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Annual trend analysis of PM_{10} and NO_2 in Non-attainment cities of Uttar Pradesh, India

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Abstract

Air pollution has become one of the biggest challenges for the 21st century. One of the largest states in India, Uttar Pradesh (UP), has been facing the repercussions of high air pollution levels in the form of mortality, diseases, and health risks. To monitor the levels of air pollutants, the annual trend of PM_{10} and NO_2 have been analysed for the 17 non-attainment cities (NAC) of UP from the year 2013 to 2020. The annual data, taken from the Central Pollution Control Board (CPCB) Portal has been compared with the National Ambient Air Quality Standards (NAAQS) of PM_{10} (60µg /m^3) and NO_2 (40µg/m^3).The average PM_{10} concentration of all the NAC exceeded the NAAQS by 3.1 times. Out of the 17 NACs, average PM_{10} concentrations were found to be greater than 200µg/m^3 in seven NACs. The average NO_2 levels were found below the standard, except for Meerut City. High levels of PM_{10} in the NACs of UP are a wake-up call for the policymakers that more stringent source-specific action plans are needed to be implemented in the NACs of UP to combat the growing air pollution crisis.

Keywords: Air pollution, non-attainment cities, Uttar Pradesh, Particulate Matter, National Ambient Air Quality Standards.

Introduction

Pollution has become one of the biggest contributors to worldwide death causing approximately 9 million deaths per year and this figure has remained as such since 2015[1]. Air pollution was single-handedly responsible for causing approximately 6 million deaths worldwide in 2019, and hence it has become one of the greatest concerns for the 21st century[1,2]. Out of 131 countries monitored by IQAir in 2022, only 13 countries met the prescribed standard of $PM_{2.5}$ (5µg/m^3) set by the World Health Organization (WHO)[3]. The world's most populous country, India[4], has been facing air pollution and its related health issues for a long time, which has become severe in the last few decades[5,6]. With many of its cities ranking as the most polluted cities globally, India became the eighth most polluted country in the world with an average weighted $PM_{2.5}$ concentration of 53.3 µg/m^3in 2022[3]. Air pollution-attributable deaths in India in the year 2019 were approximately 1.67 million[7]. Out of the ten most polluted cities in the world in 2022, six were from India including the national capital, New Delhi[3].

In India, the Indo-Gangetic plains (IGP) is one of the hotspots regions for air pollution[8-10]. Among the many regions present in IGP, Uttar Pradesh (UP) experiences extremely high risks of air pollution[7]. Major sources of air pollution identified in UP are road dust, vehicles, traffic congestion, industries, construction, domestic fuel, biomass burning, waste burning, and brick kilns[11-15]. Out of the total 75 districts in Uttar Pradesh, presently, only 17 cities have been designated as non-attainment cities (NAC)[5]. NACs are cities that have not met the National Ambient Air Quality Standards (NAAQS) for five years. For the present study, 17 NACs of UP have been considered which are Agra, Anpara, Bareilly, Firozabad, Gajraula, Ghaziabad, Gorakhpur, Jhansi, Kanpur, Khurja, Lucknow, Meerut, Moradabad, Noida, Prayagraj, Raebareli, and Varanasi.

To identify the increasing levels of concentration of air pollutants, different agencies like the Environment Protection Agency (EPA), the Central Pollution Control Board (CPCB) in India, and many more around the world have introduced certain air quality threshold values. These threshold values are called NAAQS and have been majorly established for six common air pollutants namely PM_{10}, $PM_{2.5}$, NO_2, SO_2, O_3, and CO. PM_{10} (particles size less than 10µm) and $PM_{2.5}$(particles size less than 2.5µm) are known as particulate matter (PM) while SO_2, NO_2, O_3, and CO are known as gaseous pollutants. EPA has called these pollutants 'criteria pollutants' since these are based on certain criteria i.e., the latest scientific research and information regarding their ill effects on health[16]. The criteria air pollutants can further be categorized into primary and secondary air pollutants based on the source of origin of these pollutants. The pollutants emitted directly from the source such as PM (PM_{10}, $PM_{2.5}$), CO, NO_2, and SO_2, are called primary pollutants, and pollutants formed via chemical reactions of the primary air pollutant with some other chemical agents in the atmosphere are called secondary pollutant such as O_3.

The six criteria air pollutants differ in their chemical behaviour, emission sources, the process of formation, and effects on human health and the environment. A brief description of these pollutants containing the sources (natural and anthropogenic) and effects (on human health, flora/fauna, and the environment) are given in Table-1. In the present study, an annual trend analysis of two criteria pollutants is done, namely; PM_{10}, and NO_2.

Table-1: Sources and Effects of Air Pollutants[17].

Pollutant	Description	Sources		Effects		
		Natural	Anthropogenic	Human	Flora/fauna	Environment
PM_{10}	Size ≤ 10µm	Coarse particles are produced by the mechanical breakup of the larger solid particles.	Road traffic emissions particularly from diesel vehicles	Cardiopulmonary problems	Leads to inhibition of photosynthetic activities.	Visibility reduction
		Wind-blown dust such as road dust, fly ash soot, agricultural processes	Industrial combustion plants, some public power generator	Asthma, bronchitis, and pneumonia in older people	Reduce plant growth	
		Physical process of crushing, grinding, and abrasion of surfaces	Commercial and residential combustion		Susceptibility to injuries caused by microorganisms and insects.	
		Photochemically produced particles such as those found in an urban haze.	Non-combustion processes (e.g., quarrying)			
		Pollen grains, mould spores, and plants and insect-plant parts	Agricultural activities			
		Non-combustible material released when burning fossil fuels				
$PM_{2.5}$	Size ≤ 2.5µm are called fine particles	Fine particles are largely formed from gases	Vehicular emissions	These penetrate the gas exchange regions of the lungs and very small particles may pass through the lung to affect other organs. Particles less than 100nm may enter the bloodstream and affect the cardiovascular system.	Disposition of the water bodies affects the aquatic ecosystem.	Aesthetic damage
	Composed mainly of carbonaceous materials (organic and elemental),	Ultrafine particles are formed by nucleation, which is the initial stage in which gas becomes a particle. These	Industrial combustion plants, some public power generation	Oxidative stress	Affects photosynthesis	Visibility reduction

Pollutant	Description	Sources		Effects		
		Natural	Anthropogenic	Human	Flora/fauna	Environment
	inorganic compounds (SO_4^{2-}, NO^{3-}, and NH^{4+}), and trace metal compounds (Fe, Al, Ni, Cu, Zn)	particles are can grow up to a size of 1µm either through condensation or through coagulation.				
			Commercial and residential combustion	Respiratory symptoms such as irritation of the airways, coughing, or breathing difficulty	Disrupts the food chain in the ecosystem.	
				Decreased lung function		
				Aggravate asthma		
				Chronic bronchitis		
				Irregular heartbeat cardiopulmonary disorder		
				Premature death of people with heart or lung disease		
Oxides of Nitrogen (NO_x)	A group of highly reactive gases that generally contain nitrogen and oxygen in varying amounts.	Lightening	High temperature and combustion (internal combustion engines, fossil-fired power stations, industrial)	Irritates the nose and throat	Water pollution affecting the aquatic ecosystem	Ground-level ozone
	NO_2 is a reddish-brown toxic gas with a characteristic sharp biting odour and is a prominent air pollutant.	Forest fires	Burning of biomass and fossil fuel	Increase susceptibility to respiratory infections.		Form atmospheric fine particulate matter burden because of oxidation to form nitrate aerosol
		Bacterial activity of soil				Causes haze and reduces visibility
						Acid rain
SO_2	Chemical compounds produced by volcanoes and industrial	Volcanoes (67%)	Combustion of fossil fuel coal, and heavy fuel oil in thermal power plants, and	Respiratory illness	Inhibits photosynthesis by disrupting photosynthetic mechanisms	Acid rain

Pollutant	Description	Sources		Effects		
		Natural	Anthropogenic	Human	Flora/fauna	Environment
	processes are also a precursor to particulates in the atmosphere.		factories			
			Paper industry	Visibility impairment	Opening of stomata is promoted by SO_2 resulting in water loss	Aesthetic damage
			Extraction and distribution of fossil fuels	Aggravate existing heart and lung disease	Cumulative effect reduces the quality and quantity of plant yield	Water pollution
			Smelting of metal (sulphide ores to produce Cu, Pb, and Zn)		At the ecosystem level, it affects the sensitive species the most altering the trophic relationships.	
			Petroleum refining			
			Combustion process in diesel, petrol, and natural gas-driven vehicles			
O_3	A secondary pollutant formed by the reaction of NO_x and VOC in the presence of sunlight		Formed by the reaction of sunlight on air containing the HC and NO_X emitted by car engines, industrial operations, and chemical solvents to form ozone.	Lung function deficits	Affects the leaves and needles of the sensitive plants causing defoliation and change of colour	Ground-level Ozone acts as a GHG
				Respiratory illness	Affects agricultural plants and trees.	Causes damage to sensitive ecosystems especially forest, parks, and wilderness areas during the growing season.
				Premature death, asthma, bronchitis, heart attack, and cardiopulmonary problems.	Reduces crop yield	Loss to species diversity.
				Ground-level ozone and pollution interfere with photosynthesis and	Increases plant's vulnerability to diseases	Changes to water and nutrient cycles.

Pollutant	Description	Sources		Effects		
		Natural	Anthropogenic	Human	Flora/fauna	Environment
				stunt the overall growth of some plant species		
CO	Colourless, odourless, and tasteless gas which is slightly lighter than air.	Produced during normal animal metabolism in low quantities and has some normal biological functions (signaling molecule)	Exhaust of internal combustion engines, especially of vehicles with petrol engines	Can cause anoxemia which reduces the blood's oxygen-carrying capacity to organs and tissues.		Contributes to the formation of smog ground-level ozone.
		Volcanic activity	Burning of fossil fuels	People with heart disease are sensitive to CO poisoning and can experience chest pain if inhaled while exercising		
		Forest and bushfires	Organic combustion in waste incineration	Effects on the fetus		
			Power station processes	Infants, elderly people, and people with respiratory illnesses are also sensitive		
			Iron smelting	Anti-inflammatories, vasodilators, and encouragers of neovascular growth		
			Burning of crop residues			

Materials and Methods

According to the National Ambient Monitoring Plan (NAMP), the CPCB and the State Pollution Control Board (SPCB) measure and record the ambient air quality data of different cities in India using two methods- Manual and Automated. The number of manual monitoring stations is comparatively higher in India whereas automated monitoring stations, also known as Continuous Ambient Air Quality Monitoring Stations (CAAQMS), are comparatively lower. The present study uses only manual data to analyse the annual trend.

Data collection and analysis: The data on ambient air quality for manual monitoring stations of CPCB has been collected from the CPCB portal[18] for NAC from the year 2013 to 2020. The data was collected for NO_2 and PM_{10} pollutants. The data has been compared with annual air quality standards for PM_{10}(60µg/m^3) and NO_2(40µg/m^3) for all seven years and analysis has been done accordingly using statistical tools.

Study Area: Uttar Pradesh, commonly known as UP, is situated in northern India with a total cover area of 240928 sq. km, making it the fourth largest state by area[16]. UP shares its borders with Nepal (north), Uttarakhand and Himachal Pradesh (northwest), Haryana, Delhi, and Rajasthan (west), Madhya Pradesh (south) Chhattisgarh and Jharkhand (southeast), and Bihar (east)[17].

The state has a humid subtropical climate with major seasons-summer, winter, and the rainy season[16,17]. The annual rainfall and temperature range from 1000mm to 1200mm and 5°C to 46°C[16]. The estimated population of UP in 2023 is 25.2 crore with a population density of about 2100 people living per square mile[4]. There is a total of 75 administrative districts in UP with Lucknow being the capital[19].

The study area map containing the 17 NAC of UP is represented in Figure 1.

Results and Discussion

Annual trend analysis of pm_{10} for 2013 to 2020: The concentration of PM_{10} in Agra ranged from 174 to 209µg/m^3 with an average concentration of 188.31µg/m^3, almost 3.1 times higher than the national standards.

The range for Prayagraj was 140.2 to 249.5µg/m^3 with an average concentration of 213.06 µg/m^3 which is 3.5 times higher than the annual standard. The range of PM_{10} in Anpara was 130.5 to 190.5µg/m^3 with an average concentration of 149.12µg/m^3 which is 2.4 times higher than the national standard. The range of PM_{10} in Bareilly was 175.5 to 240.5µg/m^3 with an average concentration of 220.93 µg/m^3 which is 3.68 times higher than the national standard.

The range of PM_{10} concentration in Firozabad was 146 to 246µg/m^3 with an average concentration of 206.20µg/m^3 which is 3.43 times higher than the national standard. The range of PM_{10} concentration in Gajraula was 136.5 to 228.5µg/m^3 with an average concentration of 188.68µg/m^3 which is 3.14 times higher than the national standard. The range of PM_{10} concentration in Ghaziabad was 203 to 285µg/m^3 with an average concentration of 244.17µg/m^3 which is 4 times higher than the national standard.

The data for the annual concentration of PM_{10} for Gorakhpur was available from 2015 to 2020 (6 years) which ranged from 139.33 to 294.66µg/m^3 with an average concentration of 195.38µg/m^3 which is 3.25 times higher than the national standard. The range of PM_{10} concentration in Jhansi was 85.5 to 119µg/m^3 with an average concentration of 103.37µg/m^3 which is 1.72 times higher than the national standard. The range of PM_{10} concentration in Kanpur was 196.37 to 224.25µg/m^3 with an average concentration of 204.73µg/m^3 which is 3.4 times higher than the national standard.

The range of PM_{10} concentration in Khurja was 157.5 to 213.5µg/m^3 with an average concentration of 189.87µg/m^3 which is 3.16 times higher than the national standard. The range of PM_{10} concentration in Lucknow was 168.6 to 246µg/m^3 with an average concentration of 200.64 µg/m^3 which is 3.34 times higher than the national standard.

The data for the annual concentration of PM_{10} for Meerut was available from 2013 to 2019 (7 years). The range of PM_{10} concentration in Meerut was 134.5 to 212.5µg/m^3 with an average concentration of 164.66µg/m^3 which is 2.74 times higher than the national standard. The range of PM_{10} concentration in Moradabad was 159.5 to 239.5µg/m^3 with an average concentration of 203.12µg/m^3 which is 3.38 times higher than the national standard. The range of PM_{10} concentration in Noida was 135.5 to 263.5µg/m^3 with an average concentration of 188.03µg/m^3 which is 3.13 times higher than the national standard.

The range of PM_{10} concentration in Raebareli was 109.66 to 177µg/m^3 with an average concentration of 148.75µg/m^3 which is 2.47 times higher than the national standard. The range of PM_{10} concentration in Varanasi was 139.5 to 243.8µg/m^3 with an average concentration of 170.25µg/m^3 which is 2.83 times higher than the standard.

Annual trend analysis of NO_2 for 2013 to 2020: The range of NO_2 concentration in Agra was 18.14 to 24.5µg/m^3 with an average concentration of 21.58µg/m^3, less than the annual concentration (40µg/m^3).

The range of NO_2 concentration in Prayagraj was 28 to 44.6µg/m^3 with an average concentration of 36.25µg/m^3. The range of NO_2 concentration in Anpara was 26 to 31.5µg/m^3 with an average concentration of 28.25µg/m^3. The range of NO_2 concentration in Bareilly was 22 to 37µg/m^3 with an average concentration of 25.56µg/m^3. The range of NO_2 concentration in Firozabad was 28 to 31.33µg/m^3 with an average concentration of 30.12µg/m^3.

The range of NO_2 concentration in Gajraula was 25.5 to 37.5µg/m^3 with an average concentration of 32µg/m^3. The range of NO_2 concentration in Ghaziabad was 28.5 to 43µg/m^3 with an average concentration of 35.68µg/m^3. The range of NO_2 concentration in Gorakhpur was 17.66 to 44.66µg/m^3 with an average concentration of 34µg/m^3. The range of NO_2 concentration in Jhansi was 16 to 22µg/m^3 with an average concentration of 19.37µg/m^3.

The range of NO_2 concentration in Kanpur was 32.75 to 45.12µg/m^3 with an average concentration of 39.29µg/m^3. For Kanpur City, concentration from 2017 to 2020 exceeded the permissible limits continuously. The range of NO_2 concentration in Khurja was 19.5 to 32 µg/m^3 with an average concentration of 22.81µg/m^3. The range of NO_2 concentration in Lucknow was 26 to 34.37µg/m^3 with an average concentration of 29.23µg/m^3.

The annual average data for the NO_2 concentration for Meerut City was present from 2013 to 2019 (7 years). The range of NO_2 concentration in Meerut was 39 to 63µg/m^3 with an average concentration of 52.33µg/m^3 which is 1.30 times higher than the annual standard. The period from 2014 to 2019 continuously exceeded the annual standards for Meerut city. The range of NO_2 concentration in Moradabad was 26.5 to 41.5µg/m^3 with an average concentration of 32.81µg/m^3.

The range of NO_2 concentration in Noida was 28 to 49.5µg/m^3 with an average concentration of 38.12µg/m^3. The range of NO_2 concentration in Raebareli was 13 to 17.33µg/m^3 with an average concentration of 16.45µg/m^3. The range of NO_2 concentration in Varanasi was 27.5 to 37.6 µg/m^3 with an average concentration of 32.67µg/m^3.

Table-2: Annual concentrations of PM_{10} of the 17 NAC from 2013 to 2020.

City	2013	2014	2015	2016	2017	2018	2019	2020
Agra	192	177.5	185.66	198	184.5	209	185.83	174
Anpara	133	130.5	136.5	131.5	153.5	190.5	171	146.5
Bareilly	232	238.5	240.5	253	195	233	200	175.5
Firozabad	246	146	194.66	223	219.66	226.33	213.66	180.33
Gajraula	136.5	178.5	177	193	206.5	224.5	228.5	165
Ghaziabad	285	241.5	259.5	235.5	280.5	245	207.75	203
Gorakhpur	-	-	139.33	154	186	217.66	294.66	180.66
Jhansi	85.5	105.5	119	115.5	113	96	95.5	97
Kanpur	201	199.62	196.37	217.12	224.25	210	197.88	191.62
Khurja	162.5	157.5	167	216	208.5	213.5	195	199
Lucknow	191.8	173.83	168.6	213.57	246	217.12	207.62	186.62
Meerut	134.5	154.5	-	157.5	152.5	176.5	212.5	
Moradabad	159.5	201	168.5	196	217	227	239.5	216.5
Prayagraj	235	249.5	251.6	195.4	140.2	231.2	221.8	179.8
Noida	141.5	135.5	153.5	176	215.5	263.5	211.75	207
Raebareli	177	160	157	141	140.66	141.33	163.33	109.66
Varanasi	145	139.5	145	-	243.8	189.6	183.6	145.2

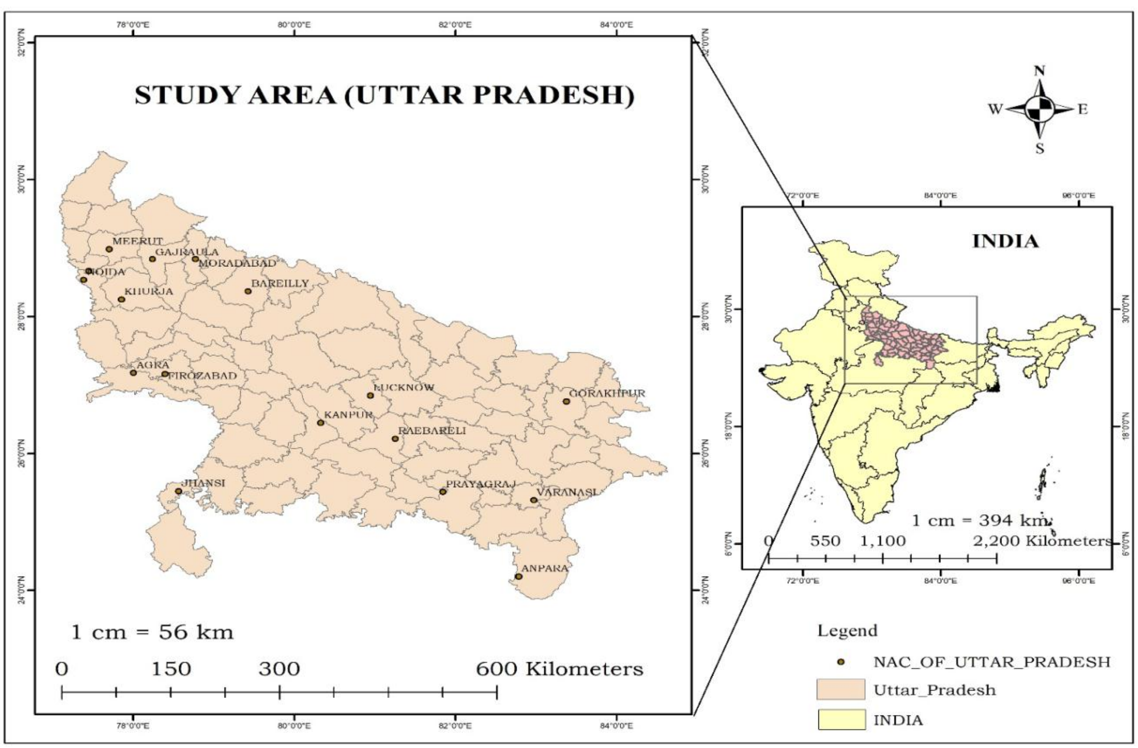

Figure-1: Map representing the State of Uttar Pradesh with its 17 non-attainment cities (NAC).

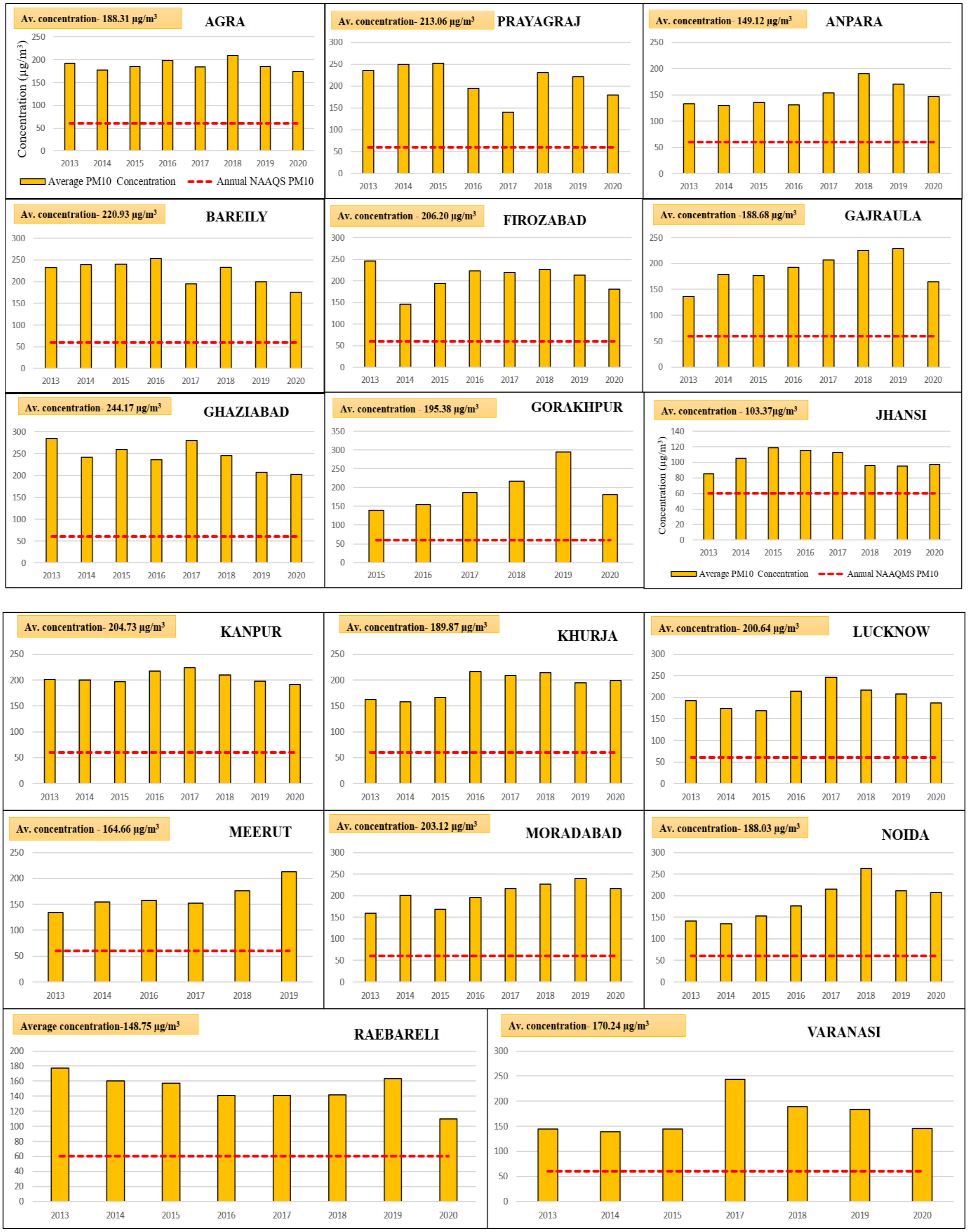

Figure-2: Concentration of PM_{10} in the 17 NAC of Uttar Pradesh from 2013 to 2020.

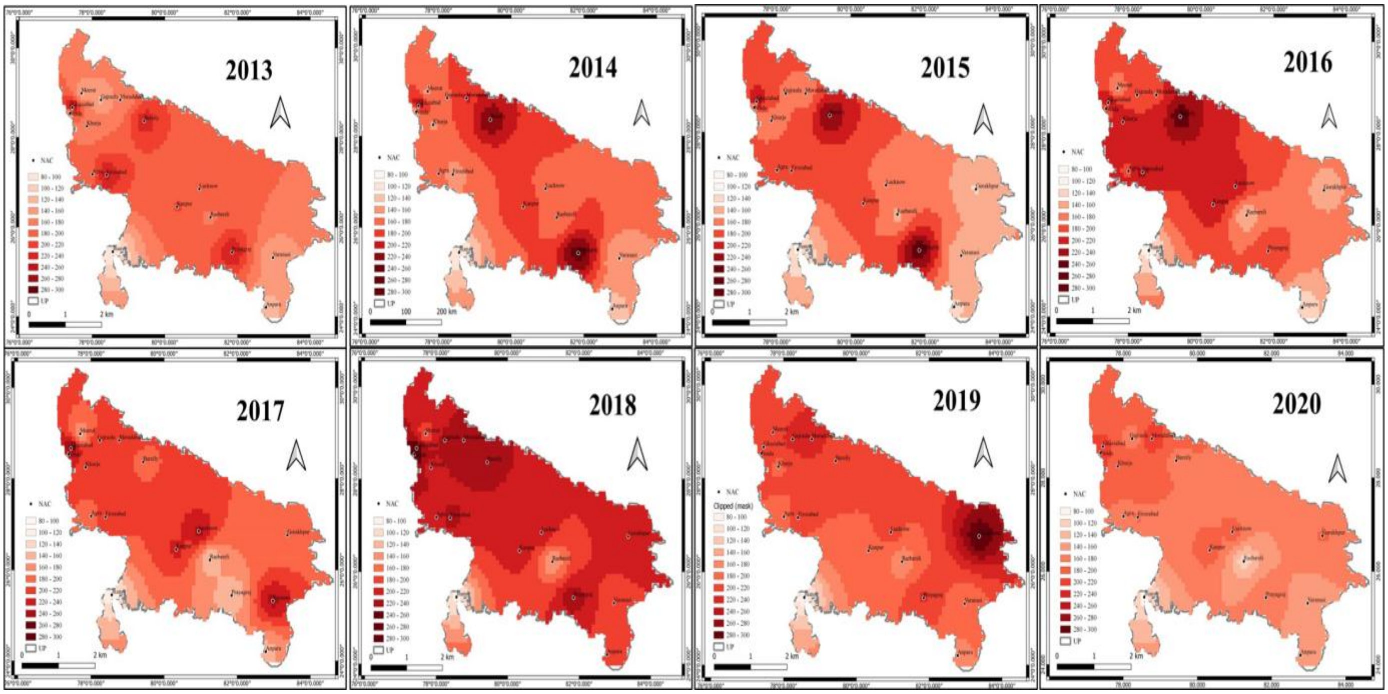

Figure-3: Map representing the concentration of PM_{10} in 17 NAC of UP from 2013 to 2020.

Table-3: Annual concentrations of NO_2 of the 17 NAC from 2013 to 2020.

CITY	2013	2014	2015	2016	2017	2018	2019	2020
Agra	22.5	18.83	21.66	22.5	19.16	21.66	24.5	21.83
Anpara	29.5	27	27	28.5	31.5	28	28.5	26
Bareilly	25	23	22.5	22	21.5	22	31.5	37
Firozabad	31.33	25.66	29.33	33	32	30.66	31	28
Gajraula	25.5	34.5	30.5	33	35.5	33	37.5	26.5
Ghaziabad	34	39.5	37	28.5	34	43	35.5	34
Gorakhpur	-	-	32.33	35.66	39	44.66	34.66	17.66
Jhansi	19.5	21.5	22	21	19	18	18	16
Kanpur	32.75	34.37	35.75	39.37	45.12	42.88	40.22	43.87
Khurja	25	20.5	23	21.5	21.5	19.5	19.5	32
Lucknow	29.4	28.16	27.8	27.14	26	29.75	31.25	34.37
Meerut	39	47.5	-	55	51.5	58	63	-
Moradabad	29	31.5	26.5	31	35	34.5	41.5	33.5
Prayagraj	29	28	33.2	37.2	40.4	44.6	42	35.6
Noida	31	28	28.5	33.5	38	52	44.5	49.5
Raebareli	16.66	16.66	16.66	17.33	17.33	17	17	13
Varanasi	27.5	32	33	-	37.6	34.2	34.4	30

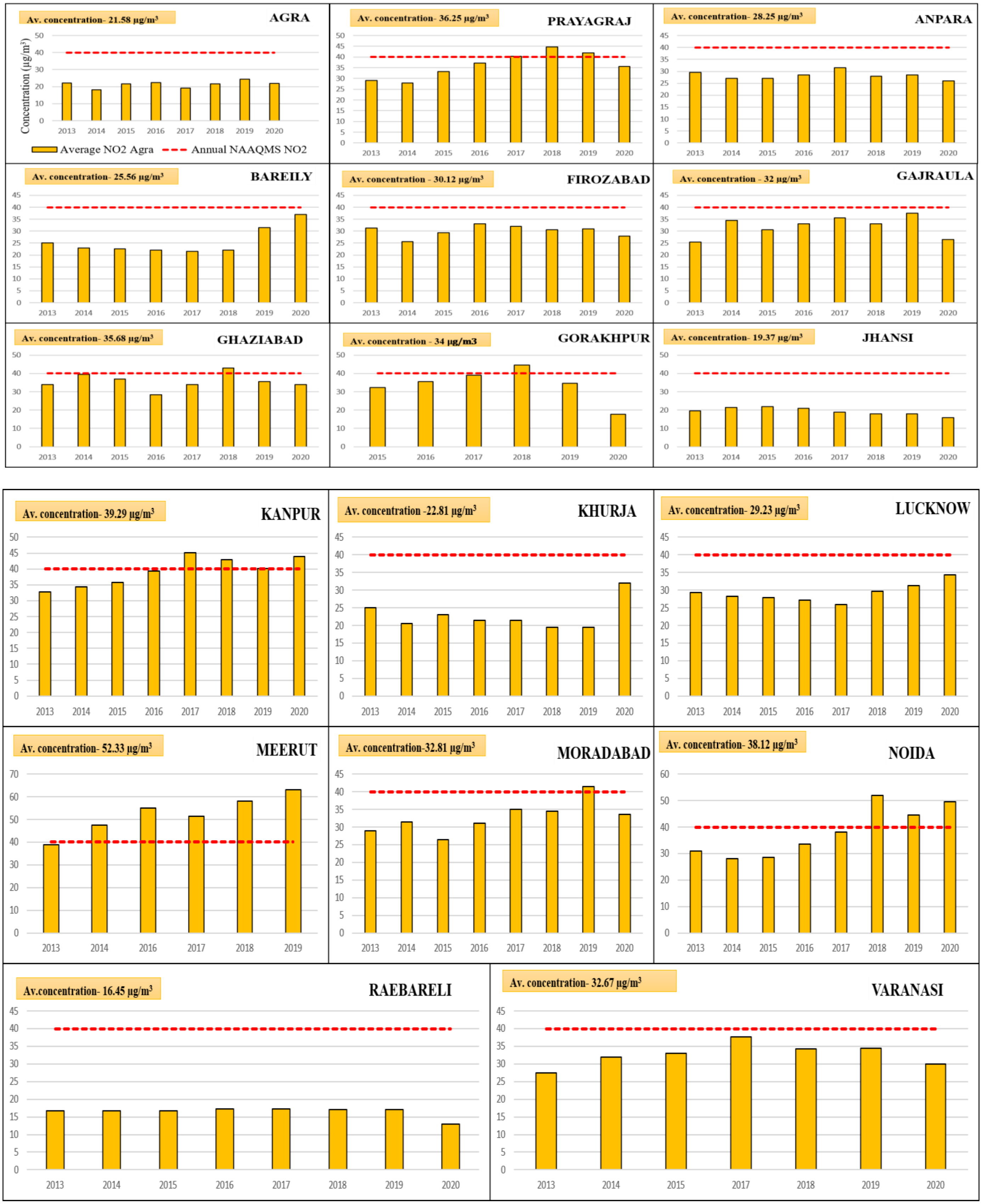

Figure-4: Concentration of NO_2 in the 17 NAC of Uttar Pradesh from 2013 to 2020.

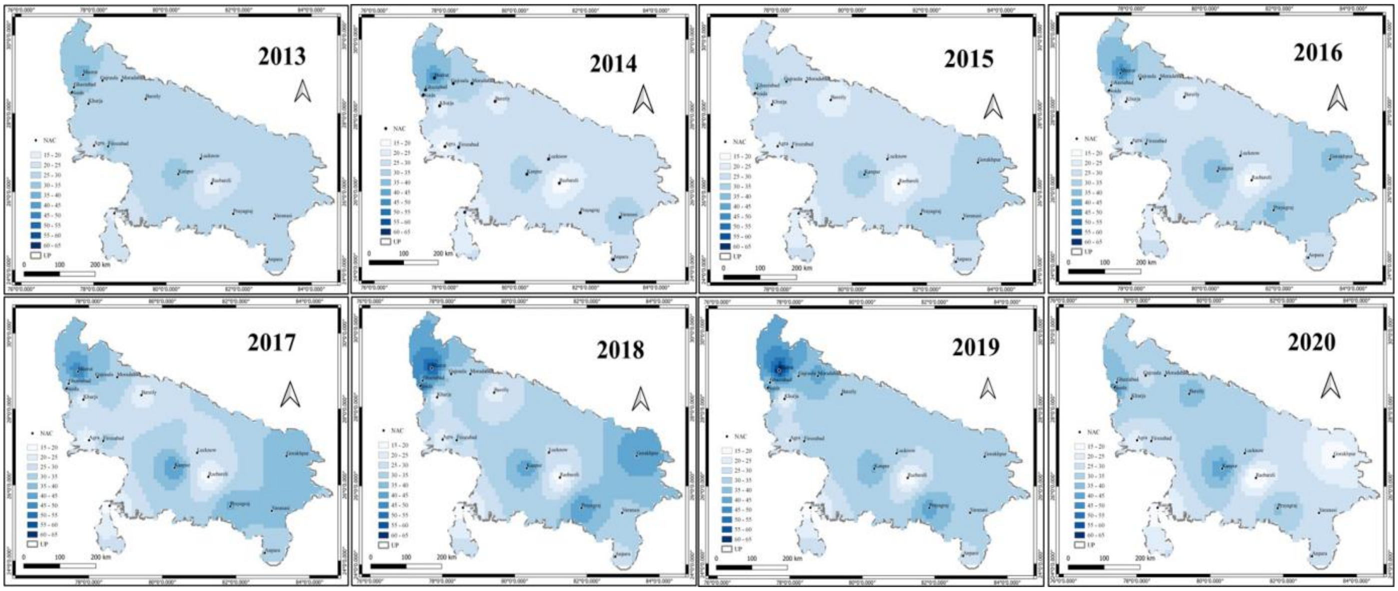

Figure-5: Map representing the concentration of NO_2 in 17 NAC of UP from 2013 to 2020.

Conclusion

Air pollution has become a crucial problem, especially in UP, where the average PM_{10} concentration of the 17 NAC exceeded the Indian NAAQS by 3.1 times. Seven of the seventeen NACs were found to have PM_{10} concentrations greater than 200 µg/m^3. Though the average concentration of PM_{10} in all the cities in 2020 was above the NAAQS, decrement in the average concentration from 206.57µg/m^3 (in 2018) to 172.33µg/m^3 (in 2020) was observed which could be due to the COVID lockdown. On an average, only Meerut City exceeded the NAAQS for NO_2 among the 17 NAC. Some of the cities showed an increasing trend for NO_2 from 2013 to 2020 namely; Meerut, Noida, and Kanpur. Six cities exceeded the NAAQS of NO_2 in 2018 while only two cities exceeded the standards in 2020 which could be due to the COVID-19 lockdown. The high concentration, especially of PM_{10} reveals that the sources of air pollution in these 17 NACs could be majorly due to dust (road dust, windblown dust, construction sites), vehicles, unpaved roads, smoke from fires, and industries. Hence, it is important to first identify the major pollutant and then the sources of that pollutant for effective implementation of action plans in NACs.

References

1. Fuller, R., Landrigan, P. J., Balakrishnan, K., Bathan, G., Bose-O'Reilly, S., Brauer, M., ... & Yan, C. (2022). Pollution and health: A progress update. *The Lancet Planetary Health*, *6*(6), e535-e547.

2. Yadav, N. K., Mitra, S. S., Santra, A., & Samanta, A. K. (2023). Understanding Responses of Atmospheric Pollution and its Variability to Contradicting Nexus of Urbanization–Industrial Emission Control in Haldia, an Industrial City of West Bengal. *Journal of the Indian Society of Remote Sensing*, 51(3), 625-646.

3. IQAir (2022). World Air Quality Report, 2022. Available at https://www.iqair.com/in-en/world-air-quality-report, Accessed on 17 March 2023.

4. World population review (2023). World Population by Count. Available at https://worldpopulationreview.com/countries, Accessed on 17 March 2023.

5. Gulia, S., Shukla, N., Padhi, L., Bosu, P., Goyal, S. K., & Kumar, R. (2022). Evolution of air pollution management policies and related research in India. *Environmental Challenges*, 6, 100431.

6. Sharma, K., Garg, A., Joshi, V., & Kumar, A. (2023). Assessment of health risks for criteria air pollutants present in 11 non-attainment cities of Uttar Pradesh, India. *Human and Ecological Risk Assessment: An International Journal*, 29(1), 103-122.

7. Pandey, A., Brauer, M., Cropper, M. L., Balakrishnan, K., Mathur, P., Dey, S., ... & Dandona, L. (2021). Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. *The Lancet Planetary Health*, *5*(1), e25-e38.

8. Devi, N. L., Kumar, A., & Yadav, I. C. (2020). PM10 and PM2. 5 in Indo-Gangetic Plain (IGP) of India: Chemical characterization, source analysis, and transport pathways. *Urban Climate*, *33*, 100663.

9. Ojha, N., Sharma, A., Kumar, M., Girach, I., Ansari, T. U., Sharma, S. K., ... & Gunthe, S. S. (2020). On the widespread enhancement in fine particulate matter across the Indo-Gangetic Plain towards winter. *Scientific reports*, 10(1), 5862.

10. Gupta, L., Bansal, M., Nandi, P., Habib, G., & Raman, R. S. (2023). Source apportionment and potential source regions of size-resolved particulate matter at a heavily polluted industrial city in the Indo-Gangetic Plain. *Atmospheric Environment*, 298, 119614.

11. CPCB (2023). Source apportionment study of Kanpur, 2010. Available on https://cpcb.nic.in/displaypdf.php?id=S2FucHVyLnBkZg==. Accessed on 18 March, 2023.

12. CPCB (2023). Clean air action plan of Meerut, 2020. Available at https://cpcb.nic.in/Actionplan/Meerut.pdf. Accessed on 18 March 2023.

13. UPECP (2023). Clean air action plan of Gorakhpur, 2020. Available at http://www.upecp.in/assets/air_pollution_action_plan/ActionPlan/Draftactionpla%20forGorakhpur.pdf. Accessed on 18 March 2023.

14. IITK (2023). Source apportionment study of Agra, 2020. Available on http://home.iitk.ac.in/~mukesh/Publications/2022_IIT%20Kanpur_UPPCB_Final-Report-Agra-Source%20Apportionment%20and%20Emission%20Inventory.pdf Accessed on 18 March 2023.

15. Agarwal, S., Saxena, D. K., & Boyina, R. (2021). Analysis of air pollutants in Covid 19 pandemic lockdown-A case study of Bareilly, UP, India. *Current Research in Green and Sustainable Chemistry*, 4, 100087.

16. EPA (2023). Criteria Air Pollutants. United States Environmental Protection Agency. Criteria Air Pollutants | US EPA

17. Saxena, P., and Sonwani, S. (2019). Criteria air pollutants: chemistry, sources, and sinks. In Criteria air pollutants and their impact on environmental health (pp.7-48). Springer, Singapore.

18. CPCB (2023). Manual Monitoring Data. Central Pollution control Board, Ministry of Environment, Forest and Climate Change, Government of India. CPCB | Central Pollution Control Board

19. State Portal (2023). Districts & Divisions. Government of Uttar Pradesh, India. Districts & Divisions | Official website of State Portal, Government of Uttar Pradesh, India (up.gov.in)

20. FSI (2019). Indian State of Forest Report, 2019, 11.28 Uttar Pradesh. Available at https://fsi.nic.in/isfr2019/isfr-fsi-vol2.pdf. Accessed on 19 March, 2023.

21. IBEF (2023). Uttar Pradesh March 2021. Available at *https://www.ibef.org/download/Uttar-Pradesh-March-2021.pdf.* Accessed on 19 March 2023.