P-ISSN: 2618-0723
E-ISSN: 2618-0731

NAAS Rating: 5.04
www.extensionjournal.com

Extension Journal

International Journal of Agriculture Extension and Social Development

Volume 8; Issue 5; May 2025; Page No. 94-99

Received: 10-02-2025
Accepted: 13-03-2025

Indexed Journal
Peer Reviewed Journal

Comparative analysis of ambient air pollutants across diverse locations in Dehradun district, Uttarakhand

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DOI: https://www.doi.org/10.33545/26180723.2025.v8.i5b.1862

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Abstract

Human health is impacted by the air quality in the environment. The air that over 1.4 billion people in cities throughout the world breathe does not meet WHO air quality criteria. It is estimated that exposure to outdoor air pollution causes between 200,000 and 570,000 deaths worldwide. According to published mortality and morbidity figures, respiratory illnesses and chronic disorders are common in Indian cities, which are among the most polluted in the world. The city of Dehra Doon is set in a valley between the Shivalik and outer Himalaya mountains. The contaminants stay confined close to ground level, and very little air moves in or out of this area. According to the guidelines of the Uttar Pradesh Special Area Development Act of 1986 and the Environmental Protection Act of 1986, the Doon Valley has been designated as an "Ecologically Fragile Zone" because of its distinct physiography. Air pollution has emerged as one of the most serious threats to public health and well-being in urban India[3]. According to a 2021 study, unsafe levels of fine particulate matter ($PM_{2.5}$) are responsible for nearly four million premature deaths globally each year, with approximately 25% of these occurring in India alone. While the focus often remains on major metropolitan cities, the issue extends far beyond them. The present study was conducted to analyze the effect of air pollutants on living beings.

Keywords: Environmental pollution, pollutants, challenges, diseases, air pollution

Introduction

Currently, unrestrained urban growth, vehicle emissions, and building activities are all contributing to the steadily growing pollution levels in Uttarakhand's Dehradun area. The natural balance of the area is in jeopardy, and the local population is at serious health risk due to the declining air quality.

Dehradun, a hill town nestled in the Doon Valley at the foothills of the Himalayas, serves as a striking example. Once known for its clean environment and scenic beauty, Dehradun has rapidly transformed into a bustling hub for business, education, and tourism in North India. However, unplanned urbanization, growing industrial activity, and rapid infrastructure development have affected the city's air quality. In recent years, Dehradun has experienced a significant decline in air quality, raising serious concerns about the health of its residents and the sustainability of its growth. Several researchers, like Nath (1999, 2009) [2, 8], Dockery (1994) [4], Kumar (1999) [6], Singha and Singha (2024) [11], and Deshpande et.al (2024) [10] have also studied air quality parameters to analyze the effects of pollutants on the environment. Figure 1(a, b, and c) shows the graphical view of the Dehradun district.

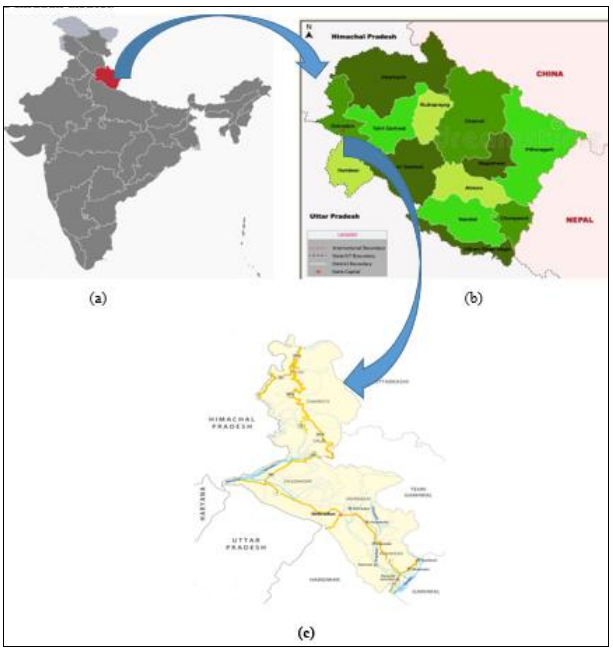

Fig 1: (a, b, and c) Geographic map of the different districts of Dehradun

Study Area

Air quality monitoring and a questionnaire-based health survey in four areas of Dehradun were conducted during September 2024 to February 2025. The selected areas included four residential areas, ISBT, Clock Tower, Raipur, and Doon University, with highly congested vehicular traffic. Figure 2 (a, b, and c) shows the traffic volume at different locations, i.e., ISBT, Clock Tower, and Raipur of Dehradun during the normal hours.

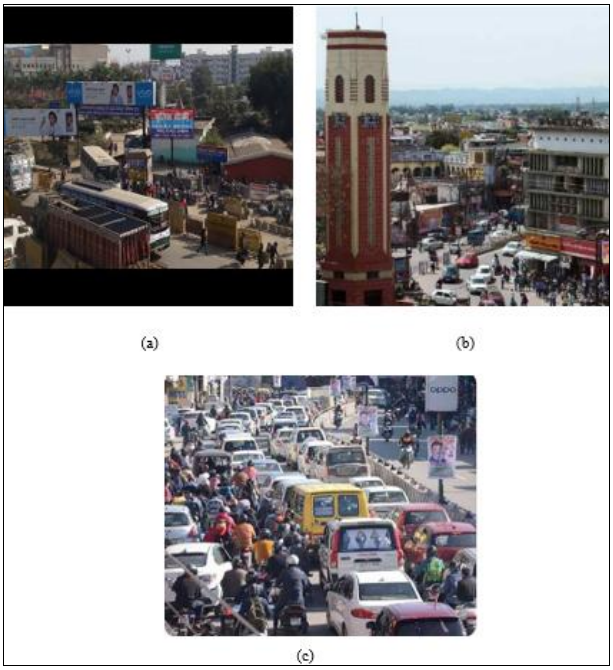

Fig 2: (a, b, and c) Traffic jam conditions at different locations of Dehradun

Significant amounts of air pollutants, including PM_{10}, $PM_{2.5}$, SO_2, and NO_2, are released due to the heavy traffic in the ISBT, Clock Tower, Raipur, and Doon University locations. These pollutants are mostly from smog and car exhaust. Humans are recognized to be seriously at risk for respiratory and cardiovascular issues as a result of these contaminants. The current study was created to examine the potential long-term effects of these air contaminants on human health in light of these worries.

Air Quality Monitoring

The monitoring of air pollutants in the present study was undertaken at four stations, four primarily residential areas. The data was collected for six summer months (September 2024 to February 2025). The following parameters, i.e., PM_{10}, $PM_{2.5}$, NO_2, and SO_2, have been studied for the present analysis. The air quality data from four locations—Clock Tower, ISBT, Raipur, and Doon University—has been analyzed based on the Air Quality Index (AQI) categorization, where pollutant levels are classified as Good (0-50), Satisfactory (51-100), Moderate (101-200), Poor (201-300), Very Poor (301-400), and Severe (>400). Table 1 and Figure 3 show the variations in the air quality parameters at different locations of Dehradun during September 2024.

Table 1: Categories of various pollutants at different locations in Dehradun (September 2024)

Sr. No.	Location	Category	PM_{10}	$PM_{2.5}$	SO_2	NO_2
1	Clock Tower	Residential	120.45	54.99	5.42	19.2
2	ISBT		126.37	54.57	8.27	20.16
3	Raipur		120.74	49.42	4.77	17.87
4	Doon University		33.14	17.64	5.22	5.81

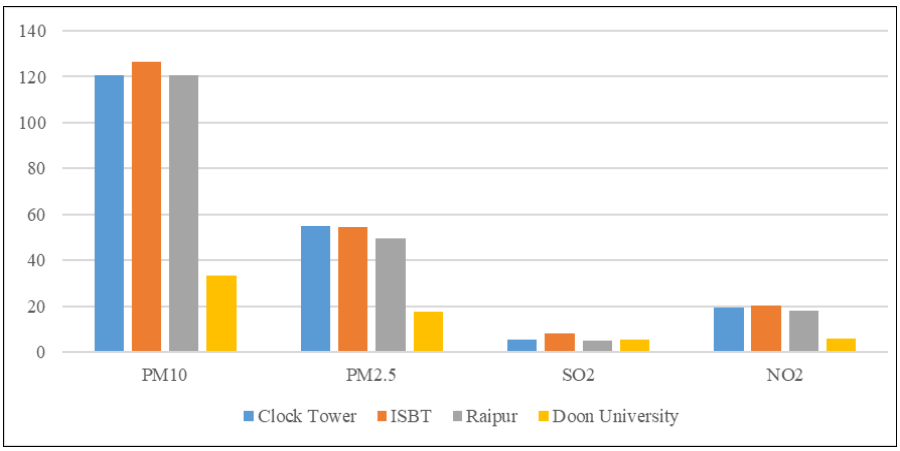

Fig 3: Pollutant variation in Dehradun at different locations

Figure 3 show the values of PM_{10} at Clock Tower (120.45 µg/m³), ISBT (126.37 µg/m³), and Raipur (120.74 µg/m³) are all in the Moderate category, suggesting a significant amount of particle pollution that may make it difficult for elderly people, children, and those with heart or lung conditions to breathe. The $PM_{2.5}$ levels at these three sites, which range from 49.42 to 54.99 µg/m³, fall between the Satisfactory and Moderate ranges, indicating that sensitive people may experience mild respiratory irritation. Doon University, in comparison, is notable for having far lower levels of PM_{10} (33.14 µg/m³) and $PM_{2.5}$ (17.64 µg/m³), putting it in the Good category for both metrics, indicating little to no harm to the public's health. All sites had values of SO_2 and NO_2 that fall well within the Good to Satisfactory range for gaseous pollutants, with SO_2 ranging from 4.77 to 8.27 µg/m³ and NO_2 from 5.81 to 20.16 µg/m³. ISBT had the highest NO_2 level (20.16 µg/m³), which is still within the Good range. Table 2 and Figure 4 show the variations in the air quality parameters at different locations of Dehradun during September 2024.

Table 2: Categories of various pollutants to varying locations in Dehradun (October 2024)

Sr. No.	Location	Category	PM_{10}	$PM_{2.5}$	SO_2	NO_2
1	Clock Tower	Residential	139.01	60.38	9.28	20.93
2	ISBT		152.4	62.33	11.7	21.25
3	Raipur		147.51	58	8.55	20.53
4	Doon University		83.41	48.43	0.82	1.59

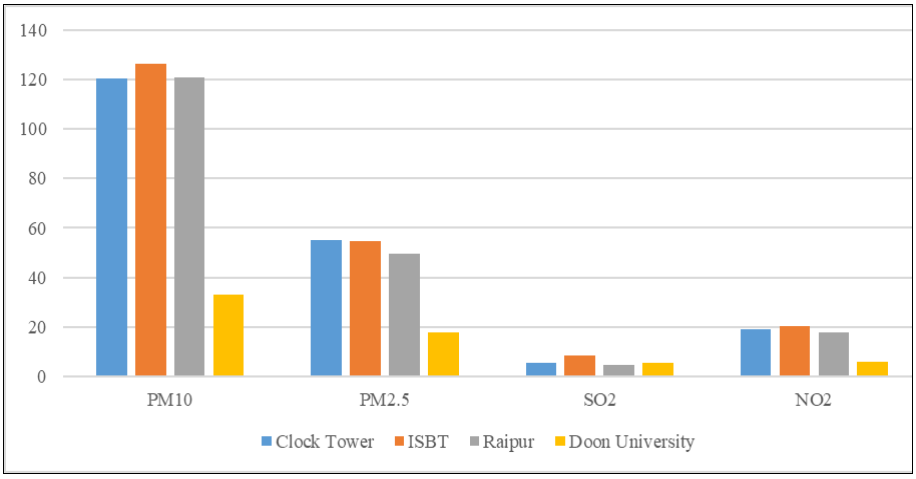

Fig 4: Pollutant variation in Dehradun at different locations

According to the air quality data, shown in Table 2 and Figure 4, ISBT, Clock Tower, and Raipur are classified as having moderate levels of PM_{10} and $PM_{2.5}$, with values ranging from 139.01 to 152.4 µg/m³ for PM_{10} and 58 to 62.33 µg/m³ for $PM_{2.5}$. These levels signal possible health effects for vulnerable populations. Although they are comparatively greater in ISBT and Clock Tower, gaseous pollutants SO_2 and NO_2 stay within acceptable bounds across these places. On the other hand, Doon University exhibits significantly reduced pollution levels, with minimum amounts of SO_2 (0.82 µg/m³) and NO_2 (1.59 µg/m³), as well as PM_{10} (83.41 µg/m³) and $PM_{2.5}$ (48.43 µg/m³) in the Satisfactory range, suggesting a cleaner and healthier environment.

Table 3: Categories of various pollutants at different locations in Dehradun (November 2024)

Sr. No.	Location	Category	PM_{10}	$PM_{2.5}$	SO_2	NO_2
1	Clock Tower	Residential	191.14	103.55	9.4	21.12
2	ISBT		201.26	101.62	11.13	21.45
3	Raipur		186.21	90.62	8.13	20.24
4	Doon University		100.6	74.94	0.78	2.3

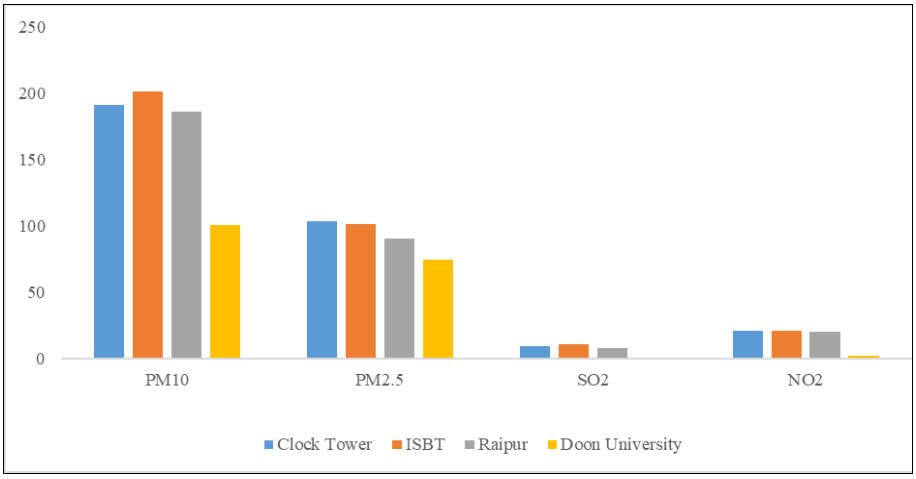

Fig 5: Pollutant variation in Dehradun at different locations

According to the air quality data, shown in Table 3 and Figure 5, based on the air quality data collected from various locations in Dehradun, significant variations in pollutant levels have been observed. The Clock Tower area, categorized as a residential zone, shows the highest $PM_{2.5}$ concentrations at 103.55 µg/m³ and PM_{10} at 191.14 µg/m³, indicating poor air quality and potential health risks for residents. ISBT also records elevated pollutant levels,

particularly PM_{10} (201.26 µg/m³) and SO_2 (11.13 µg/m³), suggesting high traffic-related emissions. Raipur exhibits moderately high levels of particulate matter, while Doon University reports the lowest pollution levels across all parameters, with PM_{10} at 100.6 µg/m³ and SO_2 at only 0.78 µg/m³, likely due to its greener surroundings and reduced vehicular activity. These findings emphasize the urgent need for pollution control measures, especially in densely populated and high-traffic areas.

Table 4: Categories of various pollutants at different locations in Dehradun (December 2024)

Sr. No.	Location	Category	PM_{10}	$PM_{2.5}$	SO_2	NO_2
1	Clock Tower	Residential	207.44	102.65	10.1	21.56
2	ISBT		216.61	102.47	11.12	21.86
3	Raipur		209.53	93.14	8.2	20.67
4	Doon University		73.92	58.5	0.82	2.62

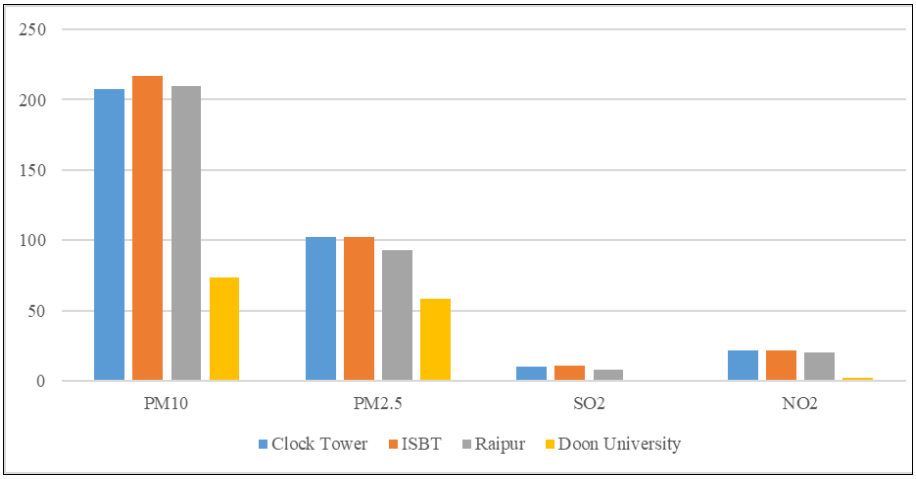

Fig 6: Pollutant variation in Dehradun at different locations

Table 4 and Figure 6 shows that the Clock Tower, ISBT, and Raipur have entered the Poor category for PM_{10} levels (ranging from 207.44 to 216.61 µg/m³) and the Moderate to Poor category for $PM_{2.5}$ (93.14 to 102.65 µg/m³), indicating unhealthy air conditions that may cause respiratory discomfort, especially for sensitive groups. SO_2 and NO_2 levels, though slightly elevated at ISBT and Clock Tower, remain within acceptable limits. In contrast, Doon University shows significantly better air quality, with PM_{10} (73.92 µg/m³) and $PM_{2.5}$ (58.5 µg/m³) in the Satisfactory range, and very low SO_2 (0.82 µg/m³) and NO_2 (2.62 µg/m³), reflecting a much cleaner environment.

Table 5: Categories of various pollutants at different locations in Dehradun (January 2024)

Sr. No.	Location	Category	PM_{10}	$PM_{2.5}$	SO_2	NO_2
1	Clock Tower	Residential	213.07	102.3	9.87	21.7
2	ISBT		222.91	102.73	11.3	21.52
3	Raipur		211.98	93.54	8.53	20.38
4	Doon University		91.88	70.66	0.64	2.31

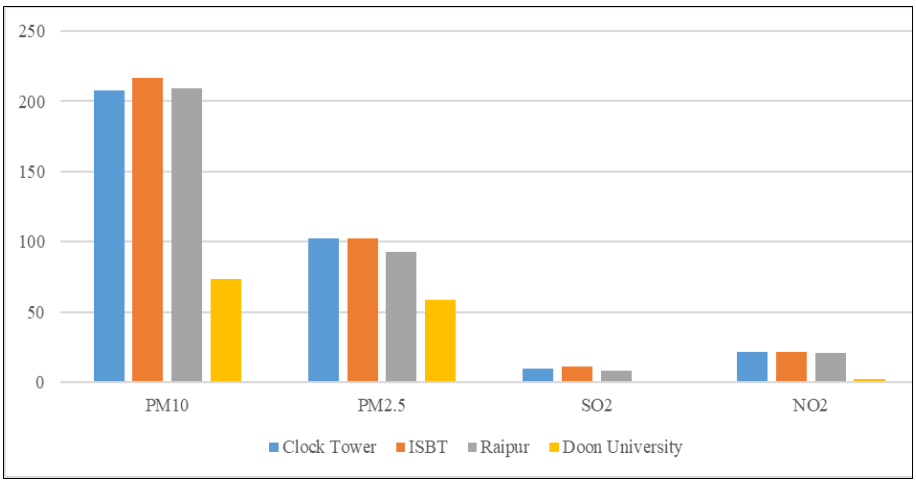

Fig 7: Pollutant variation in Dehradun at different locations

Table 5 and Figure 7 shows that the air quality data indicates that Clock Tower, ISBT, and Raipur fall under the Poor category for PM_{10} (ranging from 211.98 to 222.91 µg/m³) and Moderate to Poor for $PM_{2.5}$ (93.54 to 102.73 µg/m³), suggesting a high pollution load that can cause health issues, especially for sensitive groups. SO_2 and NO_2 levels are moderately elevated but remain within safe limits. In contrast, Doon University records much lower pollution, with PM_{10} (91.88 µg/m³) in the Satisfactory range and $PM_{2.5}$ (70.66 µg/m³) in the Moderate range, along with minimal SO_2 (0.64 µg/m³) and NO_2 (2.31 µg/m³), reflecting a significantly cleaner and healthier environment.

Table 6: Categories of various pollutants at different locations in Dehradun (February 2025)

Sr. No.	Location	Category	PM10	PM2.5	SO2	NO2
1	Clock Tower	Residential	223.14	101.66	10.08	21.76
2	ISBT		227.61	103.07	11.04	21.24
3	Raipur		217.03	92.25	9.31	20.69
4	Doon University		75.6	32.38	0.59	1.88

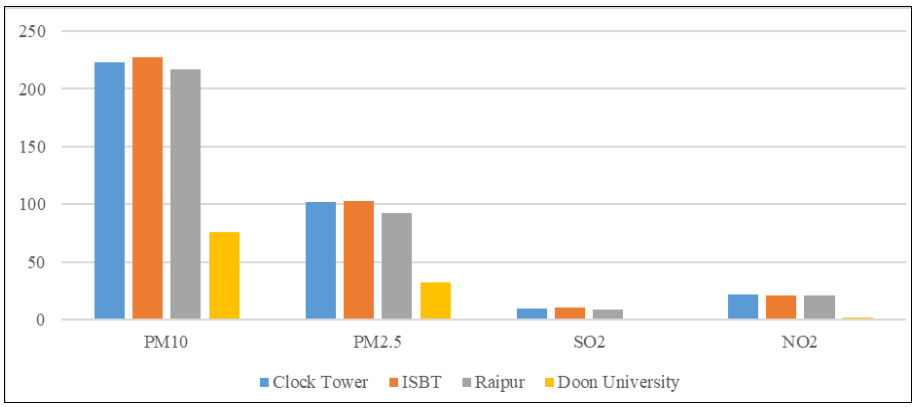

Fig 8: Pollutant variation in Dehradun at different locations

Table 6 and Figure 8 shows that According to the air quality data, Clock Tower, ISBT, and Raipur are classified as having poor PM_{10} levels (ranging from 217.03 to 227.61 µg/m³) and poor to moderate $PM_{2.5}$ levels (92.25 to 103.07 µg/m³), which can hurt public health, especially for vulnerable populations. Although they are still within acceptable bounds, SO_2 and NO_2 levels are comparatively higher in these locations. Doon University, on the other hand, reports significantly cleaner air, with extremely low SO_2 (0.59 µg/m³) and NO_2 (1.88 µg/m³) values, PM_{10} (75.6 µg/m³) in the Satisfactory range, and $PM_{2.5}$ (32.38 µg/m³) in the Good range, suggesting a healthy and low-pollution environment. Figure 9 shows the compiled results of the present study.

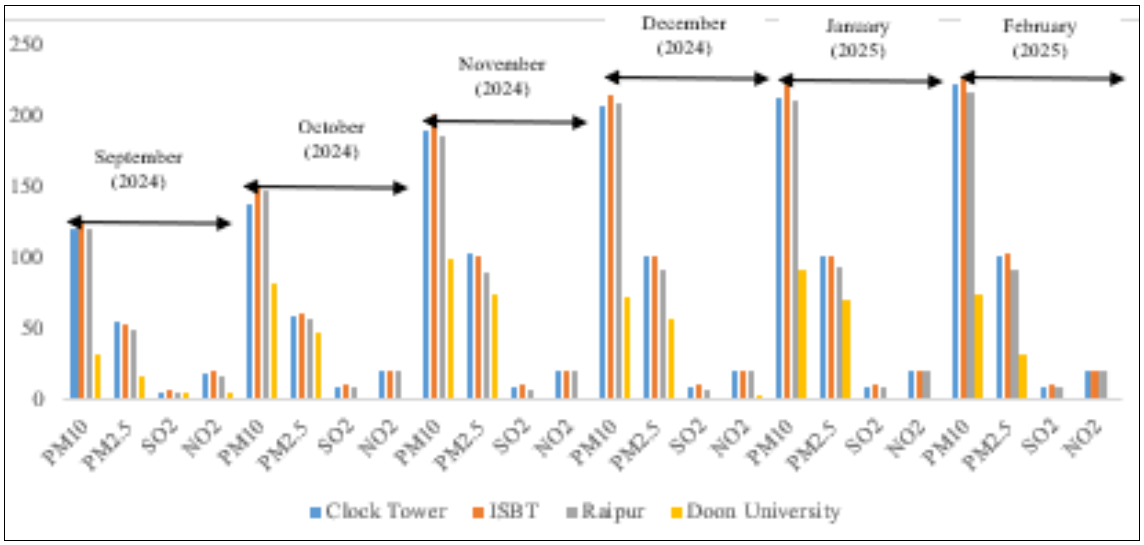

Fig 9: Comparison of Air pollutants (PM $_{10}$, $PM_{2.5}$, SO_2 and NO at various locations of Dehradun

Impact of Air Pollutants on Human Health

A health analysis based on the Air Quality Index (AQI) reveals a significant impact of environmental pollutants on public health. Air pollution has become a serious environmental problem, especially in cities with heavy traffic. Particulate matter (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) are some of the most dangerous air pollutants. Because of its microscopic size, PM_{10} and $PM_{2.5}$ can enter the circulation and penetrate deeply into the respiratory tract, resulting in cardiovascular

illnesses, respiratory problems, and decreased lung function. Asthma and bronchitis can worsen with extended exposure to SO_2, which is known to irritate the eyes, throat, and lungs. Similarly, NO_2 can reduce the immune response to lung infections and contribute to respiratory inflammation. People with pre-existing medical issues, the elderly, and children are especially susceptible to these contaminants. Thus, public health and sustainable urban life depend on comprehending and reducing the negative health effects of these air contaminants.

Observation to reduce Air pollutants in the Environment

- Encourage Public Transportation: To cut down on the number of cars on the road, promote the use of buses, metros, and shared transportation.
- Implement Vehicle Emission Control Measures: Encourage routine vehicle maintenance, phase out outdated or high-emission cars, and enforce stringent emission regulations (such as BS-VI in India).
- Make the Switch to Clean Fuels and Electric cars (EVs): To cut exhaust emissions, promote the use of CNG, electric, and hybrid cars.
- Enhance Traffic Flow Management: To cut down on idle time at signals, ease traffic, and encourage efficient vehicle movement, employ intelligent traffic systems (ITS).
- Create Green Belts and metropolitan Forests: To absorb pollutants and serve as natural air filters, plant trees and other vegetation beside roadsides and in metropolitan areas.
- Encourage non-motorized transportation by establishing secure routes for bicyclists and pedestrians to lessen reliance on cars.
- Use Low Emission Zones (LEZ) or Congestion Pricing: To lessen traffic congestion during peak hours, restrict or tax vehicle access into congested city areas.
- Frequent Road Cleaning and Dust Suppression: To reduce road dust, a significant source of PM_{10}, use vacuum sweepers and water sprinklers.

Conclusion

A distinct seasonal fluctuation and geographical difference in pollution levels are evident from the six-month air quality data (September 2024-February 2025) gathered at four places in Dehradun namely Clock Tower, ISBT, Raipur, and Doon University.

$PM_{2.5}$ levels at Clock Tower climbed from 54.99 µg/m³ to 101.66 µg/m³ during the same time, while PM_{10} levels surged dramatically from 120.45 µg/m³ in September to 223.14 µg/m³ in February. From 5.42 µg/m³ and 19.2 µg/m³ in September to 10.08 µg/m³ and 21.76 µg/m³, respectively, by February, SO_2 and NO_2 levels likewise gradually increased. Similarly, $PM_{2.5}$ rise from 54.57 µg/m³ to 103.07 µg/m³, and PM_{10} rise from 126.37 µg/m³ to 227.61 µg/m³ at ISBT. NO_2 levels varied between 20.16 µg/m³ and 21.24 µg/m³, but SO_2 levels increased from 8.27 µg/m³ to 11.04 µg/m³.

Although Raipur's pollution levels were marginally lower than those of Clock Tower and ISBT, $PM_{2.5}$ increased from 49.42 µg/m³ to 92.25 µg/m³, and PM_{10} increased from 120.74 µg/m³ in September to 217.03 µg/m³ in February. For six months, SO_2 levels rise from 4.77 µg/m³ to 9.31 µg/m³, while NO_2 levels changed from 17.87 µg/m³ to 20.69 µg/m³.

Doon University, on the other hand, kept its air comparatively cleaner. While SO_2 and NO_2 stayed extremely low, ranging between 0.59 and 5.22 µg/m³ and 1.59 and 5.81 µg/m³, respectively, PM_{10} levels increased from 33.14 µg/m³ in September to 75.6 µg/m³ in February, while $PM_{2.5}$ levels increased from 17.64 µg/m³ to 32.38 µg/m³.

The results show a notable rise in particle and gaseous pollutants throughout metropolitan areas throughout the winter, most likely as a result of temperature inversion, low wind speed, and vehicle emissions. Doon University, a comparatively greener and less crowded area, continuously recorded the lowest pollution levels, underscoring the influence of both human activity and the environment on air quality.

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