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The Potential Environmental Impact of Polycyclic Aromatic Hydrocarbons emitted from Brick Factories

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Abstract

The potential environmental and health impacts of polycyclic aromatic hydrocarbons (PAHs) emitted from brick industries of west delta in Egypt are not well-addressed. The current study focuses on characterization of PAHs' emission and their health risk assessment arising from brick factories, during summer and winter seasons of 2013. Concentrations of different PAHs were measured in air and soil. Air samples of 12h and soil were collected at different sampling sites. PAH compounds were quantified by using GC. The distribution of individual PAH compounds in the air samples were generally decreased with increasing molecular weight and vice versa in soil samples. PAH compounds with two to four aromatic rings were the predominant in the air samples during the period of study. Low dispersive conditions during winter due to the low temperature trap PAHs pollutant over the study area for long periods and consequently increasing the levels of these pollutants during winter. The contribution of B(a)A to the total carcinogenic activity, TCA, was 49.18% showing a higher contribution, during winter season. The TCA was 8.62 ng/m^3 with a high contribution to particulate-phase. The higher contribution of the total carcinogenic activity (TCA) was related to HMW more than LMW PAHs, which are the most hazardous substances to human health. The estimated life time lung cancer risk due to exposure to PAHs emitted from brick industries, only, at that region was about 9.64 cases of lung cancer /100000 persons. We therefore conclude that the lung cancer risk due to PAH exposures in that region cannot be neglected and should be considered for any future health protection program.

Keywords: Polycyclic aromatic hydrocarbons, PAHs, air quality-brick factories, health risk assessment.

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous class of organic compounds that are widely distributed as environmental pollutants and have both anthropogenic and natural sources (Xue and Warshawsky, 2005). PAHs are semi-volatile organic compounds, and present in both gaseous and particulate phases. They have very low water solubility, are highly lipophilic and soluble in organic solvents (Fetzer, 2000). They represent an important class of environmental contaminants because of their persistence that demonstrated adverse health effects. The partitioning

of PAH compounds between the particulate and gaseous phases depends on the atmospheric conditions, the nature of aerosol, the interactions between the compound and the aerosol, and the overall behavior of the compound in the atmosphere (Esen et al., 2008). Although produced naturally by forest fires and volcanoes, most PAHs in ambient air are the result of man-made processes (Esen et al., 2008), such as: Combustion of fuels e.g. coal, wood, petroleum product, or oil; Burning refuse, used tires, polypropylene, or polystyrene; Coke production, waste incinerators and motor vehicle exhaust.

There are more than a hundred known PAHs, of which seventeen are actively monitored by the US EPA. The seventeen were singled out because there are more information on these than on the others, exhibit

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harmful effects that are representative of the PAHs and there is a greater chance that human can be exposed to these PAHs than to the others, especially at hazardous waste sites (Esen et al., 2008, ATSDR, 1995, Xue and Warshawsky, 2005). PAHs occur in all environmental matrices, air, water, soil and food, predominantly entering through the atmosphere. They enter surface water through wet and dry atmospheric deposition, hydrocarbon spillages, rainwater runoff into water bodies, and industrial effluent discharge, especially from hydrocarbon processing industries; e.g. coal gasification sites, coking plants, and bitumen and asphalt production plants. During any formation process, and subsequently in the matrices to which population can be exposed, PAHs are always present as a group and not as individual compounds (Gachanja, 2005).

PAHs can enter human body through lungs via inhaling air containing them, cigarette smoke, wood and coal smoke, hazardous waste sites and smoke from many industrial sites may contain PAHs. Drinking water and swallowing food contaminated with dust particles containing PAHs are other routes of exposure. PAHs can enter human body with skin contact to soil containing high levels of PAHs near hazardous sites (Esen et al., 2008, ATSDR, 1995). PAHs have been identified to be one of the major toxic air pollutants, and some of their degradation products have been known as carcinogenic, mutagenic, and allergenic agents to human health (Xue and Warshawsky, 2005).

Red brick-making is a significant industrial sector in Egypt, owing employment for about 50 thousand people. Almost all brick factories in Egypt exist in inhabitant areas at the Nile river pathway, where there are 1100 brick factories (McPhie and Caouette, 2007). Many studies have measured PAHs in sediments (Mohamed, 2011) and atmospheric particulates (Hassan and Khoder, 2012) but little attention has been paid to the PAHs compounds generated from brick factories in west delta of Egypt which combust heavy oil fuel in their production process. The aim of the present study was to evaluate the concentration levels of PAH compounds in the atmosphere of west delta of Egypt, in area of brick factories, and evaluate health risks associated with inhalation of PAH compounds.

MATERIALS AND METHODS

Description of Sampling Site

Kafr-El-Zayat city was selected as the main study area due to the presence of many brick factories; almost all of them use heavy oil as a fuel. It is located in the subtropical climatic region, and the privilege wind direction is northern (Figure 1).

Sampling

Twelve air samples were collected from three locations at a height of 12m above the ground level, at the roof of local resident houses which are located in the area of Kafr-El-Zayat Region. In the area that extended from 200 to 2000 m (away from Cairo-Alexandria agriculture road and adjacent to the river Nile bank). Sampling was taken place through summer season of 2013 (June and July) and winter season of 2013 (November and December) three samples from three locations each month. Eighteen soil samples were collected from three locations 200 m, 1000 m, and 2000 km (away from Cairo-Alexandria agriculture road and adjacent to the river Nile bank) as indicated in the Figure (1). Soil sampling was taken place through summer season of 2013 (June and July) and winter season of 2013 (November and December). Nine samples during summer and other nine during winter

Air samples collected on glass fiber filters (Whatmann GFA), with 99% collection efficiency (National Academy of Science, 1973), using a recalibrated high volume air sampler pump, for 12 hour period, with a pump flow rate of 70 L/min. Before sampling, the glass fiber filters were impregnated in acetone to remove all organic compounds, and stored in desiccators until sampling (Yamasaki et al., 1982). After sampling, GFFs were stored in aluminum foil packages sealed in plastic bags in a freezer until analyzed. Soil samples were collected in a solvent pre-cleaned aluminum foil and preserved in the refrigerator until the analysis.

PAHs Analysis and Extraction

The filters and soil samples were dried, and reweighed to obtain concentrations. The filters and soil samples were stored in dark until analyzed (Gustafson and Dickhut, 1997). PAHs were analyzed using a gas chromatography (GC) fitted with a Flame Ionization Detector (FID) followed by mass spectrometer detector (MSD) for identification of PAHs (ATSDR, 1990, US EPA, 2001) PAHs were extracted with 10 ml of DCM/n-hexane (1:1), fractionated by column chromatography, and eluted with 20 mL of n-hexane/dichloromethane (1:1, v:v), according to methods previously described (Zhu et al., 2008). A 2 µl of the extract was injected on GC-FID, Model HP 6890, equipped with HB5 capillary column (30m x 320µm x 0.25µm). The GC was calibrated with a diluted standard solution of 16 PAH compounds (Supelco, Inc., Bellefonte, PA), including; Naphthalene (NAP), Acenaphthylene (ACY), Acenaphthene (ACE), Phenanthrene (PHE), Fluorine (FLU), Anthracene (ANC), Fluoranthene (FLA), Pyrene (PYR), Benzo(a)anthracene (BaA), Chrysene (CRY), Benzo (b)fluoranthene (BbF), Benzo (k) fluoranthene (BkF),



Figure 1. Map of the sampling sites.

Benzo (a)pyrene (BaP), Dibenzo (a,h)anthracene (DBA), Indeno (1,2,3-c,d)pyrene (IND) and Benzo (ghi) perylene (Bgp).

Mass spectrometer (thermo-scientific ISQ, 2009) with helium carrier gas (1ml min⁻¹) equipped with column as GC-FID (TG-1 MS) was also used. The mass transfer line temperature was 300°C and ion source temperature was 220°C. The mass spectrometer was operating in the electron ionization mode with electron energy of 70 eV and quadrupole mass analyzer with mass range 50-500 mu. NIST library-08 was used for compound identification depending on its mass spectrum. The instrument was calibrated by injection of the standards component mixture at three different concentrations (5, 10 and 20 ng/μl), for PAHs prior to analysis of the samples.

Health risk assessment methodology

The health risk of carcinogenic PAH compounds in the

study area were estimated by using Toxic Equivalent Factors (TEFs) for individual PAH compounds, as previously described (Ramirez et al., 2011). These factors have been devised as a means of comparing the carcinogenicity of the individual PAH compounds to the carcinogenicity of B(a)P. The cancer potency of each PAH compound was assessed on the basis of its benzo (a) pyrene equivalent concentration (BaP_{eq}). The BaP_{eq} concentrations for the individual PAH compounds were calculated by multiplying the individual PAH concentration by its corresponding TEF value. Lifetime lung cancer risk of PAHs in the atmosphere is defined by the WHO, as the estimated lifetime lung cancer risk from PAHs in the atmosphere based on the unit risk (UR). UR is 8.7 cases per 100,000 people with chronic inhaled exposure to 1 ng/m³ B(a)P (UR = 8.7 × 10⁻⁵) over a lifetime of 70 years. The risk of developing lung cancer can thus be calculated as:

$$\text{Lifetime lung cancer risk} = \text{BaP}_{\text{eq}} (\text{ng/m}^3) \times \text{UR}$$

The corresponding number of lung cancer cases in population around the site that could be attributed to PAH was calculated as follows: population exposed (number of inhabitants) \times lifetime lung cancer risk. The exposed population in the related site is 23,460 inhabitants, based on local Egyptian ministry of health office-census statistics.

RESULTS AND DISCUSSION

The mean concentrations of PAHs at the sampling sites of Kafr-El-Zayat city for air and soil samples during the study period for summer and winter seasons are shown in Tables 1 and 2, and Figures 2 and 3. The total PAH concentrations ranged 22.57 to 57.99 ng/m³ in air samples, and ranged 575.87 to 572.68 ng/g in soil samples, during summer and winter, respectively. PAH compounds were classified according to the number of aromatic rings into: 2-rings, NAP, 1-MNAP and 2-MNAP; 3-rings, ACY, ACE, FLU, ANT and PHE; 4-rings, FLA, PYR, BAA and CHR; and 5-rings, BBF, BKF, BAP and DBA; 6-ring including BGP and IND. The low molecular weight PAHs were recorded at the highest levels during winter in air and soil while high molecular weight PAHs were at the highest levels in soil during summer (Figures 2 and 3). The total PAH concentrations in soil were between 8 and 100 times more than in air during summer, while in winter were between 9 to 10 times compared to winter samples. It was previously mentioned (Sicre et al., 1987), as the molecular weight decreases the PAHs became more volatile and can be easily dispersed in the atmosphere rather than deposited and accumulated in the soil, which can explain the recorded results of the presence of higher concentrations of HMW PAHs in soil than that of LMW PAHs. World Health Organization stated the PAH levels in soil in unpolluted areas to be 5-100 $\mu\text{g}/\text{kg}$ (5 -100 ng/g) (WHO/IPCS, 1998). In the present study the PAH mean level was 573.96 ng/g with a maximum level of 3238.8 ng/g, which far exceeded that level.

In air, PAH compounds with five aromatic rings were of the highest level (10.58 ng/m³), followed by six aromatic rings (3.65 ng/m³). The total particulate phase mean level was 14.23 ng/m³ with a SD of 6.45 and a maximum concentration of 58.9 ng/m³ and the total LMW plus HMW mean level was 40.28 ng/m³ with a SD of 21.16 and a maximum level of 150.03 ng/m³. In air samples the mean levels of LMW PAHs is higher than that of HMW PAHs. These results are in agreement with the theoretical fact that the higher molecular weight PAHs are generally less volatile and attached to the particulate phase while the reverse is true for the lower molecular weight PAHs which are usually found in the gaseous phase (Fang et al., 2004). The distribution of PAH compounds in the particulate and gaseous phases depends on molecular

weight (Odabasi et al., 1999). The predominant PAH compounds in the particulate phase were the four to six PAH rings (Fon et al., 2007). PAH compounds with two to three aromatic rings were detected predominantly in the gaseous phase (Ohura et al., 2004). Consistent with the observations of previous investigators, reduced chemical and photochemical degradation, due to lower sunlight intensity and temperature, and differences in ozone level can contribute to the higher PAH concentrations in winter than in summer season (Esen et al., 2008, Kiss G., Varga-Punchony et al., 1998). Negative correlation was found between the concentrations of PAH compounds and ozone (Tsapakis and Stephanou, 2005). High temperature along with enhanced photodecomposition of PAHs in summer leads to a decrease in the concentration of PAHs (Cincinelli et al., 2007, Sharma et al., 2007). The mean contribution of the total gaseous (LMW) PAHs concentrations to the total (particulate + gaseous) PAHs concentrations (55.86% in winter and 29.87% in summer) in the study were lower than those found in Bursa, Turkey (66% in winter and 89% in summer) (Vardar et al., 2008) and in Guangzhou, South China (98.2% in summer), whereas the contribution of the total gaseous PAHs in winter was higher than that found in Guangzhou, South China (53.80% in winter) (Li et al., 2006).

Table 3 shows the diagnostic ratios of PAHs concentrations. The mean concentration ratios of B(a)A /CHR were 4.34, 4.05 and 4.05 in the summer, winter and total period of study, respectively, indicating freshly emitted PAHs from local sources or air masses that are not aged. The mean level ratios of [FLu/(FLu + PYR)] were 0.42, 0.48 and 0.5 in the summer, winter and total period of study in air samples, respectively, suggesting that PAH emissions were due to fossil fuel combustion (Sharma et al., 2007). The concentration ratios of B(a)P/ B(ghi)P are used to investigate the emission sources of PAHs. In addition, the concentration ratio of ANT/ (ANT + PHE) is used to estimate the presence of PAHs from fossil fuels inputs (Yunker et al., 2002). If the above mentioned ratio is lower than 0.1, it indicates that the source is of non-burned fossil fuel inputs, while if the ratio is higher than 0.1, combustion sources may prevail. In the present study, the mean concentration ratios of ANT/ (ANT + PHE) were 0.3, 0.55 and 0.4 during the summer, winter and total period of study, respectively, indicating combustion related to emission sources, the obtained ratios were close to the oil combustion ratios, 0.36-0.57, reported in China (Yang et al., 2002). These findings are similar to ratios which were measured for diesel engines, 0.38-0.64 (Hassan and Khoder, 2012), and industrial areas, 0.23-0.89 (Yang et al., 2002).

Benzo (a) pyrene has often been used as a key indicator for PAHs risk assessment. The health risks associated with exposure to PAH compounds in the study area were estimated by using Toxic Equivalent

Table 1. Mean levels of the individual PAH compounds and different categories of PAHs based on aromatic rings number and molecular weight in the air samples of Kafr-El-Zayat region during the winter and summer seasons, 2013.

PAH compounds	PAH abbreviations	Levels of PAHs in air (ng/m ³)			
		Winter		Summer	
		Mean (ng/m ³)	SD	Mean (ng/m ³)	SD
Naphthalene	NAP	7.53	1.41	ND	ND
Σ2-ring PAHs	Σ2-ring PAHs	7.53	1.41	ND	ND
Acenaphthalene	ACY	3.12	0.3	ND	ND
Acenaphthene	ACE	0.30	0.03	2.40	0.1
Flurene	FLO	0.58	0.01	ND	ND
Phenanthrene	PHE	0.23	0.01	4.27	0.3
Anthracene	ANT	7.98	2.4	3.02	0.2
Σ3-ring PAHs	Σ3-ring PAHs	12.22	2.75	9.69	0.9
Fluoranthene	FLU	3.62	0.33	0.25	0.01
Pyrene	PYR	4.40	0.34	4.97	0.2
Benzo(a) anthracene	B(a)A	4.38	1.22	4.03	0.15
Chrysene	CHR	1.02	0.25	ND	ND
Σ4-ring PAHs	Σ4-ring PAHs	13.42	2.14	9.25	0.8
Σ LMW PAHs	Σ- LMW PAHs	33.17	7.3	18.94	3.0
Benzo(b) Fluoranthene	B(b)F	10.55	1.05	2.92	0.3
Benzo(K) flurancene	B(k)F	0.65	0.11	0.72	0.03
Benzo(a) pyrene	B(a)P	4.75	0.74	ND	ND
Dibenzo(a,h) anthracene	D(a,h)A	1.57	0.03	ND	ND
Σ5-ring PAHs	Σ5-ring PAHs	17.52	1.93	3.63	0.1
Indeno(1,2,3,c,d) pyrene	IND	7.07	1.18	ND	ND
benzo(ghi) perylene	B(ghi)P	0.23	0.02	ND	ND
Σ6-ring PAHs	Σ6-ring PAHs	7.30	1.2	ND	ND
Σ HMW PAHs	Σ-HMW PAHs	24.82	3.13	3.63	0.2
Σ LMW+HMW PAHs	Σ-LMW+HMW PAHs	57.99	6.43	22.57	3.0

Table 2. Mean levels of the individual PAH compound and different categories of PAHs based on aromatic rings number and molecular weight in the soil samples from Kafr-EL-Zayat region during the winter and summer seasons, 2013.

PAH compounds	PAH abbreviations	Levels of PAHs in Soil (ng/g)			
		Winter		Summer	
		Mean (ng/g)	SD	Mean (ng/g)	SD
Naphthalene	NAP	53.23	5.82	16.55	3.45
Σ2-ring PAHs	Σ2-ring PAHs	53.23	5.82	16.55	3.45
Acenaphthalene	ACY	16.27	1.1	9.19	0.9
Acenaphthene	ACE	0.64	0.01	2.54	0.8
Flurene	FLO	15.02	2.01	3.92	0.45
Phenanthrene	PHE	15.08	1.01	25.71	2.63
Anthracene	ANT	22.22	3.02	66.03	4.85
Σ3-ring PAHs	Σ3-ring PAHs	69.23	12.97	107.38	13.08
Fluoranthene	FLU	46.04	6.89	11.26	1.47
Pyrene	PYR	22.93	4.03	22.25	4.87
Benzo(a) anthracene	B(a)A	102.47	10.07	1.16	0.06
Chrysene	CHR	25.32	3.01	1.2	0.87
Σ4-ring PAHs	Σ4-ring PAHs	196.77	24	35.88	7.27

Table 2. Continue

Σ LMW PAHs	Σ - LMW PAHs	319.22	42.79	159.8	23.8
Benzo(b) Fluoranthene	B(b)F	36.61	2.8	7.74	0.98
Benzo(K) flurancene	B(k)F	19.77	5.3	91.91	6.87
Benzo(a) pyrene	B(a)P	37.08	4.01	29.4	3.25
Dibenzo(a,h) anthracene	D(a,h)A	7.28	1.07	99.31	9.41
Σ5-ring PAHs	Σ 5-ring PAHs	100.74	13.18	228.37	20.51
Indeno(1,2,3,c,d) pyrene	IND	125.65	20.87	178.18	11.46
benzo(ghi) perylene	B(ghi)P	27.08	6.9	9.52	1.02
Σ6-ring PAHs	Σ 6-ring PAHs	152.73	27.77	187.7	12.48
Σ HMW PAHs	Σ -HMW PAHs	253.46	40.95	416.07	32.99
Σ LMW+HMW PAHs	Σ -LMW+HMW PAHs	572.68	83.74	575.87	56.79

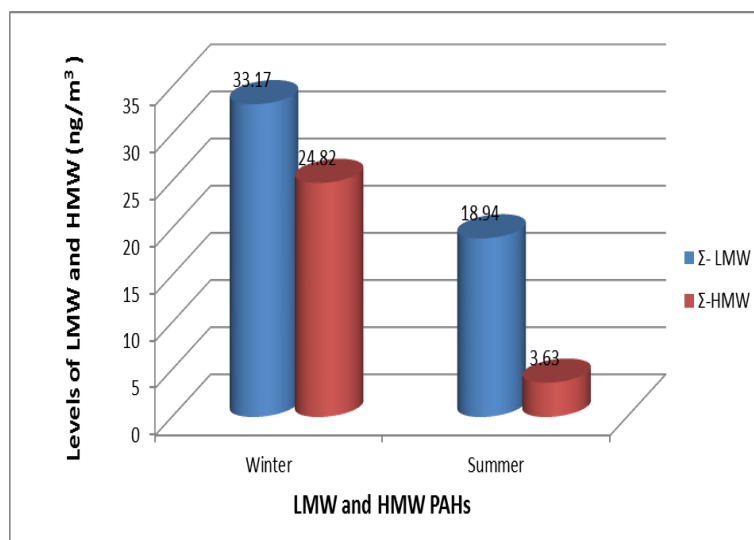


Figure 2. Mean levels of LMW and HMW PAHs during summer and winter season in air samples from Kafr-EL-Zayat region, in 2013.

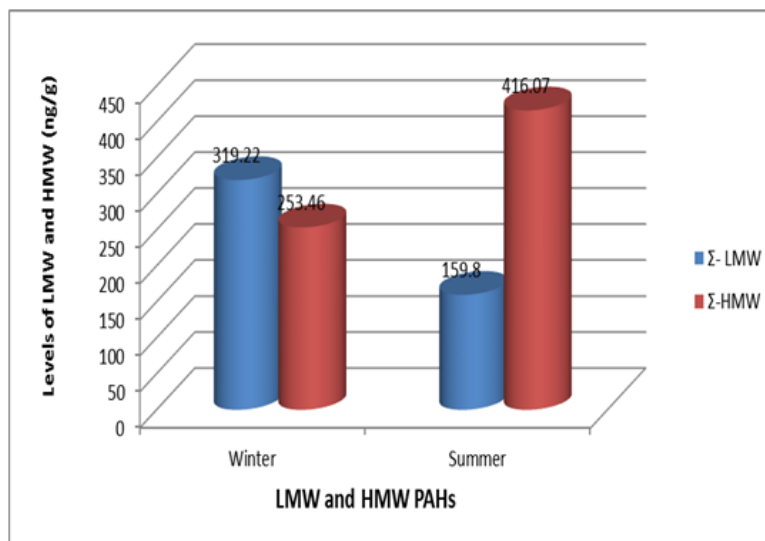


Figure 3. Mean levels of LMW and HMW PAHs during summer and winter season in soil samples from Kafr-EL-Zayat region, in 2013.

Table 3. Diagnostic concentration ratios of selected PAHs compounds in air samples

PAHs Ratio	Summer	Winter	All period
PHE/ANT	2.30	1.81	1.47
ANT/ANT + PHE	0.30	0.55	0.40
FLU/PYR	0.42	1.87	2.01
FLU/FLU + PYR	0.42	0.48	0.5
B(a)A/CHR	4.34	4.05	4.05
IND/B(ghi)P	18.72	4.79	4.64
$\frac{\sum \text{ of two and three ring}}{\sum \text{ of four and five ring}}$	0.48	0.43	0.41
B(a)A/(B(a)A + CHR)	0.81	0.80	0.80
IND/(IND + B(ghi)P)	0.95	0.83	0.82

Factors (TEFs) for individual PAH compounds. Table 4 shows the B(a)P equivalent concentrations for PAH compounds in air and soil samples during summer and winter in Kafr-EL-Zayat region; and Table 5 shows the total carcinogenic activity percentage (TCA %) of most hazardous PAHs during summer, winter and all period of study in soil and air samples (Figures 4 and 5). BAA, BBF, BAP, DBA and IND are probably considered human carcinogens, whereas ACY, ANC, BgP, FLA, PYR and FLU are not classified as promoters of cancer risk (IARC, 1983). In the current study, the total carcinogenic compounds, during summer season, was 0.82 ng/m³, with a high contribution of gas – phase PAHs, reached to 55.69% and low contribution of particulate-phase PAHs 5.55%. The contribution of B(a)A to the total carcinogenic activity, TCA, was 49.18% showing a higher contribution, during winter season, the TCA was 8.62 ng/m³ with a high contribution of particulate – phase, PAHs, reached to 94.453% and low contribution of gas-phase PAHs 5.547%, the contribution of B(a)p to the TCA was 55.08% showing a higher contribution. The risk of inhaling carcinogenic PAH compounds depends on whether the PAH compounds enter the lungs in gaseous form or whether they are inhaled on particulate matter which penetrate into the lungs and exert their carcinogenicity over long periods of time.

Lifetime lung cancer risk of 16 PAHs in the atmosphere are calculated in the above table. The estimated lung cancer risk ranged from 2.54E-08 for Flo to 2.07E-04 for B(a)P, the total lifetime lung cancer risk is 4.11E-04 (4.11 lung cancer cases per 10,000 person exposed), the compounds that contributed most to the total estimated risk were B(a)P (50.3%), D(a,h)A (16%) and B(b)F(14%) combined contribution, about 20%). Although gas-phase PAHs had the highest average concentration of the individual PAHs (26.05 ng/m³), it made a small contribution to the overall risk because of its low TEF. An average lifetime lung cancer risk of 4.11 × 10⁻⁴ (4.11 cases per 10,000

people exposed) was estimated for the study area as a whole (Table 6, Figures 4 and 5). Assuming a homogeneous exposure of 23,460 inhabitants of Kafr-El-Zayat, 9.64 cases of lung cancer can be attributed to this PAHs exposure. Furthermore, in the absence of major indoor PAH sources, such as tobacco smoking, A study in Southern Europe and the Mediterranean area (in the Tarragona region) observed some spatial and seasonal variability in PAH concentration and the contribution of gas- phase PAHs to the total BaP_{eq} value was between 34% and 86%. The total estimated average lifetime lung cancer risk due to PAH exposure in the study area was 1.2 × 10⁻⁴ (Ramirez et al. 2011). Cooking fumes, and residential heating, outdoor PAHs can also substantially contribute to indoor PAH levels (WHO, 1987).

According to the WHO “Air Quality Guidelines for Europe”, each country has to determine its own acceptable risk levels. However, the risk estimate for the study area was higher than 10–5, the upper-bound excess lifetime cancer risk recommended by the WHO for carcinogens in drinking water (Bostrom et al., 2002), and higher than the 10–6 risk that is the U.S. EPA guideline. We therefore conclude that the lung cancer risk due to these PAH exposures cannot be negligible and should be taken into account for health protection in the future.

CONCLUSION

The present study confirms the contribution of combustion of heavy oil fuel of brick industry to atmospheric PAHs in Kafr-El-Zayat city, west Delta of Egypt, that can contribute to lung cancer incidence at that region. The pollution of PAHs should be managed and further work is needed to develop this preliminary investigation, including more measurements in other locations, showing similar industrial activities.

Table 4. B(a)P equivalent concentrations for PAH compounds in air and soil samples during the summer and winter in Kafr-EL-Zayat region, 2013.

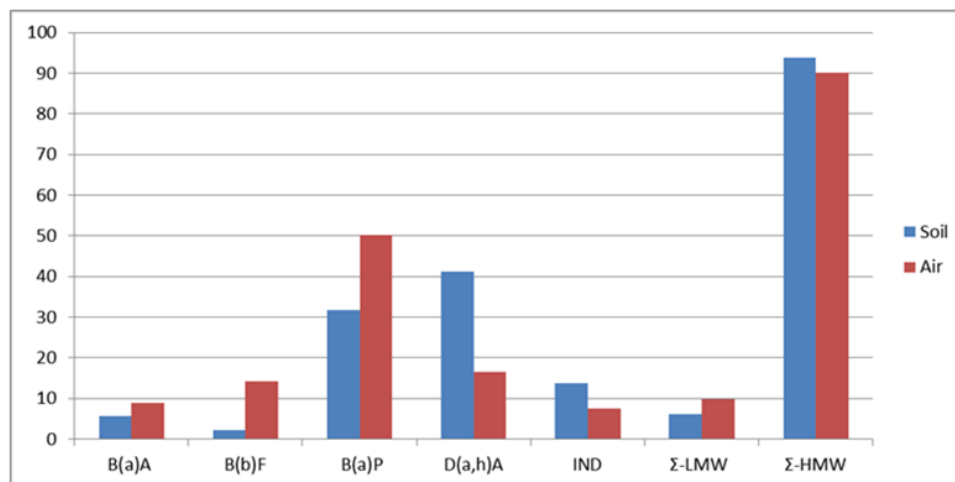
Pahs	TEF	Summer				Winter				All period			
		Soil		Air		Soil		Air		Soil		Air	
		Mean Conc (ng/g)	BaPequiv Conc (ng/g)	Mean Conc (ng/m3)	BaPequiv Conc (ng/m3)	Mean Conc (ng/g)	BaPequiv Conc (ng/g)	Mean Conc (ng/m3)	BaPequiv Conc (ng/m3)	Mean Conc (ng/g)	BaPequiv Conc (ng/g)	Mean Conc (ng/m3)	BaPequiv Conc (ng/m3)
NAP	0.001	16.55	0.02	0.00	0.00	53.23	0.05	7.53	0.01	38.55	0.04	3.77	0.00
ACY	0.001	9.19	0.01	0.00	0.00	16.27	0.02	3.12	0.00	13.44	0.01	1.56	0.00
ACE	0.001	2.54	0.00	2.40	0.00	0.64	0.00	0.30	0.00	1.40	0.00	1.35	0.00
FLO	0.001	3.92	0.00	0.00	0.00	15.02	0.02	0.58	0.00	10.58	0.01	0.29	0.00
ANT	0.010	25.71	0.26	4.27	0.04	15.08	0.15	0.23	0.00	19.33	0.19	2.25	0.02
PHE	0.001	66.03	0.07	3.02	0.00	22.22	0.02	7.98	0.01	39.74	0.04	5.50	0.01
FLU	0.001	11.26	0.01	0.25	0.00	46.04	0.05	3.62	0.00	32.13	0.03	1.93	0.00
PYR	0.001	22.25	0.02	4.97	0.00	22.93	0.02	4.40	0.00	22.66	0.02	4.68	0.00
B(a)A	0.100	1.16	0.12	4.03	0.40	102.47	10.25	4.38	0.44	61.95	6.19	4.21	0.42
CHR	0.010	1.20	0.01	0.00	0.00	25.32	0.25	1.02	0.01	15.67	0.16	0.51	0.01
B(b)F	0.100	7.74	0.77	2.92	0.29	36.61	3.66	10.55	1.06	25.06	2.51	6.73	0.67
B(k)F	0.100	91.91	9.19	0.72	0.07	19.77	1.98	0.65	0.07	48.62	4.86	0.68	0.07
B(a)P	1.000	29.40	29.40	0.00	0.00	37.08	37.08	4.75	4.75	34.01	34.01	2.38	2.38
D(a,h)A	1.000	99.31	99.31	0.00	0.00	7.28	7.28	1.57	1.57	44.09	44.09	0.78	0.78
IND	0.100	178.18	17.82	0.00	0.00	125.65	12.56	7.07	0.71	146.66	14.67	3.53	0.35
B(ghi)P	0.010	9.52	0.10	0.00	0.00	27.08	0.27	0.23	0.00	20.06	0.20	0.12	0.00
Total carcinogenicity activity (TCA)		157.11		0.82		73.66		8.62		107.04		4.72	
Contribution of B(a)A to the TCA (%)		0.74		49.18		13.91		5.08		5.79		8.91	
Contribution of B(b)F to the TCA (%)		0.49		35.58		4.97		12.23		2.34		14.26	
Contribution of B(a)P to the TCA (%)		18.71		0.00		50.34		55.08		31.77		50.29	
Contribution of D(a,h)A to the TCA (%)		63.21		0.00		9.89		18.17		41.19		16.59	
Contribution of IND to the TCA (%)		11.34		0.00		17.06		8.19		13.70		7.48	

Table 5. Percentage of total carcinogenic activity (TCA%) of most hazardous PAHs during summer, winter and all period of study in soil and air samples.

Contributions to TCA%	Summer		Winter		All period	
	Soil	Air	Soil	Air	Soil	Air
Contribution of B(a)A to the TCA	0.74	49.18	13.91	5.08	5.79	8.91
Contribution of B(b)F to the TCA	0.49	35.58	4.97	12.23	2.34	14.26
Contribution of B(a)P to the TCA	18.71	0.00	50.34	55.08	31.77	50.29
Contribution of D(a,h)A to the TCA	63.21	0.00	9.89	18.17	41.19	16.59
Contribution of IND to the TCA	11.34	0.00	17.06	8.19	13.70	7.48
Contribution of Σ -LMW PAHs to the TCA	0.329	55.686	14.700	5.547	6.26	9.90
Contribution of Σ -HMW PAHs to the TCA	99.671	44.314	85.300	94.453	93.74	90.10

Table 6. Estimated lifetime lung cancer risk due to exposure to PAHs in air in Kafr-EL-Zayat region.

PAHs	Mean Conc. (ng/m ³)	B(a)P equiv. Conc. (ng/ m ³)	Estimated lifetime lung cancer risk BaP _{eq} (ng/m ³) × UR (8.7E ⁻⁰⁵)	Percent of relative contributions of individual PAHs to the Estimated lifetime lung cancer risk (%)
NAP	3.767	0.004	3.28E-07	0.080
ACY	1.558	0.002	1.36E-07	0.033
ACE	1.350	0.001	1.17E-07	0.029
FLO	0.292	0.000	2.54E-08	0.006
ANT	2.252	0.023	1.96E-06	0.477
PHE	5.500	0.006	4.79E-07	0.116
FLU	1.934	0.002	1.68E-07	0.041
PYR	4.683	0.005	4.07E-07	0.099
B(a)A	4.208	0.421	3.66E-05	8.912
CHR	0.508	0.005	4.42E-07	0.108
Σ -LMW PAHs	26.053	0.468	4.07E-05	9.901
B(b)F	6.734	0.673	5.86E-05	14.260
B(k)F	0.683	0.068	5.95E-06	1.447
B(a)P	2.375	2.375	2.07E-04	50.293
D(a,h)A	0.784	0.784	6.82E-05	16.593
IND	3.533	0.353	3.07E-05	7.482
B(ghi)P	0.117	0.001	1.02E-07	0.025
Σ -HMW PAHs	14.226	4.255	3.70E-04	90.099
Total carcinogenic activity (TCA)		4.72	4.11E-04	100

**Figure 4.** Relative contribution of some individual PAHs, LMW PAHs and HMW PAHs to TCA during all period of study in soil and air samples from Kafr-EL-Zayat region, 2013.

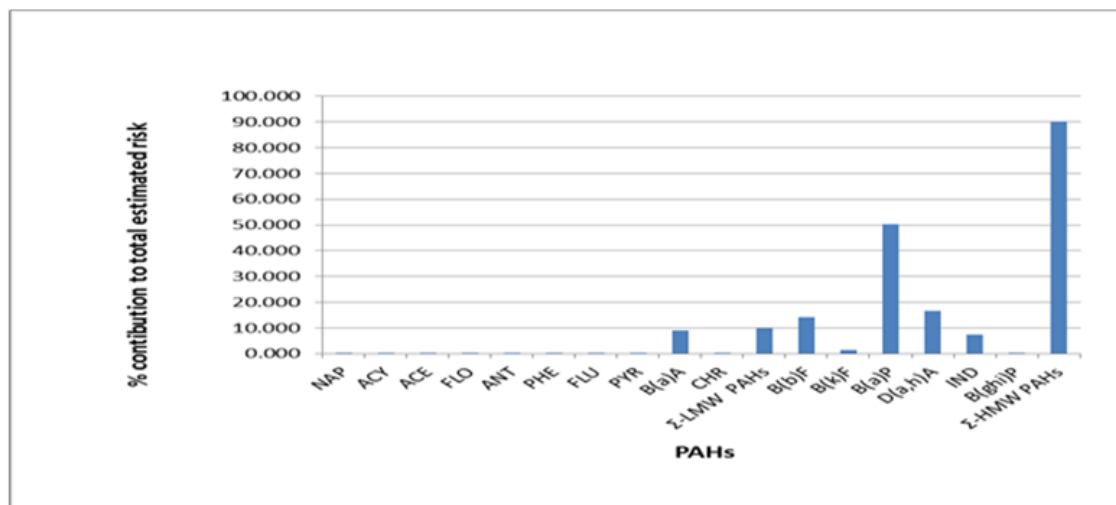


Figure 5. Relative contribution of some individual PAHs, LMW PAHs and HMW PAHs to total estimated lung cancer risk in Kafr-EL-Zayat region, in 2013.

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