# CLASSIFICATION OF KEY TYPES AND PREDICTING TRANSPORT PATHWAY OF AEROSOLS OVER IGB FROM SATELLITE-DERIVED ATMOSPHERIC OPTICAL DATA

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## ABSTRACT

When about 900 million people in northern India experienced poor air quality as a result of intense fog, haze, and smog during the post-monsoon/winter period and dust storm activity during the summer, the scientific community paid particular attention to the high aerosol loading over the entire Indo-Gangetic Basin (IGB) region. The objective of the current study was to conduct the first long-term comparison analysis to quantify the aerosol features throughout the biomass burning (October–November) and dusty (April–June) periods employing Lahore, Delhi, and Kolkata satellite measurements over IGB from 2004 to 2018 at three separate places. Throughout the whole research period, Kanpur had the greatest aerosol optical depth (AOD) values for the biomass (0.74 0.35) and dusty period (0.63 0.34). Anthropogenic aerosol (AA) type emissions during the biomass burning era whereas clean condition (CC) aerosol type was dominating over Kolkata (69%), were determined to be prominent over Lahore (52%) and Delhi (56%) On the other hand, during the dusty period, Lahore (37%) and Delhi (30%) had the biggest contributions of desert dust (DD), whilst Kolkata (42%), had the highest concentrations of CC type aerosol. The potential source sectors and the pathways for the transmission of pollutants have been thoroughly established at all of the stations using the concentration weighted trajectory (CWT) studies with the backward air mass trajectories and the potential source contribution function (PSCF) analyses. The upper and middle IGB region, as well as local regions, were found to be the main sources of the large levels of aerosol above the stations, according to the results.

**Keyword:** *Dust Aerosol, IGB, Biomass burning, optical properties, Cluster Analysis.*

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## 1.INTRODUCTION

Aerosols, one of the most variable components of the Earth's atmosphere, are known to have a considerable influence on the radiative balance and temperature of the planet. Depending on their physical and optical properties, aerosols can either absorb or deflect solar and terrestrial radiation, which warms or cools the planetary system (Moorthy et al., 2009). Hygroscopic aerosols can also function as condensation nuclei, which can have an indirect impact on precipitation and cloud albedo. Aerosols can have a harmful impact on people's health and can make it harder to see in urban and industrial regions. The Indo-Gangetic Basin (IGB), one of the world's largest and densest agricultural basins, is located in northern India and is thought to be one of the world's hotspots for enhanced aerosol loading. It has a complex combination of different emission sources, each with their own unique seasonal characteristics. The IGB is one of the most susceptible areas to the adverse health effects of aerosols due to the region's large population and extensive pollution (Apte et al., 2015). As a result, various modelling and observational investigations were carried out to better characterise the aerosols over the area. Various anthropogenic activities, which are mostly linked to the creation of secondary aerosols and the natural aerosol fluxes, primarily desert dusts from long-range transport, are usually blamed for the increased aerosol loading over the region (Srivastava et al., 2021). A significant quantity of agricultural residue burning occurs annually throughout the IGB, particularly in the post-monsoon season in the Punjab, Haryana, and western Uttar Pradesh regions. These areas are known as India's "bread basket" since they generate over two thirds of the country's food grains. The post-monsoon period's favourable weather conditions over the area cause a significant buildup of fine particles over the IGB. The result is that the area experiences severe smog conditions, which may increase risks to human health and significantly worsen the quality of the air at both the local and regional levels. The Great Indian Desert (also known as the Thar Desert), Oman, and Southwest Asian areas all contribute significantly to the region's high levels of transported dust aerosols during the pre-monsoon and/or summer seasons. The movement of dust particles from dry and semi-arid regions, which have a major impact on distant regions' climates, is one of the most important natural causes of air pollution. The Saharan dust event proved that dust particles may climb to a vertical height of several kilometres into the upper atmosphere. The IGB is one of the most polluted regions, and during the pre-monsoon season, dust aerosols account for a sizeable fraction of the overall aerosol loading. The stability of the atmosphere might be affected, which could modify the Indian summer monsoon rainfall by changing the heating profile of the atmosphere. Despite the fact that the total aerosol loading is higher over the IGB than the rest of India, the numb er of hazy days was found to increase at a relatively higher rate over Central India (2.6 days/year) than over the IGB (1.7 days/year). This is largely due to the relative increase in biomass burning emissions over the Central India region (Thomas et al., 2019). On the other hand, during the pre-monsoon/summer season, the area is badly harmed by the transported dust particles from the adjacent Desert areas. 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.

In a global climatology of aerosol optical depth (AOD) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) from 2000 to 2006, South Asia has the highest yearly mean in comparison to the rest of the world. (2008) Remer et al. This was mainly attributable to the observed increase in anthropogenic aerosol emissions over South Asia, which were caused by the region's rapid industrialization, u rbanisation, and population growth in preceding decades. Using the AOD data from the multi-angle imaging spectroradiometer (MISR) between 2000 and 2010, a substantial upward trend in anthropogenic aerosols was also seen across the Indian subcontinent (Dey and Di Girolamo, 2011). Aerosol data from satellite sensors has been cross-checked against the Middle Eastern AERONET stations in order to confirm the accuracy of satellite-based outputs. The link between AOD and AE collected from the Moderate Resolution Imaging Spectroradiometer is used in a modified classification strategy to explore the relative contribution of the primary aerosol species across the IGB (MODIS). To get insight into the spatiotemporal distribution and seasonal cycle of aerosol types acros s the area, the results are evaluated. It is also discussed how accurate MODIS-derived AODs are in comparison to AERONET AODs across the IGB. An increased geographical and temporal coverage of the phenomenon has been made possible by a satellite-based categorization, which has helped to attain this aim.

As a result of their reflective properties, dust, organics, sea salt, and sulphate aerosols chill the atmosphere by reflecting solar energy back into space (Bilal et al., 2013). However, certain aerosols have characteristics that make them more absorbent than scattering (Li et al., 2016).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 ngstr om exponent are the two major columnar aerosol parameters used to categorise aerosols (AE). 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. Based on AE values, Mielonen div ided aerosols into fine and coarse particles. The AE was also utilised by Russell et al. (2010) to identify various aerosol types. Mhawish et al. have assessed AOD retrieval techniques for a range of aerosol types, including coarse, fine, and mixed aerosols (2017). AOD and AE can be used in conjunction to identify different kinds of aerosols, according to a number of studies. Marine aerosols are most likely those with low AOD and AE values, whereas dust aerosols are frequently classified as those with high AOD and low AE values. However, high levels of both AOD and AE are used to identify anthropogenic aerosols. In the literature, aerosols are most frequently categorised as follows: (1) wind-borne dust, (2) urban, industrial, and continental aerosols produced by burning fossil fuels, (3) marine and sea salt aerosols, (4) biomass burning and carbonaceous smoke from forest fires, and (5) mixed type aerosols. Radiative force across an area can be either positive or negative depending on the aerosol type. Therefore, a thorough study of aerosol characteristics and the identification of various aerosol types throughout various regions of the world contribute to a better understanding of how aerosols affect radiation and climate. 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 .

In the Present study , a long term assessment of two aerosol parameters i.e. AOD and AE is done over IGB form satellite derived data to understand the effect of many anthropogenic activities .The study was conducted for a period of 15 years from 2005 to 2020 over three rapid growing cities over IGB .Classification of main aerosol types over IGB is done form values of AOD and AE. The main method for evaluating the temporal change and geographical distribution of aerosols is satellite remote sensing. The cluster analysis using air mass back-trajectories was used to further analyse probable source regions and the transit routes of these aerosols.

## 2.SITE DESCRIPTION

### 2.1 Lahore

Lahore is located at 31.5204° N and 74.3587° E longitude. Lahore, the capital of Punjab, is the 26th-largest city in the world and the second-largest metropolis in Pakistan after Karachi. Lahore is the biggest city in Punjab. Lahore, one of the richest cities in Pakistan, is expected to have a GDP (PPP) of $84 billion in 2019. It is the biggest city in Pakistan, one of the most socially liberal, forward-thinking, and multicultural cities, and the recent historic and modern cultural hub of the broader Punjab region.

### 2.2 Delhi

According to the 2011 Census, Delhi, which is situated in the north-western region of the IGB, has a population of over 17 million people and a total area of roughly 1500 km2. Delhi is bordered by the Himalayas in the north, the central Indian plains in the south, and the Thar Desert in the west-southwest. Numerous small and medium-sized businesses surround the station, and there are also around 7 million registered cars, which are the main sources of air pollution above the station. Both cities are situated in IGB (as seen in Fig. 1), an area in the northern section of India that is among the world's most densely inhabited and polluted. Due to its location on the Indus River's bank and the region's massive population load brought on by rising urbanisation and the emissions that result from a variety of human activities, the whole IGB serves as the primary food basket for Pakistan and India . Due to its distinctive geography and proximity to the vast Himalayan mountain ranges to the north, the entire region is more prone to the confinement of large and diversified aerosols.

### 2.3 Kolkata

Kolkata serves as the administrative centre of India's West Bengal state. The city is located on the eastern bank of the Hooghly River, roughly 80 km west of the Bangladeshi border. According to the 2011 Census, Kolkata is the seventh-most populous city in India, with over 14.1 million people residing in the Kolkata Metropolitan Area and over 45 lakh people living inside the municipal limits. It is the third-most populous metropolitan in India in terms of population. By 2021, there will be around 15 million registered voters in the Kolkata metropolitan area. Kolkata is home to India's only substantial riverine port as well as its oldest active port. In India, Kolkata is regarded as the centre of culture. It has the most Nobel laureates of any Indian city.

## 3. Data Analysis and Instrumentation

### 3.1 Aqua and Terra MODIS data

The Terra and Aqua satellites' Moderate-Resolution Imaging Spectroradiometer (MODIS) crosses the equator at around 10:30 and 1:30 (local time), respectively (Levy et al., 2007). Regularly obtaining the aerosol optical depth (AOD at 550 nm) and Angstrom exponent (AE at 412-470 nm) from MODIS, respectively, required the Deep Blue (over land) and Dark Target (over ocean) algorithms. AOD data obtained from MODIS over land using the Deep Blue (DB) technique (both on Terra and Aqua satellites) have been used in the current analysis.

### 3.2 AERONET DATA

For the purpose of measuring aerosols, AERONET is a vast ground-based network of CIMEL skyradiometers and sunphotometers. It offers comprehensive, real-time global aerosol characteristics. There are three levels of access to AERONET data: level 1.0 offers prescreened data, level 1.5 includes automatically cloud-screened data. Due to its high degree of precision, AOD data from AERONET are frequently used to validate satellite data. In this study, satellite retrievals at 10 sites around the IGB are evaluated using daily level 2.0 AERONET from version 3 data.

### 3.3 HYSPLIT DATA

To comprehend the likely source industries and the transportation routes. The backward air mass trajectories of detected air pollutants Discovered using the hybrid single particle lagrangian trajectory (hysplit) All three of the models (draxler and hess, 1998) were examined. Stations between 2004 and 2018, the research period. To determine the Air pollutants' probable transit routes across the stations, the sectors that might serve as their sources, and the potential source Using meteoinfo software, contribution function (pscf) and cluster analyses were carried out on 5-day backward air mass trajectories (wang, 2014). Using ncep reanalysis meteorological data, the 5-day backward air mass trajectories were estimated every 24 hours at a height of 1000 m above the ground.

## 4. RESULT AND DISCUSSION

### 4.1 Classsification of Aerosols

To attempt a preliminary identification of the primary aerosol species over IGB, the conventional approach of AOD 500nm vs AE (440-870nm) relationship is applied. Using all instantaneous values, Figure 8a shows the scatter plot between AOD (500 nm) and AE (440-870 nm). The data scatter is typical of the presence of various aerosol types over IGB, such as biomass burning, urban-industrial, desert dust, and clean-marine, as found over several sites in India, including Hyderabad (Kaskaoutis et al., 2009), Dibrugarh (Pathak et al., 2012), Pune Delhi and Kanpur (Kaskaoutis et al., 2012), as well as Delhi and (Kaskaoutis et al., 2011b).

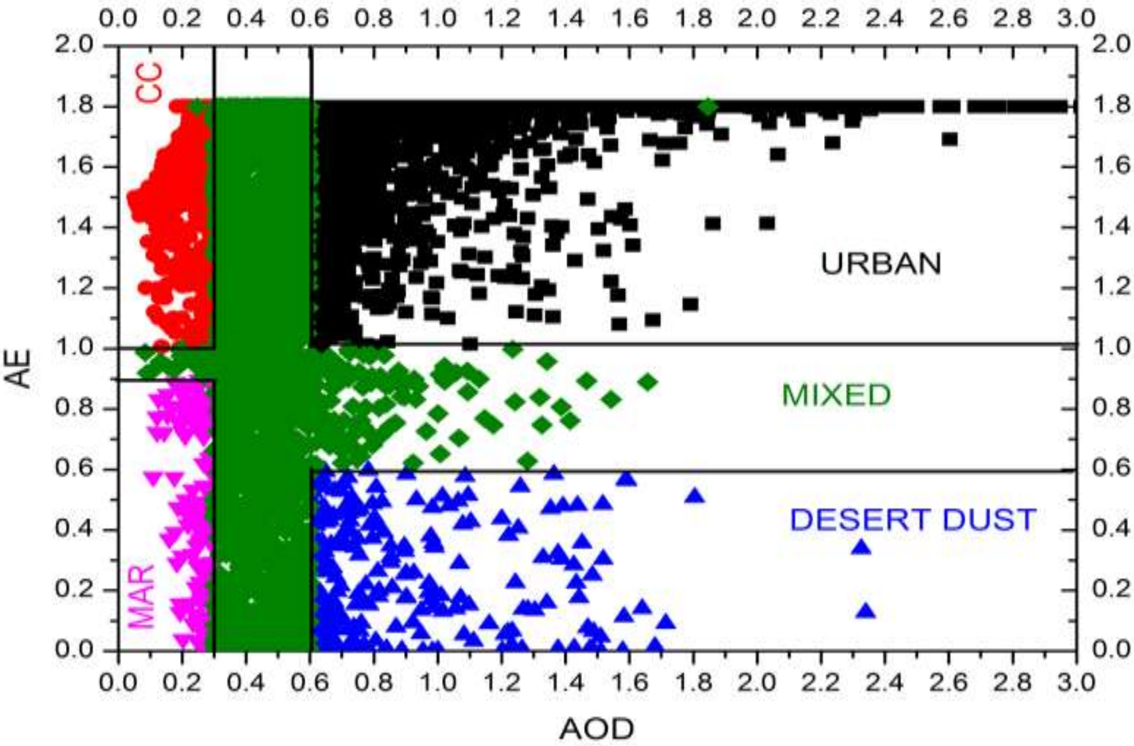


**Fig 1**: Scatter plot of AOD500 versus α440–870 nm for identification of the dominant aerosol types

AOD500 < 0.3 for AE (440–870 nm) has a wide range (0.1–1.4), which is typical of many aerosol species mixed with the environment. AE (440-870nm) often assumes large (>1.0) or modest (0.6) values for AOD500 > 0.5-0.6, which correlate to turbid conditions brought on by biomass burning or desert dust particles, respectively. Some threshold values were established to quantify the contribution of the primary aerosol kinds. In further detail, clean continental (CC) aerosols are defined as having AOD 500nm 0.3 and AE (440-870 nm) >1.0, whereas marine-influenced aerosols (Mar) are defined as having AOD 500nm 0.3 and AE (440-870 nm) 0.9. Cases related to heavy urban/industrial plumes or turbid atmospheres dominated by transported biomass-burning aerosols (BB/UI) are for AOD500 > 0.6 and AE (440-870) > 1.0, whereas desert dust aerosols (DD) are for AOD500 > 0.6 and AE (440- 870) 0.6. (Fig. 8a). Mixed aerosols (Mix), which make up the bulk of cases (56.3%), are classified as cases that don't fit into any of the aforementioned categories. Due to the site's proximity to the Arabian Sea, marine-influenced aerosols account for a sizeable portion there (18.2%), whereas BB/UI aerosols have a very little impact (5.7% of the time). In reality, it was found that the smoke plumes from the burning of agricultural crop remnants in the north of the Indus Valley had very little of an influence on the research location (Kaskaoutis et al., 2014). Desert dust aerosols constitute a significant portion of the atmosphere, accounting for 10.6%, while CC conditions over IGB are observed in 9.1% of cases. This is due to the proximity of the Thar Desert and other arid areas in southwest Asia, which produce large amounts of dust that cover the entire region in the spring and summer. The varying threshold values chosen for particular aerosol types that may considerably differentiate the findings make it difficult to compare the current results with those from earlier research conducted over India.

It is also used to assess how aerosol features change over IGB, using the visual method developed by Gobbi et al. (2007) that combines and its spectral variation (dAE) with the fine-mode radii (Rf) and fine-mode percent () as grid parameters in grouped AOD. The change in AE, (AE40-675-AE675-870) pairs with because coagulation, humidification, and the addition of fine and coarse particles are some of the aerosol modification processes in the atmosphere that have been researched in a number of prior studies.

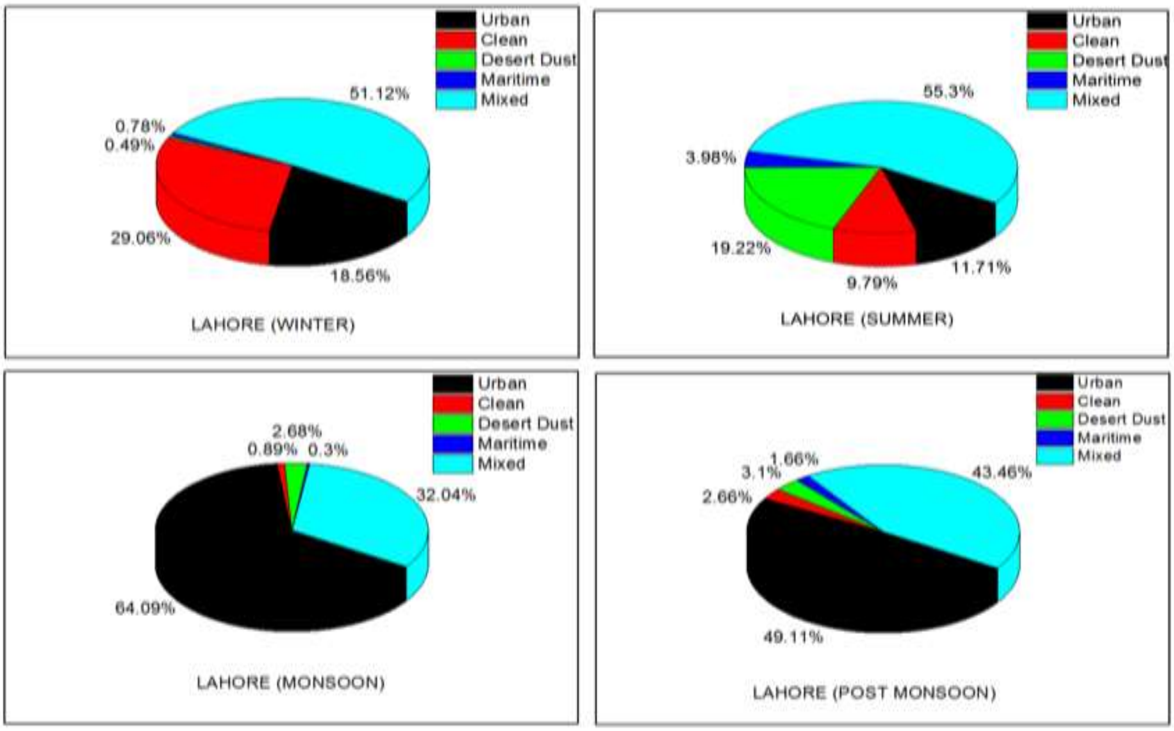


**Fig 2**: percentage of each aerosol type over Lahore in all the seasons

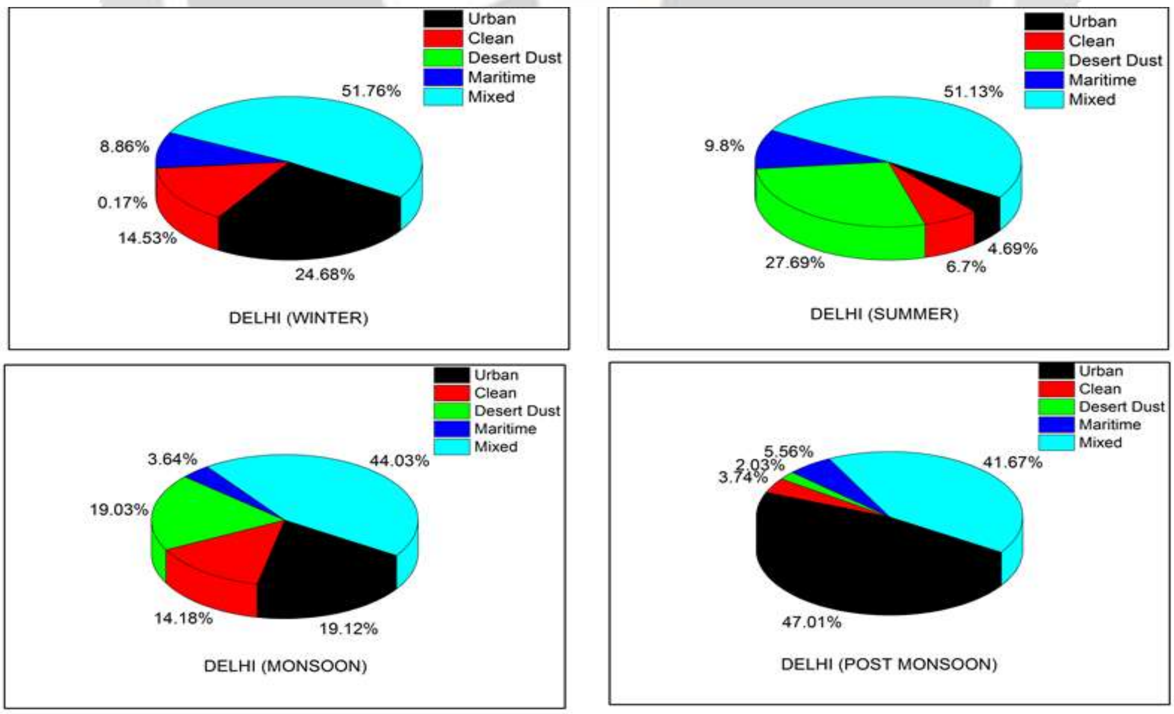


**Fig 3**: percentage of each aerosol type over Delhi in all the seasons

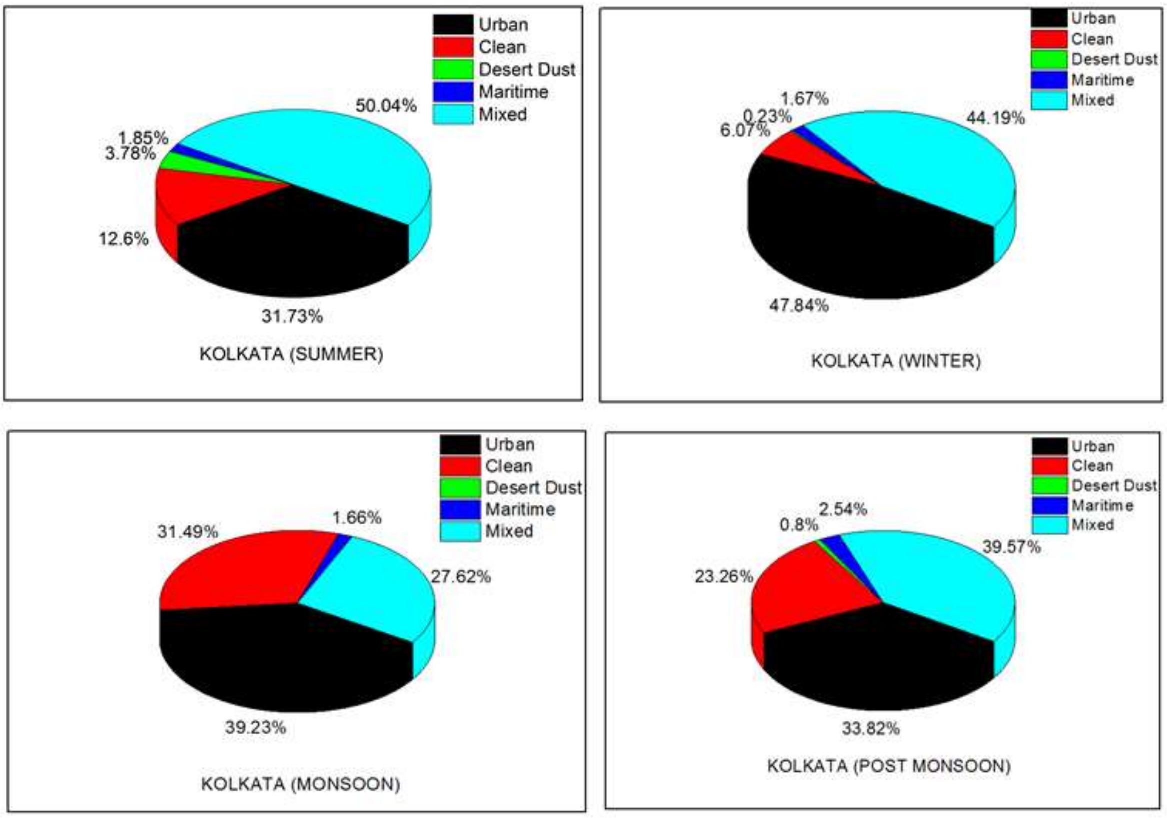


**Fig 4**: percentage of each aerosol type over Kolkata in all the seasons

**4.2 Identification of sources and the significance of pollutant transport routes across the stations**

To create air mass backward trajectories in predetermined beginning locations, the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model is frequently employed. The Global Forecast System (GFS) model uses meteorological data supplied by the Global Data Assimilation System (GDAS) to place observations into a gridded model space in order to initiate or initialise weather forecasts using observational data. The standard GDAS data (GDAS1, accessible at (ftp:/arlftp.arlhq.noaa.gov/pub/archives/gdas1) has a horizontal resolution of 1°, which is equivalent to 100 km 100 km and 23 vertical layers.

The main objectives of this study are, first, draw HYSPLIT backward trajectories all the ten major polluted cities of IGB generated from GDAS datasets over 120-hour periods.The study is carried out over a period of 15 years from 2005 -2019.

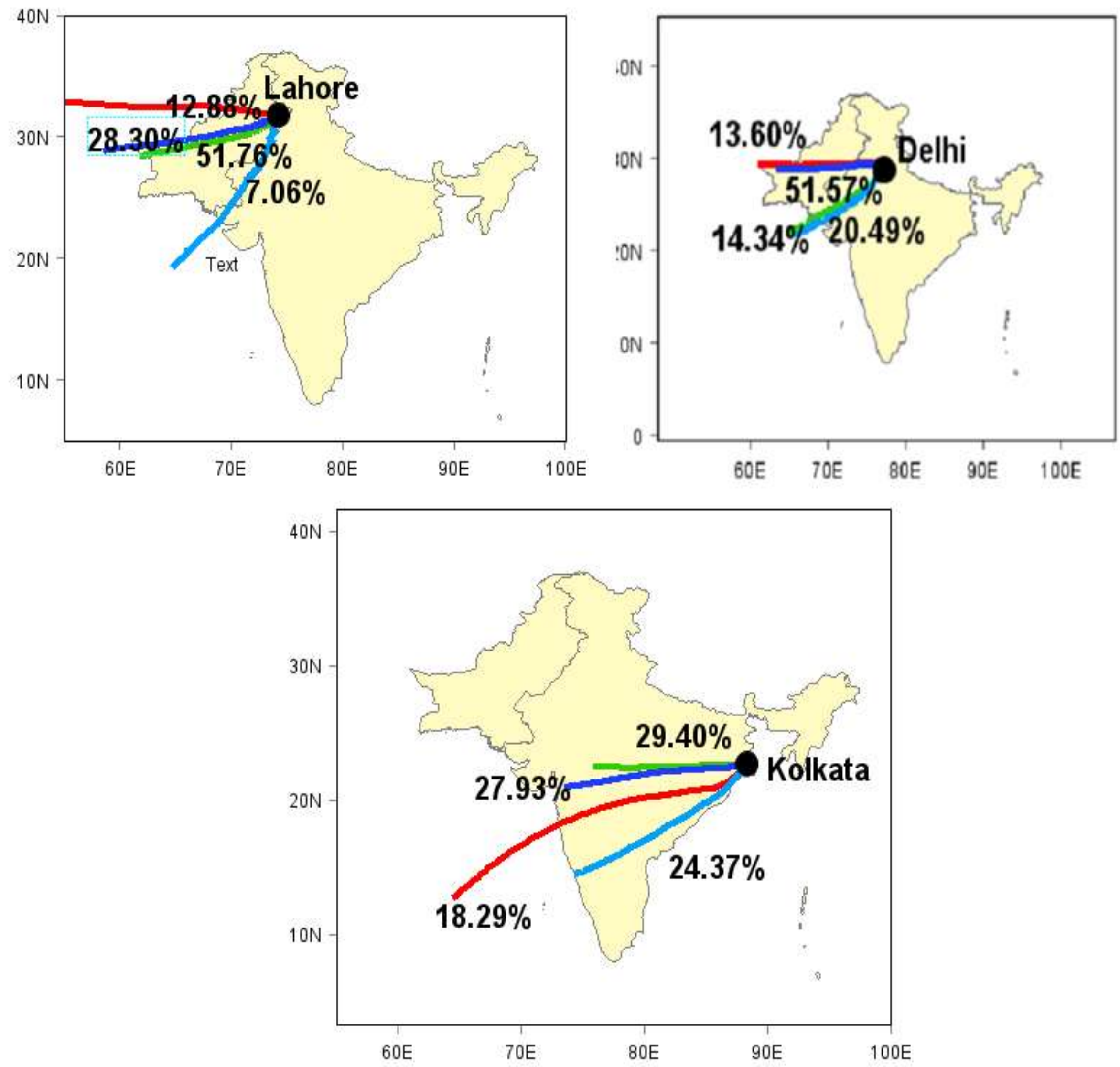


**Fig 5**:Transport Pathway of Aerosols at Lahore, Delhi and Kolkata

## 5. CONCLUSION

For the first time, the current study examined the aerosol optical and Radiative forcing and material characteristics over Indo Gangetic Basin. The primary conclusions are presented here. The aerosol features were evaluated on a daily, monthly, and seasonal basis. investigation of spectral SSA and VSDs on a monthly and seasonal basis. With the increased dust levels from March to August, while the aerosol field might be mainly absent from October to February. Mixed with almost equal quantities of fine andVSDs with coarse-mode particles . The AOD in Delhi is compared to both the biomass period and the dusty era.less than AOD in Kolkata and Lahore. Value of AE in a dusty environment period at all sites is shorter than the biomass period, which depict a time of dust when the particles are larger, whereas biomass progressively smaller particle sizes over time. PSCF dominated (PSCF > 0.7) during the biomass era, we also discovered.from the northwest with the greatest PSCF score demonstrates that the AOD concentrations were greater everywhere throughout the dusty period coming from the west-southwest, or from the Arabian Sea and There is a little portion of Pakistan there, but Delhi is also visible. a few other areas where AOD is more prevalent, including states of Jharkhand and Bihar.

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