

THE PAST, PRESENT AND FUTURE OF CO₂, NO₂, SO₂ & CH₄ IN PUNJAB REGION, INDIA

H.K. Romana^{1*}, D.P. Shukla²

¹PhD Scholar, IIT Mandi, Himachal Pradesh, India - d19010@students.iitmandi.ac.in

²IIT Mandi, Himachal Pradesh, India- dericks@iitmandi.ac.in

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ABSTRACT:

Anthropogenic activities have caused inferior quality of environment and threatens all living forms on the planet. Everyday human activities create havoc to earth's climate. Any change in green-house gases affects the balance of earth's ecosystem. The major concern of increased trace gases is their ability to trap sun's energy, which is rising surface temperature. The rise in temperature is causing many extreme climatic events, melting of glaciers, uneven rainfall pattern, floods and droughts etc. The land of five rivers, Punjab is chosen as study area. The major green-house gases emission source is crop residue burning. This study forecast concentration of carbon dioxide, nitrogen dioxide, sulphur dioxide and methane for year 2021-2025 using satellite data. The methodology involves time series analysis using linear regression for three different iterations with different training period. The results shows that maximum concentration for CO₂ in the year 2025 for 1st iteration is 424.46±5.58 ppm, 2nd iteration is 424.37±7.93ppm and 3rd iteration is 425.21±4.55ppm. The maximum concentration for SO₂ rises to 0.19±0.03 DU for 1st iteration, 0.18±0.02DU for 2nd iteration and 0.19±0.03DU for 3rd iteration. Similarly, NO₂ concentration rises to 24.45±2.56ppm for 1st iteration, 23.57±2.67ppm for 2nd and 26.85±2.99ppm for 3rd. Also, CH₄ concentration rises to 1933.44±12.00ppbv for 1st iteration, 1932±13.81ppbv for 2nd and 1934±12.02ppbv for 3rd iteration. The study further concluded that the type of aerosols in the study area can be majorly categorized in anthropogenic aerosols. They are evenly distributed in the other three categories

1. INTRODUCTION

Air pollution is the cause for 4.2 million deaths annually due to exposure to fine particulate matter (PM) (WHO, 2018). Around 91% of the Earth's inhabitants reside in areas having high air pollution levels as per WHO limits. Currently, WHO has updated the guidelines (table 1) and made it stricter in an attempt to lower the pollution levels. At present, climate change is the imminent treat faced by humanity and the developing countries will be the most vulnerable. Indian metro cities have rising pollution at a dangerous rate (Chauhan et al., 2010). Policies to implement sustainable living, power generation, and efficient effluent discharge around the globe would help reducing air pollution. Detailed monitoring and future pollution projections will help policy makers to draft appropriate policies as per type of sources. This study focuses on forecast of air pollution in Punjab region of India using satellite data. Punjab, called as the food basket of India, produces 20% of wheat, 11% rice and 13% of cotton for the country while occupying just 1.53% of land of India. The main sources of pollution in this area are biomass burning during post monsoon harvest, exhaust from thermal power plants and industries (Jethva et al., 2018).

With advancement and expansion of irrigation network, agricultural area has increased in Northern India (Badarinath, et al., 2006). Furthermore, the crop yield has improved with use of advanced equipment, leaving behind even greater crop residue (Ravindra et al., 2019a). In the lack of appropriate residue management measures, the increased crop residue is left to burn in the field (Figure 2) (Ravindra et al., 2019a). The emissions from this biomass burning pollute the whole Indo-Gangetic Plain

(IGP) with particulate matter, organic carbon, trace and green-house gases (Bikkina et al., 2019; Mittal et al., 2009; Sarkar et al., 2013; Jain et al., 2014; Ravindra et al., 2019a,b). Emissions from crop residue burning can travel thousands of miles and can sometimes travel till Arabian sea and central-south India (Badarinath et al., 2009a,b). In addition to this, Punjab has many textile industries (Ludhiana, Amritsar), leather and rubber industries (Jalandhar), pharmaceuticals (Mohali), diesel engine and parts (Ludhiana), steel rolling mills (Mandi Gobindgarh) and thermal power plants (Bathinda, Rupnagar, Chandigarh). The emissions from these industries also add on to the already enhanced air pollution level of Punjab region. In order to manage and mitigate air pollution, proper monitoring is vital.

Previous literature is mainly focused on air quality degradation from stubble burning (Sarkar et al., 2018; Singh and Kaskaoutis, 2014). These studies also suggest that the crop residue burning exacerbate air pollution in Indo-Gangetic Plains (Amann et al., 2017). Furthermore, some recent studies (Sahoo et al., 2020; Singh et al., 2020; Gope et al., 2021) focused on air quality change during COVID-19 lockdown in this region.

The main objective of this study is to forecast concentration of carbon dioxide, methane, nitrogen dioxide and sulphur dioxide as per the trend of past concentrations. The study uses time series analysis and linear regression to forecast trace gases in the study area of Punjab. Type of aerosols present in the study area are also attributed based on AOD and AE. The result of study shows that if proper mitigation measures are not ensured, air quality will deteriorate in Punjab region.

*Corresponding Author

Trace element	Averaging time	2005 Standard ($\mu\text{g}/\text{m}^3$)	2021 Standard ($\mu\text{g}/\text{m}^3$)
PM _{2.5}	Annual mean	10	5
PM ₁₀	Annual mean	20	15
NO ₂	Annual mean	40	10
SO ₂	24-hour mean	20	40

Table 1: Air quality standards comparison of year 2005 and 2021 set by World Health Organization

2. STUDY AREA, MATERIAL AND METHODS

2.1 Study Area

Punjab is a north-western state of India and is a home of 28 million people having agriculture as their main occupation that covers ~50,000 sq kms. (Figure 1). Nearly 84% of the geographical area of Punjab i.e., 4119 Ha is used for agriculture during 2019-2020 (Chaudhuri, 2020). The main crops grown are rice, wheat, maize, bajra, gram, sugarcane and cotton. For this study a grid of 2° x 2° was selected ranging from latitude 29° N to 31° N and longitude 74° E to 76° E.

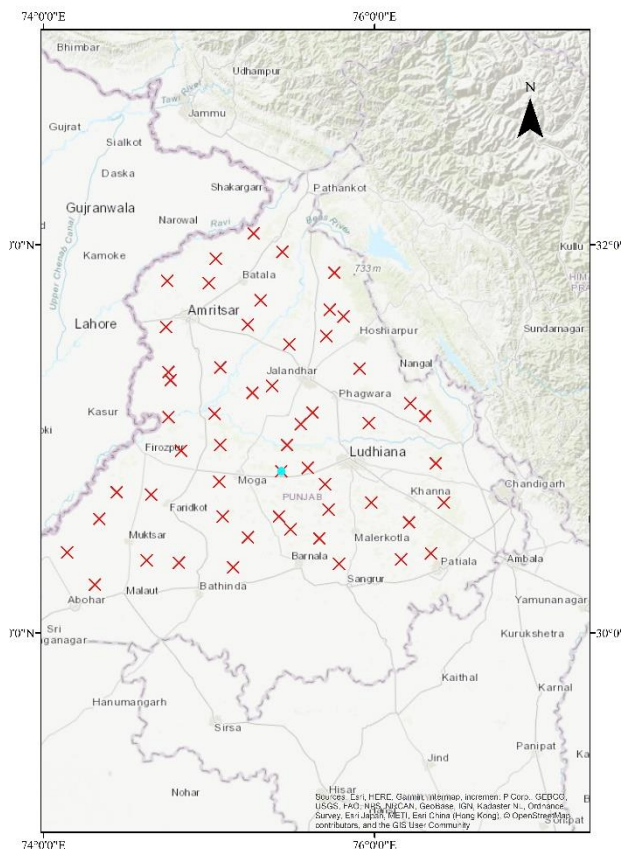


Figure 1: Map of study area- Punjab (North-western state), also known as food basket of India.



Figure 2: Crop residue burning in study area
P.C.: Author

2.2 Materials

Data used in the study was downloaded from Giovanni online data system, developed and maintained by the NASA GES DISC. Data for Sulphur Dioxide and Nitrogen Dioxide was downloaded from Ozone Monitoring Instrument (OMI) from 2005 to 2020, Methane (2005-2020) and Carbon dioxide (2005-2015) from Atmospheric Infrared Sounder (AIRS). Details of spatial and temporal resolution of the data is given in Table 2.

S. No.	Pollutant	Sensor	Data Time	Spatial Resolution	Data value
1	AOD	MODIS	2005-2020	1°X1°	
2	AE	MODIS	2005-2020	1°X1°	
3	SO ₂	OMI	2005-2020	0.25°X0.25°	
4	NO ₂	OMI	2005-2020	0.25°X0.25°	
5	CO ₂	AIRS	2003-2020	2°X2.5°	1
6	CH ₄	AIRS	2003-2020	1°X1°	4

Table 2: Details of spatial and temporal resolution of data downloaded from NASA Giovanni.

2.3 Methodology

The daily data collected was pre-processed using box and whisker plots to exclude outliers and then converted to monthly data. The processed data was then used to forecast concentration using time series analysis and linear regression. The classical multiplicative model for time series analysis can be described as:

$$Y_t = S_t \times I_t \times T_t \quad (1)$$

Where, Y_t = Original Data/ Predicted data
 S_t = Seasonal Component,
 I_t = Irregularity Component,
 T_t = Trend Component

With the use of centre moving average (CMA), the training data was de-seasonalized (S_t), irregularity (I_t) was removed and trend component (T_t) was estimated using linear regression. Using equation (1) future concentrations were calculated for year 2021-2025 as described in figure 3. Three iterations were done to train

the data. First iteration used initial 10 years for training, and next 5 years as testing data and forecasted for next 5 years. Second iteration used 12 years data for training, 3 years for testing and forecasted for 5 years. Third iteration used 8 years data as training, 7 years data for testing and forecasted for 5 years. In case of CO₂ the three iterations were modified to 8 years, 9 years and 7 years for training. Root mean square error was calculated to observe the best suited iteration for the forecast.

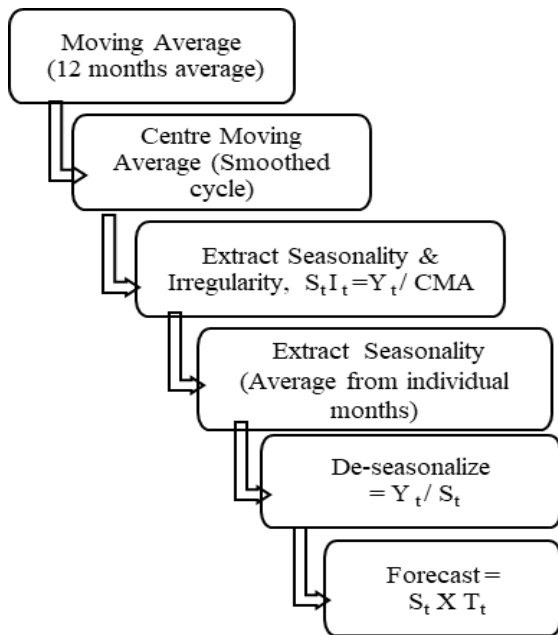


Figure 3: Detailed flowchart of steps followed in methodology i.e., time series analysis.

3. RESULTS

The forecast shows that all trace gases are on the rise and without appropriate mitigation measures air quality will continue to deteriorate. These trace gases can alter the balancing act of earth's temperature, giving rise to abnormalities in the ecosystem. Following sub-section shows results of time series analysis, and a detailed summary is described in table 3

3.1 Pre-processing

A box plot is a way for graphical description of numerical data through their quartiles in descriptive statistics. Individual points plotted beyond the box plot's whiskers represent outliers. For correct analysis their removal is important. Mathematically outliers can be calculated using:

$$Outliers < Q_1 - (IQR \times 1.5) \quad (2)$$

$$Outliers > Q_3 + (IQR \times 1.5) \quad (3)$$

Where, *IQR* = Inter-quartile Range, *Q*₁ = First Quartile of the data, *Q*₃= Third Quartile of the data.

In this study we used the equation (2) and (3) to estimate the outliers and were then removed from the data. The pre-processed data without outliers was used for time series analysis. The box plot without outliers for methane and nitrogen dioxide are shown in figure 4. Similar plots were prepared and analysed for carbon dioxide and sulphur dioxide.

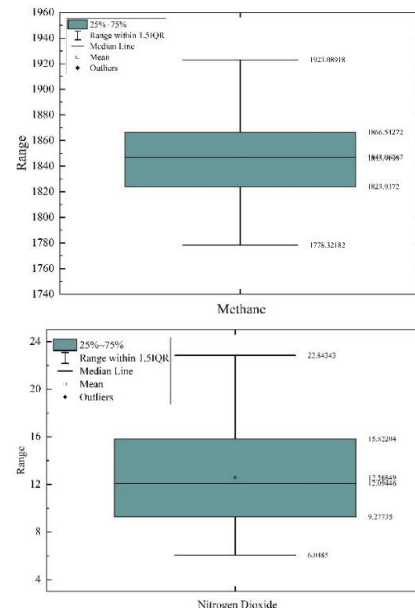


Figure 4: Box and whisker plot of Methane and Nitrogen dioxide after removing outliers using IQR.

3.2 Methane

Methane is short lived pollutant with an exceptional anatomical structure that effectively traps heat. On a timescale of 100 years, methane is 28 times more forcible as compared to carbon dioxide and 80 times more forcible on a 200-year timescale. About 60% of methane released in the atmosphere results from anthropogenic activities (UNEP,2018). It is also naturally released from wetlands, volcanos, wildfires and oceans etc. High methane in atmosphere can attribute to low vegetation cover and high temperature. Methane concentration decreases with high rainfall and high relative humidity.

The study shows that in the original data the minimum concentration of methane has increased from a 1778.3 ppbv in 2005 to 1845.46 ppbv in 2020. The maximum concentration has increased from 1846.47 ppbv in 2005 to 1923.08 ppbv in the year 2020 as shown in figure 5.

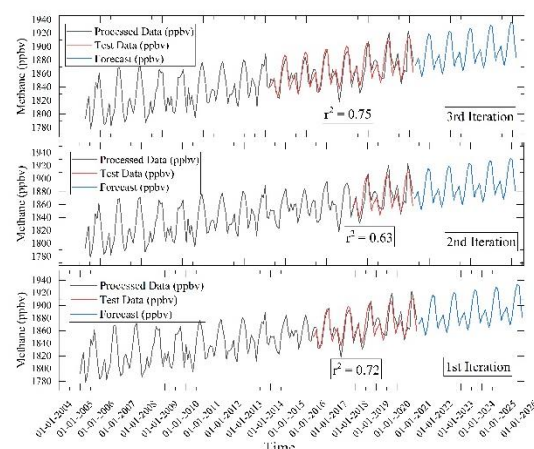


Figure 5: Forecast of Methane from year 2021 to 2025 using three iterations according to different training periods. First iteration uses 10 years data for training and 5 years as test. Second iteration uses 12 years data for training and 3 years as test. Third iteration uses 8 years data as training and 7 years as test.

The results of first iteration shows that the minimum forecast concentration in the year 2025 can rise to a value of 1869.72 ppbv in May and the maximum concentration can rise to a value of 1933.43 ppbv in September with an RMSE of ± 12.0 ppbv. Second iteration shows that minimum forecast concentration can increase to 1868 ppbv in May 2025 and maximum forecast concentration to a value of 1932 in September 2025 with an RMSE of ± 13.81 . Third iteration for methane attributes that the maximum concentration in the year 2025 may rise to a value of 1936 ppbv and minimum concentration to 1872 ppbv with an RMSE of ± 11.35 ppbv as depicted in figure 5.

3.3 Carbon dioxide

The odourless and tasteless characteristics of carbon dioxide makes it difficult to detect the rise in concentration. High levels of CO₂ are beneficial for the growth of plants. However, too high concentration can ruin the crops. A 0.05% of earth's atmosphere is occupied by carbon dioxide. If the entire atmosphere switches to CO₂, our planet's environment and climate would closely resemble to that of Venus. (NASA, 2016) Hence, it is vital to monitor carbon dioxide concentrations in the atmosphere.

The study shows that in the original data the minimum concentration of carbon dioxide has increased from 377.12 ppm in 2005 to 399.11 ppm in 2020. The maximum concentration has increased from 381.28 ppm in 2005 to 407.71 ppm in the year 2020 as shown in figure 6.

The results of first iteration shows that the minimum forecast concentration in the year 2025 can rise to a value of 422.08 ppm in July and the maximum concentration can rise to a value of 424.46 ppm in April with an RMSE of ± 5.58 ppm. Second iteration shows that minimum forecast concentration can increase to 421.88 ppm in July 2025 and maximum forecast concentration to a value of 424.37 ppm in April 2025 with an RMSE of ± 7.93 . Third iteration for methane attributes that the maximum concentration in the year 2025 may rise to a value of 425.21 ppm and minimum concentration to 422.72 ppm with an RMSE of ± 4.55 ppm as described in figure 6.

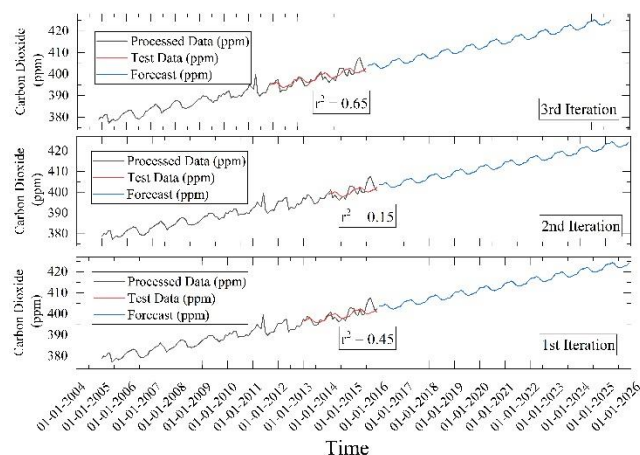


Figure 6: Forecast of Carbon dioxide from year 2016 to 2025 using three iterations according to different training periods. First iteration uses 8 years data for training and 2 years as test. Second iteration uses 9 years data for training and 1 years as test. Third iteration uses 7 years data as training and 3 years as test.

3.4 Sulphur dioxide

Sulphur dioxide is highly toxic, colourless and pungent smelling gas. It mixes in water and is converted to sulfuric acid, primary ingredient of acid rain. This acid rain can harm agriculture, alter

soil pH and turn water bodies acidic, making them unfit for use. High SO₂ concentration leads to formation of other sulphur oxides. They can react with other elements in the atmosphere to form secondary aerosols (Scrtelet et al., 2011). In nature, high concentration is observed during winters when temperature is low and low concentration are observed during summers when temperature is high (Barrie et al., 1985)

This work shows that the original data that minimum concentration of sulphur dioxide has increased from a 0.04 DU in 2005 to 0.06 DU in 2020. The maximum concentration has increased from 0.11 DU in 2005 to 0.13 DU in the year 2020 as described in figure 7.

The results of first iteration shows that the minimum forecast concentration in the year 2025 can rise to a value of 0.074 DU in July, and the maximum concentration can rise to a value of 0.19 DU in November with an RMSE of ± 0.03 DU. Second iteration shows that minimum forecast concentration can increase to 0.07 DU in July 2025 and maximum forecast concentration to a value of 0.18 DU in November 2025 with an RMSE of ± 0.028 . Third iteration for methane attributes that the maximum concentration in the year 2025 may rise to a value of 0.19 DU in November and minimum concentration to 0.07 DU in July with an RMSE of ± 0.03 DU.

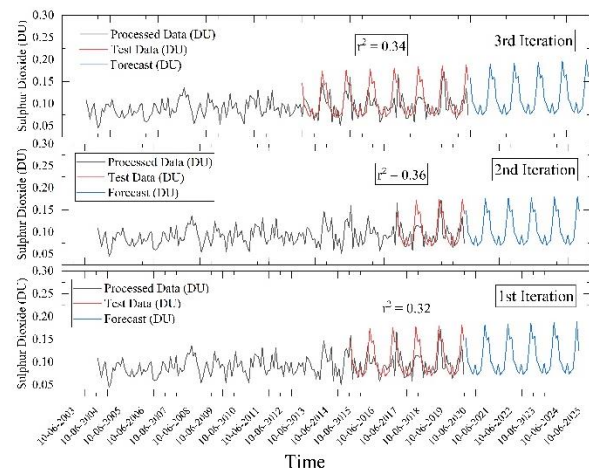


Figure 7: Forecast of Sulphur dioxide from year 2021 to 2025 using three iterations according to different training periods. First iteration uses 10 years data for training and 5 years as test. Second iteration uses 12 years data for training and 3 years as test. Third iteration uses 8 years data as training and 7 years as test.

3.5 Nitrogen dioxide

Nitrogen dioxide is a reddish brown, pungent, acidic, corrosive and highly reactive gas. It is largely released into atmosphere as a result of fuel combustion. It is also produced by automobiles, power plants and off-road machinery. It also contributes to particulate matter concentration in the atmosphere. In nature, high concentration is observed during winters when temperature is low and low concentration are observed during summers when temperature is high (Hargreaves et al., 1992).

This work shows that in the original data the minimum concentration of methane has increased from a 6.30 ppm in 2005 to 7.26 ppm in 2020. The maximum concentration has increased from 12.05 ppm in 2005 to 16.09 ppm in the year 2020 as shown in figure 8.

The results of first iteration shows that the minimum forecast concentration in the year 2025 can rise to a value of 9.60 ppm in August and the maximum concentration can rise to a value of 24.45 ppm in December with an RMSE of ± 2.56 ppm. Second iteration shows that minimum forecast concentration can increase to 9.26 ppm in August 2025 and maximum forecast concentration to a value of 23.57 ppm in December 2025 with an RMSE of ± 2.67 . Third iteration attributes that the maximum concentration in the year 2025 may rise to a value of 26.85 ppm in December and minimum concentration to 10.53 ppm with an RMSE of ± 2.99 ppm.

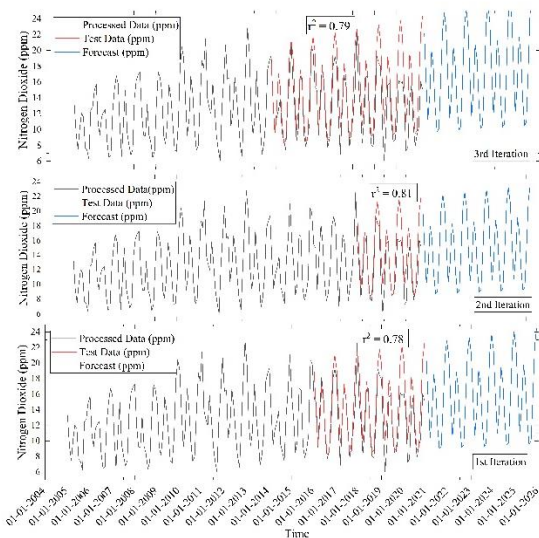


Figure 8: Forecast of Nitrogen dioxide from year 2021 to 2025 using three iterations according to different training periods. First iteration uses 10 years data for training and 5 years as test. Second iteration uses 12 years data for training and 3 years as test. Third iteration uses 8 years data as training and 7 years as test.

Pollutant	Iter.	RMSE	Max. Conc. in 2025	Min. Conc. in 2025
Methane (ppbv)	1st	12.00	1933.43 in September	1869.72 in May
Methane (ppbv)	2nd	13.81	1932 in September	1868 in May
Methane (ppbv)	3rd	11.35	1936 in September	1872 in May
Sulphur Dioxide (DU)	1st	0.03	0.19 in November	0.07 in July
Sulphur Dioxide (DU)	2nd	0.028	0.18 in November	0.07 in July
Sulphur Dioxide (DU)	3rd	0.03	0.20 in November	0.07 in July
Nitrogen dioxide (ppm)	1st	2.56	24.45 in December	9.60 in August
Nitrogen dioxide (ppm)	2nd	2.67	23.567 in December	9.26 in August
Nitrogen dioxide (ppm)	3rd	2.99	26.85 in December	10.53 in August

Carbon dioxide (ppm)	1st	5.58	424.46 in April	422.08 in July
Carbon dioxide (ppm)	2nd	7.93	424.37 in April	421.88 in July
Carbon dioxide (ppm)	3rd	4.55	425.21 in April	422.72 in July

Table 3: Details of forecast concentrations for 3 iterations and respective root mean square error

3.6 Aerosol Optical Depth and Angstrom Exponent

The measure of aerosol scatter in a column of air from sensor (Earth's Surface) to the top of the atmosphere is known as aerosol optical depth. They are fine particles blown up from dust, anthropogenic particles and secondary aerosols from anthropogenic activities (Twomey, 1977). They contribute in climate change, as they influence cloud formation, lower the sun radiation approaching our planet's surface.

Angstrom Exponent symbolize the particle size of aerosols. The scatter plot between aerosol optical depth and angstrom exponent can help determine type of aerosol present in the atmosphere. According to literature, various types of aerosols are defined based on AOD and AE thresholds. The source of aerosol is considered as anthropogenic when AOD (<0.9) and AE (>0.9), biomass burning aerosols when AOD (>0.9) and AE (>1), continental pollutants when AOD (<0.7) and AE (<0.9), dust aerosols when AOD (>0.7) and AE (<0.6) (Tiwari et al., 2017).

The type of aerosols in the study area can be majorly categorized in anthropogenic aerosols (figure 9). They are evenly distributed in the other three categories.

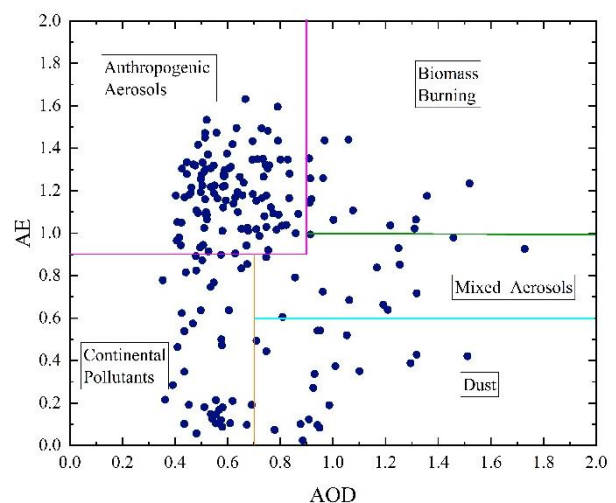


Figure 9: Types of aerosols present in Punjab region based on optical depth during 2005-2020.

CONCLUSION

In the year 2021, WHO revised the guidelines for air quality standards. Also, during nationwide lockdown, the air quality improved considerably in the study area (Sahoo et al., 2020; Singh et al., 2020; Gope et al., 2021). However, as the unlocking phases started, air quality started degrading. The reduced pollutant concentrations during lockdown shows that our planet's environment can quickly replenish itself. If appropriate and consistent measures are adhered, pollution can be reduced. Studies have shown that stubble burning is the major contributor

to pollution in Punjab (Sarkar et al., 2018; Singh and Kaskaoutis, 2014). As the crop residue burning pollutants travel along IGP, it gives rise to pollution, smog and haze etc (Bikina et al., 2019; Mittal et al., 2009; Sarkar et al., 2013; Jain et al., 2014; Ravindra et al., 2019a,b). It is vital to monitor and mitigate pollution in the study area.

This study aims to predict concentration of carbon dioxide, sulphur dioxide, nitrogen dioxide and methane in business-as-usual conditions. This research will help policy makers to implement techniques for pollutant concentration reduction in the study area and similar demographic and geographic areas. The result of the study concludes that in current business-as-usual scenario, the concentration of all pollutants under observation will continue to rise. Further, the study shows that majority of particulate matter are a result of anthropogenic activities and biomass burning. In detail study concludes that

- The original data shows that the concentration of Sulphur dioxide increased from 0.04 DU in 2005 to 0.11 DU in 2020, Nitrogen dioxide from 6.30 ppm to 16.10 ppm in 2020, Carbon dioxide from 377.12 ppm in 2005 to 407.71 ppm in 2015 and methane increases from 1778.32 ppbv in 2003 to 1923.08 ppbv in 2020 in Punjab.
- The forecast shows that maximum concentration in the year 2025 can reach to a value of 26.85 ppm for Nitrogen dioxide, 0.20 DU for Sulphur dioxide, 425.21 ppm for carbon dioxide and 1936 ppbv for Methane.
- The type of aerosols in the study area can be majorly categorized in anthropogenic aerosols. They are evenly distributed in the other three categories

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