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Health Risk Assessment of Polycyclic Aromatic Hydrocarbons in Surface Soils at North Baiji City, Iraq.

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Abstract

Four major factories (Petroleum Refineries Company, Detergents Plant, Thermal Power Plant, and Gaseous Power Plant) are located to the north of Baiji City. They release pollutants in form of gases, liquids and solids; they find their way to the surrounding environment. To assess the environmental pollution of the area, 18 samples of surface soil distributed around the industrial establishments were collected and analyzed to determine the concentration of polycyclic aromatic hydrocarbons (PAH) components which are often targets in the environmental checking. Identification and quantification of the 16 PAHs components was accomplished using High Performance Liquid Chromatography (HPLC) had a model Shimadzu LC-10 AVP. The total concentrations of 16 PAHs were ranged from (94.9) to (416.3) µg/kg with an average value of (217.5) µg/kg. The most abundant PAHs was Fluorene followed by Acenaphthylene, Naphthalene, Chrysene, Phenanthrene, Benzo(b)fluora-nthene, Fluoranthene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(g,h,i)perylene, Dibenzo(a,h)anthracene, Indeno(1,2,3-cd) pyrene, Pyrene, Acenaphthene, Anthracene, and Benzo(k)fluoranthene.

Seven possible carcinogenic PAHs (∑7c-PAHs) accounted 38.9 % to the total PAHs. The petroleum combustion and biomass combustion were the main sources of PAHs in the surface soil. The mean values of cancer risk levels for children via ingestion, dermal contact, and inhalation were ($6.02*10^{-7}$), ($7.51*10^{-7}$) and ($5.91*10^{-12}$) respectively, suggesting no potential health hazards, while these for adults were ($1.78*10^{-6}$), ($3.16*10^{-6}$) and ($1.40*10^{-10}$) respectively, implying potential health risks via ingestion and dermal contact, but not via inhalation exposure. The total value of $ILCR_{ing+drm+inh}$ for children and adults via three exposure pathways were ($2.43*10^{-5}$) and ($8.90*10^{-5}$) respectively, indicating potential health risks.

Keywords: Polycyclic aromatic hydrocarbons (PAHs), risk assessment, rural soils, soil contamination.

تقييم المخاطر الصحية للهيدروكاربونات الاروماتية متعددة الحلقات في الترب السطحية شمال مدينة بيجي، العراق.

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الخلاصة

أربع مصانع ضخمة (شركة مصافي الشمال، مصنع المنظفات، محطة كهرباء بيجي الحرارية ومحطة كهرباء بيجي الغازية) تقع الى الشمال من مدينة بيجي وتطلق ملوثات على شكل غازات، مواد سائلة وصلبة الى البيئة المحيطة. لتقييم التلوث البيئي في المنطقة، تم جمع وتحليل 18 عينة تربة سطحية موزعة حول المنطقة الصناعية لتحديد المركبات الهيدروكاربونية الاوروماتية متعددة الحلقات وكمياتها باستخدام جهاز

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الكروماتوغراف السائل عالي الاداء . ان التركيز الكلي لستة عشر مركب هيدروكاربوني اروماتي متعدد الحلقات تراوح بين 94.4 الى 416.3 مايكروغرام/كيلوغرام بمعدل 217.5 مايكروغرام/كيلوغرام. ان المركب الهيدروكاربوني الاروماتي متعدد الحلقات الاكثر وفرة في التربة السطحية لمنطقة الدراسة كان فلورين ثم يتبعه اسينافثالين ، نفثالين ، كريسين ، فينانثرين ، بنزو(ب)فلورانثين ، فلورانثين، بنزو(أ)انثراسين، بنزو(أ)بايرين، بنزو(ط ،ح، ز)بايرلين، دايبنزو(أ ، ح)أنثراسين، أندينو(1,2,3 ج ، د)بايرين، بايرين، أسينافثين، أنثراسين و بنزو(ك)فلورانثين. يعتبر حرق الوقود الاحفوري وحرق النباتات المصادر الرئيسية للمركبات الهيدروكاربونية الاروماتية متعددة الحلقات في التربة السطحية. معدل قيم مستويات المخاطر السرطانية للاطفال عن طريق الهضم، التماس الجلدي والاستنشاق كانت ($6.02*10^{-7}$)، ($7.51*10^{-7}$) و ($5.91*10^{-12}$) على التوالي، متضمنة عدم وجود مخاطر سرطانية محتملة، بينما تلك المتعلقة بالبالغين كانت ($1.78*10^{-6}$)، ($3.16*10^{-6}$) و ($1.40*10^{-10}$) على التوالي، متضمنة وجود مخاطر سرطانية محتملة عن طريق الهضم والتماس الجلدي وعدم وجود مخاطر عن طريق الاستنشاق. ان القيمة الكلية للاصابة تدريجيا بالسرطان مدى الحياة (ILCR) عن طريق الهضم، التماس الجلدي والاستنشاق للاطفال والبالغين كانت ($2.43*10^{-5}$) و ($8.90*10^{-5}$) على التوالي متضمنة مخاطر سرطانية محتملة.

Introduction:

Rapid growth of the world population and the pursuit of material prosperity have generated a massive expansion in industrial and agricultural production in recent decades. The associated increase in energy consumption and the generation of waste have dramatically increased the pressure on the natural environment and have led to changes in the composition of the atmosphere, soil, fresh water resources, seas, and oceans. This, in turn, has led to unbalancing of natural ecosystems and a deterioration of environmental quality [1]. Soil is an essential component of all terrestrial ecosystems, where the majority of earth's fauna and flora biodiversity resides [2]. Polycyclic aromatic hydrocarbons are an important group of environmental pollutants. They are introduced into the environment from both natural (e.g., oil seeps, forest fires and volcanic activity) and anthropogenic sources (e.g., petrochemical industrial effluents, coal tar processing wastes, combustion processes) [3]. PAHs are a large group of organic compounds with two or more fused aromatic rings. They are mutagenic and carcinogenic environmental contaminants that are widely present in the air, water and aquatic systems، soils and sediments [4]. Although PAHs are described as carcinogenic, only the following are considered as possible human or animal carcinogens: benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene,and indeno(l,2,3-cd)pyrene [5]. Soil is the primary steady reservoir and sinks for PAHs in the terrestrial environment, because PAHs are readily absorbed by organic matter in soil and difficult to degrade [6].

Besides, the accumulation of PAHs in soil may lead to contamination of food chains, which could cause a potential risk to human health [7]. In developing countries, there is a lack of information about presence and distribution of PAHs and other toxic substances in soils.

This study intends to be a comprehensive study on PAHs in soils of north Baiji city. The main objectives are: (1) to determine concentrations and distributions of PAHs; (2) to elucidate potential sources by PAHs diagnostic ratio analysis; and (3) to assess the health risk caused by carcinogenic PAHs.

Study area:

The study area is located around the industrial district (i.e. North Refineries Company, Detergents plant, Thermal Power Plant and Gaseous Power Plant) to the north of Baiji City and lies in between northern 351160 to 371087 and eastern 3862912 to 3887201 Figure-1. The rural area within the studied area including many villages are; Al-hinshi, Shwaish and Al-bojwari villages they are located to the east to northeast of North Refineries Company and detergents plant and to the south to southeast of Thermal and Gaseous power plants. Breej village is located to the north of industrial district. Baiji city is located to the south of industrial district. Al-600 house and Baiji-Mousel highway are located to the west of industrial district. On the east bank of Tigris River there is Al-laqlaq village.

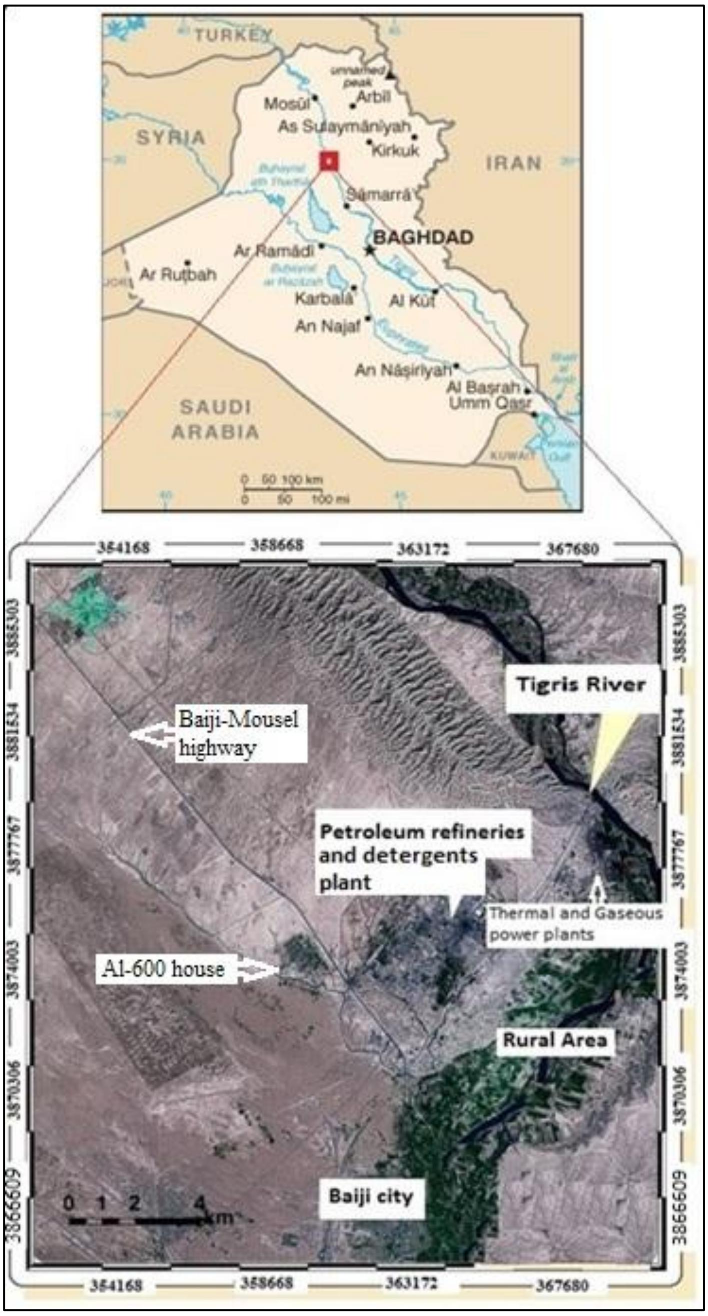

Figure 1- the study area

Sample Collection:

Eighteen sampling sites were chosen for collection of soil from depth (0 – 25 cm), after removing leaves, grass and any large external objects Figure-2, Table-1. The sampling was conducted in October 2013.

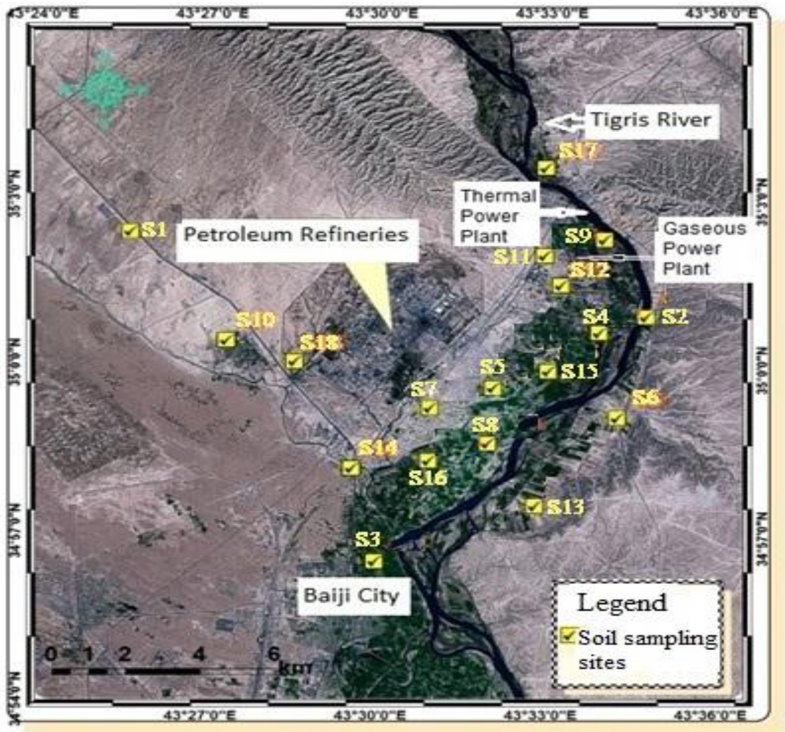

Figure 2- Locations of soil sample in the studied area.

Table 1- coordinates of sampling sites of Soil.

Site No.	Location	Eastern	Northern
S1	Jazerat Al-arab Fuel Station	356546	3878539
S2	Al-laqlaq village	370370	3875698
S3	Jedaida village	363072	3867670
S4	Shwaish village	369122	3875162
S5	Al-bojwari village	366271	3873376
S6	Al-laqlaq village	369855	3872260
S7	Al-bojwari village	364576	3872706
S8	Al-bojwari village	366115	3871530
S9	Al-hinshi village	369273	3878246
S10	Al 600 house	359100	3874945
S11	Al-hinshi village	367647	3877717
S12	Shwaish village	368653	3876146
S13	Al-laqlaq village	367371	3869482
S14	Al-bojwari village	362448	3870724
S15	Campus of Al-mansour oils factory	367744	3873903
S16	Al-bojwari village	364532	3870971
S17	Breej village	368050	3881401
S18	Petroleum institute	360927	3874257

Analytical procedure:

Samples taken for PAHs analysis should be stored in glass containers, protected from light and refrigerated until extracted. 100 gm. of soil were mixed with 1 litter methanol: chloroform (50:50, v/v), agitated for 1 h, keep the mixture to settle down for 3 h, then decantation the extract and repeated once, collect the two extract, then concentrated the mixture by evaporating the solvent with a stream of liquid N2 until reach nearly 0.5 ml, then add some of mobile phase to reach 5 ml. The mixture was passed through 2.5 µm disposable filters, and then 5 µl were injected on HPLC column. The concentration for each compound were quantitatively determined by comparison the peak area of the standard with that of the samples.

The High Performance Liquid Chromatography (HPLC) was used to determine PAHs in air filters and soils. This equipment is of model Shimadzu LC-10 AVP.

PAH Diagnostic Ratios Analysis:

Source identification is of great significance for the determination of control strategies for environmental pollution. PAHs diagnostic ratios have recently come into common use as a tool for identifying and assessing pollution sources [8]. The potential source of the PAHs in the soil was assessed in order to ascertain their actual origin. Petrogenic input can occur due to oil spillage or human discharge of petroleum by products while pyrolytic sources include combustion processes involving fossil fuel, forest fire, and grass fires. A number of studies have demonstrated the use of PAHs isomer ratios for source identification such as Ant/ (Phn+Ant) vs. Fla/(Pyr+Fla) and BaA/(BaA+Chr) vs. Ipy/(Ipy+Bpe) [8], [9], [10], [11], [12]. The compounds involved in each ratio have the same molar mass, so it is assumed they have similar physicochemical properties. Based on the PAH isomer ratios in source identification compiled by [13], the Fla/(Fla+Pyr) ratio,0.4 indicates petroleum input as a source; 0.4–0.5 indicates petroleum (liquid fossil fuel, vehicle and crude oil); and.0.5 indicates combustion of biomass and coal. In addition, an Ant/(Phn+Ant) <0.1 implies a petroleum source, >0.1 implies combustion as a source [8]. Ratio of BaA/(BaA+Chr) < 0.2 and Iyp/(Iyp+Bpe) < 0.2 indicated petrogenic and petroleum sources, $0.2 <$ Iyp/(Iyp+Bpe) < 0.5 and $0.2 <$ BaA/(BaA+Chr) < 0.35 mean petroleum combustion, including liquid fossil fuels, vehicle, and crude oil combustion, and Iyp/(Iyp+Bpe) > 0.5 and BaA/(BaA+Chr) > 0.35 indicate that the source of PAHs are biomass and coal combustion [13].

Health Risk Assessment Model of Carcinogenic PAH:

Human health risk assessment calculations were based on the assumption that residents, both children and adults, are directly exposed to soil through three main pathways (a) ingestion; (b) dermal absorption and (c) inhalation of soil particles present in the air [14]. Ingestion of soil occurs by eating soil particles and/or licking contact surfaces (e.g., hands). Dermal absorption occurs through exposed skin, while soil is inhaled both by mouth and nose during breathing. Particles <10 µm (PM_{10}) are the more relevant in this process, although larger fractions of inhaled soil are, probably, decomposed in the gastrointestinal track. It is assumed that all contaminants are absorbed; both by the gastrointestinal tract or the lung [15]. Toxicity equivalent (TEQ) method was used to assess the eco-toxicological risk at a specific site. The total BaP equivalent concentration (BaP_{eq}) was calculated by the sum of BaP_{eq} for 7 carcinogenic PAH using toxicity equivalent factors presented in Table-3. The total BaP was calculated as [16] :-

$$\text{Total BaP} = \sum iCi * TEFi \qquad (1)$$

Where Ci is the concentration of individual 16 PAHs, and TEFi is the corresponding toxic equivalency factor.

Residents are exposed to surface soils surrounding the three major plants through three main pathways: ingestion, inhalation, and dermal contact with soil particles. According to [17], [18], the Incremental Lifetime Cancer Risk (ILCR) model was used to calculate the risk of residents exposed to PAHs via surface soils surrounding industrial districts. The chronic daily intake (CDI) (milligrams per kilogram per day) of PAHs was estimated using the following formulae:

$$CDI_{ingestion} = \frac{Csoil*Ing\ R*EF*ED}{BW*AT} * CF \qquad (2)$$

$$CDI_{dermal} = \frac{Csoil*SA*SFsoil*ABS*EF*ED}{BW*AT} * CF \qquad (3)$$

$$CDI_{inhalation} = \frac{Csoil*Inh\ R*EF*ED}{PEF*BW*AT} * CF \qquad (4)$$

Where: C_{soil} is the total BaP-equivalent concentration in µg/kg. Ing R is ingestion rate of soil (milligrams per day), EF is the exposure frequency (days per year), ED is the exposure duration (years), CF is the conversion factor,BW is the average body weight (kilograms), AT is the average life span (days), SA is the surface area of the skin that contacts the soil (square centimeter), SF soil is the skin adherence factor for soil (milligrams per square centimeter), ABS is the dermal absorption factor (chemical specific), Inh R is the inhalation rate (cubic meters per day), and PEF is the particle emission factor (cubic meters per kilogram).

These parameters were presented in Table-2, which was based on the Risk Assessment Guidance of US.EPA and related publications.
The Incremental Lifetime Cancer Risk (ILCR) is evaluated as

$$ILCR = CDI * CSF \quad (5)$$

Where CSF is the carcinogenic slope factor (mg/kg/day) $^{-1}$was based on the cancer-causing ability of BaP; $CSF_{ingestion}$, CSF_{Dermal} and $CSF_{Inhalation}$ of BaP were 7.3, 25 and 3.85 (mg/kg/day), respectively [19], [20].

Table 2- Parameters used in cancer risk assessment

Exposure variables	unit	Child	Adult	Reference
Ingestion ratio of soil (IR_{soil})	mg/day	200	100	[18]
Exposure frequency (EF)	day/year	180	365	[21]
Exposure duration (ED)	year	6	70	[18]
Body weight (BW)	kg	15	60	[22]
Average life span (AT)	days	25,55	25,55	[18]
Dermal exposure area (SA)	cm^2	2,800	5,700	[18]
Dermal adherence factor (AF)	mg/cm^2	0.2	0.07	[18]
Dermal adsorption fraction (ABS)	------	0.13	0.13	[18]
Inhalation ratio (IR_{air})	m^3/day	5	20	[23]
Particle emission factor (PEF)	m^3/kg	$1.36*10^9$	$1.36*10^9$	[18]

Results and Discussion

PAH profiles in surface soils at north Baiji City:

In this study, 16 individual PAHs namely Naphthalene (Nap), Acenaphthylene (Any), Acenaphthene (Ane), Fluorene (Fle), Anthracene (Ant), Phenanthrene (Phn), Fluoranthene (Fla) , pyrene (Pyr), Benzo(a)anthracene (BaA), Chrysene (Chr), Benzo(b)fluoranthene (Bbf), Benzo(k)fluoranthene (Bkf), Benzo(a)pyrene (Bap), Dibenzo(a,h)anthracene (DBA), Benzo(g,h,i)perylene (Bpe) and indeno (1,2,3-c,d) pyrene (Ipy) were analyzed and quantified.

The maximum and minimum concentration of individual PAH compounds were in the order Fle > Any > Npt > Chr > Phn > Bbf > Fla > BaA > BaP > Bpe > DBA > Iyp > Pyr > Ane > Ant > Bkf, as in Figure-3.

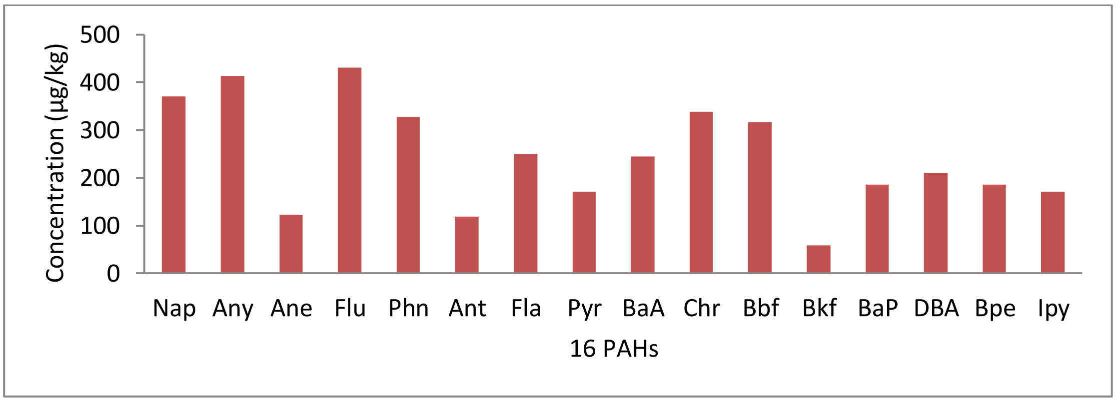

Figure 3- Concentration of individual 16 PAHs compounds in the surface soil at north Baiji city.

Table-3 shows the descriptive statistics for concentrations of 16 PAHs in surface soils at north Baiji city. The overall concentration of 16 USEPA priority PAHs in surface soils were ranged from (94.9) µg/kg to (416.3) µg/kg with a mean concentration (217.5) µg/kg. The highest concentration of ∑ 16 PAHs was at S1, which may due to the closeness from fuel station, while the minimum concentration was at S17, and this may due to the distance from industrial district and prevailing wind effect Figure-4.

Table 3- Range, mean and total of individual PAHs in the surface soils of study area in comparison with [25].

16 PAH compounds	Type of PAHs	TEF [24]	Range µg/kg		Mean µg/kg	[25] µg/kg
			Min.	Max.		
Naphthalene	LMW		3.5	47.8	20.6	140
Acenaphthylene	LMW		ND	116.5	29.5	3400
Acenaphthene	LMW		ND	29	15.3	-----
Fluorene	LMW		ND	112.5	25.4	2300
Phenanthrene	LMW		3	37.9	18.2	-----
Anthracene	LMW		0.5	42.3	6.6	17000
Fluoranthene	HMW		2.5	32.8	13.9	2300
Pyrene	HMW		ND	31.6	12.2	1700
Benzo(a)anthracene	HMW	0.2	0.05	70.2	13.6	0.15
Chrysene	HMW	0.1	ND	89.6	21.1	15
Benzo(b)fluoranthene	HMW	0.8	ND	51	19.8	0.15
Benzo(k)fluoranthene	HMW	0.03	ND	25.5	11.7	1.5
Benzo(a)pyrene 0.28	HMW	1.0	ND	33.2	13.2	0.015
Dibenzo(a,h)anthracene	HMW	10	ND	30.1	13.1	0.015
Benzo(g,h,i)perylene	HMW		ND	32.3	11	-----
Indeno(1,2,3-cd)pyrene	HMW	0.07	0.5	20.6	9.5	-----
∑ 16 PAHs			94.9	416.3	217.5	
∑ LMW_{PAHs}			33	305.8	99.1	
∑ HMW_{PAHs}			39.2	292	118.5	
∑ 7 carcinogenic PAHs			12.8	263.6	84.8	

LMW= Low molecular weight, HMW= High molecular weight; ND=Not detection

∑LMW_{PAHs} values ranged from 33 (µg/kg) at S5 to 305.8 (µg/kg) at S4 with a mean value of 99.1 (µg/kg), while ∑HMW_{PAHs} values ranged from 39.2 (µg/kg) at S17 to 292 (µg/kg) at S1 with a mean value of 118.5 (µg/kg) Table-3. ∑HMW_{PAHs} values were higher than ∑LMW_{PAHs} at most of soil sites Figure-5 and this due to volatilization of ∑LMW_{PAHs} from soil which may be substantial [26]. Although PAHs are described as carcinogenic, only the following are considered as possible human or animal carcinogens: benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, and indeno(l,2,3-cd)pyrene [5]. The lowest value of ∑ 7 carcinogenic PAHs was 12.8 (µg/kg) at S17, while the highest value was 263.6 (µg/kg) at S1, with a mean value of 84.8 (µg/kg) Table-3. Distribution of ∑ 7 carcinogenic PAHs are shown in Figure-6. The highest value is located close to fuel station which considers a main source for PAHs emissions.

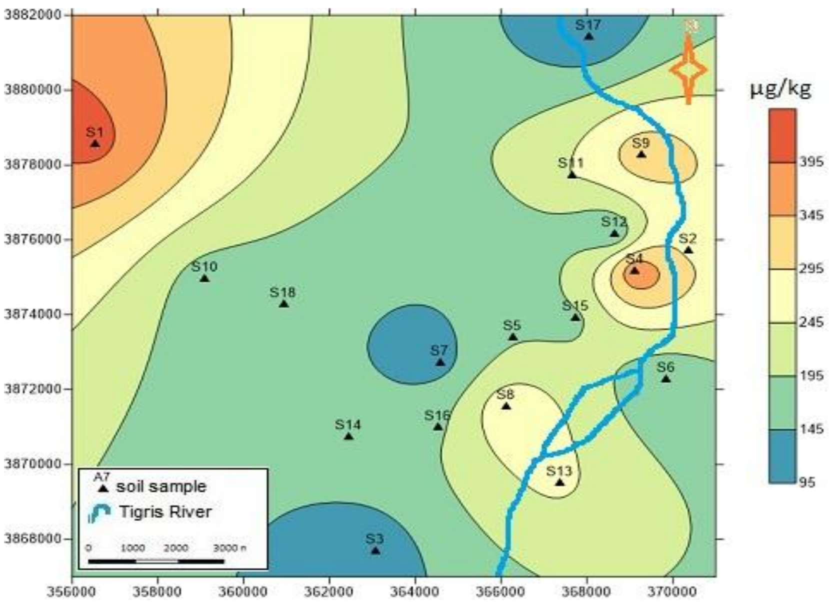

Figure 4- Spatial distribution of total 16 PAHs in the surface soils of the study area.

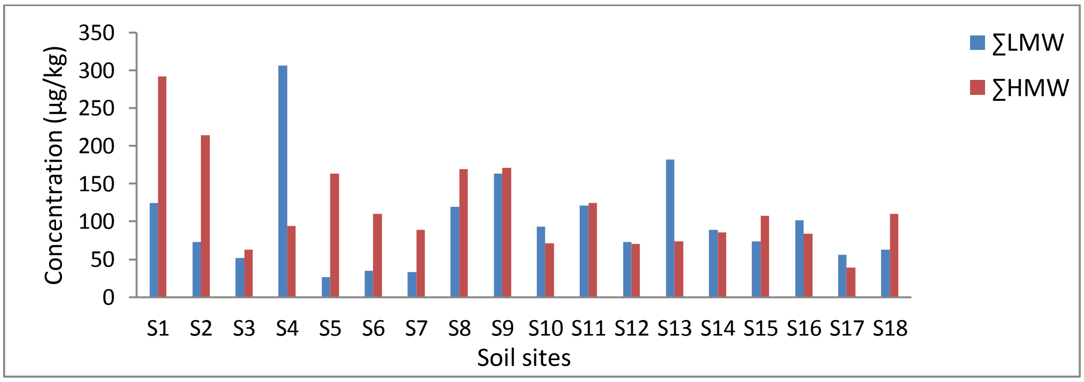

Figure 5- Distribution of $\sum LMW_{PAHs}$ and $\sum HMW_{PAHs}$ in the surface soil

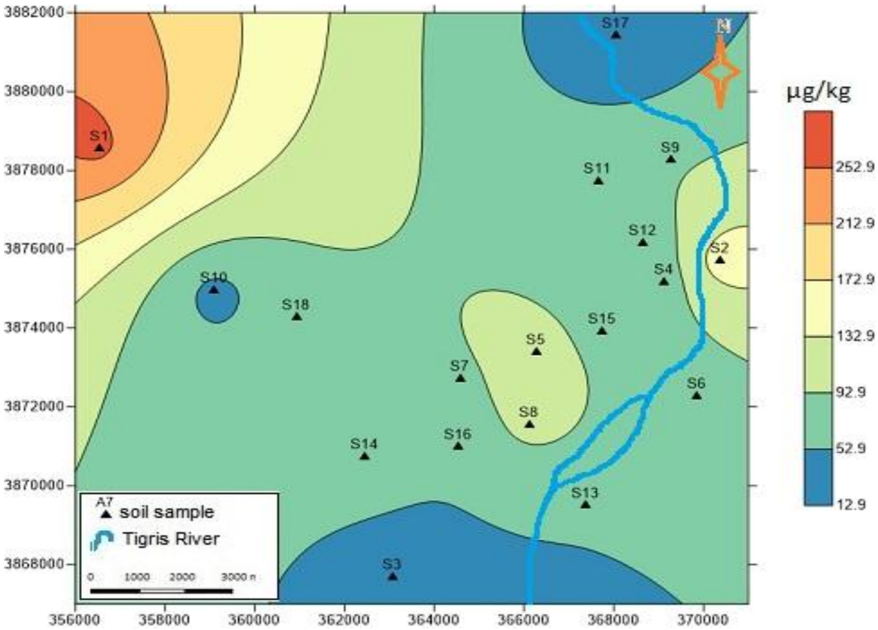

Figure 6- Spatial distribution of ∑7 carcinogenic PAHs in the surface soil

Potential sources of 16 PAHs:

The concentrations and patterns of PAHs in soils could reflect the source characteristics [27]. In the present study, the values of Fla/(Fla+Pyr) ranged from 0.4 to 1.0 and the values of Ant/(Ant+Phn) were between 0.05 to 0.55. Figure-5 shows the cross plot of Fla/(Fla+Pyr) vs. Ant/(Ant+Phn), indicating that the sources of PAHs in soils could be classified into four distinct groups. About 55.5% and 33.3% of the sampling sites exhibited the typical characteristics of petroleum (liquid fossil fuel, vehicle and crude oil) combustion Figure-7D and the signature of biomass and coal combustion Figure-7B, respectively. About 5.5% and 5.5% of the remaining sites showed the signature of a mixture containing petroleum and combustion Figure-7A and Figure-7C respectively. Hence, the primary source of PAHs in the surface soil at north Baiji City could be considered as combustion. The PAH sources of 66.6% of the sampling sites Figure-7 A, C and D were related with petroleum, indicating petroleum played an important role for refinery and generating electric power due to the presence of three major plants (Petroleum refineries company, thermal power plant and gaseous power plant) which depend on fossil fuel combustion. The values of BaA/(BaA+Chr) ranged from 0.05 to 1.0, while values of Ipy/(Ipy+Bpe) were between 0.12 to 1.0. Figure-6 represents isomer ratio of BaA/(BaA+Chr) vs. Ipy/(Ipy+Bpe), assuming about 33.3% and 33.3% of the sampling sites exhibited the typical characteristics of petroleum (liquid fossil fuel, vehicle and crude oil) combustion and the signature of biomass and coal combustion Figure-8B and C. About 16.6%, 11.1% and 5.5% of the remaining sites showed the signature of a mixture containing petroleum and combustion Figure-8A, Figure-8D and Figure-8E respectively. Therefore, the primary source of PAHs in the surface soil at north Baiji City could be considered as combustion. The PAH sources of 66.6% of the sampling sites Figure-8A, B, D and E related to petroleum, indicating an important role of petroleum in soil pollution.

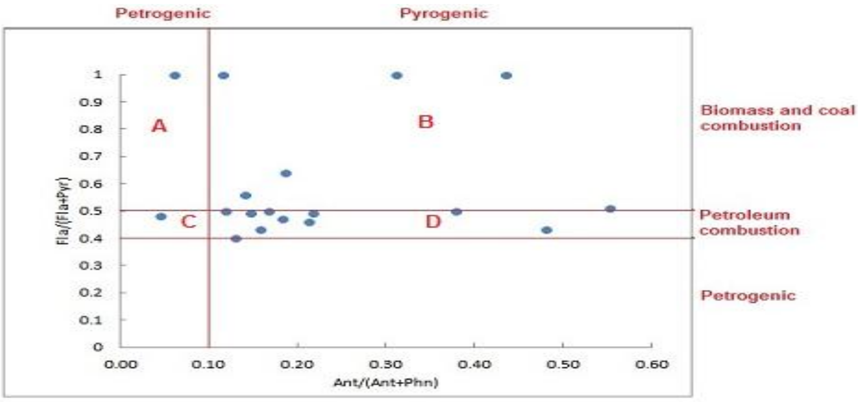

Figure 7- Cross plots for the ratios of Fla/(Fla+Pyr) vs. Ant/(Ant+Phn)

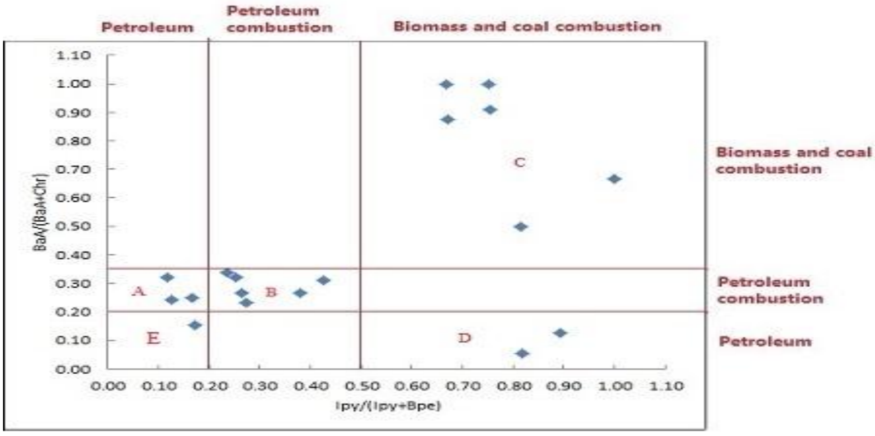

Figure 8- Cross plots for the ratios of BaA/(BaA+Chr) vs. Ipy/(Ipy+Bpe)

Risk assessment of PAHs:

Table-4 refers to Descriptive Statistics of Data on Incremental Lifetime Cancer Risks (ILCRs) in surface soils at north Baiji city. Cancer risk between (10^{-6}) and (10^{-4}) indicated potential health risk according to [28], while greater than (10^{-4}) suggests high potential health risk [29]. The highest value of $ILCR_{(C)}$ and $ILCR_{(A)}$ via ingestion exposure were $1.50*10^{-6}$ and $4.43*10^{-6}$ respectively, suggesting potential health risk. Both highest values are located at S1 Figure-9A, may due to closeness from fuel station, while the lowest value of $ILCR_{(C)}$ and $ILCR_{(A)}$ were $1.71*10^{-7}$ and $5.06*10^{-7}$ respectively, indicating no potential health risk. Both lowest values are located at S6 Figure-9A. The lowest value of $ILCR_{(C)}$ and $ILCR_{(A)}$ via dermal exposure were $2.13*10^{-7}$ and $8.99*10^{-7}$ respectively, suggesting no potential health risk. Both lowest values are located at S6 Figure-9B, may due to the location of this site on the west of petroleum refineries, which means away from effects of prevailing winds. The highest value of $ILCR_{(C)}$ and $ILCR_{(A)}$ via dermal contact were $1.87*10^{-6}$ and $7.88*10^{-6}$ respectively, indicating potential health risk. Both highest values are located at S1 Figure-9B, may due to closeness from fuel station which considers a main source for PAHs emissions. The lowest value of $ILCR_{(C)}$ and $ILCR_{(A)}$ via inhalation exposure were $1.68*10^{-12}$ and $3.97*10^{-11}$ respectively, suggesting no potential health risk. Both lowest values are located at S6 Figure-9C, may due to the location of this site at the west of petroleum refineries, which means away from effects of prevailing winds. The highest value of $ILCR_{(C)}$ and $ILCR_{(A)}$ were $1.47*10^{-11}$ and $3.48*10^{-10}$ respectively, indicating no potential health risk. Both highest values are located at S1 Figure-9C, may due to closeness from fuel station which considers a main source for PAHs emissions. The lowest value of $\sum ILCR_{(C)}$ and $\sum ILCR_{(A)}$ via ingestion, dermal and inhalation exposure were $3.84*10^{-7}$ and $1.40*10^{-6}$ respectively, indicating no potential carcinogenic hazards for children, but potential health risks for adults. Both lowest values are located at S6 Figure-9D, may due to the location of this site at the west of petroleum refineries, which means away from effects of prevailing winds. The highest value of $\sum ILCR_{(C)}$ and $\sum ILCR_{(A)}$ via three exposure pathways were $3.37*10^{-6}$ and $1.23*10^{-5}$ respectively, suggesting there is potential carcinogenic health hazards via three exposure pathways (i.e. ingestion, dermal and inhalation). Both highest values are located at S1 Figure-9D, and this may due to closeness from fuel station which considers a main source for PAHs emissions.

Table 4- Descriptive statistics of data on incremental lifetime cancer risks (ILCRs) in surface soils at north Baiji City.

ILCRs	Child			Adult		
	Min.	Max.	Mean	Min.	Max.	Mean
Ingestion	$1.71*10^{-7}$	$1.50*10^{-6}$	$6.02*10^{-7}$	$5.06*10^{-7}$	$4.43*10^{-6}$	$1.78*10^{-6}$
Dermal	$2.13*10^{-7}$	$1.87*10^{-6}$	$7.51*10^{-7}$	$8.99*10^{-7}$	$7.88*10^{-6}$	$3.16*10^{-6}$
Inhalation	$1.68*10^{-12}$	$1.47*10^{-10}$	$5.91*10^{-12}$	$3.97*10^{-11}$	$3.48*10^{-10}$	$1.40*10^{-10}$
$\sum ILCR_{ing+drm+inh}$	$3.84*10^{-7}$	$3.37*10^{-6}$	$1.35*10^{-6}$	$1.40*10^{-6}$	$1.23*10^{-5}$	$4.94*10^{-6}$
Total	$1.13*10^{-4}$					

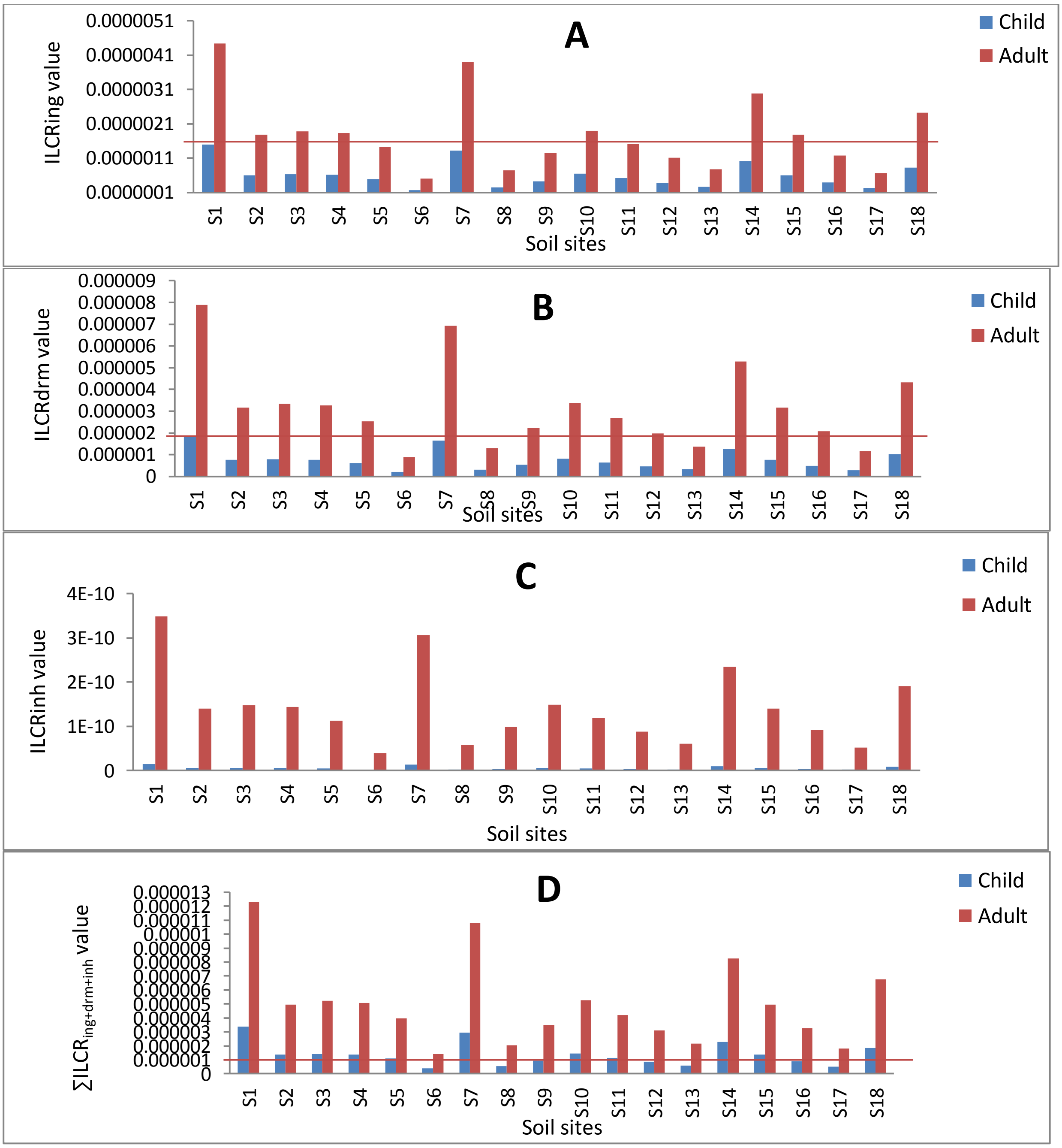

Figure 9- $ILCR_{ing}$ (A), $ILCR_{drm}$ (B), $ILCR_{inh}$ (C) and $\sum ILCR_{ing+drm+inh}$ (D) for children and adults in the surface soil

Conclusions:

Polycyclic aromatic hydrocarbons were analyzed in 18 surface soil samples collected from north Baiji City. The distribution, possible sources and health risk assessment were also evaluated. The total concentrations of 16 PAHs were varied from (94.9) to (416.3) µg/kg with an average value of (217.5) µg/kg. The possible source of PAHs in the study area could be petroleum and biomass combustion. The risk assessment criteria for the study area refer to potential health risk for adults via ingestion and dermal contact exposure. Adults are more susceptible for adverse health effects than children.

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