Characterizing Particulate Matter Pollution in Kanpur: Sources, Distribution, And Health Implications

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Abstract
The purpose of this study was to examine the PM10 and PM2.5 levels of the air in Kanpur, India, as well as the chemical composition of the air in terms of heavy metals and the PM10 component, BSOF. Three sites were chosen for sampling: the Juhi Colony (JC) (residential site), IIIT (control site), and the Kanpur Central Railway Station (KCRS) (commercial site). Between February 2024 and July 2024, a total of eight-eight 24-hour samples were taken at these sites for PM2.5 and PM10. To determine the levels of heavy metals and the hazardous organic component by measuring BSOF, the PM10 samples that were collected were submitted to chemical analysis. The levels of BSOF (1 to 170 mg m–3), PM10 (45 to 589 mg m-3), PM2.5 (25 to 200 mg m-3), and heavy metals were greatest at KCRS, then JC and IIT. The research came to the conclusion that Kanpur's total air quality was much worse than that of other cities in India and beyond. As with PM10 and PM2.5, the concentrations of heavy metals were about five to ten times greater than those seen in European cities. The investigation came to the conclusion that PM2.5 monitoring and control needed to be addressed. For a preliminary evaluation, a linear model was proposed to forecast PM2.5 using frequently measured parameters, PM10 and BSOF, since regular monitoring of PM2.5 can take some time.

Keywords: Air quality, IIT, Kanpur, PM2.5, PM10

1. Introduction

Human health has been shown to be significantly impacted by particle concentration increases (Rückerl et al., 2011). Particulate matter has been linked to an increased incidence of maternal mortality, instances of high blood pressure, and several other health hazards, according to Global Burden of Disease (GBD) statistics (Kassebaum et al., 2014; Troeger et al., 2018). More damaging than ambient pollution is the interior air pollution brought on by burning solid as well as non-solid fuels for heating along with cooking (Gordon et al., 2014; Clark et al., 2013). Compared to their overall mass concentrations, the particles' size and chemical makeup are more to blame for potentially harmful health impacts. Particles with an aerodynamic diameter of less than 1.0 µm, often known as the submicron fraction, are harmful to human health because they may enter the lung's alveolar zone deeply (Pope and Dockery, 2006). It is estimated that exposure to submicron particles in indoor and outdoor microenvironments may be responsible for 4% to 8% of premature deaths worldwide, based on daily mortality data (Pope and Dockery, 2006). According to a thorough analysis of chronic respiratory disorders, in India in 2016 (Salvi et al., 2018), air pollution increased the number of “disability-adjusted life years (DALYs)” attributable to “chronic obstructive pulmonary disease (COPD)” by over 50%. Additionally, the health of humans may be negatively impacted by the presence of trace levels of hazardous substances such as metals and “polycyclic aromatic hydrocarbons (PAHs)” in fine particle loading. Numerous studies have clearly shown that exposure to PAHs in certain occupational as well as ambient environments increases the risk of lung cancer (Armstrong et al., 2004; Shen et al., 2014). According to a global study on the risk of lung cancer caused by PAHs from various sources, burning biomass accounts for the majority of the source (~40%), followed by emissions from burning coke (13%), emissions from vehicle exhausts (9%), burning residential and industrial fossil fuels (14%), as well as aluminium production (12%) (Shen et al., 2014). According to studies, diesel exhaust exposure, which is asphalt factories, waste incineratitar distillation, on, and tobacco smoking are among the occupational settings where PAHs might result in cardiac issues (Lee et al., 2011).

Numerous epidemiological studies have shown a statistical correlation between ambient fine particle concentrations and health impacts, particularly with regard to the submicron fraction (PM1), which has the ability to deeply enter the lung's alveolar area (Schwartz et al., 1996; Pope, 2000). Around the world, numerous metropolitan and highly industrialised locations have a plethora of mass concentration, distribution, and chemical component data for ambient PM2.5 and

PM10. But when it comes to PM1, not much is known, and even less has been done. Particles with an aerodynamic diameter of less than 2.5 µm, known as PM2.5, are fine particles found in urban areas. They are primarily produced by atmospheric gas-to-particle conversion processes or secondary anthropogenic combustion products, which are primarily from vehicular traffic and electricity-related activities (Hildemann et al., 1991; Schauer et al., 1996; Kleeman and Cass, 1998). Generally, "organic carbon (OC)," "sulphate (SO4 2-)," "nitrate (NO3 -)," as well as "elemental carbon (EC)" have been widely quantified and reported as the main components of urban ambient PM2.5 (Brook et al., 1997; Chan et al., 1997; Kyotani and Iwatsuki, 2002; Saradhi et al., 2008).

According to the USEPA (1995), elemental carbon (5%), organic matter (30 to 60%), nitrates and sulphates (25 to 35%), metals (o1%), as well as other substances make up the majority of PM2.5. It is necessary to choose criteria that take into consideration both the organic and inorganic components of PM2.5 in order to represent PM2.5 indirectly. BSOF is a measure of the organic component that indicates neutral and aromatic chemicals. In terms of the inorganic fraction, a portion of PM10 may be used to represent it. Therefore, if the issue is thoroughly researched, there may be a method to depict PM2.5 based on levels of PM10.

The goal of this research was to assess the inhalable PM10 and respirable PM2.5 levels in the air in Kanpur, India, the study region.

2. Site Description

The research area for this study was the Indian city of Kanpur, as mentioned in the introduction. With a population of over 3 million, "Kanpur is located on the Gangetic Plane in the north-central region of India (longitude 881220 E as well as latitude 261260 N)." The total investigation included the following steps: (i) choosing a sampling site and collecting samples; (ii) analysing the samples in a lab; and (iii) interpreting the findings. Three sites were chosen for the sampling process: "an urban commercial, an urban residential, and a control site." The primary land-use was taken into consideration when choosing the sampling location; Indian Institute of Technology (IIT) was the control, Juhi Colony (JC) was the residential area, Kanpur Central Railway Station (KCRS) was the commercial (Fig. 1). No area could be fully isolated as either control, residential, or commercial. The laboratory investigation focused on measurements of BSOF (in PM10), heavy metal (in PM10), PM10, as well as PM2.5.

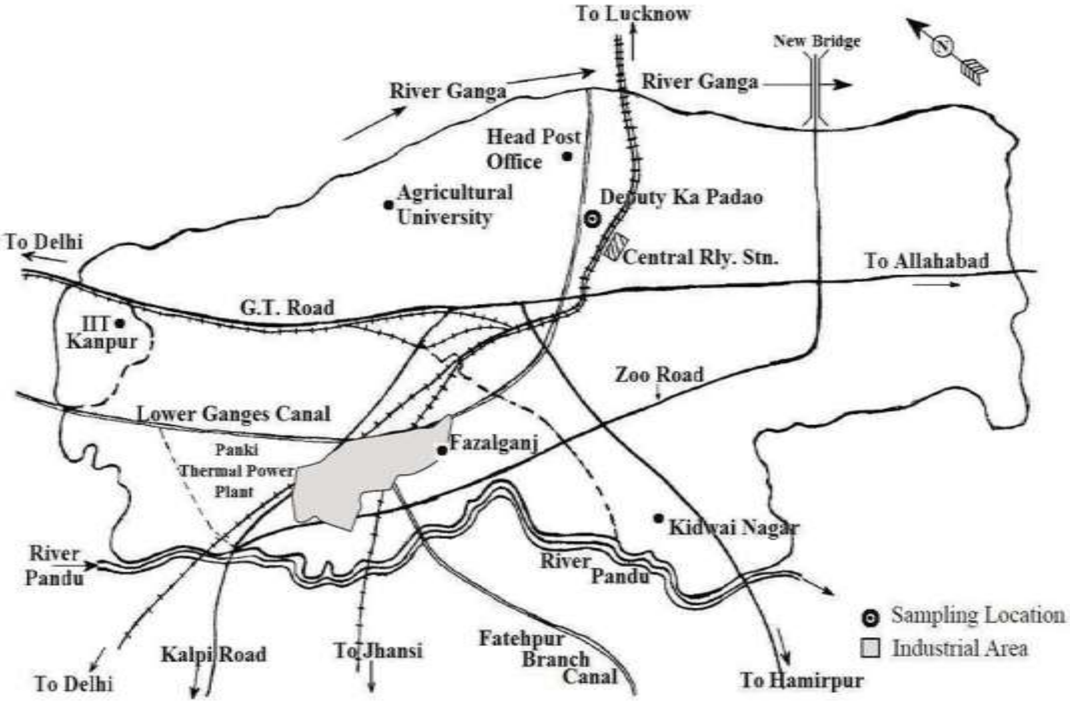


Figure 1. The location of the Kanpur air quality monitoring program (Shukla, 2010)

There is no Kanpur PM emission inventory available. The main sources of particulate emissions are the following: "construction sites, vehicles (with 350,000 registered vehicles in the city), industries using heavy oil and coal, burning of refuse (leaves), use of captive diesel generator sets (frequent power outages), and domestic use of soft coal for cooking."

3. Materials and method

At each site, sampling for PM10 and PM2.5 was done concurrently, and at least 18 samples were taken overall (Table 1). Table 2 provides information on the particle sampler and filter sheets.

Table 1. Schedule for collection of air samples

Sampling location	**PM10 and PM2.5**	
	Sampling months	**Number of samples**
IIT	February, 2024	15
KCRS	March, 2024 April, 2024 May, 2024	18 15 18
JC	June, 2003 July, 2003	11 11

Table 2. Instruments used for sampling and their specifications

Sampler type	**Model**	**Particle size**	**Flow rate**	**Filter paper**
Hi-volume sampler (for PM10)	APM 450, Envirotech, New Delhi	10 mm and less	0.9–1.2 m3 min-1	Whatman GF/A of 800 1000size
Wins-Anderson impactor (for PM2.5)	APM550, Envirotech, New Delhi	2.5 mm and less	16.67 l min-1 or 1 m3 h-1	Millipore filter of 47 mm diameter

Prior to and following the sample, filters were conditioned in a desiccator for twenty-four hours. The first and final weighing of filter sheets was completed in a humidity-controlled environment using a 440 Metler balance with a sensitivity of 0.00001 g.

3.1. Sample collection and storage

The balance (APM 440, Metler) was used to weigh the desiccated filter sheets twice. To prevent the filter papers from being contaminated while being transported, the conditioned and weighed filter papers were put in a cloth-lined envelope (PM10) as well as filter holder (PM2.5) before being sent to the field for sampling.

Initial volume and timer readings for PM2.5 and the manometer reading for the PM10 sampler were recorded on the field monitoring sheet prior to the sampling process. Prior to the samplers being started, the pre-weighed and coded filter sheets were put into the filter holders of the corresponding samplers and tightened. The samplers for PM2.5 and PM10 were both run for a full day of sampling. PM10 and PM2.5 concentrations were computed gravimetrically using the data input in the field data sheet in the pre-established format both before and after each round of sampling.

Following the sample process, the PM2.5 filter sheets were extracted using forceps and inserted into the cassette, which was then covered with aluminium foil. In a similar manner, the PM10 filter paper was sealed in an envelope and covered in aluminium foil before being returned to the lab. The samples were kept wrapped in aluminium foil to stop photo-oxidation from destroying organic components. The weighted filter sheets were kept in the freezer until further chemical analysis was performed to check for BSOF and heavy metals.

3.2. Quality control in sampling

i. The flow rate at which the PM2.5 sampler is intended to operate is 16.6770.83 l min-1 (Chow and Watson, 1998). To ensure that the variations in flow rate were within acceptable bounds, daily computations of the flow rate (based on timer and gas meter readings) were performed.

ii. Likewise, a flow rate of 1 m3 min-1 must be used for the PM10 sample. To make sure that the flow rate changes were within the range of 0.9–1.1 m3 min-1, the PM10 sampler's manometer measurement was obtained three or four times a day. The volume was determined by using the average flow rate.

iii. When the filter in the Wins-impactor seems clogged, as determined by the operator, or after 72 hours of sampling (Chow and Watson, 1998), a new filter has to be installed. Moreover, the filter has to be submerged in three to four droplets of silicon oil at all times. This resulted to the impactor's filter paper being either changed or lubricated on a frequent basis, depending on what was required.

3.3. Heavy metals’ estimation

Chemical speciation is the next stage in the evaluation of air quality after particle collection. Heavy metals (Pb, Zn, Fe, Ni, Cd, and Cr) in PM10 were examined for this reason. Heavy metals were extracted and analysed in accordance with USEPA technique IO-3.2 (USEPA, 1999). The technique allows for the digestion of PM10 samples on glass fibre filters using either a microwave-assisted digestion system or a hot-acid digestion system (USEPA, 1999). The microwave digesting procedure is suggested by the reference. A laboratory microwave digestion machine (Ethos, Milestone, Italy) was used to break down one-fourth of the filter sheets using a 15 ml hydrochloric and nitric acid combination (3:1) for 23 minutes at around 1801C. After being broken down, the digested material was filtered, filled to the proper volume, and kept in plastic bottles.

Using an Atomic Absorption Spectrophotometer (AAS) (GBC Avanta S, Australia), every heavy metal was examined. The device was calibrated for Pb, Fe, Zn, Cr, Cd, and Zn prior to sample analysis. Stock solutions (of 1000 ppm) were generated and diluted to the range of working standards for each individual metal in accordance with the USEPA procedure. These working standards were used to create the calibration graphs in the 0.04–0.8 optical density linear range. For every metal, the device was calibrated at three distinct levels.

The same extraction as well as analytical method used for PM10 filter sheets was used to investigate the background heavy metal concentrations of blank filter paper. To ensure repeatability and low background metal concentrations, the method's recommended 5% of samples were collected as blanks and examined for the presence of certain metals.

3.4. The heavy metal analysis and quality control

i. The following protocol was adhered to in order to prevent contamination from many sources:
ii. To prevent sample contamination, all of the glassware as well as filter assembly underwent acid washing as well as oven drying.
iii. To verify that the interference from the filter papers in the sample wasn't present, three blanks were examined for each heavy metal. It was discovered that every metal in the filter blanks was over the lowest detectable limit. It was discovered that sampled filter sheets had a greater metal content than blank filters.
iv. To verify the repeatability, each third sample underwent two analyses.
v. Three rounds of extractions were carried out for one of the filter papers, as well as the samples were examined to verify that the metals were evenly distributed over the paper by comparing the concentration differences.

3.5. BSOF

Using ASTM test method 4600-87 (ASTM D4600-87, 1990), the hazardous organic fraction in terms of BSOF in PM was determined. The approach is gravimetric. “The National Institute of Occupational Safety and Health” in the United States has suggested this approach for representing organic compounds (OC) in ambient air.

For PM10 air samples, 20 millilitres of HPLC-grade benzene were applied to a quarter of the PM10 filter paper in glass containers or bottles that had been cleaned and oven-dried.” Glass caps and sealer were used to seal the bottles/vessels to prevent the loss of “organic fraction during ultrasonication. The samples were ultrasonically treated at room temperature for a duration of 20 minutes. The extracted materials were put through a glass fibre filter with a 0.54 mm opening under vacuum. Each sample was extracted twice using ultrasonication, and the extract was transported to 50 ml beakers that had been cleaned, oven dried, and pre-weighed. To prevent contamination, perforated aluminium foil was placed over the beaker's mouth. In 15–20 hours, the benzene extract evaporated in the oven at 401°C until it was completely dry. When the beaker had dried, it was weighed using a 5-digit balance (APM440, Metler). The weight difference is the fraction of dissolved BSOF in benzene that can be converted to mg m–3.

Glass fibre filter paper was used to analyse four filter blanks for BSOF. A variation of 1.5% to 2% was observed in the BSOF of the filter blank. It is required by quality control procedures that the beginning and final weight differences in beakers be larger than or equal to 0.001 g. In all cases, this was the case.

4. Results and discussion

4.1. PM

The levels of PM10 and PM2.5 at the 3 sites where sampling was conducted are shown in Figs. 2 and 3. At IIT, the mean PM10 concentration was found to be 80 mg m-3. The national air-quality requirement for India (100 mg m-3) is not met by the average PM10 levels at KCRS as well as JC, which were found to be comparable at 272 and 281 mg m-3, respectively. But at JC, there was a lot greater variation in PM10.

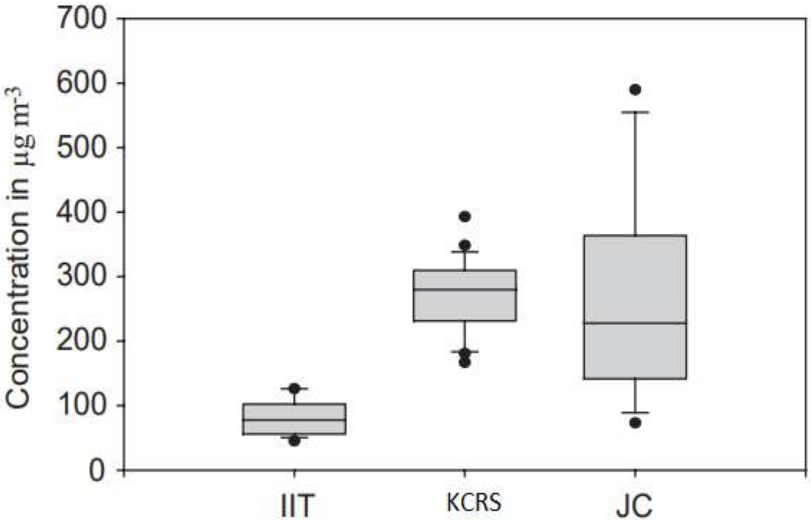


Figure 2. PM10 levels in Kanpur

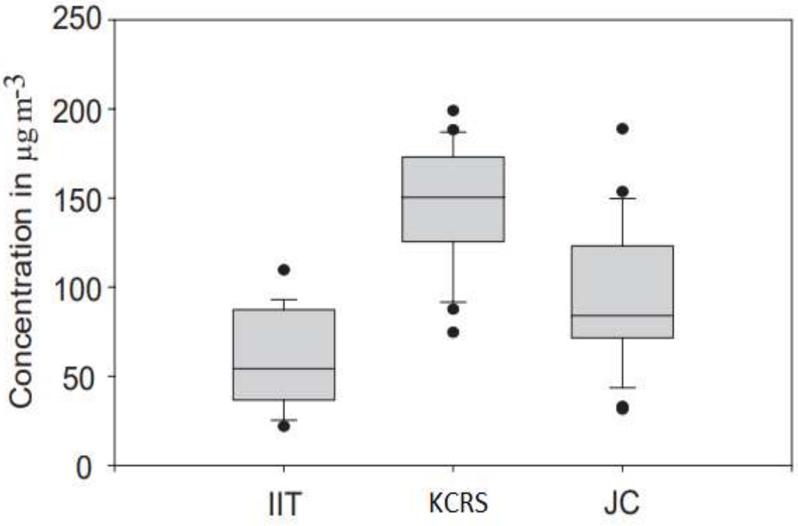


Figure 3. Kanpur's PM2.5 readings

At IIT, the average PM2.5 level was the lowest, at 61 mg m-3. It was discovered that the average PM2.5 concentration at KCRS was 146 mg m-3, around 2.5 times higher than the values at IIT. 95 mg m-3 of PM2.5 was typical at JC. An intriguing picture is shown when the PM2.5 results from the various sample locations are compared (Fig. 3). The average PM10 concentrations at KCRS and JC were comparable, while KCRS had much higher PM2.5 (146 mg m-3) than JC (95 mg m-3). It raises an important point: even while PM10 is a more accurate measure of total suspended particulate matter (TSP), it could not accurately depict the presence of more dangerous tiny particles (PM2.5). In the Indian context, this is especially critical since a considerable amount of PM10 may be locally created, wind-blown dust in the coarse fraction (PM10–PM2.5), which may not be as toxic as PM2.5. Examining the PM2.5/PM10 ratios (Table 3) further highlights the possibility that PM2.5 levels are not accurately reflected by PM10 levels. Despite the fact that the average PM10 level at KCRS is lower or comparable to that at JC, the location's PM2.5/PM10 ratio is much greater, suggesting a higher fine fraction of PM10 there. Due to the proximity of a small road and a major national highway, where heavy-duty vehicles are often seen, the high PM2.5 levels at KCRS may be linked to emissions from these sources.

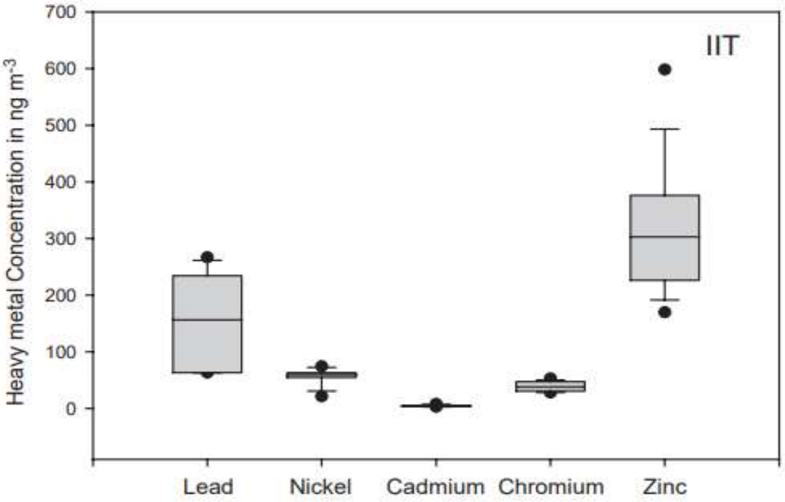
Table 3. PM2.5 to PM10 ratio

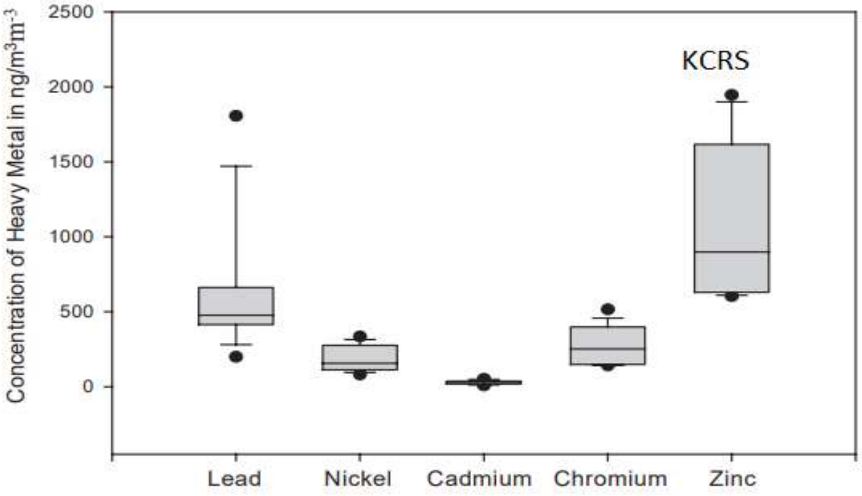
Location	**IIT**	**KCRS**	**JC**
PM2.5/PM10	0.74	0.56	0.45

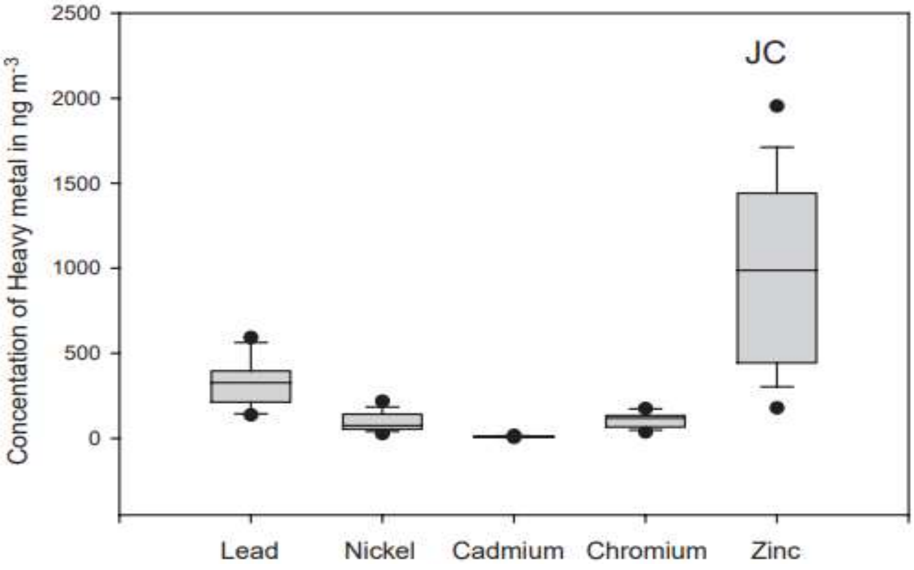
Urban areas in Kanpur have PM10 levels that are higher than those in metropolises like Kolkata and Mumbai and about the same as those in Delhi (272.707 64.64 mg m-3 (KCRS) and 281.977170.57 mg m-3 (JC) (Sharma et al., 2003). While determining the causes of the high levels in Kanpur was not the aim of this study, it is evident that there are significant emissions in Kanpur if one compares the climatic conditions in Delhi and Kanpur (the two cities are around 250 km apart). Regarding PM2.5 concentrations, no research has measured PM2.5 in India. The PM2.5 levels in Kanpur are about ten times greater than those in US and European cities, nevertheless, when one compares them. Kanpur's high PM2.5 levels indicate that measuring and controlling PM2.5 is unquestionably necessary.

4.2. Heavy metals

The heavy metals Pb, Fe, Zn, Ni, Cd, and Cr were examined in this investigation using PM10 air samples (Fig. 4). Figure 4 shows that the greatest concentrations of heavy metals are found at KCRS, with JC and IIT following closely after. The PM2.5 levels as well as metal contents show a similar pattern of fluctuation, indicating that IIT has the least pollution, followed by JC and KCRS. This is consistent with the fact that the majority of heavy metals are linked to tiny particles, which increases their toxicity. The second noteworthy fact is that lead is still present in the ambient air and may still be harmful to health even after unleaded petrol was introduced.


IIT
Heavy metal Concentration in ng m-3
700
600
500
400
300
200
100
0
Lead
Nickel
Cadmium
Chromium
Zinc


KCRS
Concentration of Heavy Metal in ng/m3m-3
2500
2000
1500
1000
500
0
Lead
Nickel
Cadmium
Chromium
Zinc


JC
Concentation of Heavy metal in ng m-3
2500
2000
1500
1000
500
0
Lead
Nickel
Cadmium
Chromium
Zinc

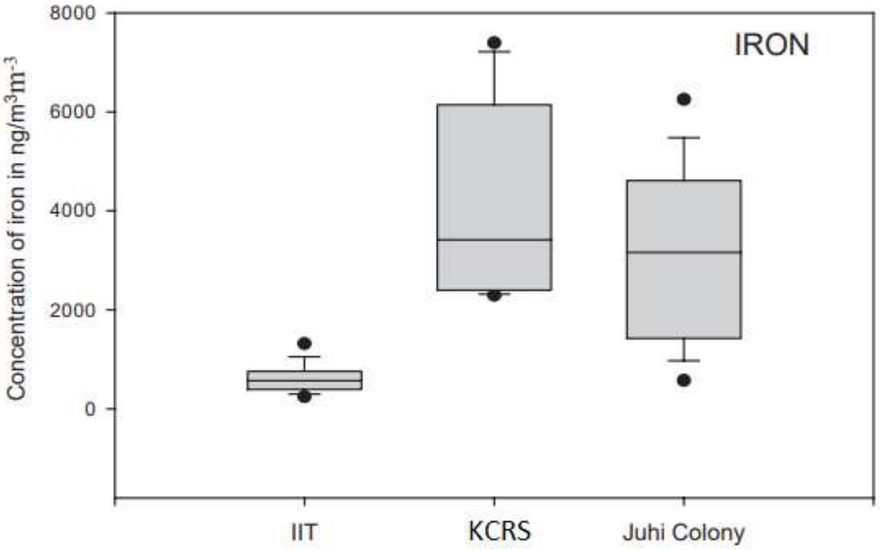


Figure 4. Levels of heavy metals in Kanpur's ambient air (ng m-3).

The amounts of heavy metals discovered in the current Kanpur investigation were compared to those discovered in studies carried out at several other locations (Table 4). All of the metal levels were shown to be five to ten times higher than those in European nations like Norway as well as Spain. At 133 ng m-3 and 251 ng m-3, respectively, Pb and Zn levels in Taiwan are comparable to those at control site IIT (150 and 320 ng m-3). The study's Fe levels were found to be similar to those in Taiwan and Spain, while Delhi's levels were said to be very high. All metal concentrations were found to be greater in Delhi than in Kanpur, although the average concentration difference was not very significant—the exception being Fe. It is clear from this conversation that Kanpur has a much greater heavy metal pollution load than other nations, albeit it is likely lower than Delhi's levels.

Table 4. Comparison of heavy metal levels at various locations

Location	**Pb (ng m-3)**	**Zn (ng m-3)**	**Ni (ng m-3)**	**Cd (ng m-3)**	**Cr (ng m-3)**	**Fe (mg m-3)**
Spain (Querol et al., 2002)	8–698	28–479	0.1–21	0.1–4	0.1–22	0.20–10
Taiwan (Fung and Wong, 1995)	133	251	—	—	656	6.99
Norway (Berg et al., 1996)	0.36–10.36	0.96–46.68	0.09–5.71	0.01–0.28	0.21–1.56	—
Delhi (Balachandran et al., 2000)	600–1900	400–800	—	20–150	300–700	5–20
Mumbai (Kumar et al., 2001)	1060 ± 300	—	160 ± 40	—	150 ± 60	—
Present study	70–1030	200–1630	40–270	2–43	32–400	0.30–6.17

4.3. BSOF

The organic composition of PM was measured using benzene as well as ether as solvents. The ether soluble organic fraction (< 50%) for the same samples was much lower than the BSOF, according to the results. The findings of BSOF alone are detailed in the paragraph that follows. Table 5 and Fig. 5 provide the BSOF results. While 200 mg m-3 has been cited as the work place standard for BSOF, the ambient air-quality requirement need to be much lower. An acceptable amount of 20 mg m-3 for BSOF is obtained if one adopts a safety factor of 10 (Mastrangelo et al., 1996), which has indicated a factor of safety of 10 or higher. One may compare the BSOF at different places to a 20 mg m-3 value (Asante-Duah, 1998). Like PM2.5 and heavy metals, BSOF is well beneath the permissible limit of 20 mg m-3 and is least at IIT. At KCRS (106762 mg m-3), however, the level of BSOF is very high, suggesting significant quantities of organic chemicals, including PAHs. In addition, BSOF levels at JC are higher than those at IIT (977 mg m-3) and are higher than the tentative value of 20 mg m-3 (48742 mg m-3).

Table 5. BSOF in PM10

Location	**IIT**		**KCRS**		**JC**	
	(% by w/w)	(mg m-3)	(% by w/w)	(mg m-3)	(% by w/w)	(mg m-3)
BSOF	9.87 ± 4.79	9.13 ± 7.03	40.00 ± 19.96	106.71± 62.38	10.32 ± 7.99	48.48 ± 42.35

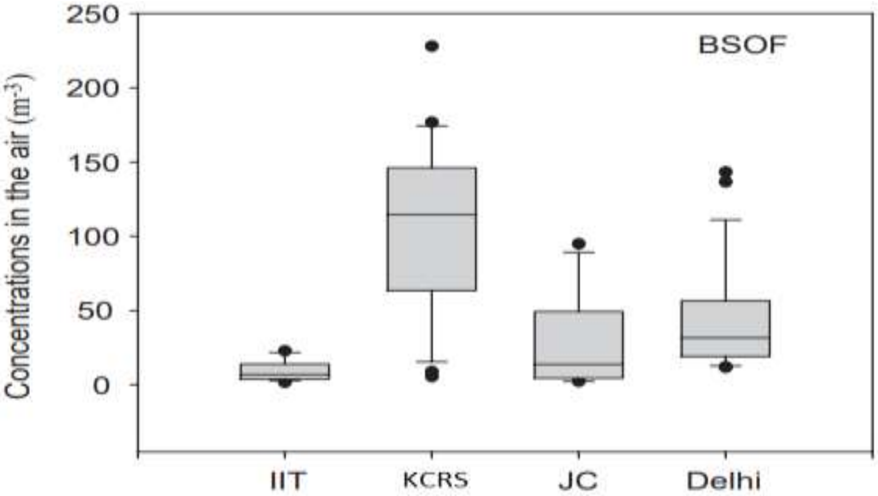


Figure 5. BSOF in PM10 (mg m-3)

4.4. PM10 and BSOF levels an indicator of PM2.5

Thus far, the data and discourse have shown that there is a very high concentration of metals, BSOF, and PM2.5 in PM10. It implies that air is dangerous due to fine particle matter and its chemical makeup, necessitating immediate action. It's possible that comparable circumstances exist in other Indian cities.

Equipment and sample procedures must be changed as part of the alterations needed for PM2.5 monitoring as well as chemical speciation in laboratories. There are a lot of “PM10 monitoring stations (about 300) in India.” At least not in the near future, it is not simple to replace all PM10 monitoring with PM2.5 monitoring everywhere. Additional infrastructure (such as modified sample equipment as well as filter paper (Quartz/Teflon), more accurate balancing, specialised labour, and adjustments to quality assurance and quality control) will be needed for PM2.5 monitoring. Nevertheless, until systematic PM2.5 monitoring can be implemented, it is necessary to evaluate PM2.5 contamination in some manner.

The primary constituents of particulate matter include nitrates, organic materials, heavy metals, sulphates, as well as elemental carbon (PM2.5). It is necessary to choose criteria that take into consideration both the organic and inorganic components of PM2.5 in order to represent PM2.5 indirectly. In terms of the organic component, neutral and aromatic compounds are indicated by BSOF. Therefore, one might argue that BSOF may stand in for the organic component of PM2.5. With respect to the inorganic portion of PM2.5, it may be represented as a portion of PM10.

PM10, PM2.5, as well as BSOF measurements have been made for this investigation. It is possible to “model PM2.5 as a function of PM10, BSOF,” and other independent variables thanks to the concurrent data that is now accessible. Initial data analysis revealed a correlation of 0.82 between PM2.5 and BSOF and 0.72 between PM2.5 and PM10, respectively. An effort has been made to use the data on “PM10 and its BSOF” contents to create a statistical model for PM2.5 in the section that follows.

5. Conclusion

According to the study's findings, Kanpur's total air quality was much worse than that of other cities in India and beyond. Heavy metal levels were around five to ten times greater than those in European cities, much like PM10 and PM2.5. In metropolitan areas, the benzene soluble fraction (106762 as well as 48742 mg m-3) likewise showed a significant level of organic content. The investigation found that the problem of PM2.5 monitoring and control needed to be addressed. A potential method for estimating PM2.5 pollution levels based on PM10 levels and their organic composition as determined by the benzene-soluble organic fraction is to model PM2.5.

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