

Research Article

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Characteristics, source, and health risk assessment of aerosol polyaromatic hydrocarbons in the rural and urban regions of western Saudi Arabia

<https://doi.org/10.1515/chem-2022-0229>

received July 24, 2022; accepted October 16, 2022

Abstract: Air quality represents one of the most important parameters determining indoor microclimate and human comfort. Thus, the current study reports a comprehensive study on the dominant sources, organic compositions, and potential health impacts of the polyaromatic hydrocarbons (PAHs) in the atmospheric particle matters (PMs) ranging from 2.5 μm (PM_{2.5}) to 10 μm (PM₁₀) size in the rural and urban regions of western (Jeddah city) Saudi Arabia collected over 1 year between 2014 and 2015. The levels of PAHs in two locations namely Obhur (Urban) and Hada Alsham (Rural) were monitored over 1 year (2014 and 2015) using the gas chromatography coupled mass spectrometry. The level of ΣPAHs in Obhur (819.25 ng/m^3) has a significantly high concentration of PAHs compared to Hada Alsham (Rural) (675.26 ng/m^3). Indeno(1,2,3-CD)pyrene was the major contributor with an average value of 215.66 ng/m^3 followed by benzo[k]fluranthene with a concentration of 150.68 ng/m^3 , respectively. The major contributors were indeno[1,2,3-cd]pyrene, benzo[k]fluranthene, dibenzo[a,h]anthracene, benzo[g,h]perylene, and benzo[b]fluranthene are the major contributors with contributing percentages of 26.32, 18.39, 9.07, and 8.29%, respectively. The rest of

all compounds were below 4%. The highest concentrations of PAHs in Obhur (1836.99 ng/m^3) and in Hada Alsham (1107.40 ng/m^3) were observed in winter in January 2014. PAHs with 4–6 aromatic ring components are primarily emitted by high temperature combustion. The average values for the BaA/(BaA + Chr) and Flt/(Flt + Pyr) ratios at Obhur were found 0.58 and 0.43 and at Hada Alsham were found 0.63 and 0.38, respectively, indicating that coal/biomass burning is the major source of PAHs. Hada Alsham (rural area), the transportation system, is a significant contributor to the observed PAHs. These results reflect Saudi Arabia's traffic load in both rural and urban areas. On road sites, the impact of petroleum combustion and vehicular emissions was also identified. The sum of the incremental lifetime cancer risk (ILCR) for all congeners for infants along the Obhur location was 2.13×10^{-6} and 1.38×10^{-6} , respectively. ILCR values were less than 1.0×10^{-4} , implying that PAH exposure posed an acceptable potential cancer risk in this study. Various local emission sources contributed more PAHs in many Saudi urban areas, increasing the risk of lung cancer, and the health risk. PAHs have an associated large surface area and are capable of deposition in the respiratory system with high efficiency. The total health risk assessment study also helps in alarming the toxicity at both the locations.

Keywords: polyaromatic hydrocarbon, rural and urban, incremental lifetime cancer risk, level of PAHs, health risk assessment, sample location

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1 Introduction

Polyaromatic hydrocarbons (PAHs) have been recognized as a main component of contaminated airborne components, with several of their constituents being identified as carcinogenic, mutagenic, and allergenic human health

mediators [1]. Conferring to recent epidemiological research, inhaling airborne particulate matter (PM) increases human morbidity and mortality [2–6]. Inhaled PM (2.5 m) can be deposited in the lung and migrate from there via systemic circulation to the heart and other distal organs [7]. Incomplete coal and petroleum combustion have been linked with the high levels of atmospheric soot particles [8]. The segmentation of PAH complex species into PM and vaporous levels varies with the atmospheric environment, vapor types, interactions with the mixture and vapor, and overall performance of the mixture in the air [9–11].

PAHs are classified into two types based on their molecular weight: (i) those with number of aromatic rings lower than four phenyl rings identified as low molecular weight compounds, while those with four or more rings are high molecular weight compounds. PAHs are mostly colored and crystalline at room temperature [12–14]. The multiple and the number of aromatic rings containing various organic constituents and the functional groups attached to these rings distinguish PAHs [12]. Dehydrogenation and fusion of hydrocarbon molecules by C–C bond formation changes the color of PAHs from colorless, white, or yellow to red or brown at temperature 500–800 K and at 800–100 K, decrease in intermolecular distance and benzene ring polycondensation changes the color from yellow, red, or brown to dark brown or black as reported earlier [15]. Vehicle emissions, industries, lubricating oil, road surface weathering, asphalt pavement, tire wear, and construction and demolition activities are the primary sources to PAH contamination in urban road dust [16–18].

To the best of our knowledge, more than 200 PAHs have been discovered, with some of them being highly toxic substances that cause significant harm to both the ecosystem and human health [19]. US EPA has classified 16 PAHs into sediments, soil, and water as priority pollutants because of their health risk and carcinogenic nature, including naphthalene (Nap), acenaphthylene (Acy), acenaphthene (Ace), fluorene (Fle), phenanthrene (Phe), anthracene (Ant), fluoranthene (Fla), 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 (IDP) [19–21]. The overall main sources of PAHs include oil seepage, bitumen evaporation, and spontaneous fires as natural sources, while incomplete combustion of biomass and fossil fuels are primarily as an anthropogenic source of PAHs in the atmosphere, particularly particle-bound PAHs. [22,23]. Fuel type and combustion conditions have also significant impacts on the level of PAH emissions [24,25].

Recently, Yu et al. [26] have studied the risk of lung cancer associated with PAHs emitted from gas cooking in Taiwan. On the other hand, during autumn and winter in rural households of Henan Province, China, Wu et al. [27] have determined precisely the concentrations and composition of 16 PAHs adsorbed to PM₁₀ and PM_{2.5}. The dispersion of PAHs during cooking and the emission rates and exposure dynamics to individuals working in kitchens during the time of cooking have been fully studied by Gao et al. [28]. On the other hand, a series of organic constituents produced from food emissions such as fatty acids, organic ions such as acetate, formate, methane sulfonate, pyruvate, succinate, and others, and molecular markers have been reported [29,30]. PAHs released into the atmosphere are followed by rapid partitioning into particulate and gaseous phases and undergo complex transport and conversion before being deposited in water bodies, soil, animal bodies, and vegetation [27,28]. In contrast to the Eastern Saudi Arabia, where the atmospheric background is a cumulative assimilation of all sources in route to the general north-to-south flow of weather patterns, Jeddah (the Western Saudi Arabia) receives air primarily from the desert and includes densely populated areas [30]. Furthermore, long-range atmospheric transport of coarse and fine PM affects Jeddah. Thus, the overall goals of the current study are focused on: (1) judging the air quality in Jeddah city and rural region in terms of the dominant sources of PAHs; (2) assigning the most probable organic compositions of PMs ranging from 2.5 µm (PM_{2.5}) to 10 µm (PM₁₀) in the air of Jeddah; (3) assigning the potential health impacts of the PAHs in various locations in Jeddah Urban and Rural areas over 1 year; (4) identifying the levels and profiles of PAHs emissions in PM_{2.5} and PM₁₀ in the selected locations in the western region (Jeddah) city; and finally (5) using the background PAH concentrations at Obhur and Hada Alsham, the baseline of inhalation exposure values for public health in Saudi Arabia could be assigned.

2 Materials and methods

Particle size-fractionated PM samples were collected from top of the medium size building in the city of Jeddah (Obhur) and the rural area of Hada Alsham [26].

2.1 Sample collection

A MiniVol Portable Air samplers (AirMetrics Inc.), which draw air at a flow rate of 5 L/min through a particle size

separator (impactor) and then through a 47 mm filter was used. The 10 and 2.5 μm particle size separation was achieved by impaction (or dichotomous sampler). The fine fractions (PM_{2.5}) were deposited onto 25 mm diameter polycarbonate filters (Nucleopore, Costar Corp.) with 0.4 μm pore size whereas the coarser (PM₁₀) was collected onto 47 mm diameter polycarbonate filters, with 1 μm pores for the determination of the organic content of the atmospheric PM. For every five samples, field blanks were obtained to ensure quality control. A 2.0 g of pre-washed sodium sulfate (Na_2SO_4) was evenly placed on Al foil for each blank sample and gathered with the vacuum cleaner in the same manner as the dust samples. The samples were finally sieved with a 250 μm mesh to obtain homogenized results. For the organic components and toxicity study, atmospheric PM samples were critically collected using high volume cascade impactors. The size-segregated PM was also collected using high volume air samplers (Tisch, Env. Cleves, OH) retrofitted with a High Volume Cascade Impactor (HVCI) TE-230 (Tisch Env. Cleves).

2.2 Instrumentation and sample preparation

An appropriate measured aliquot of dust samples (typically between 50 and 100 mg) was collected in a 12 mL glass centrifuge tube. Internal requirements were spiked into the samples, which were formerly allowed to equilibrate overnight at room temperature. The samples were extracted three times using 4 mL of hexane/acetone (4/1, v/v) and ultrasonicated for 30 min, followed by centrifugation at 2,000 rpm for 10 min. For instrumental analysis, the pooled extracts were preconcentrated to 1 mL under a gentle stream of nitrogen. A Shimadzu Gas chromatography coupled mass spectrometry (GC-MS) was used in the selective ion-monitoring mode. A fused silica capillary column (DB-530m 0.25 mm $\times$ 0.25 m) was also used for sample isolation. Injector and ion source temperatures were used at temperature of 80 and 230°C, respectively. The oven temperature was programmed to start at 80°C at a rate of 1.0°C/min and then increased to 180°C at 12°C/min, 230°C at 6°C/min, 270°C at 8°C/min (held for 2 min), and finally 300°C at 30°C/min (held for 12 min). Ions m/z 128, 136, 152, 154, 164, 166, 178, 188, 202, 228, 240, 256, 258, 264, 276, 278, and 288 were monitored for different PAHs.

The concentrations of PAHs in the extracts were analyzed by GC-MS (QPplus-2010, Shimadzu, Japan) utilizing electron ionization conditions. The preliminary temperature of the column oven was 250°C. A HP 5MS, 30 m capillary column was used (30 m $\times$ 0.25 mm i.d. $\times$ 0.25 μm , 5%

phenylmethyl siloxane, Agilent HP-5MS) with 60°C (2 min hold) temperature program of 60°C (2 min hold), ramp 5°C/min to 310, and 5 min hold. Helium was used as the carrier gas (2 mL/min).

2.3 Quality assurance/quality control

For each set of vehicle dust samples, laboratory blanks [extraction and clean up producer in the same way as dust samples but without dust samples were used as a part of the quality assurance protocol, field blanks ($n = 3$) to insure no contamination coming from solvent or glass wares] ($N = 10$). Indoor dust certified reference materials (CRMs) from National Institute of Standards & Technology SRM 2585 ($N = 3$) were also analyzed for method validation. In parallel, the dust samples were analyzed with the CRMs to account for eventual external contamination during sampling, sample preparation, and instrumental analysis and also to evaluate method accuracy. The lowest point of calibrations curve was used as limits of quantification. To avoid Amber glasses under fume hood without light were used to avoid the photo degradation of analytes, during extraction and clean up steps.

2.4 Health risk assessment

To assess the cancer risk attributed to carcinogens, the incremental lifetime cancer risk (ILCR) which was expressed as the lifetime average daily dose (LADD) multiplied by the BaP slope factor was used. The cumulative probabilities of the total risk were also evaluated by means of Monte Carlo simulation. Lifetime was also divided into three groups according to age (infants: 0–1 years, children: 2–18 years, and adults: 19–70 years). The total LADD is the sum of the LADD values of the above three age groups. The values of LADD and ILCR can be calculated employing the following equations, respectively:

$$\text{LADD} = \frac{C \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}, \quad (1)$$

$$\text{ILCR} = \text{LADD} \times \left\{ \text{CSF} \times \sqrt[3]{\frac{\text{BW}}{70}} \right\} cf, \quad (2)$$

where C is the background equivalent concentration (BEC) and it can be calculated using the method of Jung et al. [30]. The carcinogenic risk of a PAH mixture can be expressed via its total BaP_{eq} concentration (BEC), which is calculated by using the following equation [31]:

Table 1: The TEFi values of each PAH congener

PAH	TEF
Ace	0.001
Acy	0.001
Flo	0.001
Phe	0.001
Ant	0.01
Flu	0.001
Pyr	0.001
BaA	0.1
Chr	0.01
BbF	0.1
BkF	0.1
BaP	1
DahA	1
IcdP	0.1
BghiP	0.01

$$BEC = \sum C_i \times TEF_i, \quad (3)$$

where TEFi is the toxicity equivalency factor of PAH congener [31]. The TEFi values of each PAH congener are given in Table 1 [32]. The meaning and value of the other parameters used for analysis in the equations were derived and presented in Table 2.

3 Results and discussion

3.1 Distribution pattern of PAHs

Saudi Arabia's climate is a major contributor to rising pollution levels as a dry region with little precipitation. In most parts of the Saudi Arabia, the average annual rainfall is less than 150 mm. Jeddah receives 53.5 mm (2.1 in) of rainfall per year on average [26,30]. The topography of the land also has an impact on air pollution. On

the other hand, the desert covers the majority of Saudi Arabia, resulting in a high concentration of wind-transported dust in inhabited areas' air sheds. Thus, recently, air pollution rises in lockstep with socioeconomic development, and traffic is a major contributor in the current study.

The present study was assessed the level of PAHs along the two locations, Obhur (Urban) and Hada Alsham (Rural) for 1 year. The data were collected from January 2014 to December 2014. The location of Obhur showed significantly higher concentration of Σ PAHs. The average value of Σ PAHs for 1 year along the Obhur and Hada Alsham was 819.25 and 675.26 ng/m³, respectively. The average distribution of various PAHs along Obhur location from the whole year 2014 is shown in Figure 1. As can be seen in Figure 1, indeno[1,2,3-*cd*]pyrene was the major contributor with an average value of 215.66 ng/m³ followed by benzo[*k*]fluranthene with a concentration of 150.68 ng/m³, respectively. The major contributors were indeno[1,2,3-*cd*]pyrene, benzo[*k*]fluranthene, dibenzo[*a,h*]anthracene, benzo[*g,h*]perylene, and benzo[*b*]fluranthene with contributing percentages of 26.32, 18.39, 9.07, and 8.29%, respectively. The levels of the rest of all compounds were found below 4%. These results can be attributed the different sources of PAHs involved in both locations. In Abhor location, coal/biomass burning is most likely the major source of PAHs, whereas in Hada Alsham (rural area), transportation system represents the main source of PAHs. Moreover, petroleum combustion and vehicular emissions were also participated in the observed trend.

Figure 2 represents the month ways variation of each compound of PAHs along the Obhur for whole the year from January to December 2014. Figure 2 clearly shows the dominance of indeno[1,2,3-*cd*]pyrene and benzo[*k*]fluranthene over the course of a year. Figure 3 also depicts the total of all observed PAHs and the seasonal pattern of PAHs in Obhur from January to December 2014 from Obhur. The obtainable results shed light on the

Table 2: The parameter description

Parameters	Represents	Units	Infant	Children	Adult
	Age	Years	0–1	2–18	19–70
BW	Body weight	kg	9.1 ± 1.25	29.7 ± 5.62	71.05 ± 13.6
IR	Inhalation rate	m ³ /day	5.36	11.41	15.73
EF	Exposure frequency	Days/year	350	350	350
ED	Exposure duration	Year	0–1	0–17	0–52
AT	Average time	Days	25,550	25,550	25,550
cf	Conversion factor		10 ^{−6}	10 ^{−6}	10 ^{−6}
CSF	Cancer slope factor	mg/kg day	3.14	3.14	3.14

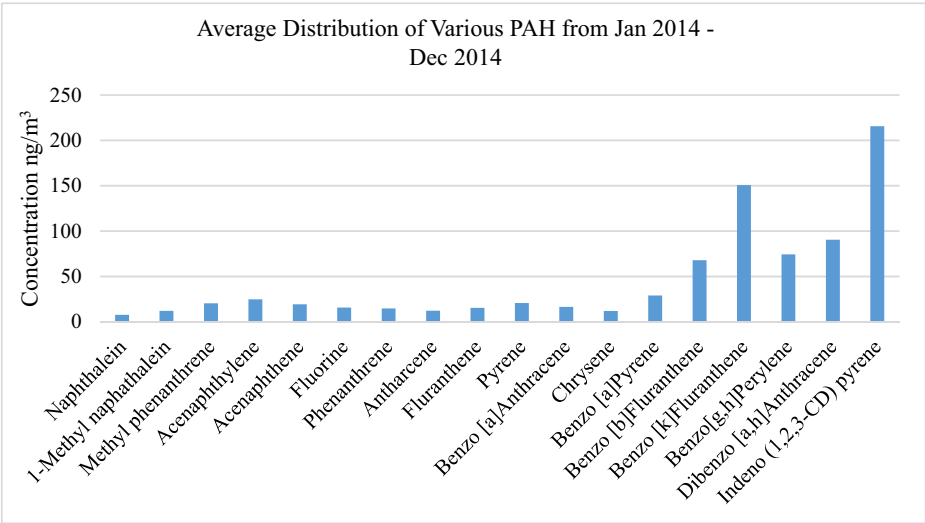


Figure 1: The average distribution of various PAHs along the Obhur location from the whole year 2014.

higher level of PAHs in the winter season (January, February, and December) as compared to the summer season. However, an elevated level of PAHs was detected in August 2014. The highest concentration of PAHs was

observed in January 2014, with a concentration of 1836.99 ng/m^3 .

Figure 4 depicts the average distribution of various PAHs along the Sham Alhada location for the entire year 2014.

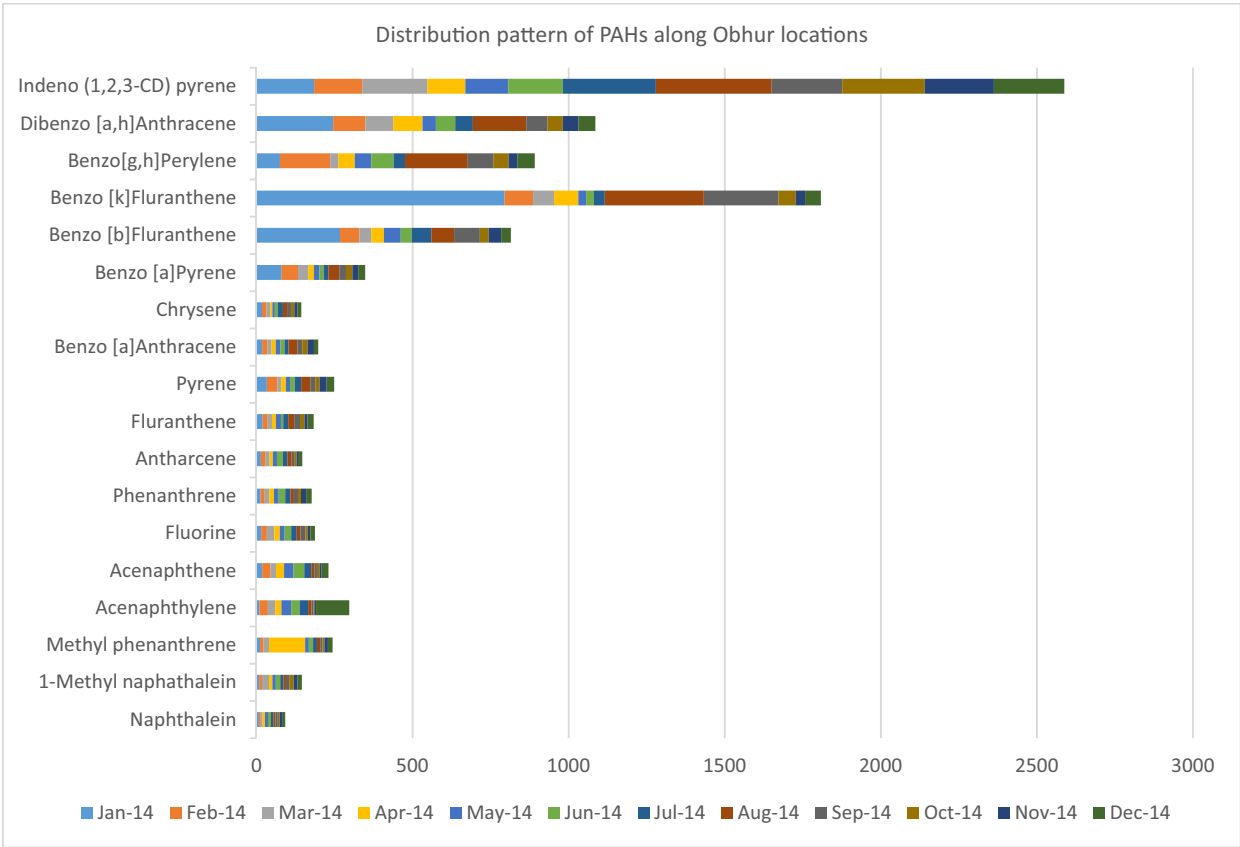


Figure 2: Monthly variation of PAHs in the air samples from Obhur.

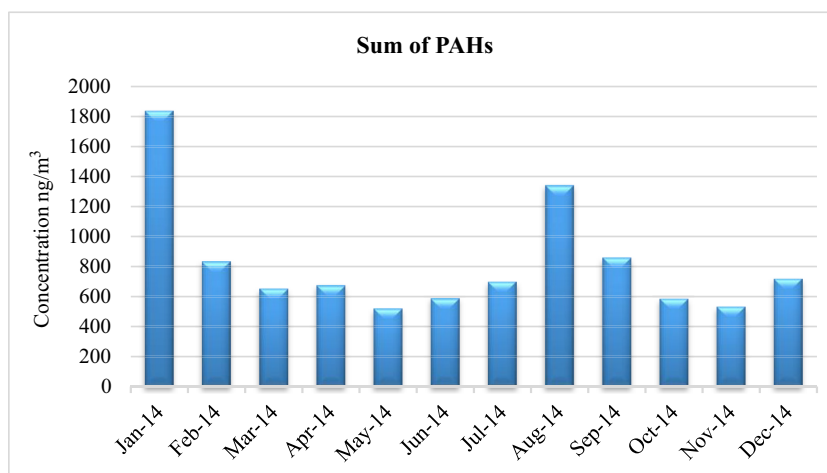


Figure 3: The sum PAHs on monthly basis from January 2014 to December 2014 from Obhur.

The average value of indeno[1,2,3-*cd*]pyrene (326.70 ng/m³) was clearly shown to be the major contributor, followed by dibenzo[*a,h*]anthracene (47.78 ng/m³). In this study, the significant determinants were indeno[1,2,3-*cd*]pyrene, dibenzo[*a,h*]anthracene, benzo[*g,h*]perylene, benzo[*k*]fluoranthene, and benzo[*b*]fluoranthene, which contributed 48.38, 7.07, 6.43, 5.61, and 5.25%, respectively. The remnants of the compounds were all below 4%. Figure 5 depicts the month-to-month variation of each compound along the Hada Alsham for the entire year. Indeno[1,2,3-*cd*]pyrene levels were significantly higher in all months of 2014 when compared to other PAH levels. Except for indeno[1,2,3-*cd*]pyrene, the rest of the PAHs had significantly lower distribution patterns when compared to the urban area (Obhur).

The levels of all PAHs detected in Hada Alsham from January to December 2014 are illustrated in Figure 6. As can be seen, in the Obhur, the observed results do not vary greatly depending on the season. However, an

elevated level of PAHs was detected in January 2014. The rest of the months followed a similar pattern. The highest concentration of PAHs was observed in January 2014, with a concentration of 1107.40 ng/m³. On the other hand, the lowest concentration was observed in November 2014, with a concentration of 486.62 ng/m³. The data also revealed that the PAHs with four to six aromatic ring components are primarily emitted at high temperature combustion and gradually migrates from the particulate phase to the gaseous phase in the atmosphere [31–34]. On the other hand, domestic heating may have a greater impact on PAH levels in residential areas during the winter. Population density and airborne PAH concentrations are known to be positively correlated [35,36]. Local activities are completely different in the current observation where in the case of the Obhur region that close to the Red Sea and has a lot of shipping activities, which are most likely affect PAHs distribution pattern [26,32].

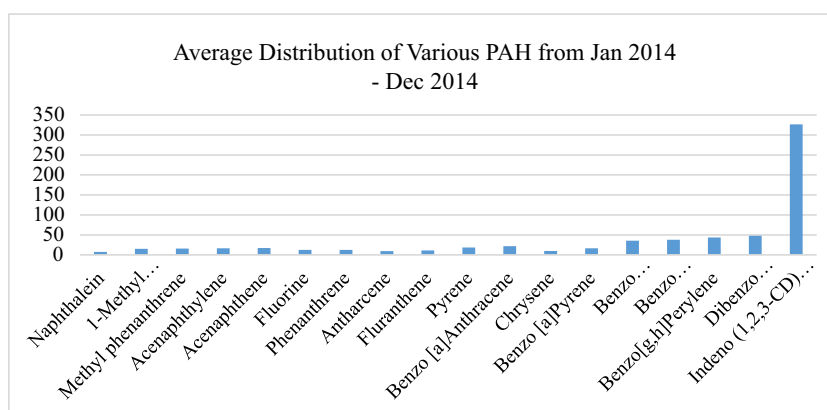


Figure 4: The average distribution of various PAHs along the Obhur location from the whole year 2014.

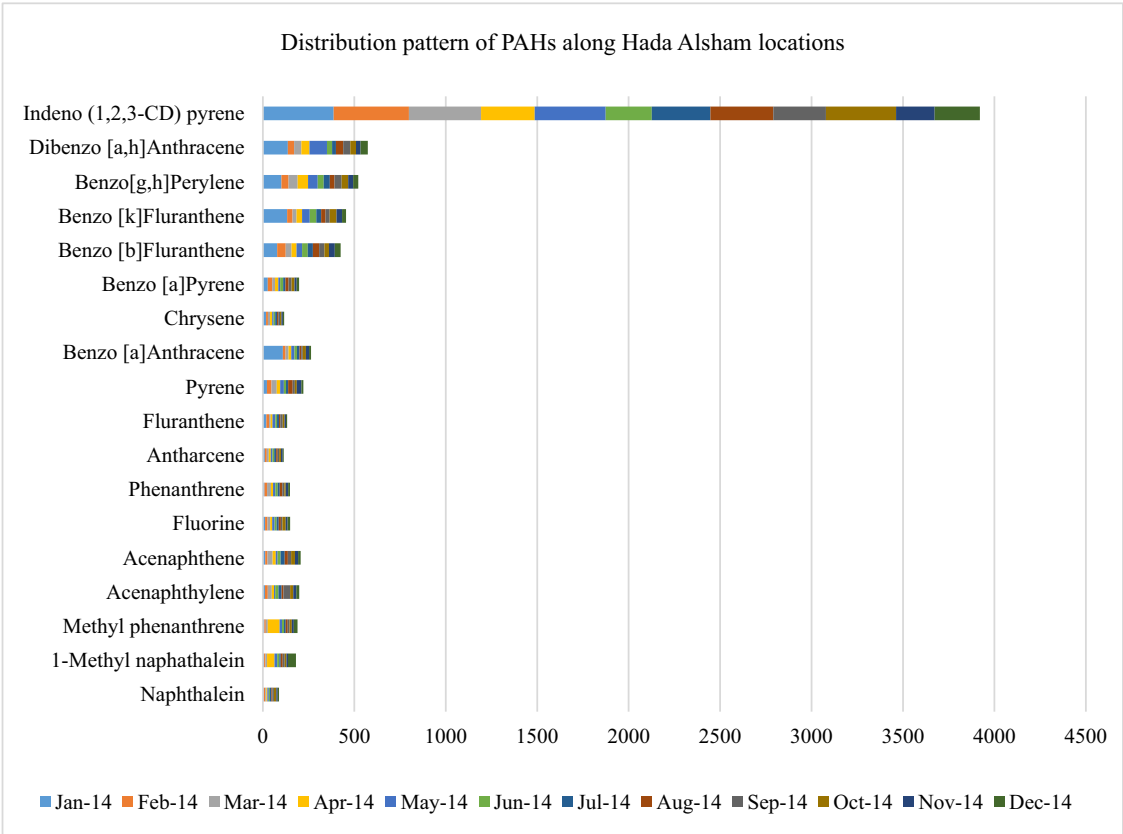


Figure 5: Monthly variation of PAHs in the air samples from Hada Alsham.

Aside from that, nearby industries and man-made activities along the coast are known to play a significant role in PAHs distribution. The transportation system was the significant contributor for the observed PAHs along the Hada Alsham (rural area). In terms of non-occupational exposure, residents living in rural areas [35,36]

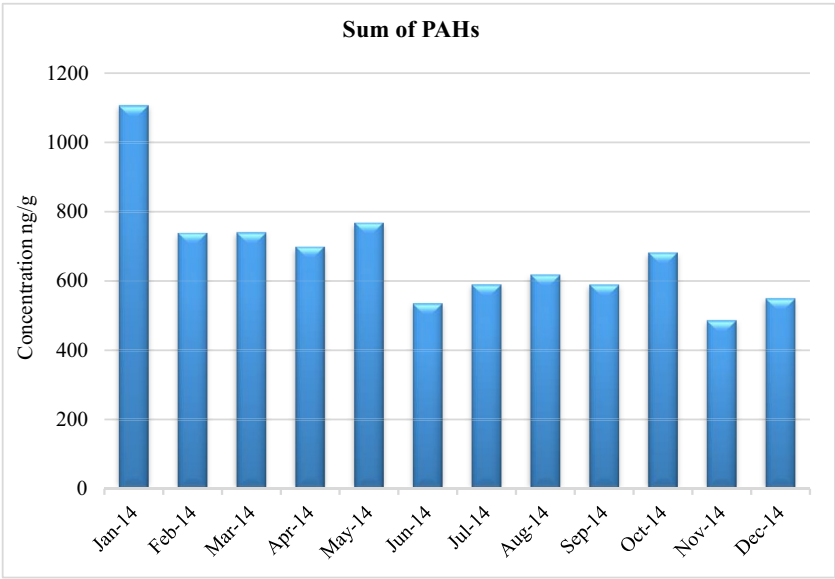


Figure 6: The sum PAHs on monthly basis from January 2014 to December 2014 from Hada Alsham.

generally inhale higher PM-bound PAH concentrations than residents living in urban areas [37,38]. This behavior is most likely attributed to rural residents still primarily use solid fuels such as coal and wood for cooking and heating, despite the fact that these sources emit a high level of PAHs due to their low combustion efficiency, whereas urban residents primarily use clean fuels such as liquefied petroleum gas and natural gas.

3.2 The sources of PAHs

Pyrogenic, petrogenic, and biological PAH sources are the main three sources of PAHs in the environment where when natural materials are subjected to high temperatures and low oxygen concentrations, pyrogenic PAHs are formed [39–41]. Destructive extraction and thermal splitting of oil residues into simpler hydrocarbons are examples of pyrolytic practices. Meanwhile, other inadvertent procedures emerge as a result of partial oil incineration in vans, imperfect burning in woodland, and inadvertent ignition of gas oils in central heating systems over 350–1,200°C during the pyrogenic procedures represent another source of PAHs. In metropolitan areas, pyrogenic PAHs were frequently found in higher concentrations as well as in areas near PAH sources. It is worth noting that, rudimentary oils contain PAHs that are produced over time at temperatures ranging from 100 to 150°C. PAHs may also be produced, via specific shrubs and microorganisms, or may be produced because of plant destruction naturally or via anthropogenic activities [42].

Diagnostic PAH concentration ratios were used to identify potential emission sources. The ratio of the sum of the concentrations of nine major non-alkylated compounds [fluoranthene (Fl), pyrene (Py), benz[*a*]anthracene (BaA), chrysene (Chry), benzo[*a*]fluoranthene (BbF), benzo[*a*]pyrene (BaP), benzo[*e*]pyrene (BeP), indeno[1,2,3-*cd*]pyrene (IcdP), and benzo[*ghi*]perylene (BghiP)], expressed as concentrations of PAH (CPAHs) to the total concentration of the PAHs, expressed as TPAHs (CPAHs/total PAH (TPAHs)), has been frequently used as a characteristic value for PAHs produced by combustion [43,44]. To identify properly the source of PAHs, the methylphenanthrene-to-phenanthrene ratio (MP/P) has been also used [43]. MP/P ratios ranging from 1 to 8 indicate an increase in mobile sources or input from unburned fossil fuel [44]. Emissions from stationary combustion sources where the fuel burns at higher temperatures have ratios less than 1. CPAHs/TPAHs were also used as a diagnostic parameter for mobile or stationary sources.

The ratios BaA/(BaA + Chry), BeP/(BeP + BaP), Fl/(Fl + Py), and IcdP/(IcdP + BghiP) are also used for source reconciliation [43–47]. At the Obhur, except for March and April 2014, the current study found an MP/P ratio of less than 1. The graph depicts emissions from stationary combustion sources where the fuel burns at higher temperatures. However, it is reflected as increased mobile sources or input from unburned fossil fuel in March and April. Hada Alsham, on the other hand, shows MP/P ratios ranging from 0.55 to 5.58. These values were found between 1.0 and 8 in April, May, October, and December, revealing the mobile sources or input from unburned fossil fuel. During the rest of the months, it tracks emissions from stationary combustion sources where fuel burns at higher temperatures. The mean values of CPAHs/TPAHs at Obhur (0.787) and at Hada Alsham (0.84) were found twice the value reported for non-catalyst-equipped (0.41) and catalyst-equipped (0.51) automobiles and heavy-duty diesel trucks from Pasadena, USA (0.30) [48,49] and twice the mean value reported for urban samples (0.43/0.04) and higher than rural samples of Heraclion [50].

To understand the PAH emission sources in Obhur and Hada Alsham, diagnostic ratios were used to evaluate potential sources in previous research [51]. Two diagnostic ratio pairs were used: BaA/(BaA + Chr) versus Flt/(Flt + Pyr). With thresholds of 0.20 and 0.35, the first ratio, BaA/(BaA + Chr), can be used to distinguish petrogenic sources, coal combustion, and vehicular emissions [52], while with a threshold of 0.50, the second ratio, Flt/(Flt + Pyr), indicates petroleum combustion or coal/biomass burning [53,54]. The mean values for the BaA/(BaA + Chr) and Flt/(Flt + Pyr) ratios at Obhur were found 0.58 and 0.43, respectively, and at Hada Alsham were found 0.63 and 0.38, indicating that coal/biomass burning is the major source of PAHs. The impact of petroleum combustion and vehicular emissions on road sites was also identified as illustrated in Figures 7 and 8.

The calculated proportions of BaA/(BaA + Chr), which are more important than the presence of diesel engines and limited industrial areas, ranged between 0.4 and 1.0 at all testing locations. These results were similar to the relative amounts calculated for diesel cars and vans, which ranged between 0.38 and 0.64 [55,56], and manufacturing sites, which ranged between 0.23 and 0.89 [53,54]. The observed results reflect Saudi Arabia's traffic load in both rural and urban areas. Furthermore, due to a variety of meteorological conditions and other factors, outdoor air pollutants degrade or transform in the atmosphere. Furthermore, despite the fact that there have been numerous environmental observation studies on PM-bound PAHs conducted over the last

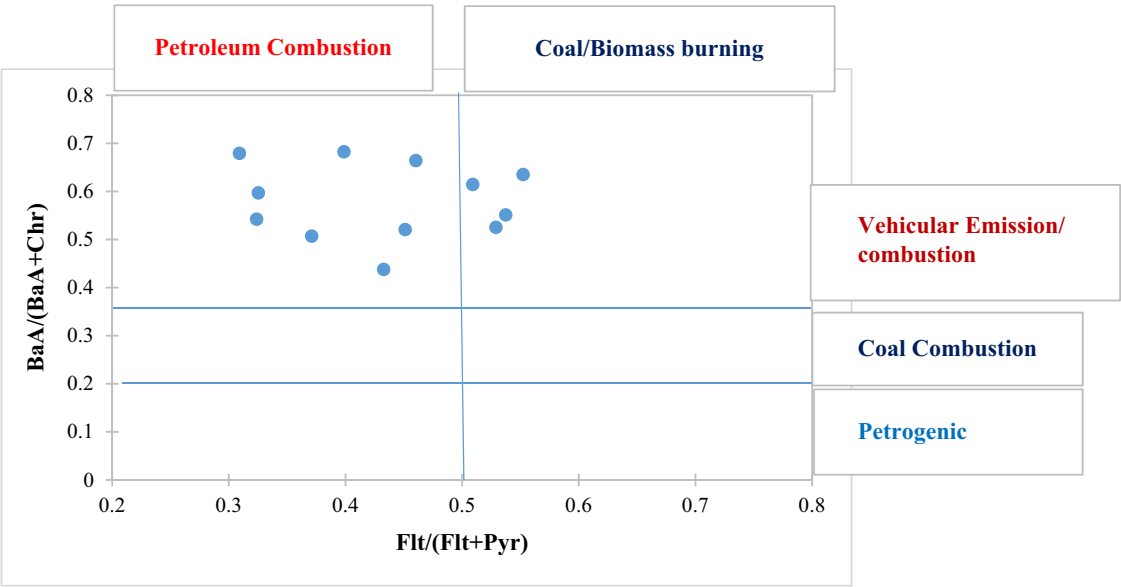


Figure 7: Scatter plots for two diagnostic ratios: $BaA/(BaA+Chr)$ and $Flt/(Flt+Pyr)$ in Obhur. The horizontal and vertical lines are the thresholds for each emission source.

few decades, different countries and regions have focused on different aspects of PM-bound PAH research.

3.3 Health risk assessment

Using the background PAH concentrations at Obhur and Hada Alsham, the study calculated the baseline of inhalation

exposure values for public health. The ILCR was calculated by multiplying the LADD by the BaP slope factor to assess the cancer risk attributed to carcinogens. Furthermore, using Monte Carlo simulation, the cumulative probability of the total risk was calculated. Infants (0.0–1 year), children (2–18 years), and adults (19–70 years) were divided into three age groups. The sum of the LADD values for the three age groups mentioned above is the total LADD. An ILCR value of 1×10^{-6} was defined as insignificant or “essentially

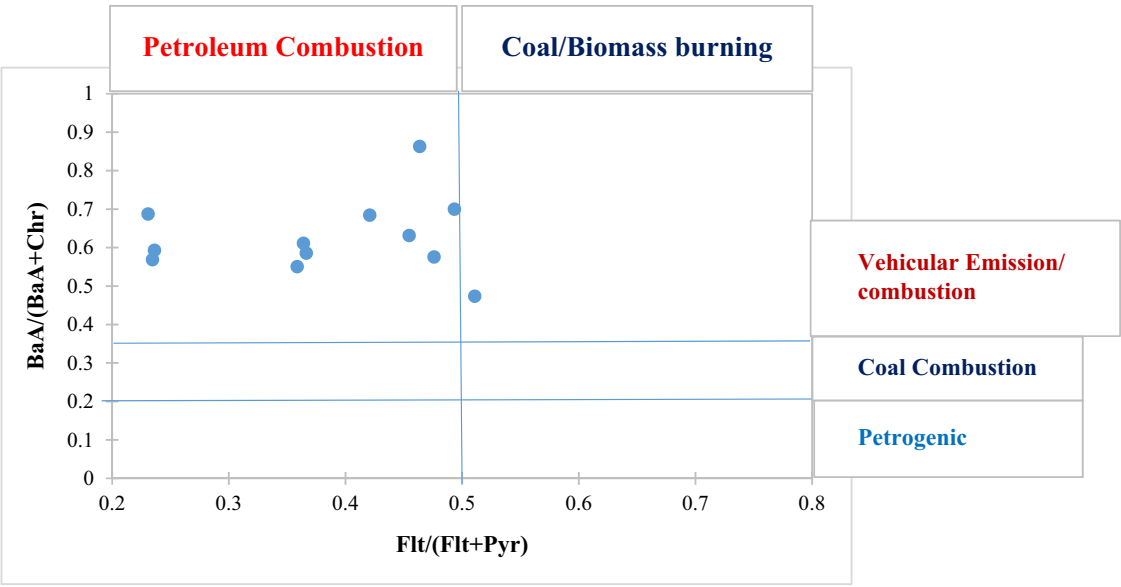


Figure 8: Scatter plots for two diagnostic ratios: $BaA/(BaA+Chr)$ and $Flt/(Flt+Pyr)$ in Hada Alsham. The horizontal and vertical lines are the thresholds for each emission source.

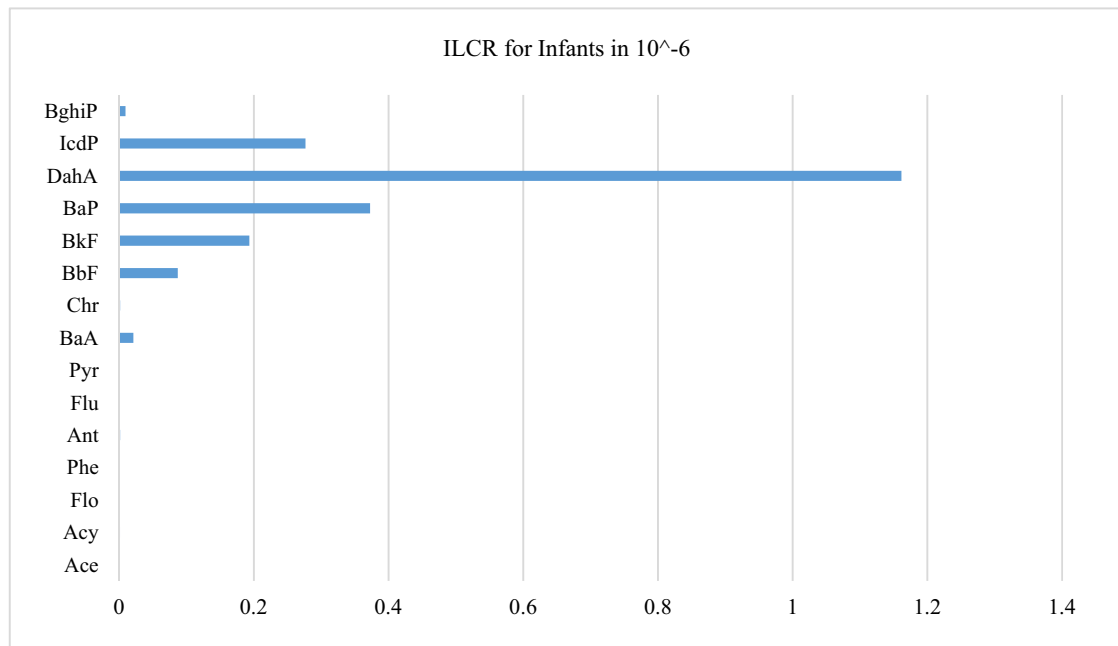


Figure 9: The probability density of the current ILCR at Obhur for infants.

negligible,” because it is comparable to the risk level of some common human activities like diagnostic X-rays and fishing [22]. An ILCR value between 1×10^{-6} and 1×10^{-4} was regarded as acceptable, while a value of greater than 1×10^{-4} was regarded as serious [56,57]. The probability density of the current ILCR for infants in the current study is depicted in Figures 9 and 10.

To provide a clearer picture, all ILCR values were displayed on a scale of 10^{-6} . The sum of ILCR for all congeners for infants along the Obhur and Hada Alsham locations

was 2.13×10^{-6} and 1.38×10^{-6} , respectively. The value represents the infants’ likely risk in both locations. Figures 11 and 12 depict the ILCR values for the children at both locations in the same way. The sum of ILCR for all congeners for children along the Obhur location was 34.99×10^{-6} and 22.6×10^{-6} at Hada Alsham, respectively. The value represents the children’s likely risk at both locations. In both locations, the risk factor for infants is approximately 16 times higher. Figures 13 and 14 also demonstrate the ILCR values for adults in both locations. The total ILCR

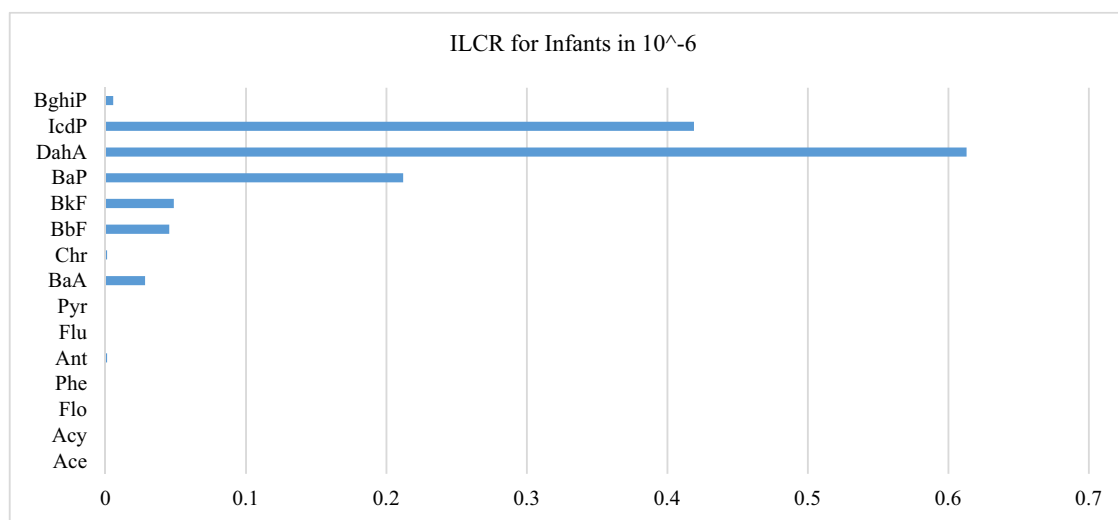


Figure 10: The probability density of the current ILCR at Hada Alsham for infants.

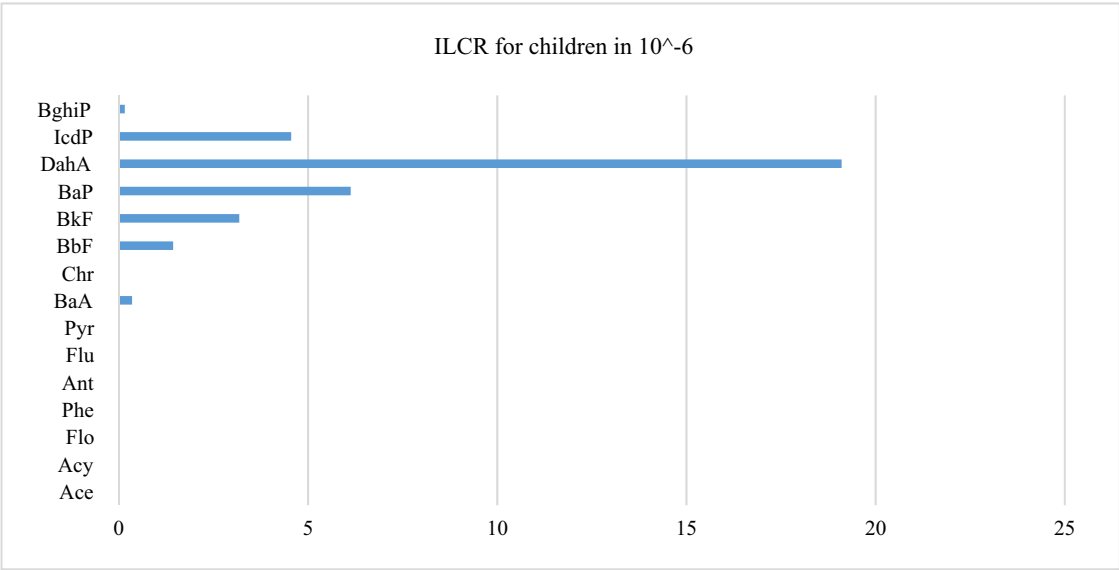


Figure 11: The probability density of the current ILCR at Obhur for children.

for all congeners for adults along the Obhur location was 82.50×10^{-6} , while it was 53.40×10^{-6} at Hada Alsham. The value represents the children’s likely risk at both locations.

The risk factor for infants is approximately 38 times higher in both locations, and it is approximately two times higher in both locations for adults. Several studies have estimated the contribution of ingestion of residential dust to total PAH exposure [58,59]. According to Gevao et al. [60], dust ingestion accounts for 42% of non-dietary PAH intake in children and 11% in adults. According to Chuang et al. [59], dust/soil ingestion accounts for 24% of total carcinogenic PAH intake in children and 7% in adults. However, in the present study, both ILCR values

decreased in the following order: adults > children > infants; both ILCR values were less than 1.0×10^{-4} , implying that PAH exposure posed an acceptable potential cancer risk in this study.

4 Conclusion and future perspectives

In summary, the current study successfully investigated the level of PAHs in aerosol samples collected between 2014 and 2015 in Jeddah’s rural and urban areas. Obhur

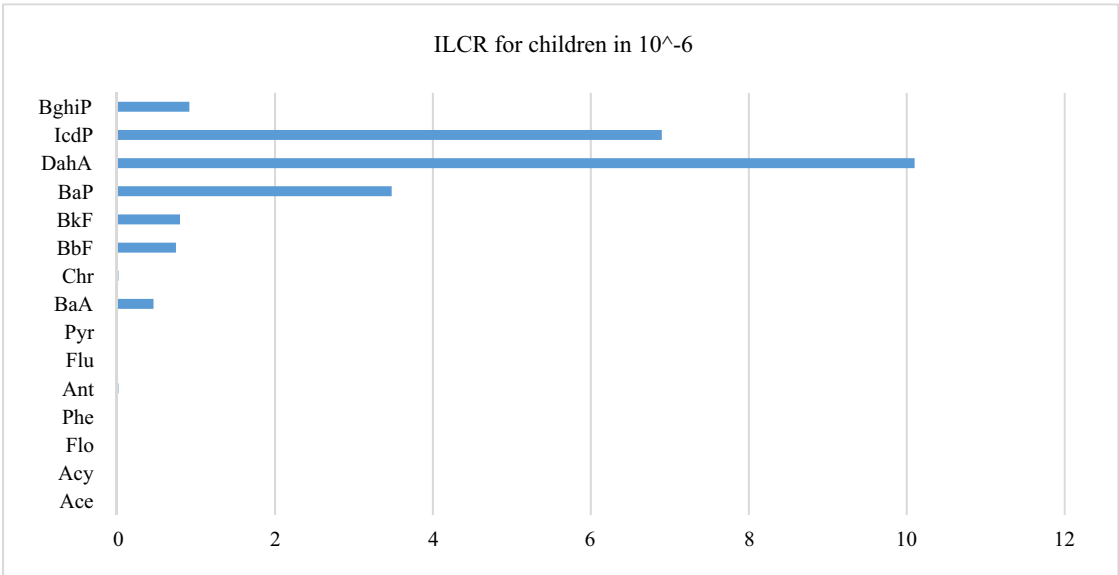


Figure 12: The probability density of the current ILCR at Hada Alsham for children.

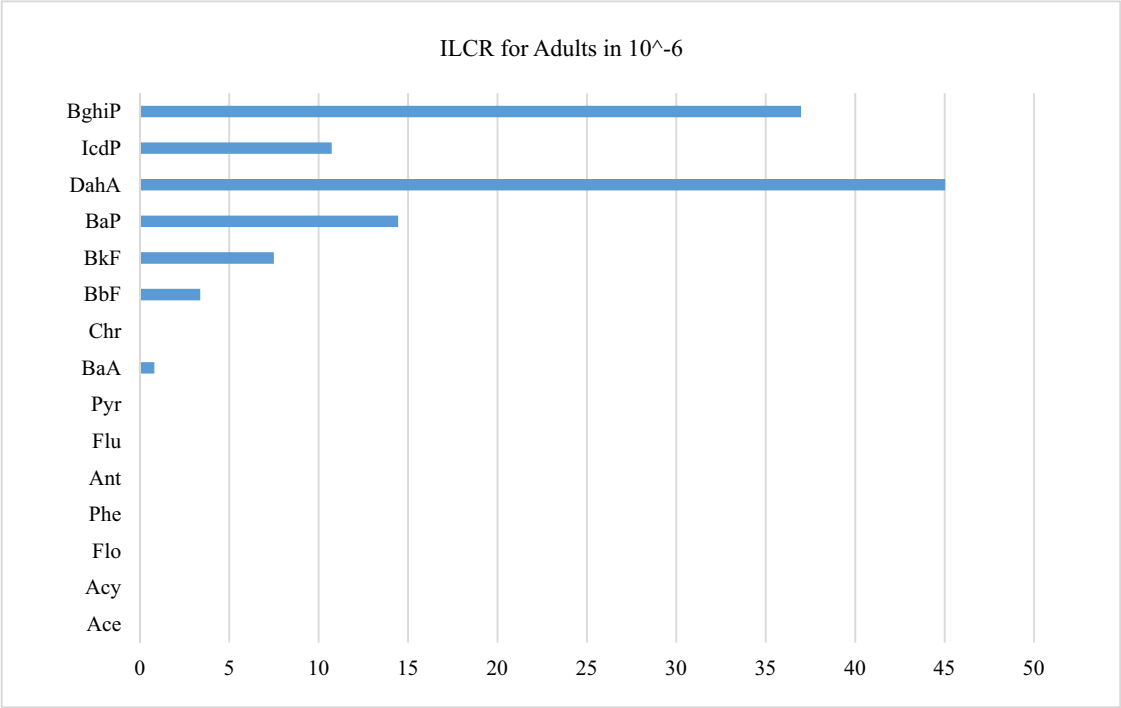


Figure 13: The probability density of the current ILCR at Obhur for adults.

has a significantly higher concentration of PAHs when the concentrations in the two locations are compared. The Obhur region, for example, is close to the sea and has a lot of shipping activity, which will affect the distribution pattern of PAHs. Aside from that, nearby industries and man-made activities along the coast will be

important. Hada Alsham, on the other hand, was in a rural area, but the region's transportation system is a significant contributor to the observed PAHs. According to the source factor, coal/biomass combustion is the primary source of PAHs. On road sites, the impact of petroleum combustion and vehicular emissions was also

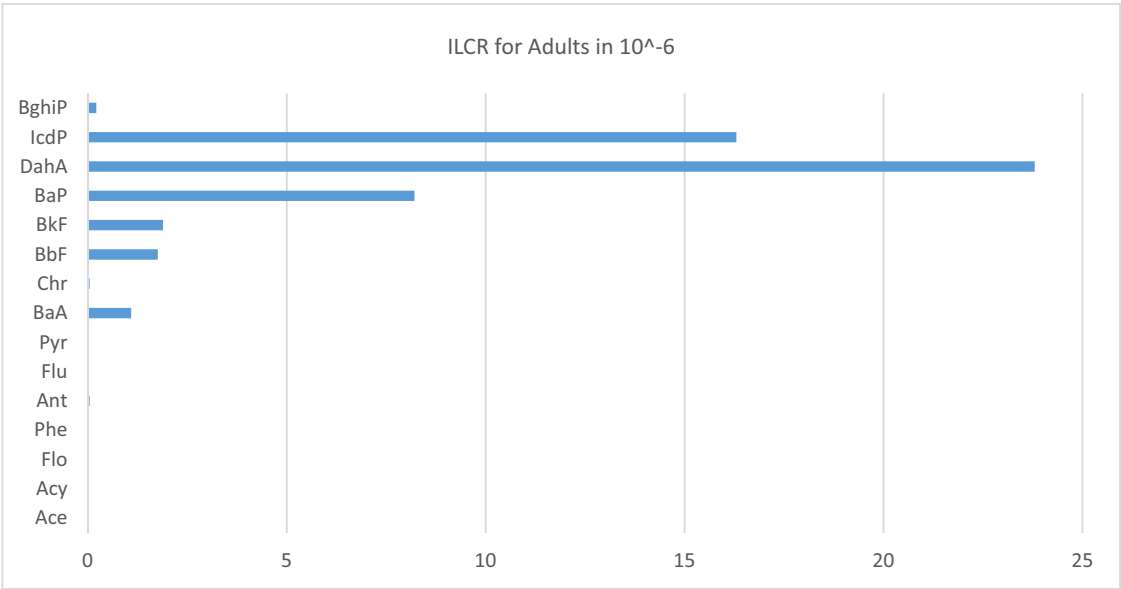


Figure 14: The probability density of the current ILCR at Hada Alsham for adults.

identified. Various local emission sources contributed more polycyclic aromatic hydrocarbons in many Saudi urban areas, increasing the risk of lung cancer, and the health risk was relatively high in these areas. The total health risk assessment calculation for infants, children, and adults reveals that the cancer risk assessment values were vulnerable to health issues, which is a major concern on these sites. Assigning the potential health impacts, base line, and the emissions sources of PAHs in PM_{2.5} and PM₁₀ in various in Saudi Arabia is of great importance for constructing the baseline of inhalation exposure values for public health in Saudi Arabia could be assigned.

Acknowledgements: This study was funded by King Abdulaziz City for Science and Technology (KACST), Riyadh, KSA. Grant Number: “11-ENV1539-03.” The authors are grateful to KACST and to the Science and Technology unite (STU), KAU, for their support.

Funding information: This work was supported by King Abdulaziz City for Science and Technology (KACST), Riyadh, KSA. Grant Number: “11-ENV1539-03”.

Author contributions: All authors made significant contributions for data acquisition, suggestions, and writing – original draft preparation revisions and article editing during its preparation and approved the final version. M.I. Orif performed all experiments, data acquisition, and writing – original draft preparation, M.S. El-Shahawi performed revisions, manuscript editing, data acquisition, and data analysis. Other authors performed reviewing and editing, resources, and funding acquisition.

Conflict of interest: Authors report that they have no competing financial benefits or personal relationships that could have appeared to affect the work in this manuscript.

Ethical approval: The conducted research is not related to either human or animal use.

Data availability statement: The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

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