AEROSOL TRENDS AND SPATIO-TEMPORAL VARIATION OVER INDO GANGETIC BASIN FROM SATELLITE DERIVED ATMOSPHERIC OPTICAL DATA

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ABSTRACT

From January 2007 to December 2017, long-term aerosol characteristics over the Indo-Gangetic Basin (IGB) were evaluated using satellite-derived aerosol parameters. Over the Indo Gangetic Basin, the study reveals consistently high aerosol optical depth (AOD 0.7) with a decadal rising trend (20%). Angstrom exponent (AE) data from Lucknow in the central IGB (25%) and Lahore in the north (18%) indicate a relative rise in fine-mode aerosols at Lucknow (30%), respectively. Data from Kolkata in the eastern IGB also indicate an increase in the AOD. Single scattering albedo (SSA) does not, however, demonstrate. The Aerosol Optical Depth exhibits an upward trend with any discernible decadal trend at both stations, with a noticeable rise at Delhi (26%) compared to Lucknow (20%).The result points to relative dust aerosol dominance over Lucknow. Additionally, assessments were conducted in two sub-periods: 2007-2013 and 2013-2020, in order to comprehend the influence of developing activities. It's interesting to note that between 2007 and 2012, Lahore saw a relative increase in AOD of 31%, compared to Lucknow's 22% between 2013 and 2020. The results reveal that the region's vigorous development activities have an impact on both the vertical and horizontal aerosol load. The emission inventory corroborates with the trend and variability of optical characteristics for distinct sub-periods.

Keyword : *Aerosols Decadal trend, Indo-Gangetic Basin ,Emission inventory ,Anthropogenic activity.*

INTRODUCTION

Aerosols are one of the most variable components of the Earth's atmosphere, which have been recognized as a major factor influencing Earth's radiative balance and climate. The main influence of aerosols on climate patterns is inconsistencies in the radiation budget with either direct or indirect impacts. There is still a lot of confusion regarding the origins of aerosols in the climate system among known air substances that vary in both space and time. However, it is noted that there are still significant ambiguities regarding their impacts on the environment and climate, and their degree of understanding is comparably lower than that of greenhouse gases (IPCC, 2013).According to estimates, the increased aerosol burden linked to new human activities has obscured around one-third of the continental warming caused by greenhouse gases.

With a range of emission sources and different seasonal features, the Indian subcontinent, particularly the Indo-Gangetic Basin (IGB) in the northern part of India, has been recognised as a regional aerosol hotspot.The Indo-Gangetic plain (IGP) is one of the world's biggest river basins. According to the 2001 census, it has a population density of 500 to 1000 people per square kilometre, making it one of the world's most polluted areas. The Himalayas to the north, Vindhyan Satpura mountains to the south, Thar Desert and Arabian Sea to the west, and Bay of Bengal to the east, all encircle this area. Due to the lower temperature and shallow boundary layer during the winter, high aerosol concentrations at the surface and in the vertical column were observed at various places in the IGP. The inversion layer lingers at low altitudes throughout the winter because of the lower temperatures, and the poor boundary layer formation helps to retain the particles inside this layer (Komppula et al., 2012). As a result of the favourable climatic circumstances and high aerosol concentration over IGP, fog formation and visibility deterioration are frequent wintertime occurrences over several places in IGP. This area has been a hotbed for environmental study because of its distinctive terrain and a variety of aerosol emissions from heavily inhabited and industrialised regions over IGP, including dust, black carbon, nitrate, sulphate, and organics. Numerous studies utilising both ground-based measurements and satellite data have indicated that the IGP area experiences significant aerosol loading all year round. Additionally, it has been demonstrated that the atmospheric processes in the area have an impact on the atmosphere's chemistry, composition, and temperature on both a large regional scale and a global one. Premonsoon mineral dust and monsoon sea salt have a significant impact on IGP, but postmonsoon fine mode aerosols predominate.

Aerosol microphysical and optical property measurements offer useful data that can help to minimise the uncertainty in both global and regional climate models. Around the world, many aerosol classification techniques have been employed to categorise aerosol types based on various aerosol microphysical and optical characteristics (Schmeisser et al., 2017; Valentini et al., 2020). The aerosol optical depth (AOD) and the Angstrom exponent (AE) are the two major columnar aerosol parameters used to categorise aerosols . The former serves as a stand-in for the size of aerosols, whereas the former serves as an indicator of the amount of aerosol loading. The AE was also utilised by Russell et al. (2010) to identify various aerosol types. Mhawish et al. 2017 have assessed AOD retrieval techniques for a range of aerosol types, including coarse, fine, and mixed aerosols . Aerosols with low AOD and AE values are most likely marine aerosols, whereas those with high AOD and low AE values are often categorised as dust aerosols. However, anthropogenic aerosols may be identified by their high values for both AOD and AE.

Due to the lack of a ground-based optical measuring network, the main method for determining the temporal variation and regional to global spatial distribution of aerosols is satellite remote sensing. Due to the significant degree of uncertainty, many satellite-derived aerosol products have been compared to measurements made on the ground at numerous locations around the world using sunphotometers.

The goal of the current study is to evaluate many aerosol properties over a long period of time using data from various satellite observations over the IGB in order to determine how emerging anthropogenic activities would affect them. The study was carried out in the ten metropolitan megacities located throughout the IGB between the years of 2005 and 2020. Each of these cities is one of the fastest-growing in the upper, central, and lower IGB. It's interesting that the measurement time was chosen since the area was experiencing extensive growth, which may have contributed to the high load of human emissions.

2. SITE DESCRIPTION

Lahore, Lucknow, and Kolkata, the measurement sites shown over the IGB in Figure 1, are located in urban areas with semi-arid climates, and assessments of the climatology and variations in aerosol properties are conducted for these two highly urbanised cities. Extreme summer temperatures of 45 degrees Celsius and chilly winters with lows of 3 degrees Celsius characterise the climatic conditions in both locations.

2.1 Lahore

Lahore is situated in latitude 31.5204° N and longitude 74.3587° E.Punjab's main city, Lahore, is the second-largest metropolis in Pakistan after Karachi and the 26th-largest city in the world. The largest city in Punjab is Lahore. One of Pakistan's wealthiest cities, Lahore has a 2019 projected GDP (PPP) of $84 billion. It is one of Pakistan's most socially liberal, progressive, and cosmopolitan cities and the largest metropolis as well as the recent historic and contemporary cultural centre of the greater Punjab area.

2.2 Lucknow

Lucknow is situated in latitude 26.8 ° N and longitude 80.9 E. This city, which is situated in the Gomati River's northwest, has shown significant expansion in its size over time, going from 143 km2 in 2001 to 310 km2 in 2011. According to Census 2001, Lucknow's population was expected to be 2.2 million in 2001 and 2.8 million in 2011. (Census, 2011). Development of the city has been made possible by the building of ring highways and metro lines. Over the past few decades, the city's vehicle density has increased by about 10% a year. The largest contribution to overall air pollution in Lucknow is determined to be automotive emissions and accompanying windblown road dust caused by motor activities, followed by metro construction work (Kumar et al., 2020).

2.3 Kolkata

The state of West Bengal in India has Kolkata as its capital. The city is about 80 km west of the Bangladeshi border and is situated on the Hooghly River's eastern bank. With over 14.1 million people living in the Kolkata Metropolitan Area and over 45 lakh people living inside the city boundaries, Kolkata is the seventh-most populated city in India as per the 2011 Census. In terms of population, it is India's third-most populated metropolis. The Kolkata metropolitan region would have around 15 million registered voters in 2021. India's only significant riverine port and its oldest functioning port are both located in Kolkata. Kolkata is recognised as India's cultural epicentre. Of all the Indian cities, it boasts the most Nobel laureates.

3. Data Analysis and Instrumentation

3.1 MODIS Data

The Terra and Aqua satellites were launched by NASA's Earth Observing System (EOS) to track the properties of the Earth, the atmosphere, and the oceans. Since its launch in February 2000, the Moderate Resolution Imaging Spectrometer (MODIS), a crucial instrument carried by the Terra and Aqua satellites, has provided very accurate observations of aerosol and clouds on Earth (Xiong et al., 2009). The MODIS, which is distinguished by excellent spatio-temporal resolution, monitors the upwelling radiation at the top of the atmosphere in 36 channels from 0.41 m to 14.2 m. It has a large swath of 2330 km, spatial resolutions of 250 m, 500 m, and 1000 m, and temporal resolution of 1-2 days. Using the Deep Blue (over land) and Dark Target (over ocean) algorithms, the MODIS on board the Terra and Aqua satellites offers comprehensive worldwide coverage of aerosol optical characteristics. The equator is crossed by the Terra and Aqua satellites at around 10:30 and 1:30 p.m. (local time), respectively. Level 3 MODIS Terra and Aqua mean data (MYD08 D3v6) of AOD and Angstrom exponent (AE) across land throughout the period from 2005 to 2020 were utilised in the current investigation.

3.2 AERONET Data

In order to measure aerosols, AERONET is a network of numerous ground-based CIMEL sunphotometers and skyradiometers. It gives full real-time aerosol characteristics for the whole world. Three levels of AERONET data are available: level 1.0, which contains pre-screened data; level 1.5, which contains automatically cloud-screened data. Since AERONET's AOD data are so precise, they are frequently used to validate satellite data. In this study, satellite retrievals at 10 sites across the IGB are validated using the daily level 2.0 AERONET from version 3 data.

3.3 Trend Analysis

Aerosol optical characteristics time series from two sites in IGB were analysed for long-term trends. In Kaskaoutis et al. (2012), the approach of trend analysis is described. The trend analysis was performed to daily mean data of several aerosol optical characteristics received from MODIS and AERONET for both sites throughout the period of 2005-2020.

$$x\ \% = (a * \frac{N}{x}) * 100$$

where N is the total number of days during the study period, x is the variable, x is the mean value, and an is the slope value from the linear regression analysis. The p value, which was determined to be less than 0.05 for statistically significant deviations at the 95% confidence level, was also used to verify the slope's statistical significance.

4. Result and Discussion

4.1 Decadal mean AOD spatial and temporal distribution from 2005 to 2020

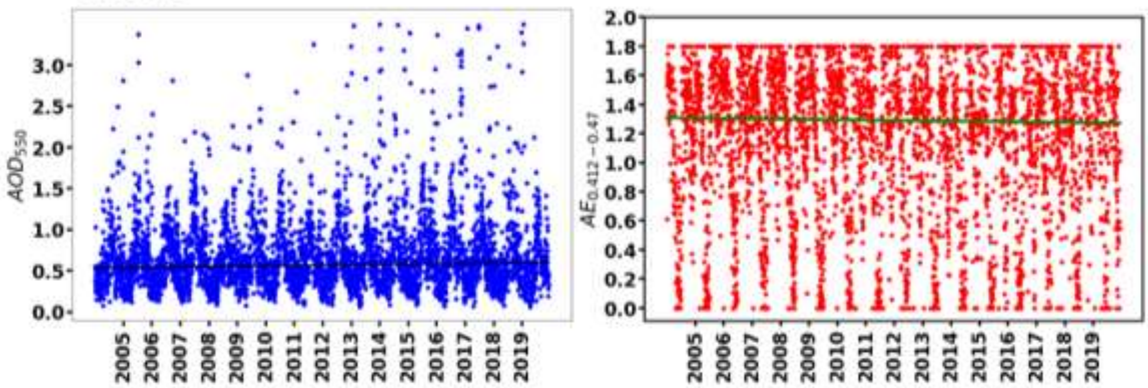
The geographical distribution of the decadal monthly mean AOD over India from 2005 to 2020 is depicted in Fig. 1. The IGB shows a significant aerosol burden with an annual AOD > 0.5. Over the western portions of the IGB during the pre-monsoon (because to higher dust effects) and post-monsoon months (due to enhanced agricultural burning impacts), as well as in the eastern sections of the IGB throughout the winter month, the persistence of abnormally high AOD (>0.7) was recorded. The eastern aerosol pool shares many of the same features as the western aerosol pool, emitting varied amounts of aerosols mostly from burning fossil and biofuels as well as agricultural waste and leftovers (Banerjee et al., 2017).

Table displays the AOD and AE trends for the years 2005 to 2020 in Lahore, Lucknow, and Kolkata. The trend/day, % change, and statistical characteristics of decadal trends for each aerosol parameter The corresponding figures show the results of the significance test, as shown by the p values at the two stations. The graphic displays the temporal a distribution of averaged daily data with a decadal mean and huge scatter values of AOD, from 0.05 to 3.02 from 0.06 to 3.40, with a mean value of 0.69 ± 0.48 in Lucknow, and 0.65 ± 0.42 at Lahore.

Table 1: Decadel Trend of Aerosols from 2005 to 2020

		Mean	Trend/yr	% variation	P value	N
2005-2020						
LAHORE						
	AOD	0.68 ± 0.45	0.007665	14.87508	**<0.0001**	4800
	AE	1.14 ± 0.55	-0.00548	-6.01083	**0.005**	4800
LUCKNOW						
	AOD	0.64±0.42	0.00803	14.65821	**<0.0001**	4308
	AE	1.16±0.6	0.0087965	8.909391	**0.003**	4308
KOLKATA						
	AOD	0.65 ± 0.46	0.018542	28.00527	**<0.0001**	3608
	AE	1.46 ± 0.38	-0.00511	-3.25486	**0.000**	3608

LAHORE



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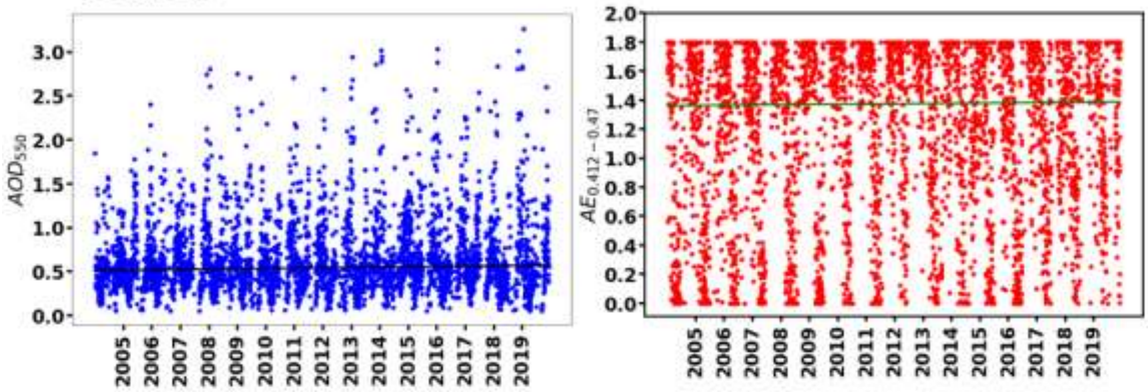

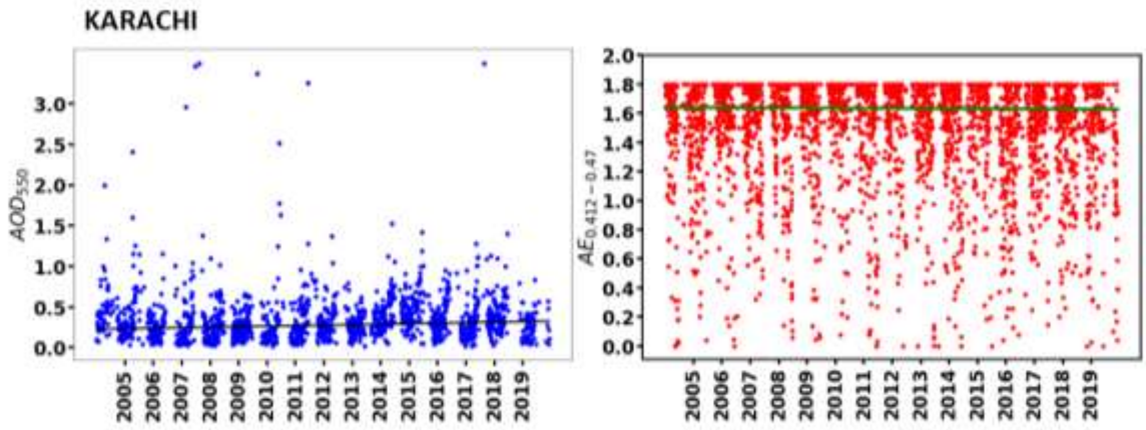

Fig 1: Decadel Trend of Aerosols from 2005 to 2020

4.2 Seasonal Trend of Aerosols from 2005-2020

The seasonal AOD and AE trends in Lahore, Lucknow, and Kolkata are shown in the table for the period 2005 to 2020. The related figures illustrate the results of the significance test, as evidenced by the p values at the two stations. They show the trend/day,% change, and statistical features of decadal trends for each aerosol parameter.

Table 2:Winter Season trend of aerosols form 2005-2020

	MEAN	ST DEV	N	P VALUE	TREND/DAY	%
LUCKNOW						
AOD	0.749	0.526	1251	**<0.0001**	5.97E-05	9.970461
AE	1.510	0.370	1251	0.093	0.00012	9.9494
LAHORE						
AOD	0.547	0.522	1107	**<0.0001**	5.28E-05	10.68168
AE	1.443	0.310	1044	0.067	-0.0002	-14.4796
KOLKATA						
AOD	0.730	0.484	1317	**<0.0001**	5.62E-05	10.13839
AE	1.592	0.297	1317	**0.001**	-2.5E-05	-2.0595

Table 3:Summer season trend of aerosols form 2005-2020

		MEAN	ST DEV	N	P VALUE	Trend/Day	%
LUCKNOW							
	AOD	0.549	0.325	1752	**<0.0001**	-1.8E-05	-5.88331
	AE	0.730	0.582	1752	**<0.0001**	0.000061	14.6315
LAHORE							
	AOD	0.594	0.354	1766	0.474	-4.9E-06	-1.36886
	AE	0.707	0.569	1570	**0.038**	-2.3E-06	-0.50007

KOLKATA							
	AOD	0.675	0.511	1357	**<0.0001**	5.92E-05	11.89431
	AE	1.408	0.447	1357	**0.009**	2.22E-05	2.138569

Table 4:Monsoon season trend of aerosols form 2005-2020

		MEAN	ST DEV	N	P VALUE	Trend/day	%
LUCKNOW							
	AOD	0.502	0.339	397	**0.003**	3.14E-05	2.484948
	AE	1.313	0.520	397	**0.039**	0.00019	5.75877
LAHORE							
	AOD	0.860	0.397	1092	0.121	1.64E-05	2.078249
	AE	1.400	0.371	1092	0.960	-5.9E-05	-4.6139
KOLKATA							
	AOD	0.527	0.372	182	**0.032**	0.000454	15.68922
	AE	1.594	0.308	182	**0.003**	-0.00049	-5.624

Table 5:Post Monsoon season trend of aerosols form 2005-2020

		MEAN	ST DEV	N	P VALUE	Trend/Day	%
LUCKNOW							
	AOD	0.762	0.383	906	**<0.0001**	0.0005	4.682188
	AE	1.457	0.382	906	**0.002**	-3.5E-05	-2.20279
LAHORE							
	AOD	0.770	0.479	932	**0.206**	2.44E-05	2.948744
	AE	1.246	0.428	932	**<0.0001**	-4.9E-05	-3.63902
KOLKATA							
	AOD	0.518	0.282	750	**<0.0001**	4.02E-05	5.819903
	AE	1.474	0.347	750	**<0.0001**	-0.00006	-3.03882

4.3 Annual Trend of Aerosols

The average of the daily averages of the AOD and AE for Lahore, Lucknow, and Kolkata was used to compute the monthly mean of various optical characteristics, which is depicted in Fig. at the time of study. AOD was discovered to rise starting in March and peak in June or July. months at both locations, following which it starts to decline until September. At both locations, a second peak was seen in October and November. AODs in Kolkata ranged from 0.38 ± 0.11 (in September) to 0.98 ± 0.16 (in November) over the course of the research period, while at Lucknow AOD shifted between 0.41 ± 0.07 (March) and 0.92 ± 0.25. (January).

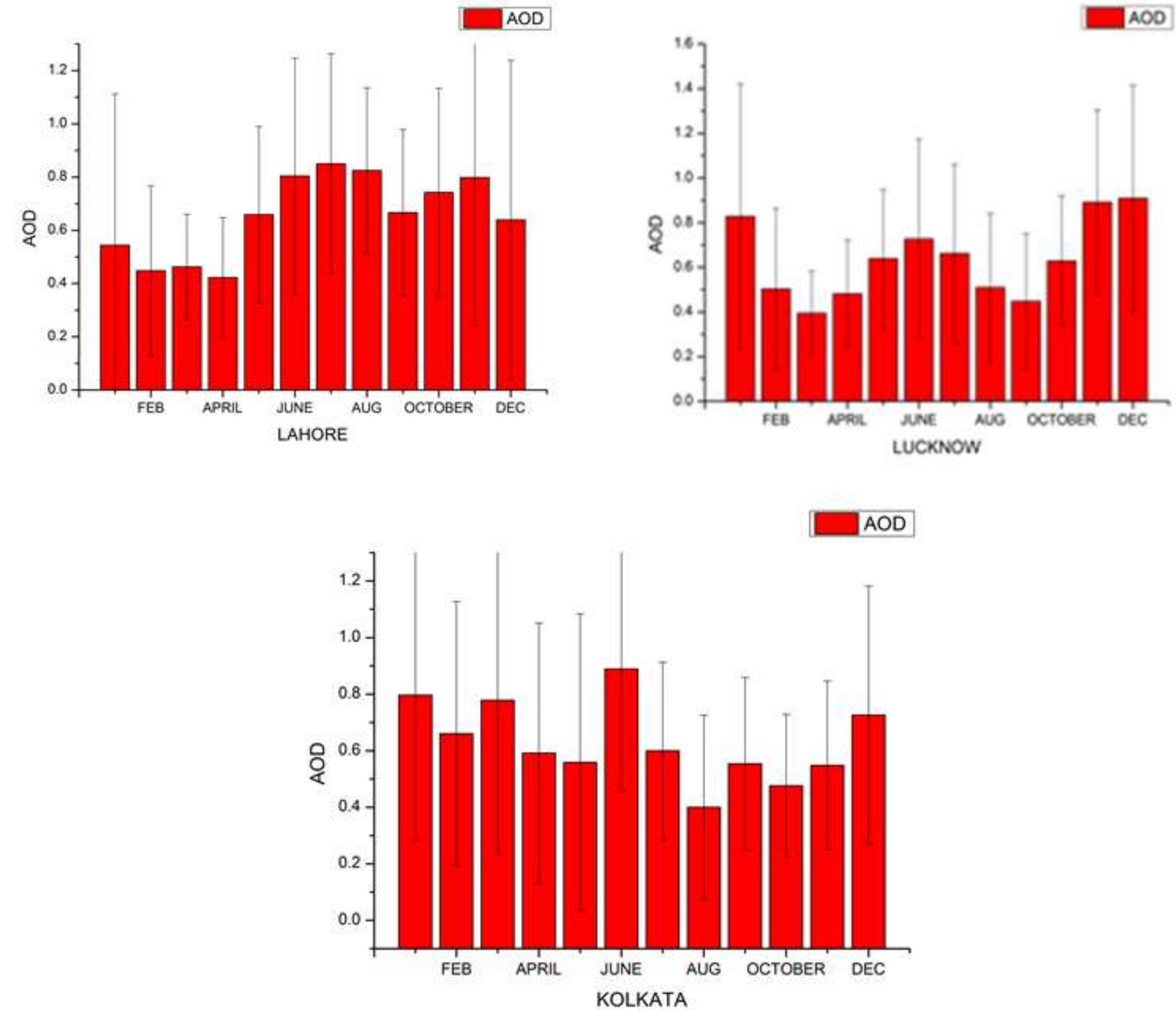

Fig 2:Monthly Variation of Aerosols averaging from 2005-2020

4.4 Aerosol inter-annual variation

The variability in all the metrics at both sites is observed to have an intriguingly distinct trend before and after 2012. The inter-annual variability in the AOD in Lucknow is nearly consistent until 2012, at which point an increasing trend is seen. At Delhi, however, the opposite was seen. Due to the extensive development work being done on stations like transportation, industries, constructions, etc., this may be connected to the numerous emissions from the rising human activities (Kishore et al., 2019). It should be mentioned that the Common Wealth Game (CWG), which was held in Delhi in 2010, served as the impetus for the major construction projects in Delhi pertaining to roads, the metro, buildings, and other infrastructure. Similar to this, work on the Lucknow metro's construction project began in 2012.The measured data has been studied in two sub-periods from 2005-13 and 2013-17 in order to better understand the implications of such developmental activities in relation to the rising anthropogenic activities at both locations. The next section contains the analysis's specifics.

5. CONCLUSIONS

Decadal assessments of long-term observations of satellite-derived columnar AOD, AE have been conducted between 2005 and 2020 in Lucknow, Lahore, and Kolkata in IGB's central, western, and eastern regions, respectively. High aerosol loading over the IGB, which exhibits considerable monthly, seasonal, and yearly variability, was indicated by the high decadal mean AODs (0.63), with virtually equal rising trends of 10% reported at both sites. At all three locations, the high decadal mean AE (>1.0) with an upward trend was also seen. Lucknow (6%) has a more marked increasing decadal trend in AE than Kolkata (3%), suggesting a relative rise in fine-mode aerosols at Lucknow (30% greater than Kolkata). Seasonal Analysis also shows peak of aerosols in Winter Season (mainly January and December). We measure variations in AOD and particle size to assess the seasonal pattern of trends in all three sites. There is a noticeable difference in the kinds of aerosols present in the various locations, with coarser particles predominating in Lahore while mixed and fine aerosols predominate in Lucknow and Kolkata.

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