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Characterization and Source identification of Atmospheric Polycyclic Aromatic Hydrocarbons in Visakhapatnam, India

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Abstract

Polycyclic aromatic hydrocarbons (PAHs) are considered to be hazardous atmospheric contaminants due to their carcinogenic and mutagenic properties. In the present study, 16 particle bound polycyclic aromatic hydrocarbons were determined in air particulate matter samples (PM_{10}) collected during March 2010 to February 2011 at an industrial cum residential area in Visakhapatnam, Andhra Pradesh. The samples were investigated for atmospheric concentrations, seasonal variation and potent sources of PAHs. Particulate matter samples were collected on glass fiber filter papers using high Volume Sampler and analyzed by HPLC/UV-VIS detector. The annual concentrations of total PAHs varied between 23.3 to 104.9 ngm^{-3}. The dominating PAHs were Acy, Ace, Phen, Pyr, B(ghi)P, B(a)P, and B(k)F. The PAHs concentrations were found to be elevated in winter than summer and monsoon. The total PAHs concentration during winter was about twice than the concentrations in summer and about 2.6 times higher than the concentration in monsoon. Higher PAHs concentrations in winter were mainly due to the privileged meteorological conditions in winter. The two and three ring PAHs were predominant than four, five and six ring PAHs and contributed to about 56% of total PAHs. The correlation studies showed that meteorological conditions such as temperature, relative humidity and rainfall strongly affected the PAHs concentrations. Principal component analysis (PCA) studies of the data indicated that coal combustion, diesel and gasoline powered vehicular emissions, lubricating oil burning and stationary sources like steel plant were the major sources of PAHs at study site.

Keywords: PAHs, seasonal variation, correlation, principal component analysis.

Introduction

The expanding human population pressure is causing aggressive industrial growth in developing countries. But, increased energy demands for industries and commercial establishments have resulted in serious environmental destruction[1]. Thousands of industrial effluents are generating untreated toxic waste in air, water, and soil. The impact of this environmental disaster is studied in last few years like influence of dye industrial effluent on soil, impact of industrial effluent discharge on agricultural soil, levels of heavy metals in urban sewage water and impact of human activities on quality of water etc[2-5]. Polycyclic aromatic hydrocarbons are the toxic organic compounds getting attention due to their carcinogenic and mutagenic properties[6]. At ambient temperature PAHs are present in air both in gaseous and particulate phase. Low molecular weight PAHs tend to be more concentrated in the vapor-phase while the high molecular weight are often associated with particulates. Particle-bound PAHs are considered to be the most hazardous to human health as particulates with aerodynamic diameters 10µm (PM_{10}) and 2.5µm ($PM_{2.5}$) are easily inhaled and exposure of them may cause lung cancer, morbidity and cardiopulmonary diseases[7]. PAHs are generated and emitted during incomplete combustion processes of fossil, non-fossil fuels and the release of petroleum products. PAHs originate mainly from anthropogenic sources such as household fuel burning, vehicular emissions, various industrial emissions and agriculture burnings. PAHs can persist in the environment for long time and they show ability to get transported at long distances[8]. They get accumulated in industrial and heavy traffic areas and also found in remote regions.

PAHs and their derivatives have shown carcinogenic and mutagenic effects. Studies have proved that workers exposed at coke ovens in coal coking, coal gasification, asphalt foundries and aluminum production plants suffered with lung cancer. It was found that chimney sweepers suffered from skin cancers and scrotal cancers due to high dermal exposure to the PAH compounds[9]. In last few years, a lot of work is carried out on airborne PAHs in many cities all around the world. In India the studies on PAHs are carried out in various cities like Mumbai, Delhi and Tiruchirapalli[10-12].

The current study focuses on the concentration, seasonal variation and the estimation of potent sources of particle bound PAHs at Visakhapatnam through the sampling program of one year. For this city, not much data is available on particle bound PAHs. So, this work will provide information about the levels of these toxic and mutagenic compounds and will be helpful to set control measures to prevent their harmful effects on environment.

Material and Methods

Sampling site and sample collection: Visakhapatnam (Latitude 17°41’18”N, Longitude 83°13’07”E), commonly known as “Vizag” is the second largest city in the state of Andhra Pradesh on the east coast of India. The population is around 1.7 million as per census 2011. The rapid urbanization has resulted in the increased utilization of fossil fuels for transportation and industrial purposes. The city has tropical type of climate with excessive humidity. The summer season is from March to June when the temperature is around 45°C. The monsoon season is from July to October with irregular showers and the North-East winds are the major source of rainfall. The annual rainfall was about 95 centimeters during study period. The winter season is from November to February with average temperature of 25°C.

For the study, sampling location was selected at an industrial cum residential area named “Paravada”. The site is about 8 km away from the national highway. The site has many industries in surrounding area such as NTPC (Simhadri), Bharat Heavy Plates, Steel Plant, BHPV and Nehru pharma city etc. Figure-1 shows the map of sampling site at Visakhapatnam.

Sampling was carried out from March 2010 to February 2011. For sampling USEPA guidelines were followed. PM$_{10}$ samples were collected using High Volume Sampler (Envirotech Respirable Dust Sampler, APM 460) and glass fiber filter papers of size 18 x 20 cm^2. The sampling was conducted weekly once for 24 h at the rate of 1.1 m^{3}min^{-1}. Filter papers were kept in desiccators before and after sampling to remove the moisture. After sampling, the filter papers were wrapped in aluminum foils and kept at cold place until extraction and analysis.

Extraction and Analysis of PAHs: One forth portion of the filter paper was cut into pieces and taken into conical flasks. They were extracted with 30 ml of HPLC grade n-hexane for 1h using ultrasonic technique. The extracts were filtered and concentrated to about 1ml. Then it was subjected to a column cleanup process. The extract was loaded on the top of a column (10 cm×1.0 cm i.d.) packed with slurry of silica gel. The column was eluted with n-hexane to give a fraction enriched with PAH. The PAH containing fraction was concentrated to 1ml by passing gentle stream of ultra-pure nitrogen. After this, it was stored in test tubes. The analysis of the extracts was carried out for 16 EPA priority PAHs including Naphthalene [Naph], Acenapthylene [Acy], Acenapthene [Ace], Fluorene [Fluo], Phenanthrene [Phen], Anthracene [Anth], Fluoranthene [Flt], Pyrene [Pyr], Benzo(a)Anthracene [B(a)A], Chrysene [Chry], Benzo(b) Fluoranthene [B(b)F], Perylene[Pery], Benzo(k) Fluoranthene [B(k)F], Benzo(a) Pyrene [B(a)P], Benzo(ghi)Perylene [B(ghi)P], and Indeno (1,2,3- cd)Pyrene [IP].

The identification of PAHs was carried out using HPLC (high performance liquid chromatography) system supplied by Shimadzu, LC-10 AD, Japan. In this system, column length was 250 mm and inner diameter was 4.6mm. It was filled with porous spherical particles. A guard column was also provided with length 10 mm and inner diameter 4.6-mm. For the analysis, mobile phase used was Acetonitrile (88%) and water (12%) mixture in isocratic mode. The flow rate was maintained at 0.85 ml/min. A UV-VIS detector was used which was set at 254 nm for identification of the peak of PAH compounds. The output signal of the detector was analyzed by Jasco–Borwin workstation.

Quality control: After sampling, all filter papers were kept at low temperature and extracted before 15 days from the sampling. The concentrations of PAHs were calculated using the retention times and areas under the peaks of the samples with standards. The limit of detection of the chromatographic method determined through serial dilution of the PAH standard varied between 0.007 to 0.016 ng for the different compounds. Blanks filter papers were extracted and blank samples were also run during analysis to avoid gravimetric and instrumental error.

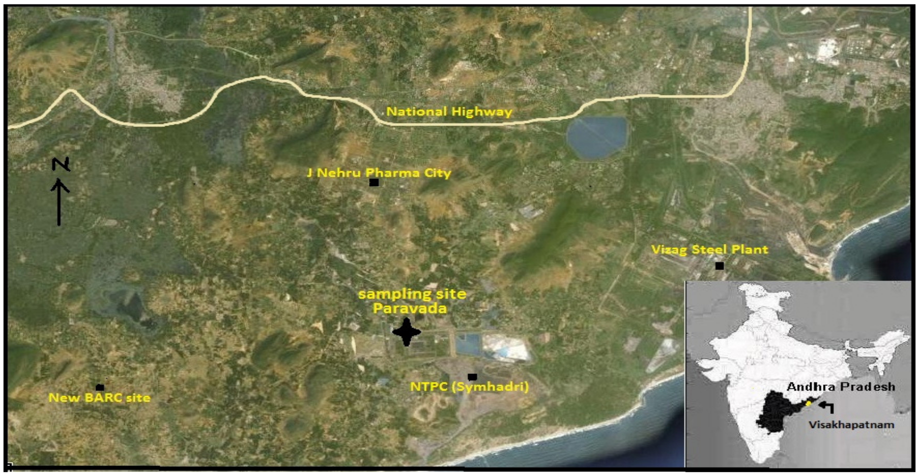

Figure-1
The map showing sampling site at Visakhapatnam

Results and Discussion

Concentrations of PM_{10} and PAHs: The annual average concentrations of individual PAHs measured in the PM_{10} are presented in table-1. The concentrations of individual PAHs varied between 0.11 to 18.5 ngm^{-3}. The concentrations of total PAHs (TPAHs) varied between 23.4 and 104.9 ngm^{-3} with average concentration of 57 ngm^{-3}. Maximum TPAHs concentration was observed in the month of January (101.1 ngm^{-3}) while minimum TPAHs concentration was observed in the month of August (24.3 ngm^{-3}). TPAHs concentrations showed variability due to meteorological variations during the sampling period. Concentrations of Acy, Fluo, Ace and Phen were highest amongst all PAHs. These are the significant low molecular weight PAHs found in fly ash from coal based power plant[13]. Significantly high levels of B(ghi)P and Phen which are generally contributed by motor vehicle emissions were observed in the samples. The concentrations of B(a)P, B(a)A, Chry, Pyr and B(k)F were also found high which are potent carcinogenic. The sources of Fluo, Phen and IP are incomplete combustion and pyrolysis of fuels[7].

Table-1
Minimum (MIN), maximum (MAX) and average (AVG) concentrations of individual PAH in ngm^{-3} at Visakhapatnam

Pahs	Min	Max	Avg
Naph	1.0	6.3	3.0
Acy	7.4	18.5	12.5
Fluo	1.5	9.7	5.0
Ace+Phen	3.5	16.1	9.1
Anth	0.7	6.3	2.8
Flt	0.7	4.3	1.8
Pyr	0.6	10.8	3.6
Chry+BaA	0.6	5.9	2.2
BbF	0.3	5.9	2.0
BkF	0.3	6.7	2.4
Pery	0.2	3.9	1.2
BaP	0.2	3.5	1.7
IP	0.1	5.6	2.0
BghiP	2.6	17.7	7.7

The sum of the major combustion specific compounds which include Fluo, Pyr, B(a)A, Chry, B(b)F, B(ghi)p, B(a)P, IP and B(k)F was found to be 23.4 ngm^{-3} and the ratio of their sum with the sum of the 16 EPA-PAHs (∑COMB/TPAHs) was 0.41. IARC listed carcinogenic PAHs were further classified as 'probably carcinogenic' to humans (namely BaA, BaP and DbA) and as 'possibly carcinogenic' to humans (namely BbF, BkF and IP). These potent carcinogenic PAHs (excluding DbA) accounted for 18% of the total PAHs.

Table-2 shows the present results compared with the data of other cities in India and all over the world with similar background. It was found that TPAHs concentrations were quite higher in other metropolitan cities like Agra, Delhi and Tiruchirapalli in India and cities in Hong Kong and Taiwan than Visakhapatnam[7,11-15]. While concentrations in cities from Greece and Turkey were lower than the present study[16,17].

Distribution of PAHs having different number of Benzene Rings: PAHs are classified by the presence of number of aromatic rings. The classification is as follows: 2-rings including Nap; 3-rings including Acy, Ace, Flu, Phen and Ant; 4-rings including Flt, Pyr, B(a)A and Chry; 5-rings including B(b)F, B(k)F, B(a)P, Pery and 6-rings including IP and B(ghi)P. PAHs having more aromatic rings, in general, represent higher molecular weights. Figure-2 shows the percentage composition of PAH compounds having different number of Benzene Rings. There were high concentrations of 2 and 3 ring PAHs which contributed around 6% and 50% of total PAHs mass. The PAHs with 4, 5 and 6 rings PAHs contributed 13%, 13% and 18%, respectively.

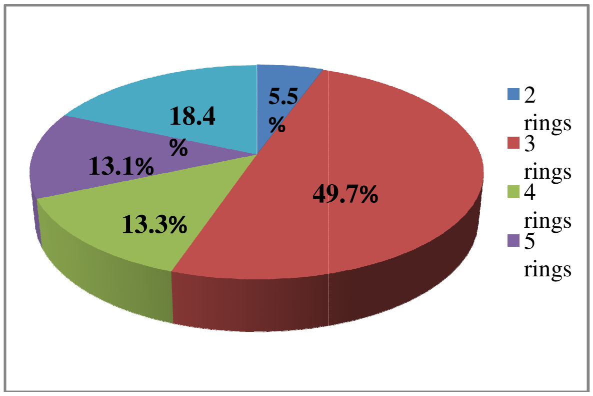

Figure-2
Percentage Composition of PAH compounds having different number of Benzene Rings

Seasonal Variations: Table-3 represents seasonally analyzed data of each PAHs concentration. It was found that the concentrations of PAHs are higher in the winter than in the monsoon and summer which is in accordance with earlier studies where particle bound PAHs concentrations were higher in winter than summer and monsoon[14]. The average concentrations of TPAHs were 88.9; 46.1 and 34 ngm^{-3} for winter, summer and monsoon, respectively. It was also observed that an average winter concentration of TPAH was about twice than the average summer TPAH concentration and about 2.6 times higher than average monsoon TPAH concentrations. Generally, the levels of concentrations of TPAHs throughout the year mainly depend upon atmospheric conditions. The concentrations of PM and related PAHs in atmosphere, generally decrease with increasing temperature and frequency of the rain[16]. In winter, slow speeds of wind and cold temperatures decrease the dispersion of pollutants. Therefore, PAHs concentrations are found higher in winter. In summer, increased dispersion of pollutants is observed due to fast speeds of wind and hot temperature. This leads to decrease in the concentration of PAHs in summer[11]. In monsoon, the PAHs are washed away due to rainfall causing less concentration as compare to winter and summer[14].

The effect of meteorological conditions on PAHs was well explained when winter to summer (W/S) concentrations and winters to monsoon (W/M) concentrations ratios were compared. The W/S and W/M ratios for individual PAH at the study area are given in figure-3. The W/S ratio for TPAHs was around 1.9 and that of the W/M ratio was around 2.6. The W/M ratios were higher than the W/S ratios which shows that for removal of PAHs from the atmosphere, wash out effects due to precipitations in monsoon are stronger than other PAH removing effects like photo degradation, biodegradation, chemical oxidation and various atmospheric effects in the summer.

One more reason behind the higher concentrations of PAHs in winter could be the higher emissions from combustion of fossil fuels for cooking and other central heating activities[16,17]. Also their levels in the ambient environment depend upon traffic and the industrial activities[18].

Table-2
Mean/Range of TPAHs concentrations (ngm^3) in various countries around the world with different backgrounds and methods of extraction

Countries	**Cities**	**Extraction /Analysis**	**Mean/Range of TPAH (ng/m3)**	**Samples collected**	**Site discription**
India (Present study)	Visakhapatnam	Acetonitrile-water/HPLC	57 ngm-3	PM_{10}	Industrial/residential
India	Agra[4]	DCM /GC-FID	40 - 2500	SPM	Industrial
India	Delhi[14]	DCM /GC-MS	33.1- 81.5	PM_{10}	Roadside/residential
India	Tiruchirapalli[15]	DCM: methanol/HPLC	232.7	$PM_{2.5}$	Residential
Hong kong	Kwun Tong[19]	DCM / GC-FID	2- 269	PM_{10}	residential/industrial
Taiwan	Taichung[20]	DCM /GC-MS	180.62	$PM_{2.5}$	Residential
Greece	Elefsina[21]	Acetonitrile/HPLC	0.6- 38.3	PM_{10}	Industrial
Turkey	Zonguldak province[22]	hexane - acetone/HPLC	28	PM_{10}	Industrial

Table-3
Seasonal variation of PAHs showing minimum (MIN), maximum (MAX) and average (AVG) concentrations and standard deviation (SD) of PAHs in ngm^{-3} in (a) winter, (b) summer, (c)monsoon seasons

PAHs	Summer				Monsoon				Winter			
	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd
Naph	1.2	3.9	2.1	0.7	1.0	3.4	2.0	0.9	3.3	6.3	4.7	0.8
Acy	9.9	15.8	12.3	1.8	7.4	11.4	9.3	1.3	12.5	18.5	15.8	1.8
Fluo	2.3	7.2	4.6	1.4	1.5	4.8	2.5	0.9	5.4	9.7	7.8	1.3
Ace+Phen	5.9	11.4	8.4	1.7	3.5	9.3	5.7	1.8	10.2	16.1	13.0	2.0
Anth	1.0	4.0	2.4	0.9	0.7	3.0	1.5	0.8	3.0	6.3	4.4	0.9
Flt	0.9	2.6	1.3	0.5	0.7	2.5	1.1	0.6	1.6	4.3	3.0	0.8
Pyr	0.9	4.0	2.0	1.2	0.6	3.1	1.3	0.9	3.6	10.8	7.4	1.9
Chry+BaA	0.9	2.7	1.4	0.5	0.6	3.7	1.3	1.0	1.3	5.9	3.8	1.3
BbF	0.7	1.9	1.2	0.4	0.3	2.6	0.9	0.7	2.0	5.9	3.7	1.2
BkF	0.6	2.9	1.1	0.5	0.3	2.1	0.9	0.7	3.5	6.7	5.0	0.9
Pery	0.3	2.9	1.0	0.8	0.2	1.0	0.4	0.2	1.0	3.9	2.1	0.9
BaP	0.2	2.9	1.5	0.7	0.5	2.5	1.0	0.6	1.3	3.5	2.5	0.7
IP	0.1	5.6	1.9	1.7	0.4	2.5	1.0	0.6	1.4	4.6	2.9	0.9
BghiP	3.0	7.2	4.8	1.1	2.6	8.3	5.1	1.6	5.7	17.7	13.0	3.5
Total	32.4	65.9	46.1	10.6	23.4	56.1	34.0	11.2	65.6	104.9	88.9	12.2

Correlation of PAHs with PM_{10} and other meteorological parameters: The meteorological parameters, such as precipitation, temperature and relative humidity during 2010 and their correlations with TPAHs concentrations in PM_{10} are displayed in table-4a and table-4b. The correlation coefficient was calculated using Pearson Correlation Coefficient. TPAH concentration showed strong positive correlation with $PM_{10.}$ Strong negative correlation was observed between TPAH and the parameters like temperature and relative humidity. Moderate negative correlation was observed between TPAHs and precipitation. This suggests that, in ambient air the concentration of particulate matter and related PAHs generally decrease with increasing wind speed, rainfall and humidity[16]. Thus, it can be concluded that meteorological conditions strongly affect the PAHs showing a seasonal variability in their concentrations.

Potential sources of PAHs and study of Diagnostic ratios: In many recent studies, the different PAH compounds were used as tracers to identify their diverse sources. It was observed that B(k)F, B(ghi)P and IP can be the tracers for vehicular emissions while the particulate matter samples enriched in B(ghi)P and coronene are characteristic of gasoline engines and Anth, Phen, Flt, pyr were identified as the tracers for wood combustion. Phen, Flt are characteristic of coal combustion while B(a)P, B(ghi)P are tracers for wood combustion and Pyr, B(ghi)p, B(b)F and B(k)F are the tracers for heavy-duty diesel vehicles[18].

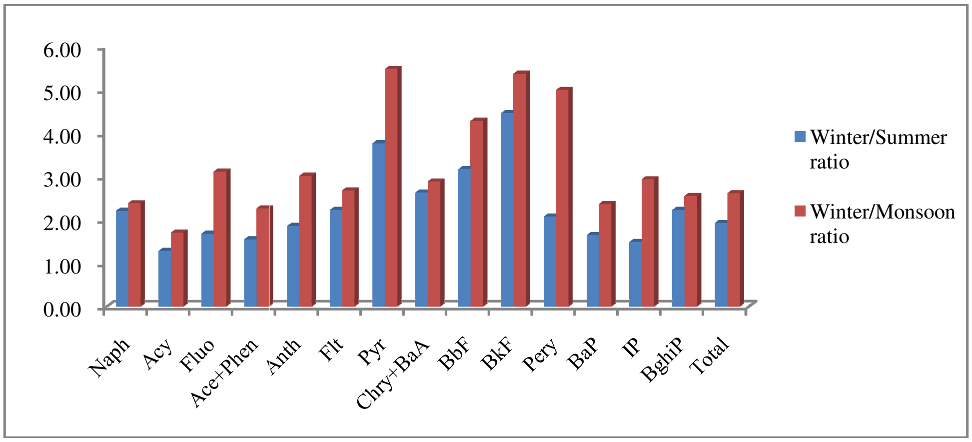

Figure-3
Winter/Summer and winter/monsoon ratios of concentrations of PAHs at Visakhapatnam

Table-4a
The meteorological parameters in Visakhapatnam in the year 2010-11

	Min temp	**Max temp**	**Avg temp**	**Precipitation**	**Rel humidity**
	°C	**°C**	**°C**	**mm**	**%**
January	17	28.9	22.9	17.4	70
February	18.9	31.3	25.1	25.2	72
March	22	33.8	27.9	29	75
April	25.1	35.3	30.2	37.6	76
May	26.7	36.2	31.5	77.8	77
June	26.3	35.3	30.8	135.6	74
July	25.1	32.9	29	164.6	76
August	25	32.7	30	181.2	77
September	24.6	32.5	28.5	224.8	78
October	23.3	31.7	27.5	234.3	74
November	20.6	30.4	25.5	95.3	68
December	17.6	28.9	23.5	37.9	64

Table-4b
Correlation coefficients of TPAHs with meteorological parameters

Parameters	**Average temp**	**precipitation**	**Relative Humidity**	**PM_{10}**
	(°C)	**(mm)**	**(%)**	**(μgm^{-3})**
Correlation coefficients with TPAHs	-0.91	-0.68	-0.87	0.81

Along with this, for preliminary assessment of sources of PAHs, Molecular diagnostic ratios of PAHs which frequently found together are studied. There values are compared with values in published literature. In this study, the ratio IP/ (IP+B(ghi)P) showed value of 0.19 which is given for petrogenic source in literature[19]. Also value 0.64 was obtained for the Fluo/(Fluo+Pyr) ratio which shows coal combustion ranging between 0.46-0.76[19]. The ratio Ind/B(ghi)P had value 0.26, which indicates gasoline engine[20]. Further the B(b)F/B(k)F ratio was found to be 0.95 with a value >0.5 which is given for diesel emissions[21]. The value 0.41 was observed for ratio Flt/Flt+Pyr ranged between 0.27-0.53 which attributes to gasoline emission[22]. Thus, the diagnostic ratio study shows that gasoline and diesel power vehicles and coal combustion are the main sources of PAHs in Vizag. Table-5 represents the diagnostic ratios for the PAHs in this study compared with literature values to attribute the specific sources.

Potential Source identification using factor analysis: Factor analysis or Principal component analysis is a useful method for source identification of PAHs which is based on multivariate data analysis[23]. In this, large number of data set is reduced to small number of independent variables. For this study, the number of extracted principal components corresponds to the sources of PAHs. The analysis was carried out using SPSS software version 9. “Factor loadings” obtained after the varimax rotation give the correlation between the variables and the factors. Data were included in the matrix only if the Eigen value for the factor is greater than 1.

Table-6 represents the results of PCA applied to data at study site. It represented five factors. The first factor was responsible for 51.89% of the total variance. It consists of high loadings of Naph (0.722), Ace+ Phen (0.832), Chry+B(a)A (0.814), B(b)F (0.511), B(a)P (0.699). This factor is indicative of coal combustion[24,25]. Second factor showed 16.11% of the overall variance. It was highly loaded with Acy (0.853), Fluo (0.883), B(b)F (0.534), Pery (0.583), B(a)P (0.449) and IP (0.426). This factor strongly indicates emission from gasoline vehicles[14,18]. The third factor was showing 7.6% of the total variance. This factor was strongly loaded with highly carcinogenic PAHs like Pyr (0.702), B(k)F (0.726), Pery (0.497) and B(ghi)P (0.868) which can be attributed to diesel powered vehicles as B(k)F is the tracer for diesel powered vehicular[10,19,26]. The forth factor showed 5.77% of the overall variance with high loadings of Flt (0.874) and IP (0.540). It could be identified as marker of combustion of lubricating oil[18,27].

Table-5
Diagnostic Ratios for the PAHs compared with literature values to attribute the specific sources

Diagnostic ratios	This Study		range/mean in literature	Source	References
	Mean	Range			
IP/ (IP+BghiP)	0.19	0.09-0.21	0.18-0.2	Petrogenic source	27
Fluo/ (Fluo+Pyr)	0.64	0.46-0.76	>0.5	Coal combustion	27
IP/BghiP	0.26	0.10-0.51	<0.4	gasoline engine	28
BbF/BkF	0.95	0.6-1.4	>0.5	Diesel emission	29
Flt/Flt+Pyr	0.41	0.27-0.53	≈ 0.4	gasoline emission	30

Table-6
Results of PCA applied to concentrations of PAHs with varimax rotation

Pahs	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Naph	0.722	0.253	0.280	-	0.119
Acy	-	0.853	0.190	0.182	0.273
Fluo	0.212	0.883	0.109	-	-
Ace+Phen	0.832	0.116	0.155	0.210	-
Anth	-	0.271	0.178	0.130	0.919
Flt	0.352	0.151	-	0.874	0.175
Pyr	0.467	0.229	0.702	-	0.179
Chry+BaA	0.814	-	0.380	0.236	-
BbF	0.511	0.534	0.296	0.232	-
BkF	0.281	0.424	0.726	0.199	0.149
Pery	-	0.583	0.497	0.153	-
BaP	0.699	0.459	0.147	0.139	-
IP	0.407	0.657	0.330	0.540	0.230
BghiP	0.270	0.132	0.868	-	-
Variance (%)	51.89	16.11	7.60	5.77	5.09
Cumulative(%)	51.89	68.01	75.61	81.39	86.48
Source	Coal combustion	Gasoline emission	Diesel emmision	Lubricating oil burning	Stationary sources

Loading greater than 0.4 is considered

The fifth factor was responsible for 5.09% of the total variance. This factor was strongly loaded with Anth (0.919). Anth mainly indicates stationary sources like steel industry, power plant etc[14,24]. Thus the dominant sources of PAHs in the ambient air of Vizag were mainly coal combustion, diesel and gasoline powered vehicles, lubricating oil burnings and stationary sources like power plant and steel industry.

Conclusion

For the study, the concentrations of TPAHs varied between 23.4 and 104.9 ngm^{-3} with average concentration of 57ngm^{-3}. The dominating PAHs were Acy, Ace, Phen, Pyr, B(ghi)P, B(a)P, and B(k)F. The two and three ring PAHs were predominant than four, five and six ring PAHs and contributed to about 56% of total PAHs. The potent six carcinogenic PAHs mentioned by IARC accounted for 18% of the total PAHs. The PAHs concentrations were found to be elevated in winter than summer and monsoon. The total PAHs concentration during winter was about twice than the concentrations in summer and about 2.6 times higher than the concentration in monsoon. The average W/S ratio for TPAH was 1.9 and that of the W/M ratio was 2.6. The inverse correlation between PAHs and temperature, relative humidity and rainfall suggested that these meteorological conditions strongly affect the PAHs concentrations. Molecular diagnostic ratios and principal component analysis (PCA) studies of the data indicated that coal combustion, diesel and gasoline powered vehicular emissions, lubricating oil burning and stationary sources from steel plant were the major sources of PAHs at study site. Coal combustion and stationary sources are signatures of thermal power plant and steel industry. The reason for such a high concentration of PAHs in the ambient air of Vizag can be the increased vehicular traffic and use of fossil fuels due to growth in human population.

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