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Effects of Atmospheric Aerosol Types on Ultraviolet Flux at Different Stations in Indo-Gangetic Plain†

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Abstract: Atmospheric aerosols play a crucial role in the scattering and absorption of solar radiation, directly influencing the UV flux reaching the Earth's surface. This study investigates the impact of different atmospheric aerosol types on the ultraviolet (UV) flux at four stations over Indo-gangetic plain (IGP). For this study, high-resolution 1°x1° UVA and UVB data was obtained from Clouds and the Earth's Radiant Energy System (CERES). Various aerosol types present in the atmosphere were categorized based upon their optical properties and their quantitative influence on UVA and UVB flux was examined. Ground-level aerosol products were obtained from the NASA-based Aerosol Robotic Network (AERONET) at four stations in the IGP. Based on the optical properties of aerosols (fine mode fraction, single scattering albedo, aerosol optical depth and angstrom exponent), four distinct atmospheric aerosol types were inferred, namely, dust dominant (DT), polluted continental dominant (PCD), black carbon dominant (BCD), and organic carbon dominant (OCD). It is observed that the AOD of different aerosol types when separated do not seem to have made significant effects on UVA/B radiation (except at Kanpur), possibly due to statistically smaller data set. For the entire combined AOD the effects on UVA/B become quite significant at all the stations which shows that a unit rise in AOD leads to a reduction in 5-7 Wm^{-2} in UVA and 0.14-0.23 Wm^{-2} in UVB.

Keywords: Aerosol types; UVA; UVB; AERONET; CERES

1. Introduction

The aerosol radiation interaction has become an emerging and challenging concept in present scenario. As atmospheric aerosols act like attenuator for the incoming radiation, it significantly affects the radiation budget. These aerosols play a vital role in global and climatic changes through various atmospheric interaction in accordance to their optical, micro-physical and radiative properties [1], [2]. Aerosols are of various types due to their origins and chemical compositions, accordingly their classification encompasses diverse methodologies. In the context of overseeing air quality, aerosols are commonly categorized into four main types: dust dominant (DT) (including desert dust, soils, volcanic ash, etc.), polluted continental dominant (PCD) (originating from urban/industrial activities or human-involved biomass burning), black-carbon dominant (BCD) (high absorbing aerosols like incomplete combustion of carbon materials, etc.) and organic carbon dominant (OCD) (includes low absorbing aerosols and nitrates) [3], [4] . The Ultraviolet radiation (UVR) part of solar spectrum is broadly classified as UVA (0.40-0.32μm) and UVB (0.32-0.28 μm) radiations which are highly influenced by these distinct aerosol types present in atmosphere in various forms.

The Indo-Gangetic Plain (IGP), covers most of northern India and eastern part of Pakistan which includes large scale agricultural activities, enormous demographic challenges and increasing industrialization has led to increase in the anthropogenic activities,

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leading to consistently increase in aerosol over the region (became global hub for intense aerosol loading) [5], [6]. Many studies have shown the implication of different aerosol particles over the region but still the interaction and effects of the pertaining aerosol types on UVA and UVB radiation have been lacking from long duration [7]. The present study on effect of distinct aerosol types on UVA and UVB at different stations of IGP is trying to fill the existing gap up to some extent.

As aerosols modulates UV radiation, this present study investigates the effects of various aerosol types on UVA and UVB radiation across different locations within the Indo-Gangetic Plain (IGP) region. The four sites of IGP region are Kanpur, Jaipur, Karachi and Lahore and the duration of study is one year (Jan, 2021 to Dec, 2021). We identified the annual concentration and percentage contribution of each type of aerosols. Effects of each aerosol type have been studied on the UVA and UVB radiation at four different sites of IGP considered for study.

2. Methodology

2.1. Observational Sites and Data Collection

The study have been conducted over the four different locations in the Indo-Gangetic plain (IGP) are (a) Kanpur, (b) Jaipur, (c) Karachi and (d) Lahore as described in Table 1. The aerosol product, aerosol optical depth (AOD), fine mode fraction (FMF), single scattering albedo (SSA), aerosol optical depth (AOD) and angstrom exponents (AE) were obtained from AERONET [11], during Jan, 2021 to Dec, 2021. The satellite retrieved UVA/B flux has been taken from CERES (Clouds and Earth's Radiant Energy System). The daily CERES data were obtained at spatial resolution of (1°X 1° gridded data) [12] for all-sky conditions [Table. 1].

2.2. Methodology

The optical properties of aerosols such as FMF, SSA, AOD and AE have been used to categorize distinct aerosol types following previous reported findings at different sites of IGP [13], [14]. The categorization used for different aerosols types using SSA (0.4 μm) and FMF (0.5 μm) are as follows:

- For Dust Dominant (DT): FMF< 0.4 with SSA>0.8
- For Polluted Continental Dominant (PCD): 0.4≤ FMF≤ 0.6 with any SSA value
- For Black Carbon Dominant (BCD): FMF>0.6 with SSA ≤0.9
- For Organic Carbon Dominant (OCD): FMF>0.6 with SSA >0.9

The method used for inference of different aerosol types by AOD (0.5 μm) and AE (0.44-0.87 μm) is determine as follows:

- For Dust Dominant (DT): AE< 0.6 with any AOD values
- For Polluted Continental Dominant (PCD): 0.6≤ AE≤ 1.0 with any AOD values
- For Organic Carbon Dominant (OCD): AE≥1.0 with AOD > 1.0values
- For Black Carbon Dominant (BCD): AE≥1.0 with AOD ≤1.0.

3. Result and Discussions

3.1. Annual Concentration of Distinct Aerosol Types

In the current study, one year of AOD data was categorised in terms of DT, PCD, BCD and OCD at all the four study sites Kanpur, Jaipur, Karachi and Lahore (Table. 1). The percentage contribution of each type of aerosols over the four stations is shown in Fig. 1. As it can be noticed from the figure that the DT shows higher contribution over Karachi and Jaipur at 55.48 % and 30.80 % respectively, while a lesser contribution is seen at Lahore and Kanpur with 16.01 % and 9.45 % respectively. This large concentration of DT is due to dust deposition over the IGP region which is transported from western region

(i.e. Thar Desert). Due to high anthropogenic activities (i.e. mining, industrial wastes, vehicular emission) the PCD were found to be maximum at Lahore with 22.31% whereas 17.98% at Kanpur, 19.92% at Karachi and 15.60% at Jaipur. On regional perspective, at Kanpur the mostly contributing aerosol type were BCD (43.32 %), second highest OCD (29.73 %) then PCD (17.98 %) and DT (9.45 %). At Jaipur, BCD (37.32%) has the highest contribution followed by DT (30.80 %), OCD (16.28 %) and PCD (15.60 %). At Karachi, DT showed highest contribution with (55.48%) followed by BCD (21.55%) and OCD showed minimum with (3.34 %). At Lahore, OCD with (31.74%) showing highest concentration, BCD (29.95 %) followed by PCD (22.31%) and DT (16.01 %).

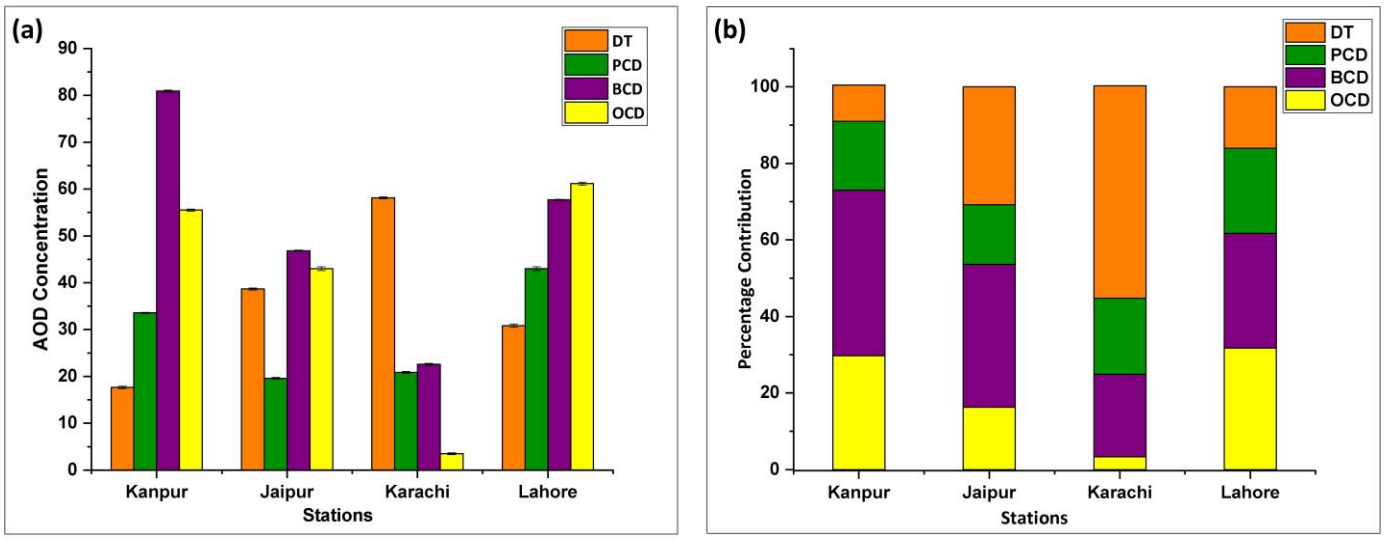


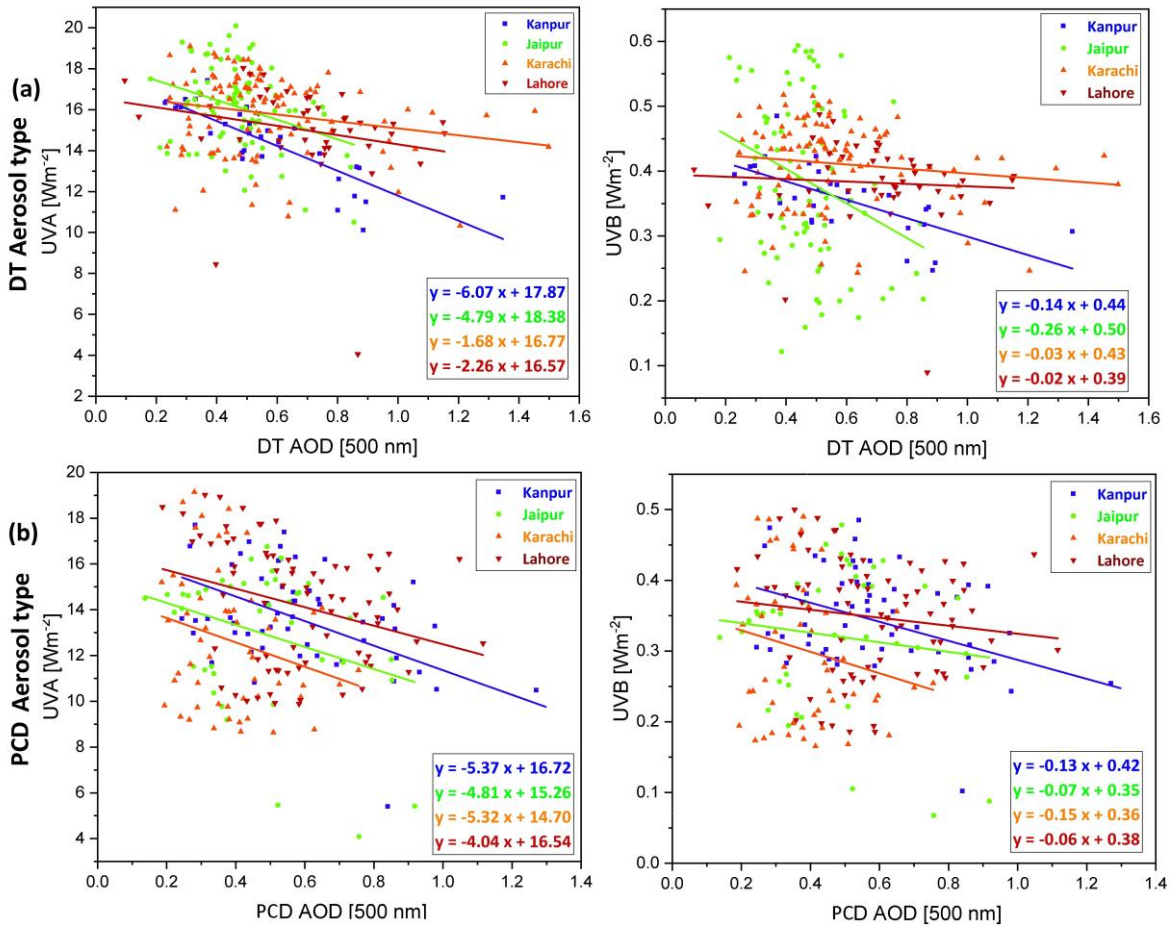
Figure 1. (**a**) Annual AOD Concentration of each aerosol types; (**b**) Annual percentage contribution of each aerosol types at four study sites of IGP region.

Table 1. Mean and standard deviation, annual contribution (%) of distinct aerosol types and study site details: coordinates, Altitude and CERES gridded coordinates for UVA and UVB radiation for the four stations of IGP.

Study Sites	Altitude (m asl)	Duration	Aerosol types	Mean ± standard deviation	Annual contribution (%)
Kanpur [26.51°N, 80.23° E]	126	Jan, 2021-Dec,2021	DT	0.59 ± 0.25	9.45
			PCD	0.60 ± 0.23	17.98
			BCD	0.59 ± 0.21	43.32
			OCD	1.35 ± 0.36	29.73
Jaipur [26.92°N, 75.78° E]	431	Jan, 2021-Dec,2021	DT	0.47 ± 0.14	30.80
			PCD	0.48 ± 0.20	15.60
			BCD	0.44 ± 0.20	37.32
			OCD	1.36 ± 0.41	16.28
Karachi [24.94°N, 67.13° E]	10	Jan, 2021-Dec,2021	DT	0.57 ± 0.25	55.48
			PCD	0.39 ± 0.14	19.92
			BCD	0.48 ± 0.19	21.55
			OCD	1.17 ± 0.10	3.34
Lahore [31.47°N, 74.26° E]	217	Jan, 2021-Dec,2021	DT	0.70 ± 0.23	16.01
			PCD	0.58 ± 0.19	22.31
			BCD	0.61 ± 0.21	29.95
			OCD	1.36 ± 0.34	31.74

3.2. Relationship Between Distinct Aerosol Types and UVA and UVB Radiations

The CERES based UVA and UVB was studied at four sites with four distinct aerosol types. The rate of decrease of UVA and UVB fluxes with increase in each aerosol type AOD (negative correlation) is shown in Fig. 2. The slope of aerosol types AOD vs. UVA/B linear fit regression line for DT, PCD, BCD and OCD shows the change in UVA/B fluxes per unit change in AOD. For BCD type aerosols Kanpur showed the highest decrease in UVA and UVB fluxes with unit increase in AOD at -6.47 Wm^{-2} and -0.22 Wm^{-2} respectively, whereas the minimum change is seen for OCD with -4.87 Wm^{-2} and -0.15 Wm^{-2} respectively. At Jaipur, the highest decrease in UVA flux is found in PCD type of aerosols with -4.81 Wm^{-2} per unit increase in AOD, whereas the highest decrease in UVB is noticed in DT type of aerosols with -0.26 Wm^{-2} per unit increase in AOD. At Karachi, the highest decrease in UVA flux is found in PCD type of aerosols with -5.32 Wm^{-2} per unit increase in AOD, and the same type showed highest decrease in UVB also (-0.15 Wm^{-2}). At Lahore the PCD aerosols showed maximum influence on UV flux with -4.04 Wm^{-2}per AOD in UVA and -0.06 Wm^{-2} per AOD in UVB. It may however be noted that the correlation coefficients for the regression between UVA/B flux and AOD for the segregated different types of aerosols is quite low (<0.5 in most of the cases), possibly due to the smaller size of the data when segregated. It was therefore decided to see the effects of AOD on UVA/B for the entire combined aerosol types and it was found to be quite significant at all the stations (Fig. 3). It shows at all these four stations in IGP, a unit rise in AOD leads to a reduction in 5-7 Wm^{-2} in UVA and 0.14-0.23 Wm^{-2} in UVB. The correlation coefficient for this regression for combined AOD and UVA/B flux also improves significantly. Further, the linear fit analysis done for the slopes of aerosol types AOD vs. UVA/B is highly significant with p-value <0.01. Earlier studies have also found the similar correlation values between AOD and UVA/B fluxes [15].



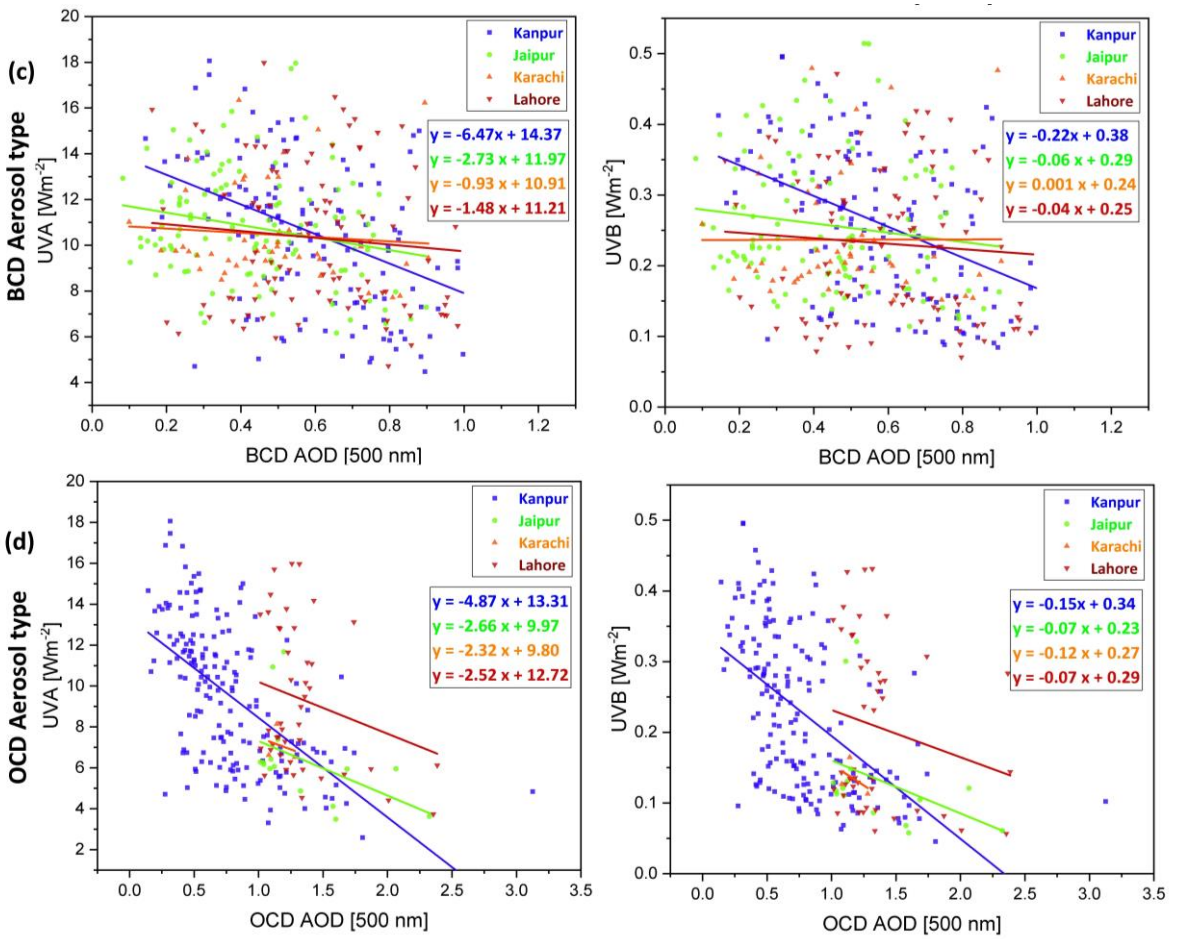


Figure 2. Scatter plot of distinct aerosol types vs. UVA/B with the linear fit regression line (best fit line) shows the negative correlation at each study site of IGP region.

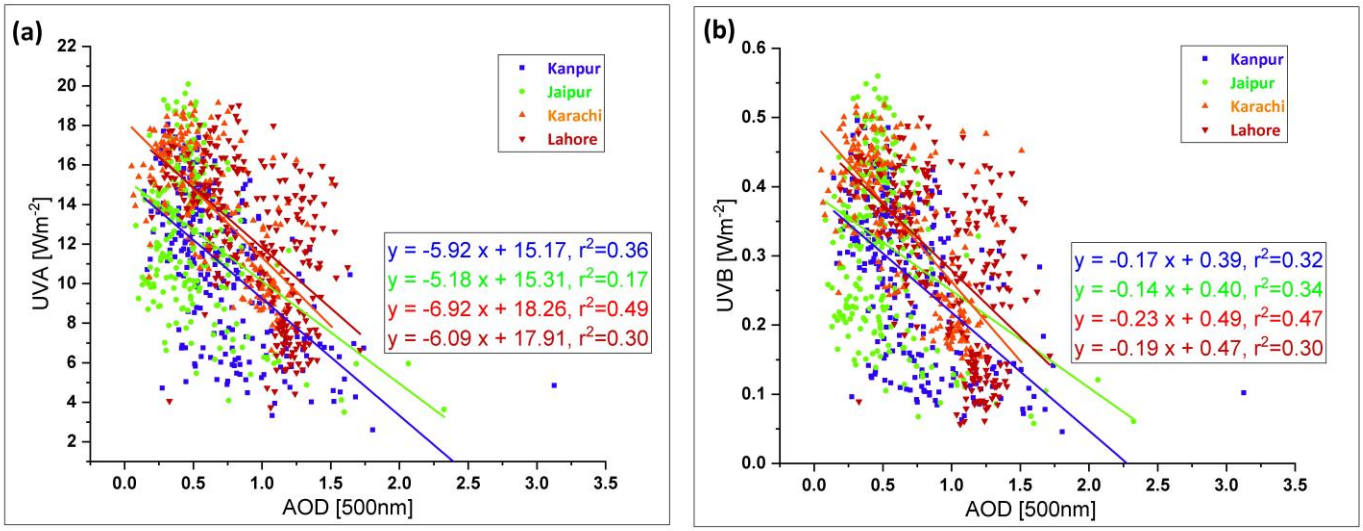


Figure 3. Scatter plot of (**a**) AOD vs. UVA and (**b**) AOD vs. UVB with the linear fit regression line (best fit line) over the four IGP sites during Jan, 2021 to Dec, 2021.

4. Conclusions

The effect of distinct aerosol types on UVA/B radiation have been studied for Jan, 2021 and Dec, 2021 at four sites of IGP, i.e., Kanpur, Jaipur, Karachi and Lahore during Jan 2021 - Dec 2021. The following preliminary conclusions may be made:

- Different stations showed dominance of different types of aerosols in the IGP. DT types dominated at Karachi with 55.48%, OCD dominated at Lahore (31.74%), BCD at Kanpur (43.32%) and BCD at Jaipur (37.32%). The polluted continental PCD has a significant contribution at all the stations contributing in the range 15-22%.
- Different aerosol types are shown to decrease the UVA/UVB flux with per unit increase in AOD. The black carbon dominant BCD type aerosol showed the highest capacity to decrease the UVA Flux, followed by DT, OCD and PCD.
- The correlation coefficients between UVA/B flux and AOD for the segregated aerosol types was <0.5 in most of the cases, possibly due to the smaller size of the data. So to see the effects of AOD on UVA/B for the entire combined aerosol types was studied and it was found that at four stations in IGP, a unit rise in AOD leads to a reduction in 5-7 Wm^{-2} in UVA and 0.14-0.23 Wm^{-2} in UVB.

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Data Availability Statement: The datasets developed during the current study are available from AERONET and CERES website is provided on reasonable request.

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