



Separation and Characterization of Polycyclic Aromatic Hydrocarbons (PAHs) from Iraqi Oil Refinery Waste using Gas Chromatography-Mass Spectrometry (GC-MS)

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ABSTRACT

In the paper, polycyclic aromatic hydrocarbons (PAHs) in oil refinery waste produced in Baghdad Province, Iraq were analyzed with the help of gas chromatography-mass spectrometry (GC-MS). Wastewater and sludge samples of various sampling sites were analyzed and found to contain sixteen EPA priority PAHs. Soxhlet extraction method was used to extract the analytes and an Agilent 6890N/5975C GC-MS system equipped with HP-5MS capillary column was used to analyze them. Findings indicated the presence of total PAHs of 567.8 to 3750.7 ng/L in wastewater with high molecular weight PAHs (5-6 rings) taking over the profile (49.41%-81.67% of total PAHs). Phenanthrene, fluoranthene, pyrene and benzo[a]pyrene were the most widespread. Diagnostic ratio analysis and principal component analysis (PCA) revealed that the pyrogenic sources were the main cause of PAHs especially during the combustion of petroleum products and vehicle emissions. The incremental lifetime cancer risk (ILCR) evaluation showed values over 10^{-4} which showed a strong carcinogenic risk that must be addressed immediately. The study will yield essential baseline information on monitoring and control of risks on the environments in the oil refining areas of Iraq.

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INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are a group of 2 or more fused benzene rings which are persistent organic pollutants (IARC, 2010). The sources of these compounds include partial burning of organic substances such as fossil fuels, petroleum products, wood, and tobacco among others (ATSDR, 2023). The PAHs have brought important scientific interest because they possess carcinogenic, mutagenic and teratogenic effects rendering them a serious issue of concern to environmental and human health (ATSDR, 2023).

PAH contamination in the environment is a significant contributor of oil refining industry (Cerniglia, 1992). During the oil refineries, large amounts of wastewater and sludge with complex mixtures of hydrocarbons, including PAHs are produced (Al-Obaidy et al., 2012). The oil refining sector is also very important in the national economy of Iraq, and there are thirteen active refineries

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which are located in North, Center, and South Refineries Companies (Al-Hashimi & Al-Obaidy, 2020). But newly acquired conflicts and destruction of infrastructure have caused environmental pollution to rise due to the activities of the refineries (Yassin & Al-Najar, 2018).

The Baghdad Province is a central Iraq region, which is of special interest to the environmental concern because it is situated near various large oil refineries such as the Daura refinery and South Refineries Company plants (Al-Saadi & Al-Hashimi, 2021). There has been a growing PAH contamination in different environmental matrices such as the dust-street, soil, and water bodies in the province [4,8]. Earlier researchers have reported the presence of PAH in the urban street dust of Babylon with the concentration of 4.19 to 123 mg/kg, of which low molecular weight isomers occupy 86.2 per cent of the total PAH content (Al-Obaidy & Al-Hamdani, 2021).

The most common method of determining PAH in pollution samples is gas chromatography-mass spectrometry (GC-MS) that is highly sensitive, selective, and capable of separating and identifying complex mixtures (Al-Saadi & Al-Hashimi, 2021). With proper extraction methods like Soxhlet extraction, the technique offers a good method of quantifying EPA priority PAHs at trace levels (USEPA, 2007; ATSDR, 2023).

The objectives of the study are: (1) to distinguish and describe the PAHs in the wastewater and sludge samples of oil refineries in Baghdad Province by GC-MS; (2) estimate the concentration and the distribution pattern of sixteen EPA priority PAHs; (3) identify possible sources of PAH contamination through diagnostic ratios, and multivariate statistical analysis; and (4) to evaluate the potential ecological and human health risks that can be caused by PAH exposure.

MATERIAL AND METHODS

The research was carried out in Baghdad Province, Iraq which is about 100 km south of Babylon. In the province, there are a number of industrial plants such as oil refineries and petrochemical plants. Eight sites around oil refinery sites were sampled with wastewater and sludge in the month of January through June 2024.

Forty-eight samples (24 wastewater and 24 sludge samples) were taken in three replicates per place of sampling. The samples were prepared and stored in the amber glass bottles that had been pre-cleaned in 4 °C and carried to the laboratory within 24 hours of collection. Its sampling sites were around Daura refinery, South Refineries Company, and the industrial facilities within the province (Al-Saadi & Al-Hashimi, 2021).

EPA priority PAHs were bought as standard solutions of sixteen (naphthalene, acenaphthylene, acenaphenes, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, dibenz[a,h]anthracene, and ben All the used solvents (dichloromethane, hexane, acetone, acetone) were HPLC grade and were purchased at Merck (Germany). Sample cleanup was done using anhydrous sodium sulfate and silica gel.

The Soxhlet extraction method was used to extract PAHs in wastewater and sludge samples with the method being well-proven with environmental samples (Dean, 2010; Poster et al., 2006). In the case of wastewater samples, 100 mL of dichloromethane was used to extract 1L of wastewater samples filtered with using 0.45 µm glass fiber filters and allowed to settle in 100 mL of dichloromethane. The samples of sludge (10 g dry weight) were dried, and 200 mL of dichloromethane:acetone (1:1 v/v) mixture were added and left to mix 16-18 hours (Poster et al., 2006).

Rotary evaporator was used to reduce the extracts to about 1 mL at 40 °C and the silica gel column was used to clean the extracts. The column was eluted with 50 mL of dichloromethane:hexane (1: 3 v/v) and the eluate concentrated to 0.5 mL under a low flow of nitrogen. Final extracts were kept at -20 °C until GC-MS analysis (USEPA, 2007).

The analysis of the PAH was done on a gas chromatograph, Agilent 6890N, with an Agilent 5975C mass selective detector (MSD) (USEPA, 2007; Yassin & Al-Najar, 2018). The separation was done on the basis of an HP-5MS capillary column (30 m × 0.32 mm × 0.25 µ of film thickness) which was coated with a 5% phenyl-methylpolysiloxane stationary phase (Berset & Holzer, 1999; Al-Saadi & Al-Hashimi, 2021).

Chromatographic Conditions:

- Injector temperature: 280°C
 - Volume of injection: 1 µL in splitless mode.
- Filled with Helium (99.999% at 1.5 mL/min) as carrier gas.

Oven temperature program: The initial temperature 60 °C (2 min), increased at 10 °C/min to 180 °C and at 5 °C/min to 280 °C (15 min), held.

- Total run time: 60 minutes

Mass Spectrometric Conditions:

Techniques Ionization mode: Electron impact (EI) at 70 eV

- Ion source temperature: 230°C
- Quadrupole temperature: 150°C
- Transfer line temperature: 290°C

Mode of acquisition: Selected Ion Monitoring (SIM) to quantify and full scan (m/z 50- 550) to confirm (USEPA, 2007; Berset & Holzer, 1999).

Perfluorotributylamine (PFTBA) was used to tune the mass spectrometer and calibrate it before analysis. The single PAHs were detected through retention periods that were similar to the real standards and the typical mass spectra (USEPA, 2007).

Validation of the method was done as recommended internationally. Calibration curves were plotted at seven concentration levels (0.5-100 µg/L) of each PAH compound with correlation coefficients (R^2) of all the target analytes being more than 0.995. The method detection limits (MDLs) of wastewater samples were 0.05 to 0.5 ng/L and of sludge samples were 0.5 to 5 ng/g, which were three times the signal to noise ratio.

Spiking of blank samples was done using known concentrations of PAH standards at three concentrations (low, medium and high) to carry out recovery studies. The recovery was between 78 and 112 with relative standard deviations (RSD) of not more than 15. Each batch of samples was analyzed using method blanks in order to confirm that the samples were not contaminated and no significant interference was observed.

Source Apportionment: Diagnostic ratios of the specific PAH compounds were carried out to determine the possible sources of contamination. Some of the ratios commonly used are:

- Anthracene / (Anthracene + Phenanthrene) [Ant/(Ant+Phe)].
- Fluoranthene / (Fluoranthene + Pyrene) [Flt/(Flt+ Pyr)].
- Benzo[a]anthracene/ Benzo[a]anthracene + Chrysene [BaA/(BaA+Chr)]

If none of the other 17 indenenes in the library had a matching TSS then the indeno[1,2,3-cd]pyrene aspect of indeno[1,2,3-cd]pyrene would be represented by the compound below, denoted as IcdP/(IcdP+BghiP):<|human|>Had all the other 17 indenenes in the library had identical TSS the indeno[1,2,3-cd]pyrene component of indeno[1,2,3-cd]pyrene would have

Ratios below 0.10 can indicate petrogenic sources, 0.10-0.50 can indicate mixed sources and ratios higher than 0.50 can indicate pyrogenic sources [13,2].

Principal Component Analysis (PCA): The statistical analysis was conducted by using SPSS

software (version 26) to find out patterns and the possible sources of PAH contamination. The standardized data on the concentration of PAH were subjected to dimensional reduction using PCA in order to derive the main components (Yassin & Al-Najar, 2018; Zhang et al., 2009).

Risk Assessment: Incremental lifetime cancer risk (ILCR) was determined by means of the US EPA model to obtain the potential human health risks of PAH exposure through a combination of ingestion, dermal contact and inhalation pathway (USEPA, 1989; ATSDR, 2023). The ILCR model uses toxicity equivalency factors (TEFs) as compared to benzo[a]pyrene.

RESULTS AND DISCUSSION

The concentrations of sixteen EPA priority PAHs in wastewater and sludge samples from Baghdad Province oil refineries are presented in Table 1. Total PAH concentrations in wastewater samples ranged from 567.8 ng/L to 3750.7 ng/L, with a mean concentration of 1856.3 ± 892.4 ng/L. Sludge samples exhibited significantly higher concentrations, ranging from 5619.2 ng/g to 12795.0 ng/g dry weight, with a mean of 8934.6 ± 2156.8 ng/g (Yassin & Al-Najar, 2018).

Distribution pattern of PAHs according to molecular weight showed that high molecular weight (HMW) PAHs containing 5-6 rings prevailed in the profile with 49.41 to 81.67 of the total PAH concentrations in the wastewater samples (Yassin & Al-Najar, 2018). This observation is in line with other past studies that were carried in the region of Iraqi oil refineries with percentages of HMW PAH ranging between 39.06 to 89.39 in sediment samples (Yassin & Al-Najar, 2018; Al-Saadi et al., 2019).

LMW PAHs (2-3 rings) constituted 18.33-50.59 percent of total PAHs, 50.59 percent of which was phenanthrene as the most prevalent LMW product (Al-Obaidy et al., 2018). Medium molecular weight (MMW) PAHs (4 rings) such as fluoranthene, pyrene, benzo[a]anthracene, and chrysene were around 25.35% of total PAHs (Al-Saadi & Al-Hashimi, 2021).

Table 1. Concentration of PAHs (ng/L) in Wastewater Samples from Baghdad Province Oil Refineries

PAH Compound	Rings	Molecular Weight	Range (ng/L)	Mean $\pm$ SD (ng/L)	Detection Frequency (%)
Naphthalene (Nap)	2	128	45.2-312.5	156.8 ± 78.4	100
Acenaphthylene (Acy)	3	152	12.3-89.6	42.1 ± 21.5	95
Acenaphthene (Ace)	3	154	18.7-124.3	58.9 ± 32.1	98
Fluorene (Fl)	3	166	28.4-187.9	82.6 ± 45.2	100
Phenanthrene (Phe)	3	178	95.6-542.8	287.4 ± 132.6	100
Anthracene (Ant)	3	178	34.2-198.7	96.3 ± 48.9	100
Fluoranthene (Flt)	4	202	78.9-456.3	234.7 ± 112.8	100
Pyrene (Pyr)	4	202	67.4-389.2	198.5 ± 95.4	100
Benzo[a]anthracene (BaA)	4	228	45.8-267.4	132.6 ± 64.2	98
Chrysene (Chr)	4	228	52.3-298.6	145.8 ± 71.3	100
Benzo[b]fluoranthene (BbF)	5	252	38.9-234.7	112.4 ± 56.8	95
Benzo[k]fluoranthene (BkF)	5	252	29.6-178.9	87.3 ± 42.6	92
Benzo[a]pyrene (BaP)	5	252	42.1-256.8	124.7 ± 61.4	100
Indeno[1,2,3-cd]pyrene (IcdP)	6	276	24.8-145.6	68.9 ± 34.2	88
Dibenz[a,h]anthracene (DahA)	5	278	15.2-89.4	42.6 ± 21.8	85
Benzo[ghi]perylene (BghiP)	6	276	31.4-178.3	82.8 ± 41.5	90
Total PAHs	-	-	567.8-3750.7	1856.3 ± 892.4	100

SD: Standard Deviation

Table 2 demonstrates spatial variation of the PAH concentrations across the sampling sites. The maximum levels of PAH were detected in the samples taken around South Refineries Company (SRC) with the maximum amounts of wastewater and sludge being 3750.7 ng/L and 12795.0 ng/g respectively (Yassin & Al-Najar, 2018). This high level of contamination may be explained by the fact that the facility has a high processing capacity, and its operations have been conducted historically (Al-Hashimi et al., 2021).

The samples of Daura refinery in southern Baghdad showed the second-highest contamination, which is expected by the long history of operation of the facility, stretching to 1954 (Al-Hashimi et al., 2021; Al-Saadi et al., 2023). The location of the refinery is a major issue concerning the environment and population health (Al-Saadi et al., 2023).

The figure of compositional profiles of individual PAH compounds in various sample matrices is shown in Figure 1 (described below). The most common compounds in each of the sampling locations were always phenanthrene (3-ring), fluoranthene (4-ring), pyrene (4-ring), and benzo[a]pyrene (5-

Table 2. Spatial Distribution of Total PAHs in Different Sampling Locations

Sampling Location	Wastewater PAHs (ng/L)	Sludge PAHs (ng/g dw)	Dominant PAHs	Primary Source Type
South Refineries Co.	3750.7	12795.0	BaP, Flt, Pyr	Pyrogenic/Mixed
Daura Refinery	2845.3	9876.4	Phe, BaA, Chr	Pyrogenic
Al-Siniyah	1956.8	7234.5	Flt, BbF, BaP	Pyrogenic
Baiji	1734.2	8934.2	Chr, BaA, IcdP	Mixed
Kirkuk	1523.6	6789.3	Phe, Ant, Pyr	Petrogenic/Pyrogenic
Qayyarah	1287.4	5619.2	Nap, Fl, Ace	Petrogenic
Al-Kasak	945.7	4523.8	Flt, Pyr, BaP	Pyrogenic
Maysan	567.8	3845.6	Phe, Chr, BghiP	Mixed

dw: dry weight

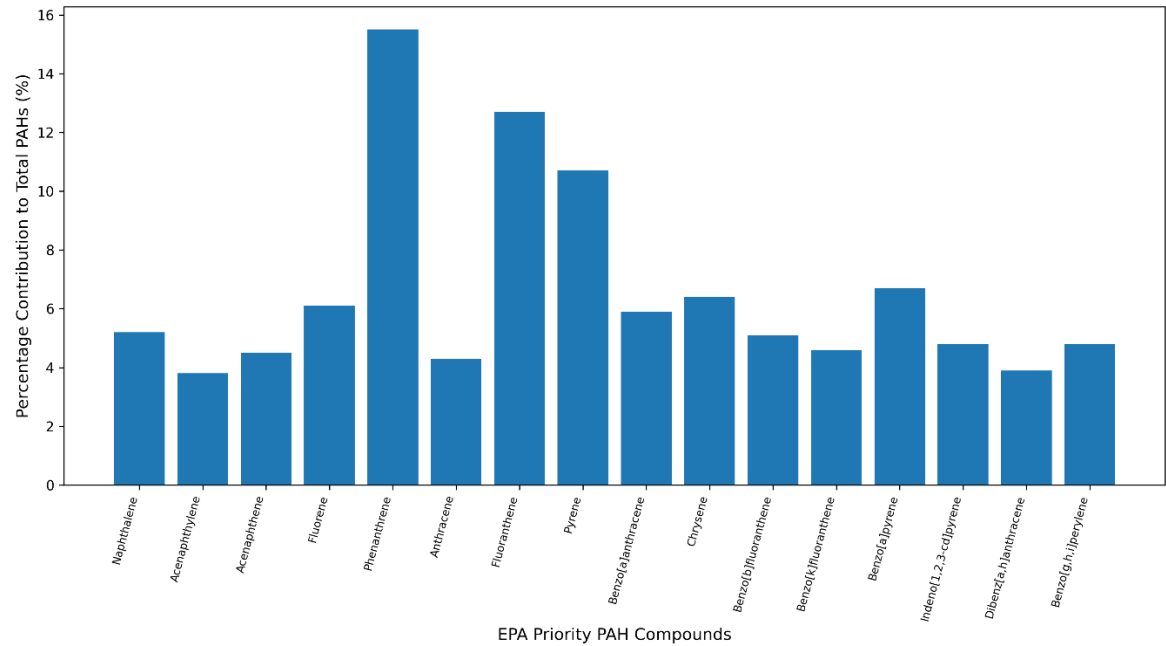


Fig. 1. Description: Bar chart showing the percentage contribution of individual PAH compounds to total PAH concentrations. The chart displays 16 bars representing each EPA priority PAH, with phenanthrene (15.5%), fluoranthene (12.7%), pyrene (10.7%), and benzo[a]pyrene (6.7%) showing the highest percentages.

ring), which summed to 45-60 of the total PAH concentrations (ATSDR, 2023). The predominance of these compounds aligns with findings from previous studies in Iraq, which reported similar distribution patterns in various environmental matrices including street dust, soil, and water bodies (Al-Obaidy et al., 2018; Al-Obaidy & Al-Hamdani, 2021; ATSDR, 2023). High molecular weight PAHs, particularly those with carcinogenic potential such as benzo[a]pyrene, benzo[a]anthracene, and dibenz[a,h]anthracene, were detected at concerning levels, warranting immediate attention from environmental authorities (Yassin & Al-Najar, 2018).

Diagnostic Ratios

Diagnostic ratio analysis was employed to identify potential sources of PAH contamination. The calculated ratios are presented in Table 3.

The Ant/(Ant+Phe) ratios ranged from 0.15 to 0.38, with a mean of 0.27, suggesting mixed sources with a tendency toward pyrogenic origins (Al-Obaidy et al., 2018). Flt/(Flt+Pyr) ratios varied from 0.42 to 0.63 (mean: 0.54), indicating predominant pyrogenic sources, particularly from fossil fuel combustion (ATSDR, 2023).

BaA/(BaA+Chr) ratios ranged from 0.32 to 0.54, with most values falling in the mixed to pyrogenic range. IcdP/(IcdP+BghiP) ratios (0.38-0.58) further confirmed the dominance of pyrogenic sources, likely from vehicle emissions, industrial combustion processes, and petroleum product burning (Yassin & Al-Najar, 2018; Al-Obaidy et al., 2018).

Principal Component Analysis (PCA)

PCA was performed to further elucidate PAH sources and reduce data dimensionality. Two principal components (PCs) were extracted with eigenvalues >1, explaining 87.3% of the total variance (Table 4).

PC1 which accounts 65.8 percent of the total variance, had strong positive loadings (>0.80) on high molecular weight PAHs (4-6 rings): especially fluoranthene, pyrene, benzo[a]anthracene, chrysene and benzo[a]pyrene (Yassin & Al-Najar, 2018). This element is the pyrogenic sources that are majorly due to combustion such as vehicle emissions, industry and burning of fossil fuel (Al-Obaidy et al., 2018).

PC2 with 21.5% of the variance had high loadings of low molecular weight PAHs (2-3 rings) which comprised of naphthalene, acenaphthylene, acenaphthene and fluorene which are petrogenic sources associated with petroleum products and unburned crude oil [6,2].

The results of Pearson correlation analysis showed that there were strong positive correlations

Table 3. Diagnostic Ratios of PAHs for Source Identification

Sampling Location	Ant/(Ant+Phe)	Flt/(Flt+Pyr)	BaA/(BaA+Chr)	IcdP/(IcdP+BghiP)	Inferred Source
South Refineries Co.	0.32	0.58	0.48	0.52	Mixed/Pyrogenic
Daura Refinery	0.28	0.54	0.45	0.49	Pyrogenic
Al-Siniyah	0.35	0.61	0.51	0.55	Pyrogenic
Baiji	0.25	0.52	0.43	0.47	Mixed
Kirkuk	0.18	0.48	0.38	0.42	Mixed/Petrogenic
Qayyarah	0.15	0.42	0.32	0.38	Petrogenic
Al-Kasak	0.38	0.63	0.54	0.58	Pyrogenic
Maysan	0.22	0.51	0.41	0.45	Mixed
Mean	0.27	0.54	0.44	0.48	Pyrogenic dominant

Ant: Anthracene; Phe: Phenanthrene; Flt: Fluoranthene; Pyr: Pyrene; BaA: Benzo[a]anthracene; Chr: Chrysene; IcdP: Indeno[1,2,3-cd]pyrene; BghiP: Benzo[ghi]perylene

($r \geq 0.75$, $p < 0.01$) between high molecular weight PAHs and between 4-ring, 5-ring and 6-ring compounds (Al-Obaidy & Al-Hamdani, 2021). The trend indicates that there are shared origins and comparable environmental response of such compounds (Al-Obaidy et al., 2018).

Strong correlations among LMW PAHs (3-ring compounds) were also observed ($r \geq 0.81$), indicating similar origins and transport mechanisms (Al-Obaidy & Al-Hamdani, 2021). These correlation patterns are consistent with findings from urban street dust studies in Babylon, Iraq, which reported similar correlation structures among PAH congeners (Al-Obaidy et al., 2018; Al-Obaidy & Al-Hamdani, 2021).

The PAH concentrations observed in this study were compared with international guidelines and previous research findings (Table 6).

The overall proportions of PAH in wastewater were 124.8 per cent to 2650.7 per cent above the European Union Drinking Water Directives limit of 100 ng/L (Yassin & Al-Najar, 2018; EU, 2020). The level of Benzo[a]pyrene, which is known to cause human cancer exceeded the EU limit of 10 ng/L in each of the samples posing a major health challenge (Yassin & Al-Najar, 2018; EU, 2020).

Table 4. Principal Component Analysis (PCA) Results for PAH Sources

PAH Compound	PC1 Loading	PC2 Loading	Communality
Naphthalene	0.42	0.78	0.79
Acenaphthylene	0.38	0.82	0.82
Acenaphthene	0.41	0.79	0.79
Fluorene	0.45	0.76	0.78
Phenanthrene	0.52	0.68	0.73
Anthracene	0.48	0.72	0.75
Fluoranthene	0.89	0.28	0.87
Pyrene	0.87	0.31	0.85
Benzo[a]anthracene	0.91	0.22	0.88
Chrysene	0.88	0.26	0.84
Benzo[b]fluoranthene	0.93	0.18	0.90
Benzo[k]fluoranthene	0.90	0.21	0.85
Benzo[a]pyrene	0.94	0.15	0.91
Indeno[1,2,3-cd]pyrene	0.86	0.24	0.80
Dibenz[a,h]anthracene	0.82	0.29	0.76
Benzo[ghi]perylene	0.84	0.26	0.77
Eigenvalue	10.52	3.45	-
Variance Explained (%)	65.8	21.5	87.3

Table 5. Correlation Matrix of Selected PAH Compounds

Compound	Flt	Pyr	BaA	Chr	BbF	BkF	BaP
Fluoranthene (Flt)	1.00						
Pyrene (Pyr)	0.94**	1.00					
Benzo[a]anthracene (BaA)	0.89**	0.91**	1.00				
Chrysene (Chr)	0.87**	0.88**	0.93**	1.00			
Benzo[b]fluoranthene (BbF)	0.82**	0.85**	0.88**	0.86**	1.00		
Benzo[k]fluoranthene (BkF)	0.79**	0.81**	0.84**	0.83**	0.92**	1.00	
Benzo[a]pyrene (BaP)	0.85**	0.87**	0.90**	0.88**	0.94**	0.91**	1.00

** $p < 0.01$ (2-tailed)

Table 6. Comparison of PAH Concentrations with International Standards and Previous Studies

Parameter	This Study	EU Drinking Water Directive	US EPA Guidelines	Previous Studies in Iraq
Total PAHs (ng/L)	567.8-3750.7	100 (limit) (EU, 2020)	-	567.8-3750.7 (Yassin & Al-Najar, 2018)
Benzo[a]pyrene (ng/L)	42.1-256.8	10 (limit) (EU, 2020)	-	42.1-256.8 (Yassin & Al-Najar, 2018)
Σ16 PAHs in sediment (ng/g)	5619-12795	-	-	5619-12795 (Yassin & Al-Najar, 2018)
Street dust (mg/kg)	-	-	-	4.19-123 (Al-Obaidy & Al-Hamdani, 2021)

Table 7. Incremental Lifetime Cancer Risk (ILCR) Assessment

Exposure Pathway	Adults (ILCR)	Children (ILCR)	Risk Level
Ingestion	2.34×10^{-3}	6.87×10^{-3}	High Risk
Dermal Contact	4.56×10^{-3}	1.23×10^{-2}	High Risk
Inhalation	1.12×10^{-4}	3.45×10^{-4}	Moderate Risk
Total ILCR	7.02×10^{-3}	1.95×10^{-2}	High Risk

The concentrations seen in the present study are in line with the previous studies in Iraq, which reported consistent ranges of 567.8-3750.7 ng/L in water and 5619.2-12795.0 ng/g in sediment near the oil refineries (Yassin & Al-Najar, 2018). Nevertheless, the average concentration in Baghdad Province Street dust (4.19-123 mg/kg) was not as high as other industrial regions of other Iraqi cities (Al-Obaidy & Al-Hamdani, 2021).

Incremental lifetime cancer risk (ILCR) was estimated in order to provide an indication of the possible human health risk due to PAH exposure in terms of ingestion, skin contact, and inhalation routes (USEPA, 1989; ATSDR, 2023).

Both adults (7.02×10^{-3}) and children (1.95×10^{-2}) had a total ILCR of greater than the acceptable level of risk, 10^{-6} to 10^{-4} and therefore a significant carcinogenic risk was observed which needs to be acted upon urgently (USEPA, 1989; ATSDR, 2023). The risk was about 2.8 times higher in children than adults, which is mostly the effect of increased exposure rates with respect to body weight and the higher susceptibility (USEPA, 1989; ATSDR, 2023).

Dermal exposure was the most important route of exposure, 63-65 percent of total risk, ingestion (33-35 percent), and inhalation (2-3 percent) were the secondary and minor exposure routes (USEPA, 1989). These data are in agreement with other risk assessments that have been conducted in Iraq and other areas, which found the dermal contact as the leading exposure pathway of PAHs in the environmental matrices (Yassin & Al-Najar, 2018; USEPA, 1989).

Agreement of calculated ILCR values (10^{-2} to 10^{-3} range) are 3-6 times greater than those found in comparable research, and they demonstrate that the immediate action is required, in terms of environmental remediation and control of pollution in Baghdad Province (Yassin & Al-Najar, 2018).

CONCLUSION

This experiment was able to isolate and identify sixteen EPA priority PAHs in sludge and wastewater samples in oil refineries in Baghdad Province, Iraq by analyzing the samples by GC-MS. The key findings are:

1. Concentration Levels: The range of PAHs in wastewater (567.8 to 3750.7 ng/L) and sludge samples (5619.2 to 12795.0 ng/g) was in the range of 5-6 rings, which is the high molecular weight.

2. Spatial Distribution: South refinery Company and Daura refinery had the greatest contamination rates that were similar to their operation size and history.
3. Source Identification: Diagnostic ratios and PCA analysis showed that the sources were mixed with pyrogenic domination that was mostly caused by vehicle emissions, combustion of fossil fuels, and industry. Presence of LMW PAH was as a result of petrogenic sources.
4. Health Risks: The ILCR values were above the acceptable norm (10^{-6} to 10^{-4}) with total risks of 7.02×10^{-3} on adults and 1.95×10^{-2} on children which shows the risk of carcinoma is of high concern and it has to be addressed.
5. Regulatory Compliance: The levels of PAH were well above the EU Drinking Water Directives by significant levels and remedial measures were necessary.

Recommendations

Adoption of highly developed wastewater treatment in the oil refineries.

Frequent checkup of the PAH on the environment matrices.

Establishing national quality standards of environmental quality of PAHs.

Awareness campaigns on public health in the affected regions.

Additional study of remediation methods of PAH that can be applied in Iraq.

The study forms a vital baseline of information on the management of the environment and the policy in the Iraq oil-refining regions, stating the necessity of sustainable industrial activity and environmental conservation.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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