respectively.

The surface T_{max} and T_{min} over Varanasi shows an increasing trend during summer period while declining trend in the annual average temperature for Varanasi. It might be due to AOD that play a major role in reducing the solar radiation reaching the surface. Higher AOD values as well as changes in cloud properties contribute to this difference. However, long term data analyses are required for understanding decadal changes and policy implications for the region.

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