PROFILE AND SOURCE IDENTIFICATION OF POLYCYCLIC AROMATIC HYDROCARBONS IN DUST DEPOSITED ON LEAVES OF STREET TREES AS INDICATORS OF AIR POLLUTION SOURCES IN CAIRO

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ABSTRACT: Polycyclic aromatic hydrocarbons (PAHs) were determined in paved street dust and dust deposited on leaves of street trees (leaves dust) in two urban areas in greater Cairo (Ramsis in the city centre of Cairo and Haram). The concentrations of the individual PAH compounds in paved street dust and leaves dust in Ramsis area were higher than those found in Haram area. The total PAH concentrations were: 92.32 and 40.41 μg/g in paved street dust and 337.81 and 175.51 μg/g in leaves dust in Ramsis and Haram areas, respectively. The concentrations of total and individual PAH compounds in the main street were higher than those found in the substreets in both study areas. The main street/substreet concentration ratios of the total PAHs were 2.29 and 4.01 for paved street dust and 2.22 and 2.27 for leaves dust in Ramsis and Haram areas, respectively. The total carcinogenic PAH compounds represented 55.10% and 54.12% of the total concentration of PAHs in paved street dust and 54.79% and 53.17% of that in leaves dust in Ramsis and Haram areas, respectively. The profile of the individual PAH compounds and the distribution of PAHs with different ring numbers in the paved street dust and leaves dust in both study areas indicate that the heavy PAH compounds (four to six aromatic rings) were the predominant compounds. Moreover, the light molecular weight/high molecular weight PAH concentration ratios and the ratios of the sum of major combustion specific compounds (ΣCOMB) to the sum of PAHs (ΣCOMB/ΣPAHs) in paved street dust and leaves dust indicate that combustion activities greatly affected the PAH concentration in the paved street dust and leaves dust in both study areas. In addition, the phenanthrene/anthracene (PHE/ANT) and fluoranthene/pyrene (FLT/PYR) concentration ratios indicate that pyrogenic sources were the predominant sources of PAHs in paved street dust and leaves dust in both urban areas in Cairo. The benzo(a)pyrene/benzo(ghi)perylene (BaP/BGP), benz(a)anthracene/chrysene (BaA/CRY) and indeno(1,2,3,–cd)pyrene/benzo(ghi)perylene (IND/BGP)

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Abbreviations:

PAHs = polycyclic aromatic hydrocarbons
NA = naphthalene
ACY = acenaphthylene
ACE = acenaphthene
FLU = fluorene
PHE = phenanthrene
ANT = anthracene
FLT = fluoranthene
PYR = pyrene
BaA = benz(a)anthracene
CRY = chrysene
BbF = benzo(b)fluoranthene
BaP = benzo(a)pyrene
DBA = dibenzo(a,h)anthracene
IND = indeno(1,2,3,–cd)pyrene
BGP = benzo(ghi)perylene

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concentration ratios indicate that PAHs in Ramsis and Haram areas were more influenced by vehicular exhaust emissions than other sources. Diesel vehicles were the dominant sources of PAHs in Ramsis area, whereas gasoline vehicles were the dominant sources in Haram area.

KEY WORDS: Polycyclic aromatic hydrocarbons (PAHs), profile, source identification, carcinogenic compounds, street dust, dust on leaves, urban areas, greater Cairo

INTRODUCTION

Anthropogenic and natural particulates and contaminants from an extensive range of urban and industrial sources and processes finally settle on the ground surface and on leaves surface of plants under the effect of atmospheric removal processes (dry and/or wet deposition). Paved street dust and dust deposited from air on leaves of street trees (leaves dust) represent an accumulation of contributions from a variety of urban source types. Street dust is of particular concern due to its potential health risk to children through their hand-to mouth activities (Fergusson and Kim, 1991; Fergusson, 1992) and it could degrade the quality of urban water runoff (Sartor and Caboury, 1984). It carries a high amount of contaminants such as metals and organic pollutants (Kim et al., 1998; Yunker et al., 2002). In addition, it acts as an important source of house dust (Adgate et al., 1998) and urban atmospheric particulate matter (Harrison et al., 1997).

Dust deposited from air on leaves of street trees as well as paved street dust act as important sources of particulate organic emission in urban atmosphere. Polycyclic aromatic hydrocarbons (PAHs) are one of the most important contaminant groups in both leaves dust and paved street dust because they can cause significant risk to human health. Resuspended by wind and vehicle-induced turbulence, PAHs in leaves dust and paved street dust are injected into the atmosphere and act as an important emission source of these pollutants. In addition, PAHs in paved street dust may be released to air during the removal of paved street dust and consequently may be deposited on surfaces throughout daycare facilities and surrounding playgrounds. Therefore, humans may be exposed to PAHs of leaves dust and paved street dust via inhalation or through direct contact with dust deposits. Inhalation of PAHs causes allergic responses, cancer and impaired foetal development (WHO, 1998; Pope et al, 2002; Perera et al., 2004). Moreover, the oxidised and nitrated reaction products of these compounds have been found to be more potent carcinogens and mutagens than their parent PAHs (Pitts et al., 1980).

Polycyclic aromatic hydrocarbons (PAHs) are a large group of organic compounds composed of two or more fused aromatic rings. They are a group of chemicals that are long-lived and ubiquitous in the environment (Baek et al., 1991; Wilcke, 2000). In the atmosphere, PAHs are partitioned between the particulate and the gaseous phase and the carcinogenic PAH compounds are mostly associated with particulate matter especially its fine size range (Cautreels and Van Cauwenberghe, 1978; Caricchia et al., 1999; Kendall et al., 2001). PAHs are emitted in the environment through natural and anthropogenic sources. Volcanoes and forest fires are the most important natural sources of PAHs (Wilcke, 2000; Kim et al., 2003). Anthropogenic sources of PAHs are more abundant than natural sources. Anthropogenic PAHs are mainly formed as by-products of incomplete combustion of organic materials during industrial activities, residential heating, power generation, incineration, and vehicle emissions, as a result of pyrolitic processes (Khalili et al., 1995; Harrison et al., 1996; Garban et al., 2002; Mastral et al., 2003; Dyke et al., 2003; Di Lella et al., 2006; Luo et al., 2006). Traffic was the major determinant for both the concentrations of PAHs and the genotoxic activity in urban air (Pyysalo et al., 1987; Tuominen et al., 1988; Westerholm et al., 1989). In the ambient environment, PAH levels depend to a great extent on a number of factors, such as type of fuel, amount of oxygen available for combustion and temperature (Sharma et al., 2007). Moreover, the final PAH levels may be further influenced by photodegradation, biodegradation, chemical oxidation and physico-chemical characteristics of the atmosphere (Lima et al., 2004). Dry deposition predominates in the vicinity of urban/ industrial areas, whereas wet deposition predominates in more remote areas (Golomb et al., 1997).

Street dusts in West Germany contained 1.0 μg/g of fluoranthene and 0.53 μg/g of benzo(a)pyrene (Herrmann, 1981). The sum of concentrations of nine major PAH compounds (pyrene, fluoranthene, benzo(a)anthracene, chrysene, benzofluoranthenes, benzo(a)pyrene, benzo(e)pyrene, indeno(c,d)pyrene and benzo(ghi)perylene) ranged from 1.4 to 4.92 μg/gm in paved street dust with asphalt in Tokyo Metropolitan area (Takada et al., 1991). The total PAH concentration in paved road dust in urban Pasadena, CA, USA was 58.68 μg/g (Rogge et al., 1993) and 12.56–93.70 μg/g in urban Birmingham (Smith et al., 1995). Total PAH concentration ranged from 434 to 1247 ng/g with levels of carcinogenic PAHs representing 29 to 45% of PAHs in street dust in the central area of Niterói City, RJ, Brazil (Pereira Netto et al., 2006).

There is a lack of information on PAH concentrations in dust deposited on leaves of street trees and in paved street dust in Greater Cairo which could provide important information on the state of environmental pollution of urban areas and be used as a useful indicator of the PAH pollution sources.

Therefore, the purposes of this study were to (1) determine the levels of PAHs in dust deposited on leaves of street trees and in paved street dust in two urban areas in Greater Cairo, (2) compare the difference in concentrations of these pollutants between the main street and substreets, (3) investigate the profiles of PAHs in both urban areas in order to identify the possible sources of these pollutants.

MATERIALS AND METHODS

Sampling sites

Greater Cairo (Cairo, Giza and Shoubra El-Khiema) is considered to be one of the most polluted megacities in the world. Vehicle fuels used in Greater Cairo are mainly unleaded gasoline and diesel, and some vehicles use compressed natural gas (CNG). Paved street dust and deposited dust from air on leaves of the street trees (leaves dust) in the main street and substreets were collected from two urban areas in Greater Cairo. The sampling sites were selected according to traffic density. The first site was in the city centre of Cairo (Ramsis), located to the south of the industrial area of Shoubra El-Khiema. Ramsis is the most commercial and heaviest traffic area in Greater Cairo and Ramsis street is the main street in this area. The second one was in an urban area in Giza (Haram), located to the southwest of the city centre of Cairo. It is characterized by relatively high traffic density and Haram street is the main street in this area.

Sample collection

At each site, leaves dust and paved street dust in the main street and substreets were collected in September 2004 by using a sweeping tool, put in plastic bags and then transferred to the laboratory. All samples were air-dried at room temperature in dark place. Paved street dust samples were sieved with a 30-mesh sieving screen (pore size 500 × 500 μm) to remove large particles, leaves of plants, etc. Then, the paved street dust and leaves dust samples were moisture equilibrated for at least 12 h in desiccators and weighted. After weighting, the paved street dust and leaves dust samples were extracted, concentrated, cleaned-up and re-concentrated for the PAHs analysis.

PAH analysis

Known amounts (1 g) of paved street dust and leaves dust samples were Soxhlet extracted with a solvent solution (the mixture of n-hexane and dichloromethane, 500 mL/L of each) for 24 h (Chen et al., 1997). The extracts were then concentrated to about 3 mL on a rotary evaporator for the clean-up procedure (Park et al., 2001). The collected eluant from the clean-up procedure was concentrated to 1 mL on a rotary evaporator and stored at 4°C till analysis.

A gas chromatograph (GC) (Hewlett-Packard HP6890), fitted with a Flame Ionization Detector (FID) was used. A HP-5 (30 m × 320 μm × 0.25 μm) capillary column with hydrogen as carrier gas was used. The GC was calibrated with a diluted standard solution of 15 compounds (PAH mixture, Supelco, Inc., Bellefonte, PA), and the concentrations of the target PAH compounds were quantified using this external standard solution. The concentrations of the following PAHs were determined: naphthalene (NA); acenaphthylene (ACY); acenaphthene (ACE); fluorene (FLU); phenanthrene (PHE); anthracene (ANT); fluoranthene (FLT); pyrene (PYR); benz(a)anthracene (BaA); chrysene (CRY); benzo(b)fluoranthene (BbF); benzo(a)pyrene (BaP); dibenzo(a,h)anthracene (DBA); benzo(ghi)perylene (BGP) and indeno(1,2,3,–cd)pyrene (IND).

Statistical analysis

Student's *t* test was used to estimate the significant difference between the mean concentrations of PAH compounds in Ramsis and Haram areas and between the mean concentrations in the main street and substreets according to Gregory (1963).

RESULTS

The minimum, maximum and arithmetic mean concentrations of the individual PAH compounds in paved street dust collected from Ramsis and Haram areas are summarized in *Table 1*. From this table, it can be observed that the most abundant PAH compounds were BbF, BGP, IND, DBA and CRY in Ramsis area, and BGP, DBA, BbF, CRY and BaP in Haram area. The maximum concentrations of the individual PAH compounds were found in paved street dust collected from Ramsis area. The differences in mean concentrations of the individual PAH compounds between Ramsis and Haram areas were statistically significant ($p<0.05$). The mean concentrations of the individual PAH compounds in paved street dust ranged from 0.72 μg/g for NA to 13.01 μg/g for BbF in Ramsis and from 0.41 μg/g for NA to 6.59 μg/g for BGP in Haram. In addition, the concentrations of the total PAH compounds in paved street dust were 92.32 μg/g in Ramsis and 40.41 μg/g in Haram (*Fig. 1*), and the difference in mean concentrations was statistically significant ($p<0.01$).

TABLE 1. Concentrations of the individual PAH compounds (μg/g) in paved street dust collected from Ramsis and Haram areas

	Ramsis				Haram			
	Minimum	Maximum	Mean	S.D.	Minimum	Maximum	Mean	S.D.
NA	0.31	1.25	0.72	0.37	0.17	0.72	0.41	0.21
ACY	0.37	1.48	0.86	0.44	0.19	0.82	0.46	0.25
ACE	0.48	1.91	1.11	0.56	0.20	0.92	0.52	0.29
FLU	0.43	1.69	0.99	0.50	0.22	1.07	0.59	0.35
PHE	0.76	3.01	1.76	0.89	0.28	1.56	0.83	0.53
ANT	0.58	2.29	1.34	0.68	0.20	1.20	0.64	0.36
FLT	2.98	11.72	6.87	3.46	0.76	3.80	2.10	1.25
PYR	2.01	8.01	4.67	2.38	0.62	3.08	1.70	1.01
BaA	2.85	10.74	6.40	3.07	1.01	4.12	2.37	1.28
CRY	4.55	17.99	10.53	5.32	1.43	9.12	4.70	3.28
BbF	6.34	21.12	13.01	5.59	1.79	11.23	5.89	4.07
BaP	4.11	14.52	8.79	3.95	1.35	9.06	4.69	3.30
DBA	4.73	16.89	10.64	4.89	1.96	11.96	6.27	4.29
IND	5.52	19.98	11.98	5.63	0.53	5.49	2.65	2.20
BGP	6.11	20.38	12.56	5.44	1.94	12.65	6.59	4.20

Notes: S.D., standard deviation. All the differences of mean concentrations in the Table are statistically significant at $p< 0.05$. For the full terms of abbreviations see the List of Abbreviations.

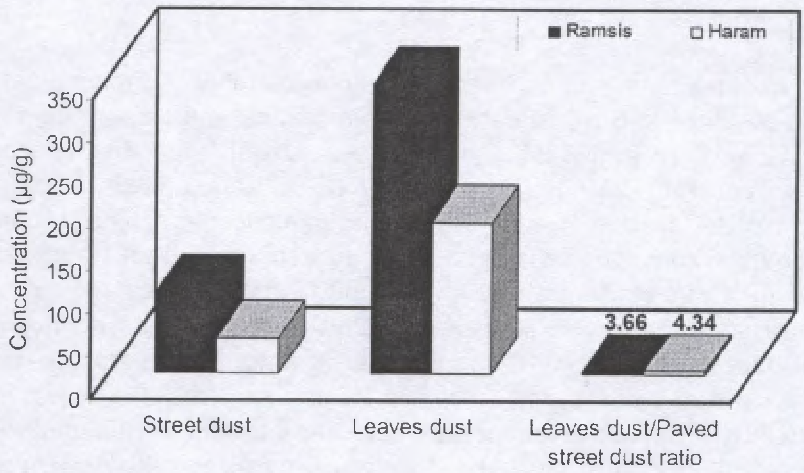

Fig. 1. Total concentrations of PAH compounds in paved street dust and leaves dust samples collected from Ramsis and Haram areas

The minimum, maximum and arithmetic mean concentrations of the individual PAH compounds in deposited dust on leaves of street trees collected from Ramsis and Haram areas are summarized in *Table 2*. It is clear that the most abundant PAH

TABLE 2. Concentration of the individual PAH compounds (µg/g) in dust deposited on leaves of street trees collected from Ramsis and Haram areas

	Ramsis				Haram			
	Minimum	Maximum	Mean	S.D.	Minimum	Maximum	Mean	S.D.
NA	1.19	4.54	2.69	1.31	0.61	2.51	1.45	0.75
ACY	1.41	5.34	3.18	1.53	0.71	2.85	1.63	0.87
ACE	1.86	6.91	4.13	1.96	0.71	3.07	1.75	0.95
FLU	1.67	6.12	3.68	1.72	0.79	3.22	1.87	0.97
PHE	2.86	10.84	6.44	3.11	1.12	4.43	2.59	1.31
ANT	2.23	8.26	4.94	2.34	0.81	3.63	2.05	1.14
FLT	11.29	42.43	25.31	12.14	4.12	17.23	9.91	5.25
PYR	7.61	28.99	17.22	8.36	3.32	14.41	8.22	4.47
BaA	10.39	39.63	23.56	11.30	5.12	19.34	11.47	5.58
CRY	16.88	65.45	38.67	19.07	10.13	38.30	22.71	11.07
BbF	22.08	78.82	47.16	20.71	10.49	40.94	23.97	12.21
BaP	18.78	46.96	32.53	12.03	12.40	31.89	21.00	7.20
DBA	17.32	66.33	39.21	18.82	15.12	36.22	24.89	9.43
IND	20.32	66.66	42.65	17.91	4.95	21.13	12.00	6.71
BGP	28.35	67.82	46.44	19.00	15.17	46.97	30.00	11.40

Notes: See as in *Table 1*.

compounds in leaves dust were BbF, BGP, IND, DBA and CRY in Ramsis area, and BGP, DBA, BbF, CRY and BaP in Haram area. The maximum concentrations of the individual PAH compounds in the leaves dust were found in Ramsis area. Significant differences were found between the mean concentrations of the individual PAH compounds in Ramsis and Haram areas ($p<0.05$). The average concentrations of the individual PAH compounds in leaves dust ranged from 2.69 μg/g for NA to 47.16 μg/g for BbF in Ramsis and from 1.45 μg/g for NA to 30.00 μg/g for BGP in Haram. Moreover, the total PAH concentrations in leaves dust were 337.81 μg/g in Ramsis area and 175.51 μg/g in Haram area (*Fig. 1*), and the difference in mean concentrations was statistically significant ($p<0.01$). In both study areas, the total PAH concentrations in leaves dust were higher than those found in street dust (*Fig. 1*); the leaves dust/street dust total PAH concentration ratios were 3.66 in Ramsis and 4.34 in Haram areas.

The average concentrations of the individual PAH compounds in paved street dust and leaves dust collected from the main street and substreets in Ramsis area are presented in *Figs. 2* and *3*, respectively. It can be noticed that, the maximum concentrations of the individual PAH compounds in paved street dust and leaves dust were found in the main street. Significant differences ($p<0.001$) were found between the mean concentrations of the individual PAH compounds in the main street and substreets. The average concentrations of the individual PAH compounds in street dust ranged from 1.04 and 0.41 μg/g for NA to 17.92 and 8.10 μg/g for BbF in the main street and substreets, respectively (*Fig. 2*). In addition, the total PAH concentrations in street dust were 128.58 μg/g in the main street and 55.95 μg/g in the substreets (*Fig. 4*), and the difference in mean concentrations was statistically significant ($p<0.001$). The main street/substreets total PAH concentration ratio was 2.29 (*Fig. 4*). In leaves dust at Ramsis, the average concentrations of the individual PAH compounds ranged from 3.78 and 1.61 μg/g for NA to 65.02 and 30.09 μg/g for BbF in the main street and substreets, respectively (*Fig. 3*).

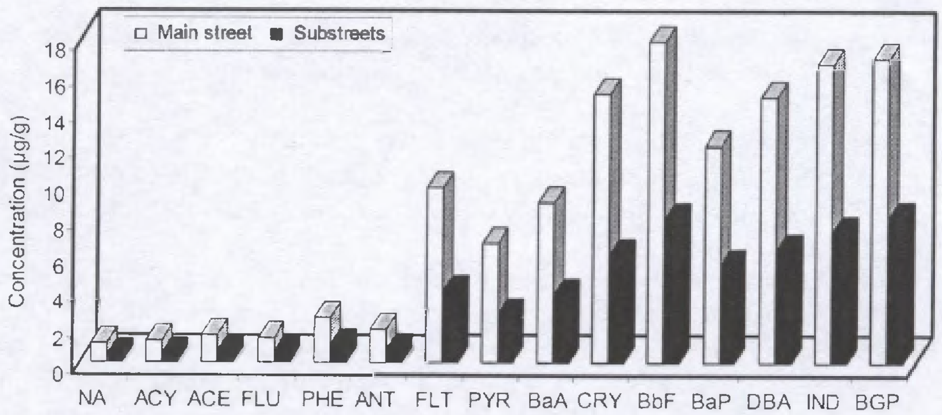

Fig. 2. Comparison between the concentrations of the individual PAH compounds in paved street dust samples collected from the main street and substreets in Ramsis area. (The full terms of abbreviations see in the list of abbreviations)

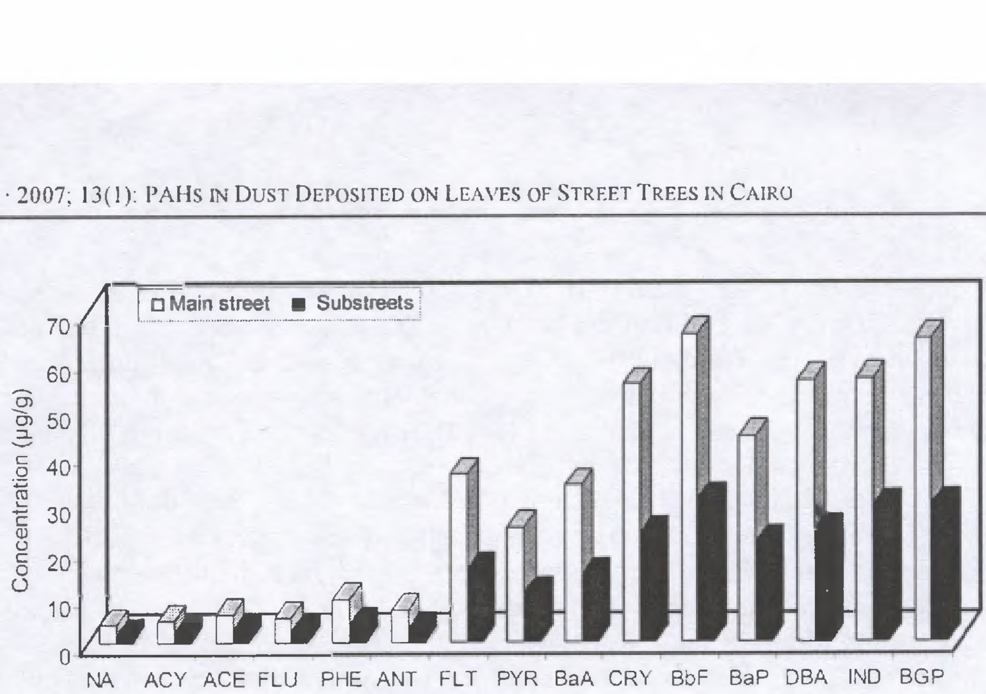

Fig. 3. Comparison between the concentrations of the individual PAH compounds in leaves dust samples collected from the main street and substreets in Ramsis area. (The full terms of abbreviations see in the list of abbreviations)

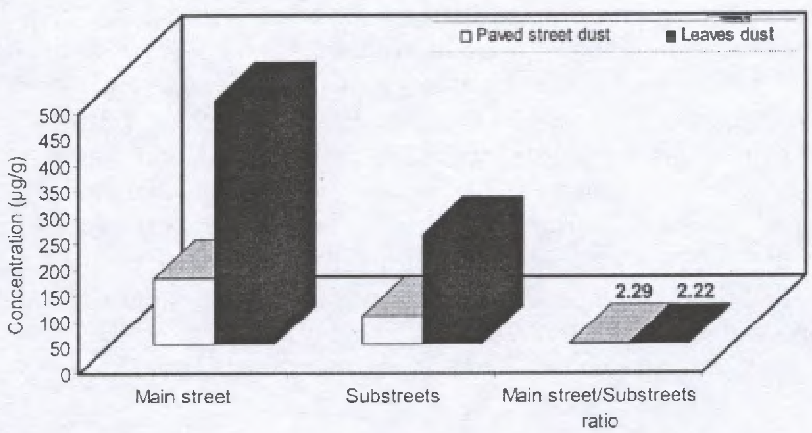

Fig. 4. Total concentrations of PAH compounds in paved street dust and leaves dust collected from the main street and substreets in Ramsis area

Moreover, the total PAH concentrations in leaves dust were 465.73 µg/g in the main street and 209.29 µg/g in the substreets, and the difference in mean concentrations was statistically significant ($p<0.001$). The main street/substreets total PAH concentration ratio was 2.22 (*Fig. 4*).

At Haram area, the maximum concentrations of the individual PAH compounds in paved street dust and leaves dust were also observed in the main street (*Figs. 5* and *6*). The difference in mean concentrations of the individual PAH compounds in the main street and substreets was statistically significant ($p<0.001$). The mean concentrations of the individual PAH compounds in paved street dust ranged from 0.60 and 0.23 µg/g for NA to 10.59 and 2.59 µg/g for BGP in the main street and substreets, respectively (*Fig. 5*). Moreover, the concentrations of the total PAH compounds were 64.67 µg/g in the main street and 16.11 µg/g in the substreets, and the difference in mean concentrations was statistically significant ($p<0.001$). The main street/substreets total PAH concentration ratio was 4.01 (*Fig. 7*). In leaves dust at Haram, the concentrations of the individual PAH compounds ranged from 2.08 and 0.82 µg/g for NA to 39.86 and 20.20 µg/g for BGP in the main street and substreets, respectively (*Fig. 6*). In addition, the concentrations of the total PAH compounds in leaves dust were 243.91 µg/g in the main street and 107.14 µg/g in the substreets, and the difference in mean concentrations was statistically significant ($p<0.001$). The main street/substreets total PAH concentration ratio was 2.27 (*Fig. 7*).

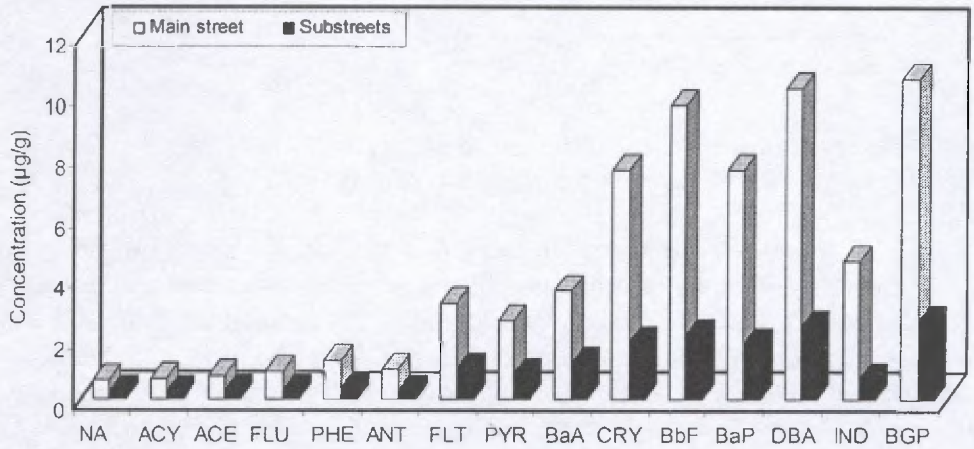

Fig. 5. Comparison between the concentrations of the individual PAH compounds in paved street dust samples collected from the main street and substreets in Haram area. (The full terms of abbreviations see in the list of abbreviations)

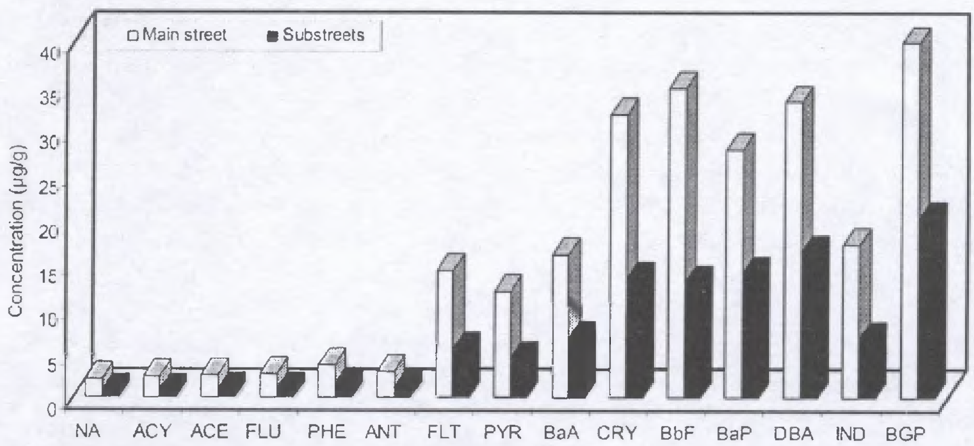

Fig. 6. Comparison between the concentrations of the individual PAH compounds in leaves dust samples collected from the main street and substreets in Haram area. (The full terms of abbreviations see in the list of abbreviations)

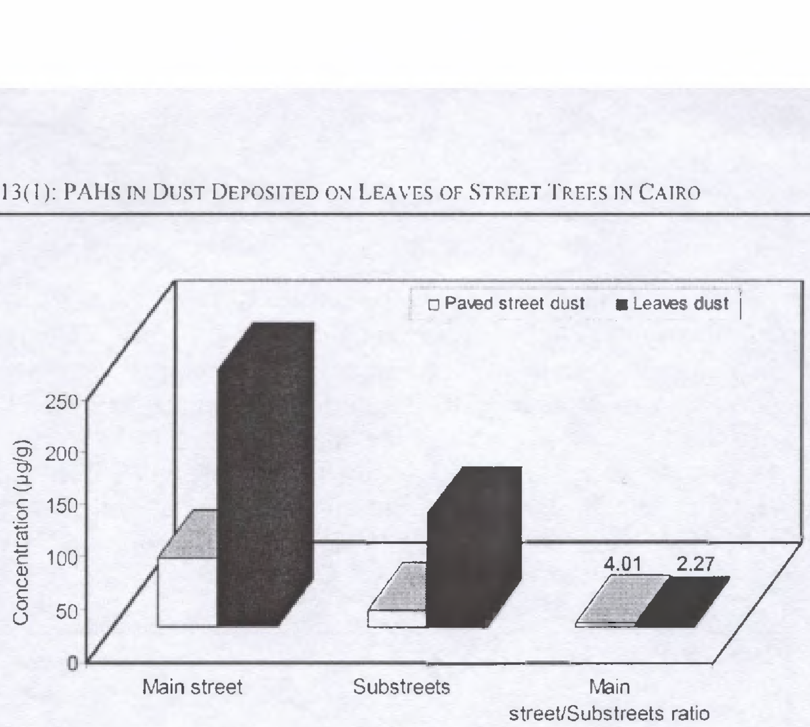

Fig. 7. Total concentrations of PAH compounds in paved street dust and leaves dust collected from the main street and substreets in Haram area

The relative concentration in percentage of the individual carcinogenic PAH compounds to the total concentrations of PAHs in paved street dust and leaves dust collected from Ramsis and Haram areas are graphically represented in *Figs. 8* and *9*, respectively. As it can be seen, the distributions of the individual carcinogenic PAH compounds in paved street dust and leaves dust in Ramsis area were very similar, with BbF as the most abundant compound followed by IND, DBA, BaP and BaA (*Fig. 8*). The mean relative concentrations of the individual carcinogenic PAH compounds in street dust and leaves dust were: 6.93% and 6.97% for BaA, 14.09% and 13.96% for BbF, 9.52% and 9.63% for BaP, 11.53% and 11.61% for DBA and 12.98% and 12.62% for IND (*Fig. 8*). At Haram area, the distributions of the individual carcinogenic PAH compounds in paved street dust and leaves dust were also very similar (*Fig. 9*), DBA was the most abundant compound followed by BbF, BaP, IND and BaA. The mean relative concentrations of the individual PAH carcinogenic compounds were 5.86% and 6.53% for BaA, 14.58% and 13.66% for BbF, 11.61% and 11.96% for BaP, 15.51% and 14.18% for DBA and 6.56% and 6.84% for IND in paved street dust and leaves dust, respectively (*Fig. 9*).

The profile of the individual PAH compounds (a relative concentration in percentage of the individual PAH compounds to the total concentrations of PAHs) in paved street dust and leaves dust collected from Ramsis and Haram areas are graphically represented in *Figs 10* and *11*, respectively. It is clear that the profiles of PAH compounds in paved street dust and leaves dust collected from Ramsis area were very similar, with BbF as the most abundant compound followed by BGP, IND, DBA, CRY, BaP, FLT, BaA, PYR, PHE, ANT, ACE, FLU, ACY and NA (*Fig. 10*). The mean relative concentrations of the individual PAH compounds in paved street dust and leaves dust were: 0.78% and 0.80% for NA, 0.93% and 0.94% for ACY, 1.20% and 1.22% for ACE, 1.10% and 1.09% for FLU, 1.91% and 1.91% for PHE, 1.45% and 1.46% for ANT, 7.45% and 7.49% for FLT, 5.10% and 5.10% for PYR, 6.93% and 6.97% for BaA, 11.42% and 11.45% for CRY, 14.10%

and 13.96% for BbF, 9.52% and 9.63% for BaP, 11.53% and 11.61% for DBA, 12.98% and 12.62% for IND and 13.60% and 13.75% for BGP (*Fig. 10*). At Haram area, the profiles of the individual PAH compounds in the paved street dust and leaves dust were also very similar, BGP was the most abundant compound followed by DBA, BbF, CRY, BaP, IND, BaA, FLT, PYR, PHE, ANT, FLU, ACE, ACY and NA (*Fig. 11*). The mean distributions of the individual PAH compounds were 1.01% and 0.83% for NA, 1.14% and 0.93% for ACY, 1.29% and 1.00% for ACE, 1.46% and 1.06% for FLU, 2.05% and 1.48% for PHE, 1.58% and 1.17% for ANT,

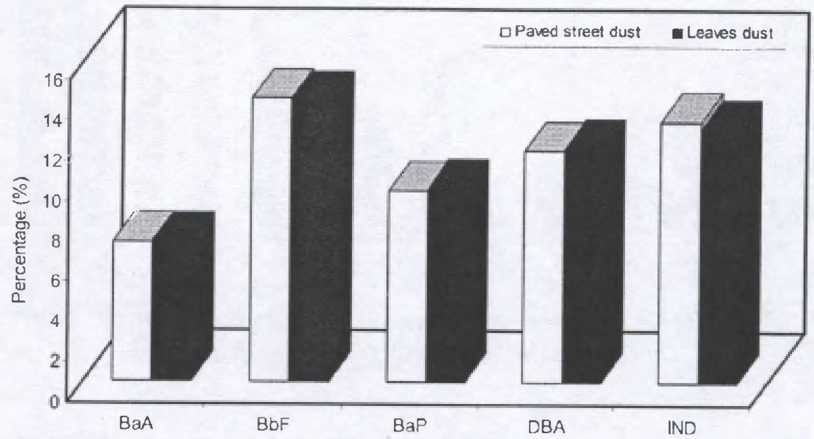

Fig. 8. Relative concentrations in percentage of the individual carcinogenic PAH compounds to the total concentrations of PAHs in paved street dust and leaves dust collected from Ramsis area. (The full terms of abbreviations see in the list of abbreviations)

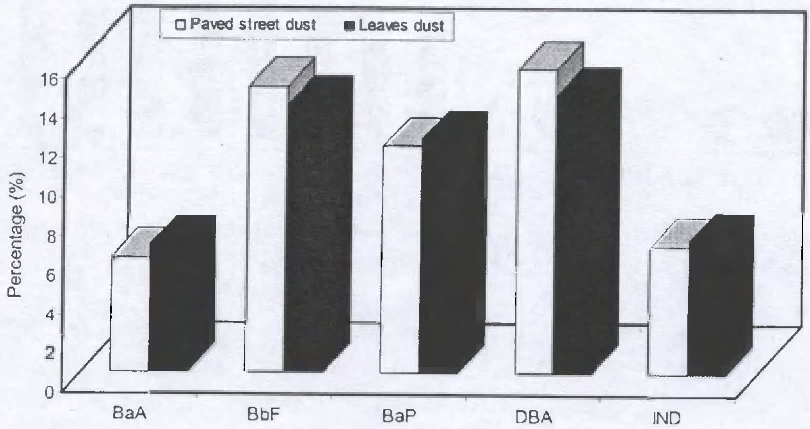

Fig. 9. Relative concentrations in percentage of the individual carcinogenic PAH compounds to the total concentrations of PAHs in paved street dust and leaves dust collected from Haram area. (The full terms of abbreviations see in the list of abbreviations)

5.20% and 5.64% for FLT, 4.21% and 4.68% for PYR, 5.86% and 6.53% for BaA, 11.63% and 12.94% for CRY, 14.58% and 13.66% for BbF, 11.61% and 11.96% for BaP, 15.51% and 14.18% for DBA, 6.56% and 6.84% for IND and 16.31% and 17.09% for BGP in paved street dust and leaves dust, respectively (*Fig. 11*).

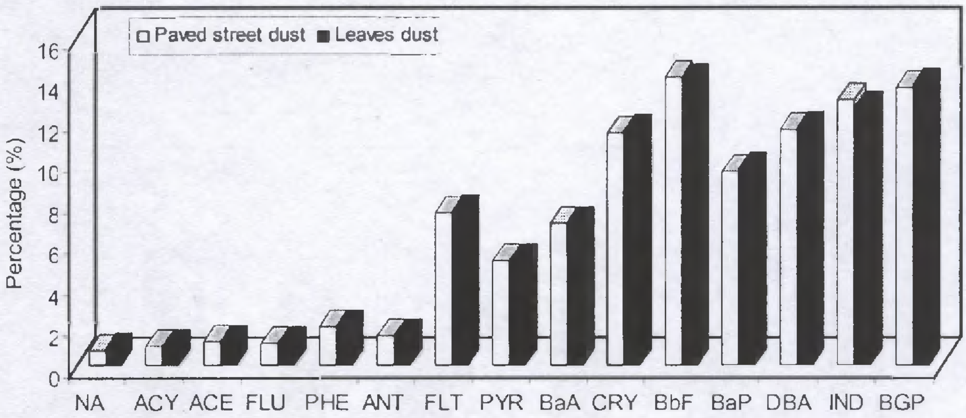

Fig. 10. Profile of PAHs in paved street dust and leaves dust samples collected from Ramsis area. (The full terms of abbreviations see in the list of abbreviations)

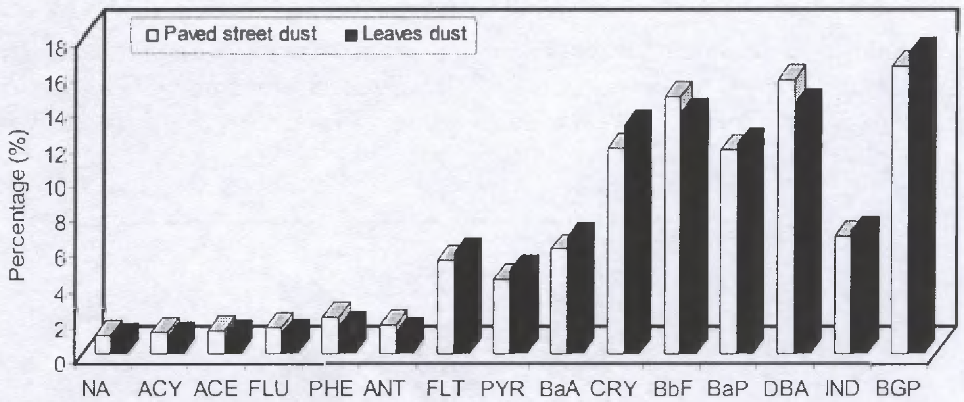

Fig. 11. Profile of PAHs in paved street dust and leaves dust samples collected from Haram area. (The full terms of abbreviations see in the list of abbreviations)

The distribution of PAHs with different aromatic ring numbers in paved street dust and leaves dust collected from Ramsis and Haram areas is graphically represented in *Figs. 12* and *13*, respectively. It can be noticed that, the relative concentrations in percentage of the PAH compounds with different aromatic ring numbers to the total concentrations of PAHs in paved street dust and leaves dust collected from Ramsis area were very similar, PAH compounds with five aromatic rings were the most dominant compounds followed by four aromatic rings, six aromatic rings, three aromatic rings and two aromatic rings (*Fig. 12*). The mean distributions of the aromatic rings were 0.78% and 0.80% for two aromatic rings, 6.56% and 6.62% for three aromatic rings, 30.89% and 31.01% for four aromatic rings, 35.19% and 35.20% for five aromatic rings and 26.58% and 26.37% for six aromatic rings in paved street dust and leaves dust, respectively (*Fig. 12*). At Haram area, the distribution of PAH compounds with different aromatic ring numbers in paved street dust and leaves dust was also very similar, PAH compounds with five aromatic rings were the most dominant compounds followed by four aromatic rings, six aromatic rings, three aromatic rings and two aromatic rings (*Fig. 13*). The mean distributions of the aromatic rings in paved street dust and leaves dust were: 1.01% and 0.83% for two aromatic rings, 7.52% and 5.64% for three aromatic rings, 26.90% and 29.80% for four aromatic rings, 41.70% and 39.80% for five aromatic rings and 22.87% and 23.93% for six aromatic rings (*Fig. 13*).

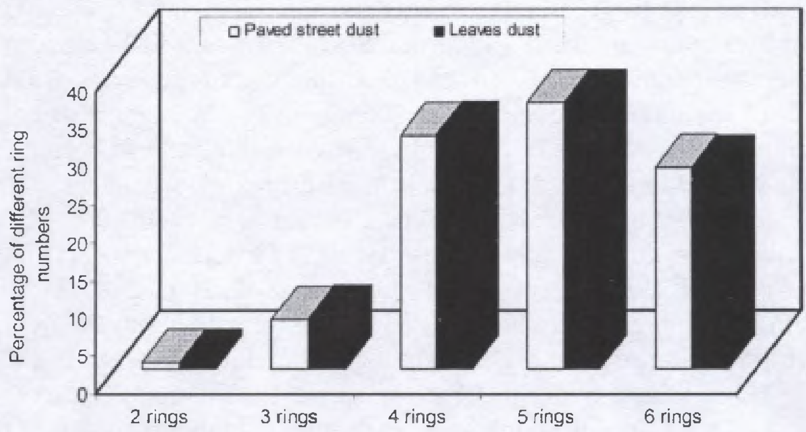

Fig. 12. Distribution of PAHs with different ring numbers in paved street dust and leaves dust samples collected from Ramsis area

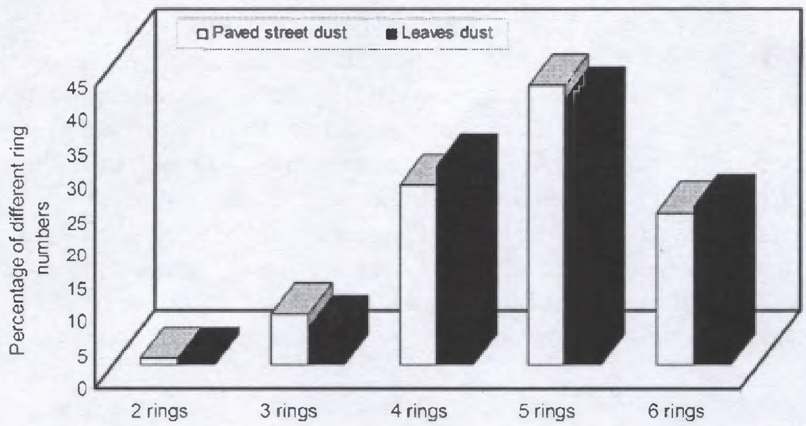

Fig. 13. Distribution of PAHs with different ring numbers in paved street dust and leaves dust samples collected from Haram area

DISCUSSION

PAH concentration in the atmosphere is influenced by many factors such as photodegradation, biodegradation, chemical oxidation and physico-chemical characteristics of the atmosphere as well as combustion processes and the type of fuels. PAHs in street dust and dust deposited on the leaves of trees probably come from the suspended particulates that deposit on the streets and that are produced by many types of combustion processes occurring in urban areas. The concentrations of the total and individual PAH compounds in the paved street dust and leaves dust were higher in Ramsis than those found in Haram. The total PAH concentrations in paved street dust and leaves dust collected from Ramsis were on average 2.28 and 1.92 times higher than those found in Haram. The observed high levels of PAHs in Ramsis are mainly due to the high traffic density, since Ramsis is the most commercial and heaviest traffic area in greater Cairo. In addition, suspended particulate matter transported by winds from the big industrial area of Shoubra El-Khiema to the north of the city centre (Ramsis) may also lead to an increase in the levels of PAHs in the atmosphere of the city centre and, consequently, in paved street dust and dust deposited from air on the leaves of street trees. Motor vehicles have been identified as the most significant source of airborne PAHs in urban areas (Dunbar et al., 2001; Manoli et al., 2002; Samara, et al., 2003; Khillare et al., 2005; Chang et al., 2006; Sharma, et al., 2007). In urban road dust, vehicle exhaust, tyre and asphalt/pavements are the major contributors of PAHs (Rogge et al., 1993; Murakami et al., 2003, 2005; Pengchai et al., 2004, 2005). In the present study, the PAH concentrations in paved street dust collected from Ramsis area were higher than those found in urban areas in other cities (Herrmann, 1981; Takada et al., 1991; Rogge et al., 1993; Pereira Netto et al., 2006). At Haram, the PAH concentrations in street dust were higher than those reported by Herrmann (1981), Takada et al. (1991) and Pereira Netto et al. (2006), and lower than those reported by Rogge et al. (1993).

The present study indicated also that the concentrations of the total and individual PAH compounds in leaves dust were higher than those found in the paved street dust in both study areas. The leaves dust/paved street dust concentration ratios of the total PAHs were 3.66 and 4.34 for Ramsis and Haram areas, respectively. The observed high levels of PAHs in leaves dust may be due to the high concentrations of fine particles deposited on leaves compared with those deposited on streets. Such fine particles contain more PAHs. On the other hand, paved street dust collected from the ground could be contaminated with soil, which may dilute the concentration of PAHs in paved street dust. The PAH compounds were mostly distributed to the small particles (Bae et al., 2002). PAHs are mainly generated by combustion sources and emitted in the gas phase or associated with ultrafine particles, and then become associated with coarse particles by volatilization and condensation (Wu et al., 2006).

The highest levels of the total and individual PAH compounds in paved street dust and leaves dust were found in the main street in both study areas. This is mainly due to the higher emission of PAHs in the main street from the high traffic density. These results indicate that humans living along the main street with heavy traffic density are exposed to higher concentration of PAHs. Urban surface and road dusts were observed to contain decreasing PAH concentrations with increasing distance from major roadways (Smith et al., 1995). At a distance far from the traffic source, the individual PAH components were found to have lower concentrations and reduced by 22.2% and 55.7%, at the 30- and 100-m sites, respectively, from the traffic source (Lee et al., 1995).

The carcinogenic PAH compounds are of high molecular weight, composed of four to six aromatic rings (IARC, 2001) The total carcinogenic PAH compounds of high molecular weight (BaA, BbF, BaP, DBA and IND) represented 55.10% and 54.12% of the total concentration of PAHs in paved street dust and 54.79% and 53.17% of that in leaves dust collected from Ramsis and Haram areas, respectively.

The main sources of anthropogenic PAHs in the environment are the release of un-combusted petroleum products and combustion processes. The profile of the individual PAH compounds and the distribution of PAHs with different ring number in the paved street dust and leaves dust in both study areas indicate that the heavy PAH compounds (four to six aromatic rings) were the predominant compounds, which are considered as products of combustion origin (Masclet et al., 1987; Budzenski et al., 1997). In addition, the light molecular weight (LMW; two to three aromatic rings) and the high molecular weight (HMW; four to six aromatic rings) PAH concentration ratios were 0.08 and 0.09 in paved street dust and 0.08 and 0.07 in leaves dust in Ramsis and Haram areas, respectively. Moreover, the ratios of the sum of major combustion specific compounds (ΣCOMB: FLT, PYR, BaA, CHR, BbF, BaP, IND and BGP) to the sum of PAHs (ΣCOMB/ΣPAHs) were 0.81 and 0.76 in paved street dust and 0.81 and 0.79 in leaves dust in Ramsis and Haram areas, respectively. These results also indicated that combustion activities contributed greatly to the PAH concentrations in the paved street dust and leaves dust in both study areas.

The ratios of PHE/ANT within the 3-ring PAH group and FLT/PYR within the 4-ring PAHs group were used to form molecular indices (Colombo et al., 1989; Baumard et al., 1998). These ratios are used to distinguish petrogenic and pyrogenic sources of PAHs. The distribution of PAHs is dependent on temperature (Alberty and Reif, 1988). Phenanthrene (PHE) is thermochemically more stable than ANT, so the PHE/ANT concentration ratio is temperature dependent; low temperature is characterized by high values of PHE/ANT concentration ratio and high temperature sourses, such as the incomplete combustion of organic materials (coal burning, wood burning and vehicular exhaust emission) are characterized by low values of PHE/ANT concentration ratio (Tang et al., 2005). High temperature processes result in low PHE/ANT concentration ratio and petrogenic contamination leads to much higher values of PHE/ANT concentration ratio (Azimi et al., 2005). A PHE/ANT concentration ratio of less than 10 and FLT/PYR concentration ratio of greater than 1 indicate that PAHs come from pyrogenic source and PHE/ANT concentration ratio of greater than 15 and FLT/PYR concentration ratio of less than 1 indicate petrogenic origins of PAHs (Baumard et al., 1998). In the present study, PHE/ANT concentration ratios in paved street dust and leaves dust were: 1.31 and 1.30 in Ramsis and 1.30 and 1.26 in Haram, respectively. In addition, FLT/PYR concentration ratios were 1.47 and 1.24 in paved street dust and 1.47 and 1.21 in leaves dust collected from Ramsis and Haram areas, respectively. These ratios indicate that pyrogenic source was the predominant source of PAHs in paved street dust and leaves dust in both urban areas in Cairo. Vehicular exhaust emission was the main source of PAHs in the atmosphere of both study areas, and consequently in paved street dust and dust deposited on leaves of street trees. Therefore, it can be said that the PAHs come from pyrogenic sources in both urban areas of Cairo and may be linked to the traffic densities which emit huge quantities of PAHs. This finding is confirmed by the BaP/BGP and BaA/CRY concentration ratios which were used to investigate the emission sources of PAHs. The BaP/BGP concentration ratio higher than 0.60 indicates the presence of vehicular exhaust emission (Pandey et al., 1999). In addition, BaA/CRY concentration ratio was 0.53 ± 0.06 for motor vehicle emission (Dickhut et al., 2000). In the present study, the BaP/BGP concentration ratios were 0.70 and 0.71 in paved street dust and 0.70 and 0.70 in leaves dust collected from Ramsis and Haram areas, respectively. Moreover, BaA/CRY concentration ratios in paved street dust and leaves dust were: 0.60 and 0.60 in Ramsis and 0.50 and 0.50 in Haram, respectively. These ratios imply that PAHs in paved street dust and leaves dust were more influenced by vehicular exhaust emissions than other sources. To identify the traffic sources, the IND/BGP concentration ratio was further examined. Caricchia et al. (1999) reported that the IND/BGP concentration ratio for gasoline engines is about 0.40, while the ratio for diesel engine approaches 1. In the present study, the IND/BGP concentration ratios were 0.95 in paved street dust and 0.92 in leaves dust in Ramsis area, indicating stronger contribution of diesel vehicles rather than gasoline vehicles. At Haram area, the IND/BGP concentration ratio was 0.40 in paved street dust and leaves dust, suggesting higher contribution from gasoline vehicles than diesel ones.

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