Perception-based study of ambient air pollution in Dehradun city and validation of low-cost air quality sensor

Dissertation Submitted in the partial fulfillment of the requirement for the degree of

Master of Science in Environmental Science

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Declaration

Declaration I declare that the work presented in the Dissertation entitled 'Perception based study of ambient air pollution in Dehradun city and validation of low-cost air quality sensor' being submitted to the School of Environmental & Natural Resources, Doon University, Dehradun for the award of Master in (Subject) is my original researchwork.

The Dissertation embodies the results of investigations, observations, and experiments carried out by me. I have neither plagiarized any part of the dissertation nor have submitted same work for the award of any other degree/diploma anywhere.

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SEM 365

Date-

Certificate

This is to certify that the Dissertation entitled Perception-based study of ambient air pollution in Dehradun city and validation of low-cost air quality sensor submitted by Ankita Rawat has been done under my supervision. It is also certified that the work in this Dissertation embodies original research and hard work of the candidate. The assistance and support received during the course of investigation and all the sources of literature have been fully acknowledged.

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Abstract

The deterioration of air quality, particularly in metropolitan areas, is related to both local-scale circumstances and the dispersion of air pollutants. In the Uttarakhand city of Dehradun, the burning of fossil fuels, industrial pollutants, open sewage systems, rubbish burning, and cars all significantly contribute to air pollution. This study is part of a project by ICIMOD "Cites study on exposure and impact of air pollution in the HKH regions" as the Hindu Kush Himalayan (HKH) region has been impacted lately by an increase in air pollution emissions from urban, industrial, and rural sources. These pollutants degrade the surrounding air quality and further contribute to several health issues. A person's health, finances, social life, and mental state are all impacted by air pollution. Results of air quality monitoring have revealed that the city is significantly polluted as the PM2.5 and PM10 levels are considerably over the acceptable level established by the CPCB. The goals of the current study were to determine how different occupational groups perceived air pollution among the general population and to correlate the perception data with the data on air pollution. 400 surveys for 4 occupational groups- drivers, vendors, labourers, and office workers. When compared to office employees, vendors, drivers, and labourers spend a disproportionate amount of time closer to roads, dirt, and dust and are therefore more susceptible to air pollution. In this study, we attempted to assess how various occupational groups perceived seasonal variation in air pollution to the available data on air pollution. The data given by the Uttarakhand pollution control board under the NCAP policy was used to validate the public's view of seasonal change in air pollution. Particulate matter (PM), in the case of Dehradun, is widely acknowledged as one of the most serious hazards to both human health and the environment. This study tries to understand the variance of particulate matter in the city. Since installing and maintaining traditional real-time air quality monitoring equipment is expensive, in the current study we validated the low-cost sensor data (M200) using CAAQMS to assess the sensor's accuracy. The research has also made an effort to develop some measures for reducing emissions in the city.

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Chapter 1

1.1 Introduction

The act of introducing contaminants into the air that are harmful to humans and other living beings, or that degrade the environment or materials is referred to as "air pollution". Despite the fact that a wide range of natural occurrences (fire, volcanoes, etc.) may cause a variety of pollutants to be released into the surroundings, the primary cause of environmental air pollution is anthropogenic activities. Hazardous chemicals can accidentally leak into the environment, but industrial facilities and other operations also generate a multitude of air pollutants that might be harmful to both human health and the environment. Air pollution is a global concern and human health is affected by it in various degrees based upon their exposure and immunity level (Aggarwal and Jain, 2015; Jain and Khare, 2010; Bajaj et al, 2017). The most vulnerable groups to the effects of air pollution are those who work outside, without using adequate safety procedures, they perform their jobs in a polluted environment. The city is surrounded by dense forest comprising chiefy of Sal tree (Shorea robusta), and the climate is generally temperate. The city offers a lot of growth opportunities for people from surrounding mountainous regions (Dutta et al. 2015). Dehradun city was placed at thirty-first position in the list of top 100 polluting cities in the world (WHO., 2016).

Studying air pollution near roads has revealed how dynamic traffic-related pollution is in both space and time. Traffic is an increasingly dominant contributor to air pollution in Dehradun city. The street sellers, commercial drivers, and construction and industrial labours who frequently set up shop and work along busy roadways to draw in as many clients as possible, run the danger of having their health deteriorate. Because automotive emissions enter the lower troposphere and are thus directly inhaled by people during breathing, they are more destructive than other types of pollution. Major air pollutants include SOx, NOx, SPM, and RSPM, as well as inorganic, organic, and metal pollution, are mostly produced by automotive emissions.

Increased energy demand from the domestic, transportation and industrial sectors was brought on by rapid population growth and extensive infrastructure development. As a result, emissions of hydrocarbons, particulate matter (PM), carbon monoxide (CO) nitrogen oxides (NOx), sulphur dioxide (SO2), and rose. The PM10 and PM2.5 values were reported by the Uttarakhand Pollution Control Board to be substantially above standard. (https://cpcb.nic.in/Actionplan/Dehradun.pdf). PM2.5 and PM10 are Dehradun's main source of pollution concern.

1.2. Particulate matter

The environment is affected by particulate matter that comes from a variety of anthropogenic and natural sources. There are several ways to categorize PM, but one of the key factors is the aerodynamic diameter. It is defined as sphere of unit density sphere that has the same settling velocity as the particle. (Hindu,1982). The size distributions are used to express particles most frequently, and they can be represented by mass, number, or volume. PM is often divided into two categories, namely primary and secondary particles. Those particles that are directly released into the environment as a result of chemical, physical, or mechanical processes can be categorized as primary particulate matter. Particles produced as a result of the conversion of gases into particles in the atmosphere are secondary particulate matter. The following terms can be used to classify particulate particles.: RSPM (respirable suspended particulate matter) PM_{10} (particulate matter <10 µm), $PM_{2.5}$ (particulate matter <2.5 µm), PM_1 (particulate matter <1 µm), SPM (total suspended particulate matter), etc. In this study, our prime concern was PM_{10}, and $PM_{2.5}$.

Particles with a diameter of 2.5 microns or less are significantly more hazardous to health than those with a diameter of less than 10 microns or 10 microns (PM10), despite the fact that PM10 can lodge in the lungs. The lung barrier can be breached by PM2.5, allowing it to enter the bloodstream. Chronic particle exposure raises the risk of lung cancer, as well as respiratory and cardiovascular problems.

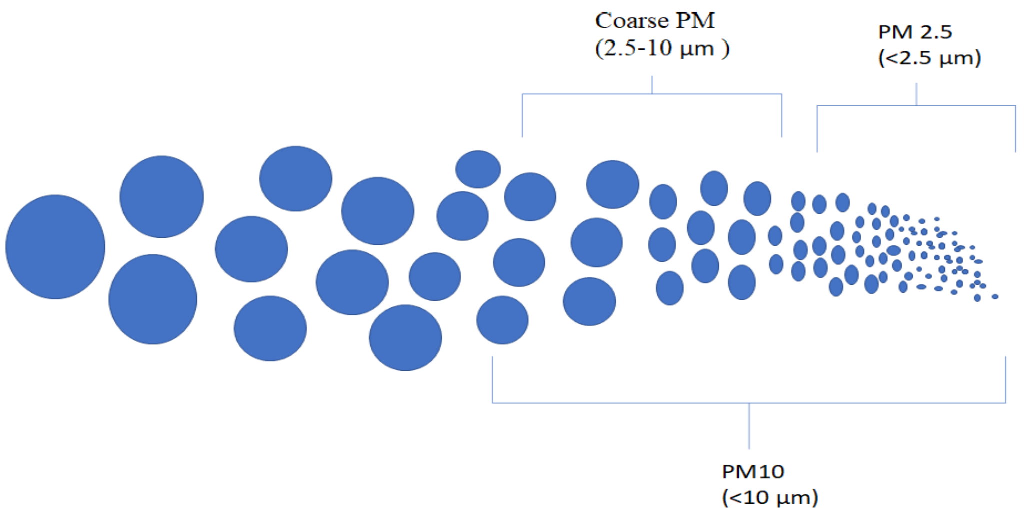


Fig 1. Different sizes of particulate matter

1.2.1. Source of Particulate matter

These particles can be made up of hundreds of different compounds and come in a wide range of sizes and forms. Some are released directly from sources including fires, smokestacks, unpaved roads, fields, and construction sites.

The majority of airborne particles are produced through intricate chemical processes that entail pollution from industry, power plants, and reactions, including sulphur dioxide and nitrogen oxides. A large amount of the PM2.5 pollution and a sizable portion of the PM10 pollution found in outdoor air are produced by emissions from the burning of gasoline, oil, diesel fuel, or wood. PM10 also contains dust from industrial sources, wind-blown dust from open areas, pollen, and bacterium pieces. It also includes dust from wildfires, landfills, and agriculture.

1.3. Air pollution in Dehradun

Pollution levels for all of the criterion pollutants have increased as a result of the city's quick expansion and rising pollutant emissions. SPM and RSPM, two indicators of ambient air quality in Dehradun, were discovered to have higher concentrations. and to have exceeded NAAQ's maximum permissible levels (2009).

Most of the pollutions in the city are through vehicular load. According to World Health Organization (WHO) assessment released in 2016, Dehradun is the world's 31st most polluted city. It is the 15th most polluted city in India. The WHO report is based on the quantity of PM2.5, or fine particulate matter, that is prevalent in the air in a certain area. The central pollution control has devised a system to observe the air quality index in order to better understand the air quality of the pollutants. The Air Quality Index is a technique for categorizing air quality in terms of how it affects human health.

1.3.1. Government stand

The AIR (Prevention and Control of Pollution) Act and the Environment Protection Act were passed by the Indian government in 1981 and 1986, respectively, to enable continuous monitoring of air quality in the country. Under the AIR (Prevention and Control of Pollution) Act, the Central Pollution Control Board (CPCB) established a countrywide ambient air quality monitoring system in 1986 to obtain data on air pollution using an extensive network of monitoring stations around the nation (CPCB 2003, 2012, 2015). The Uttarakhand Pollution Control Board has three manual ambient air quality monitoring stations in Dehradun (UKPCB) (https://cpcb.nic.in/Actionplan/Dehradun.pdf). The ambient air quality of three pollutants – PM10, NOx and SOx are measured by monitoring stations, Monitoring of PM2.5 began in January 2019. One continuous ambient air quality monitoring station is located in Dehradun, and it is situated at Doon University, Mothrowala. The Uttarakhand Pollution Control Board is also intending to locate two more monitoring stations, one in Prem Nagar and another in IT Park. The status of different air quality monitoring stations in the city of Dehradun is shown in Fig 2.

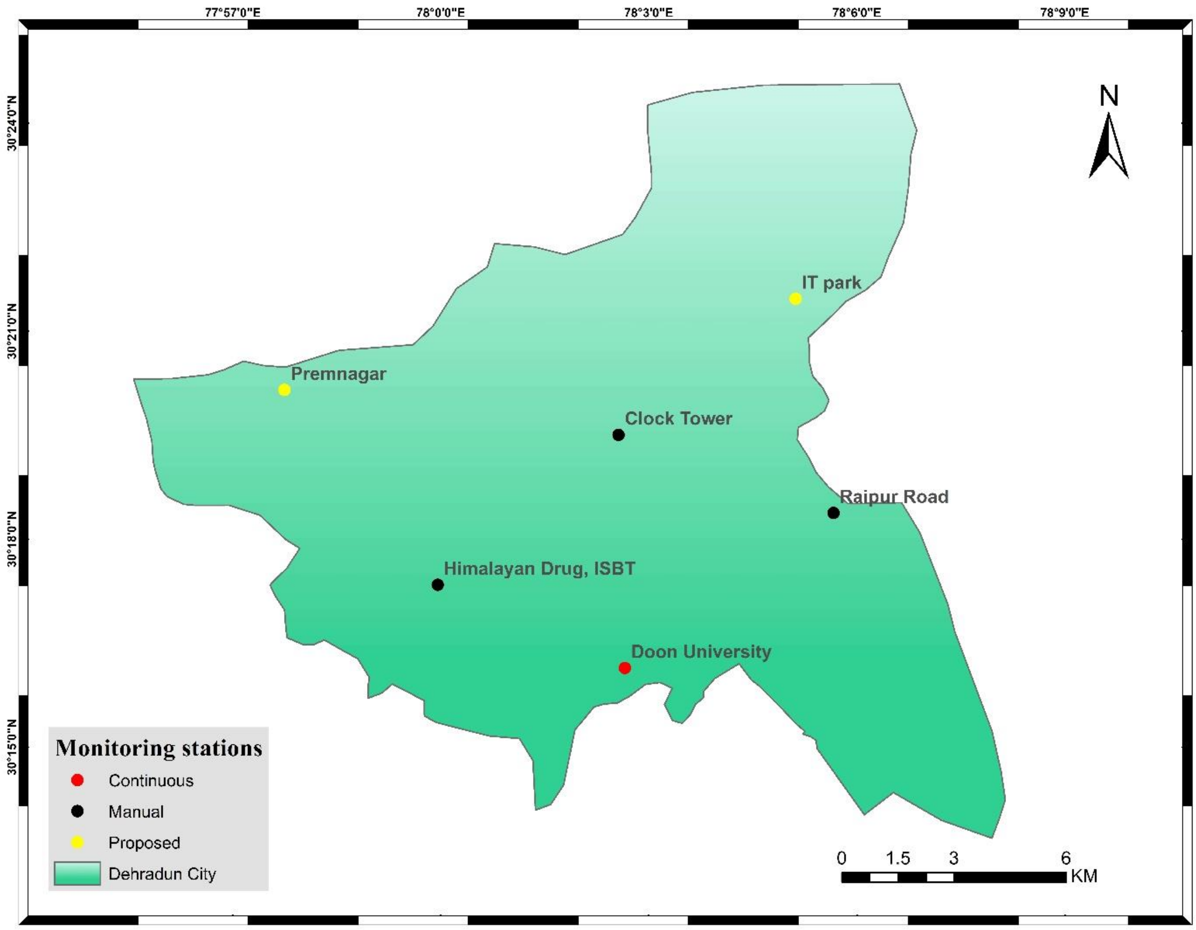


Fig2. Monitoring station in Dehradun city

According to the National Air Quality Index, the government has produced a Graded Response Action Plan for execution under the different Moderate & Poor, Very Poor, Severe, and "Severe or Emergency" are the AQI classifications. The calculation of the air quality index is based on any three air quality measures, one of which must be particulate matter (either PM10 or PM2.5). In the table1 below, the Air Quality Index (AQI) is depicted. The weekly AQI data of Dehradun city (https://ueppcb.uk.gov.in/pages/display/98-aqi-weekly-data) indicate that situation of the city ranges from moderate to poor.

Table 1 The Central Pollution Control Board's Air Quality Index

Air Quality Index	**Category**	**Possible Health Impact**
0-50	Good	Minimal Impact
51-100	Satisfactory	Minor Breathing discomfort to sensitive people
101-200	Moderate	Breathing discomfort to the people with lungs, asthma and heart diseases
201-300	Poor	Breathing discomfort to most people on prolonged exposure
301-400	Very Poor	Respiratory illness on prolonged exposure
401-500	Severe	Affects healthy people and seriously impactsthose with existing diseases

1.4. Aim and Objective

The overall aim of this thesis is to increase the knowledge and: -

1. To study the public Perception of air pollution in different occupational groups
2. To correlate the perception data with the data on air pollution
3. To validate the low-cost sensor data with CAAQMS

Chapter 2

2.1. Overview

The study of air pollution has been carried out throughout the world to learn, understand and find mitigation methods for air pollution.

It is well recognised that air pollution has a negative impact on human health, particularly on how well the respiratory system works. Age, socioeconomic level, exposure time, environmental factors, and pre-existing health conditions all affect how susceptible an individual is to air pollution. One of the key pollutants is atmospheric particulates (Gujar BR, Ravindra k, Nagpure AS., 2016). Large quantities of chemical compounds are emitted into atmosphere as result of anthropogenic processes (Shiva Nagendra et al. 2016). These emissions lead to a complex array of chemical and physical transformations resulting in apparently diverse effects as photochemical air pollution, acid deposition, long-range transport of chemicals and global weather modifications (Atkinson 1990). As one of the criterion air pollutants (USEPA, 2015) atmospheric particulate matter (PM) is complex and difficult to comprehend in terms of its source, shape, content, size distribution, and mixing state (Banerjee et al., 2015). Being exposed to intense ambient PM concentration has been linked to significant health issues. (HEI 2004; Pope et al., 2006; WHO 2004). The morphological characteristics of air particles and knowledge of the chemical species that are related with them can serve as indicators to locate the emission sources. For instance, some typical indicators of a vehicle's emission include copper (found in brake linings), aluminium (fin piston wear), zinc (found in tyre wear), and manganese (additives in unleaded gasoline), iron (found in brake wear and tear). (Srivastava et al., 2016).

Particulate pollution studies are receiving more attention despite having been researched for longer due to its detrimental impacts on air quality, public health, climate, and, agricultural production. (Seinfeld and Pandis 2016; Stocker et al. 2013; Zhang et al. 2017). There have been several studies. These results emphasize the importance of monitoring atmospheric PM10, particularly in data-deficient areas. Furthermore, it is widely known that exposure to carcinogenic heavy metals linked to PM10 can significantly increase human carcinogenicity. (Izhar et al. 2016)

The physical and chemical properties of the PM are related to the association between exposure to PM concentration and related health consequences. (Srimuruganandam et al. 2011). Additionally, the chemical property of the PM has a major impact on cloud acidification and many other atmospheric phenomena, such as cloud formation, visibility, solar radiation, and precipitation, rain and fog (Hong et al., 2002; Celis et al., 2004).

Automobile exhausts and certain industrial pollutants contain NO2, which by photochemical reaction produces O3and effects allergic asthmatics by augmenting allergic responses (Steinberg et al., 1991). Similarly SO2, NO, particulate matter and acid aerosols effect pulmonary function and cause inflammation of bronchial mucous (Karen and Michak, 1991; Giuseppe and Francesco, 1993).

The health hazards of exposure to atmospheric PM1 (submicron particles with an aerodynamic diameter of 1 m), PM2.5 (fine particulates with an aerodynamic diameter of 2.5 m), and PM10 (respirable particulates with an aerodynamic diameter of 10 m) have been studied in India. (Izhar et al. 2016). Alternatively, the issues caused by particle matter (PM10 and PM2.5 μm) (Bodor et al. 2020; Markra et al. 2011), arising from industrialization and urbanization have continuously increased the need for comprehensive, effective long-term pollution controls (Al-jeelani 2016). Hence, in order to control and maintain air quality, it is mandatory to determine the potential pollution sources and emissions both locally and globally. For example, the PM10 mean value for short-term (24-h mean) is 50 μg/m3 (WHO 2006, 2016) and in the urban environment is frequently exceeded especially if there is a strong industrial background. However, owing to large Spatio-temporal variations in the chemical composition of PM, more studies are needed for data-deficient areas. In addition to assessing human health risks, source apportionment studies will help in formulating effective mitigation strategies for ambient PM (Panwar et al. 2020). However, information of the atmospheric PM-associated elemental composition is scarcely available over complex terrains (Prabhu et al. 2019).

2.2. Source of air pollution

Transportation, industry, agriculture, power, waste treatment, burning biomass, residential construction, construction waste, and demolition waste are the seven key sectors into which the different causes of air pollution are categorized. Transport is widely recognised to be a Signiant and increasing source of air pollution world wide (Colvile et al. 2001). In instance, past studies (Chauhan and Joshi 2008; Chauhan et al. 2010) focusing on the regional zone (Dehradun and nearby sites) found that the main causes of air pollution in this area are transportation vehicles and industrial emissions. The road transport sector is a major source of PM emissions in urban areas. The particles from the vehicles are the result of a combustion process and consist mainly of carbon and unburned or partially burned organic compounds (U.S.EPA, 1996; Gupta et al., 2006).

These analyses also showed that despite the quantity of particle matter exceeds the standards, the gaseous pollutants in this area are often always well within Indian air quality regulations (Chauhan et al. 2010; Awasthi et al. n.d. Deep et al. 2017). Air pollutants can be transferred to the foothills of the Himalayas from sources in distant locations, in addition to the impact of local emissions (Srivastava et al. 2014, Sarangi et al. 2014, Solanki et al. 2013, Ojha et al. 2017).

2.3. Status of Transportation sector

According to data from 2018, there were 6,02,939 two-wheelers, 7,674 three-wheelers, and 2,14,688 four-wheelers, respectively. While, according to 2021-2022 data, the two-wheeler Private- 564573, Public- 800, three-wheeler 1256, and four-wheeler 4196is there, with the total registered vehicle of 8,26,608. Vehicles have multiplied dramatically in number. According to the Uttaranchal Urban Development Department (UUDD) in 2007, the growth rate for registered automobiles was 326 % (UUDP, 2007).

2.4. Low- Cost sensors

Several studies are looking into the feasibility of using low-cost sensor platforms to collect data on air quality. Examples are Citi-Sense-MOB and OpenSense (https://gitlab.ethz.ch/tec/public/opensense) (Castell et al., 2015) that detect changes in urban air pollution using mobile devices. A variety of air pollutants may now be monitored via sensor platforms, and new technology is constantly being developed (Aleixandre et al. 2012, Snyder et al. 2013, Piedrahita et al. 2014). Monitoring air quality can benefit greatly from low cost sensor systems. High-resolution air quality maps may be created using sensor nodes placed on vehicles or deployed as dense networks (ubiquitous monitoring) (Hasenfratz et al. 2015, Schneider et al. 2016). PM_{10} and $PM_{2.5}$ measurements are mandated by legislation (Castell et al. 2017). But there is considerable debate over whether mass-based assessments are actually relevant for evaluating the health impacts of particulate pollution and if number-based measurements should instead be encouraged (Kumar et al. 2010). Significantly fewer research have been conducted on these aspects (Castell et al. 2017; deSouza et al. 2017; Hagan et al. 2018; Sayahi et al. 2019; Weissert et al. 2017). The effects of various environmental factors, such as temperature and relative humidity, on the performance of low-cost sensors and relative humidity (RH) (Feinberg et al. 2018; Liu et al. 2019), composition of air pollutant (Castell et al. 2017) and gas disturbance (Lin et al. 2015; Mead et al. 2013). Because field settings are more challenging than laboratory ones, the use of low-cost sensors in the field may cause sensor drift to increase (Sun et al., 2017). Since this requires a longer deployment period, limited research have been done on how the ambient conditions impact the long-term stability of low-cost sensor performance (Liu et al. 2020).

Chapter 3

3.1. Methodology and Study Area

3.2. Study Area

The study was carried out across Dehradun, where there is a high population concentration. The study site has a total area of 300 km^2 and is situated (latitude: 30.30°N, longitude: 78.09°E, altitude: 640 m above mean sea level). (https://dehradun.nic.in). Geographically, it is situated in the Doon valley, which is surrounded by the Shiwalik and middle Himalayas. In 2000, Dehradun was made the capital of Uttarakhand state, and since then, A growing number of migrants are emerging in Dehradun.

According to the 2011–2022 census, there were 5.6 lakh people living in Dehradun, with 2.7 females and 2.9 males (https://dehradun.nic.in/population/). The city has been rapidly expanding its urban areas to accommodate the large influx of migrants. The city was built as a retreat from the hot summers of the plains and is home to a number of educational institutions, including the Indian Military Academy, ITBP Academy, and ICAR-Indian Institute of Soil and Water Conservation as well as other organizations like the Zoological Survey of India (ZSI) and the Forest Research Institute (FRI). This region serves as a gateway to Mussoorie, a very well-known vacation spot in North India, particularly in Uttarakhand. Fig 3 Display the study area.

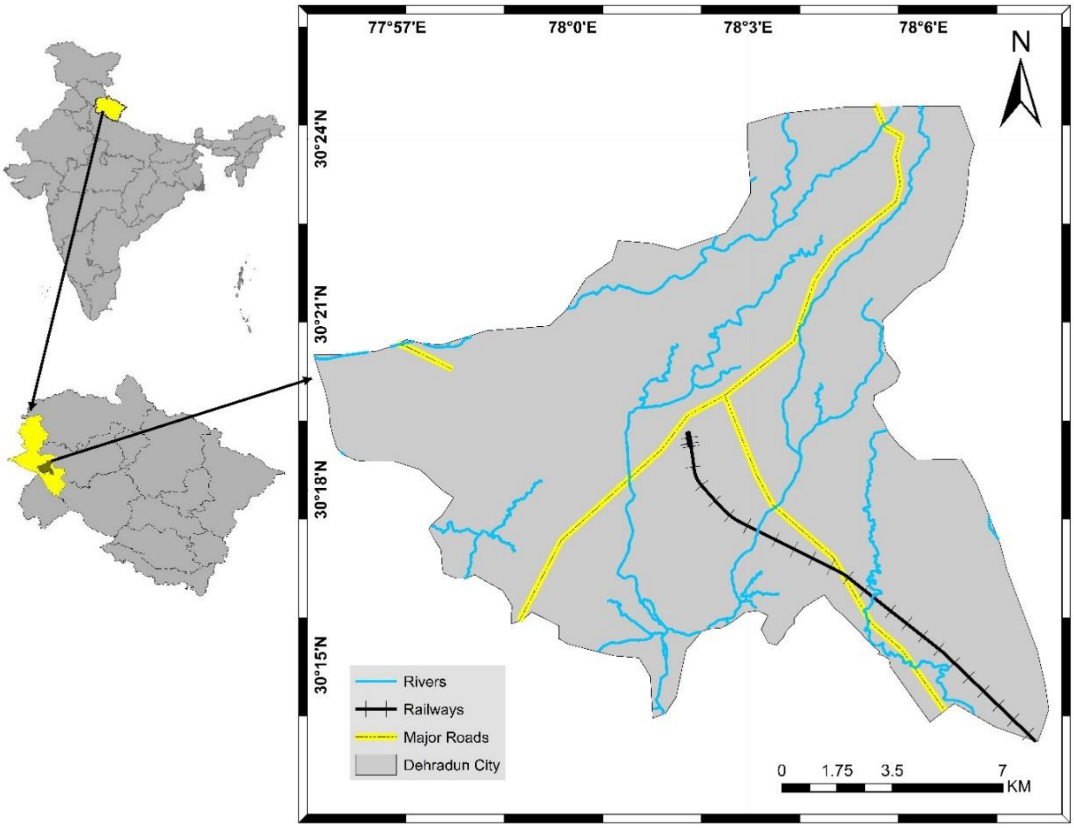


Fig 3. left side- map of India showing the Uttarakhand in yellow shade, on bottom map of Uttarakhand showing Dehradun. On right- map of Dehradun city

3.3. Methodology

The methodology involves conducting a field study, gathering primary and secondary data, identifying sites for sampling, and overseeing and analyzing the samples. 400 surveys overall across four occupational categories were collected. i.e., Drivers, labours, vendors, and office workers. Details of the survey are shown in the table: 2.

Table 2. Data of 400 surveys

Category	**Male**	**Female**	**Total**
Drivers	100	0	**100**
Labourers	70	30	**100**
Street Vendors	82	18	**100**
Office Workers	57	43	**100**
Total	**309**	**91**	**400**

3.3.1 Data Collection

3.3.1.1. Survey

Four occupational groups—drivers, vendors, labourers, and office workers—were divided for the survey portion of the study. Office workers were chosen as the contradicting group to examine the varied opinions depending on the nature of work and work environment. The three groups, namely drivers, vendors, and labourers, are considered the low-income group, or the marginal groups. There were 400 surveys conducted overall, 100 of which were for each occupational category. The whole city of Dehradun was covered throughout the survey period, as can be seen in the fig 4. As Dehradun city is one of the 30th most polluted city according to WHO report. In an effort to make it easier to comprehend the issue and address it, the survey was made to be carried out in the workplace and during working hours. Fig. 5 image (a) and(b) display an example of how we conducted the survey. For collection of data Kobo collect was used.

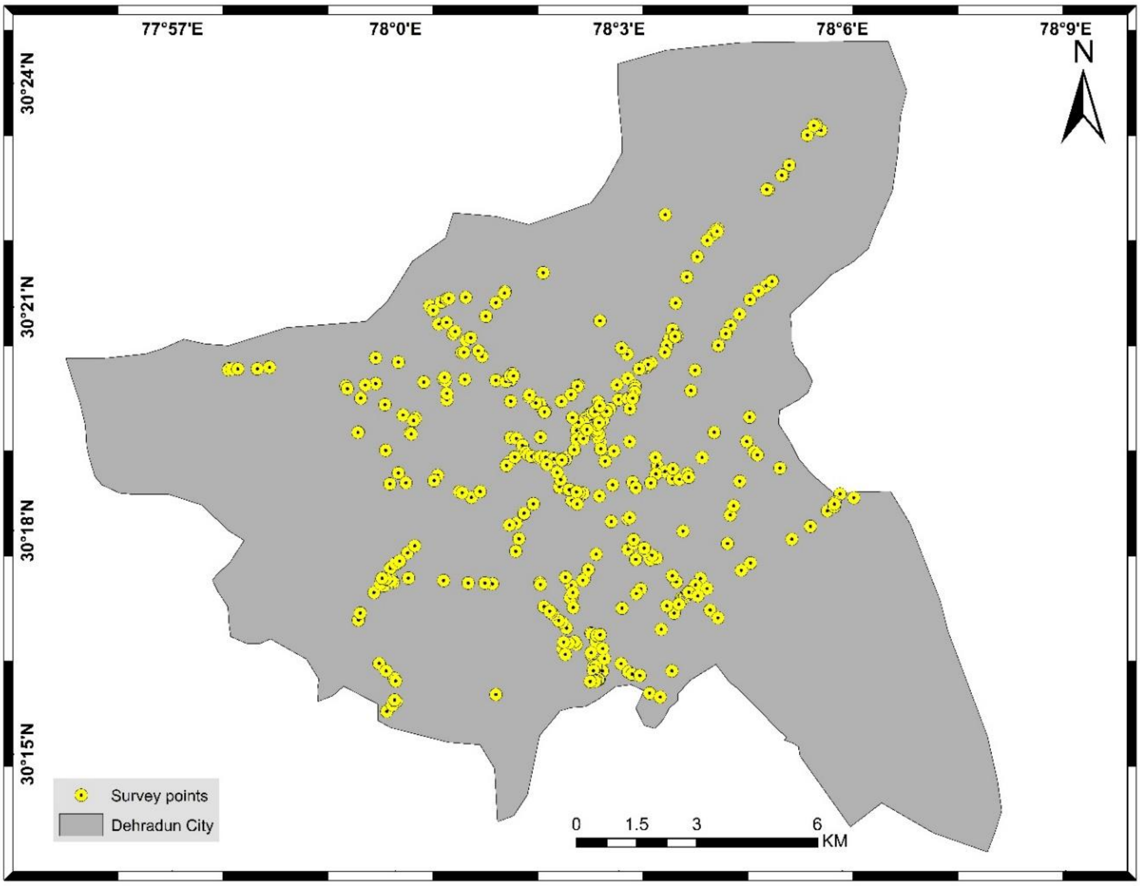


Fig 4. Representation of 400 survey on Dehradun city

(a) (b)

Fig 5. (a) and (b) Display survey of a local people

3.3.1.2. Low-cost sensor

The study employed the low-cost M2000 sensor. In the study, we looked at the low-cost sensor's accuracy. The M2000 air quality monitor uses a number of sensors to measure various pollutants, including PM2.5, PM10, CO2, particles, temperature, and humidity. To compute the PM2.5 and PM10 multi-channel concentration, particles present are passed via a professional light source from QSI, which uses the MIE scattering principle and a smart particle inversion algorithm. Fig. 6 show the low-cost sensor.

We used the device in the same setting as the CAAQMS for the study, and we observed and collected data from both instruments simultaneously and independently. Following a 10- to 15-minute period of placement in the environment, the device was used, and readings were then collected. Morning, afternoon, and evening observations were made in order to assess the instrument's accuracy in various environments. Same process was carried out for a duration of 31 days.

The instrument has a special alarm mechanism that activates when it is in areas with high and moderate levels of pollution and goes off when it is in a good environment, making it easy to observe the data. Histograms and bar graphs accurately depict how each pollutant has changed over the last 24 hours. It has the ability to export data via USB connection, which may be imported into a PC as historical data or a CSV report. Since there hasn't been much study on this device, we sought to examine its accuracy using CAAQMS because low-cost sensors can be the norm for short-term studies in the future.

Fig 6. Low-cost sensor

3.3.1.3. CAAQMS (continuous ambient air quality monitoring station)

High-end IoT technology is used by continuous ambient air quality monitoring stations (CAAQMS) for automatic data collection, transport, and analysis at the central server. Real-time data transfer to the network is done at customizable intervals of 2 to 30 minutes. The data is automatically processed with cutting-edge AI at the hub, then preserved or utilised appropriately. With a variety of analyzers and operating systems, the CAAQMS monitors pollutants, minimising the possibility of human error while producing data quickly and transmitting it. The public can access the generated data online via a digital display board, Fig. 7 shows the display of air pollution data. The Uttarakhand State Pollution Control Board and Doon University Dehradun established, and operationalized Uttarakhand's CAAQMS in

Dehradun. It is located in Doon University Mothrowala Dehradun. Fig. 8 show the CAAQMS installed.

Similar to how low-quality sensor data was collected, CAAQMS data was also obtained.. Readings were taken after the CAAQMS had been observed for 10 to 15 minutes. Both low cost and CAAQMS data were collected simultaneously.

Fig 7. Display board of air pollution data, Dehradun city
Source (http://surl.li/ctrbp)

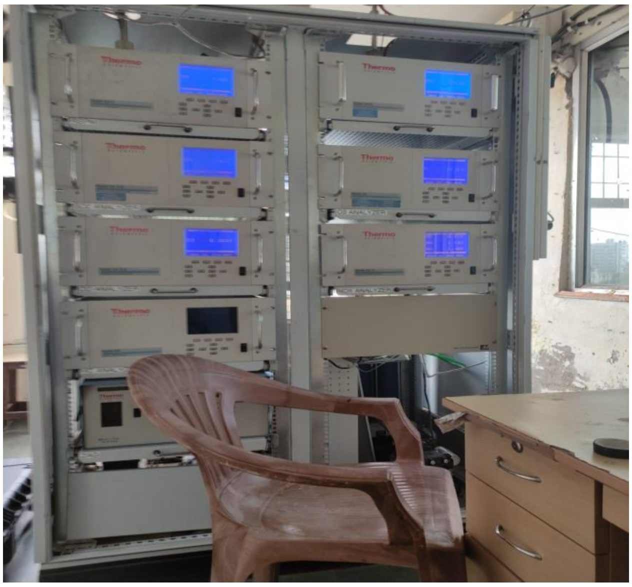


Fig 8. Data Display of CAAQMS

3.3.1.4. NCAP (National Clean Air Programme)

The Union Ministry of Environment, Forests, and Climate Change introduced the National Clean Air Programme in 2019. The programme is an effort to reduce pollution, and one of its main objectives is to cut the amount of coarse and fine particulate matter in the atmosphere by at least 20% by the year 2024. 102 cities from 23 UTs and states have been selected for this programme. Dehradun is one of the non-attainment cities in Uttarakhand, where three manual air monitoring stations have been set up by the government i.e., ISBT, Clock Tower and, Raipur. The Uttarakhand Pollution Control Board website has these stations' data readily available, which was later utilised in the study (https://ncaputtarakhand.in/)

3.4. Application and software used;

3.4.1. Kobo collect

For data collection Kobo collect was used, A useful platform for data collection is offered by Kobo Toolbox, which works well with both your laptop and your mobile devices, such as smartphones and tablets. This app is designed to gather data and input it into your Kobo Toolbox account. It is a free application. Because Kobo Collect is mobile and the forms may be utilized offline, we used an android version for our study.

The geolocation of the subject can be easily determined using the data, making it easier to use.. Kobo application have special features like tables, multiple option preference, date and time option, audio and video recording etc. Total of 400 survey was collected and observed using kobo collect.

3.4.2. Analysis

Microsoft Excel was utilized for the data analysis. For Android, Windows, iOS, and, macOS Microsoft built the spreadsheet programme called Microsoft Excel. Additionally, it supports pivot tables, the Visual Basic for Applications macro programming language (VBA), graphing tools, and computing or computing capabilities. In our, study excel was used for data cleaning, analysis, and graphical representation of the data.

Chapter 4

4.1. Result

4.1.1. General characteristic of occupational categories

To study and assess public opinion about the level of ambient air pollution in the city of Dehradun, a survey was created. The four occupational groups were selected based on their regular activity and exposure rates. Labour, driver, and vendor exposure to the consequences of air pollution is highest for those who spend the majority of their workdays outdoors. Office workers, on the other hand, spend the majority of their time indoors and only venture outside for commute. The study was conducted with the understanding that various occupational groups may experience air pollution differently depending on the total time spent working outdoors and the location of the work.

4.1.2. Impact of air pollution

Study looked at how individuals generally felt about air pollution by analysing how it affected them. It was discovered that a significant population is affected by air pollution on a daily basis. Out of 400 questionnaires, 207 people mentioned feeling the effects of air pollution, whereas 192 people noticed no such effects. It indicates that a bigger percentage of individuals believe that air pollution is a hindrance to the daily lives of normal people, Table.3 represent the data of respondent. Of the four groups, labourers and vendors are the ones that are most affected by the air pollution because they operate in a dangerous atmosphere and are constantly exposed to dust and dirt particles. The office worker is next, and roughly half of the respondents believe that air pollution has an impact on them. Finally, less than half percentage of drivers believe that air pollution is having an effect on them.

Table 3. Data of different respondent based on occupation

Occupation	**Sum of Experienced impacts of air pollution?**
Driver	44
Labour	55
Office	53
Vendor	55
Grand Total	**207**

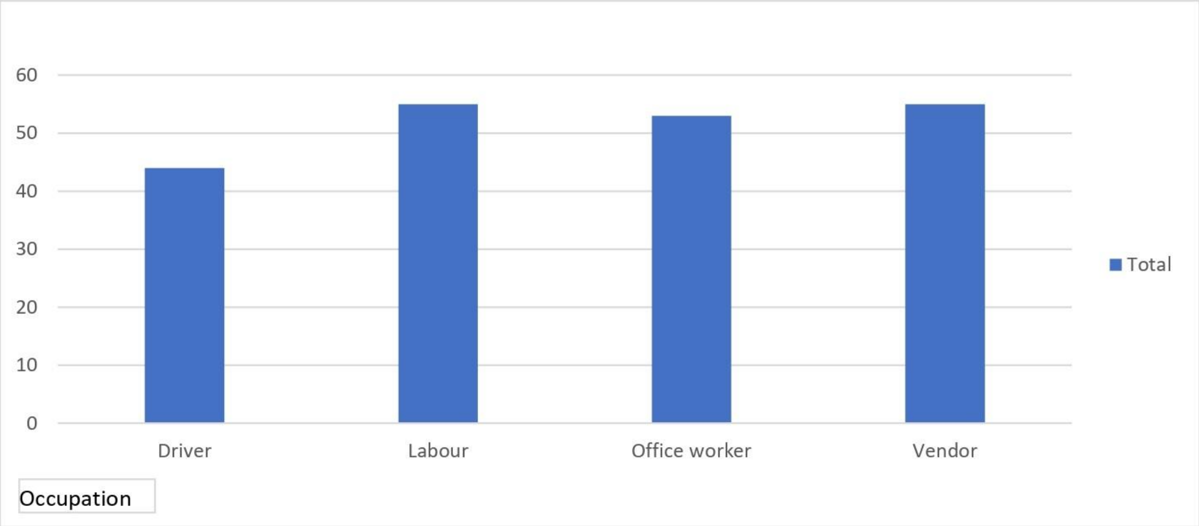


Fig 9. Impacted by air pollution

4.1.3. Mental Health

Air pollution has a significant influence on a person's mental health in addition to the environment and physical health. With this study, we sought to understand how air pollution affects the general public's mental health. To comprehend the effects, four categories—Anxiety, anger, tension at home, verbal altercations and spats, physical altercations —were separated. These factors give a rudimentary notion of how the general population is affected by or may be affected by air pollution. The fig. 10 makes it very evident that people's primary concern is anger, and each occupational category identifies anger as a problem that is affecting them as a result of rising air pollution. Drivers, vendors, and labourers are also shown to experience anger more frequently than office workers, but office workers are those that experience anxiety the most. Table.4 shows several fields of categories and how those fields are affecting people.

Table 4. Data for behaviour change due to air pollution

Occupation	Anxiety	Anger	Tension at home	Verbal altercations and spats	Physical altercations
Driver	24	44	9	18	1
Labour	22	51	6	18	1
Office worker	22	44	2	6	1
Vendor	29	46	10	13	3
Grand Total	**97**	**185**	**27**	**55**	**6**

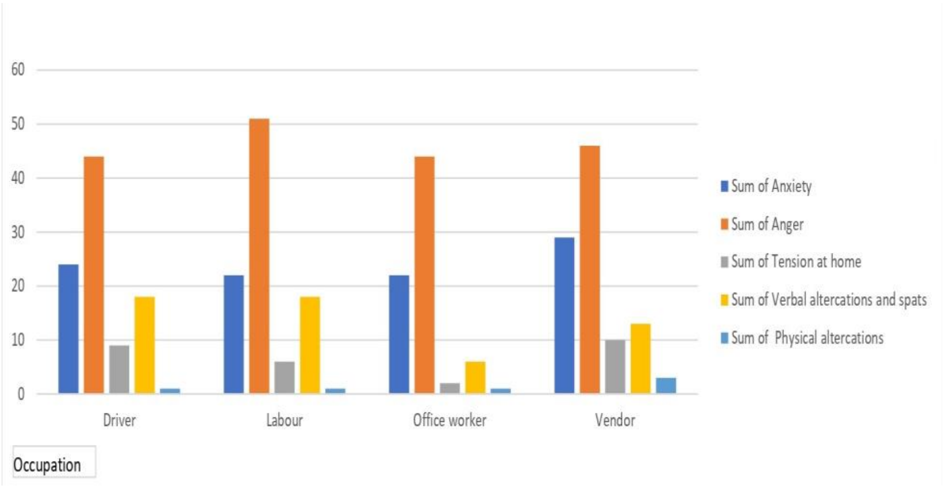


Fig 10. Behavioural change with respect to occupational group

4.1.4. Migrant based on occupational group

When the basic structure of the population of Dehradun city was determined using occupational migrant data, it was discovered that almost half of the population, or 194 out of 400 persons, were migrants who arrived to Dehradun from other cities and states. Distribution was carried out at the state level. It was discovered that the majority of people who moved to Dehradun were from the neighbouring state of Uttar Pradesh. A significant number of individuals moved from various regions of Uttarakhand. Bihar has a considerable number of migrants as well.

Most of the migrants from Uttar Pradesh came into the labour and driver categories. Whereas in Uttarakhand, the majority of the migrants were office workers who followed vendors. People migrate to Dehradun in search of work. This might be explained by the fact that this city has developed into a significant economic, educational, and cultural hub in north India since it became the capital of the recently created Uttarakhand state in the year 2000. (Singh et al., 2013). Dehradun is also a well-known tourist destination among the general public in addition to being a commerce centre with rapid expansion. Thus, as the business and tourism sectors expand, the service sector's expansion likewise quickens, aggravating population increase. (Tiwari et al. 2017).

Table 5. Migrant based on different occupational group

Occupation	UP	Bihar	Uttarakhand	MP	Delhi	Punjab	Maharashtra	Haryana	Jharkhand	Chandigarh
Driver	25	3	9	1	0	0	0	0	1	0
Labour	22	12	11	1	2	3	0	0	1	1
Office worker	11	3	25	3	2	1	2	1	1	0
Vendor	15	9	23	0	3	0	0	0	0	0
Grand Total	**73**	**27**	**68**	**5**	**7**	**4**	**2**	**1**	**3**	**1**

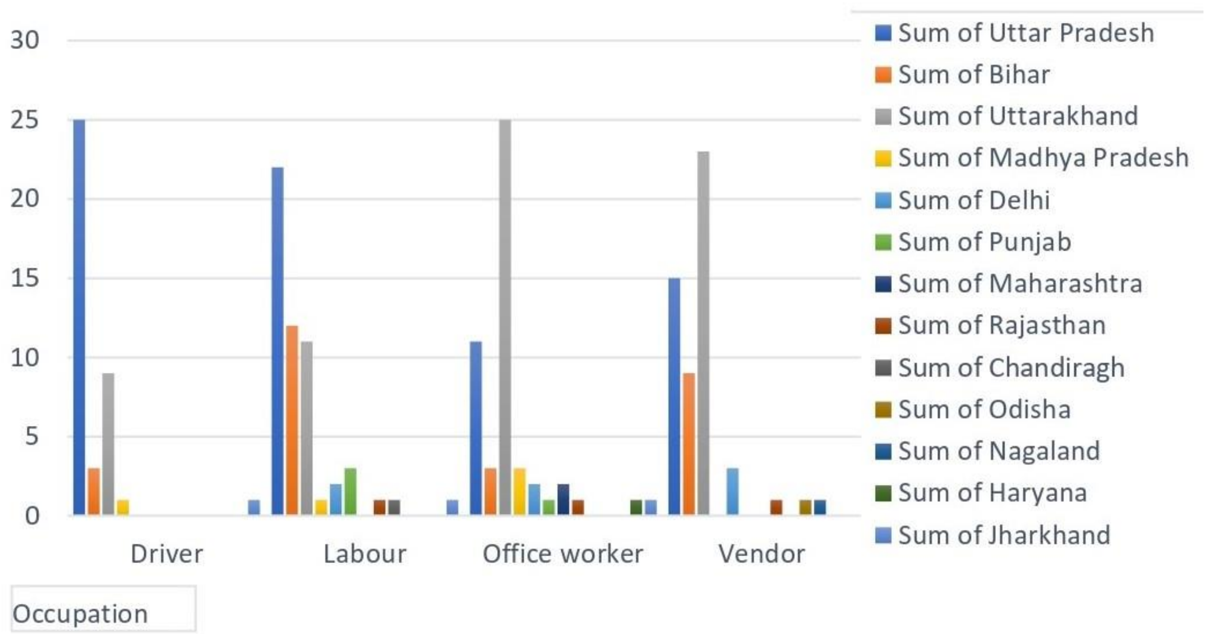


Fig 11. Migrant based on different occupational group (state wise)

4.1.5. Air quality of the city

Analysis was done on the opinions of various occupational groups depending on the state from which they had relocated, Dehradun had varying levels of air pollution. here were five levels of air quality: Poor, Fair, Good, Very Good, and Excellent. The majority of the people in Uttar Pradesh believes that the pollution condition in Dehradun is fair and good, if we look at perceptions based on state. However, if we look to Uttarakhand, we see that most people do not think the pollution here is all that good.

When seen occupation wise drivers from Uttarakhand consider air quality to be poor. Labours however think that the air quality is fair in the city. Vendor consider the quality of air to be somewhat fine. If we compare the response of People from Uttarakhand and Uttar Pradesh we can clearly see the difference, people from Uttar Pradesh feel more confident about the quality of air in Dehradun city. Fig. 12 represents the perception about air quality of Dehradun city. The level of categories fair, and, good is much higher than the poor.

Fig 12. Air quality of Dehradun city

4.1.6. Air quality during the day

The different occupational groups were asked about their opinion on times of day that the various occupational groups believed to have the most air pollution. The day was divided into four sections: morning, afternoon, evening, and night. More than half of the population believes that the afternoon is the most polluted period of the day, according to the data in the table. 6

When viewed occupation-wise, it is evident that all four occupational groups—65 labourers and drivers, 58 market sellers, and 51 office workers—considered the afternoon to be the most hazardous period in terms of pollution. The information on air quality throughout the morning, noon, evening, and night is displayed in Fig. 13 There were small number of people which considered morning and evening time to be most polluted time of day, whereas according to some research, traffic throughout the morning and evening rush hours had two PM peaks. (Bathmanabhan et al. 2010). People's perceptions may differ from the facts.

Table 6. Time the city is most polluted

Occupation	Morning	Afternoon	Evening	Night
Driver	26	65	36	5
Labour	26	65	32	2
Officeworker	19	51	53	3
Vendor	12	58	34	3
Grand Total	**83**	**239**	**155**	**13**

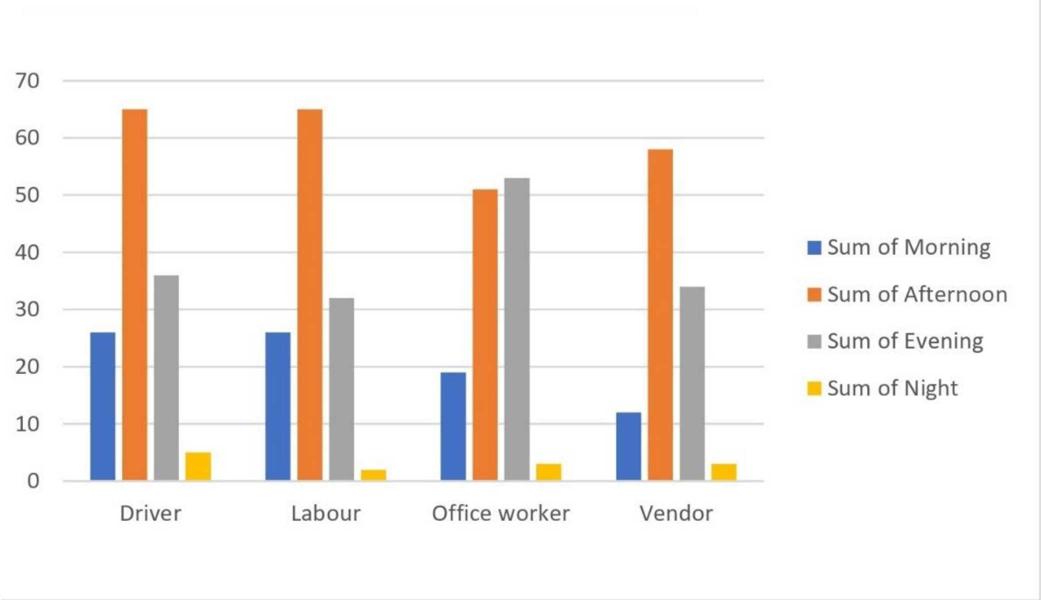


Fig 13. Representation of time period of air pollution throughout the day

4.1.7. Monthly variation

In Dehradun, the changes in pollutant concentrations on a monthly average were studied. It is evident from Fig. 14 that the majority of the populace believes that May is the month with the worst air quality. All four occupational categories agree that May is the month with the highest air pollution. Monthly averages clearly demonstrate that the number of days with favourable air quality was highest in December (~65%) (Gupta et al. 2008). Beginning in January, there are fewer days with good air quality on average each month until August, when there are just 23% of days with high air quality. From September, the state of the air quality improves once more until December (Gupta et al. 2008).

Table. 7 indicates that the most of people believe that when it comes to air quality, February, September, October, and November are the best months., while the minority believe that November and December are the months with poor air quality. The four months with poor air quality are thought by most people to be March, April, May, and June.

Table 7. Data for month with poor air quality

Occupation	January	February	March	April	May	June	July	August	September	October	November	December
Driver	4	2	28	55	86	75	4	5	**3**	**3**	5	4
Labour	2	1	24	53	85	77	13	2	**1**	**3**	6	3
Office worker	10	3	30	51	73	57	9	4	**2**	**11**	16	13
Vendor	3	0	37	65	87	64	12	4	**1**	**1**	1	4
Grand Total	**19**	**6**	**119**	**224**	**331**	**273**	**58**	**15**	**7**	**18**	**28**	**24**

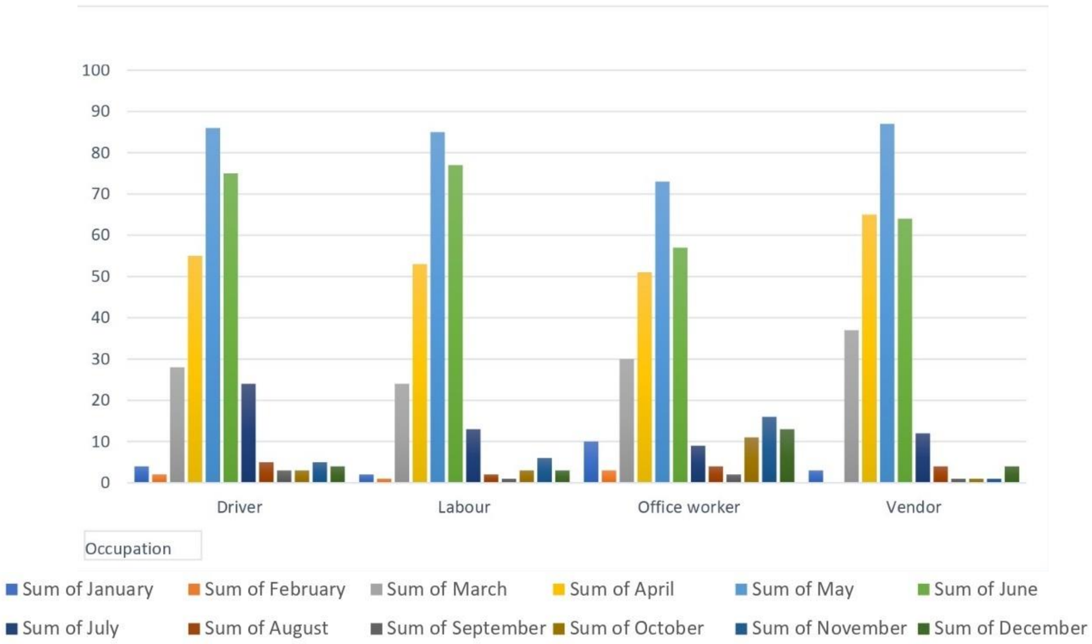


Fig 14. Represent variation of opinion about air pollution on monthly basis

4.1.8. Source of Pollutant

The causes of air pollution in the city of Dehradun were broken down into six categories: Vehicular emission, Industrial emission, Road and construction dust, Garbage burning, Open sewage, and, Household air pollution. The chart makes it abundantly evident that people believe that vehicle emissions, as well as road and construction dust, are the major sources of pollution in the city of Dehradun. The two sources of pollution that are thought to have the least impact on Dehradun's environment are household and industrial. Fig. 15 depicts the various air pollution sources as seen by various occupational groups. In addition to the impact of local emissions, air pollutants can be transferred to the foothills of the Himalayas from sources in distant places (Solanki et al. 2013; Sarangi et al. 2014; Srivastava et al. 2014; Ojha et al. 2017).

Table 8. Sources of air pollution

Occupation	Vehicular emission	Industrial emission	Road and construction dust	Garbage burning	Open sewage	Household air pollution
Driver	96	14	65	55	9	9
Labour	95	12	55	37	25	5
Office worker	94	17	65	35	17	3
Vendor	95	4	59	30	16	1
Grand Total	**380**	**47**	**244**	**157**	**67**	**18**

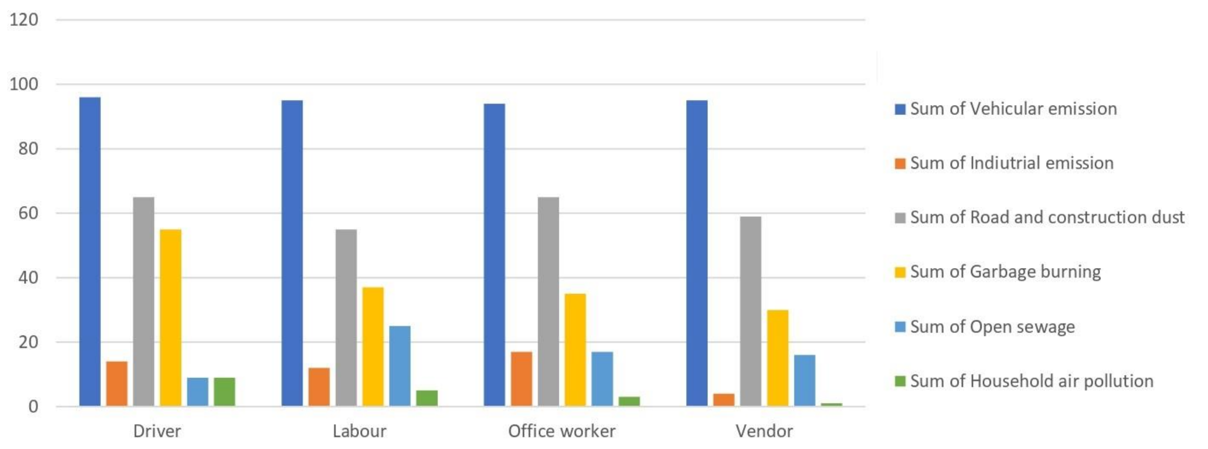


Fig 15. Sources of air pollution with perception of different occupational group

4.2. Seasonal variation

In the city of Dehradun, seasonal variations in air pollution were taken into consideration. In accordance with the National Clean Air Program (NCAP), the data from the perception was then compared to the data provided by the Uttarakhand Pollution Control Board. The data is readily obtainable on the Uttarakhand Pollution Control Board's website (https://bit.ly/3AhDAS1). The NCAP data was collected during the years of 2012 and 2021. The city has three manually operated air quality monitoring stations: Clement Town, ISBT, and Raipur. The seasonal variance was calculated using data from these three sites.

Dehradun, the concentration of SO2 and NO2 is always under the Indian air quality standard (Chauhan et al. n.d.). But the concentration of PM10 and SPM exceeds the Indian air quality guideline in this area (Joshi et al. 2005; Joshi et al. 2008; Chauhan et al. 2008; Chauhan et al. 2010; Chauhan. 2010). In order to safeguard the environment and public health from air pollution, the government announced National Ambient Air Quality Standards (NAAQS) for 12 pollutants in 2009. The NAAQS standard for India is shown in the table. 9

4.2.1. Survey data of seasonal variation

In order to study the seasonal variations of the pollutants, people were asked about season of month when the air pollution is particularly bad. The metrological parameters were divided into winter, rainy, and, summer. It is clearly seen in the fig.16 that most of the population feel like summer is the time when air pollution is maximum in the city. If we look into the data on the basis of occupation- Drivers have the opinion that summer is the time of year when pollution is bad and winter is the best time if we think about air pollution, labours, and, vendors have the same opinion as of the driver about the seasonal variation of air pollution, where as there is some variation in opinion of Office worker, they don't consider winter to be the season with best air condition.

Most of the people relate air pollution to heat and temperature and feel summers are the worst when considered in air pollution. Although the average temperature is still between 35 and 36 degrees Celsius, the summertime temperature can reach up to 41 degrees. When the highest daytime temperature exceeds the usual by 4-6 ◦C, there are often 1-2 days of heat waves (Deep et al. 2019). Even while most days in the winter are not extremely cold, the temperatures can drop to 1-2 degrees Celsius for a few days when the cold winds from the adjacent Himalayan mountains make the winters severe. Mist and fog, especially during the evenings and early mornings, are other characteristics of Dehradun's winters. (Deep et al. 2019).

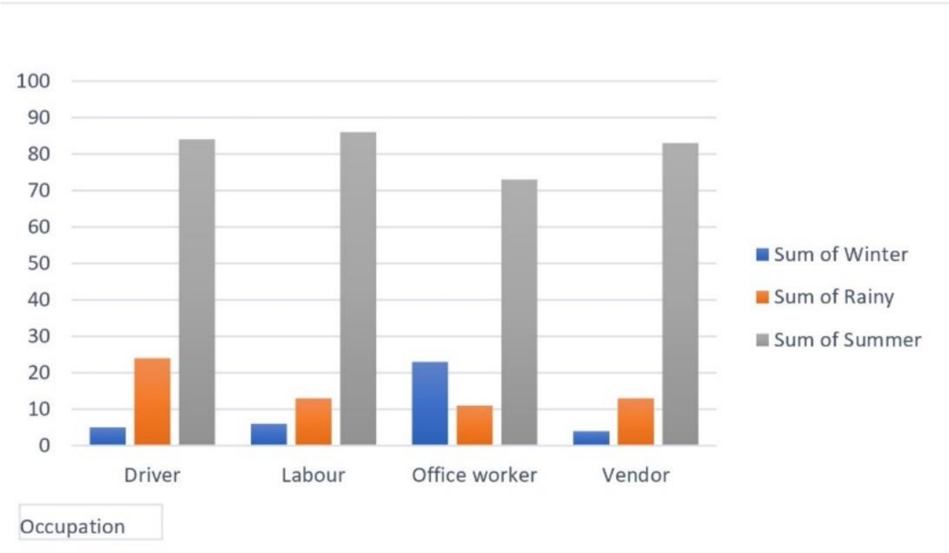


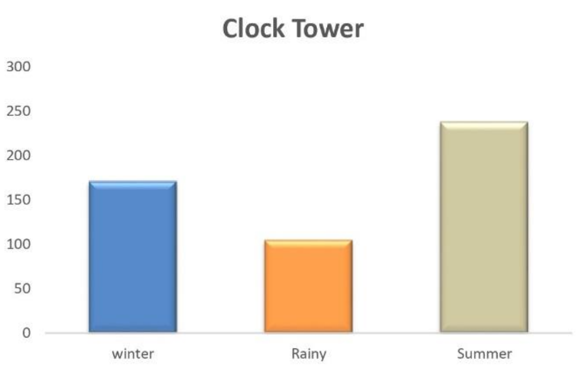
Fig 16. Seasonal variation (perception based)

4.2.2. NCAP Data

Data for years 2012- 2021 were taken for this study. Three manual air monitoring station are present in Dehradun city i.e., ISBT, Clock Tower, and Raipur, data from all the station was used for the city so that we can actually picture the status of air pollution throughout the city. The data was divided into winter, rain, and, summer. As particulate matter is considered as on of the critical pollutant in Dehradun, therefore we took particulate matter are the pollutant for our study. Dehradun, an urban region in northern India, was named as the 31st most polluted city in the world in terms of PM pollution in a study published by the World Health Organization (WHO 2016).

4.2.2.1. Seasonal variation 2012

Clock Tower, ISBT, Raipur show same trend of pollution in the year 2012. The concentration of pollutant is most in the summer season with average of 238.36, 204.43, and, 213.2 in Clock Tower, Raipur, and ISBT respectively. Whereas in winter the average was 171.32, 171.2, 194.33.



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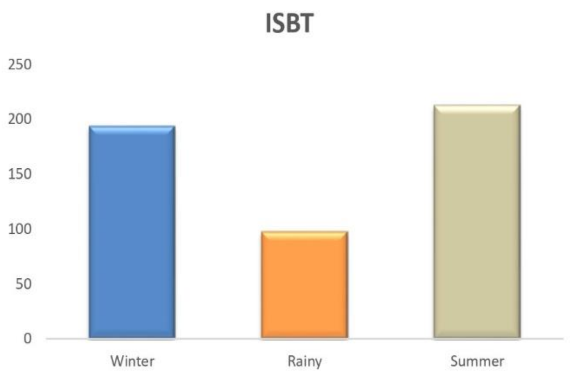

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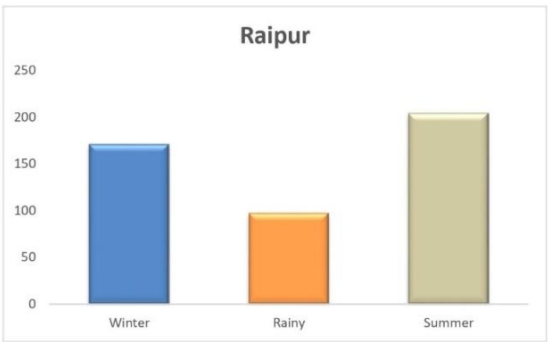
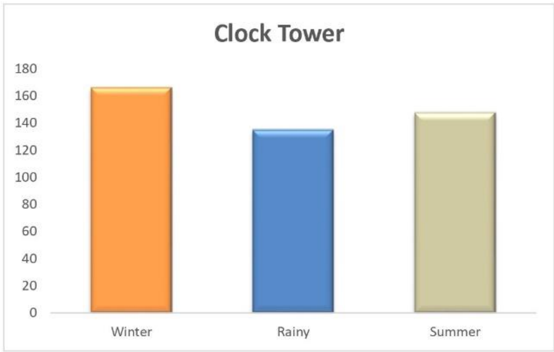


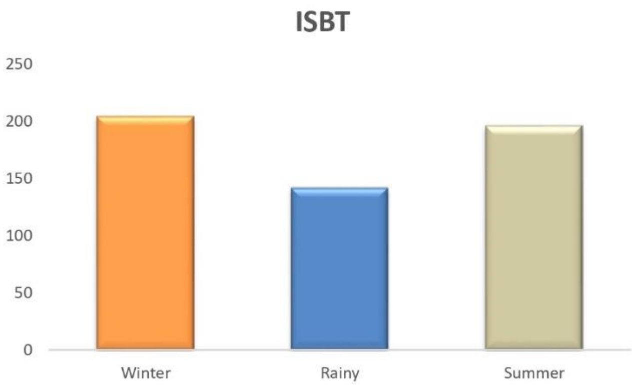
(c)

Fig 17. seasonal variation- 2012 (a) Clock Tower, (b) ISBT, and, (c) Raipur

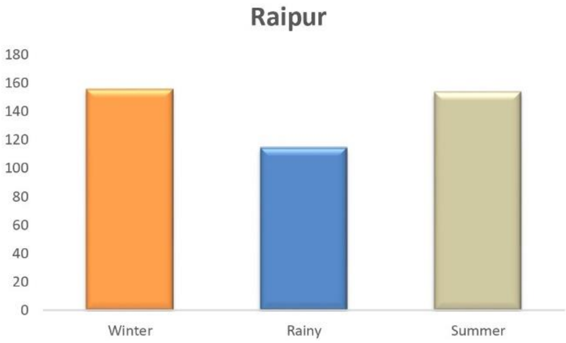
4.2.2.2. Seasonal variation 2014

Clock Tower, ISBT, and, Raipur showed same trend of air pollution. Winter had the highest average concentration of pollutant in all the stations. Average concentration in winter was 166.55, 156, 204.93 for Clock Tower, Raipur, and ISBT respectively and for summer 147.94, 154.2, 196.7. From the data it is clearly seen that the difference between the average concentration of winter and summer was not that big.





(a) (b)

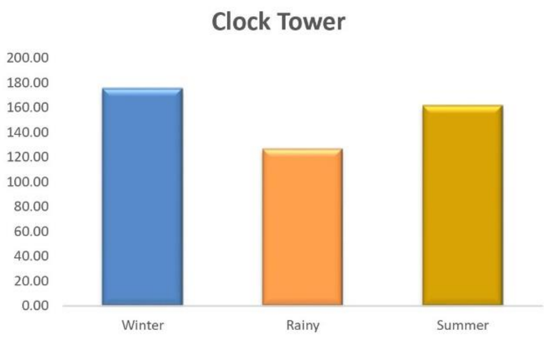


(c)

Fig 18. seasonal variation- 2014 (a) Clock Tower, (b) ISBT, and, (c) Raipur

4.2.2.3. Seasonal variation 2015

Clock Tower, ISBT, Raipur all three station showed the same pollution data. The average concentration of pollutant during winter was 175.88, 173.43, 254.47 Clock Tower, Raipur, and ISBT respectively and in summer the average was 162, 147.41, 237.77



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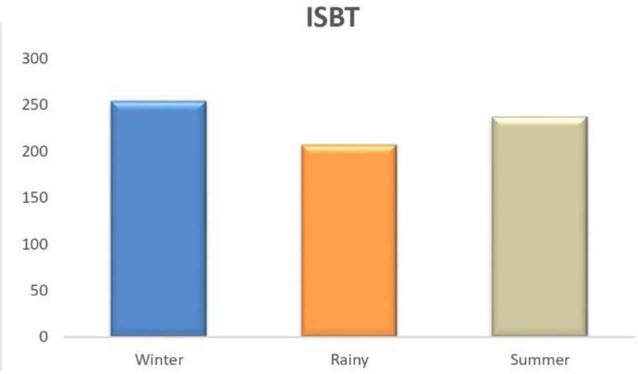

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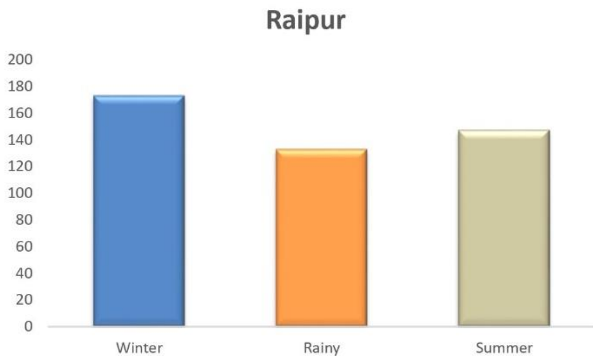


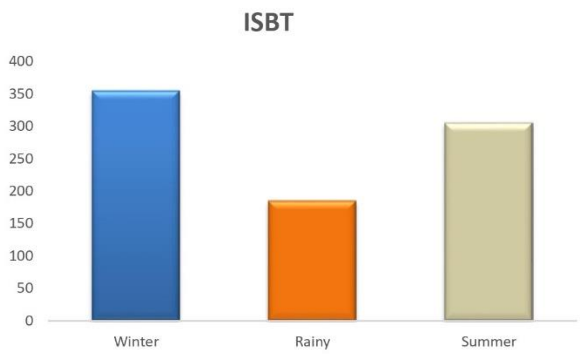
(c)

Fig 19. seasonal variation- 2015 (a) Clock Tower, (b) ISBT, and, (c) Raipur

4.2.2.4. Seasonal variation 2016

Clock Tower, ISBT, had the same trend of seasonal variation, both the station showed that winter had the maximum average concentration of pollutant than the summer. The average concentration of pollutant in different station in summer was 176.67, 349, 305.8 Clock Tower, Raipur, and ISBT respectively and in winter Clock Tower had 195.67, Raipur was 203.8, ISBT was 355.51.

(a)



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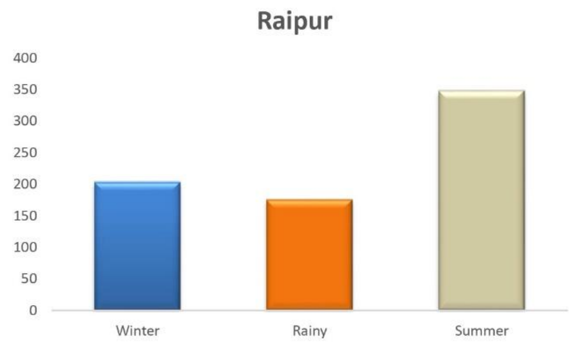

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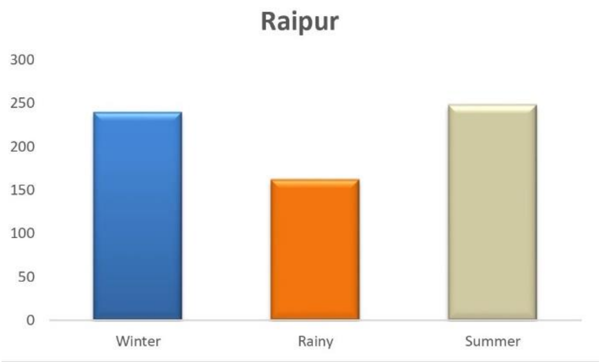
Fig 20. seasonal variation- 2016 (a) Clock Tower, (b) ISBT, and, (c) Raipur

4.2.2.5. Seasonal variation 2017

With average concentration 232.55, 248.79 in summer and average concentration 181.35 240.35 in winter Clock Tower, Raipur respectively showed higher average in summer than winter. ISBT had different trend it showed higher average concentration in winter, but the difference in the concentration of pollutants was not that big i.e., 342.57, 317.15 winter, summer respectively.

(a)

(b)



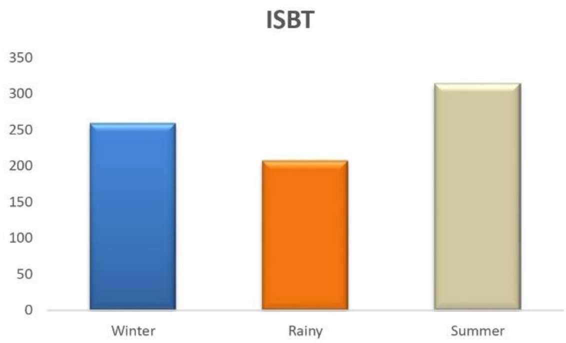
(c)

Fig 21. seasonal variation- 2017 (a) Clock Tower, (b) ISBT, and, (c) Raipur

4.2.2.6. Seasonal variation 2018

Summer had an average concentration 219.74 193.49 314.58 in Clock Tower, Raipur, and ISBT station respectively. Whereas in winter the average concentration was 172.06 Clock Tower,168.21, Raipur, 259.25 ISBT. It is very clear from the data that in year 2018 the concentration of pollutant was higher during the summer time.

(a)



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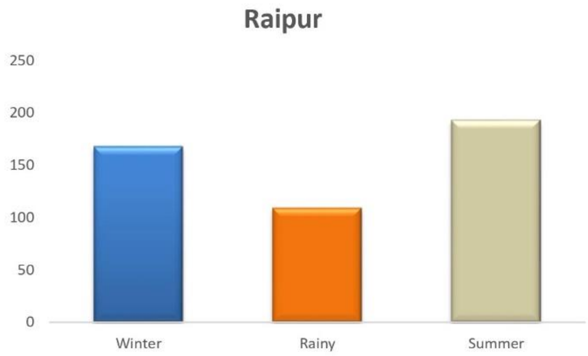


(c)

Fig 22. seasonal variation- 2018 (a) Clock Tower, (b) ISBT, and, (c) Raipur

4.2.2.7. Seasonal variation 2019

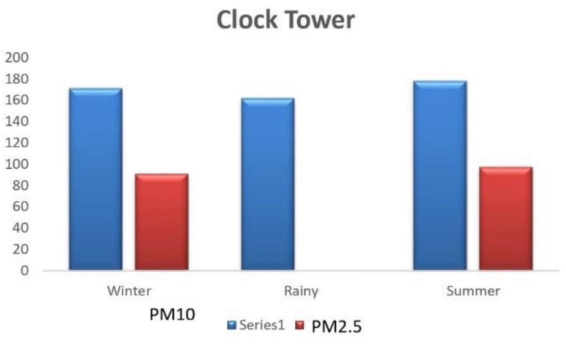
From 2019 PM2.5 was also installed in all the three monitoring stations. Both the pollutant PM10 and PM2.5 were higher in concentration during the summer in all the three station except in Raipur PM2.5 had higher average concentration during winter.

Table 10. Average Concentration during Winter (2019)

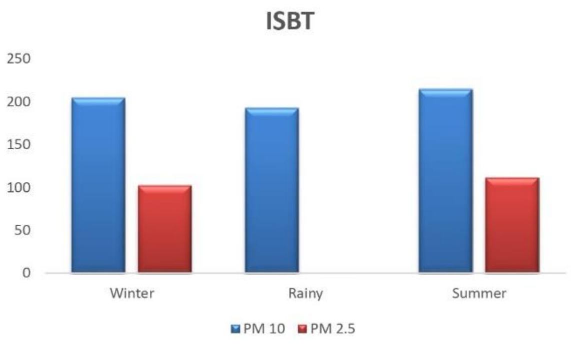
Stations	PM10	PM2.5
Clock Tower	171.39	91.17
Raipur	122.94	76
ISBT	204.89	102.67

Table 11. Average concentration during summer (2019)

Stations	PM10	PM2.5
Clock Tower	178.22	97.39
Raipur	127.89	68.73
ISBT	214.79	111.76



(a)



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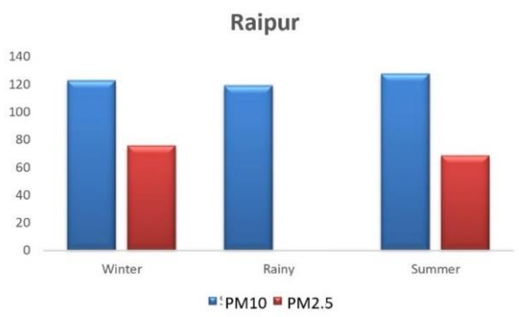


(c)

Fig 23. seasonal variation- 2019 (a) Clock Tower, (b) ISBT, and, (c) Raipur

4.2.2.8. Seasonal variation 2020

In the year 2020 both the pollutant PM10, PM2.5 showed similar average concentration in all the three stations. Table.12 and 13 shows that the average concentration was higher during the winter period. PM10 had average concentrations 176.12, 146.27, 186.59 in Clock Tower, Raipur, ISBT respectively. PM2.5 had 92.74 in Clock Tower, 84.22 Raipur, and, in 101.94 ISBT.

Table 12. Average Concentration during Winter (2020)

Stations	PM10	PM2.5
Clock Tower	176.12	92.74
Raipur	146.27	84.22
ISBT	186.59	101.94

Table 13. Average Concentration during summer (2020)

Stations	PM10	PM2.5
Clock Tower	123.26	47.62
Raipur	98.4	54.05
ISBT	125.75	71.75

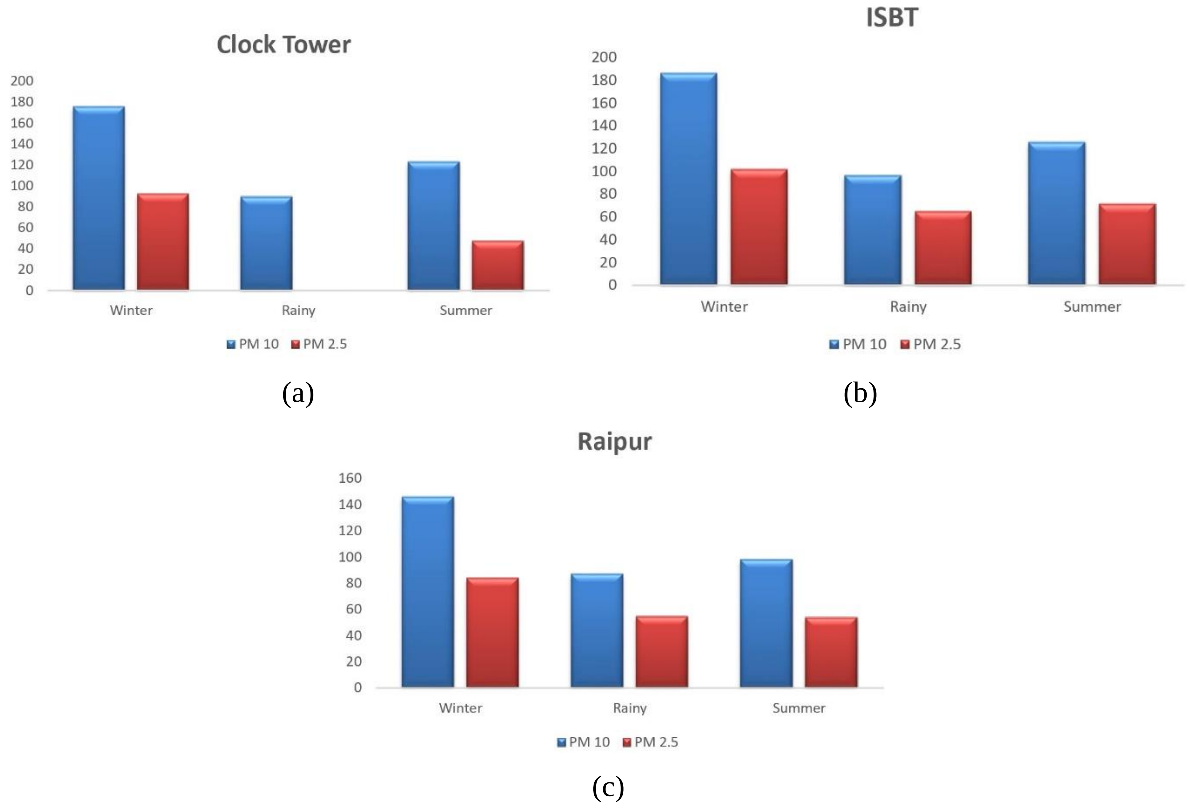


Fig 24. seasonal variation- 2020 (a) Clock Tower, (b) ISBT, and, (c) Raipur

4.2.2.9. Seasonal variation 2021

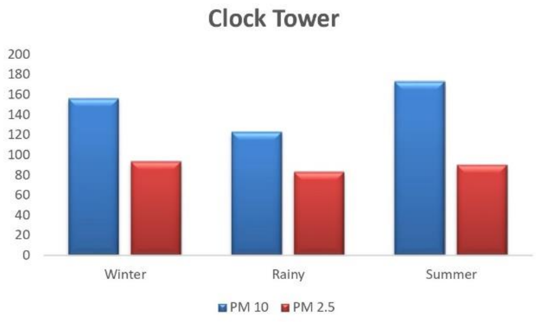
In the year 2020 both the pollutant PM10, PM2.5 showed similar average concentration in all the three stations Clock Tower, Raipur, and ISBT. The average concentration of both the pollutant were higher in the winter.

Table 14. Average Concentration during Winter (2021)

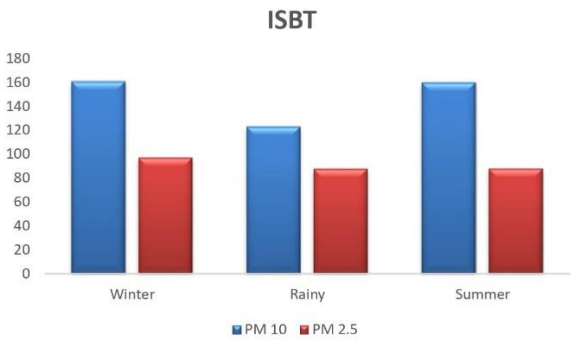
Stations	PM10	PM2.5
Clock Tower	156.26	93.47
Raipur	146.72	86.06
ISBT	161.09	97.28

Table 15. Average Concentration during summer (2021)

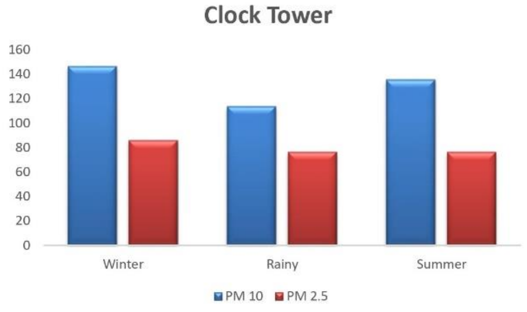
Stations	PM10	PM2.5
Clock Tower	173.24	90.15
Raipur	135.68	76.57
ISBT	160.15	88.12



(a)



(b)



(c)

Fig 25. seasonal variation- 2021 (a) Clock Tower, (b) ISBT, and, (c) Raipur

Table 9. Indian National Ambient Air Quality Standards (NAAQS)

			Concentration	
S. No.	Pollutant	Time-weighted average	Industrial Areas, Residential, Rural & other Area	Ecological Sensitive Area
1	Sulphur Dioxide (SO_2)	Annual Average	50 µg/ m^3	20 µg/ m^3
		24 hours	80 µg/ m^3	80 µg/ m^3
2	Oxides of Nitrogen as(NO_2)	Annual Average	40 µg/ m^3	30 µg/ m^3
		24 hours	80 µg/ m^3	80 µg/ m^3
3	Suspended PM	Annual Average	60 µg/ m^3	60 µg/ m^3
		24 hours	100 µg/ m^3	100 µg/ m^3
4	Respirable Suspended PM	Annual Average	40 µg/ m^3	40 µg/ m^3
		24 hours	60 µg/ m^3	60 µg/ m^3
5	Ozone (O_3)	8 hours	100 µg/ m^3	100 µg/ m^3
		1 hours	180 µg/ m^3	180 µg/ m^3
6	Lead	Annual Average	0.5 µg/ m^3	0.5 µg/ m^3
		24 hours	1.0 µg/ m^3	1.0 µg/ m^3
7	(CO)	8 hours	2 mg/ m^3	2 mg/ m^3
		1 hours	4 mg/ m^3	4 mg/ m^3
8	Ammonia	Annual Average	100 µg/ m^3	100 µg/ m^3
		24 hours	400 µg/ m^3	400 µg/ m^3
9	Benzene (C_6H_6)	Annual Average	5 µg/ m^3	5 µg/ m^3
10	Benzo (a) Pyrene (BaP)- particulatephase only	Annual Average	1 ng/ m^3	1 ng/ m^3
11	Arsenic	Annual Average	6 ng/ m^3	6 ng/ m^3
12	Nickel	Annual Average	20 ng/ m^3	20 ng/ m^3

4.3. Accuracy of low-cost sensor

With the help of CAAQMS, which has been set up at Doon University in Dehradun, the accuracy of low-cost sensors was evaluated. For one month, the study was conducted. Temptop M2000, a low-cost sensor, was used to monitor the pollutants PM10 and PM2.5. To determine the instrument's accuracy, correlation and regression analyses were used. A R2 value near 0 represents a complete absence of connection, whereas an R2 value approaching 1 demonstrates a close to perfect agreement. In CAAQMS and M2000 Fig. 26, PM10 exhibits strong resemblance. The values of both instruments differed by -+ 10 points. Fig. 27: The Temtop M2000 sensors and accompanying CAAQMS PM10 data displayed extremely good correlations (R^2> 0.76).

While the difference between the readings of the CAAQMS and M2000 for PM2.5 in Figure 2 is readily visible. The established correlation betwixt the PM2.5 data found and the CAAQMS in the Fig 29 is about R>0.66 and R^2 >0.44.

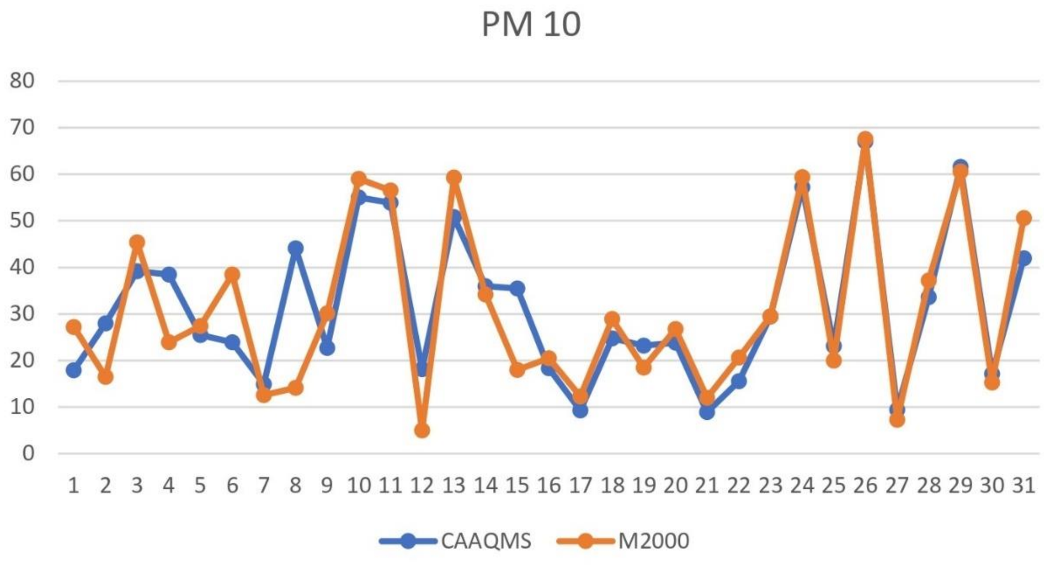


Fig 26. Data of CAQMS and M2000 for PM10

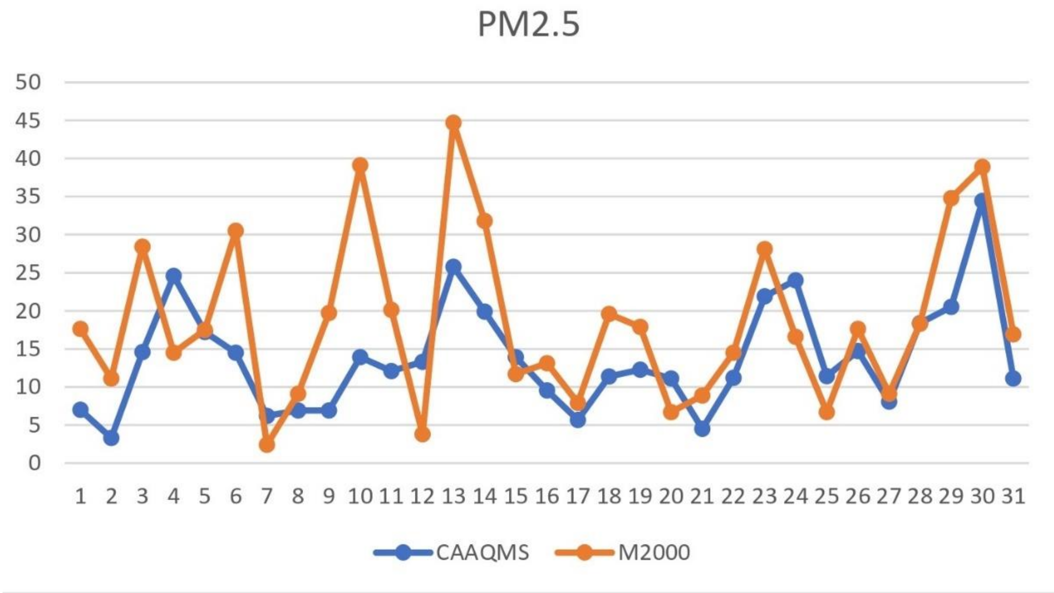


Fig 27. Data of CAQMS and M2000 for PM2.5

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.872473
R Square	0.761209
Adjusted R Square	0.752681
Standard Error	9.112186
Observations	30

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	7411.214	7411.214	89.25738	3.32E-10
Residual	28	2324.894	83.03194		
Total	29	9736.108			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.20068	3.690303	-0.05438	0.957018	-7.75992	7.358563	-7.75992	7.358563
17.9	0.982138	0.103956	9.447613	3.32E-10	0.769193	1.195083	0.769193	1.195083

Fig 28. PM10 Regression Data

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.666344
R Square	0.444014
Adjusted R Square	0.424158
Standard Error	8.470376
Observations	30

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1604.341	1604.341	22.361	5.82E-05
Residual	28	2008.924	71.74727		
Total	29	3613.264			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	3.954333	3.474533	1.13809	0.264728	-3.16293	11.07159	-3.16293	11.07159
7	1.042785	0.220521	4.728742	5.82E-05	0.591069	1.494501	0.591069	1.494501

Fig 29. PM2.5 Regression Data

4.4. Discussion

The study's findings indicate that a notable number of people are affected by air pollution. It was discovered that more than half of the population had experienced mental or physical effects as a outcome of air pollution table 3. A sizable population has experienced mental health problems including anxiety and anger. Labours, drivers, and vendors have higher levels of mental strain because to their continual exposure to the outside environment. Population growth in Dehradun is problematic. after becoming Uttarakhand's capital. The majority of migrants in Dehradun come from Uttar Pradesh, a neighbouring state, as well as from other cities and villages in Uttarakhand. The majority of the labourers and drivers in Dehradun come from Uttar Pradesh. People from Uttar Pradesh believe that the air in Dehradun is good, however people from Uttarakhand do not share this opinion. In recent years, Dehradun's air quality has gotten worse. People's perceptions about the condition of the city's air pollution source were very accurate. They believe that the major contributor of city air pollution is vehicle emissions, road dust, and construction dust. Approximately (72%) of Delhi City's total air pollution load is caused by vehicular emissions, with industrial (19%) and household (9%) sources following closely behind(CPCB, 2001), about one fourth of the respondent felt that garbage burning is also a major problem with regards to air pollution. The observed variances are also influenced by changes in both the emissions and other meteorological conditions (Ojha et al. 2012, Dumka et al. 2017, Tiwari et al. 2017). It was discovered that a considerable number of individuals, including drivers, vendors, labourers, and office workers, felt the air quality is poor in the afternoon. There was a slight variation in their perception of office employees, according to them the worst air pollution occurs in the evening. All four groups believe that March, April, May, and June are the months with the worst air quality while, in reality, these months are premonsoon and monsoon season, and the PM concentration are actually detected to be higher in January and February. A temperature inversion during the winter, which can last for many days, can stabilise the valley's atmosphere and isolate it from the surrounding air circulations (Ganbat and Baik, 2016).

4.4.1. Validation of low-cost sensor

According to the study's findings, the low-cost sensor significantly resembles the CAAQMS for PM10 with regression ($R2>0.76$), and for PM2.5 ($R2>2.0.44$). In Fig. 30, it is evident that there is little fluctuation in the data points for CAAQMS and M2000. If we look at Fig. 31, the data points for PM10 appear to be quite near to the regression line. When it comes to PM2.5, the data points are dispersed over the regression line and there are few significant differences between the CAAQMS and M2000 data points (see fig. 32). With the data we cannot predict the accuracy of the sensor, there is need of more research to be doneThe sensor could be used to quantify the pollution in the air as it shows variation of -+10 in general.

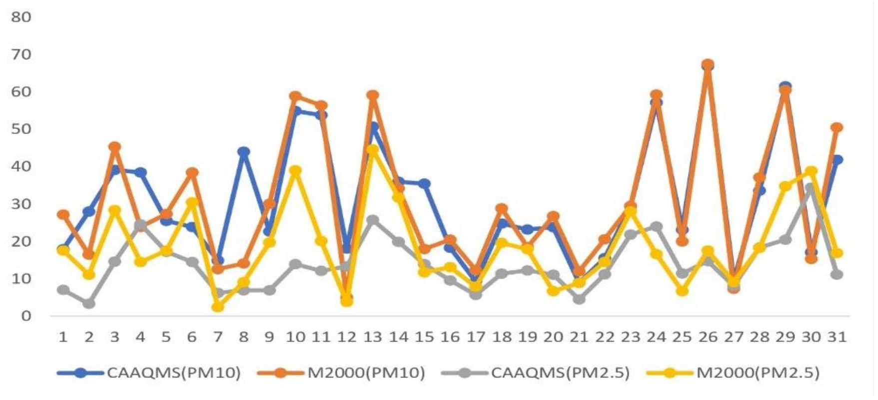


Fig 30. Combined data of CAAQMS and M200 for PM10 AND PM2.5

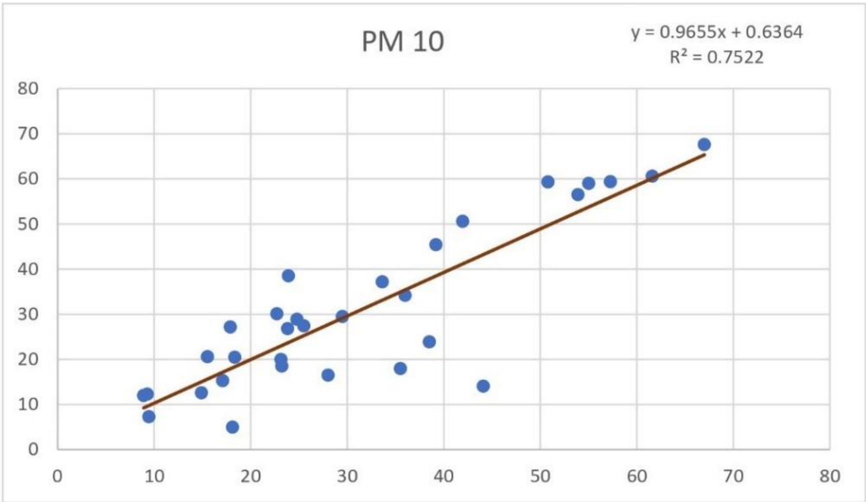


Fig 31. Linear rigression for PM 10 (CAAQMS & M2000)

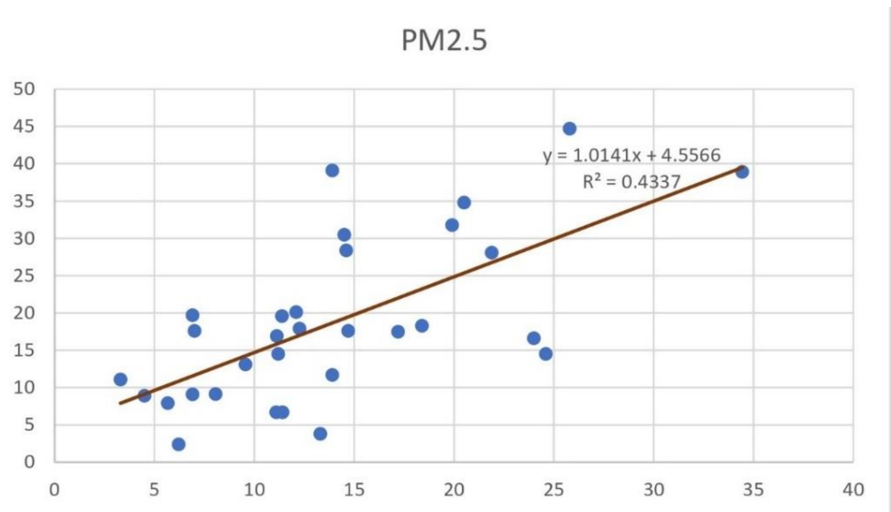


Fig 32. Linear rigression for PM2.5 (CAAQMS & M2000)

4.4.2. Perception and factual data of air pollution

With the study, we looked for discrepancies between actual air pollution variance and how people perceived air pollution. According to the study, the majority of people believe that summer is the worst time for air pollution. All four occupational groups appear to have similar feelings, as can be seen from the data. However, according to air pollution statistical data, NCAP data, air pollution was worst in the winter. With the exception of the years 2012, 2017, and 2018, it was discovered that the winter in years 2014, 2015, 2016, 2020, and 2021 had the highest concentrations of air pollution. The increased mass concentration of $PM_{2.5}$ and PM_{10} during the winter has also been observed in Guwahati based on measurements taken throughout the year (Tiwari et al. (2017). There is a common misconception regarding the seasonality of air pollution. Many people believe that their air pollution is at its highest in the summer, followed by the Rain, and that the winter season is the best. Vendors, drivers, and labourers, three of the occupational groups, feel similarly about seasonality, whereas office workers believe that the summers are the worst, followed by the winters, which are approximately in the middle, and that the monsoon season is best in terms of air pollution.

Chapter 5

5.1. Conclusion

In the present study, we tried to understand how people view air pollution and how it affects their daily lives. We also attempted to relate the perception data to the actual air quality data (NCAP) for three manual monitoring stations (ISBT, Clock Tower, Raipur) in order to determine the discrepancy and similarity between perceived and actual levels of air pollution. For the study we conducted 400 surveys in the Dehradun city for four occupational groups- driver, vendor, office worker, and labour. It was shown that people's perceptions of air pollution differed depending on their occupational group, the region they belong to, and their location of employment. Based on observation of study -

- The majority of individuals believe that air pollution affects their daily lives and causes them to experience mental stress. Occupational groups exposed to outdoor air pollution are more likely to experience the effects of air pollution.
- While migrants from other states believe that Dehradun's air quality is good, locals as well as migrants from other cities or villages in Uttarakhand believe that Dehradun's air quality is not so great. Due to inversion, which causes low wind conditions and layer stratification in the atmosphere that prevents the large-scale mixing of pollutants, valleys frequently experience significant levels of pollution(Guilbaud et al., 1970).
- According to all four occupational groups, the worst period for air pollution is in the afternoon. It is misconception because morning and evening are when Dehradun's pollution levels are at their highest.
- In the instance of the city of Dehradun, it has been discovered that people believe summer to be the worst season because they associate air pollution with heat and warmth; thus, there is a need for awareness because of this common assumption. People are unaware of the problem with air pollution.
- The common belief that road development, construction, and emissions from vehicles are major contributors of air pollution is accurate. The city has a tourist inflow as a result of being close to several popular tourist destinations. Most vehicles in Dehradun run on diesel and petrol rather than compressed natural gas (CNG), and the quality of public transportation is not good.
- More research on the air quality sensor is required, according to a study of the low-cost sensor. The PM2.5 measurements were less accurate than the PM10 data. The regression

value PM10 came out to be R^2>0.76 and for PM2.5 it was $R^{2>}$0.44. When the sensor was used in the city outdoors, the data varied depending on the location. Pollutant concentrations were higher at the ISBT and Clock Tower than in Raipur and other places. PM_{10} and SPM concentrations were found to be higher at ISBT and CT (Deep et al. 2019) owing to increased local traffic emissions and activities using open fires for heating throughout the winter. With the study we can say that, the sensor may be used for quick research projects and daily, personal air pollution monitoring.

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