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# Indoor and Ambient Air Exposure of PAHs and Fine Particulate to Women and Children: Health Impacts in terms of Morbidity

## February 2002 – June 2005

**Alena Bartonova and Mukesh Sharma (eds)**

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| | **Indian Institute of Technology Kanpur, Kanpur, India** |
| NILU | **Norwegian Institute for Air Research, Kjeller, Norway** |

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- Indian Institute of Technology, Kanpur and the Norwegian Institute for Air Research, Kjeller
- All participants that volunteered for medical examinations and for using their premises for sampling.

# 1. Introduction to Project

## 1.1. Background

This document constitutes a condensed report on the project, “Indoor and Ambient Exposure of PAHs and Fine Particulate to Women and Children: Health Impacts in terms of Morbidity" completed under the aegis of Indo-Norwegian Programme of Institutional Cooperation (INPIC); jointly implemented by the Indian Institute of Technology Kanpur (IITK), Kanpur, India, and the Norwegian Institute for Air Research (NILU), Kjeller, Norway. The Chest and Tuberculosis Department of GSVM Medical College, Kanpur was invited to assist in clinical tests and their interpretations. The project commenced on March 1, 2002 and will be closed formally on July 31, 2005. With the specific objectives to disseminate the project findings and to share the subject knowledge amongst wider scientific and technical community, IIT Kanpur and NILU, Norway are organizing a seminar on ***Indoor and Ambient Air Exposure of Fine Particulate and PAHs: Health Perspectives*** during June 24-25, 2005 at IIT Kanpur; this report is presented in the seminar for wider circulation and information dissemination.

## 1.2. Project Objectives

Recent air pollution and health effect studies world over have focused on fine particulates and their inorganic and organic contents. To develop the scientific understanding of exposure and health effects of fine particulates, one needs to carry out epidemiological study by monitoring actual pollutant exposure and changes in body responses. Cohort-based studies are effectively used to understand cause effect relationship of pollutant exposure.

The specific objective of the project was to design and implement a cohort-based epidemiological study in Kanpur to understand the health impacts of exposure to pollutants both in terms of lung function impairment and risk assessment. Although the study had initially focused on women and children, a limited number of male subjects were also recruted to perform spirometry tests.

The focus of the study was on sampling, monitoring and exposure assessment of PM2.5 (fine particulate), CO, NOx, metals and PAH (Polycyclic Aromatic Hydrocarbons) with concurrent measurements of lung functions including PEFR (Peak expiratory flow rate) $FEV_1$ (forced expiratory volume in one second) and FVC (forced vital capacity). The study profile included four locations (urban and rural sites), three seasons, over 230 subjects (male, female and children), varying type of houses and fuel usage. The major tasks involved in the project and their sequencing are presented in Figure 1.

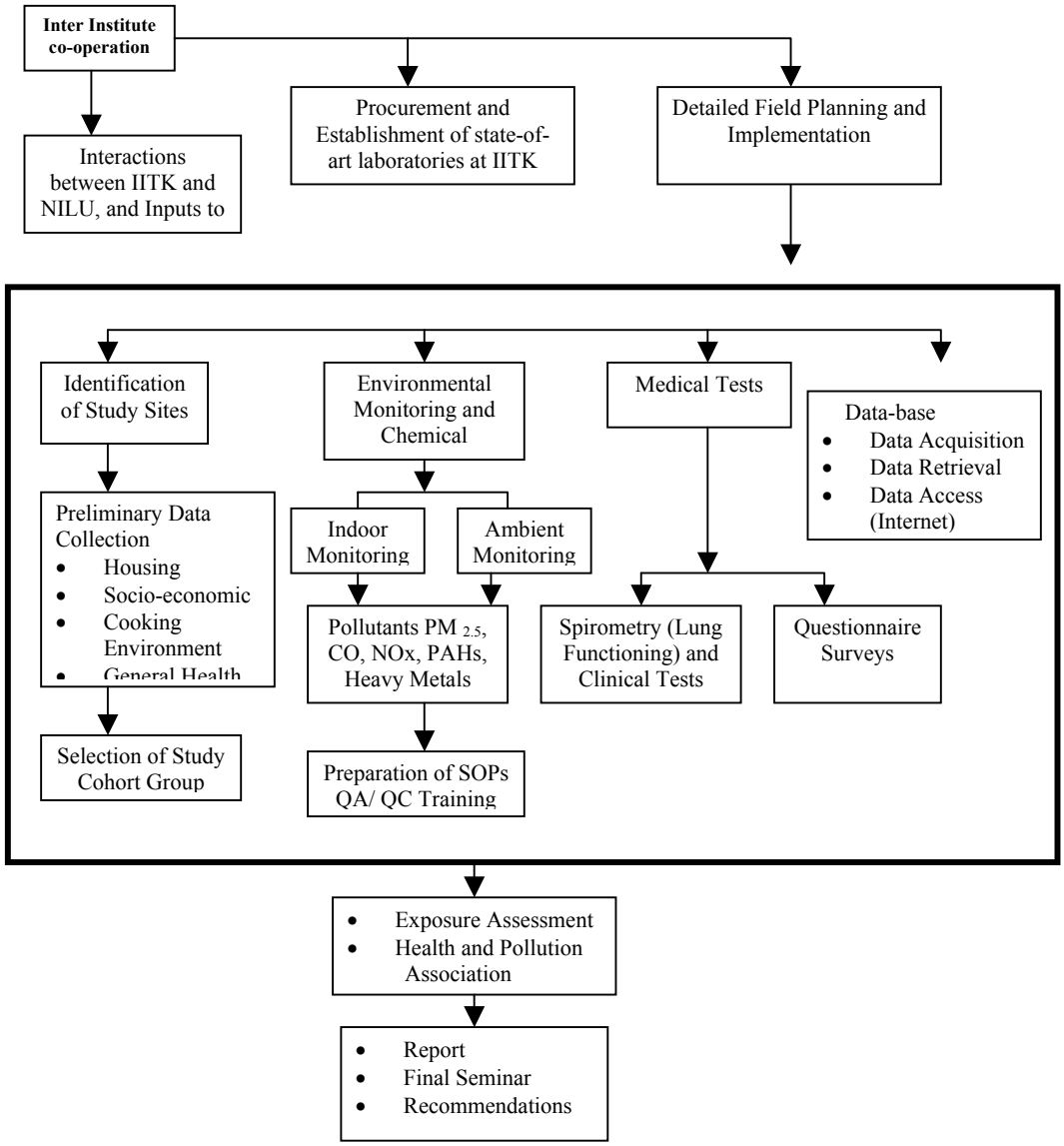



Figure 1 Overview of the Project. Indoor and Ambient Air Exposure of PAHs and Fine Particulate to Women and Children: Health Impacts in terms of Morbidity

# 2. Sampling and Analysis: Methods and Quality Assurance

## 2.1. Sampling Sites and Cohorts

The four sites for the study were: (i) Bharat Purva (BP; rural site), (ii) IIT Kanpur (IITK; control site) (iii) Juhi Lal Colony (JLC; urban residential area) and (iv) Lohar Bhatta (LB; urban slum).

**Bharatpurva (BP)**

Bharatpurva is a small village (population about 225) located at a distance of about 20 Km North-West (NW) of Kanpur Railway station (Figure 2). The village has no electric power supply, and most of the people are engaged in agricultural activities for their living. This site can be taken as a typical rural site. Cow-dung cakes along with wood are commonly used as the cooking fuel, with *Chulha* (stove) of mud as the main cooking appliance. Kitchens are mostly closed rooms, made of mud and straw, with little or no scope for ventilation. Some of the kitchens are part of the livingroom or bedroom.

**IITK (Control Site)**

IITK is located 18 Km NW of Kanpur Railway Station on GT Road. This site is an institutional cum residential area. Although a large fraction of population in IIT Kanpur is in middle to higher income group, a relatively small population residing in servant quarters of IITK represents economically weaker section. Therefore, this is an ideal control site. LPG is the most commonly used fuel, but some of the households use wood and kerosene.

**Juhi Lal Colony (JLC)**

This is a typical residential site with a population of around 800 people. Although there are no major roads in its close vicinity (in about 1 km), however, this location is in the middle of city with major traffic corridors all around and two large industrial areas (Kakadev and Panki) in its upwind direction. In addition, area around this location is full of urban activities with movements of man, material and trading.

**Loharbhatta (LB)**

Loharbhatta presents a typical urban slum in populous Kanpur City. This site is located at about 7 Km in NW of Kanpur Railway Station off the GT Road (Figure 2). Due to high population density in such localities, houses are contiguous and closely packed. Wood and coal are the main fuels used for cooking. Most of the households use mixed fuels including LPG, coal, kerosene and wood. However some households use the cleaner fuels like LPG and kerosene only.

**Cohort Size and Distribution**

156 individuals participated in the computer-aided spirometric tests (one measurement per participant per period). Of these, 55 participated in at least two periods. Distribution of participants is given in Table 1 and location wise in Fig.3.

Peak expiratory flow measurements were taken each morning and each evening under supervision of the project staff. In all, 190 subjects participated, of those, 117 in more than one period. (Table 2).

In all, 240 participants (165 women or girls) are registered with at least one spirometric measurement. All participants were prescreened not to have any lung disease, and were non-smokers.

Table 1. Number of participants in spirometric tests, by sex, age group.

| | | Sex | | | | |
|---|---|---|---|---|---|---|
| | | Male | | Female | | |
| | | Age category | | Age category | | |
| | | Child (<14) | Adult | Child (<14) | Adult | Total |
| No. of periods participated | 1 | 2 | 39 | 9 | 51 | 101 |
| | 2 | 1 | 7 | 2 | 33 | 43 |
| | 3 | | | 2 | 10 | 12 |
| Total | | 3 | 46 | 13 | 94 | 156 |

Table 2. Number of participants in PEFR measurements.

| | | Sex | | |
|---|---|---|---|---|
| | | Male | Female | Group Total |
| No. of periods participated | 1 | 19 | 54 | 73 |
| | 2 | 16 | 40 | 56 |
| | 3 | 8 | 53 | 61 |
| Group Total | | 43 | 147 | 190 |

## 2.2. Sampling and Analysis: Materials and Methods

### Standard Operating Procedures (SOPs) for Sampling and Analysis

SOPs for field sampling of ambient and indoor air monitoring and chemical characterization of particulate matter filter samples were prepared through inter-institutional cooperation between NILU and IITK. The SOPs for medical tests were prepared in consultation with GSVM Medical College, Kanpur. Specifically, the following SOPs were prepared (Table 3).

Table 3. List of SOPs.

| SOP Number | Details |
|---|---|
| IITK-001 | Selection of air quality monitoring stations |
| IITK-002 | Sampling of PM2.5 in ambient air using WINS impactor |
| IITK-003 | Sampling of Indoor air pollutants |
| IITK-004 | Measurement of pollutants using personal samplers |
| IITK-005 | Analysis of sulfates in filter samples |
| IITK-006 | Extraction of heavy metals using microwave digestion system |
| IITK-007 | Quantification of heavy metals on AAS |
| IITK-008 | Extraction of PAHs from filters papers using ultrasonic bath |
| IITK-009 | Analysis of PAHs using high performance liquid chromatography |
| IITK-010 | Operating procedure for spirometry lung tests |

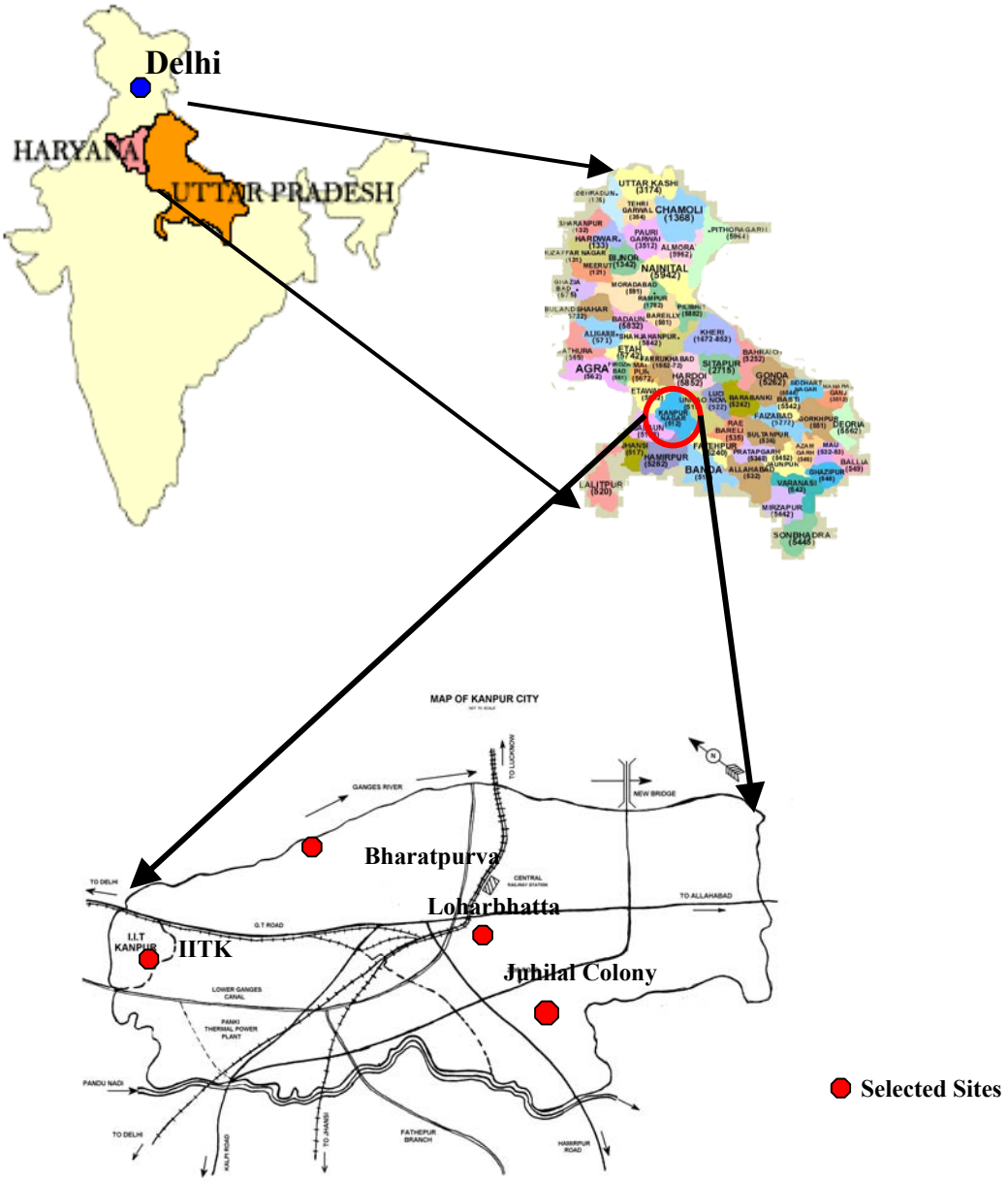



Figure 2 shows the location map of Kanpur and study sites.

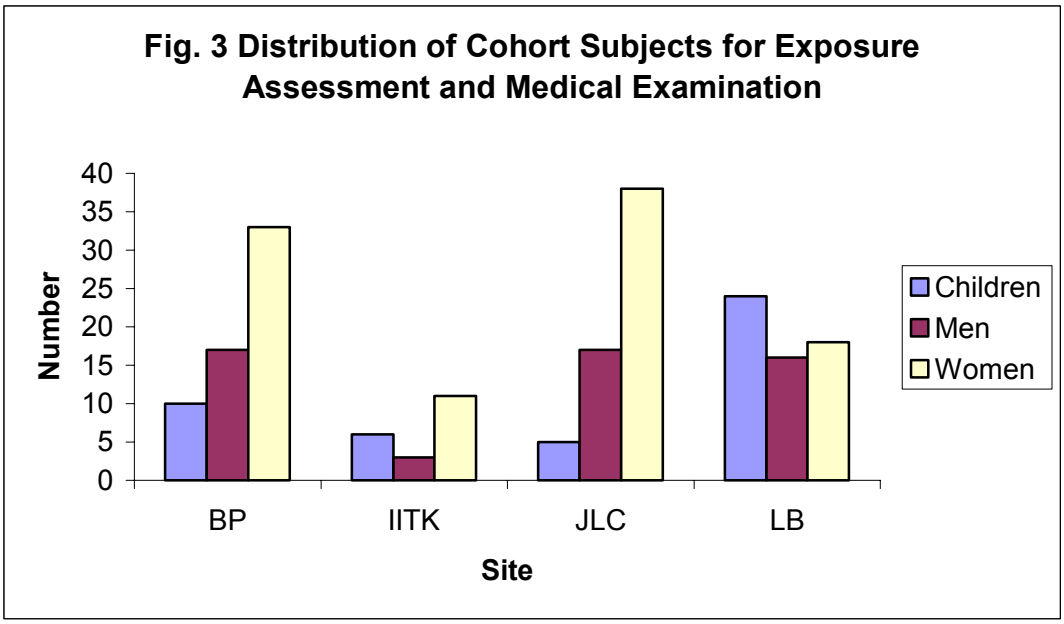



Figure 3 Distribution of cohort subjects for exposure assessment and medical examination.

In brief, the SOPs included step-wise procedures, specifications of sampling and analytical equipment, calibration procedures, and quality control and assurance protocols. The specified SOPs have been followed in the study and this should ensure consistency in sampling and analysis and collection of quality data.

## 2.3. Sampling Equipment

Under this study three kinds of experimental studies have been carried out. These include (i) ambient and indoor air monitoring of PM2.5 (ii) speciation of PM2.5 samples for PAHs and heavy metals and (iii) lung functions and clinical tests. The details of instruments and their applications used in the project are presented in able 4.

able 4. Details of Instruments and their Applications

| S. No. | Instrument | Make | Application |
|---|---|---|---|
| 1. | Indoor Particulate Sampler | Grimm, Germany, Model 1.108 | To measure indoor levels of TSP, $PM_{10}$, PM2.5 and PM1 |
| 2. | Indoor-outdoor Particulate Sampler | Grimm, Germany, Model 1.107 | To measure indoor levels of TSP, PM10, PM2.5 and PM1, temperature and humidity |
| 3. | Multistage high volume sampler | Tisch, TE-6001, USA | To measure ambient levels of PM10 and PM2.5 |
| 4. | Personal Particulate Sampler | SKC, USA, Model: | To measure personal exposure of PM2.5 |
| 5. | Indoor sampler for gases | Yes-205, Canada | To measure indoor NO, NO2 and CO |
| 6. | Spirometer | Spirobank, Italy | To examine lung functions, PEFR, FEV1, FVC |
| 7. | Microwave Digestion System | Ethos+. Milestone, Italy. | To extract metals from particulate filter |
| 8. | Micro Balance | APM 440, Metler | For gravimetric analysis and weighing |
| 9. | Atomic Absorption Spectrophotometer(AAS) | GBC, Avanta, Australia | For metal analysis |
| 10 | High Performance Liquid Chromatography (HPLC) | Merck, Hitachi, Germany | For PAH analysis |

## 2.4. Sampling Procedures

Tisch High Volume cascade impactor was calibrated using top loading field calibrator (Transfer standard traceable to positive displacement roots meter) supplied by Rockwin flow meters model 3M175, with the help of a Delhi based company, M/s Environtech Pvt Ltd, before the start of each season's sampling.

During the sampling, operator used tweezers and gloves to handle filter paper and PUF (poly urethane foam to capture volatiles) and the filter paper was removed timely and was carried to laboratory in proper boxes and envelope to save the exposed filter from any kind of contamination. The exposed filters were

desiccated for 24 hrs before and after the sampling and thereafter analyzed gravimetrically using a 5-digit Mettler Toledo balance.

Personal sampling was done using SKC, USA personal samplers comprising light pump and 25mm PTFE with ring support filters. The personal sampler was adjusted at 4L/min flow rate to collect PM2.5 particulates. The exposed filters were desiccated for 24 hrs before and after the sampling and there after analyzed gravimetrically using a 5-digit Mettler Toledo balance.

Indoor Sampling was done in kitchen and bedroom for TSP, $PM_{10}$, $PM_{2.5}$, $PM_{1.0}$, $NO_2$, NO, CO, temperature and humidity in 3-4 houses at each location in each season using GRIM sampler (for PM) and YES sampler (for gases).

## 2.5. Chemical Analysis

Exposed filters were chemically analyzed for organic and inorganic pollutants. All chemicals used were HPLC grade or AAS grade.

**Heavy Metals**

One quarter of the exposed High Volume filters were digested using 16ml $HNO_3$ ExcelaR Grade ( Glaxo) and 4ml $H_2O_2$ p.a (Merck) in a microwave digester system (Ethos-E, Milestone, Italy). After digestion the solution and remaining filters were cleaned/filtered using Millipore 2.2 micron PTFE filter and thereafter diluted to 25ml using ultra-pure MilliQ water. All the TFM containers of MDS were cleaned using 5ml of $HNO_3$ and 3ml of $H_2O_2$.

**PAHs**

PAHs were extracted from the exposed filters using Toulene (HPLC grade, Merck) in ultrasonic bath and thereafter cleaned using a chromatographic sintered column with 10 gm of 250-270 mesh silica gel and then concentrated up to 2-3ml. This extract was then exchanged with acetonitrile (HPLC grade, Merck) through rotary evaporator.

The PAH were determined on a HPLC system (Lachrom, Merck Germany) using quaternary gradient system, fluorescence detector and 5u 20cm RP PAH column (Merck). Both external (promochem, Germany) and internal standards (Pyrene-

d10; Cambridge Isotope Laboratories) were used to ensure proper calibration and compound recovery.

**Particulate Matter**

All particulate measurements, including $PM_{10}$, $PM_{2.5}$ (ambient air), $PM_{2.5}$ (personal sampler) were analyzed gravimetrically. Before and after the sampling the filter papers were desiccated for twenty four hours and there after weighed on a five digit micro balance (APM440 Metler, Switzerland).

## 2.6. Quality Control Procedures in Project implementation

Quality assurance and quality control (QA/QC) in entire project planning and implementation at all levels was designed in advance and hand on training was imparted project team before beginning of any sampling and analysis. The major features of QA/QC are briefly described here.

- Site selection: Sites were carefully selected to get representative samples of indoor and ambient air. In addition to sampling, selection of house for sampling were to cover various types of domestic fuel, construction material and ventilation (details of site selection are included in the first Annual Report 2002-03 (Sharma and Bartonova, 2003).
- Standard operating procedures (SOPs) for entire project planning and implementation were developed, peer reviewed by NILU experts and project personnel were trained in the field and in the laboratory by NILU experts specifically to follow the SOPs. Whenever necessary the SOPs were adjusted to meet the field challenges.
- SOPs included type of equipment (with specifications), sampling and calibration methods with their frequency, height and distance of measurement from source (e.g. from stove).
- The SOPs for chemical analysis, included description of methods, standards to be used, laboratory and field blanks, internal and recovery standards, data base, screening of data, record keeping, traceability of calculations and standards.

- The medical tests were strictly conducted by professional registered medical personnel with minimum qualification of MBBS.

For example, a brief QA/QC adopted for metal analysis is presented below.

- Standard of known concentration was run after every 10 samples (during analysis) to check the instrument drift and to assure the consistency in results.
- Field Blanks for summer and Post Monsoon sampling was used to check the contamination in the handling of filter paper during sampling.
- Known concentration samples, received from NILU, Norway, were run with the samples for Summer and Post Monsoon samples to ensure quality control in metal analysis.

# 3. Sampling Results and Interpretations

## 3.1. Sampling Plan

There were five components of sampling at each location: (i) Daily PEFR (evening and morning) for each subject (ii) Ambient air (iii) Indoor air (iv) Personal air and (v) Spirometry lung function. The sampling was spread over 2003-2005.

Figure 4 presents the details of sampling plan executed in the project implementation. In all three seasons, winter summer and post-monsoon were covered.

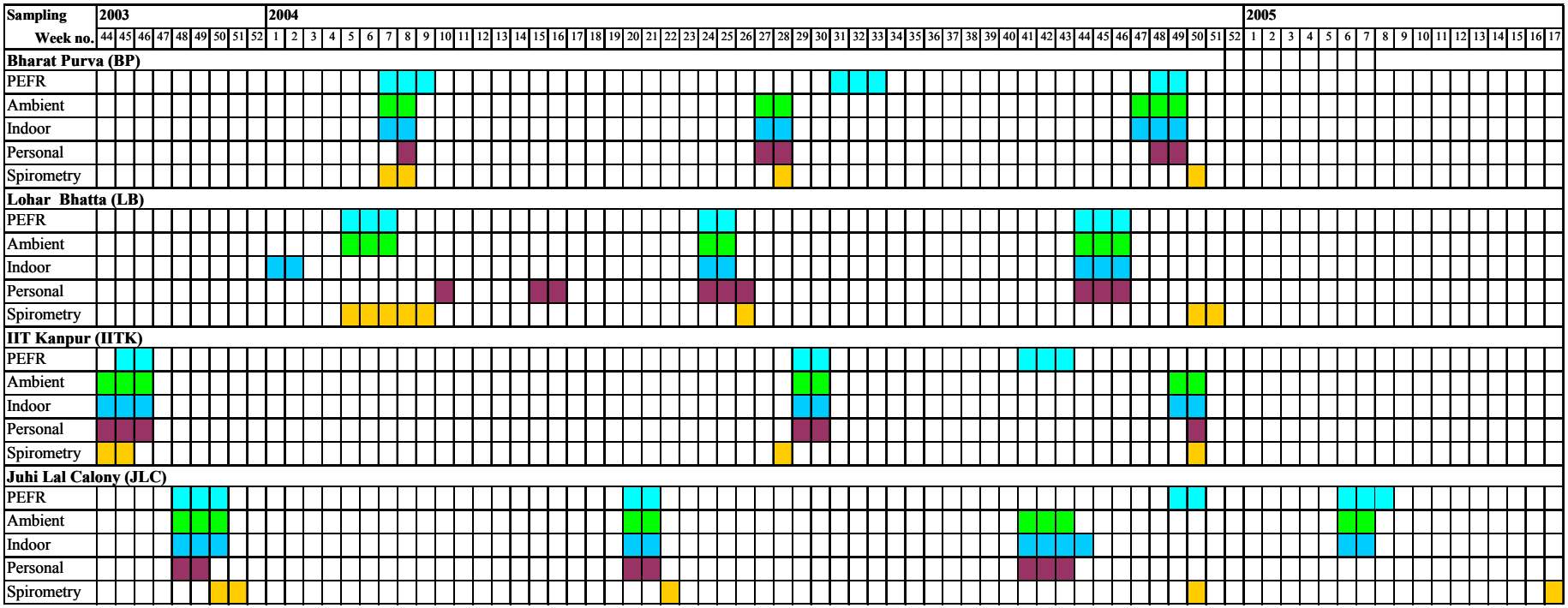



Figure 4. Sampling plan Executed during Project Implementation.

## 3.2. Results and Discussion

### 3.2.1. Ambient Air

Figure 5 presents the overall ambient air levels of PM2.5 at all four locations in various seasons.

**Winter**

As seen from Figure 5, in winter months, PM2.5 levels at IITK (control site) are the lowest followed by village site, BP and then two urban sites (LB and JLC). Although there is no major source of pollution at BP but uses of solid fuels, especially cow-dung cake and wood can contribute to high particulate pollution in ambient air. There was also a road with moderate traffic at a distance of about 1.5 km from the BP site and that may also contribute to $PM_{2.5}$.

The two urban locations (JLC and LB) have shown very high daily average level of $PM_{2.5}$ (375 (JLC) and 387 (LB) $\mu g/m^3$). These levels are very high compared to the air quality standard of the USEPA (65 $\mu g/m^3$ 24-hour average). This certainly indicates alarming level of pollution of fine particulate, and these levels, may have significant bearing on public health in terms of both morbidity and mortality.

It may be mentioned that it is expected that pollution levels ($PM_{2.5}$) will be high in the winter months due to low mixing heights and calm conditions in the atmosphere, which results in stagnation of the pollutants.

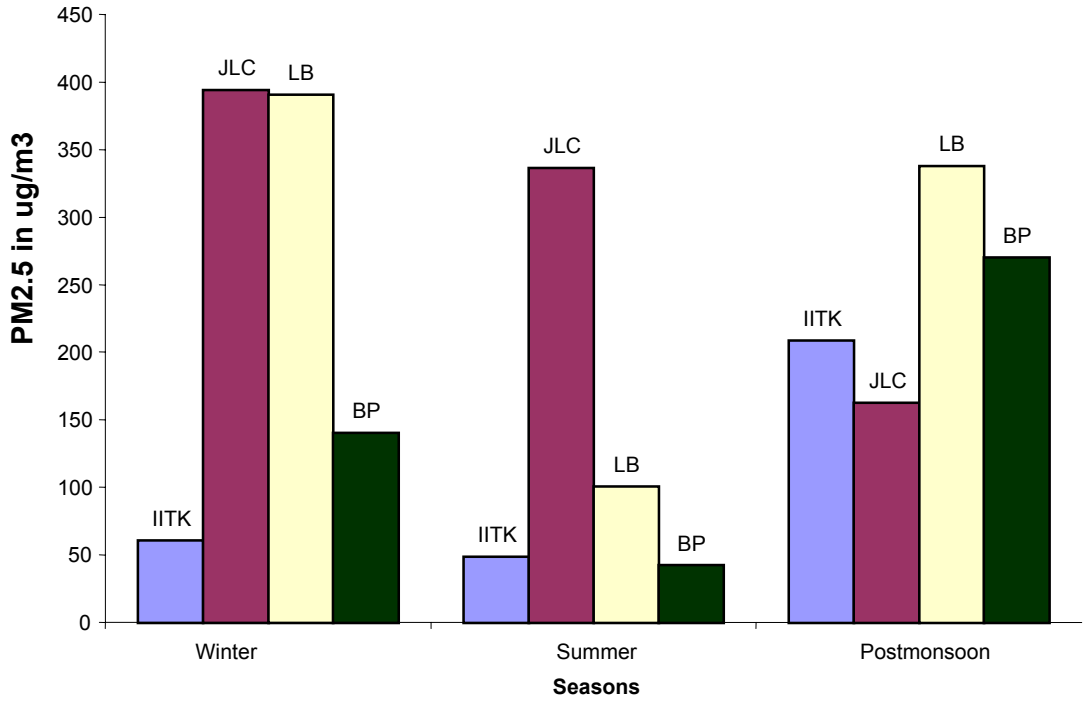



Figure 5 Ambient Air $PM_{2.5}$ Levels at four sites (24-hr)

**Winter Vs Summer**

As seen from Figure 5, the ambient air pollution levels at BP ($PM_{2.5}$: 42 μg/m$^3$) and IITK ($PM_{2.5}$: 49 μg/m$^3$) were much lower than the urban sites in summer months. The important point is that in winter the levels were much higher at all locations including at BP which then showed the $PM_{2.5}$ levels as 140 μg/m$^3$. It is to be noted that winter season is characterized by low winds and low mixing height resulting in poor dispersion. It was also noticed (on some occasion) that in the village site (i.e. BP), there was a tendency to burn any combustible material for heating in the winter. Results signify that the levels obtained at the BP and IITK will be the background levels those will be typically found in India.

The two urban locations (JLC and LB) have shown much higher levels compared to IIT and BP. $PM_{2.5}$ levels are very high at JLC ($PM_{2.5}$: 344 μg/m$^3$). The $PM_{2.5}$ levels compared to the air quality standard of the USEPA (65 μg/m$^3$ 24-hour average) are more than five times higher. What is more alarming is the fact that at JLC, even in summer, the levels are not coming down like other locations. The typical levels of $PM_{2.5}$ common in urban cities in Norway are: 5-10 μg/m$^3$ (summer) and 10-20 μg/m$^3$ (annual average). This certainly indicates alarming

level of pollution of fine particulate, and these levels, may have significant bearing on public health in terms of both morbidity and mortality in JLC area.

**Post Monsoon**

The post-monsoon sampling could begin only in the month of October as rains continued even in the month of September 2004. As a result, the sampling had to spread over October-December months to cover all four locations. It appears that extension of sampling period had its impact on air quality levels. It is clear from Figure 5 that the levels were lower at JLC and higher at BP and IIT. It is in contrast to results obtained from summer and winter samplings. The probable reason for such a change in the air quality is the fact that during October month (just after heavy rains in September), the soil was wet and had high moisture content in soil will minimize re-suspension of dust from soil and perhaps more importantly, all pollutants including $PM_{2.5}$ were washed out due to rains prior to sampling in October. However, at other locations, BP and IIT, when sampling could be taken up in November and December, winter was already setting in. Winter months are characterized by low wind speed and inversion, resulting in high concentrations of pollutants. Moreover, the built up of pollutant also take place in winter months compared to September and October months which are very clean periods.

### 3.2.2. Indoor Air

**Particulate Matter**

The sampling results of indoor sampling in various seasons in the kitchen area are shown in Figure 6.

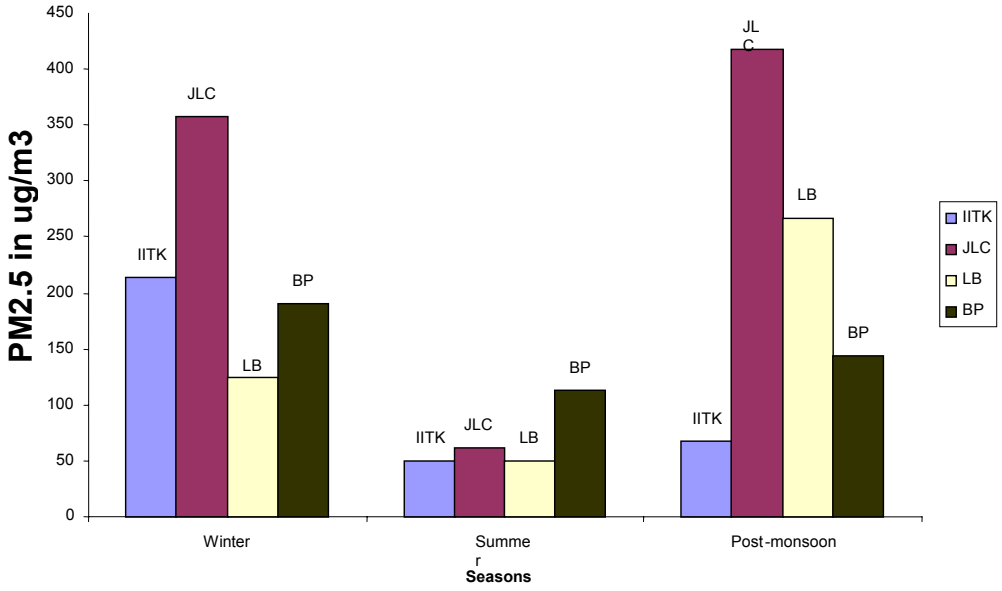



Figure 6 Indoor PM2.5 Levels at four sites (24-hr)

It is clear from Fig. 6 that seasons have profound impact on indoor air quality. While cooking fuel and pattern remains the same in all seasons, the levels have dropped significantly in summer months. The other interesting point is that pollution problem is severe at urban slums than at the village site. It may be noted that while the peak concentration levels may be higher at the rural site but on a 24-hr basis levels drop as outside air is clean but this does not happen at the urban sites where all round 24-hr levels remain fairly high and constant in the indoor environment due to high pollution levels in outside air.

**CO (Carbon Monoxide)**

Figure 7 presents the indoor CO levels at four sites in various seasons. Once again the impact of outside ambient air seems to be important as indoor air is more polluted at urban locations than site at IITK and even if compared to the village site, which was expected to have high CO levels. It may be noted that while the peak CO concentration levels may be higher at the rural site but on a 24-hr basis, levels drop as outside air is clean but this does not happen at the urban sites where

all round 24-hr CO levels remain fairly high and constant in the indoor environment due to high CO pollution levels in outside air.

As an alternate to understand the CO levels, there is a need to understand peak values. An attempt has been made to examine the variability in CO concentration (Table 5).

Table 5. Statistical Parameters for CO Concentrations

| Parameter | CO Concentration, mg/m$^3$ (Winter) | | | |
|---|---|---|---|---|
| | LB | BP | IITK | JLC |
| Max (5-min avg) | 60 | 60 | 36 | 57 |
| Mean | 6 | 3 | 2 | 4 |
| Std Deviation | 8 | 9 | 3 | 5 |
| COV*, % | 133 | 300 | 150 | 125 |

*Coefficient of Variation (Standard deviation/mean)

Analysis in Table 5 suggests that variability and maximum concentration is the highest in the village site but the average concentration is low, because as soon as cooking is over, levels come down because of dilution from outside air. But at the urban site, CO levels are consistently high (low variability; low COV) indicating continuous source of CO emissions. IITK is the cleanest site as both indoor emissions are insignificant and outside air is also clean.

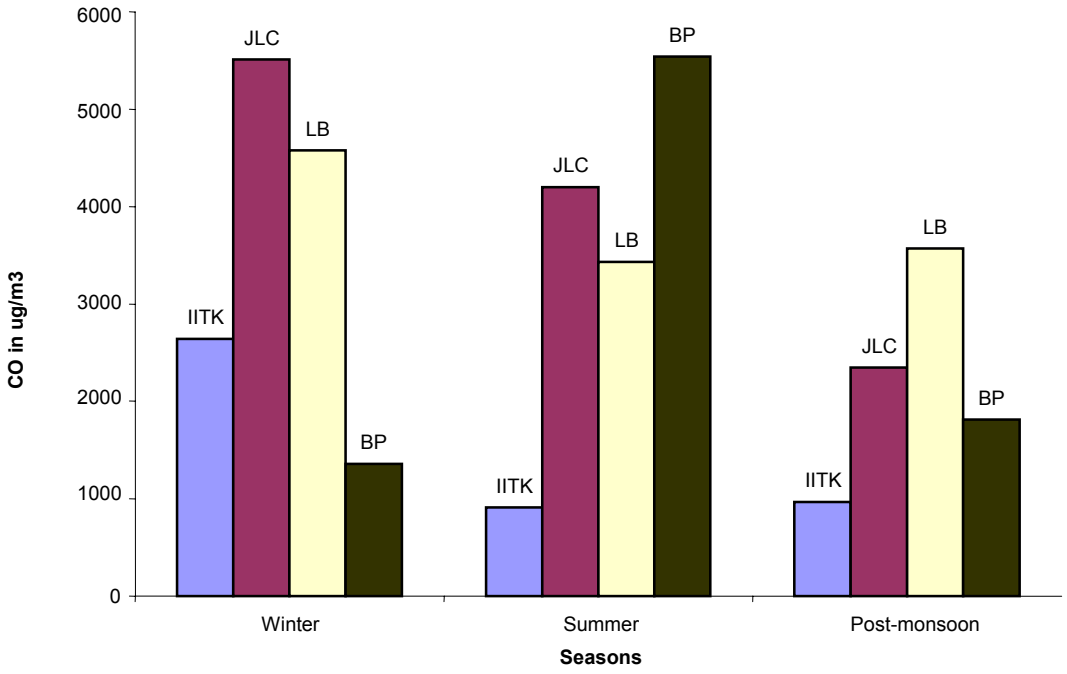



Figure 7 Indoor CO Concentration in different seasons, µg/m$^3$ (24-hr)

**$NO_X$ (Oxides of Nitrogen)**

Figure 8 presents the NOx levels observed in various seasons at four locations. The 24-hour NOx levels are generally low (less than 20 ug/$m^3$) almost at all locations in all seasons except at BP and IIT where the values were high (50-60 ug/$m^3$) and one-time at LB (38 ug/$m^3$). Since most of the cooking appliances in village and urban slums do not have high combustion temperature the low levels are expected. High NOx levels (in a relative sense) at IIT cannot be explained. Although not reported here, the variability of NOx levels were high at BP indicating local emissions while cooking. At other locations, variability was low indicating contribution of sources outside the indoor environment.

### 3.2.3. Ambient Vs Indoor PM2.5 Levels

Generally, it is seen that indoor levels are lower (0.75 times of ambient air) than outside ambient air levels (Figure 9). This is particularly important for $PM_{2.5}$. It appears that a sizeable fraction of $PM_{2.5}$ being lighter and having the buoyancy is above the breathing zone in ambient air (i.e. above 5-7m).

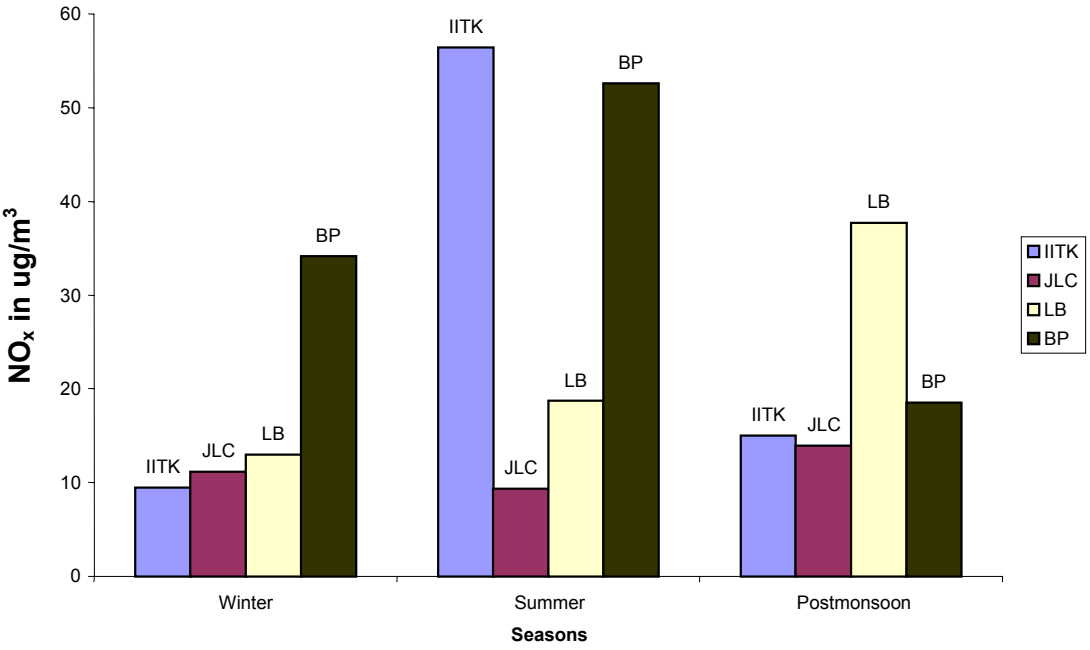



Figure 8 Indoor $NO_x$ in different seasons (24-hr).

### 3.2.4. Personal Sampling

Figure 10 shows the results of the personal sampling of $PM_{2.5.}$ The personal exposure comes as the mixture of ambient and indoor air. Personal exposure should largely come from the indoor air (that may be influenced by ambient outside air) as women and children spend most of the time inside the house. It is noteworthy that while ambient air levels were relatively low at the BP site, the personal exposure is quite high in almost all seasons at the village site. This reflects higher exposure to the women which are inside the house in BP. Similarly, personal exposure was high at JLC and LB due to deteriorated ambient air quality which has influenced the indoor air.

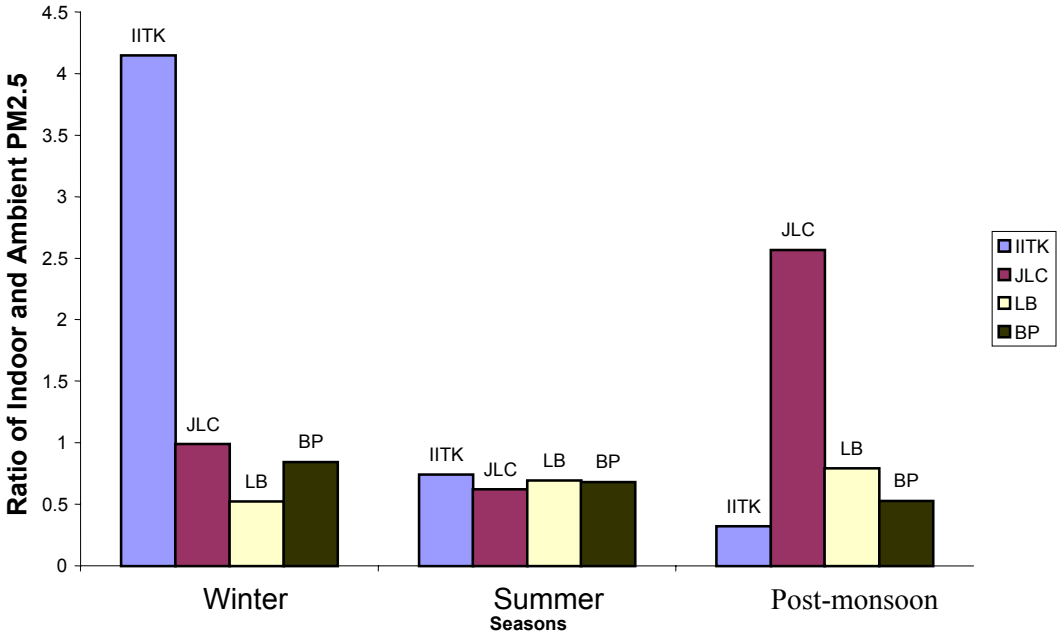



Figure 9 Indoor to Ambient PM2.5 Ratio in different seasons.

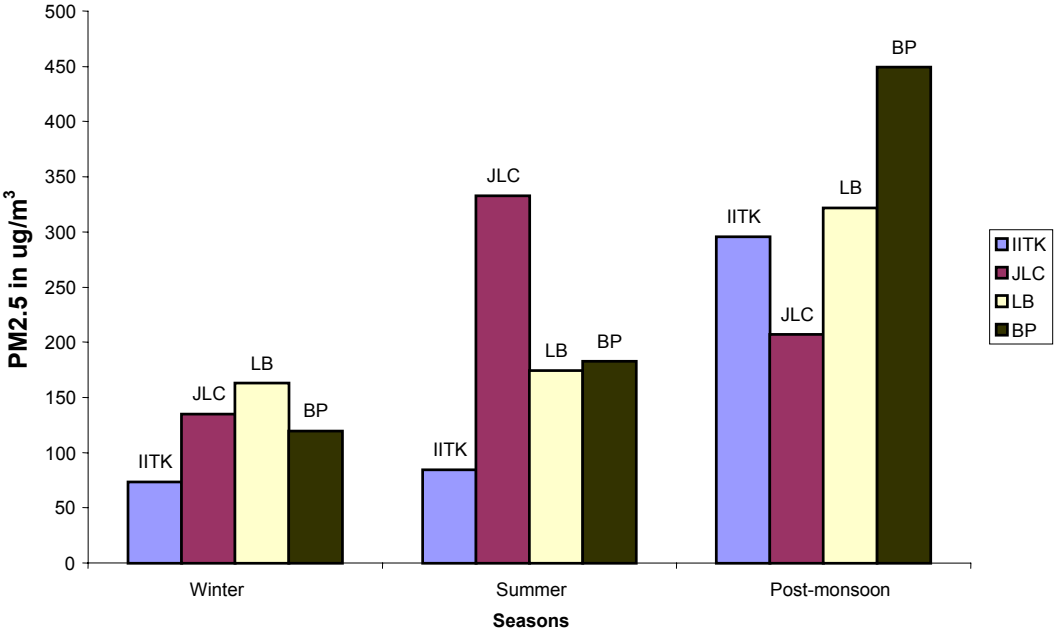



Figure 10 Personal $PM_{2.5}$ at in different seasons (24-hr).

### 3.2.5. PAHs

PAHs represent a group of organic compounds consisting of carbon and hydrogen with two or more rings. A large number of PAH species are formed in most combustion processes. In this study, 12 PAHs have been studied; Table 6 presents these PAHs with unit risk factors and abbreviations used.

Table 6. PAHs studied and their Unit Risk Factor.

| S. No. | PAH | Abbreviation | Unit risk $(\mu g/m^3)^{-1}$ | Relative Potency, to BaP |
|---|---|---|---|---|
| 1 | Phenantherene | Phn | - | - |
| 2 | Anthracene | Ant | $(1.2\text{-}13)\times10^{-2}$ | 0.28-0.32 |
| 3 | Fluoranthene | Flt | $(8.7\text{-}87)\times10^{-5}$ | 0.001-0.01 |
| 4 | Pyrene | Pyn | - | |
| 5 | Chrysene | Chn | $(8.7\text{-}870)\times10^{-5}$ | 0.001-0.1 |
| 6 | Benz (a) Anthracene | B(a)A | $(1.2\text{-}1.3)\times10^{-4}$ | .014-0.145 |
| 7 | Benz (b) Fluoranthene | B(b)F | $(0.87\text{-}1.2)\times10^{-2}$ | 0.1-0.141 |
| 8 | Benz (k) Fluoranthene | B(k)F | $(8.7\text{-}87)\times10^{-4}$ | 0.01-0.1 |
| 9 | Benz (a) Pyrene | B(a)P | $(8.7)\times10^{-2}$ | 1 |
| 10 | Dibenz(a,h) Anthracene | DB(ah)A | $(7.7\text{-}43.5)\times10^{-2}$ | 0.89-5.0 |
| 11 | Benzo(ghi)Perylenre | B(ghi)P | - | - |
| 12 | Indeno(1,2,3-cd)pyrene | INP | $(5.8\text{-}20.2)\times10^{-3}$ | 0.067-0.232 |

As seen from the Table 6, BaP and DB(ah)A have the highest potential for causing cancer. Figures 11-14 present the PAH levels in ambient air in particulate ($PM_{2.5}$). The emission pattern from almost all sources suggests that 70-80 percent of PAHs are volatile/semi-volatile PAHs (up to four ring compounds). It was found that all compounds lighter than Phn were absent in particulate and are expected to be in volatile phase. The Phn would certainly be partitioned between particulate and gaseous phase. The other semi-volatile compounds like Ant, Flt, Pyn were found in abundance at all locations and in all seasons as their emission quantities are much high compared to other compounds from most of the emission sources.

**Figure 11 (a) Particulate PAHs in JLC (winter)**
**(Total: 35 ng/m3)**

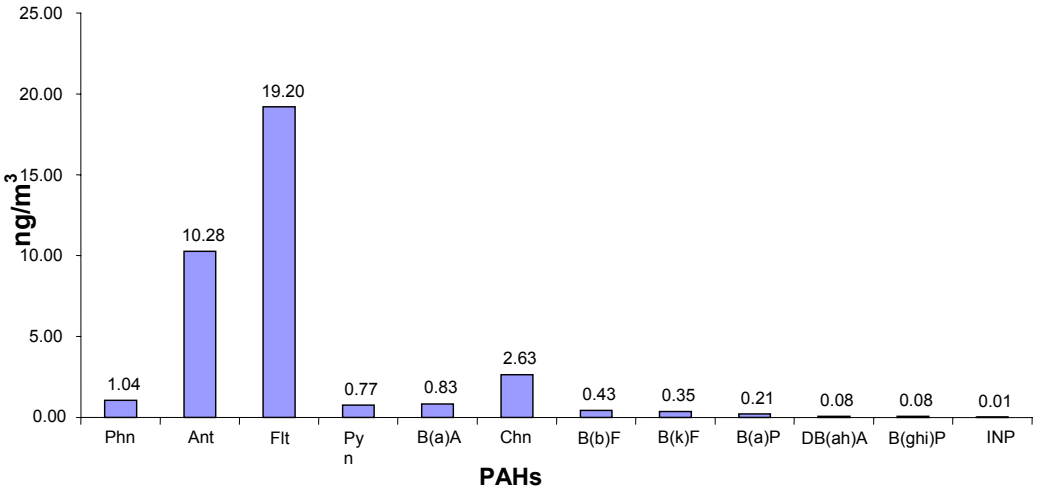



**Figure 11 (b) Particulate PAHs in JLC (summer)**
**(total: 22 ng/m$^3$)**

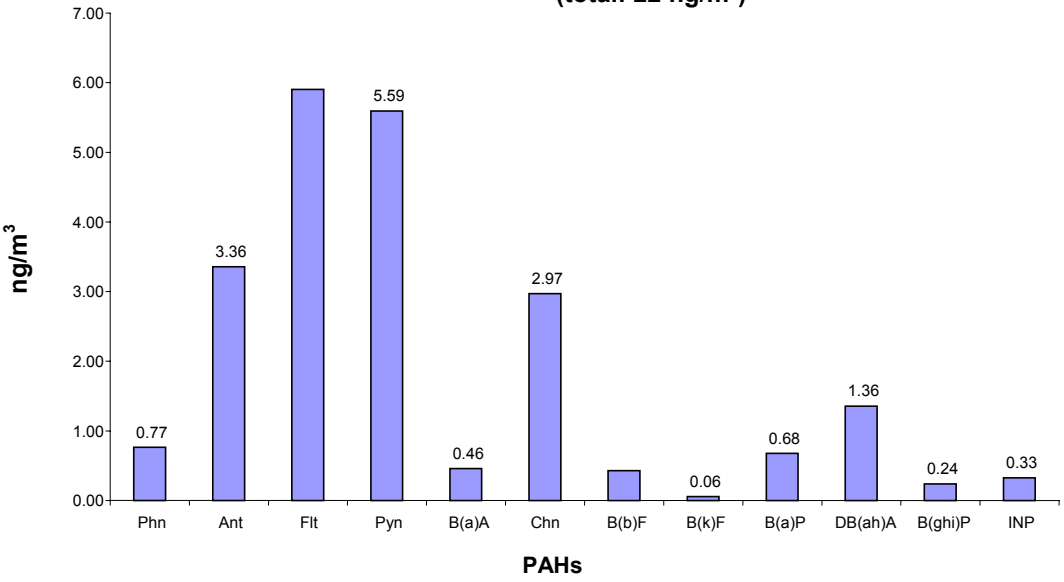


**Figure 11 (c) Particulate PAHs in JLC (Post Monsoon) (total: 27 ng/m$^3$)**

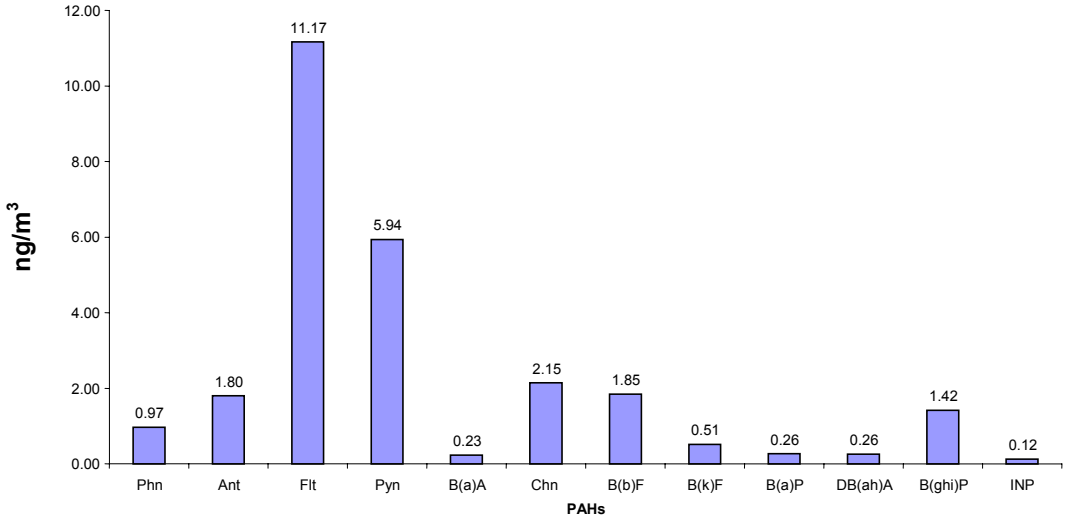



**Figure 12 (a) Particulate PAHs in LB (winter) (total: 21 ng/m$^3$)**

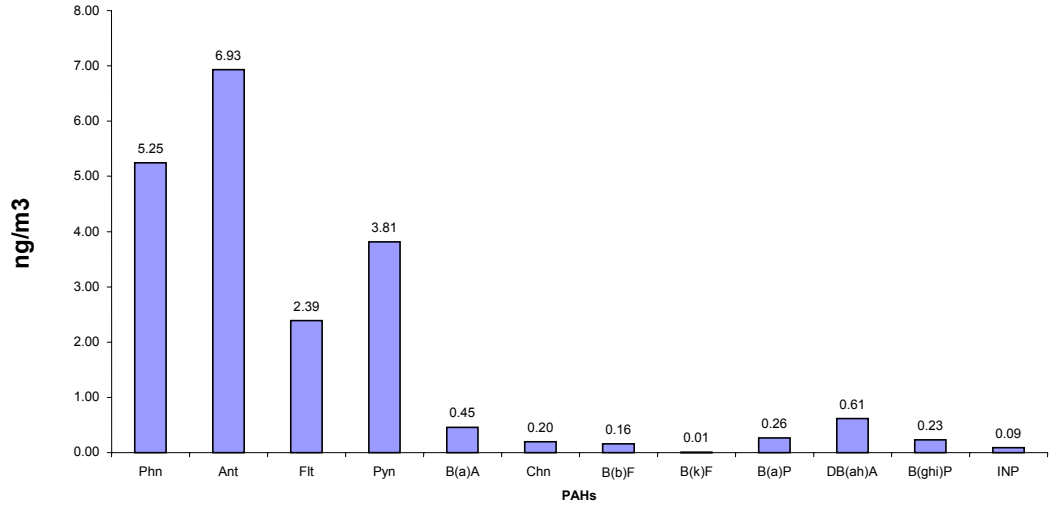


**Figure 12 (b) Particulate PAHs in LB (summer)**
**(total: 24 ng/m$^3$)**

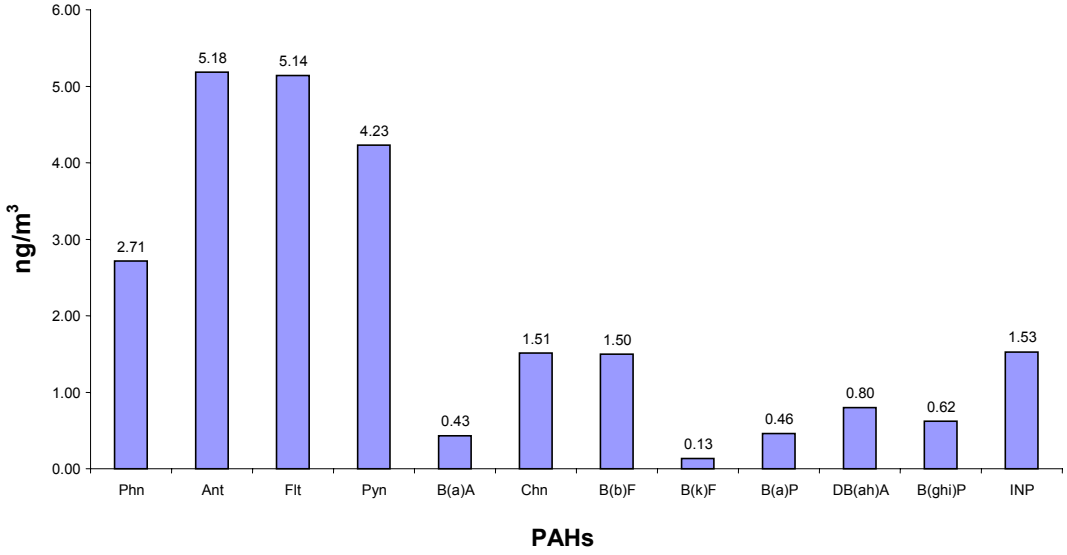



**Figure 12 (c) Particulate PAHs in LB (post-monsoon)**
**(total: 59 ng/m$^3$)**

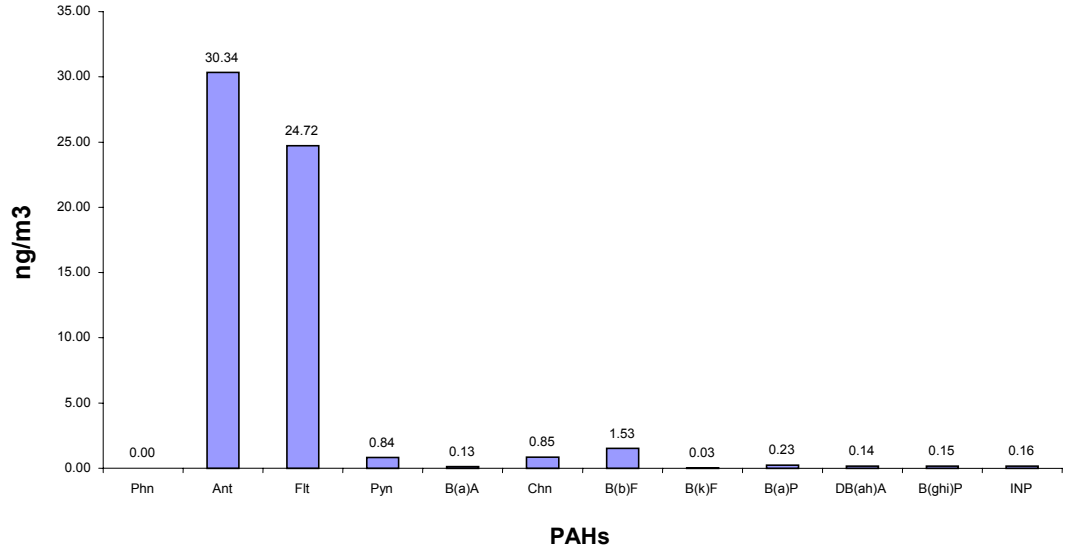


**Figure 13 (a) Particulate PAHs in IITK (winter)**
**(total: 28 ng/m$^3$)**

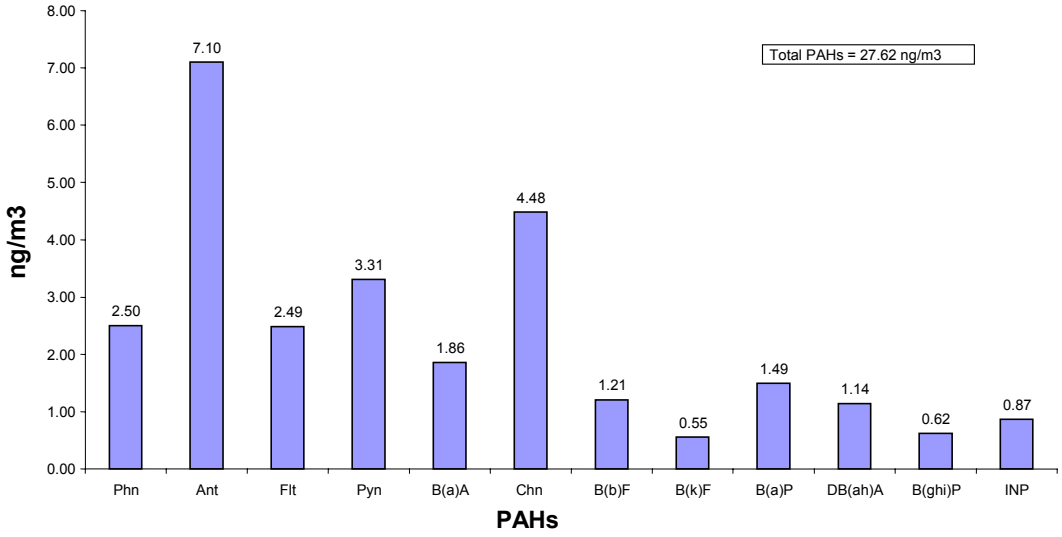



**Figure 13 (b) Particulate PAHs in IITK (summer)**
**(total: 4 ng/m$^3$)**

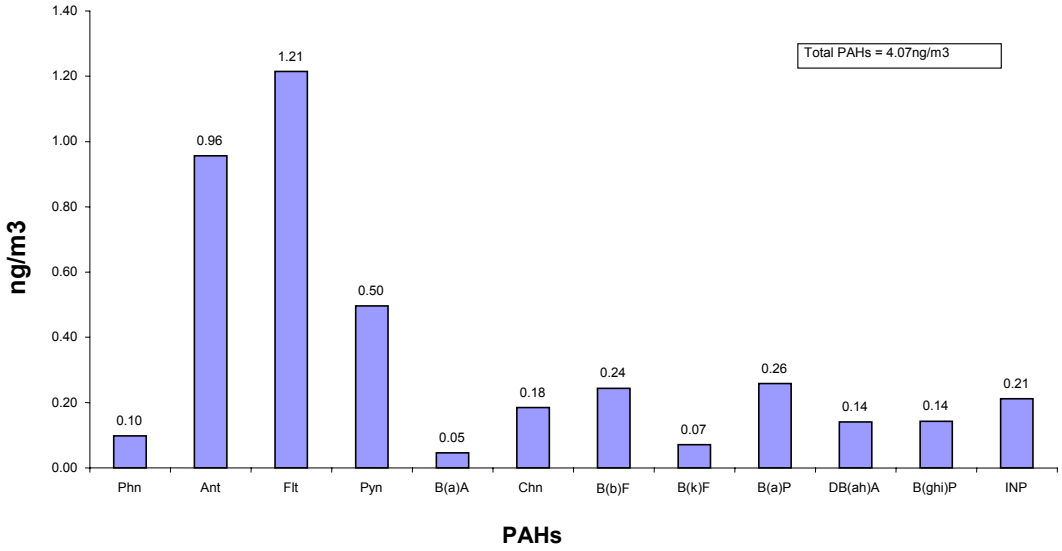
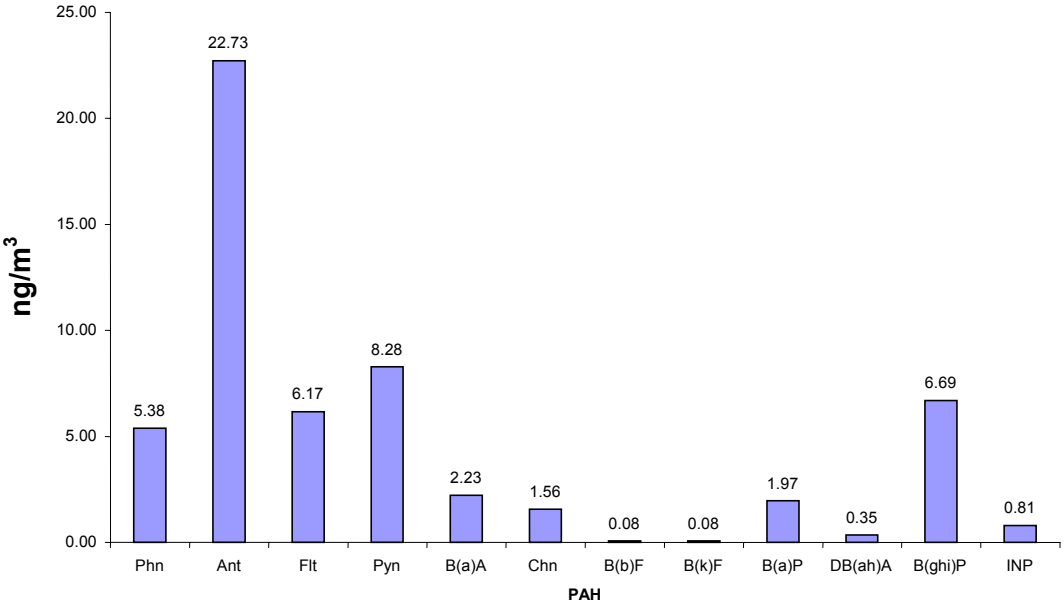


**Figure 14 Particulate PAHs in BP (winter)**
**(total: 57 ng/m$^3$)**




The total PAHs have been found in the range 4 ng/m$^3$ (at IITK) - 59 ng/m$^3$ (at LB). At JLC, the most polluted site in terms of particulate matter, PAHs were in a narrow range of 22-35 ng/m$^3$ in all seasons. Although at BP samples were few and particulate pollution low, the PAHs were high at 57 ng/m$^3$ (winter). It implies that while in villages, the general air quality may be good, but not necessarily in terms of toxic compounds. In general, the levels in summer have dropped at all locations compared to winter seasons. This can be attributed to the fact that (i) at higher temperature PAHs may be in volatile phase (ii) emission sources in summer may be few and (iii) dispersion is poor in winter months.

PAH levels observed in this study are compared with levels found at other locations in Table 7.

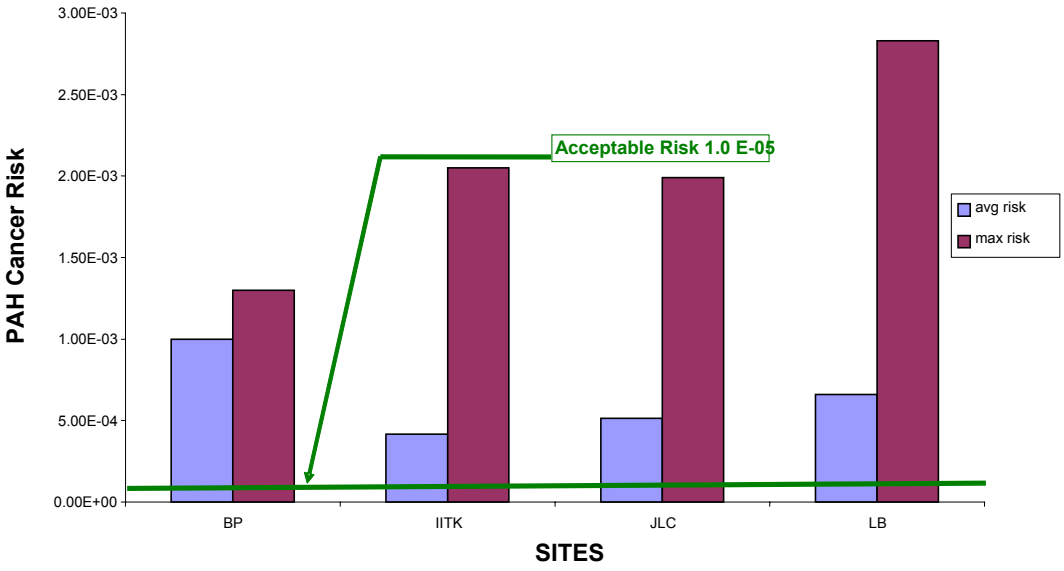
Table 7. Comparison of Observed PAH Levels.

| **Total PAHs (8-12 compounds), ng/m$^3$** | | | |
|---|---|---|---|
| Delhi (CPCB, 2003) (in $PM_{10}$) | Mumbai (Kulkarni and Venkataraman, 2000) (in $PM_{10}$) | Kanpur (present study) (in $PM_{2.5}$) | Lista, Norway (NILU, 2004) (in PM) |
| 6-53 (year 2000) | 24-38 (year 1996-97) | 4-59 (year 2003-05) | 0.01-1.32 (year 2002) |

It is clear from the above table that Kanpur is highly polluted in terms of carcinogenic PAHs, apart from high level of particulate pollution. It needs to be recognized that in the present study PAHs have been measured in $PM_{2.5}$, the levels can be even higher in Kanpur when analysis for PAHs is done on $PM_{10}$ and if volatile component is also included.

The PAH levels can also be transformed into risk estimates for respiratory cancer using the unit risk factors reported in Table 6. This plot of respiratory Risk is shown in Figure 15.

**Figure 15: PAH Cancer Risk in Kanpur**




It is noteworthy that cancer risk due to PAHs exceed at all locations and There is an immediate need to control / Prevent PAHs.

### 3.2.6. Metals

In this study, $PM_{2.5}$ air samples were analyzed for heavy metals: Pb, Fe, Zn, Ni, Cd, Mg and Cr and few samples for As and Se. In all over 130 samples were analyzed for metals covering four locations and three seasons. The results of average metal concentrations are shown in Figures 16 through 18. It can be observed from these figures that levels of heavy metal are highest at urban locations (JLC and BP) followed rural site BP and IITK. The noteworthy point is that in spite of introduction of unleaded gasoline, lead continues to be present in ambient air and a few values were even higher than Indian National Air Quality Standard of 1.0 $\mu g/m^3$ and this may pose a serious health risk. For example, the average value of lead in summer at JLC was over 3.3 $\mu g/m^3$ and the peak value was 5 $\mu g/m^3$. A preliminary investigation revealed that there are secondary lead smelters in the city and batteries containing lead are reprocessed in a large number.

The heavy metal levels found in the present study in Kanpur were compared with the studies conducted at some other places (Table 8). It was found that the levels of all the metals were 5-10 times higher than the levels in European countries like Spain and Norway. Fe levels in the present study were found comparable with the Fe levels at Taiwan and Spain, but the levels at Delhi were reported to be very high. Compared to Delhi, metal levels are higher in Kanpur. In summary, similar to PM levels, the levels of toxic metals in air are much higher in Kanpur city.

Table 8. Comparison of Heavy Metal Level at Various Locations

| **Location** | **Pb** ($ng\ m^{-3}$) | **Ni** ($ng\ m^{-3}$) | **Cd** ($ng\ m^{-3}$) | **Cr** ($ng\ m^{-3}$) | **Fe** ($\mu g\ m^{-3}$) |
|---|---|---|---|---|---|
| **Spain**[1] | 8-698 | 0.1-21 | 0.1-4 | 0.1-22 | 0.20-10 |
| **Taiwan**[2] | 133 | - | - | 656 | 6.99 |
| **Norway**[3] | 0.36-10.36 | 0.09-5.71 | 0.01-0.28 | 0.21-1.56 | - |
| **Delhi**[4] | 600-1900 | - | 20-150 | 300-700 | 5-20 |
| **Mumbai**[5] | 1060±300 | 160±40 | - | 150±60 | - |
| **Present Study(urban)** | 188-5005 | ND-2549 | ND-207 | ND-5464 | 0.2-15 |
| **Present Study (rural)** | 33-2392 | ND-906 | ND-70 | ND-44 | 0.2-8 |

1-Querol et. al. (2002), 2-Fang and Wong (1999), 3-NILU (2002b), 4- Balachandran et. al (2000), 5- Kumar et al. (2001)

**Fig. 16 (a) Ambient air Metal levels (winter)**

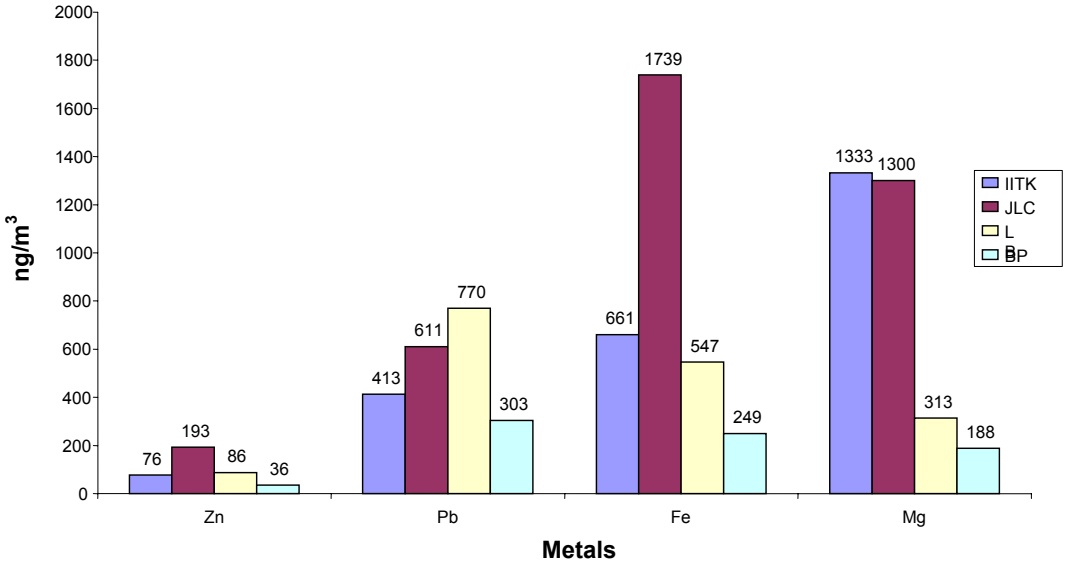



**Figure 16 (b) Ambient Air Metal Levels (winter)**

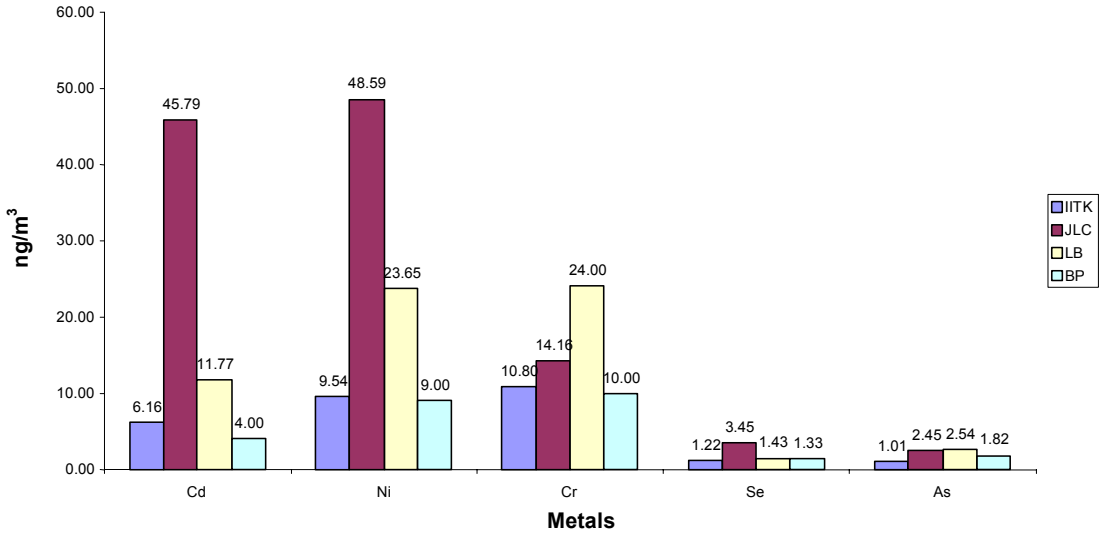


**Fig. 17(a)Anhbient Air Metals Levels (summer)**

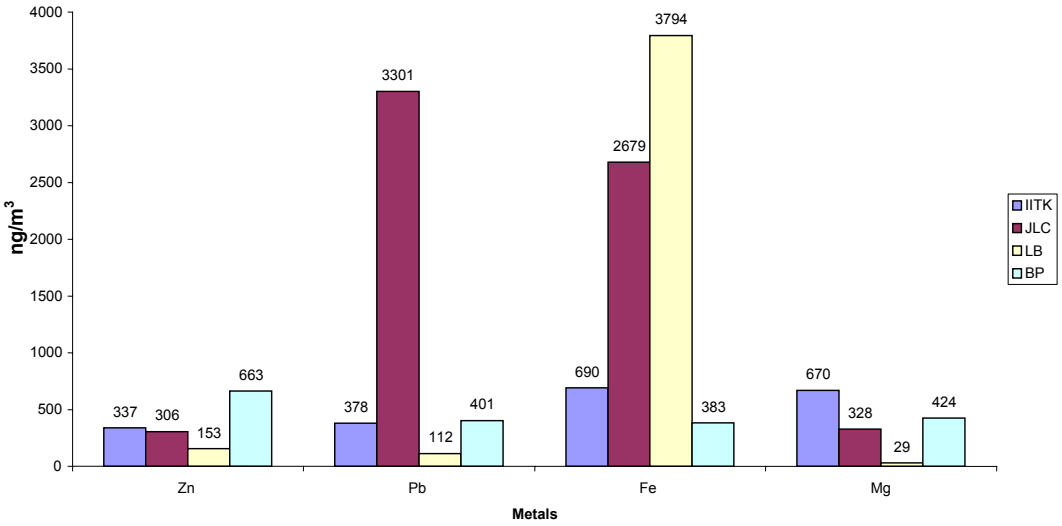



**Fig 17 (b) Ambient Air Metal Levels (summer)**

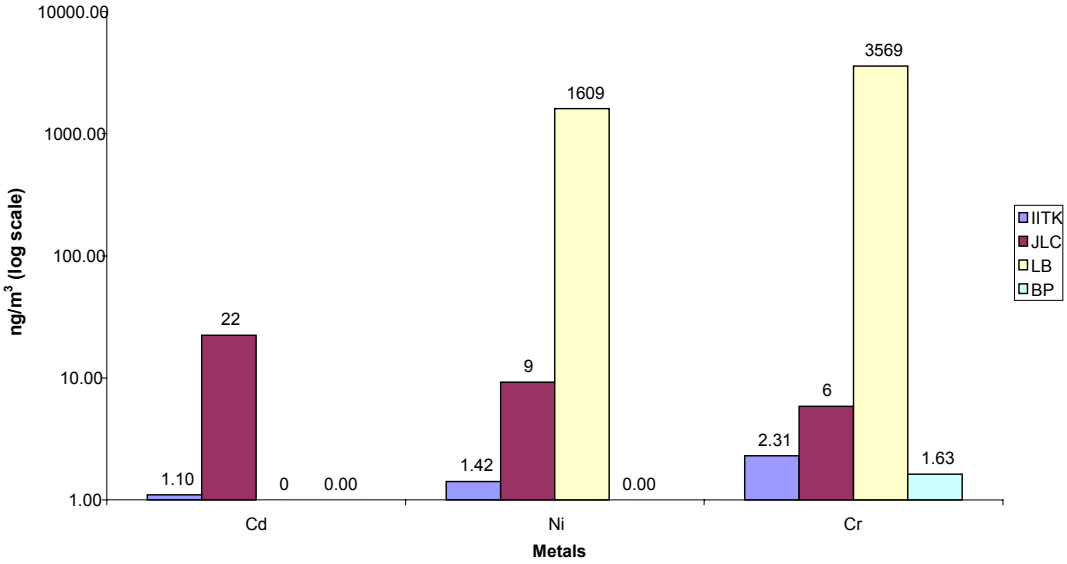


**Fig 18 (a) Ambient Air Metal Levels (Post Monsoon)**

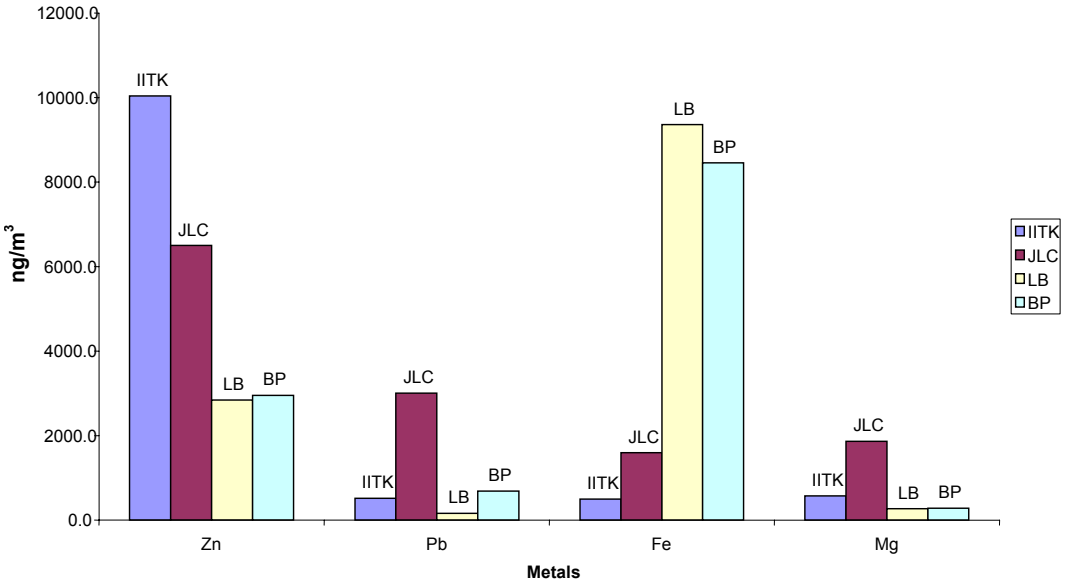
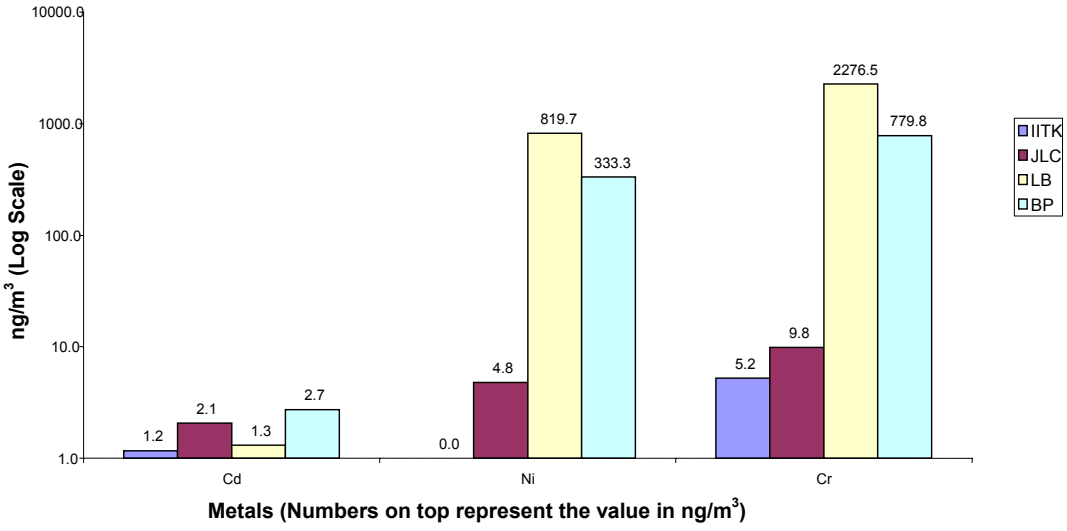



**Fig 18 (b) Ambient Air Metal Levels (Post Monsoon)**



The European Union (EU) has prescribed standards for, As, Cd, and Ni as 6 $ng/m^3$, $5ng/m^3$ and 20 $ng/m^3$ respectively. In winter, Cd levels are exceeding the standard at all locations except at BP in winter and JLC in summer at (Figures 16-18). Further, EU standard for Ni is exceeded in every season at one or the other urban locations. In summary it is concluded that Pb, Ni and Cd exceed the standards by a large margin and may pose a serious health risk.

### 3.2.7. Spirometry and Lung Function

**PEFR**

PEFR is an indicator of asthmatic condition of an individual. According to the guidelines provided by National Asthmatic Education and Prevention Program (NIH, 1997) asthmatic conditions have been classified into three zones: (i) Green (ii) Yellow and (iii) Red. This classification is based on percentage of observed PEFR value of predicted PEFR value. Predicted PEFR value (or acceptable value) of an individual depends upon sex, age and height (ATS, 1991).

- Green Zone – Observed PEFR value is above 80 % of the predicted value of individual; no symptoms of asthma.
- Yellow Zone – Observed PEFR value is more than 50 % but less than 80 % of the predicted value; beginning of asthma.
- Red Zone - Observed PEFR value is less than 50 % of the predicted value; needs medical attention.

As per the guidelines of NIH (1997), based on PEFR value, asthmatic status of individual members of cohorts was determined (Figures 19(a), (b) and (c)). A complete diagnosis was not performed on the individuals of the cohort to determine the type of disease. With the limited tests (PEFR, FVC and $FEV_1$ – described later) performed, it was not possible to state clearly if the individuals really suffered from asthma or the problem was due to dust-induced bronchitis. To differentiate between asthma and dust-induced bronchitis, post bronchodilator test was required. Nonetheless, study suggests that in the areas of high pollution

people suffers from low PEFR values which may indicate asthma or dust-induced bronchitis.

It is clear that at urban sites (LB and JLC; Figure 19 (a)) which are more polluted (in winter season) about 15-10 percent population many suffer from asthma at the level where medical attention is immediately required. This situation improves in summer months when particulate levels drop significantly (Figure 19 (b)) and then again as $PM_{2.5}$ levels start to increase in post-monsoon/winter, performance of larger populations deteriorate in terms of PEFR.

**Figure 19 (a) Distribution of PEFR values (Winter)**

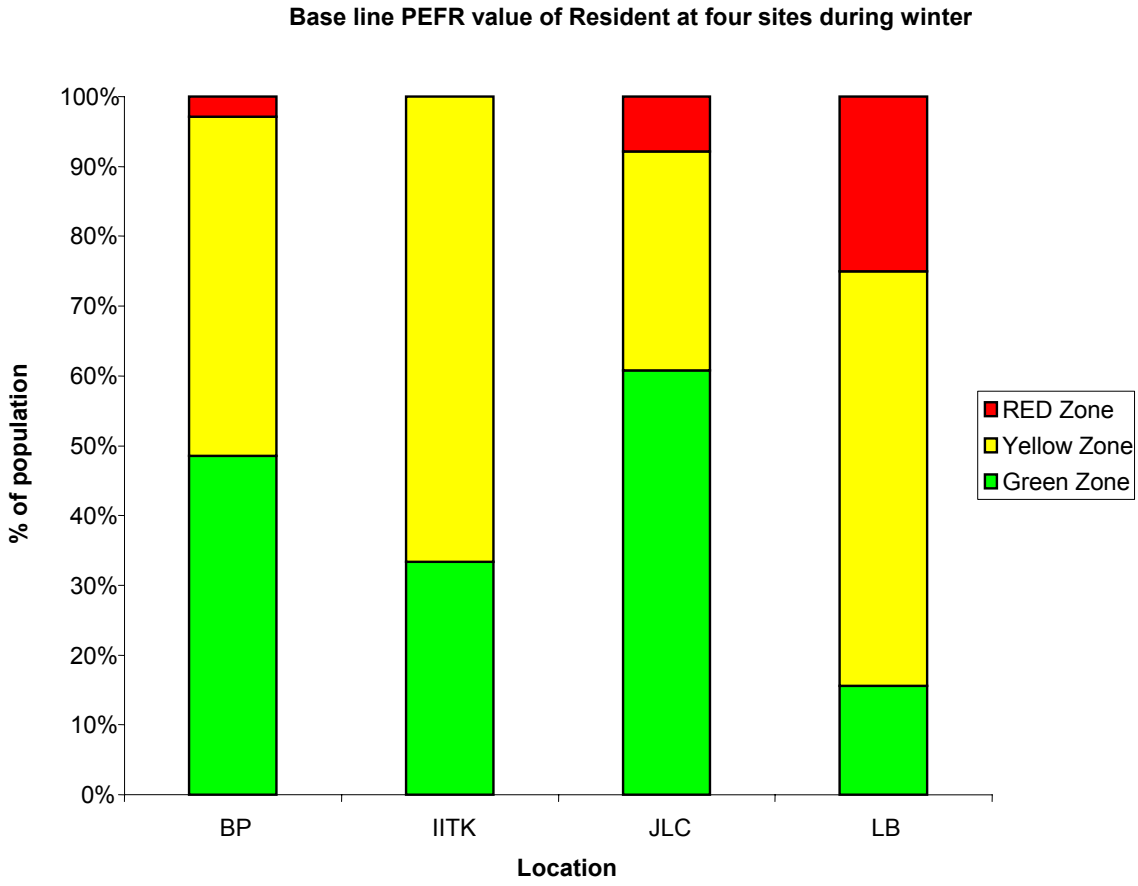


**Figure 19 (b) Distribution of PEFR Values (summer)**

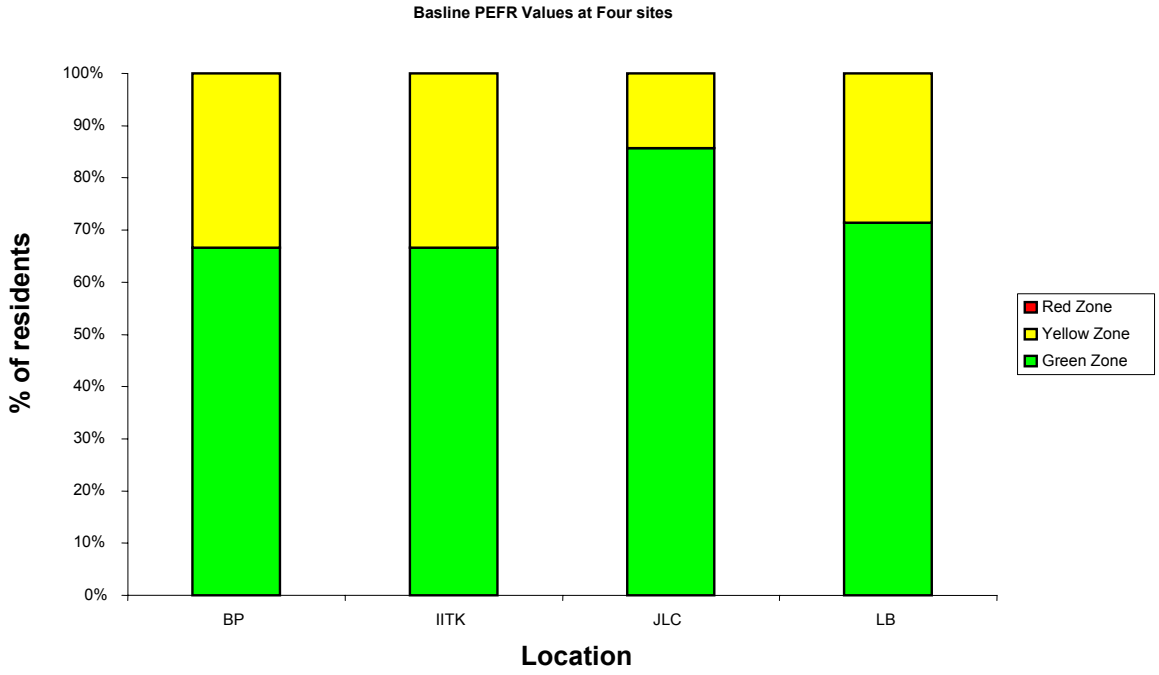
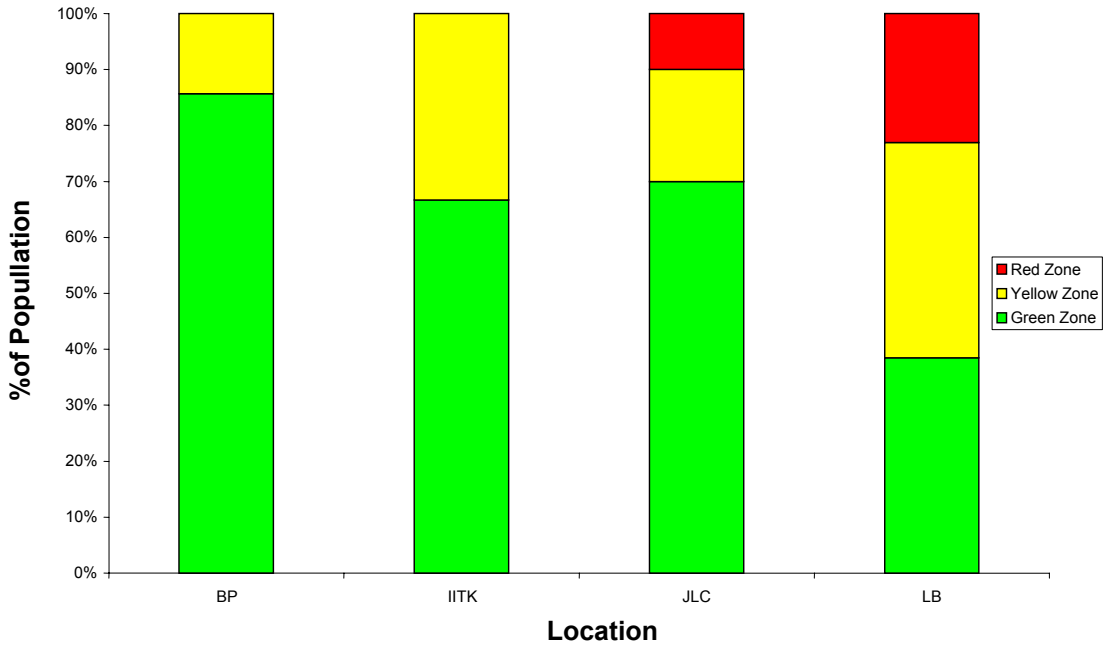



**Figure 19 (c) Distribution of PEFR Values (post-monsoon)**



**Spirometry Results and Discussion**

$FEV_1$, PEFR and FVC are the key lung function parameters that reflect long term health impact of air pollution (Bates 1999) on performance of lungs. $FEV_1$ and FVC both depend on age, height, weight, sex and race. Variations in difference between observed and predicted $FEV_1$ and FVC (difference referred to as $\Delta FEV_1$ and $\Delta$FVC) were examined with respect to pollution level (**Figures 20 through 25)**. As the lung parameters, $FEV_1$ and FVC are affected due to long-term exposure and do not show diurnal variations, no seasonal analysis has been carried out. In fact, the association between $\Delta$FEV1/$\Delta$FVC is examined with the annual mean values and exposure of PM2.5 comprising all seasons (Table 9; discussed later).

In order to clearly see the difference between predicted and observed value of $FEV_1$ and FVC, the predicted values were sorted in the ascending order as shown in **Figures 20 through 27**. It is evident from these figures that there are more persons close to predicted values at rural site and other cleaner site, IITK (in a relative sense) compared to other two urban sites, LB and JLC those are highly polluted. As it can be seen that in terms of $PM_{2.5}$ levels at LB and JLC sites are similar and again PM2.5 levels at BP and IITK are similar (Table 9), corresponding mean deviation in $FEV_1$ and FVC (observed - predicted value) are also similar respectively. However, at IITK and BP, the deviation (i.e. average of (observed values – predicted values)) is much less suggesting healthier status of population than at the urban sites. The deviations in $FEV_1$ and FVC are: (a) $\Delta$ $FEV_1$ -0.44 L (LB), -0.22 (JLC), -0.12 L (IITK) and - 0.05 L (BP) and (b) $\Delta$FVC - 0.46 L (LB), -0.31 (JLC), -0.14 L (IITK) and -0.16 (BP). It is clear that at no location population is in proper lung performance on the parameters related to air pollution.

Xiping et al. (1991) have reported change in $FEV_1$ and FVC values in Beijing as function of TSPM (Total suspended particulate matter; annual TSPM 389 $\mu g/m^3$ (residential), 261 $\mu g/m^3$ (suburban) and 449 $\mu g/m^3$ (industrial area)). They have reported mean reduction in $FEV_1$ from a clean area (with coal as cooking fuel) to polluted area as about 0.16 L and in terms of FVC the reduction was 0.34 L. One can assess change in $FEV_1$ in case of polluted and non-polluted

area in Kanpur. For example, this reduction in $FEV_1$ can be about 0.25 L (i.e. 0.33 (LB+JLC) -0.08 (IIT+BP)) and for FVC it can be 0.27 (i.e. 0.42 (JLC+LB) – 0.15 (BP+ IITK)) – this implies that for every increase of 100 μg/$m^3$ in PM2.5 level, there is an average reduction of 0.17 L in FEV1 and FVC; this finding is the similar to one reported by in Xiping et al. (1991). The study by Xiping (1991) also highlighted that in addition to ambient air monitoring, there is a need to consider indoor air pollution levels to assess the reduction in $FEV_1$ and FVC parameters which are the indicator of air pollution and health effects.

An attempt has been made to compare variations in $\Delta FEV_1$ and ΔFVC values with respect to three particulate indicators $PM_{10}$, $PM_{2.5}$ and estimated exposure based on indoor and outdoor ambient concentrations (Table 9).

Table 9. Mean variation of $\Delta FEV_1$ and ΔFVC and mean particulate concentrations

| Site | ΔFEV1 (L) (mean) | ΔFVC (L) (mean) | PM10 (μg/m3) | PM2.5 (μg/m3) | $PM_{2.5}$ Exposure, μg/d | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Winter | Sum | Post-Monsoon | Average |
| BP (n=65) | -0.05 | -0.16 | 189±44 | 151±33 | 1645 | 494 | 3185 | 1773 |
| IITK (n=21) | -0.125 | -0.14 | 151±60 | 106±46 | 671 | 539 | 2299 | 1168 |
| JLC (n=78) | -0.218 | -0.31 | 371±186 | 297±135 | 7249 | 6313 | 2826 | 5457 |
| LB (n=57) | -0.44 | -0.46 | 389±151 | 274±124 | 4291 | 1067 | 6708 | 3019 |

The results suggest that there is a definite impact of particulate pollution on lung functions. Although there is not one to one correspondence between particulate matter level and lung function on every occasion, there exist broad categories indicating high pollution levels reduce lung function parameters and vice versa.

**Fig 20: FEV1- Predicted Vs Observed at JLC (all seasons)**

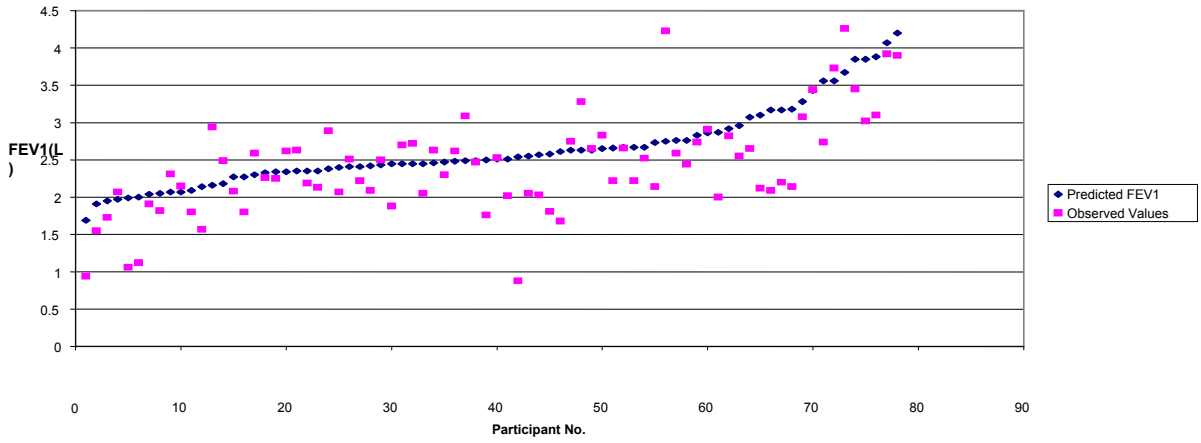



**Fig 21: FEV1- Predicted Vs Observed at LB (All Seasons)**

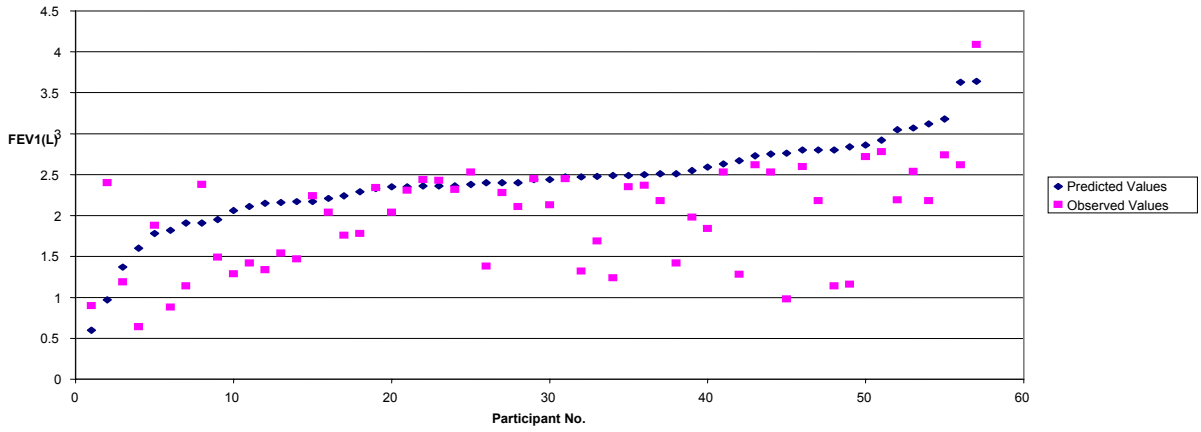



**Fig: 22 FEV1 Comparison (Predicted Vs Observed) at BP -All Seasons**

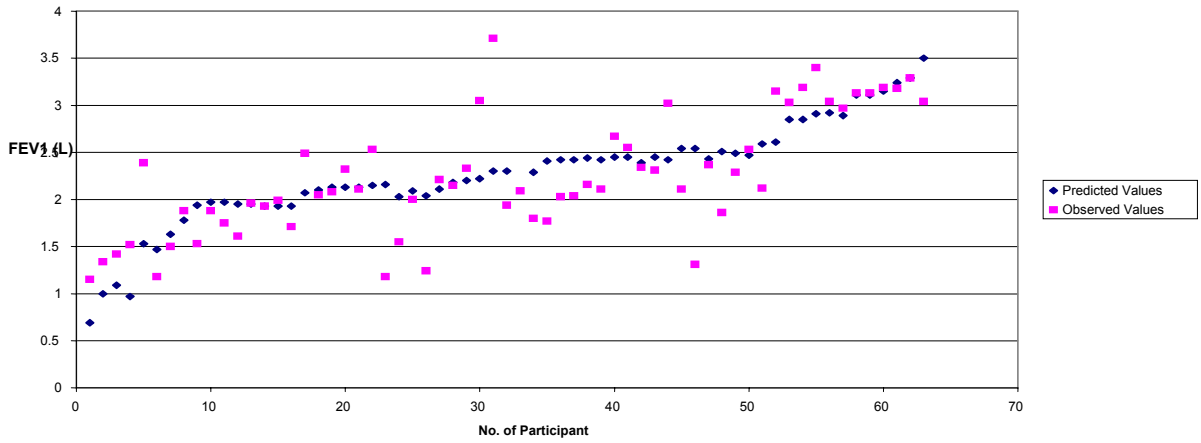


**Fig 23: FEV1 Comparison (predicted vs Observed) at IITK - (All Seasons)**

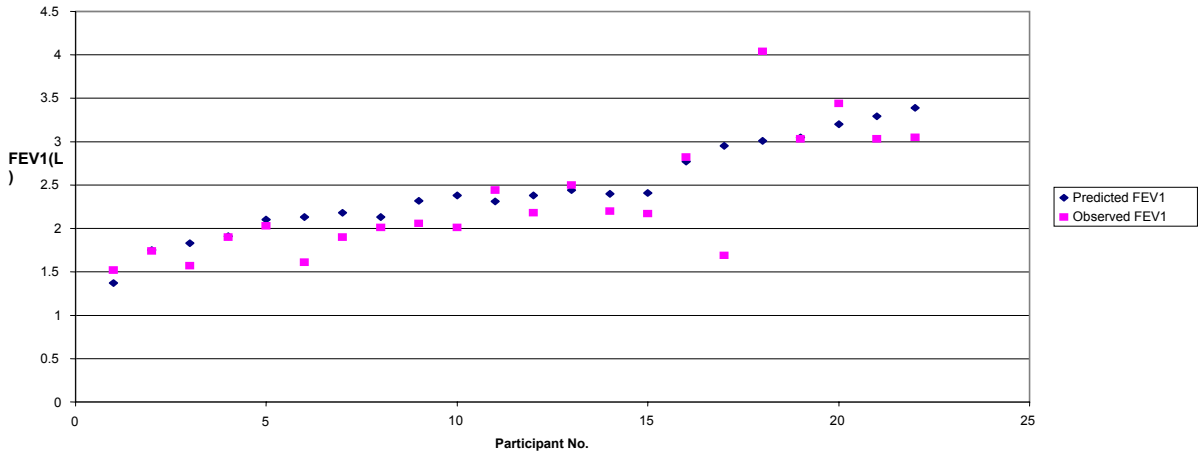



**Fig 24: Comparison of FVC (Predicted vs Observed) at JLC (all seasons)**

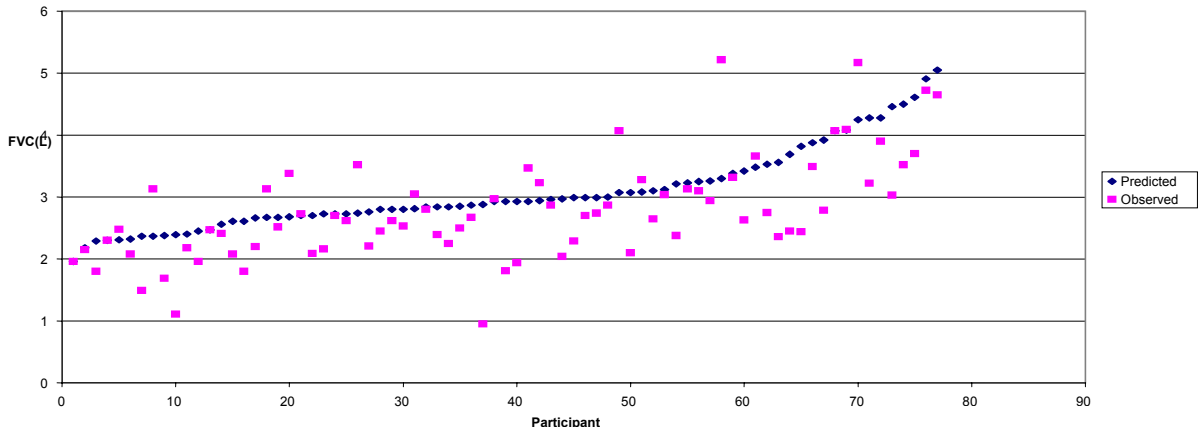



**Fig 25: Comparison of FVC (Predicted vs Observed) at LB (all seasons)**

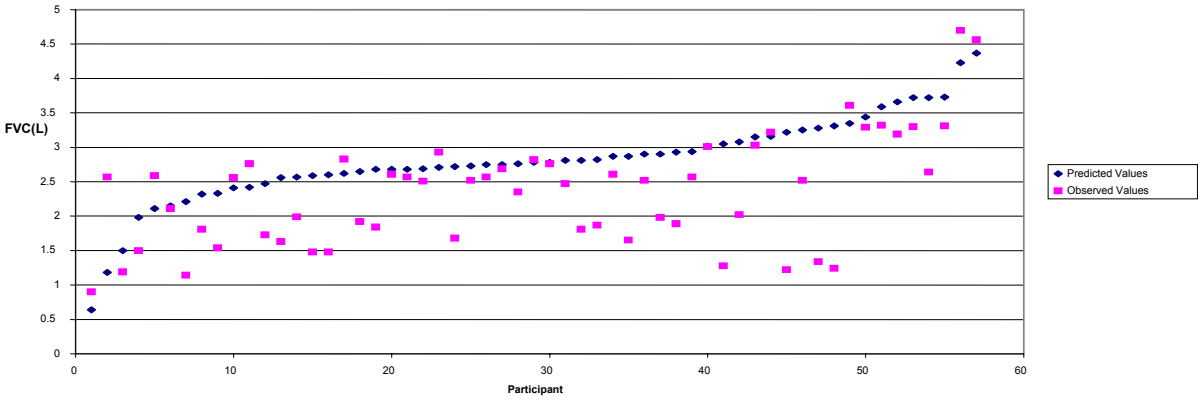


**Fig 26: Comparison of FVC (Predicted vs Observed) at BP (ALL Season)**

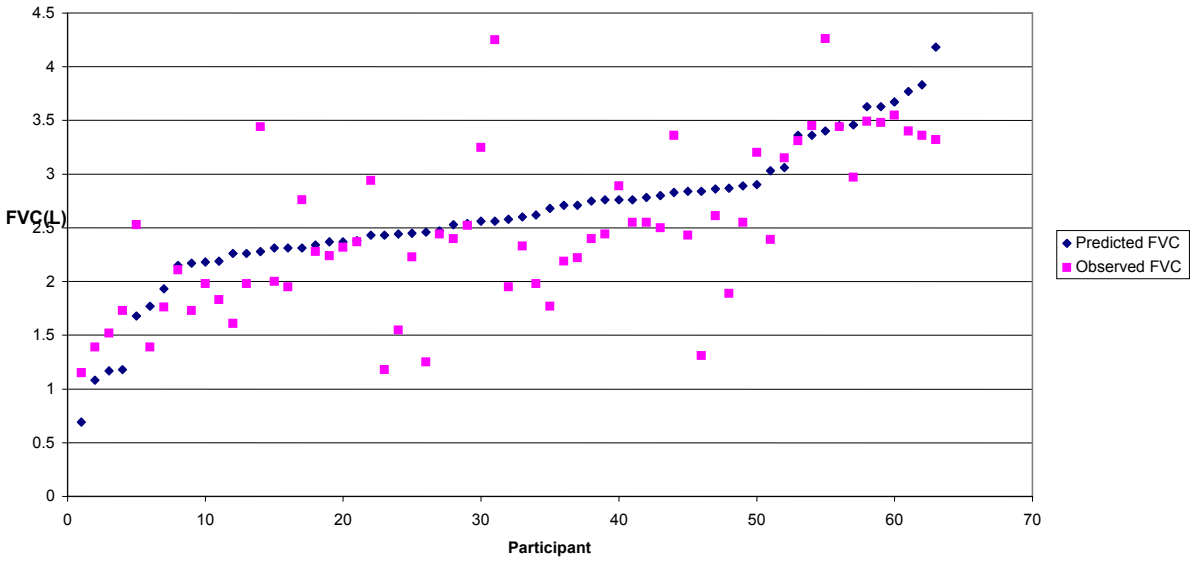
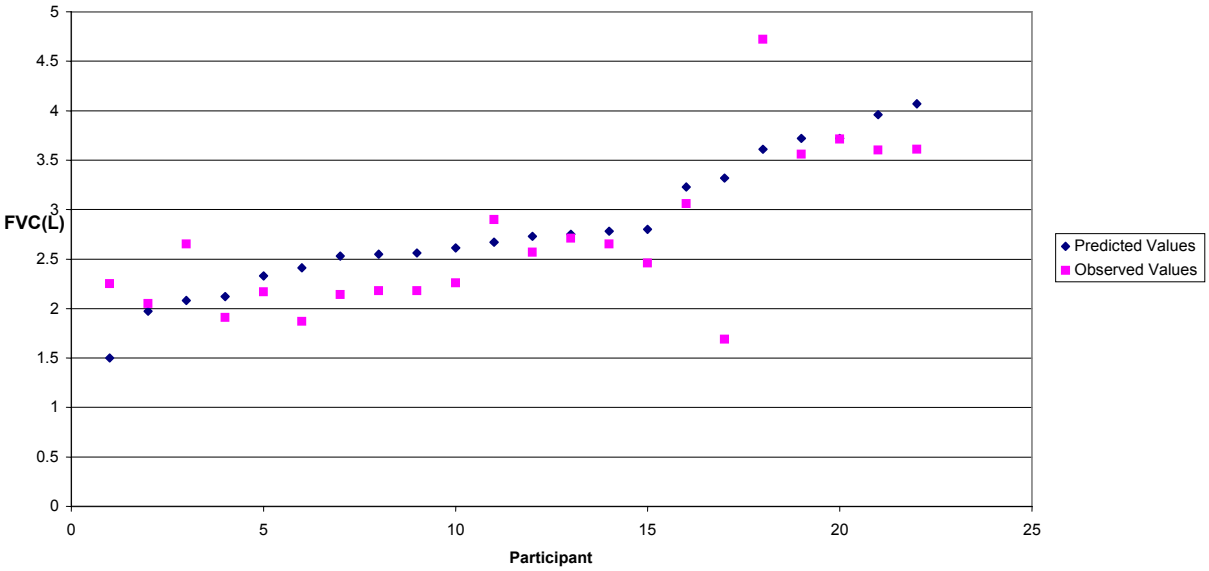



**Fig. 27 Comparison of FVC (Predicted vs Observed) at IITK (all season)**




An overview of the main parameters from computerized spirometry tests is provided in Table 10.

Table 10 Statistics for selected parameters from computerized spirometry tests.

| | | FET (s) | | | FEV1 (% predicted) | | | FVC (% predicted) | | | PEF (% predicted) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Period | No. obs. | Mean | Std. dev. | No. obs. | Mean | Std. dev. | No. obs. | Mean | Std. dev. | No. obs. | Mean | Std. dev. |
| BP | 1 | 37 | 2.0 | 0.8 | 37 | 100.1 | 21.2 | 37 | 95.3 | 23.1 | 37 | 85.3 | 25.1 |
| | 2 | 21 | 2.3 | 0.8 | 21 | 103.3 | 19.7 | 21 | 97.7 | 19.6 | 21 | 91.6 | 18.5 |
| | 3 | 7 | 1.7 | 0.9 | 7 | 93.4 | 5.9 | 7 | 111.3 | 31.3 | 7 | 99.9 | 2.6 |
| IITK | 1 | 6 | 1.7 | 0.7 | 6 | 89.2 | 13.4 | 6 | 86.7 | 13.7 | 6 | 77.1 | 11.3 |
| | 2 | 7 | 2.8 | 1.0 | 7 | 99.1 | 14.0 | 7 | 140.4 | 83.4 | 7 | 85.7 | 29.4 |
| | 3 | 9 | 2.8 | 0.8 | 9 | 86.9 | 3.5 | 9 | 94.4 | 15.0 | 9 | 86.0 | 16.2 |
| JLC | 1 | 51 | 2.2 | 0.8 | 51 | 93.7 | 20.7 | 51 | 91.2 | 21.1 | 51 | 83.6 | 21.6 |
| | 2 | 18 | 2.2 | 0.8 | 18 | 88.2 | 15.9 | 18 | 86.3 | 19.0 | 18 | 87.1 | 18.3 |
| | 3 | 10 | 2.7 | 1.1 | 10 | 84.5 | 8.8 | 10 | 99.9 | 34.4 | 10 | 87.8 | 22.2 |
| LB | 1 | 32 | 2.9 | 1.1 | 32 | 80.2 | 19.0 | 32 | 81.1 | 18.7 | 32 | 61.4 | 21.4 |
| | 2 | 12 | 2.5 | 0.9 | 12 | 90.2 | 37.3 | 12 | 89.3 | 32.7 | 12 | 91.6 | 79.5 |
| | 3 | 13 | 2.8 | 1.4 | 13 | 86.6 | 8.0 | 13 | 90.4 | 20.9 | 13 | 76.0 | 29.3 |

In addition to the computerized spirometry testing, the participants were to perform morning and evening PEF rate measurements. Table 11 provides a summary of these measurements. The results were compared to the computer spirometry results to check the quality of the data (see Figure 28 and 29). The agreement seems very good. The data will further be analyzed.

Table 11 Summary of peak expiratory flow measurements.

| Location | Period | | No. of participants | Min | Mean | Maxi | Std Dev. |
|---|---|---|---|---|---|---|---|
| BP | 1 | PEFR morning avg. (l/min) | 71 | 107 | 350 | 645 | 102 |
| | | PERF evening avg. (l/min) | 71 | 114 | 346 | 645 | 100 |
| | 2 | PEFR morning avg. (l/min) | 56 | 156 | 360 | 623 | 96 |
| | | PERF evening avg. (l/min) | 56 | 155 | 359 | 630 | 95 |
| | 3 | PEFR morning avg. (l/min) | 20 | 185 | 358 | 590 | 88 |
| | | PERF evening avg. (l/min) | 20 | 176 | 349 | 535 | 81 |
| IITK | 1 | PEFR morning avg. (l/min) | 15 | 194 | 340 | 501 | 86 |
| | | PERF evening avg. (l/min) | 15 | 214 | 349 | 500 | 81 |
| | 2 | PEFR morning avg. (l/min) | 15 | 226 | 358 | 527 | 93 |
| | | PERF evening avg. (l/min) | 15 | 206 | 342 | 507 | 91 |
| | 3 | PEFR morning avg. (l/min) | 15 | 192 | 367 | 508 | 102 |
| | | PERF evening avg. (l/min) | 15 | 210 | 365 | 514 | 100 |
| JLC | 1 | PEFR morning avg. (l/min) | 63 | 146 | 363 | 472 | 71 |
| | | PERF evening avg. (l/min) | 63 | 144 | 355 | 466 | 71 |
| | 2 | PEFR morning avg. (l/min) | 37 | 146 | 338 | 455 | 73 |
| | | PERF evening avg. (l/min) | 37 | 154 | 338 | 458 | 72 |
| | 3 | PEFR morning avg. (l/min) | 31 | 184 | 347 | 445 | 59 |
| | | PERF evening avg. (l/min) | 31 | 178 | 350 | 452 | 59 |
| LB | 1 | PEFR morning avg. (l/min) | 64 | 172 | 308 | 637 | 89 |
| | | PERF evening avg. (l/min) | 64 | 169 | 306 | 601 | 86 |
| | 2 | PEFR morning avg. (l/min) | 27 | 144 | 337 | 682 | 118 |
| | | PERF evening avg. (l/min) | 27 | 131 | 336 | 671 | 119 |
| | 3 | PEFR morning avg. (l/min) | 27 | 109 | 299 | 589 | 114 |
| | | PERF evening avg. (l/min) | 27 | 118 | 291 | 577 | 109 |

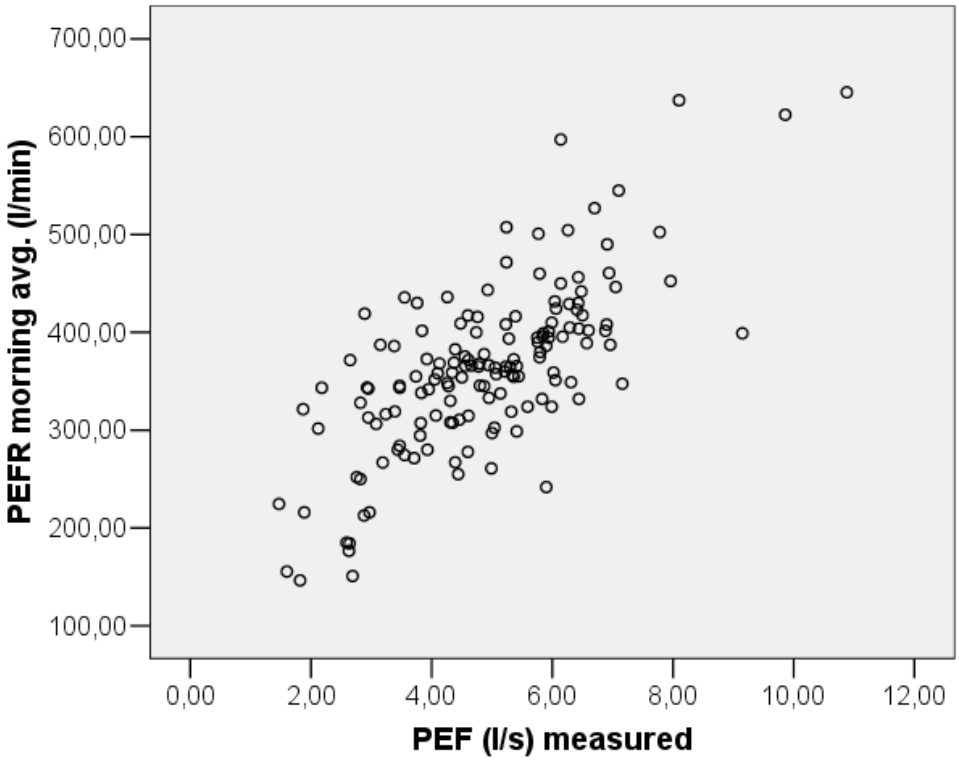



Figure 28 Relation between individual hand held instrument (morning measurement) and computerized spirometry test.

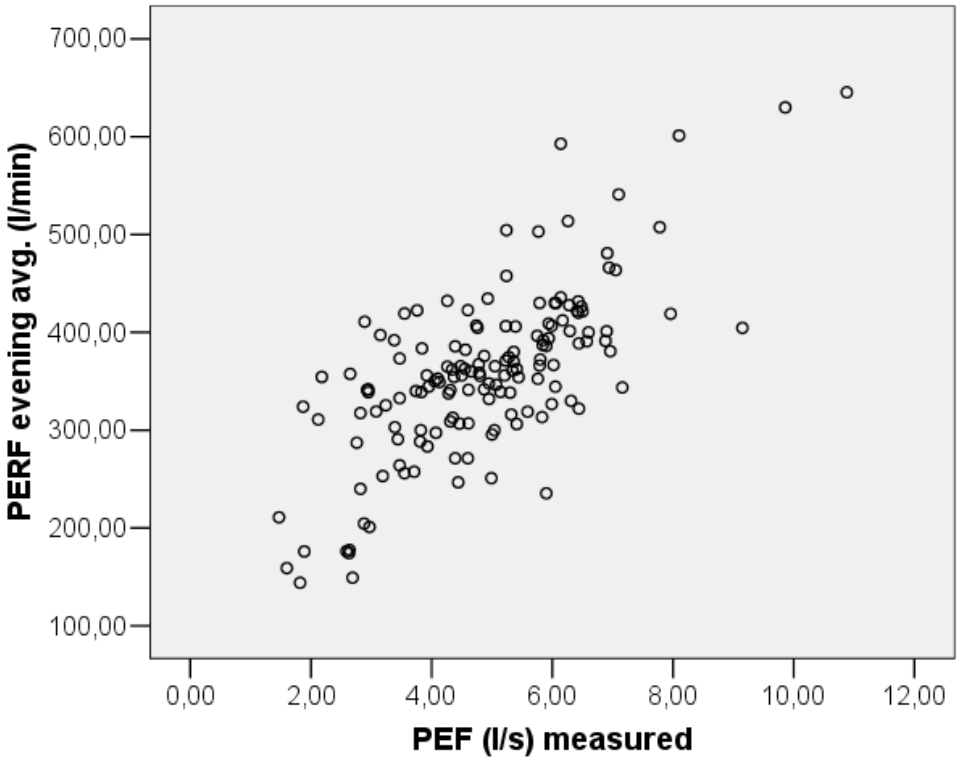



Figure 29 Relation between individual hand held instrument (evening measurement) and computerized spirometry test.

# 4. Conclusions and Recommendations

This project on air quality and health impacts has focused on monitoring and assessing the air quality of ambient, indoor and personal air and to examine the status of health of people in terms of lung functions affected by air pollution. For this purpose, a cohort-based health effect study was undertaken in Kanpur to understand health impacts of exposure to particulate matter, gaseous pollutants, metals and PAHs. The members of cohort were drawn from four sites (Juhi Lal Colony and Luharbhatta as urban sites and Bharatpurva and IIT as rural/clean site). The study profile included the above four locations, three seasons, over 230 subjects (male, female and children), varying type of houses and fuel usage. The analysis of results were carried out on normalized levels (after considering sex, age, height and weight of participating persons) to gain generalized conclusions. Results of air quality sampling suggest that air quality is deteriorated to alarming levels in terms of particulate matter and its harmful components like, metals and carcinogenic organic compounds PAHs. This deterioration in air quality has resulted in poor lung performance, which has been confirmed by this study. The interpretations of results bring several noteworthy issues to the fore. These issues are briefly presented below.

- The levels of $PM_{2.5}$ in urban areas are excessively high and the levels in the city exceed the US EPA air quality standard (65 $\mu g/m^3$) by a factor of 4 to 5 at urban sites. Such high levels will have a definite negative impact on public health and that has been confirmed by this study.

- There is a definite distinction between particulate pollution levels at urban locations and that at rural or cleaner institutional areas; urban pollution level being 2 to 4 times higher. The high levels of pollution exposure in urban areas have resulted in significant lung function deterioration. This study concluded that there was a substantial average deficit in baseline FVC and $FEV_1$ values at urban locations indicating the effect of long-term exposure to pollutants. The average population is performing at about 12-15% lower level than their expected levels of FEV1 and FVC.

- The lung performance of rural population is better than urban population but nevertheless is below the expected normal values.

- In urban areas, the findings of indoor and personal sampling (i.e. the air being inhaled by the people) indicate that it is the outdoor pollution (caused by motor vehicles, industry etc) that impacts the indoor air quality in the kitchen and bedroom resulting in no respite from pollution even while being indoors.

- The study also concluded that indoor air quality at the rural area is much worse than outside air.

- Heavy metal levels are highest at urban locations followed by levels at rural sites. In spite of introduction of unleaded gasoline, lead continues to be present in ambient air and a few values were even higher than Indian National Air Quality Standard of 1.0 $\mu g/m^3$ (average level at urban site in one season being over 3.3 $\mu g/m^3$). and this high lead level may pose a serious health risk.

- Other toxic metals like Ni and Cd exceed the air quality standards of European Union.

- In comparison to Delhi and Mumbai, the levels of carcinogenic PAHs compounds were higher in Kanpur. The high levels of PAHs pose respiratory cancer risk in Kanpur that is higher than internationally acceptable risk.

The major recommendations of the study include

(i) develop detailed air pollution emission inventory in the city of Kanpur including non-point sources and small scale unorganized industrial units

(ii) Identify air pollution sources and perform studies to understand their impact on air quality

(iii) quantify the impact of deteriorated air quality on health on population level

(iv) based on the above, plan, design and implement pollution control measures, and to monitor its effectiveness have a surveillance system in place

(v) potential pollution control measures can include transport sector e.g. introduction of CNG or other cleaner fuel, improved mass transport system, shifting of secondary lead and other metal processing units, fuel changes in industrial units, support for cleaner fuel usage for residential cooking; overall strategy should be cost effective and should address both short-term and long-term measures.

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| February 2002 – June 2005 | NILU PROJECT NO. O-102008 |
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ABSTRACT

Air pollution and respiratory health were investigated in Kanpur, India, a city of some 3 million inhabitants, 2002 to 2005. Four study sites were selected to reflect typical exposure conditions of women in lower socio-economic strata in the population, covering urban, suburban and rural conditions. Field studies (air quality and exposure monitoring and spirometry evaluation, 240 persons) were done in summer, monsoon and winter seasons. The observed particulate pollution levels were very high. 70% of the 140 days with measurements, the ambient $PM_{10}$ levels exceeded the national $PM_{10}$ standard of 100 micrograms/$m^3$, and the ambient $PM_{2.5}$ levels exceeded the US standard for $PM_{2.5}$ of 65 micrograms/$m^3$. Exceedances were observed in all sites. In addition, high levels of PAH and heavy metals in PM were found. The lung function was deteriorated in all study populations, the largest deterioration is observed in the urban slum. Lung function in women was significantly more impaired than in men. An adverse relationship between lung function and air pollution was found for several spirometry parameters.


NORWEGIAN TITLE

Innendørs og uteeksponering for PAH og fine partikler hos kvinner og barn: virkning på helse målt som nedsatt lungefunksjon


| KEYWORDS | | |
|---|---|---|
| Exposure | Particulate matter | Lung function |



ABSTRACT (in Norwegian)

Sammenhenger mellom luftforurensning og lungefunksjon ble undersøkt i Kanpur, UP, India, i perioden 2002-2005. Fire forsøkssteder ble valgt for å gjenspeile typisk eksponering av kvinner i lavere sosio-økonomiske samfunnsgrupper, både i byen og på landsbygda. Feltundersøkelser (luftkvalitetsmålinger, eksponeringsmålinger og spirometriundersøkelser av 240 personer) ble utført om sommeren, i monsoonsesong, og om vinteren. De observerte luftforurensnigsnivåer var veldig høye. Over 70% av de totalt 140 døgn med målinger overskred nasjonal $PM_{10}$ standard på 100 microgrammer/$m^3$ og 70% overskred US normen for $PM_{2.5}$ på 65 microgrammer/$m^3$. Overskridelser fant sted på alle fire undersøkte steder. I tillegg målte man høye PAH og tungmetallverdier i PM. Lungefunksjonen var nedsatt hos alle fire populasjoner, med laveste verdier i det mest forurensede området. Kvinner hadde signifikant lavere verdier enn menn. Det ble observert en nedgang i lungefunksjon med økt forurensning for flere lungefunksjonsparametere.


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