A review of airborne polycyclic aromatic hydrocarbons (PAHs) in Egypt

Assmaa M. El-Mekawy[1], Atef M.F. Mohammed[1], Salwa K. M. Hassan[1]

[1]Air Pollution Department, National Research Centre, Giza, Egypt

*Corresponding author: Asmaa M. El-Mekawy, E-mail: asmaamekawy75@gmail.com

Fax: +20 2 33370931; Tel: +20 2 33371362

Abstract

Polycyclic aromatic hydrocarbons (PAHs) makea class of organic compounds consisting of two or more fused aromatic rings in linear, angular or cluster arrangements. There are hundreds of PAH compounds in the environment, but only 16 of them are included in the priority pollutants list of US EPA. PAHs exist in the atmosphere as gases and are adsorbed to airborne particulate matter. The main aim of this article was to review the concentrations of PAHs in suspended particulate matter (PM) collected from different sites in Egypt (Outdoor and Indoor) during different periods.

The levels of PAHs in outdoor PM samples collected from Shoubra El-Kheima and Helwan in Greater Cairo were higher than WHO guideline (870 ng/m^3 for PAH in occupational settings). While the levels of PAHs in PM samples collected from El-Abasya, El Dokki, El Teppen and Damietta City were lower than WHO Guidelines. In addition, these results May be attributed to anthropogenic activities (vehicle emission, open burning, thermal power plants, industrial emission) in Shoubra El-Kheima and Helwan areas. Furthermore, the levels of PAHs in PM samples were higher than that measured in Chicago-USA, Harbin-China, Guangzhou-China, Seoul-Korea, Athens-Greece, Bursa-Turkey and Flanders- Belgium. The annual mean concentrations of ∑PAHs in indoor PM collected from 4 sites in Helwan city were 1019.8, 694.7,1038.7 and 811.1 ng/m^3 for sites 1 (Helwan center), 2 (highly traffic area in Helwan center) , 3 (Wady Hoff) and 4 (Torra) , respectively. In addition, PAHs concentrations demonstrated considerable seasonal variations, the highest levels were found during spring and summer, while the lowest values were found in winter season for all sites in Helwan city.

Keywords

Polycyclic aromatic hydrocarbons (PAHs), Suspended particulate matter, Indoor air, Outdoor air, Egypt.

Introduction

Polycyclic aromatic hydrocarbons (PAHs) or polynuclear aromatic hydrocarbons (PNAs)area class of organic compounds consisting of two or more fused aromatic rings in linear, angular or cluster arrangements. Like all hydrocarbons, PAHs contain only hydrogen and carbon.

Naphthalene is the simplest PAH, it is consisting of two fused benzene rings. PAHs are widely distributed in the atmospheric environment containing two (naphthalene) to seven (coronene) fused benzene rings, though PAHs with greater number of ringsare also found (Sander and Wise, 1997). The "ultimate"PAH is graphite, an inert material comprised of planesof fused benzene rings.

There are hundreds of PAH compounds in the environment, but only 16 of them are included in the priority pollutants list of US EPA (EPA, 2002). PAHs exist in the atmosphere as gases and areadsorbed to airborne particulate matter. The fate, transport and removal of PAHs from the atmosphere by dry and wet deposition processes are strongly influenced by the gas-particle partitioning of PAHs (Bidleman et al., 1986; Perera, 1988; Jung et al., 1998).

Physical properties of PAHs

The physical property of PAHs is governed by the size (number of carbon atoms) and shape (ring linkage pattern) of the individual molecule. All completely unsaturated PAHs are solids at room temperature and have relatively high melting and boiling points (ATSDR, 1995).

PAHs are soluble in lipid (fat), and are essentially insoluble in aqueous systems. The aqueous solubility decreases with increasing molecular size. Vapour pressure for PAHs is low and decreases with increasing molecular size (MOE, 1997). A summary of some relevant physical properties for a number of selected PAHs is provided in Table 1 (ATSDR, 1995).

Table 1: physical properties of a number of selected PAHs.

PAHs	Color	Physical state	Melting Point (°C)	Boiling Point (°C)	Density (g/cm^3 at 20°C)
Acenaphthene	White	Solid (needles)	95	96.2	1.225
Acenaphthylene	No data	Solid (prisms/plates)	92-93	265-275	No data
Anthracene	Colourless with violet fluorescence when pure; yellow with green fluorescence when impure	Solid (tablet or prism)	218	342°C-340	No data
Benz[a]anthracene	Yellow-blue fluorescence	Solid (plates needles)	158-159; 162	400°c; 435 sublimes	1.274
Benzo[a]pyrene	Pale yellow	Solid (plates or recrystall)	179-179.3	310-312	1.351
Benzo[b]fluoranthene	Colourless	Solid (needles)	168.3	No data	No data
Benzo[ghi]perylene	Pale yellow-green	Solid (plate)	273	550	No data
Chrysene	Colourless with blue or red-blue fluorescence	Solid (plates)	255-256	448	No data
Fluoranthene	Pale yellow	Solid (needles or plates)	11	~375	No data
Fluorene	White	Solid (leaflets or flakes; crystalline plates)	116-117	295	No data
Indeno[1,2,3-cd] pyrene	Yellow plates or needles	Solid (plates or needles)	163.6	530	No data
Phenanthrene	Colourless	Solid (plates, crystals or leaflets)	100	340	0.980
Pyrene	Colourless pale yellow plates	Solid (Plates or tablets)	156	393	1.271

(Continue) Table 1: physical properties for a number of selected PAHs.

PAHs	Odour	Solubility		Vapour pressure (mm Hg at 25°C)
		Water (mg/L)	Organic solvent	
Acenaphthene	No data	1.93	Alcohol, methanol propanol, chloroform, benzene, toluene,	4.47×10^{-3}
Acenaphthylene	No data	3.93	Alcohol, ether, benzene	0.029
Anthracene	Weak aromatic odour	0.076	Acetone, benzene, carbon disulphide-carbon tetrachloride-chloroform, ether ethanol, methanol	1.7×10^{-5}
Benz[a]anthracene	No data	0.010	Slightly soluble in acetic acid and hot ethanol; soluble in acetone and diethyl ether; very soluble in	2.2×10^{-8}
Benzo[a]pyrene	Faint aromatic odour	2.3×10^{-3}	Sparingly soluble in ethanol and methanol; soluble in benzene,	5.6×10^{-9}
Benzo[b]fluoranthene	No data	0.0012	Slightly soluble in benzene, acetone	5.0×10^{-7}
Benzo[ghi]perylene	No data	2.6×10^{-4}	Benzene, dichloromethane, acetone	1.03×10^{-10}
Chrysene	No data	2.8×10^{-3}	Slightly soluble in acetone, carbon disulphide, diethylether, ethanol, glacial acetic acid, toluene, hot	6.3×10^{-7}
Fluoranthene	No data	0.20 – 0.26	Soluble in alcohol, ether, benzene, acetic acid	5.0×10^{-6}
Fluorene	No data	1.68-1.98	Soluble in acetic acid, acetone, benzene	3.2×10^{-4}
Indeno[1,2,3-cd] pyrene	No data	0.062	Soluble in organic solvents	$\sim 10^{-11}$
Phenanthrene	Faint aromatic odour	1.20	Soluble in benzene, toluene, ethanol	6.8×10^{-4}
Pyrene	No data	0.077	Soluble in benzene, alcohol, toluene, carbon disulphide,	2.5×10^{-6}

Chemical properties of PAHs

The US EPA priority pollutants chose 16 polycyclic aromatic hydrocarbons. They are widespread contaminants of the environment and a number of them are either known or suspected carcinogens (Manoli and Samara, 1995). Table (2) represents the 16 PAHs; their chemical formula, molecular weight and their abbreviations (ATSDR, 1995). In addition, the chemical structures of the target PAHs are represented in Figure 1.

Table 2: Chemical identity of some polycyclic aromatic hydrocarbons (PAHs).

PAHs	Abbreviation	Chemical Formula	Molecular weight	Number of Rings
Naphthalene	NAP	$C_{10}H_8$	128.00	Two
2-Bromonaphthalene	2-BNAP	Br-$C_{10}H_7$	208.00	Two
Acenaphthylene	ACY	$C_{12}H_{18}$	152.20	Three
Acenaphthene	ACE	$C_{12}H_{10}$	154.21	Three
Fluorene	FLU	$C_{13}H_{10}$	166.20	Three
Phenanthrene	PHE	$C_{14}H_{10}$	178.20	Three
Anthracene	ANT	$C_{14}H_{10}$	178.20	Three
Fluoranthene	FLT	$C_{16}H_{10}$	202.26	Four
Pyrene	PYR	$C_{16}H_{10}$	202.26	Four
Benz[a]anthracene	BAA	$C_{18}H_{12}$	228.30	Four
Chrysene	CRY	$C_{18}H_{12}$	228.30	Four
Benzo[b]fluoranthene	BBF	$C_{20}H_{12}$	252.30	Five
Benzo[a]pyrene	BAP	$C_{20}H_{12}$	252.30	Five
Dibenz[a,h]anthracene	DBA	$C_{22}H_{14}$	278.35	Five
Benzo[ghi]perylene	BGP	$C_{22}H_{12}$	276.34	Six
Indeno[1,2,3-cd]pyrene	IND	$C_{22}H_{12}$	276.3	Six

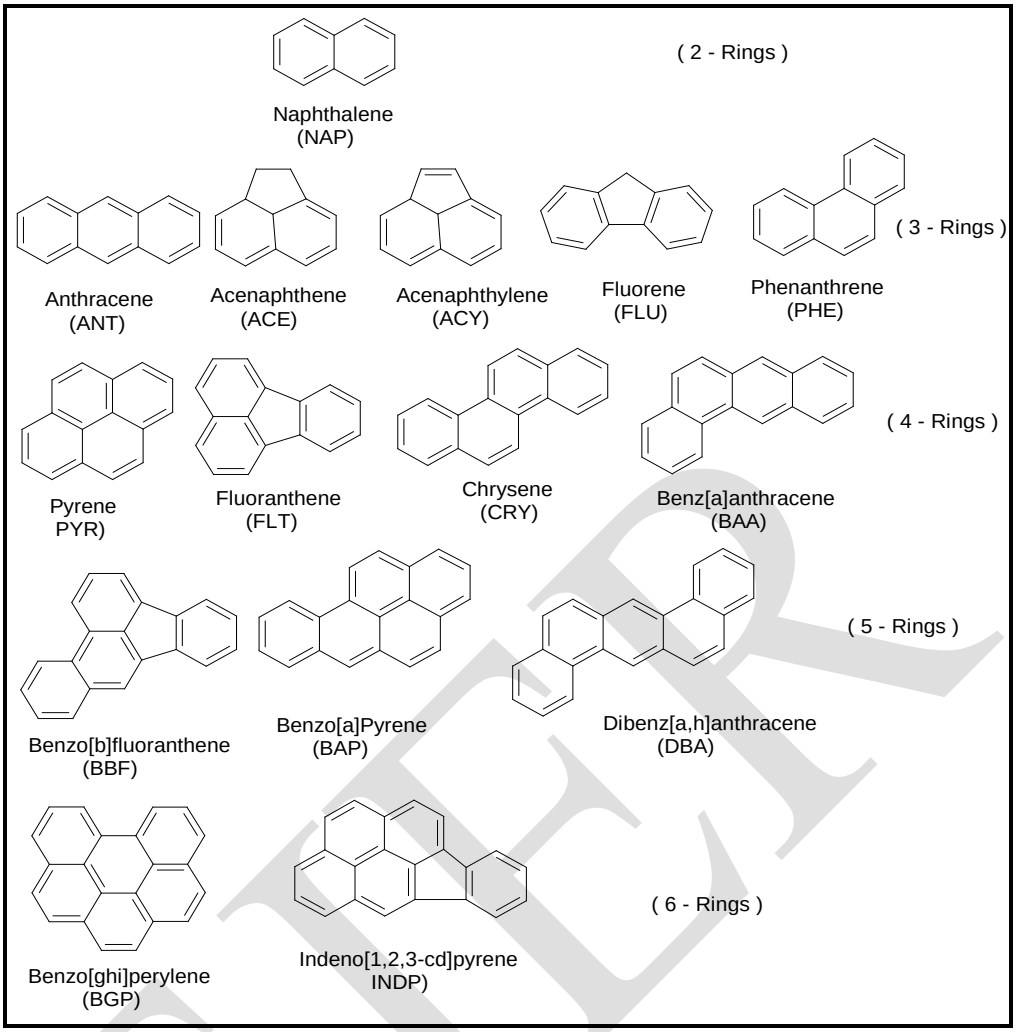

Figure 1: Ring Structure of Selected PAHs(Source: Hassan 2006)

Environmental fate of PAHs

The concentration, transport and fate of PAHs in the atmosphere depend on many factors such as source strength, weather conditions, solar radiation, exchange between the gases and particulate phases, and physical removal due to the dry and wet depositions(Bidleman et al., 1986).

Low molecular weight PAHs tend to have a higher concentration in the vapour phase, while high molecular weight ones are often associated with particulate. The lighter PAHs (Fluorene, Phenanthrene and Anthracene) exist almost exclusively in the gaseous phase (> 98%) while the heavier five to six-ring PAHs (Benzo[a]pyrene to Indeno [1, 2, 3-cd] pyrene have a strong association with the particulate phase (> 75%). Semi volatile four-ring PAHs (FLT to CHR) are found in both gaseous and particulate phase in various proportions and their amounts are primarily governed by

the ambient temperature. More semi-volatile low molecular weight PAHs appear in the vapor phase in summer (Sin et al., 2003).

PAHs in ambient air have considerable half-lives and can be transported over long distances through the atmosphere. Atmospheric transport and particle deposition is an important pathway for the movement of contaminants from urban and industrial areas to remote sites. PAHs are distributed in the atmosphere between the vapour and particulate phases in a ratio which depends on temperature and their physical properties, particularly the sub-cooled liquid vapour pressure (Stern et al., 1997).

PAHs are planar and relatively inert, but in the giant reactor of the atmosphere they participate in various chemical reactions and decompose. Most PAH are readily photo-oxidized when exposed to UV light of 300-420 nm. They undergo thermal decomposition and react with a number of atmospheric chemicals producing derivatives, which can be more toxic than the original compounds. PAHs on reaction with other atmospheric pollutant such as NO_x, SO_2, oxygen, ozone, etc., form hetero-PAHs (oxy, hydroxyl, nitro and hydroxy nitro PAH) which may be present in the gas phase as well as particulate (Hoff and Chan, 1987). The carcinogenicity and mutagenicity of many of these hetero-PAHs compounds are greater than their parent compounds (Pandey et al., 1999).

The reactions of PAHs with nitrogen oxides are of great importance since both are emitted simultaneously from the same source and can result in the conversion of inactive PAHs to nitroarenes, compounds of potent carcinogenic activity. Nitroarenes can also be formed by photochemical reactions under ambient conditions. A number of experimental studies have shown that PAH can react readily with O_3 at ambient concentrations, quinones and epoxides are possible products of such reactions (Pitts et al., 1985, 1986).

Sources of PAHs

Sources of PAHs in Outdoor Air

PAHs are originated from a wide variety of natural and anthropogenic sources. Natural sources of PAHs include volcanic activity and forest fire as shown in Figure 2 **(**Maliszewska-Kordybach, 1999; Kim, 2003; Kim et al., 2013).The anthropogenic sources of PAH can be divided into stationary and mobile categories. Stationary sources account for approximately 90% of the annual total PAH emissions with the remainder produced by mobile sources. Anthropogenic sources of PAHs are mainly

formed as a result of pyrolitic processes, especially the incomplete combustion of organic materials for energy supply such as coal, oil, gas, and wood (Mastral and Callen, 2000; Ohura, *et al.*, 2004) during industrial activities, residential heating, power generation, incineration, and vehicle emissions (ATSDR, 1995; Mastral et al., 2003; Fang et al., 2004c;Ding et al., 2005).

PAHs in the urban atmosphere are mainly of anthropogenic origin; road traffic is one of the most important anthropogenic emission sources, in urban areas contributing by as much as 74% (Omar, *et al.*, 2002). Industrial processes and burning of domestic fuels are also significant sources of PAHs (WHO, 1998). The increasing amount of aircrafts and associated emissions in recent years could also contribute to atmospheric concentrations of PAHs. Although the role of these potential sources could be important for levels of PAHs in air, they have never been surveyed in this regards anywhere in the world yet.

The predominant PAHs sources to the atmosphere include motor vehicles, incineration biomass, residential heating, plants such as coke and aluminum, open burning and power generation as stationary and mobile sources of human-produced PAHs sources (Mastral and Callen, 2000; Naumova*et al.*, 2002; Ohura *et al.*, 2004a).

Motor vehicle emissions account for around 46–90% of the mass of individual PAHs in ambient air particles in urban areas (Tonne*et al.*, 2004), while domestic heating can account for some 16% of PAHs in outdoor air in the United States, 29% in Sweden and 33% in Poland (Maliszewska-Kordybach, 1999).

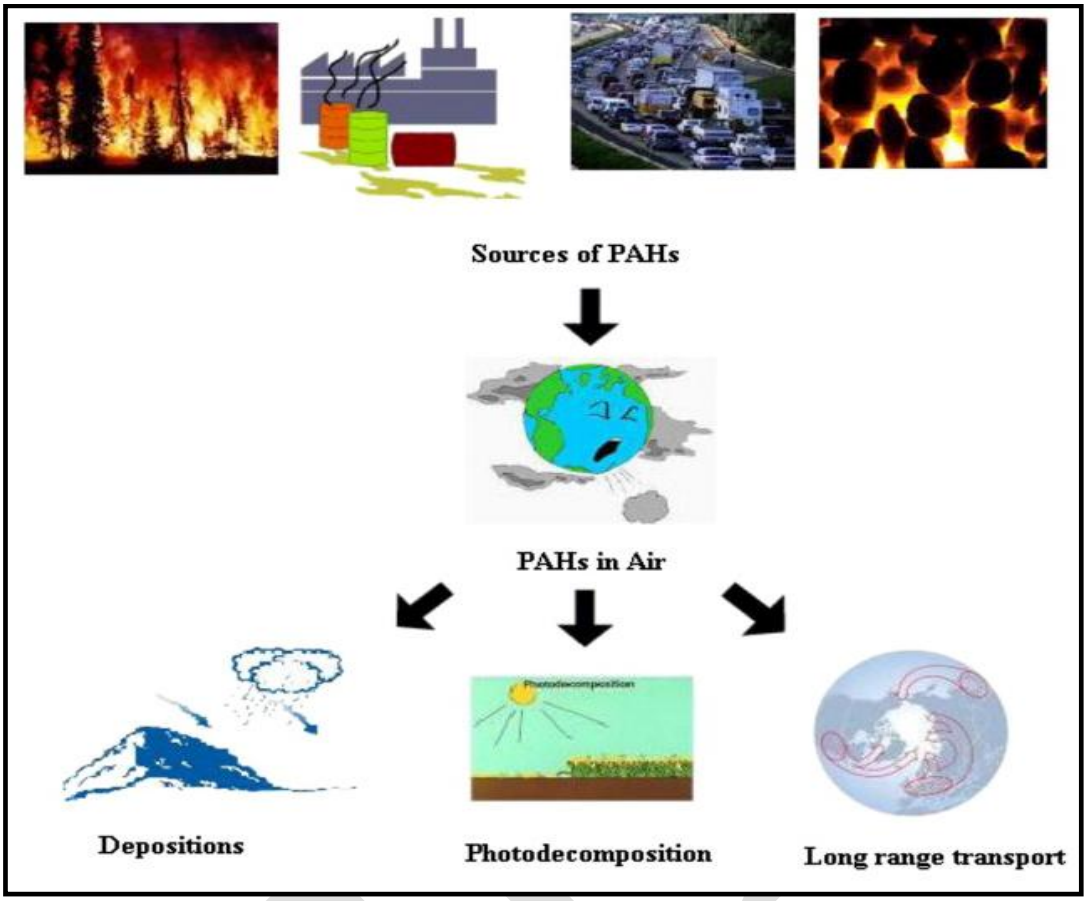

Figure 2: Schematic of the fate of PAHs in the atmosphere (source: Kim et al., 2013)

Sources of PAHs in Indoor Air

PAHs in house dust may originate from both outdoor and indoor sources. Typical indoor sources include combustion of fossil fuels and biomass for heating and cooking; burning of tobacco products, candles and incense; and cooking fumes.

Indoor emission sources of PAHs include smoking, cooking, heating, incense burning and furniture (Liu *et al*., 2001; Lung and Hu, 2003; Ohura *et al.*, 2004; Lu and Zhu, 2007).

Indoor air PAHs, especially low molecular weight ones, mainly come from indoor emission sources. Different life styles can result in different pollution patterns of PAHs in residential air. For example, using of mothball would largely emit naphthalene (Liu *et al.*, 2001), whereas cooking fume is abundant in 3-ring PAHs (Zhu and Wang, 2003). Generally in unvented stoves suggesting that exposure during the cooking period is 2–10 times higher than ambient exposure (Pandit*et al.;* 2001).

Indoor air is contaminated by PAHs, which come from infiltration of outdoor air emissions from traffic and have been found to be the main outdoor source for the

indoor PAHs concentration at urban and suburban locations in many industrialized countries (Dubowsky*et al.*, 1999).

The age of a house or building, since it reflects its condition, affects PAHs concentrations indoors. For example, the older the house the higher the PAH concentrations will be, as outdoor sources have a greater impact owing to higher air exchange through such routes as poorly fitting windows (Tong and Lam, 2000).

Concerning data reported on emission factors for benzo[*a*]pyrene (B[*a*]P) and PAHs from different fuels, these can be ranked as briquettes < wood < wood/ root-fuel mixtures according to their polluting potential, and natural gas < coal < briquettes < wood according to their benzo[*a*]pyrene (B[*a*]P) and PAHs emission factors, respectively. Different studies report different ranges of compounds, which might not be comparable. Data on emission factors from burning candles show that candles emit less PAHsthan cigarettes and fuels (Lau *et al.*, 1997).

The occurrence of PAHs in ambient air has however caused particular concern due to the continuous nature of exposure and the size of population at risk, especially in urban, suburban and industrial areas. Human exposure to PAHs is of great concern because of the mutagenic and carcinogenic properties that these compounds possess (IARC, 1983; Gretney et al., 1986; WHO, 1996; Ravindra and Van Grieken, 2001 and Saldiva et al., 2001). The International Agency for Research of Cancer (IARC) determined that benz[a]anthracene and benzo[a]pyrene are probably carcinogenic to humans, and benzo[b]fluoranthene, benzo[j]fluoranthene,benzo[k]fluoranthene, and indeno[1,2,3-c,d]pyrene are also possibly carcinogenic to humans (IARC, 1983). In turn, the US Environmental Protection Agency (EPA) has classified the following seven PAHs: benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, and indeno[1,2,3-c,d]pyrene as Group B2, probable human carcinogens (USEPA, 2002). More carcinogenic PAHs are generally found as the particulate, predominantly in the respirable particle (PM<2.5 µm) fraction (Oanh et al., 2000).

Health Effects of PAHs

PAHs associated with particles are hazardous to human health. Many of them are cytotoxic, mutagenic and carcinogenic compounds (WHO, 1998; Mastral and Callen, 2000; USEPA, 2007; IARC, 2009).

PAHs are the largest known group of carcinogens. The carcinogenic potency of individual PAHs is widely varying. Out of the sixteen PAHs listed by united state environmental protection agency (USEPA) as priority pollutants benzo[a]pyrene (B[a]P) has been classified as known carcinogen to humans (IARC, 1983; IARC, 2009), whereas other PAHs have been considered as probable (Group 2A) and possible (Group 2B) human carcinogens (IARC, 1983; IARC, 2002). In addition, PAHs were found to be mostly associated with fine particles with diameters less than 2.5 μm, which can reach the lower respiratory tract in human body, thus raising the concern about their effects on human health (Koyano*et al.,* 2001; Kume*et al.,* 2007).

Table (3) shows the carcinogenicity of sixteen (USEPA) PAHs using different classification systems of international agency for research on cancer (IARC), United States environmental protection agency (USEPA) and the concept of Toxicity Equivalency Factor (TEF) that estimates carcinogenicity relatively to (B[a]P) (Pufulete*et al.,* 2004)

PAHs are genotoxic compounds and their carcinogenicity is probably mediated by their ability to damage the DNA (Novotna *et al.,* 2007). Even exposure to low doses of PAHs might be associated with various cancers, indicating that there is no safe threshold.

The only evidence of PAH carcinogenicity in humans exists for long-term exposure (of many years) to polluted air of work places with high concentrations of PAHs, which exceed those in ambient air by orders of magnitude (Peluso*et al.,* 2001; Bostrom*et al.,* 2002).

Table 3: Classification of PAH carcinogenicity

Compound	Classification		
	IARC[a]	USEPA[b]	TEF[c]
Naphthalene	2B	C	not available
Acenaphthylene	3	not available	0.001
Acenaphthene	3	not available	0.001
Fluorene	3	D	0.001
Phenanthrene	3	D	0.001
Anthracene	3	D	0.01
Fluoranthene	3	D	0.001
Pyrene	3	D	0.001
Benz[a]anthracene	3	B2	0. 1

Chrysene	2B	B2	0.1
Benzo[b]fluoranthene	2B	B2	0.1
Benzo[k]fluoranthene	2B	B2	0.1
Benzo[a]pyrene	1	B2	1
Dibenz[a,h]anthracene	2A	B2	5
Benzo[ghi]perylene	3	D	0.01
Indeno[1,2,3-cd]pyrene	2B	B2	0.1
Dibenzo[a,l]pyrene	2A	not available	100[d]

[a]: Group 1 - carcinogenic to humans; Group 2A - probably carcinogenic to humans; Group 2B - possible carcinogenic to humans; Group 3 - unclassifiable as to carcinogenetic in humans; Group 4 - probably not carcinogenic to humans (IARC, 1983; IARC, 2002; IARC, 2009a).

[b]: Group A - human carcinogens; Group B - probable human carcinogens (B1: based on limited evidence of carcinogenicity in humans and sufficient evidence of carcinogenicity in animals; B2: based on sufficient evidence of carcinogenicity in animals); Group C - possible human carcinogens; Group D - not classifiable as to human carcinogenicity; Group E - evidence of non-carcinogenicity for humans (USEPA, 1986).

[c]: Toxicity Equivalency Factor (TEF)estimation based on the relative potency to benzo(a)pyrene (Nisbet and LaGoy, 1992).

PAHs concentrations in Outdoor Air of Egypt

Sum of total PAHs compounds in suspended particulate matter (PM) was monitored in air of different sites in Egypt. In Alexandria, Barakat (2002) found that the ∑ PAHs in PM samples collected from Heavy traffic area during July– August 2002 was 32 ng/m^3. Barakat attributed PAHs compounds to anthropogenic sources such as combustion of domestic wastes, vehicles emission and Road dust. Hassanien et al.(2001) agree with Barakat (2002), where he recorded that the ∑ PAHs in PM samples collected from urban area (El-Abasya) in Cairo during winter and summer seasons 1992-1995 and 1997 was 7.53-14.79 ng/m^3 and the main sources were anthropogenic. Change in emission patterns were probably due to change in meteorological conditions, volatilisation, petrochemical activities and the shift of equilibrium between gas and particulate phases towards the gaseous phase due to higher temperatures during the summer.

Nassar et al.(2001) found that ∑ PAHs in PM samples collected from a traffic site (El Dokki) and industrial site (El Teppen) in Greater Cairo during winter and summer seasons 2001 was 45.98 and 77.01 pmol/m^3 (20461.1 and 34269.45 ng/m^3), respectively. These concentrations were attributed to anthropogenic activities like

heavy traffic and various activities (in El Dokki) and heavy industrial activities (in El Teppen). Nassar et al. found that concentrations were higher in winter than in summer. The summer average concentrations of four-ring PAHs were higher than those of six-ring PAHs, and lower than those of five ring PAHs, while the winter average concentrations of four-ring PAHs were higher than those of both five- and six-ring PAHs. This might be because four-ring PAHs were partly transferred from the particle phase to the gas phase in summer at higher temperature.

Hassan (2006) found that ∑ PAHs in PM samples collected from Shoubra El-Kheima and Helwan in Greater Cairo were 1182.6-7129.74 and 1822- 5770.69 ng/m^3, respectively. The relative distribution of the higher molecular weight of individual PAHs compounds has the largest contribution (85.88%); whereas the lighter PAHs (two to four rings) were less abundant (14.12%). Mohammed (2012) agree with Hassan (2006), he recorded ∑ PAHs in PM samples collected from residential, industerial, traffic, agriculture areas (Shoubra El-Kheima and Helwan) in Greater Cairo during Dec.2007Nov.2008 and Dec.2008-Nov.2009 were 3684.0 - 6838.3 and 3817.4-6863.3 ng/m^3, respectively. During Dec.2007-Nov.2008 PAHs: 5-rings and 6-rings had the lowest contribution 28.3% and 40.3% for Shoubra El-Kheima and Helwan, respectively. While the lighter PAHs: 2-rings, 3-rings and 4-rings had largest contribution 71.7% and 59.7% for Shoubra El-Kheima and Helwan, respectively. During Dec.2008-Nov.2009 PAHs: 5-rings and 6-rings had the largest contribution 66.1% and 54.3% for Shoubra El-Kheima and Helwan, respectively. While the lighter PAHs: 2-rings, 3-rings and 4-rings had lowest contribution 33.9% and 45.7% for Shoubra El-Kheima and Helwan, respectively. El-Henawy (2011) found that ∑ PAHs in PM samples collected from Damietta City during February 2008 - January was 619.79 ng/m^3. Anthropogenic activities were the potential sources.

Khairy and Lohmann (2013) monitored ∑ PAHs in PM samples collected from industrial, traffic and residential area in Alexandria during winter and summer seasons, where PAHs levelswere 330-1770 and 170-1290 ng/m^3, respectively. Vehicle emissions, both diesel and gasoline contributed on average 36.0-49.0 % and 19.0-34.0 % respectively, natural gas combustion 11.0-27.0 % and, during the summer only, also evaporative/un-combusted petroleum sources were 8.00-18.0 %. Concentrations at the industrial site (average 680 ng/m^3) were significantly higher than concentrations at the residential (average 270 ng/m^3) and the traffic sites

(average 365 ng/m^3). PAH profiles were generally dominated by 2−3 rings PAHs, which represented 74−97% of the total quantified PAHs followed by 4-ring PAHs.

El-Mekawy, 2015monitored the annual mean concentrations of ∑PAHs in outdoor air of 4 sites in Helwan city during September 2010-August 2011. The highest concentrations of ∑PAHs were detected in site 2 (921.5 ng/m^3), followed by site 3 (840.4 ng/m^3), site 1 (689.7 ng/m^3) and finally site 4 (384.1 ng/m^3). El-Mekawyrecorded the highest ∑PAHs during spring season (1428 ng/m^3), while the lowest value was during autumn season (80.05 ng/m^3).El-Mekawy reported that the most abundant PAH compounds were light molecular weight (two-three-four rings) which contributed about 60.72-68.47%.While the higher molecular weight contributed about 31.53-39.28% of ∑PAHs.

The ∑ PAHs in PM samples collected from (Shoubra El-Kheima and Helwan) in Greater Cairo were higher than WHO guideline (870 ng/m^3 for PAH (BaP) in occupational settings, Han and Naeher, 2006). While the ∑ PAHs in PM samples collected from El-Abasya, El Dokki, El Teppen and Damietta City were lower than WHO Guidelines. In addition, these result may be attributed to anthropogenic activities (vehicle emission, open burning, thermal power plants, industrial emission) in Shoubra El-Kheima and Helwan areas. Furthermore, the ∑ PAHs in PM samples were higher than that measured in Chicago, USA (Σ26 PAHs was 167 ng/m^3, Simcik et al. 1999), Harbin, China (Σ16 PAHs was 100 ng/m^3, Ma et al. 2010), Guangzhou, China (Σ16 PAHs was 340 ng/m^3, Li et al. 2006), Seoul, Korea (Σ16 PAHs was 89.3 ng/m^3, Park et al. 2002), Athens, Greece (Σ14 PAHs 28.4 ng/m^3, Vasilakos et al. 2007), Bursa, Turkey during the non-heating season (Σ14 PAHs 150 ng/m^3, Esen et al. 2008) and Flanders, Belgium (Σ16 PAHs 57.8 ng/m^3, Ravindra et al. 2006), but agreement with those measured at Bursa, Turkey during the heating seasons (Σ14 PAHs 1200 ng/m^3,Esen et al. 2008).

Figure (3, 4, 5 and 6) showed that the seasonal variation of individual PAHs concentrations in air of Egypt at different sites. Where figures showed that the higher concentration of individual PAHs was recorded in El Teppen (2001) followed by El Dokki (2001), Helwan (2007), Helwan (2008), Shoubra El-Kheima (2008), Shoubra El-Kheima (2007), and Damietta (2011). In addition, figures showed that higher levels were recorded in winter season followed by autumn, spring and summer season.

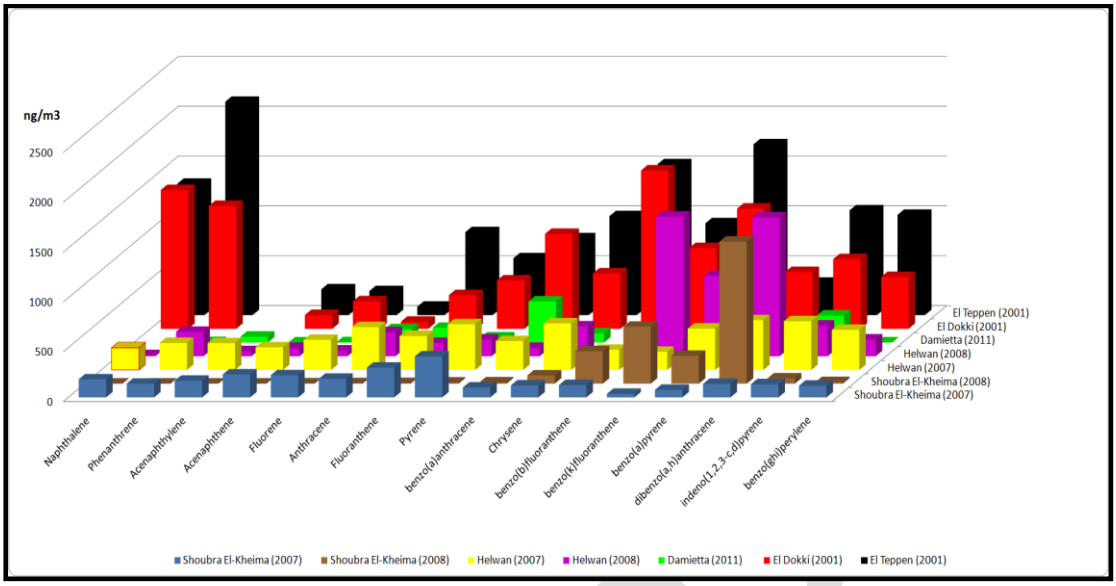

Figure 3: The concentrations of individual PAHs in air of Egypt at different sites during winter season.

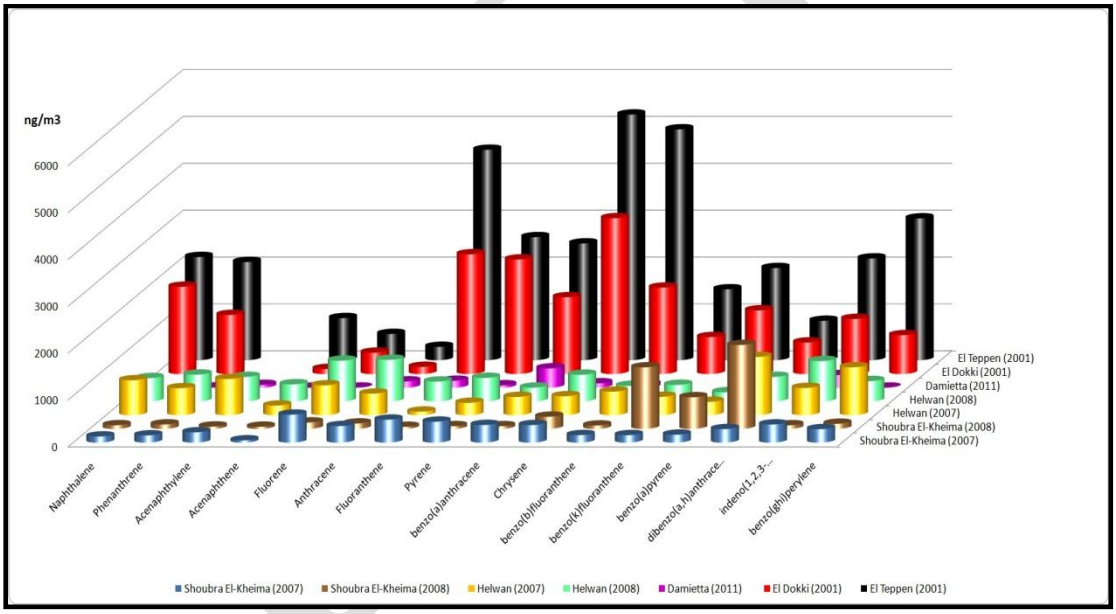

Figure 4: The concentrations of individual PAHs in air of Egypt at different sites during summer season.

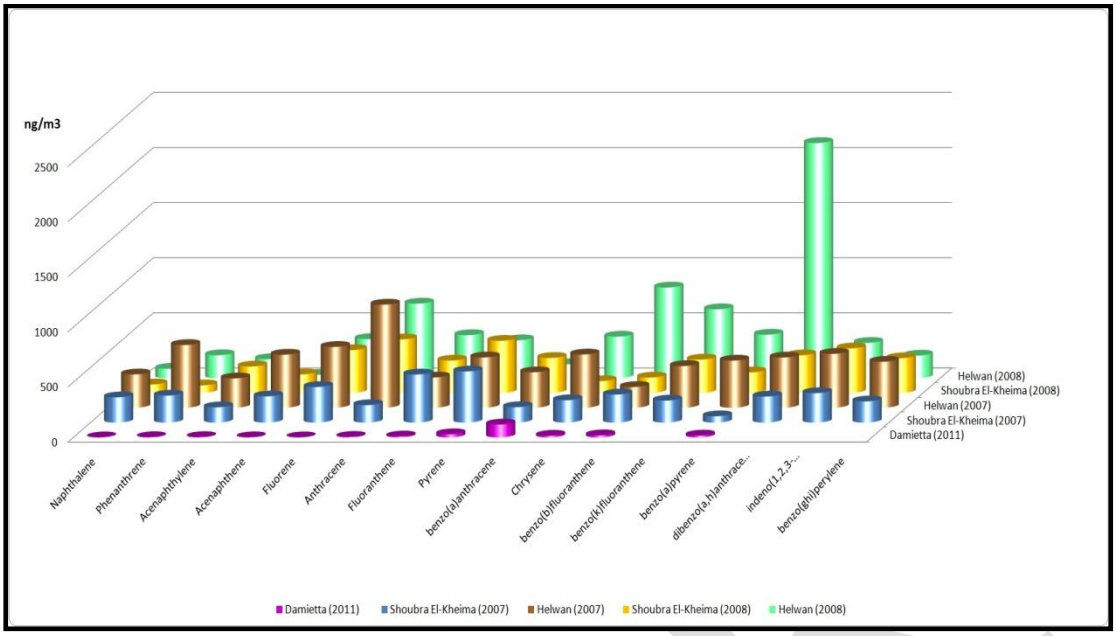

Figure 5: The concentrations of individual PAHs in air of Egypt at different sites during Autumn season.

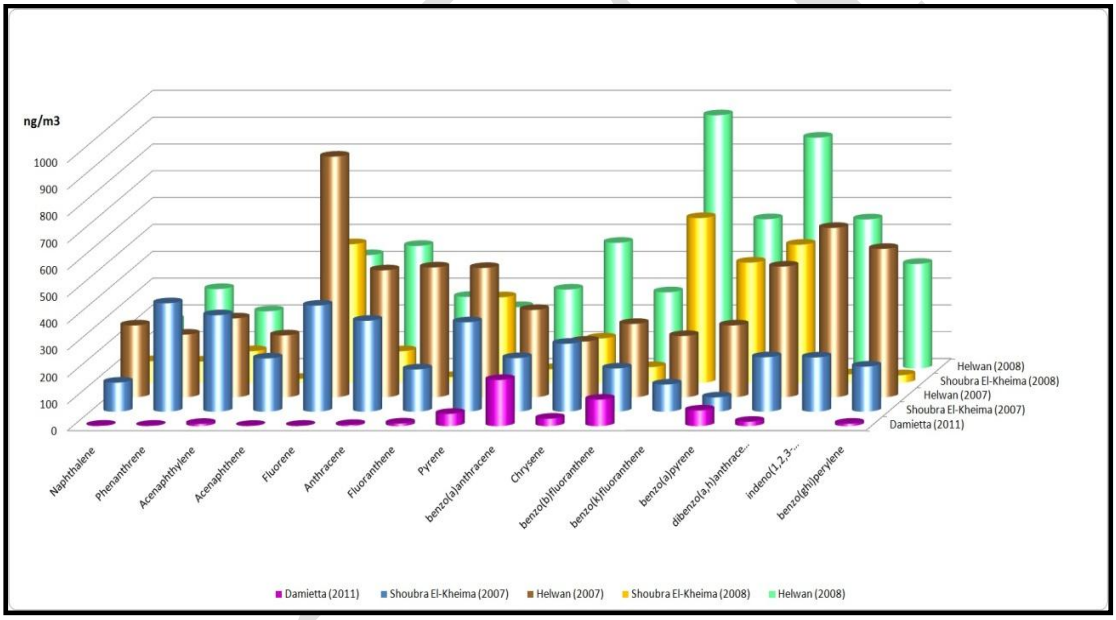

Figure 6: The concentrations of individual PAHs in air of Egypt at different sites during spring season.

PAHs concentrations in Indoor Air of Egypt

El-Mekawy (2015) found the annual mean concentrations of ∑PAHs in indoor air of 4 sites in Helwan city were 1019.8, 694.7,1038.7 and 811.1 ng/m^3 for site 1, 2, 3 and 4, respectively. In addition, the seasonal variation of PAHs concentrations showed seasonal with the highest level during spring and summer, while the lowest values were reported in winter season for all sites in Helwan city.

Conclusion

PAHs are a class of organic compounds consisting of two or more fused aromatic rings in linear, angular or cluster arrangements. There are hundreds of PAH compounds in the environment, but only 16 of them are included in the priority pollutants list of US EPA. The main aim of this article was to review the concentrations of PAHs in PM collected from different sites in Egypt,both outdoor and indoor during different periods.The concentration, transport and fate of PAHs in the atmosphere depend on many factors such as source strength, weather conditions, solar radiation, exchange between the gases and particulate phases, and physical removal due to the dry and wet depositions.

The ∑ PAHs in PM samples collected from (Shoubra El-Kheima and Helwan) in Greater Cairo were higher than WHO guideline (870 ng/m^3 for PAH (BaP) in occupational settings, Han and Naeher, 2006). While the ∑ PAHs in PM samples collected from El-Abasya, El Dokki, El Teppen and Damietta City were lower than WHO Guidelines. In addition, these result May be attributed to anthropogenic activities (vehicle emission, open burning, thermal power plants, industrial emission) in Shoubra El-Kheima and Helwan areas. Furthermore, the ∑ PAHs in PM samples were higher than that measured in Chicago, USA (Σ26 PAHs was 167 ng/m^3), Harbin, China (Σ16 PAHs was 100 ng/m^3), Guangzhou, China (Σ16 PAHs was 340 ng/m^3), Seoul, Korea (Σ16 PAHs was 89.3 ng/m^3), Athens, Greece (Σ14 PAHs 28.4 ng/m^3), Bursa, Turkey during the non-heating season (Σ14 PAHs 150 ng/m^3) and Flanders, Belgium (Σ16 PAHs 57.8 ng/m^3), but agreement with those measured at Bursa, Turkey during the heating seasons (Σ14 PAHs 1200 ng/m^3). The seasonal variation of individual PAHs concentrations showed that the higher concentration of individual PAHs was recorded in El Teppen (2001) followed by El Dokki (2001), Helwan (2007), Helwan (2008), Shoubra El-Kheima (2008), Shoubra El-Kheima (2007), and Damietta (2011). In addition, the concentrations showed that higher levels were recorded in winter season followed by autumn, spring and summer season.

The annual mean concentrations of ∑PAHs in indoor air atHelwan city were 1019.8, 694.7,1038.7 and 811.1 ng/m^3 for site 1 (Helwan center), 2 (highly traffic area in Helwan center) , 3 (Wady Hoff) and 4 (Torra), respectively. In addition, the seasonal variation of PAHs concentrations showed season with the highest level during spring

and summer, while the lowest values were reported in winter season for all sites in Helwan city.

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