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REVIEW PAPER

Atmospheric polycyclic aromatic hydrocarbons in India: geographical distribution, sources and associated health risk—a review

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Abstract Atmospheric distribution of polycyclic aromatic hydrocarbons and associated human health risks have been studied in India. However, a comprehensive overview is not available in India, this review highlights the possible sources, and associated cancer risks in people living in different zones of India. Different databases were searched for the scientific literature on polycyclic aromatic hydrocarbons in ambient air in India. Database searches have revealed a total of 55 studies conducted at 139 locations in India in the last 14 years between 1996 and 2018. Based on varying climatic conditions in India, the available data was analysed and distributed with four zone including north, east, west/central and south zones. Comparatively higher concentrations were reported for locations in north zone, than east, west/central and south zones. The average concentrations of ∑PAHs is lower in east zone, and concentrations in north, west/central and south zones are higher by 1.67, 1.47, and 1.12 folds respectively than those in east zone. Certain molecular diagnostic ratios and correlation receptor models were used for identification of possible sources, which aided to the conclusion that both pyrogenic and petrogenic activities are the mixed sources of PAH emissions to the Indian environment. Benzo(a)pyrene toxicity equivalency for different zones is estimated and presented. Estimated Chronic daily intake (CDI) due to inhalation of PAHs and subsequently, cancer risk (CR) is found to be ranging from extremely low to low in various geographical zones of India.

Keywords PAHs · Ambient air · Source apportionment · Cancer risk · India · Review

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Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a cause for worry on a global scale due to their typical characteristics of persistence, bioaccumulation, and toxicity. Incomplete combustion of coal, oil, and biomass is the main source of their release (ATSDR, 1995; Dat & Chang, 2017; Kamal et al., 2015; Williams et al., 2013a, 2013b). Despite the fact that their emissions from solid fuels (coal and wood) are often higher than those from liquid fuels (LPG and kerosene) (WHO, 2000), biomass burning nevertheless accounts for more than 50% of all PAH emissions worldwide (IARC, 2010). PAH emissions are found to be correlated with increasing urbanization, population increase, and corresponding energy demand (Fan et al., 2021; Hafner et al., 2005).

16 of the PAHs that have been found abundant are listed as priority pollutants by the US Environmental Protection Agency (USEPA) (USEPA 2015). Among 16 Priority PAHs, [naphthalene (Nap), acenaphthylene (Acy), acenaphthene (Acp), fluorene (Fle), phenanthrene (Phe), and anthracene (Ant)] are low molecular weight (L-PAH) PAHs and [fluoranthene (Flt), pyrene (Pyr), benz(a)anthracene (BaA), chrysene (Chr), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkF), benzo(a)pyrene (BaP), dibenz(a,h)anthracene (DBA), benzo(ghi)perylene (BghiP) and indeno (1,2,3-cd)pyrene (IndP)] high molecular weight (H-PAHs) (ATSDR, 1995). International Agency for Research on Cancer (IARC) categorized priority PAHs into different groups of carcinogens based on their carcinogenicity (IARC, 2010). Such as BaA and DBA as possible carcinogens in group 2A, but BaP, as a human carcinogen in group I. Nap, Chr, BkF, BbF, and IndP, categorized as potential carcinogens in group 2B.

PAHs are ubiquitous in diverse environmental compartments including the air, soil, and sediments (ATSDR, 1995; IARC, 2010). PAHs in the atmosphere gets distributed into gaseous and particle phases (PM) (Wang et al., 2009). It is reported that majority of H-PAHs are PM-bound, while L-PAHs exist in gas or vapour phase (Lai et al., 2017). Inhalation is found to be the main exposure pathway of PAHs coming from various sources such as biomass burning, tobacco smoking, forest fire, volcanic eruptions and emissions from vehicles (Dickhut et al., 2000; Li et al., 2010; Williams et al., 2013a, 2013b; Amarillo et al., 2014; Rengarajan et al., 2015; Ma & Harrad, 2015; Kaur et al., 2022). The repeated long-term exposures of the PM fraction of PAHs can accumulate and increase PAH concentrations in the tracheobronchial epithelium. However, gaseous phase of PAHs enter in to the circulatory system or lungs through alveolar epithelium (Bostrom et al., 2002). Exposure to PAHs can be genotoxic, which may bind directly to DNA or indirectly leading to DNA damage by affecting enzymes involved in DNA replication, thereby causing mutations. It is reported that absorbed PAHs are metabolized through various reactions and covalently bind to DNA (genetic material) to create DNA adducts (Abayalath et al., 2022; Bostrom et al., 2002; Gurbani et al., 2013). DNA adducts are an indicator of DNA damage that has been associated with cancer (Gaspari et al. 2003; Bosetti et al., 2007; Diggs et al., 2011; Perera et al., 2011).

There are studies carried out globally, on the health effects of PM-bound pollutants such as metals, organic carbon, elemental carbon, and water-soluble ionic species emitted from combustions of biomass materials (Abayalath et al., 2022; Pandey et al., 2013; Pongpiachan & Iijima, 2016; Pongpiachan et al., 2022). Atmospheric PM-bound PAHs have been reported for a number of locations around the world, including Kolkata (Ray et al., 2019), Delhi (Hazarika et al., 2019), national capital region (NCR) (Hazarika & Srivastava, 2016), and Amritsar (Kaur et al., 2013) in India; Birgunj and Biratnagar (Yadav et al., 2018), Bode, Lumbini, Pokhara, and Dhunche (Neupane et al., 2018) in Nepal; Kandy, Sri Lanka (Abayalath et al., 2022); Tianjin (Jin et al., 2018) & Xi'an (Li et al., 2014a, 2014b) in China; Cordoba, Argentina (Amarillo et al., 2014); Alexandria, Egypt (Khairy et al. 2013) and Eastern United States (Williams 2013a, 2013b). With regard to environmental variability, atmospheric PAH concentrations vary greatly across different Indian regions. In the northern, eastern, west/central, and southern zones, respectively, these concentrations ranged from 2.22 to 1845 ng/m^3, 6.7 to 506 ng/m^3, 2.31 to 447 ng/m^3, and 5.29 to 992 ng/m^3 (Table S1). Globally, there are numerous evaluations of the health hazards & risks associated with atmospheric PAHs (Abdel-Shafy & Mansour, 2016; Lawal, 2017; Dat & Chang, 2017; Srogi 2007; Ravindra et al., 2008; Ramesh et al., 2012; Kamal et al., 2015; Ma & Harrad, 2015; Famiyeh et al., 2021). This review thoroughly identifies the patterns of ambient air PAHs, potential sources, and related cancer risks in India.

Methodology

As per flow chart of review process (Supplementary data), keywords, including atmosphere PAHs, ambient air, PAH sources, health risk of PAHs, and India, were searched for scientific literature that was accessible through multiple databases (ScienceDirect, Scopus, Pubmed, MEDLINE, Google Scholar, ResearchGate) on atmospheric (ambient air) PAHs in India. This review included investigations carried out between 1996 and 2018 on PAHs in ambient air at 139 locations in 32 cities in different geographical zones in India over the past 14 years (2007–2021). Regardless of sampling technique, PM size, season of sampling and topography, studies currently accessible on PM bound PAHs in the Indian atmosphere were included in this review. In light of India's diverse climatic conditions (Bansal & Minke, 1988; Bhatnagar et al., 2019), the data was examined and analyzed in relation to four zones: the north, east, west/central, and south zones. India (area, 3.3 million km^2; population 1,210.2 million), geographically located between 8° 4′ and 37° 6′ latitudes north, and 68° 7′ and 97° 25′ longitudes east (India 2021).

Geographical distribution of atmospheric PAHs in India

In four zones, the mean concentration of ∑PAHs (the sum of sixteen PAHs) ranged from 174 ng/m^3 (east) to 290 ng/m^3 (north) (Table 1). Their concentrations of atmospheric PAHs varied from 2.22 to 1845 ng/m^3, 6.67 to 506 ng/m^3, 2.31 to 447 ng/m^3, and 5.29 to 992 ng/m^3 in the north, east, west/central, and south zones, respectively (Table S1). The average concentrations of ∑PAHs is lower in east zone (174 ng/m^3), and concentrations in other zones is higher with 1.67 fold (290 ng/m^3) for north zone, 1.47 fold (255 ng/m^3) for west/central, and 1.12 fold (259 ng/m^3) for south zone than east zone. The prevalent levels of atmospheric PAHs were reported in the north zone, such as Agra (Dubey et al., 2015; Masih et al., 2012; Rajput & Lakhani, 2009; Singla et al., 2012), Kanpur (Pradhi et al., 2021; Singh & Gupta, 2016), Lucknow in Uttar Pradesh (Pandey et al., 2013), Amritsar (Kaur et al., 2013), and NCR (Khillare et al., 2008; Kulshrestha et al., 2019; Shivani et al., 2018). For north India, Chanduka (2013) reported burning of biomass including crop residue as a significant contributor to elevated PM levels. Whereas, Chen et al. (2008) reported that elevated PM due to crop residue burning is linked to an increase of 58% in atmospheric PAHs. The locations

Table 1 Concentrations (ng/m^3) of atmospheric PAHs in different geographical zones in India

PAHs	North (n = 60)			East (n = 38)			West/Central (n = 14)			South (n = 27)		
	Mean	SE	% of ∑PAHs	Mean	SE	% of ∑PAHs	Mean	SE	% of ∑PAHs	Mean	SE	% of ∑PAHs
Nap	66.3	37.2	22.8	7.99	2.70	4.60	80.5	13.5	31.5	0.89	0.47	0.34
Acy	15.7	5.17	5.44	2.82	0.84	1.62	25.9	11.6	10.2	2.31	2.14	0.89
Acp	15.9	4.31	5.49	2.40	0.87	1.38	21.2	10.4	8.30	6.89	3.97	2.67
Fle	10.9	2.22	3.78	6.28	1.49	3.62	16.4	7.59	6.43	0.96	0.42	0.37
Phe	11.8	3.15	4.08	27.7	13.1	16.0	16.2	8.36	6.34	26.2	6.19	10.2
Ant	9.98	3.39	3.44	5.12	1.92	2.95	16.4	6.63	6.44	31.1	15.8	12.0
Flt	17.6	3.99	6.08	11.4	3.62	6.59	13.5	4.13	5.31	47.3	20.6	18.3
Pyr	11.0	2.94	3.81	11.7	3.34	6.75	8.46	2.99	3.31	27.9	12.2	10.8
BaA	11.3	2.46	3.92	10.4	2.24	6.04	8.47	2.75	3.32	14.5	3.49	5.62
Chr	11.9	4.60	4.12	21.6	5.28	12.5	8.27	2.76	3.24	39.1	11.7	15.1
BbF	16.9	3.20	5.82	9.24	2.19	5.32	11.7	4.36	4.60	13.6	2.73	5.26
BkF	10.8	2.20	3.73	9.54	2.32	5.50	4.90	1.38	1.92	5.80	1.19	2.24
BaP	13.3	3.01	4.58	11.5	2.11	6.67	6.43	1.83	2.52	8.73	1.86	3.38
BghiP	19.7	6.60	6.82	15.4	3.74	8.93	8.25	2.45	3.23	17.6	3.95	6.80
DBA	32.4	24.8	11.2	12.9	3.60	7.43	2.29	0.70	0.90	0.99	0.23	0.38
IndP	13.9	2.81	4.81	7.13	1.94	4.11	6.22	2.06	2.44	14.7	2.56	5.69
2-3Ring	50.7	30.0	23.2	37.4	13.6	25.8	50.7	28.4	41.3	53.9	17.2	26.6
4Ring	45.9	10.9	21.0	50.9	9.35	35.1	29.2	9.65	23.8	97.0	26.1	47.5
5Ring	37.9	7.60	17.3	25.3	4.02	17.5	19.5	5.91	15.9	25.2	4.99	12.4
6Ring	44.2	22.0	20.2	26.6	7.22	18.3	11.7	4.04	9.6	27.5	5.41	13.5
L-PAHs	91	30.0	41	42	13.6	29	62	28.4	51	54.0	17.24	26.6
H-PAHs	128	31.7	59	103	18.7	71	61	14.7	49	149	33.8	73.4
7PAHs	88	25.2	40	71	14.7	49	38	10.4	31	89	19.2	43.6
16PAHs	290	46.4	100	174	25.6	100	255	37.2	100	259	46.6	100

with elevated PAH contamination are found in the east zone are in Dhanbad (Roy et al., 2017), Kolkata in West Bengal (Gupta et al., 2007; Karar & Gupta, 2007; Saha et al., 2017), and Jharsuguda in Orissa (Devi et al., 2014; Ekka et al., 2021). While, relatively elevated PAH levels reported in the west/central zone are Pune (Roy et al., 2019), Akkalkuwa (Salve et al., 2015a, 2015b), and Raipur (Giri et al., 2013; Ramteke et al., 2018), in Chhattisgarh. In the south zone, Coimbatore (Mohanraj et al., 2011a), Chennai (Mohanraj et al., 2011b) and Tiruchirappalli (Mohanraj et al., 2012) cities were reported for significant levels of atmospheric PAHs (Table S1). Comparatively lower levels of atmospheric PAHs were reported at locations along hillsides (2.22–47 ng/m^3, Ray et al., 2017; Sharma et al., 2018), coastal areas (6.70–15 ng/m^3, Saxena et al., 2014; Sampath et al., 2015; Sharma et al., 2018). The dominant PAHs in various zones were Nap, DBA, Phe, Chr, Acy, Acp, Flt, Ant, and Pyr. (Table 1**,** Fig. 1).

Toxicity of atmospheric PAHs in India

IARC categorized seven PAHs namely; BaA, Chr, BbF, BkF, BaP, DBA, and IndP (7PAHs) as probable human carcinogens (IARC, 2010). This review concluded that concentration of atmospheric 7PAHs is comparatively low in the west/central zone (38 ng/m^3) than other zones (south, 89 ng/m^3, north, 88 ng/m^3, east, 71 ng/m^3). The contribution of 7PAHs in the north, east, west/central, and south zones, respectively, accounted for 40%, 49%, 31%, and 44% to ∑PAHs (Table 1). According to Table 1, the average BaP concentration in the north, east, west/central, and south zones is 13.3 ng/m^3, 11.5 ng/m^3, 6.43 ng/m^3, and 8.73 ng/m^3, respectively. The national ambient air quality standard (NAAQS) for BaP in ambient air in India is 1.0 ng/m^3; these values are beyond that threshold (MoEFCC 2009). The toxic equivalence factors (TEF) (Table 2) for additional PAHs in relation to BaP have been employed (Tsai et al., 2004) for calculation of carcinogenic toxicity in terms of BaP toxicity equivalency (BaPeq) by multiplying individual PAH concentration (C) in ambient air (ng/m^3) and TEF as:

$$\text{BaP toxicity equivalency (BaPeq)} = C \times TEF \quad (1)$$

In comparison to the east (29.1 ng/m^3), south (15.6 ng/m^3), and west & central zone (12.4 ng/m^3), the measured BaPeq of ∑PAHs was relatively greater in the north zone (51.9 ng/m^3) (Table 2). Combined contribution of 5 ringed (5R) and six ringed (6R) PAHs to total BaPeq is 90–96%, however, contribution from 2-3 ringed (2-3R) and 4 ringed (4R) PAHs is less than 10% to ∑BaPeq (Fig. 2 and Table 2). H-PAHs, including 7PAHs, were the predominant contributors to BaPeq and made up > 97% of the total BaP toxicity equivalency. Where, BaP and DBA were the major contributors, with 25–55% and 6–63%, respectively. Other PAHs included BbF, BaA, BkF (3.28%) and IndP were other important contributors to ∑BaPeq in different zones. It may be concluded that H-PAHs, particularly 5- and 6-ring PAHs, had a significant potential for carcinogenesis.

Distribution of potential sources of PAHs in the atmosphere in India

Identification of prospective and appropriate sources of PAHs with their individual contributions is essential for control measures of PAHs emissions to reduce environmental and human health concerns. There are numerous techniques that can apportion between different types of sources, such as pyrogenic sources (coal, wood, biomass, or oil combustion) and petrogenic sources (petroleum products) (Abdel-Shafy & Mansour, 2016). Among available methods, correlation, molecular diagnostic ratios (MDRs) of certain PAHs and principal component analysis (PCA) are typically used for the identification of possible sources of atmospheric PAHs (Abdel-Shafy & Mansour, 2016; Dat & Chang, 2017; Famiyeh et al., 2021; Katsoyiannis et al., 2011; Tobiszewski & Namiesnik, 2012). In this review, group homolog composition, MDRs, PCA and Pearson's correlation coefficient were utilized to identify potential sources of atmospheric PAHs in India.

Priority 16 PAHs with various aromatic rings were separated and are divided into two groups based on their molecular weights: L-PAHs (< four aromatic rings) and H-PAHs (≥ four aromatic rings). It is reported that L-PAHs emissions are linked from petrogenic sources including petroleum products, and burning of plant, grasses and biomass, whereas H-PAHs are dominant in pyrogenic sources including coal combustion and vehicular emissions (Elzein et al., 2020; Khalili et al., 1995; Marr et al., 1999; Ravindra et al., 2008; Singh et al., 2012; Wilcke, 2007;

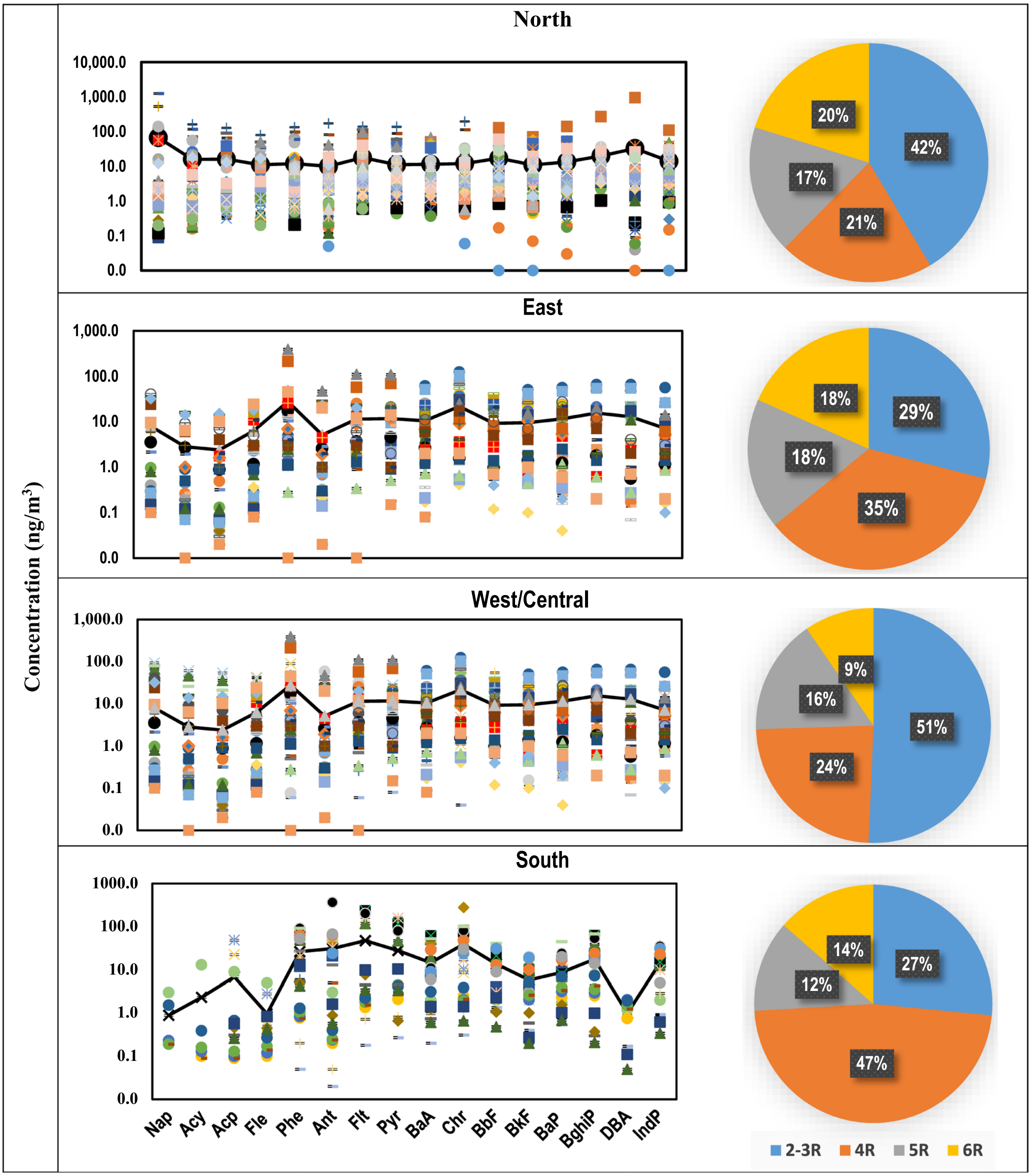


Fig. 1 Distribution of individual and group homolog of PAHs in different zones in India

Yunker et al., 2002). Comparatively, higher fraction of H-PAHs in east and south zones are indicative of pyrogenic sources including coal combustion and vehicular emissions (Fig. 3). The predominance of 2-3R PAHs in the north (23.2%) and west/central (41.3%) zones (Table 1) showed petrogenic sources, and burning of plant leaves, grass, wood and industrial oil (Elzein et al., 2020; Khalili et al., 1995; Wilcke, 2007; Yunker

Table 2 Concentrations of atmospheric BaPeq (ng/m^3) in different geographical zones in India

PAH	TEF*	North (n = 60)			East (n = 38)			West/Central (n = 14)			South (n = 27)		
		Mean	SE	% of ∑PAHs	Mean	SE	% of ∑PAHs	Mean	SE	% of ∑PAHs	Mean	SE	% of ∑PAHs
Nap	0.001	0.077	0.043	0.15	0.014	0.004	0.05	0.081	0.008	0.65	0.002	0.001	0.01
Acy	0.001	0.018	0.006	0.04	0.005	0.001	0.02	0.026	0.009	0.21	0.008	0.005	0.05
Acp	0.001	0.017	0.005	0.03	0.005	0.002	0.02	0.021	0.008	0.17	0.015	0.008	0.09
Fle	0.001	0.012	0.002	0.02	0.009	0.002	0.03	0.026	0.008	0.21	0.002	0.001	0.01
Phe	0.001	0.016	0.005	0.03	0.030	0.014	0.10	0.022	0.010	0.17	0.029	0.006	0.18
Ant	0.01	0.100	0.034	0.19	0.055	0.020	0.19	0.179	0.064	1.45	0.325	0.157	2.08
Flt	0.001	0.018	0.004	0.03	0.012	0.004	0.04	0.016	0.004	0.13	0.050	0.020	0.32
Pyr	0.001	0.011	0.003	0.02	0.012	0.003	0.04	0.010	0.003	0.08	0.030	0.012	0.19
BaA	0.1	1.26	0.268	2.42	1.048	0.218	3.61	0.847	0.246	6.83	1.45	0.336	9.30
Chr	0.01	0.120	0.046	0.23	0.217	0.051	0.75	0.090	0.026	0.73	0.391	0.113	2.50
BbF	0.1	1.82	0.341	3.51	0.924	0.211	3.18	1.17	0.401	9.46	1.36	0.261	8.72
BkF	0.1	1.08	0.220	2.09	0.954	0.225	3.28	0.490	0.125	3.95	0.580	0.114	3.71
BaP	1	13.3	3.006	25.6	11.6	2.05	39.8	6.43	1.70	51.8	8.73	1.80	55.94
BghiP	0.01	0.198	0.066	0.38	0.155	0.036	0.53	0.083	0.022	0.67	0.176	0.038	1.13
DBA	1	32.5	24.9	62.6	13.4	3.57	45.9	2.29	0.606	18.4	0.989	0.207	6.33
IndP	0.1	1.40	0.281	2.69	0.713	0.189	2.45	0.622	0.189	5.02	1.47	0.243	9.42
2-3Ring		0.17	0.05	3.06	0.09	1.23	4.11	0.12	2.31	4.91	0.24	1.03	8.15
4Ring		1.17	0.26	39.6	1.07	1.22	47.5	1.17	2.29	52.2	1.42	1.05	65.01
5Ring		15.1	3.31	56.9	12.4	2.26	48.0	12.4	3.79	42.4	11.2	2.33	25.44
6Ring		21.7	16.0	0.46	12.6	3.65	0.34	10.1	4.79	0.51	4.41	1.92	1.38
L-PAHs		0.17	0.05	0.46	0.09	1.23	0.34	0.12	2.31	0.51	0.24	1.02	1.38
H-PAHs		38.0	18.7	99.5	25.9	5.26	99.2	23.5	7.73	99.1	17.0	3.63	98.0
7PAHs		37.8	18.6	99.1	25.7	5.24	98.7	23.4	7.70	98.6	16.8	3.61	97.1
16PAHs		51.9	18.7	100	29.1	5.07	100	12.4	2.54	100	15.61	2.52	100

*Tsai et al., (2004)

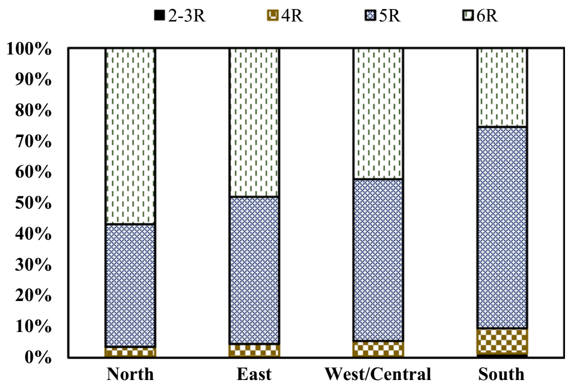


Fig. 2 Contribution of PAHs to ∑BaPeq

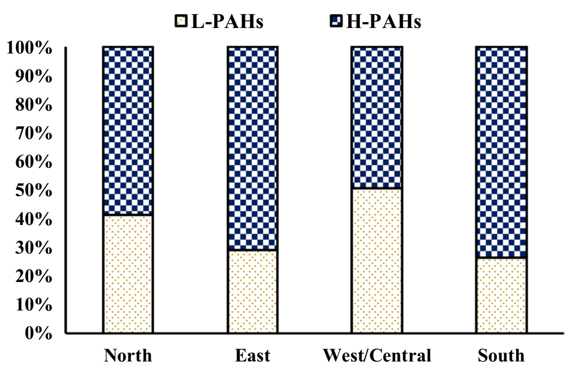
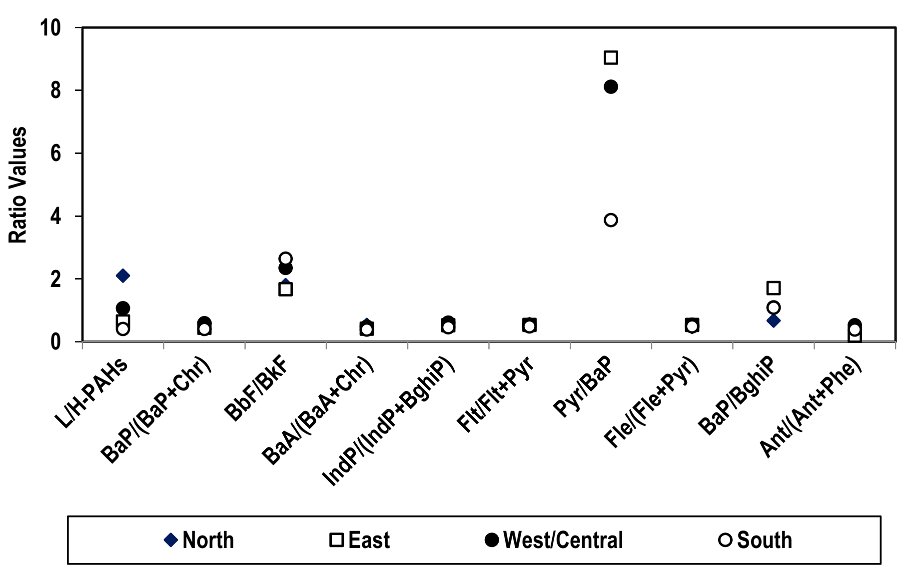


Fig. 3 Contribution of L-PAHs & H-PAHs to ∑PAHs

et al., 2002). The evidence for petrogenic origins was supported by the ratio of L-/H-PAHs (Wilcke, 2007) in the north (range, 0.02–36.4, mean 2.10) and west/central (range, 0.04–4.20, mean 1.06) zones. However, their ratios showed pyrogenic sources in the east (range, 0.01–3.82, mean, 0.64) and south (range, 0.01–1.38, mean, 0.42) zones (Fig. 4 and Table S2). The relative greater fractions of 4R PAHs and 2-3R PAHs (in the east zone and south zone) (Table 1 and Fig. 1) indicating mixed pyrogenic sources including combustion of woods, grass and industrial oil (Khalili et al., 1995; Marr et al., 1999; Wilcke, 2007). Vehicle emissions are reported as the source of 4-6R PAHs, while petrol combustion as source of 5-6R PAHs (Elzein et al., 2020; Ravindra et al., 2008). Diesel engines (Singh et al., 2012, 2013) and coal combustion (Elzein et al., 2020) are reported as the sources of L-PAHs and 3-4R PAHs, respectively. These similar patterns indicated many sources of PAHs in the Indian environment, including biomass combustion and vehicle emissions (Singh et al., 2012; Cheng et al. 2012, Saxena et al., 2016). H-PAHs predominated during the study, in the east (71%) and south (74%) zones (Fig. 3) being attributable to pyrogenic sources of petrol and oil combustion (Elzein et al., 2020; Ravindra et al., 2008) in the proximity of emissions (Wang et al., 2009), which is supported by lower ratios of L-/H-PAHs in the east (0.64) and south (0.42) zones (Fig. 4 and Table S2). This review came to the conclusion that

Fig. 4 Molecular diagnostic ratio of selected PAHs



the main sources of H-PAHs are pyrogenic activities, such as industrial, vehicular emissions and coal combustion (ATSDR, 1995; Ravindra et al., 2008; Singh et al., 2012). While the sources of L-PAH emissions in the Indian atmosphere are petrogenic and biomass combustion (grass, leaves and wood) (Khalili et al., 1995; Marr et al., 1999; Wilcke, 2007), combined with long-range atmospheric transport (LRAT). These findings are in line with prior results for sources of a similar nature (ATSDR, 1995; Khalili et al., 1995; Marr et al., 1999; Ravindra et al., 2008; Saxena et al., 2016; Singh et al., 2012, 2013; Wilcke, 2007).

The MDR of certain PAHs have been used worldwide by several authors to identify possible PAH emissions (Dvorská et al., 2011; Katsoyiannis et al., 2011; Kaur et al., 2013; Khillare et al., 2008; Kulshrestha et al., 2019; Shivani et al., 2018; Sofowote et al., 2010). During review, MDR of certain PAHs is computed and utilized for attribution of probable sources of atmospheric PAHs in India (Fig. 4 and Table S2). BaP/(BaP + Chr) ratios indicated diesel, coal, vehicles and gasoline combustion (Khalili et al., 1995). As reported (Dickhut et al., 2000), BbF/BkF indicated vehicular sources in the north and east zones as well as coal combustion in the west & central and south zones. The BaA/(BaA + Chr) ratios indicated automobile emissions (Yunker et al., 2002). IndP/(IndP + BghiP) ratio values of >0.50 for the north, east, and west/central zone supported biomass and coal combustion, whereas lower values (<0.50) for the south zone for petroleum combustion and gasoline sources (Dickhut et al., 2000; Yunker et al., 2002). Burning biomass and fossil fuels is indicated by Flt/(Flt + Pyr) ratios in the south zone, while coal, diesel engines, and gasoline were the sources in the north, east, and west/central, respectively (Simcik et al., 1999; Yunker et al., 2002). Diesel engines are linked to Pyr/BaP values (Ravindra et al., 2008). The Fle/(Fle + Pyr) ratio (<0.5) for the north and south zones showed gasoline, petrol emissions, and biomass burning, whereas the value >0.50 for the east, west/central zones suggested diesel emissions (Ravindra et al., 2008; Yunker et al., 2002). The BaP/BghiP ratios indicate automobile emissions in the north zone, while coal combustions for the east, west/central, and south zones indicate (Simcik et al., 1999). The Ant/(Ant + Phe) suggested burning of biomass and petroleum products (Ravindra et al., 2008; Yunker et al., 2002). Flu, Pyr, BaA, BbF, BkF, BaP, DBA, BghiP, and IndP are specimens of combustion PAHs (Comb-PAHs), which are also an indicator of combustion and non-combustion sources (Ravindra et al., 2008). The projected values of Comb-PAHs/$\sum$PAHs for all zones (~ 1) point to the combustion PAHs as predominating. (Table S2, Fig. 4). Based on the MDR of selected PAHs, it may be concluded that combustion PAHs basically from diesel engines, gasoline combustion, biomass burning, coal combustion and vehicular emissions are overwhelming in Indian environment. Be that as it may, coal combustion, vehicle and gasoline emissions in north zone; vehicles, diesel engines, and coal combustions in east zone; gasoline, diesel engines, biomass and coal combustion in west/central zone; and petroleum combustion, gasoline, fossil fills combustion, and biomass burning within the south zone are the major predicted sources of PAHs in different zones of India.

Based on the characteristics of the data set, a principal component (PC) analysis was carried out (Fig. 5, Table S3). Factor loading >0.3 was chosen as the lowest level of significance since loading values were low. Three PC with Eigen values >1 were selected, with $>70.0\%$ of the total variance for different zones (Table S3). For the north zone, PC1 had a high concentration of L-PAHs and 4R PAHs, accounting for 45.3% of the variance. PC2 (variance of 29.6%) was loaded with 5R and 6R PAHs. Nap and Acy were loaded into PC3 (8.11% variance). These PCs for the north zone showed combustion of biomass and coal, as well as emissions from vehicles and industries (Ravindra et al., 2008). LRAT has been documented for northern India (Kaur et al., 2013, 2022) and includes regional transport of ambient air with higher PAHs (Kalim et al., 2015, 2018, 2020) and PAH emissions from agricultural residue burning (Chen et al., 2008; Fakinle et al., 2022).

Among the three PCs for the east zone, PC1 (41.16% of the variance) suggested for pyrogenic sources (vehicle, industrial, and stationary source emissions) (Kaur et al., 2022; Cheng et al. 2012, Wilcke, 2007). According to Khillare et al. (2008), Yunker et al. (2002) and Dickhut et al. (2000), BaP, BaA, BbF, Pyr, IndP, and BghiP have been proposed as tracers of automobile emissions. While, car tires have been linked to the release of BghiP, IndP, and BaP (Famiyeh et al., 2021). PC2 (24.5% of variance) with load of Phe, Ant, Flt, and Pyr indicating combustions of biomass and coal, and diesel exhausts (Khalili et al., 1995; Marr et al., 1999; Ravindra et al., 2008). PC3 (with 17.9%

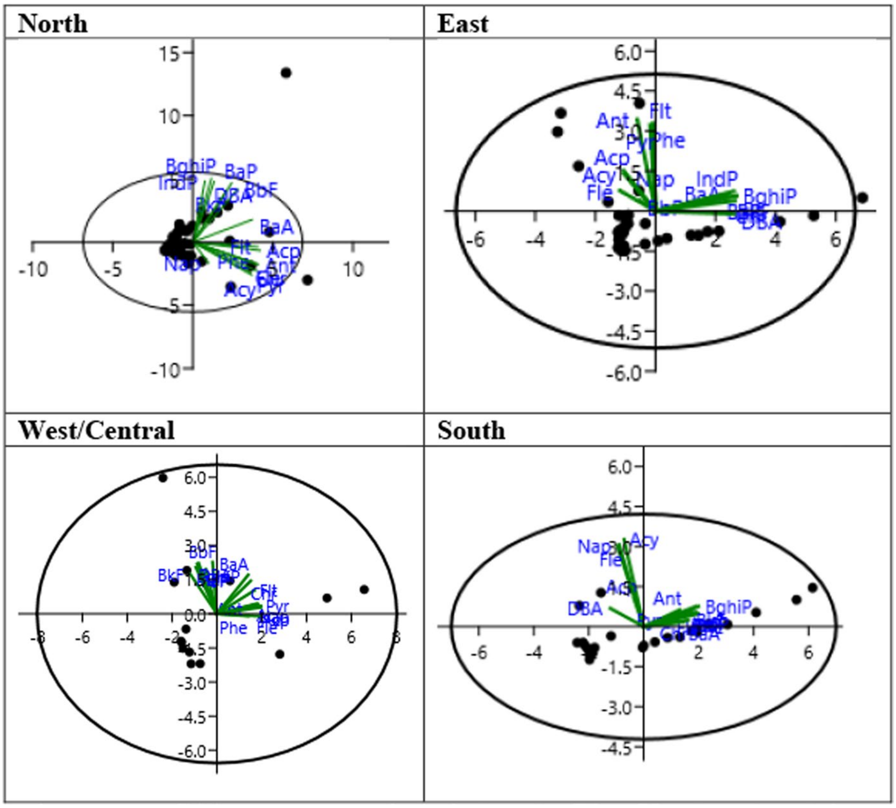


Fig. 5 Principal component plot of Factor loadings of PAHs

of variance) with presence of L-PAHs is suggestive of petrogenic origins (Ravindra et al., 2008; Wilcke, 2007). For the west/central zone, PC1 with 47.7% of the variance loaded both L-PAHs (Nap, Acp, Acy, & Fle) and H-PAHs (Flt & Pyr) suggested petroleum product and emissions from biomass and wood combustions (Kaur et al., 2022; Khalili et al., 1995; Sarkar & Khillare, 2013). The combustion of coal and diesel fuel may be the reason for the occurrence of Fle, Flt, and Pyr (Ravindra et al., 2008; Sampath et al., 2015; Wang et al., 2009). Additionally, it is reported that Fle and Pyr are pyrogenic by-products of the high-temperature burning of L-PAHs (Yang et al., 1998). In PC2 (with 31.9% of variance) H-PAHs are concentrated, and Ant, Flt, and BaP are concentrated in PC3 (10.1% of variance), suggesting pyrogenic origins from industrial emissions, automobile emissions, and biomass burning (Kaur et al., 2013, 2022; Khalili et al., 1995). Dominance of Flt, Pyr, Phe, Chr, Ant, Phe, BaA, and BbF have been proposed for coal combustion (Khalili et al., 1995; Ravindra et al., 2008). For the South zone, PC1 is loaded with both L-PAH (Phe) and 5R-6R-PAH (BbF, BkF, BaP, BghiP, and IndP). According to Marr et al. (1999), BaP, BghiP, and IndP are linked to traffic and gasoline emissions, whereas Kavouras et al. (2001) has linked BbF and BkF to the combustion of fossil fuels. PC2 with L-PAHs (NaP, Acy and Fle) was associated with oil-producing and pyrogenic sources (biomass, gasoline, fossil fuel combustion) in combination with LRAT (Ravindra et al., 2008; Wilcke, 2007; Khalili et al., 1995). Coal and diesel combustions are responsible for PC3's (11.6% variance) with high Flt and Pyr content (Ravindra et al., 2008; Sarkar & Khillare, 2013; Wilcke, 2007).

Result of PCA demonstrated the distinct PAHs sources from petrogenic (surface runoff discharges from auto service centers and petroleum spills) (Rajpara et al., 2017) and pyrogenic activities (burning of coal, biomass, and emissions from transportation and diesel engines) in India (Kaur et al., 2013, 2022; Ravindra et al., 2008; Saha et al., 2009, 2012; Sarkar & Khillare, 2013).

Results of Pearson's moment correlation coefficients (two tailed, $p < 0.01$, $p < 0.001$), shows a substantial association between various molecular weight PAHs (Tables 3, 4, 5 and 6). A significant association

Table 3 Correlation coefficient matrix for atmospheric PAHs in northern India (n = 60)

PAHs	Nap	Acy	Acp	Fle	Phe	Ant	Flt	Pyr	BaA	Chr	BbF	BkF	BaP	BghiP	DBA
Acy	0.582**														
Acp	0.109	0.715**													
Fle	0.351*	0.817**	0.848**												
Phe	0.364*	0.835**	0.595**	0.673**											
Ant	0.158	0.770**	0.750**	0.736**	0.823**										
Flt	0.109	0.640**	0.809**	0.789**	0.620**	0.726**									
Pyr	0.153	0.800**	0.830**	0.769**	0.817**	0.858**	0.841**								
BaA	−0.044	0.369*	0.696**	0.588**	0.449**	0.597**	0.571**	0.500**							
Chr	0.041	0.741**	0.697**	0.625**	0.838**	0.931**	0.687**	0.855**	0.572**						
BbF	−0.093	0.145	0.438**	0.244	0.165	0.320*	0.388*	0.184	0.719**	0.332*					
BkF	−0.107	−0.024	0.417**	0.199	−0.001	0.146	0.252	0.041	0.755**	0.106	0.858**				
BaP	−0.072	0.072	0.448**	0.222	0.041	0.152	0.359*	0.098	0.650**	0.131	0.911**	0.879**			
BghiP	−0.077	−0.108	0.031	−0.050	−0.091	−0.028	0.203	−0.087	0.326*	−0.043	0.669**	0.518**	0.758**		
DBA	−0.039	−0.061	0.101	0.006	−0.047	0.011	0.217	−0.053	0.336*	−0.025	0.649**	0.514**	0.768**	0.962**	
IndP	−0.124	−0.171	−0.074	−0.139	−0.160	−0.080	0.171	−0.136	0.226	−0.046	0.651**	0.473**	0.660**	0.882**	0.770**

Significant correlations at $p < 0.01$ are indicated as * mark, at $p < 0.001$ are indicated as ** mark

Table 4 Correlation coefficient matrix for atmospheric PAHs in eastern India (n = 38)

PAHs	Nap	Acy	Acp	Fle	Phe	Ant	Flt	Pyr	BaA	Chr	BbF	BkF	BaP	BghiP	DBA
Acy	0.926**														
Acp	0.856**	0.935**													
Fle	0.398*	0.528**	0.569**												
Phe	0.002	0.026	0.058	−0.056											
Ant	0.335	0.443*	0.514**	0.262	0.866**										
Flt	0.044	0.074	0.100	−0.066	0.978**	0.862**									
Pyr	−0.053	−0.023	0.014	0.101	0.957**	0.813**	0.947**								
BaA	−0.145	−0.186	−0.177	0.007	0.002	−0.058	0.032	0.119							
Chr	−0.105	−0.159	−0.167	−0.353	−0.038	−0.101	0.006	−0.042	0.817**						
BbF	−0.056	−0.095	−0.134	0.379*	0.148	0.052	0.089	0.256	0.036	−0.085					
BkF	−0.172	−0.210	−0.189	−0.370	0.033	−0.041	0.081	0.040	0.857**	0.933**	−0.297				
BaP	−0.012	−0.116	−0.175	−0.093	−0.016	−0.112	0.007	0.051	0.913**	0.820**	0.039	0.834**			
BghiP	−0.146	−0.191	−0.186	−0.358	0.032	−0.045	0.071	0.033	0.816**	0.933**	−0.268	0.972**	0.807**		
DBA	−0.181	−0.201	−0.190	−0.331	−0.168	−0.197	−0.130	−0.165	0.764**	0.958**	−0.182	0.912**	0.725**	0.939**	
IndP	−0.173	−0.174	−0.186	−0.319	0.075	−0.002	0.133	0.091	0.831**	0.901**	−0.241	0.931**	0.795**	0.930**	0.873**

Significant correlations at $p < 0.01$ are indicated as * mark, at $p < 0.001$ are indicated as ** mark

Table 5 Correlation coefficient matrix for atmospheric PAHs in western/central India (n = 14)

PAHs	Nap	Acy	Acp	Fle	Phe	Ant	Flt	Pyr	BaA	Chr	BbF	BkF	BaP	BghiP	DBA
Acy	0.983**														
Acp	0.975**	0.952**													
Fle	0.710*	0.677*	0.846**												
Phe	0.358	0.320	0.549	0.905**											
Ant	0.386	0.347	0.491	0.654*	0.630*										
Flt	0.629*	0.575	0.693*	0.719*	0.619*	0.888**									
Pyr	0.815**	0.778**	0.900**	0.920**	0.755**	0.677*	0.836**								
BaA	0.818**	0.799**	0.766**	0.493	0.242	0.402	0.748**	0.683*							
Chr	0.785**	0.765**	0.740**	0.488	0.227	0.613	0.848**	0.687*	0.943*						
BbF	0.130	0.111	0.081	−0.048	−0.017	−0.181	0.197	0.061	0.582	0.366					
BkF	−0.340	−0.305	−0.394	−0.445	−0.299	−0.486	−0.293	−0.427	0.071	−0.125	0.785**				
BaP	−0.188	−0.144	−0.246	−0.335	−0.272	0.230	0.276	−0.151	0.300	0.376	0.467	0.505			
BghiP	−0.313	−0.307	−0.364	−0.410	−0.259	−0.063	0.102	−0.274	0.255	0.191	0.765**	0.778**	0.861**		
DBA	−0.275	−0.232	−0.319	−0.360	−0.218	−0.079	0.087	−0.241	0.279	0.201	0.765**	0.787**	0.858**	0.953**	
IndP	−0.226	−0.210	−0.278	−0.346	−0.211	−0.410	−0.128	−0.260	0.239	0.019	0.904**	0.939**	0.544	0.853**	0.850**

Significant correlations at $p < 0.01$ are indicated as * mark, at $p < 0.001$ are indicated as ** mark

Table 6 Correlation coefficient matrix for atmospheric PAHs in southern India (n = 27)

PAHs	Nap	Acy	Acp	Fle	Phe	Ant	Flt	Pyr	BaA	Chr	BbF	BkF	BaP	BghiP	DBA
Acy	0.902**														
Acp	0.064	0.108													
Fle	0.753**	0.850**	0.852**												
Phe	−0.248	−0.167	−0.240	−0.302											
Ant	−0.113	−0.072	−0.118	−0.147	0.587*										
Flt	−0.126	−0.083	−0.123	−0.159	0.540*	0.478*									
Pyr	−0.102	−0.068	−0.116	−0.140	0.375	0.307	0.919**								
BaA	−0.219	−0.148	−0.083	−0.248	0.600**	0.077	0.312	0.231							
Chr	−0.198	−0.136	−0.140	−0.242	0.408	0.272	0.126	0.049	0.658**						
BbF	−0.253	−0.155	−0.004	−0.226	0.798**	0.432	0.272	0.120	0.712**	0.542*					
BkF	−0.118	−0.104	−0.257	−0.279	0.822**	0.595**	0.354	0.187	0.539*	0.589**	0.817**				
BaP	−0.177	−0.151	−0.145	−0.260	0.814**	0.504*	0.215	0.194	0.484*	0.410	0.711**	0.731			
BghiP	−0.154	−0.096	−0.267	−0.266	0.885**	0.473*	0.605**	0.444	0.778**	0.598**	0.770**	0.787	0.741		
DBA	0.530	0.285	−0.122	0.173	−0.449	−0.219	−0.234	−0.196	−0.419	−0.361	−0.499	−0.258	−0.312	−0.362	
IndP	−0.267	−0.164	0.229	−0.130	0.631**	0.519	0.270	0.158	0.535*	0.709**	0.772**	0.788	0.593	0.620	−0.525

Significant correlations at $p < 0.01$ are indicated as * mark, at $p < 0.001$ are indicated as ** mark

between 2-3R PAHs and 4R PAHs in the north zone pointed to industrial emissions, diesel engines and biomass burning (burning crop residue and wood) (Kaur et al., 2013; Singh et al., 2013). Association between 4 and 5R PAHs suggested pyrogenic sources including coal combustion and vehicular emissions (Khalili et al., 1995; Marr et al., 1999; Singh et al., 2012, 2013; Kaur et al., 2013). Additionally, a significant link between the 5R and 6R PAHs pointed to the combustion sources from fossil fuels, gasoline, and traffic emissions (Kavouras et al., 2001) (Table 3). A relationship between Nap, Acy, Acp, and Phe in the east zone showed petrogenic inputs from biomass burning, which is a prevalent method for meeting energy needs (Ekka et al., 2021). An association between Ant, Flt, and Pyr suggested coal combustion (Khalili et al., 1995). According to a significant link between 5 and 6R PAHs, mixed pyrogenic sources may include coal combustion, industrial and vehicle emissions, and vehicle and industrial emissions (Kaur et al., 2013, 2022; Wilcke, 2007). The main sources of PAHs in the east zone include petroleum and pyrogenic sources, such as coal and biomass burning, as well as vehicle emissions (diesel + gasoline) (Devi et al., 2014; Ekka et al., 2021; Kumar et al., 2020a, 2020b; Ray et al., 2019). Traffic emissions, diesel engines, and coal combustion were strongly significantly correlated with 3R and 4R PAHs in the west/central zones (Elzein et al., 2020; Singh et al., 2012, 2013). Correlation between L-PAHs indicated biomass burning and petrogenic activity. A substantial correlation between 4 and 5R PAHs, and burning of crop residues and wood was suggested by a link between Pyr, BaA, and Chr (Singh et al., 2013). Exhaust from heavy engine was indicated by the strong connection of 5R and 6R PAHs (Kaur et al., 2013; Kavouras et al., 2001; Marr et al., 1999) (Table 5). These connections suggested that the thermal power plant, cars (which use both diesel and gasoline), and biomass burning are the most likely sources of PAHs in west/central zone (Gune et al., 2019; Roy et al., 2019, Gosai et al. 2017; Rajpara et al., 2017; Giri et al., 2013). Strong correlations between Fle and Nap, Acy, and Acp in the south zone suggested petrogenic origins (Sampath et al., 2015). There is a strong association between Phe and Ant, BaA, Chr, and BbF with H-PAHs suggested pyrogenic sources of biomass combustion and high temperature combustion processes (Marr et al., 1999; Saha et al., 2012; Singh et al., 2013) (Table 6). According to Kalaiarasan et al. (2017), Sampath et al. (2015), and Mohanraj et al., (2011a, 2011b), the main sources of PAHs in the south zone are emissions from gasoline, diesel, and petroleum products.

According to this review, both pyrogenic and petrogenic activities are the sources of PAH emissions to the Indian environment. The burning of solid fuels (such as coal and biomass), diesel, industrial pollutants, and vehicle emissions are the main pyrogenic sources of PAHs in India. The main petrogenic sources include surface runoff, discharges from auto shops, and unintentional spills (Singare & Shirodkar, 2021; Singh et al., 2013). According to Rengarajan et al. (2015), solid fuels used in home and industrial settings are a major source of PAHs in India. Prior to this, burning coal and burning biomass have been identified as the main sources of PAH in India (Khillare et al., 2008). Biomass is said to make for about 94% of the energy used in rural India (Singh et al., 2013). Compared to LPG and kerosene, wood and coal emit more PAHs (WHO, 2000); according to IARC (2010), biomass alone is the source of

Table 7 Summary of input parameters used in calculation for cancer risk assessment

Symbol	Parameter	Unit	Value	References
C	Concentration of PAH	ng/m^3	–	Present review data
IR	Inhalation rate	m^3/day	Children, 13.5; Adult, 13	ATSDR (2005)
EF	Exposure frequency	days	365	ATSDR (2005)
ED	Exposure duration	years	Children, 12; Adult, 70	ATSDR (2005)
UCF	Unit conversion factor	–	10^{-6}	–
SFO	Slope factor	mg/kg/day	7.3 (BaP)	USEPA, (2019)
BW	Body weight	kg	Children, 35; Adult, 60	Nair and Augustine, (2018)
AT	Averaging time (EF × ED)	days	Children, 4380; Adult, 25,550	ATSDR (2005)

more than 50% of all global PAH emissions. The main causes of the poorer air quality in developing India are the rise in automobiles, the demand for more energy, and the country's increasing industry to support population growth. Vehicle, industrial, coal, and gasoline combustions have been described as the main sources of PAHs (Hassan & Khoder, 2012; Lee et al., 1995; Wild & Jones, 1995).

Prediction of cancer risk

Equations 2 and 3 were used to estimate chronic daily intake (CDI) of PAHs and subsequent cancer risk (CR) (Zhang et al. 2009; ATSDR 2005; USEPA, 2019), since the inhalation pathway was taken into account for human exposure for this review.

$$CDI\left(\frac{\frac{mg}{kg}}{day}\right) = \frac{C \times IR \times EF \times ED}{BW \times AT} \times UCF \quad (2)$$

$$CR = CDI \times CSF \quad (3)$$

Summary of input parameters used for CDI and CR assessment are presented in Table 7. Acceptable limits of CR values of 10^{-6}–10^{-4} are for possible CR, values of $> 10^{-4}$ is for high possible risk (WHO, 2000). Further, various values of CR have been categorized by various agencies such as $\leq 10^{-6}$ for very low; 10^{-6}<—$< 10^{-4}$ for low, 10^{-4}—$< 10^{-3}$ for moderate, $10^{-3} \leq$—$< 10^{-1}$ for high and $\geq 10^{-1}$ for very high CR (USEPA, 2019; NYS DOH 2007; ATSDR 2005).

For adults, the estimated CDIs (Table S4) of PAHs was used to estimate CR, which was shown to be higher in the north zone compared to other zones (Table 8 and Fig. 6). In the north, east, west/central, and south zones, the mean values for adults and children were, respectively, 4.89×10^{-5} and 1.64×10^{-5}, 3.13×10^{-5} and 1.05×10^{-5}, 1.07×10^{-5} and 3.68 y 10^{-6}, and 1.39×10^{-5} and 4.85×10^{-6}. The order of CR's 90th percentile is for East > north > west/central > south (Table 8)., the estimated CR due to H-PAHs to humans is low ($< 10^{-4}$), and for L-PAHs, it is very low ($< 10^{-6}$) (Fig. 6). The 25th and 50th percentiles are low ($< 10^{-4}$) and the 5th percentile is very low ($< 10^{-6}$) respectively. The CR to human adults and children caused by atmospheric PAHs in various

Table 8 CR of atmospheric PAHs different geographical zones in India

Zones	PAHs	Adult					Children				
		5th	25th	50th	90th	Mean	5th	25th	50th	90th	Mean
North	∑PAH	5.34×10^{-9}	3.92×10^{-6}	1.51×10^{-5}	6.12×10^{-5}	4.89×10^{-5}	4.31×10^{-9}	1.32×10^{-6}	5.31×10^{-6}	2.06×10^{-5}	1.64×10^{-5}
	L-PAH	2.83×10^{-11}	1.21×10^{-10}	4.78×10^{-10}	2.41×10^{-9}	1.53×10^{-9}	1.04×10^{-11}	4.20×10^{-11}	1.63×10^{-10}	8.34×10^{-10}	6.14×10^{-10}
	H-PAH	3.20×10^{-9}	3.92×10^{-6}	1.51×10^{-5}	6.12×10^{-5}	4.89×10^{-5}	1.28×10^{-9}	1.32×10^{-6}	5.31×10^{-6}	2.06×10^{-5}	1.64×10^{-5}
East	∑PAH	3.83×10^{-7}	3.02×10^{-6}	1.95×10^{-5}	7.46×10^{-5}	3.13×10^{-5}	1.57×10^{-7}	1.04×10^{-6}	6.46×10^{-6}	2.49×10^{-5}	1.05×10^{-5}
	L-PAH	2.49×10^{-11}	3.45×10^{-11}	9.34×10^{-11}	3.40×10^{-9}	7.65×10^{-10}	8.24×10^{-12}	1.14×10^{-11}	3.09×10^{-11}	1.16×10^{-9}	2.65×10^{-10}
	H-PAH	3.83×10^{-7}	3.02×10^{-6}	1.95×10^{-5}	7.46×10^{-5}	3.13×10^{-5}	1.57×10^{-7}	1.04×10^{-6}	6.46×10^{-6}	2.49×10^{-5}	1.05×10^{-5}
West/Central	∑PAH	3.76×10^{-7}	1.82×10^{-6}	5.23×10^{-6}	3.12×10^{-5}	1.07×10^{-5}	1.66×10^{-7}	6.31×10^{-7}	1.78×10^{-6}	1.04×10^{-5}	3.68×10^{-6}
	L-PAH	1.38×10^{-10}	2.57×10^{-10}	4.15×10^{-10}	7.43×10^{-9}	2.74×10^{-9}	4.56×10^{-11}	8.49×10^{-11}	1.37×10^{-10}	2.46×10^{-9}	9.44×10^{-10}
	H-PAH	3.72×10^{-7}	1.82×10^{-6}	5.22×10^{-6}	3.12×10^{-5}	1.07×10^{-5}	1.65×10^{-7}	6.31×10^{-7}	1.78×10^{-6}	1.04×10^{-5}	3.68×10^{-6}
South	∑PAH	1.29×10^{-6}	5.21×10^{-6}	9.68×10^{-6}	2.75×10^{-5}	1.39×10^{-5}	4.39×10^{-7}	1.76×10^{-6}	3.32×10^{-6}	9.57×10^{-6}	4.85×10^{-6}
	L-PAH	3.11×10^{-11}	6.62×10^{-11}	2.68×10^{-10}	8.22×10^{-9}	4.06×10^{-9}	1.03×10^{-11}	2.46×10^{-11}	8.88×10^{-11}	2.72×10^{-9}	1.34×10^{-9}
	H-PAH	1.29×10^{-6}	5.21×10^{-6}	9.67×10^{-6}	2.75×10^{-5}	1.39×10^{-5}	4.39×10^{-7}	1.76×10^{-6}	3.31×10^{-6}	9.57×10^{-6}	4.85×10^{-6}

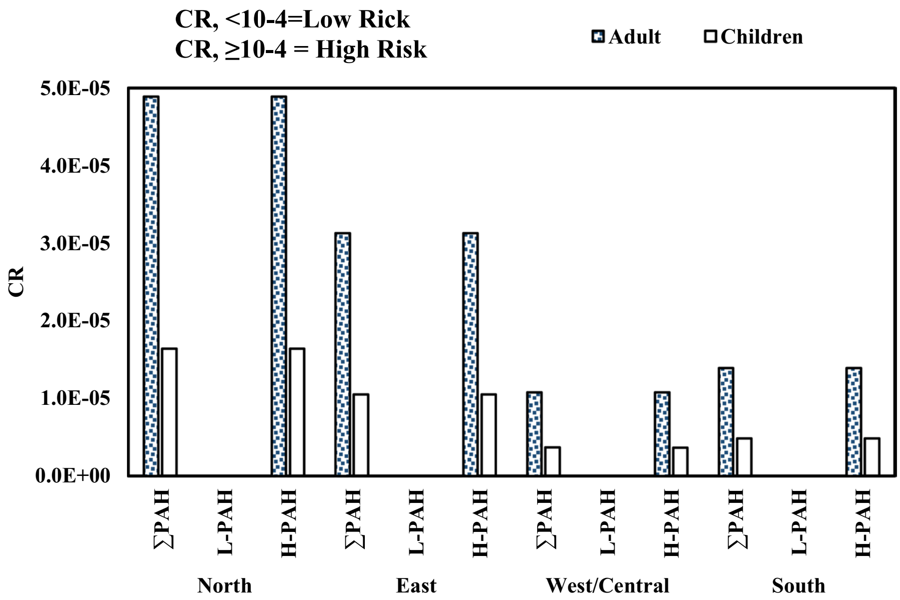


Fig. 6 Cancer risk (CR) due to atmospheric PAHs in different zones in India

geographical zones of India is therefore extremely low to low, according to this analysis of the data that is currently available (Table 8).

Conclusions

Data on atmospheric distribution of PAHs in India that have been collected from several research databases have shown that the distribution varies geographically. Despite this fact, this analysis identified the main sources, levels of exposure, and cancer risk for people in different regions. According to the assessment, there are differences in the atmospheric concentrations of BaP and ∑PAHs in different regions, with BaP surpassing the national ambient air quality standard (NAAQS) in India. The review warrants further investigation of atmospheric PAHs in India.

Commonly used methods, i.e. MDR, PCA and correlation coefficients have been used as diagnostic tools to find potential sources of atmospheric PAHs in India. Source analysis indicates that atmosphere in India has a mixture of sources including pyrogenic and petrogenic activity. The central and northern areas are dominated by petrogenic sources. Various sources of petrogenic emissions of L-PAHs have been reported in India, including petroleum products and burning wood, grass and industrial oils. The main sources of pyrogenic PAHs recorded in India include the combustion of solid fuels (such as coal and biomass), diesel, industrial pollutants and vehicle emissions. Vehicle and industrial emissions from using diesel, fossil fuels and biomass as energy sources for various activities dominate this list.

In India, the estimated CDI of inhaled PAHs in adults is higher than in children. Estimated CDI are less than 1 μg BaP/kg/day (1×10^{-3} mg/kg/day), which may pose CR of 7.3×10^{-3} (USEPA 2017). According to the CDI, the northern region is more likely to have a potentially greater CR for humans than other regions, with H-PAH as the main contributor. The CR to human adults and children caused by atmospheric PAHs varied from very low (L-PAH) to low (H-PAH) for the Indian population. The Indian government has taken several measures to reduce air pollution (MoEFCC, 2019). These approaches include switching over industries and coal based power plants to gasoline, enforcing strict regulations on industrial emissions, and reducing the amount of benzene in gasoline.

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Declarations

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