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Exposure to fine particles has been shown to cause severe human health impacts. In the present study, outdoor fine particles as well as elemental and organic carbon concentrations were measured in four locations within Mumbai city, India, during 2007–2008. The average outdoor $PM_{2.5}$ mass concentrations at control, kerb, residential and industrial sites were 69 ± 21, 84 ± 32, 89 ± 34, 95 ± 36 $\mu g/m^3$. In addition, fine particle PAHs were measured during the post monsoon season. The sum of PAHs in $PM_{2.5}$ at same above four sites were 35.27 ± 2.10, 42.96 ± 2.49, 175.76 ± 8.95 and 90.78 ± 4.74 ng/m^3, respectively. Estimating the carcinogenic potential of PAHs with equivalents of Benzo(a)pyrene (BaPE). The maximum value of BaPE (18.8) was reported in the residential site. A trend of lung cancer cases in Mumbai city is also presented. This was a preliminary study in understanding the health effects of PAHs in Mumbai city.

Keywords: $PM_{2.5}$; PAH; BaPE; cancer; Mumbai

Introduction

With increasing concern about high urban air pollution in India, air quality management is being studied with more rigor than before. After air quality monitoring began in India in the late 1960s, pollutants like SO_2, NO_2 and Suspended Particulate Matter (SPM) were monitored. Other pollutants like CO and Pb were monitored on a limited scale. In the 1990s, particulate matter with aerodynamic diameter of 10 micron (PM_{10}) was introduced in the regular monitoring. After the intervention of the Hon'ble Supreme Court of India, better technologies and cleaner fuels were introduced. Even though coarse particulate matter is decreasing, fine particles ($PM_{2.5}$) still remain an issue of concern (NEERI, 2009 citation is needed). Recently the Indian Ministry of Environment and Forest has introduced the new National Ambient Air Quality Standards for $PM_{2.5}$ as 60 $\mu g/m^3$, also known as Central Pollution Control Board standards (CPCB 2009).

Many epidemiological studies have found an association with fine particle concentrations and increased human health effect (Pope et al. 2002; Pope and

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Dockery 2006). The American Cancer Study, in particular, revealed that fine particles and sulfur oxide-related pollution was associated with approximately 4, 6 and 8% increases of all cause, cardio pulmonary and lung cancer mortality, respectively, after controlling for individual lifestyle and socioeconomic status indicators (Pope et al. 2002). Organic compounds present in fine particles, such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and unsaturated aldehydes, are known mutagens or carcinogens (He et al. 2006). Sixteen PAHs have been classified as Group A (known human) or B (probable human) carcinogens by the US Environment Protection Agency.

Indian studies on health effects of air pollution have been reviewed by the Health Effects Institute (HEI 2010). Reviewed studies mainly included cross-sectional, time series and panel studies. Long-term cohort studies are very limited in India. Most of the health studies in India considered TSP, PM_{10}, SO_2 and NO_2. Kumar et al. (2007) conducted a study using geographic information systems to link air pollution and respiratory health data. Chitranjan Cancer Research Institute, Kolkata, used questionnaire and clinical examination concerning respiratory ailments. Marked rise in *alveolar macrophages* in urban subjects of Kolkata was reported (CPCB 2001). Since 1977, several epidemiological studies to correlate the prevailing air pollution levels in Mumbai with health morbidity have been carried out by Environment Pollution Research Cell, KEM Hospital, Mumbai. Most of the health studies were conducted in cities like Delhi and Mumbai followed by Kolkata and Chennai. Limited studies have been conducted in Ludhiana, Lucknow, Chandigarh, Jalgaon and Tripura.

Apart from studies reviewed by the Health Effects Institute, another important study was conducted by the World Bank in 1997 in Greater Mumbai and estimated mortality and morbidity due to PM_{10}. The excess mortality reported due to PM_{10} was about 2,765 cases of an exposed population of 9.8 million in the city of Mumbai. Some other studies were on exposure assessment of different exposure groups such as shopkeepers, watchmen and traffic police by Kulkarni and Patil (1999). The health impacts of air pollution were documented by Shankar and Rama Rao (2002) for the Mumbai region. This study showed that health effects were significantly greater in highly polluted areas compared to low or less-polluted areas of Mumbai.

Among non-communicable diseases in India, cancer is emerging as one of the major public health concerns. Lung cancer is one of the most common cancers in the world. The pattern of lung cancer cases in India varies considerably from Western Europe and US populations. Squamous cell carcinoma is the commonest variety in India as compared to adeno carcinoma in the West. Another significant factor is the early occurrence of the disease in the Indian population ranging between 51 and 60 years of age (Bobba and Khan 2003).

In the past, much of the air pollution research in India was mainly with regard to TSP, PM_{10} aerosol and inorganic characterization. Some studies on PAHs were conducted by Masih and Taneja (2006), the CPCB (2005), Masih et al. (2010) and Bhargava et al. (2004). However the toxicity risk of PAHs in $PM_{2.5}$ was not adequately researched. Therefore, there is a need to improve the understanding of carcinogenic substances in fine aerosol. In the present study, we present the spatial variance of the carbonaceous components of fine particles from a year-long study (2007) in Mumbai, India. We characterize and quantify fine particles PAH concentrations during the post-monsoon period and estimate the carcinogenic

potential of PAHs utilizing equivalents of Benzo(a)pyrene (BaPE) and compare our results with cases of lung cancer in Mumbai.

Method

Study area

Mumbai is the commercial and industrial capital of India with a population of about 15 million. The city has been experiencing stress due to increasing urbanization. More than 1.6 million vehicles were registered in the city during the year 2008 and the percentage increase of vehicles from 1993–2003 was 50% (Transport Commissioners Office 2008). The city has traditionally been industrial; however, its profile has been changing in the last 10–15 years, where major textile industries have closed down. Though industries have been declining, the city still has 40 air-polluting industries (National Environmental Engineering Research Institute [NEERI] 2009). Mumbai has few large industries in the eastern part of the city with many refineries, fertilizer plants and a thermal power plant. However, other sources such as refuse burning, port-airport operation, small scale industries, etc., may also be influencing the local air quality.

Mumbai has a mean elevation of 11 m above sea level and consists of seven islands situated on the Konkan coast. The city is located at 18°59′39 N latitude 72°48′55 E longitude. It has a tropical savannah climate. The annual average temperature is 25.3°C, with a maximum of 34.5°C in June and minimum of 14.3°C in January. Average annual precipitation is 2,078 mm with July having the maximum rainfall. High pollution concentrations usually occur in the winter when adverse meteorological situations with weak winds may prevail. In the winter, the predominant local wind direction is northerly (NW–NE). In the summer and monsoon seasons, westerly and south westerly winds are predominant. Sea breeze is normally witnessed during the day with mean wind speeds between 1.5 and 2 m/s. Calm winds occur at night between 22:00 and 06:00 h.

Sampling sites

Air monitoring was carried out at four locations representing control (C), kerb (K), residential (R) and industrial (I) sites in Mumbai as shown Figure 1. With high vehicular usages and acute congestions, kerb site air quality has acquired high importance. The control site was located at Colaba, which was selected to assess background levels due to its proximity to the seacoast and is affected by land and sea breeze. Dadar was selected as a kerb/mixed site because of heavy traffic and commercial activities. Khar is a residential area located in the western suburbs. Mahul represents the industrial site as it is close to major industries in eastern suburbs. The characteristics of outdoor sites are presented in Table 1.

Sample collection and analysis

The ambient fine particles were monitored during summer (March–May 2007) post-monsoon (October–November 2007) and winter (December–January 2007–2008), over 24-h periods for 15 days in a season. The fine particles were collected on filter substrates utilizing two MiniVol $PM_{2.5}$ Samplers (Air Metrics, Eugene, OR, USA) with a flow rate of 5 l per min for 24 h. The two types of filters were the 46.2 mm

Figure 1. Sampling sites in Mumbai City.

PFTE Teflon Filters with 2.0 mm pore size (Whatman, PP ring supported) and 47 mm Quartz filters (Pallflex Tissue). In the particulate matter-sampling mode, air is drawn through a particle size separator and then through a filter medium. Particle

Table 1. Details of air quality monitoring sites.

Site	Type	Activity description and sources	Sampling height (m)
Colaba	Control	Protected area under Indian Navy, minimum traffic, one side surrounded by sea.	3.5
Dadar	Commercial	Commercial activity, flyovers, petrol pump, bus terminals, railway cart shed, traffic junction, multiple lane with traffic	3.5
Khar	Residential, upper income group	Residential area, vehicles, Western Express Highway, hotels/restaurants, airport, BEST & private buses, auto rickshaw, trucks, construction activity	3
Mahul	Industrial	Refineries, thermal power plant, unpaved roads, fertilizer/chemical industries, heavy duty vehicles, tankers, residential areas, sea coast	3

Possible sources at all sites: vehicles, sea spray, cooking emissions from hotels, restaurants, bakeries, and open eat outs, open burning, resuspended dust, soil, etc.

size separation is achieved by impaction. The Teflon filters were equilibrated at 20°C and 40% RH in a temperature and humidity controlled clean room chamber for 24 h before and after sampling. The particulate mass on Teflon filter was determined by weighing on an electronic microbalance (Sartorious, Model ME5) with 1 μg sensitivity. Each filter was weighed in duplicate before and after sampling and average weight was considered. The microbalance was tested daily with the National Institute of Standards and Technology (NIST) calibrated weights of 100 and 200 mg to check the performance. The quartz filters were preheated at 900°C for 3 h before monitoring to remove any background organics in the filter. The filters were kept and heated in silica crucibles covered on top with another silica crucible. After air sampling, all loaded filters were stored in a freezer at -20°C to prevent the evaporation of volatile compounds until analysis. Carbon content was first measured on the quartz filters by utilizing the Desert Research Institute (DRI) thermal optical analyzer and later the filters were subjected to PAH analysis.

The quartz filters from the post-monsoon season were combined by site to form four composite samples and PAHs were analyzed on these combined samples at the Desert Research Institute (DRI, NV, USA) using the Injection Port Thermal Desorption and Subsequent Gas Chromatography/Mass Spectrometry method. Small strips of aerosol-laden filter materials are packed into a Gas Chromatography (GC) split/split less injector liner. The organic compounds on the filter are thermally desorbed in the injection port and focused onto the head of a GC column for subsequent separation and mass spectrometric detection. Using data collected with the mass spectrometer (MS), the peak area of ions known to be present in the analytes and internal standards for the quantification process is estimated. For QA/QC, replicates at a rate of one in every 10 samples to ensure good instrument reproducibility and certified standard solutions are used to check the calibration created using a six-point calibration curve from standards mixed in-house.

PAH toxicity estimation

The toxicity equivalency factor (TEF) methodology was developed by the US Environment Protection Agency (US EPA) to evaluate the toxicity and risks of

a mixture of structurally related chemicals with common mechanism of action (Washington State Department of Ecology, 2010 need citation). A TEF is an estimate of the relative toxicity of a chemical compared to a reference chemical. Carcinogenic potential of PAHs is estimated with the equivalent of Benzo(a)pyrene (BaPE). The BaPE value is calculated with PAH concentrations weighted in relation to the carcinogenic potential of individual PAHs based on Ji et al. (2007). Previous studies by Yassaa et al. (2001), Cincinelli et al. (2007), and Wang et al. (2007) have estimated BaPE.

BaPE was calculated using the following formula:

$$\mathrm{BaPE} = 0.06(\mathrm{BaA}) + 0.07(\mathrm{BbF}) + 0.07(\mathrm{BkF}) + \mathrm{BaP} + 0.6[\mathrm{D(a,h)A}] + 0.08(\mathrm{IcdP})$$

Where, BaA = Benzo[a]Anthracene, BbF = Benzo[b]Fluoranthene, Bkf = Benzo[k] Fluoranthene, BaP = Benzo[a]Pyrene, D(a,h)A = Dibenzo[a,h]Anthracene, IcdP = Indeno[1,2,3-cd]Pyrene.

The coefficients represent the carcinogenic potential of the PAH relative to that of BaPE. PAH concentration is expressed in ng/m^3 is given in Table 4. Using the calculated BaPE, lung cancer cases were estimated as per protocol described by Pengchai et al. (2009) as follows:

$$\text{Annual number of lung cases (per million)} = \frac{\text{unit risk} * \text{sum BaP} * \text{residents (million)}}{\text{life expectancy}}$$

The population was based from the 2001 census. According to the Population Reference Bureau's 2000 World Data Sheets, life expectancy at birth for Indians is between 60–61 years (India Together 2011). The World Health Organization (WHO 1987) suggested the unit risk of 0.00008 per ng/m^3 for a lifetime of PAHs exposure, assuming one was exposed to the average level of one unit BaP concentration (1 ng/m^3).

Results and discussion

Fine particles

Descriptive statistics of fine aerosol concentrations during the different seasons is given in Table 2. Outliers were removed by 4 sigma test and later subjected to descriptive statistics. One outlier per site at the control (C), kerb (K) and industrial (I) locations and four outliers at the residential (R) location were observed. The $PM_{2.5}$ outdoor concentration at C, K, R and I ranged from 34–136 μg/m^3, 46–180 μg/m^3, 33–149 μg/m^3 and 48–190 μg/m^3, respectively. The coefficient of variation (%) at three sites K, R, I was about 38% and at C it was 30%. Variability of the data at control site was comparatively lower indicating less variation in the data set. The average outdoor $PM_{2.5}$ mass concentrations at C, K, R and I site were 69 ± 20.97, 84 ± 31.99, 89 ± 33.52 and 95 ± 36.01 μg/m^3, respectively. The average concentration of PM_{25} measured at industrial sites was higher than the other three sites. The next highest concentration was measured at residential location. The PM_{25} levels estimated at Colaba was less than the other sites which represents background site. The 50th and 95th percentile of $PM_{2.5}$ observed at C (65,101) K (82,156) R (99,146) and I (91,158) μg/m^3, respectively.

Table 2. Descriptive statistics of $PM_{2.5}$ and carbon fractions concentrations in $\mu g/m^3$ in Mumbai city (2007–2008).

	Min	Max	Average ± SD	Count
Control site				
$PM_{2.5}$	34	136	69.0 ± 21	44
OC	7.1	33.8	20.4 ± 7.5	44
EC	1.3	15.6	5.0 ± 2.7	44
TC	8.4	44.9	25.4 ± 9.7	44
Kerb site				
$PM_{2.5}$	46	180	84 ± 32	44
OC	11.7	67.5	28.4 ± 14.1	44
EC	4.6	28.3	9.2 ± 4.4	44
TC	17.2	87.8	37.6 ± 17.5	44
Residential site				
$PM_{2.5}$	33	149	89 ± 33	41
OC	9.7	63.4	31.3 ± 14.7	41
EC	1.6	18.7	7.7 ± 4.8	41
TC	11.4	76	39.1 ± 18.5	41
Industrial site				
$PM_{2.5}$	48	190	95 ± 36	45
OC	9	57.5	29.1 ± 15.1	45
EC	1.8	16.6	7.2 ± 4.0	45
TC	11.6	69.7	36.4 ± 18.3	45

The outdoor $PM_{2.5}$ concentrations exceeded USEPA's 24-hourly standard of 35 $\mu g/m^3$ at all sites. During the study period especially in post monsoon and winter season, 24-hourly average concentration of $PM_{2.5}$ exceeded national ambient air standards of India (also known as CPCB Standards). Daily levels of $PM_{2.5}$ compared with CPCB standards are given in Figure 2. During winter, lower temperatures, calm conditions, lower mixing depth and temperature inversion, restrict and confine pollutants' dispersion and dispersal. Levels remained within the CPCB standard in the summer season at three sites except for the industrial location. The highest maximum concentration of 190 $\mu g/m^3$ was detected at the industrial location during winter season and the lowest minimum concentration of 33 $\mu g/m^3$ in summer season was estimated at residential site, respectively. All season percentage exceedances of $PM_{2.5}$ standards (CPCB) at C, K, R and I site were 59, 80, 71 and 80%, respectively. Possible sources could have been vehicles, biomass burning, bakeries, liquefied petroleum gas (LPG), open eat out, sea spray, soil, vehicles, secondary aerosol formation, industries, etc., depending upon the proximity of sources near the sampling sites.

US EPA's pollutant standard index for $PM_{2.5}$ can be used for general assessment of health risks from existing air quality. The Pollution Standard Index for days monitored during the present study was estimated using US EPA's standard of 35 $\mu g/m^3$ for 24-hourly readings and is presented in Table 3. In the present study as per the pollutant standard index, most of the time air quality remained unhealthy for sensitive groups and the unhealthy. Only during winter season air quality was very unhealthy (7% and 9%) at the kerb and industrial sites due to very high $PM_{2.5}$ concentrations.

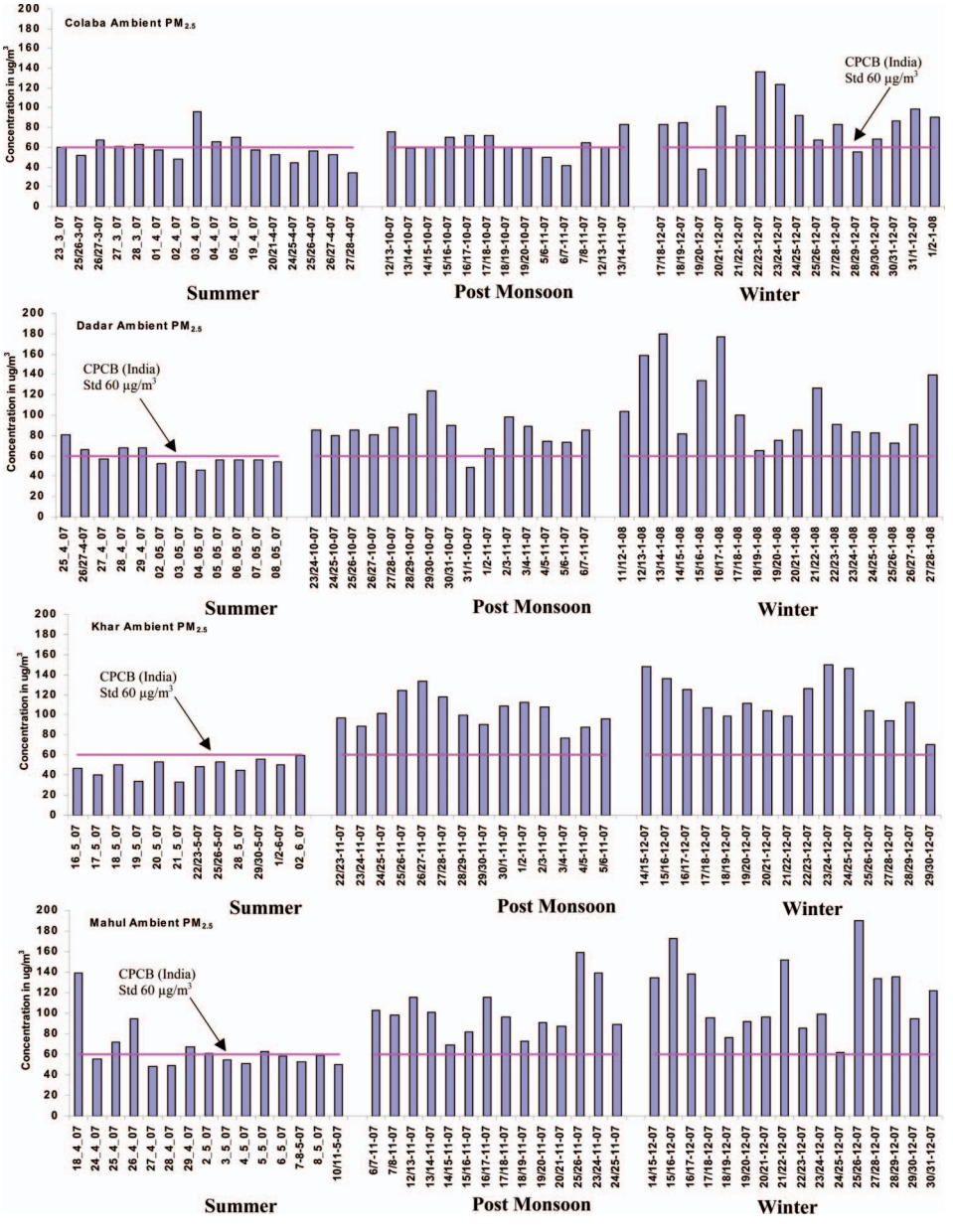

Figure 2. Concentration of $PM_{2.5}$ during summer, post monsoon and winter.

Organic carbon and elemental carbon

The average concentration of OC at C, K, R and I sites in outdoor area were 20.4 ± 7.51, 28.4 ± 14.12, 31.3 ± 14.69 and 29.1 ± 15.06 $\mu g/m^3$, while the corresponding EC concentration were 5.0 ± 2.71, 9.2 ± 4.35, 7.7 ± 4.83 and 7.2 ± 3.95 $\mu g/m^3$, respectively. The average OC contributions at C, K, R and I sites were 30, 34, 35 and 31%, respectively and EC contributions were 7, 11, 9 and 8%, respectively. The OC percent contribution which was higher at residential sites could

Table 3. Health risks from air quality in Mumbai, using US EPA's Pollutant Standard Index.

Date	Control $PM_{2.5}$#	USEPA AQI	Date	Kerb $PM_{2.5}$#	USEPA AQI	Date	Residential $PM_{2.5}$#	US EPA AQI	Date	Industrial $PM_{2.5}$#	US EPA AQI
23–24 March 2007	60	USG	25–26 April 2007	80	UN-H	16–17 May 2007	47	USG	18–19 April 2007	139	UN-H
25–26 March 2007	52	USG	26–27 April 2007	66	UN-H	17–18 May 2007	40	USG	24–25 April 2007	56	USG
26–27 March 2007	67	UN-H	27–28 April 2007	57	USG	18–19 May 2007	50	USG	25–26 April 2007	72	UN-H
27–28 March 2007	61	USG	28–29 April 2007	67	UN-H	19–20 May 2007	34	MOD	26–27 April 2007	94	UN-H
28–29 March 2007	63	USG	29–30 April 2007	68	UN-H	20–21 May 2007	53	USG	27–28 April 2007	48	USG
1–2 April 2007	57	USG	2–3 May 2007	52	USG	21–22 May 2007	33	MOD	28–29 April 2007	49	USG
2–3 April 2007	48	USG	3–4 May 2007	54	USG	22–23 May 2007	48	USG	29–30 April 2007	68	UN-H
3–4 April 2007	96	UN-H	4–5 May 2007	46	USG	25–26 May 2007	53	USG	2–3 May 2007	61	USG
4–5 April 2007	65	UN-H	5–6 May 2007	56	USG	28–29 May 2007	45	USG	3–4 May 2007	54	USG
5–6 April 2007	70	UN-H	6–7 May 2007	56	USG	29–30 May 2007	56	USG	4–5 May 2007	50	USG
19–20 April 2007	57	USG	7–8 May 2007	56	USG	1–2 June 2007	50	USG	5–6 May 2007	62	USG
20–21 April 2007	52	USG	8–9 May 2007	54	USG	2–3 June 2007	59	USG	6–7 May 2007	58	USG
24–25 April 2007	44	USG							7–8 May 2007	52	USG
25–26 April 2007	56	USG							8–9 May 2007	59	USG
26–27 April 2007	53	USG							10–11 May 2007	50	USG
27–28 April 2007	34	MOD									
2–13 Oct 2007	75	UN-H	23–24 Oct 2007	86	UN-H	22–23 Nov 2007	97	UN-H	6–7 Nov 2007	103	UN-H
13–14 Oct 2007	59	USG	24–25 Oct 2007	80	UN-H	23–24 Nov 2007	89	UN-H	7–8 Nov 2007	99	UN-H
14–15 Oct 2007	60	USG	25–26 Oct 2007	86	UN-H	24–25 Nov 2007	101	UN-H	12–13 Nov 2007	116	UN-H
15–16 Oct 2007	70	UN-H	26–27 Oct 2007	80	UN-H	25–26 Nov 2007	124	UN-H	13–14 Nov 2007	101	UN-H
16–17 Oct 2007	72	UN-H	27–28 Oct 2007	88	UN-H	26–27 Nov 2007	133	UN-H	14–15 Nov 2007	69	UN-H
17–18 Oct 2007	72	UN-H	28–29 Oct 2007	101	UN-H	27–28 Nov 2007	118	UN-H	15–16 Nov 2007	82	UN-H
18–19 Oct 2007	60	USG	29–30 Oct 2007	124	UN-H	28–29 Nov 2007	99	UN-H	16–17 Nov 2007	116	UN-H
19–20 Oct 2007	59	USG	30–31 Oct 2007	90	UN-H	29–30 Nov 2007	90	UN-H	17–18 Nov 2007	96	UN-H
5–6 Nov 2007	50	USG	31 Oct–1 Nov 2007	48	USG	30 Nov–1 Dec 2007	108	UN-H	18–19 Nov 2007	73	UN-H
6–7 Nov 2007	41	USG	1–2 Nov 2007	67	UN-H	1–2 Dec 2007	113	UN-H	19–20 Nov 2007	91	UN-H
7–8 Nov 2007	65	USG	2–3 Nov 2007	99	UN-H	2–3 Dec 2007	108	UN-H	20–21 Nov 2007	87	UN-H
12–13 Nov 2007	60	USG	3–4 Nov 2007	89	UN-H	3–4 Dec 2007	77	UN-H	25–26 Nov 2007	159	V-UN-H
13–14 Nov 2007	83	UN-H	4–5 Nov 2007	74	UN-H	4–5 Dec 2007	88	UN-H	23–24 Nov 2007	139	UN-H
			5–6 Nov 2007	73	UN-H	5–6 Dec 2007	96	UN-H	24–25 Nov 2007	89	UN-H

(*continued*)

Table 3. (*Continued*).

Date	Control $PM_{2.5}$[#]	USEPA AQI	Date	Kerb $PM_{2.5}$[#]	USEPA AQI	Date	Residential $PM_{2.5}$[#]	US EPA AQI	Date	Industrial $PM_{2.5}$[#]	US EPA AQI
			6–7 Nov 2007	85	UN-H						
	83	UN-H	11–12 Jan 2008	104	UN-H	14–15 Dec 2007	148	UN-H	14–15 Dec 2007	135	UN-H
18–19 Dec 2007	84	UN-H	12–13 Jan 2008	159	V-UN-H	15–16 Dec 2007	136	UN-H	15–16 Dec 2007	173	V-UN-H
19–20 Dec 2007	38	USG	13–14 Jan 2008	180	V-UN-H	16–17 Dec 2007	125	UN-H	16–17 Dec 2007	138	UN-H
20–21 Dec 2007	101	UN-H	14–15 Jan 2008	82	UN-H	17–18 Dec 2007	107	UN-H	17–18 Dec 2007	96	UN-H
21–22 Dec 2007	72	UN-H	15–16 Jan 2008	134	UN-H	18–19 Dec 2007	99	UN-H	18–19 Dec 2007	76	UN-H
22–23 Dec 2007	136	UN-H	16–17 Jan 2008	177	V-UN-H	19–20 Dec 2007	111	UN-H	19–20 Dec 2007	91	UN-H
23–24 Dec 2007	124	UN-H	17–18 Jan 2008	100	UN-H	20–21 Dec 2007	104	UN-H	20–21 Dec 2007	96	UN-H
24–25 Dec 2007	93	UN-H	18–19 Jan 2008	65	UN-H	21–22 Dec 2007	99	UN-H	21–22 Dec 2007	152	V-UN-H
25–26 Dec 2007	67	UN-H	19–20 Jan 2008	75	UN-H	22–23 Dec 2007	126	UN-H	22–23 Dec 2007	85	UN-H
27–28 Dec 2007	83	UN-H	20–21 Jan 2008	85	UN-H	23–24 Dec 2007	149	UN-H	23–24 Dec 2007	99	UN-H
28–29 Dec 2007	55	USG	21–22 Jan 2008	126	UN-H	24–25 Dec 2007	146	UN-H	24–25 Dec 2007	62	USG
29–30 Dec 2007	68	UN-H	22–23_Jan_08	91	UN-H	25–26 Dec 2007	104	UN-H	25–26 Dec 2007	190	V-UN-H
30–31 Dec 2007	87	UN-H	23–24 Jan 2008	83	UN-H	27–28 Dec 2007	94	UN-H	27–28 Dec 2007	134	UN-H
31–1 Dec 2007	99	UN-H	24–25 Jan 2008	82	UN-H	28–29 Dec 2007	112	UN-H	28–29 Dec 2007	135	UN-H
1–2 Jan 2008	90	UN-H	25–26 Jan 2008	72	UN-H	29–30 Dec 2007	70	UN-H	29–30 Dec 2007	95	UN-H
			26–27 Jan 2008	91	UN-H				30–31 Dec 2007	122	UN-H
			27–28 Jan 2008	140	UN-H						

[#]$PM_{2.5}$ concentrations in $\mu g/m^3$.

G = good ($PM_{2.5}$ concentration less than or equal to 15 $\mu g/m^3$);

MOD = moderate ($PM_{2.5}$ concentration between 16 and 35 $\mu g/m^3$);

USG = unhealthy for sensitive groups ($PM_{2.5}$ concentration between 36 and 65 $\mu g/m^3$: Increasing likelihood of respiratory symptoms in sensitive individuals, aggravation of heart of lung disease and premature mortality in persons with cardiopulmonary disease and the elderly);

UN-H = unhealthy ($PM_{2.5}$ concentration between 66 and 150 $\mu g/m^3$: Increased aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; increased respiratory effects in general population);

V-UN-H = very unhealthy ($PM_{2.5}$ concentration between 151 and 250 $\mu g/m^3$: Significant aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; significant increase in respiratory effects in general population);

H = hazardous ($PM_{2.5}$ concentration above 251 $\mu g/m^3$: Serious aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; serious risk of respiratory effects in general population).

be due to vehicle, biomass burning and secondary organic carbon formation. EC contribution at the kerb site was higher than the other sites, which may be due to heavy duty vehicles and the intercity bus station operating on diesel fuel near the sampling station. The EC levels would also be high next to the kerb site as the EC is a byproduct of high temperature combustion, which is due to vehicles engine burning diesel and petrol at high temperature.

PAHs

The sum of PAHs in $PM_{2.5}$ at C, K, R and I were 35.27 ± 2.10, 42.96 ± 2.49, 175.76 ± 8.95 and 90.78 ± 4.74 ng/m^3, respectively (Table 4). PAHs are the major resolved fraction of organic carbon. PAHs are organic compounds constituting carbon and hydrogen, arranged in two or more aromatic rings. PAHs result from incomplete organic matter combustion. Emissions are generally from four sources: (1) Mobile (diesel and gasoline exhaust), (2) stationary (coal fired power plants), (3) domestic (residential wood or coal combustion, environmental tobacco smoke, and (4) area sources (forest and agricultural burning, waste incineration (Bjørseth and Ramdahl 1985). 7, 12-dimethylbenz(a)anthracene and cyclopenta(cd)pyrene were highest amongst PAHs. Cyclopentapyrene is regarded as marker for gasoline fuelled cars (Yassaa et al. 2001). The other three PAH compounds which were significantly present were Benzo(a)pyrene, Benzo(ghi)perylene and indeno(1,2,3-cd)pyrene. Benzo(ghi)perylene and coronene are associated with petrol-powered vehicles (Bi et al. 2002).

The sum of US EPA priority list of 15 PAHs in $PM_{2.5}$ at C, K, R and I were 13.64 ng/m^3, 14.07 ng/m^3, 80.18 ng/m^3 and 36.94 ng/m^3, respectively. Among 15 PAHs, the highest concentration was reported for Benzo(a)pyrene followed by indeno[1,2,3-cd]pyrene. In the present study, amongst all the sites, the maximum concentration was observed in the residential area followed by the industrial site, respectively. In India, land use patterns are mixed where uneven residential areas may have significant vehicular activities or the possible sources for high concentration in residential area could be vehicular source, biomass burning, etc. In India, cooking fuel combustion is also a likely source of PAHs. Possible sources of PAHs in the vicinity of sampling sites include traffic, catalyst-equipped cars, gasoline vehicles, diesel vehicles, wood combustion, coal combustion, petroleum refining, road dust, oil burning and smelting. BaP concentrations reported in the present study were higher than reported by Yassaa et al. (2001), Cincinelli et al. (2007) and Wang et al. (2007). CPCB Zonal Laboratory, Kolkata, in collaboration with West Bengal Pollution Control Board, estimated 16 PAHs (CPCB 2005); the sum of PAHs in $PM_{2.5}$ was 10.73 ng/m^3. Outdoor sites in Mumbai show high concentration of PAHs (average of four sites) is 36.21 ng/m^3 as compared to the Kolkata study.

CPCB has added in its revised standards with an annual standard of 1 ng/m^3 for Benzo(a)pyrene as it is hazardous to health. Figure 3 show concentration of PAHs used for BaPE. The carcinogenic potential of PAHs and lung cancer cases in Mumbai city is given in Table 5. The residential site has the maximum values of BaPE with a value of 18.8. This indicates that the concentration of carcinogenic PAHs is highest in Khar and is reflected in occurrence of highest annual number of lung cancer cases (16), per million of population residing in this area and the lowest BaPE (3.5) at control site.

Table 4. PAH concentrations in ng/m^3 with uncertainty at different sites during post monsoon (2007).

	Compounds	Control		Kerb		Residential		Industrial	
		Con.	Unc.	Con.	Unc.	Con.	Unc.	Con.	Unc.
	acenaphthylene	2.432	0.122	3.237	0.162	10.427	0.521	9.113	0.456
	acenaphthene	0.081	0.013	nd	nd	0.543	0.030	nd	nd
	fluorene	0.059	0.022	0.077	0.023	0.226	0.025	0.180	0.024
#	phenanthrene	0.184	0.012	0.245	0.015	0.577	0.030	0.495	0.026
#	anthracene	0.855	0.043	0.783	0.039	2.932	0.147	2.543	0.127
#	fluoranthene	0.295	0.015	0.261	0.014	0.951	0.048	0.698	0.035
#	pyrene	0.486	0.025	0.430	0.022	1.585	0.079	1.046	0.053
#	benzo[a]anthracene**	0.553	0.028	0.445	0.022	3.589	0.179	1.339	0.067
#	Chrysene	0.648	0.033	0.552	0.028	4.234	0.212	1.744	0.087
#	benzo[b]fluoranthene**	1.348	0.071	1.243	0.066	10.574	0.529	4.219	0.212
#	benzo[k]fluoranthene**	1.179	0.061	1.089	0.056	8.548	0.428	3.623	0.182
	benzo[a]fluoranthene	0.103	0.019	0.092	0.019	1.076	0.057	0.293	0.023
#	benzo[e]pyrene	0.877	0.047	0.875	0.047	6.589	0.330	2.700	0.136
#	benzo[a]pyrene**	2.778	0.139	3.176	0.159	14.582	0.729	6.019	0.301
#	perylene	0.162	0.019	0.199	0.021	1.732	0.088	0.450	0.029
#	indeno[1,2,3-cd] pyrene**	2.093	0.106	2.409	0.121	9.872	0.494	5.457	0.273
#	dibenzo[a,h] anthracene**	0.575	0.032	0.537	0.030	3.170	0.159	1.440	0.073
#	benzo[ghi]perylene	1.371	0.072	1.550	0.080	9.544	0.478	4.309	0.216
#	coronene	0.236	0.032	0.276	0.033	1.698	0.090	0.855	0.052
	dibenzo[a,e]pyrene	0.184	0.028	0.169	0.029	1.483	0.079	0.563	0.039
	1-methylfluorene	0.059	0.021	0.046	0.022	0.102	0.022	0.113	0.022
	9-fluorenone	0.177	0.012	0.138	0.011	0.260	0.016	0.236	0.015
	dibenzothiophene	0.059	0.008	0.046	0.008	0.091	0.008	0.146	0.010
	1-methyl phenanthrene	0.059	0.020	0.061	0.021	0.170	0.022	0.113	0.020
	2-methyl phenanthrene	0.029	0.016	0.031	0.017	0.102	0.017	0.068	0.017
	9-methylanthracene	0.022	0.023	0.568	0.037	nd	nd	nd	nd
	3,6 dimethyl phenanthrene	0.015	0.018	0.015	0.019	0.034	0.019	0.023	0.019
	methylfluoranthene	0.052	0.013	0.061	0.014	0.147	0.015	0.079	0.014
	retene	0.125	0.008	0.092	0.007	0.192	0.011	0.248	0.013
	benzo(ghi)fluoranthene	0.221	0.012	0.169	0.009	0.974	0.049	0.428	0.022
	benzo(c)phenanthrene	0.081	0.008	0.061	0.007	0.328	0.018	0.180	0.011
	benzo(b)naphtha [1,2-d]thiophene	0.029	0.016	0.015	0.017	0.079	0.016	0.056	0.016
	cyclopenta(cd)pyrene	5.681	0.284	5.155	0.258	38.086	1.904	18.462	0.923
	benz(a)anthracene-7,12-dione	0.464	0.027	0.322	0.021	1.959	0.099	1.046	0.054
	methylchrysene	0.037	0.025	0.031	0.026	0.260	0.028	0.090	0.026
	7,12 dimethyl benz(a)anthracene	7.037	0.352	12.980	0.649	17.639	0.882	12.499	0.625
	7methyl benzo(a)pyrene	0.523	0.030	0.706	0.038	2.661	0.134	1.271	0.065
	benzo(b)chrysene	0.147	0.016	0.123	0.016	1.143	0.059	0.405	0.025
	picene	0.133	0.023	0.107	0.024	1.132	0.061	0.338	0.028
	anthanthrene	2.181	0.110	3.253	0.163	8.355	0.418	4.320	0.216
	dibenzo (a,h) pyrene	1.275	0.069	1.059	0.060	6.216	0.312	3.060	0.155
	dibenzo (a,i) pyrene	0.251	0.032	0.169	0.032	1.393	0.076	0.518	0.040
	dibenzo (a,l) pyrene	0.118	0.028	0.107	0.029	0.509	0.038	nd	nd

**PAHs considered for BaPE calculations; #USEPA Priority List of PAHs.

Actual lung cancer data for the year 2007 was collected from Mumbai Cancer Registry for each site. Mumbai Cancer Registry lung cancer cases are higher than predicted numbers at C, K, and I, whereas at Khar actual cases are less than predicted cases. Though various schemes for industrial emission control have led to reduction of pollution in this area (industrial site), exposure of PAHs over the years may have led to higher cancer cases. A cross-sectional study conducted by Environment Pollution Research Cell, KEM Hospital, Mumbai, on 586 males and 536 females was conducted at Mahul (industrial site) to check the effect of increased pollution in 1990. The results showed that the incidence of respiratory symptoms like cough and dyspnoea had increased by 8–13%. Furthermore, the incidence of bronchitis (4.5–7.6%), cardiac diseases (4.3–6.7%) and other chest disorders (0.1–4.4%) had risen during 1978–1990 (NEERI 2006). BaPE estimates at residential site (Khar) gives an indication that in future cancer cases may rise.

In Mumbai, cancer incidence and mortality rates were found to be very low in the younger ages. Registered cancer cases and deaths are high for a person of 65 years of age and above (Kurkure et al. 2004). The trends of lung cancer in Mumbai city is presented in Table 6. The annual percent change shows that the trend of lung cancer in females is on the rise as compared to males. The probable reasons could be genetic, the rise of female smokers, passive smoking and exposure to indoor air pollution due to use of solid fuels.

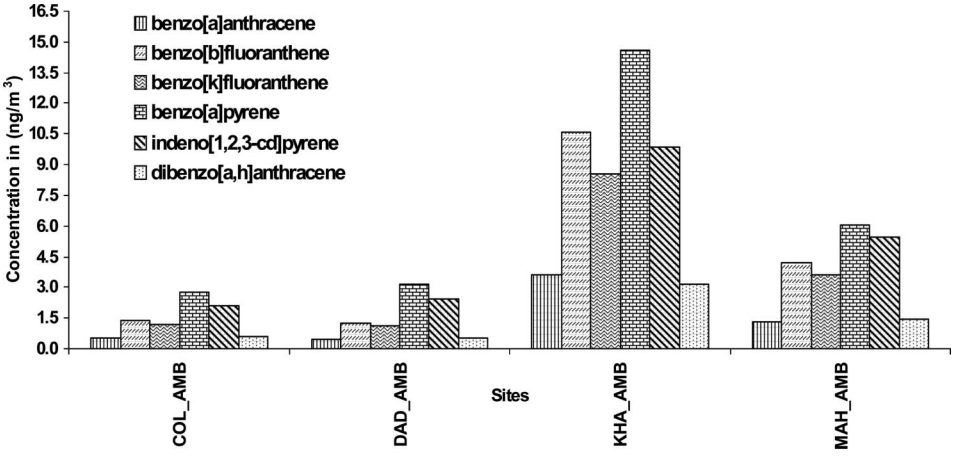

Figure 3. Concentration of PAHs considered for *BaPE*.

Table 5. Carcinogenic potential of PAHs in Mumbai city during 2007.

	Colaba	Dadar	Khar	Mahul
BaPE	3.5	3.8	18.8	7.9
Predicted lung cancer cases	1	3	16	8
Actual lung cancer cases*	8	7	10	13

*Indian Cancer Society, Mumbai, India.

Table 6. Trends of lung cancer in Mumbai city during 1982–2005.

	Year wise AAR[#] per 100,000 persons		Value of joint point AAR[#]	
Year	Male	Female	Male	Female
1982	13.3	3.2	13.4	2.9
1983	14	3.1	13.2	3
1984	12.5	3.8	13.1	3
1985	12.9	2.6	12.9	3
1986	11.7	1.8	12.8	3.1
1987	13.1	2.6	12.6	3
1988	12.2	3.2	12.5	3
1989	12.5	3.3	12.3	3
1990	13.3	2.9	12.2	3.1
1991	12.2	2.9	12	3.1
1992	11.9	4	11.9	3.1
1993	11.3	3.4	11.7	3.1
1994	11.6	3.2	11.6	3.1
1995	11.3	3.1	11.4	3.1
1996	11.8	3.2	11.3	3.2
1997	10.5	4.3	10.9	3.2
1998	10.6	3.1	10.5	3.2
1999	10.7	3	10.2	3.2
2000	9.5	3.2	9.8	3.2
2001	9.1	2.9	9.5	3.2
2002	8.5	3.1	9.2	3.2
2003	9	3.7	8.9	3.3
2004	8.9	3.3	8.6	3.3
2005	8.6	2.7	8.3	3.3
Slope	−0.217	0.012	Annual percent change (APC)	
p-value	0.001	0.421	−1.97	0.47

[#]AAR, age adjusted rate. (Source: National Cancer Registry Programme, Indian Council of Medical Research Time Trends in Cancer Incidence Rates 1982–2005, April 2009).

Conclusion

In the present study as per the pollutant standard index, most of the time air quality remained unhealthy for sensitive groups and unhealthy. Only during the winter season the air quality was very unhealthy (7% and 9%) at the kerb and industrial sites due to very high $PM_{2.5}$ concentrations. The percentage exceedances of $PM_{2.5}$ standards (CPCB) at C, K, R and I site were 59, 80, 71 and 80%, respectively. More than 50% exceedances show the non-attainment of the CPCB standard for $PM_{2.5}$ and it looks like a challenge to meet the target. In order to meet the $PM_{2.5}$ standards, it is necessary to generate time series data and plan in future to reduce attainment standards. It is essential to understand the background levels of fine particles also.

The knowledge from India is limited with regard to $PM_{2.5}$ and PAH risk assessment. This was a preliminary study in understanding the health effects of PAHs in Mumbai city. Time series analysis need to be done for PAHs and cancer in Mumbai city. To establish causal relationship for 2007, lung cancer cases and PAH concentrations has its limitation. Confounding factors like smoking, genetics may also affect the results. In spite of the limitation, estimates are proportionate and the

methodology adopted shows the association of BaPE and lung cancer cases. Present BaPE can be a good indicator to understand future cancer cases.

The movement of better knowledge generation of health impacts should be continued with focused goals for correlation of air quality monitoring results with health status of urban and rural population especially for fine particles. Also, these results need to be used for better planning of air quality management. Personal exposure research with regard to more toxic pollutants like fine particles, organic compounds like PAHs needs to be studied further. At this stage India need dose-response equations for local conditions.

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