



Eco-toxicity and health risk assessment of polycyclic aromatic hydrocarbons in surface sediments of Burullus Lake in Egypt

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ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous environmental contaminants of growing concern due to their potential ecological and human health risks. This study presents a comprehensive assessment of PAHs contamination in the surface sediments of Burullus Lake, a vital and second largest delta lake in Egypt. The aim was to evaluate the eco-toxicity and potential health risks associated with the presence of these compounds. Surface seven sediment samples were collected from various drains in the southern part of Burullus Lake. Soxhlet extraction method was employed to extract PAHs (16PAHs) from the sediment sample. Analytically, target compounds were located using HPLC. The results showed that samples contained PAHs levels ranging from 0.038×10^{-6} to 0.459×10^{-6} , which is considered heavily polluted by the European standard for PAHs pollution. Additionally, there was no apparent source of PAHs in the El-Khashah drain or the Brinbal Canal, as HPLC found none of the compounds. The most prevalent compound in sediment samples along the study area was fluoranthene. The diagnostic indices in the present study indicated that the hydrocarbons in the region originated from pyrolytic and man-made sources along the drains of Burullus Lake. The principal component analysis (PCA) and diagnostic ratios revealed that coal combustion and pyrolytic sources were responsible for the PAHs contamination in the surface sediments. The non-carcinogenic risk (*HI*), which is the product of the *HQs* for the adult and child populations, respectively, was calculated. *HI* values under 1, therefore, demonstrated that they had no carcinogenic effects on human health. *TEQs* and *MEQs* in the sediments of Burullus Lake do not have a cancer-causing impact on people. For the safety of nearby wildlife, aquatic life, and people, all activities that raise petroleum hydrocarbon levels in Burullus Lake must be adequately regulated and controlled. According to the ecological risk assessment, there is little chance that PAHs will be found in the sediments of Burullus Lake. This study underscores the urgent need for effective pollution control measures and regular monitoring of PAHs levels in Burullus Lake sediments to protect the aquatic ecosystem and public health. It also highlights the importance of considering eco-toxicity and human health risks in integrated risk assessments of PAHs-contaminated environments.

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1. Introduction

Multiple conjugated double-bond units are present in the multinucleated organic compound class known as polycyclic aromatic hydrocarbons (PAHs) (Kim KH et al., 2013). Assorted linear, angular, or cluster formations of two or more fused benzene rings next to one another via two carbon atoms

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are how PAHs are structuralized in their molecules (Meador JP 2008). They have the power to alter the biological characteristics of environmental media and can act as reliable indicators of how well the water will perform in various applications (Gebreyohannes F et al., 2015). Each organic contaminant in water and sediment will have specific physicochemical properties depending on the level and sources of environmental pollution (Sharma RC et al., 2016). The daily emission of PAHs has increased due to industrialization's rapid growth (Zhang Y and Tao S, 2009). El-Alfy MA (2023) stated that modeling sensitivity of PAHs pollution along coastal areas is vital in the future planning of

these areas. Environmental PAHs discharges have been steadily rising in developing nations. The USEPA's 16 priority PAHs were emitted at their highest levels ever in 2004 from three countries: China (114 Gg per year), India (90 Gg per year), and the United States (32 Gg per year) (Zhang Y and Tao S, 2009). As waste products of incomplete combustion of organic materials, these aromatic compounds, which are naturally present in fossil fuels, are released into the atmosphere (such as oil and gas, coal, biomass, firewood, trash, tobacco, or charbroiled meat) through incineration, vehicle exhaust emissions, oil exploration, power generation, and a variety of industrial activities (Jamhari AA et al., 2014). Aquatic life is toxically affected by high PAHs deposits on soil and sediments from estuaries, lakes, and the ocean (Olatunji OS et al., 2014). Four types of PAHs are released into the environment: Biogenic PAHs, which are produced by living things; pyrogenic or pyrolytic PAHs, which come from combustion processes; petrogenic PAHs, which come from fossil fuels; and diagenic PAHs, which come from soil and sediment transformation processes (Tongo I et al., 2017). Due to their higher toxicity, mutagenic, and carcinogenic potential, PAHs are a serious environmental concern (Douben PE, 2003). The incomplete burning of organic materials like tobacco, fossil fuels, wood, and petroleum products results in the formation of PAHs, which are common pollutants and significant contributors to air pollution. For instance, the authors has discovered a considerable number of PAHs in Iraqi street dust (Grmasha RA et al., 2023). Increased water pollution is frequently reported because of the country's rapid industrialization and urbanization. Due to PAHs toxicity as mutagenic and carcinogenic, its toxicity depends on the type of species, molecular structure, and exposure routes (Douben PE, 2003). PAHs can enter the human body through different routes; inhalation, oral intake, and dermal, causing adverse effects on human health, including some major cardiovascular and respiratory diseases (Adeniji AO et al., 2019). The United States Environmental Protection Agency (USEPA) has declared sixteen PAHs as priority pollutants based on PAHs' toxicity. Large amounts of industrial and agricultural wastes are dumped into Burullus Lake through drains. There aren't many studies that show PAHs pollution in Burullus Lake. This article describes the occurrence, distribution, and assessment of the risk to humans and the environment caused by PAHs contamination in Burullus Lake. Therefore, this study aimed to quantify the PAHs levels in the sediment of Burullus Lake. The US-EPA Hazard Quotient Risk was also used to estimate the potential level of human health risk.

2. Materials and methods

2.1. Study area

Burullus Lake is the second largest northern lake along the Nile Delta and the coast of the Mediterranean Sea in Egypt. The Mediterranean Sea borders it on the north, and agricultural land borders it on the south. It has a total area of nearly 453 km². It is characterized by typical Mediterranean

weather, including a warm, dry summer with few diurnal temperature variations and a cool, rainy winter. Most precipitation happens in the winter (Abd El-Hamid HT, 2020). Many floating vegetation types, such as reeds submerged in the lake, are responsible for changing the ecosystem of water (El-Aify MA et al., 2023). The selection of seven important stations in front of drains in Lake Burullus was estimated accurately using GPS and recording latitude and longitude as in Table 1. Sampling sites were pointed, and the source of PAHs in Burullus Lake has been attributed to activities that account for the visible presence of petroleum on the surface water and sediment, as shown in Fig. 1.

2.2. Sampling and Experimental Analysis

Seven sediment samples were systematically taken from the southern part of the Lake's drains. Stainless steel was used to collect sediment samples. Prior to analysis, the samples were stored in the refrigerator at 16°C (Kafilzadeh F et al., 2011). Drying the collected sediment samples allowed for a more thorough analysis of PAHs. A 1 : 1 mixture of n-hexane and dichloromethane was used as the extraction solvent during the expedited solvent extraction process for 12 hours. The PAHs compounds were pre-concentrated using a rotary evaporator to 145 an appropriate volume of 10 mL. After that, a solvent exchange occurred by adding 5 mL of acetonitrile, concentrated to 1 mL. The extracted sample was separated by using HPLC. Spiked standard 100×10^{-6} , and the volume of standard added 0.375 mL. Helium was used as a carrier gas for GC-MS analysis at 1.5 mL/min with an HP-5MS gas chromatography column (30 m × 0.32 mm × 0.25 μm). The injector temperature was set at 300°C, and selective ion scanning (SIM) mode was used for quantitative analysis. The oven temperature was firstly adjusted at 100°C for 1 min and then increased to 300°C at a rate of 8°C /min and was held at 300°C for 39 min. Blanks and reference samples were measured to check for analysis accuracy.

2.3. Quality assurance and quality control (QA/QC)

The quality control process included the blank method, matrix spike, and sample parallel sample for quality assurance. The internal standard was added to each sample for quality control. Both precision and recovery experiments were conducted. The recovery rate of the three test additions was 82.64%–116.28%. The relative standard deviation of the parallel samples was controlled within 15%. The detection

Table 1. Latitudes and longitudes of sampling sites in Burullus Lake.

Samples No.	Location	Longitude	Latitude
1	El-Burullus drain (east)	31.55808	31.07369
2	Brinbal Canal	31.40636	30.59241
3	El-Shakhloubah	31.41303	30.76525
4	Drain 8 (Damro)	31.429338	30.846711
5	Drain 7	31.46558	30.93819
6	El-Khashah drain	31.52844	31.08222
7	El-Hokx	31.38764	30.60425

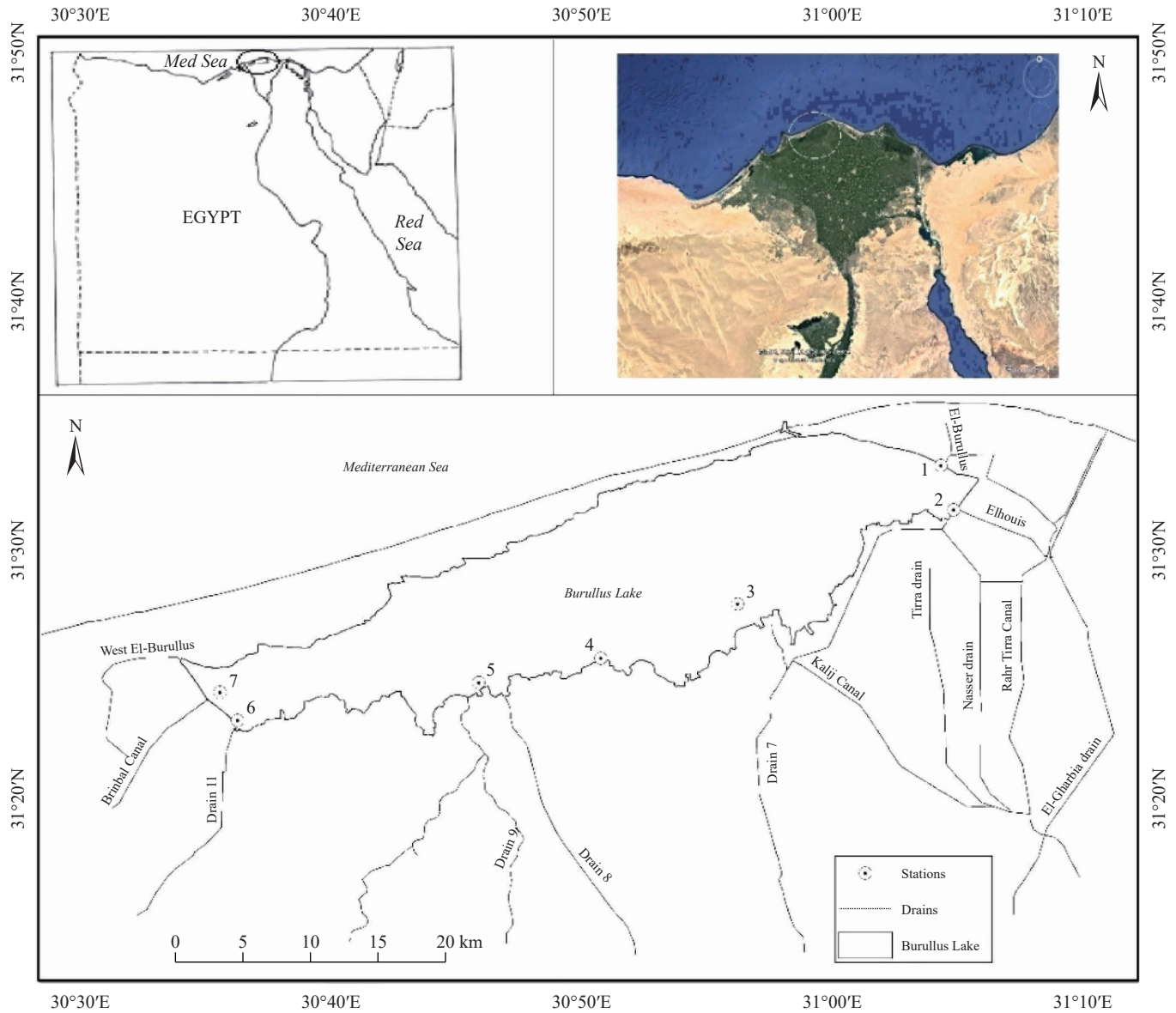


Fig. 1. Sampling sites of sediments in the study area.

limit of the instrument was 2.0–10.0 $\mu\text{g}/\text{kg}$ (Chen C et al., 2022).

2.4. PAHs Diagnostic Ratios

Statistical methods have been applied to identify the sources of PAHs, including Molecular Diagnostic Ratios (MDRs), Principal Component Analysis (PCA), Chemical Material Balance (CMB) model, Positive Matrix Factorization (PMF) method, and stable carbon isotopic ratio analysis (Yunker MB et al., 2002). MDRs were employed in this study to deduce the potential sources of PAHs, as shown in Table 2. Therefore, isomer pairs of PAHs, such as BaA/ (BaA + Chr) and Flt/ (Flt + Pyr).

2.5. Risk assessment

2.5.1. Risk evaluation for non-carcinogens

In the current study, specific indices were used as follows

Table 2. Diagnostic ratios with value ranges reported for different sources.

PAHs Ratio	Value Ranges	Source
Flt/ (Flt + Pyr)	<0.4	Petrogenic
	0.4–0.5	Petrogenic
	>0.5	Fossil fuel combustion grass/wood/coal combustion
BaA/ (BaA + Chr)	<0.2	Petrogenic
	0.2–0.35	Mixed sources
	>0.35	Combustion

to assess the risk of hydrocarbons in sediments, As stated by (US EPA, 2004):

$$ADD_{\text{derm}} = \frac{C \times CF \times Kp \times EF \times ED \times EV \times SA}{BW \times AT}$$

Where: ADD_{derm} is the average daily doses by dermal contact ($\text{mg}/\text{kg}/\text{day}$); C represents the pollutant's concentration (mg/kg); EF is the exposure frequency; ED

stands for the exposure duration; BW is the average body weight; AT is the average time; SA means the exposed skin area; Kp (cm/h) represents the dermal permeability coefficient; ET means the exposure time of shower and bathing, and CF stands for unit conversion factor (L/1000 cm). All data are mentioned in Table 3. Based on US EPA Hazard Quotient Risk Calculation (US EPA, 1989), the hazard index (HI) was calculated as the sum of the HQs for all the congeners in each sample.

$$HQ = \frac{ADD}{RFD}$$

$$HI = \sum HQ_s$$

Which is the dermal reference dose for each organic pollutant and was only available for 6 of the 16 priority PAHs as shown in Table 2.

2.5.2. Risk evaluation for carcinogens

The carcinogenic risks in the current study were determined using LADD (mg/kg/day), incremental lifetime cancer risk (ILCR), risk index (RI), and CSF (cancer slope factor for each congener). The sediment samples' CSF for BaP is 7.3 mg/kg/day (US EPA, 2015). Some equations were also used to assess the risk and toxicity of dermal contact in both adults and children:

$$ILCR = LADD \times CSF$$

$$RI = \sum ILCR$$

The toxic equivalent quotient (TEQ), also known as the cancer-causing potential of high molecular weight PAHs, and the mutagenic equivalent quotient (MEQ), also known as each congener's ability to alter human DNA (deoxyribonucleic acid), were calculated by multiplying the individual toxic equivalent factors (TEF) and mutagenic equivalent factors (MEF) of each congener with the mean concentration of each PAHs in the sediment samples:

Table 3. Parameters used for human health risk assessment calculation.

Factor	Unit	Value	
		Adult	Child
CF	mg/kg	10×10^{-6}	10×10^{-6}
AF	mg/cm ² ·event	3.327	13.212
ABS _d	days/year	0.13	0.13
EF	year	219	219
ED	event/day	9	9
EV	event/day	1	1
SA	cm ²	5700	5700
BW	kg	70	15
AT	Days/year	–	–
DAD	mg/kg·day	–	–
DA _{event}	mg/cm ² ·event	–	–
SF _{ABS}	mg/(kg/day)	8.202	8.202
SF ₀	mg/(kg/day)	7.3	7.3
RFDABS	mg/(kg/day)	0.002	0.002

$$TEQ = \sum C_n TEF_n$$

$$MEQ = \sum C_n MEF_n$$

Where TEQ: is the toxic equivalent quotient and MEQ is the mutagenic equivalent quotient. TEF_n, MEF_n, and C_n stand for the concentration of each PAHs congener (n), the toxic equivalent factor (TEF_n), and the mutagenic equivalent factor (MEF_n), respectively. The sum of the carcinogenic PAHs concentrations in all sediment samples was multiplied by the mutagenic equivalent factor (MEQ) or toxic equivalent factor (TEQ) to determine these values (Adeniji AO et al., 2019).

3. Results

3.1. Concentrations of PAHs in Burullus Lake

Burullus Lakes' PAHs concentrations and effects were described as effect range-low (ER-L) and effect range-median (ER-M), respectively, as mentioned in Table 4. The total PAHs in sediments were as follows: 0.263 µg/g, 0, 0.126 µg/g, 0.459 µg/g, 0.309 µg/g, 0, and 0.038 µg/g for samples, respectively. As shown, the concentrations of PAHs in samples 2 & 6 did not exceed the detected limit of the instrument. The concentrations of PAHs were presented in Fig. 2. Based on the correlation, Anthracene has a positive significance correlation with Fluoranthene, Pyrene, Benzo (g, h, i) Perylene, and Chrysene with 0.67, 0.69, 0.67, and 0.81, respectively. Also, Fluoranthene positively correlates with Pyrene and Acenaphthylene at 0.68 and 0.72, respectively. Finally, a high positive Benzo (g, h, i) Perylene with Chrysene as 0.97 as shown in Table 5. Based on the high positive correlation between Benzo (g, h, i) Perylene and Chrysene, a linear equation was applied, as shown in Fig. 3. The concentration of all PAHs was lower than the ER-M values, but PAHs like Naphthalene, Fluoranthene, Acenaphthylene, and Benzo (g, h, i) Perylene have higher concentration values than the ER-L. Sediment samples that accounted for; 40.8%, 35.7%, 20.6%, and 3.5% for PCs-PC-1, PC-2, PC-3, and PC-4 of the total variance were used to extract the four principal components. Inferences about possible sources of PAHs in sediments were made using the final coefficients of the eigenvectors based on the PCs (Table 6).

3.1.1. Sources of PAHs in Burullus Lake

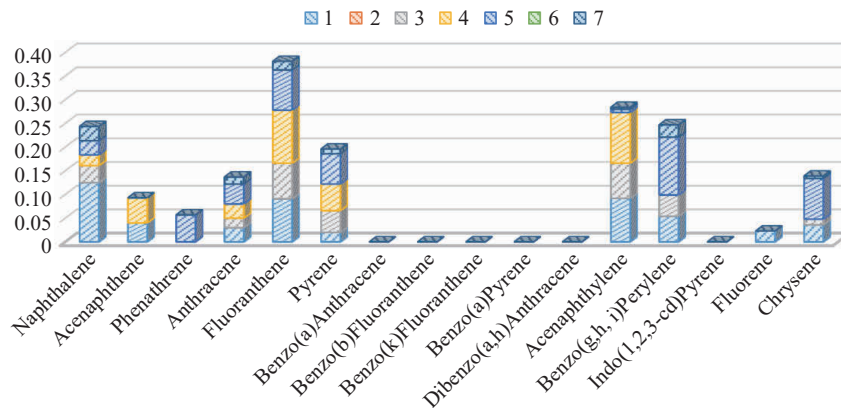
There are different main sources of PAHs in the aquatic environment; petrogenic (exploration, tanker processing, and accidents involving oil spills), pyrolytic (incomplete combustion of organic matter components such as fossils and coal), and biogenic (Shen H et al., 2013). Diagnostic ratios have been applied to identify the PAHs sources (Ravindra K et al., 2008). The Ant/Ant+Phe ratio data indicated that sites are of pyrogenic sources. According to the ratio of BaA/BaA+Chy, it means combustion sources in Burullus Lake, as shown in Fig. 4. Based on these data, the ratio of PAHs is related to pyrolytic not petrogenic, as no source of petroleum

Table 4. Concentrations of PAHs ($\times 10^{-6}$) in sediments of Burullus Lake drains.

Parameter	1	2	3	4	5	6	7	Total	Standard toxicity	
									ER-L	ER-M
Naphthalene	0.125	0	0.036	0.0227	0.03	0	0.03	0.2437	0.16	2.1
Acenaphthene	0.04	0	0	0.053	0	0	0	0.093	0.016	0.5
Phenathrene	0	0	0	0	0.057	0	0	0.057	2.4	1.5
Anthracene	0.03	0	0.02	0.03	0.042	0	0.015	0.137	8.53	1.1
Fluoranthene	0.091	0	0.075	0.112	0.085	0	0.018	0.381	0.019	0.54
Pyrene	0.02	0	0.046	0.056	0.064	0	0.01	0.196	0.665	2.6
Benzo (a) Anthracene	0	0	0	0	0	0	0	0	–	–
Benzo (b) Fluoranthene	0	0	0	0	0	0	0	0	–	–
Benzo (k) Fluoranthene	0	0	0	0	0	0	0	0	–	–
Benzo (a) Pyrene	0	0	0	0	0	0	0	0	–	–
Dibenzo (a, h) Anthracene	0	0	0	0	0	0	0	0	–	–
Acenaphthylene	0.092	0	0.074	0.107	0.007	0	0.004	0.284	0.044	0.64
Benzo (g, h, i) Perylene	0.054	0	0.045	0	0.122	0	0.026	0.247	0.085	1.6
Indo (1, 2, 3-cd) Pyrene	0	0	0	0	0	0	0	0	–	–
Fluorene	0.023	0	0	0	0	0	0	0.023	0.019	0.54
Chrysene	0.036	0	0.012	0	0.086	0	0.005	0.139	0.384	2.8
$\Sigma 16$ PAHs	0.263	0	0.126	0.459	0.309	0	0.038	–	–	–

Table 5. Correlation matrix of PAHs in sediments of Burullus Lake drains.

	Naphthalene	Anthracene	Fluoranthene	Pyrene	Acenaphthylene	Benzo (g, h, i)	Chrysene
Naphthalene	1						
Anthracene	0.10	1					
Fluoranthene	0.19	0.67	1				
Pyrene	-0.48	0.69	0.68	1			
Acenaphthylene	0.37	0.01	0.72	0.13	1		
Benzo (g, h, i)	0.10	0.67	0.05	0.36	-0.54	1	
Chrysene	0.15	0.81	0.20	0.42	-0.45	0.97	1

**Fig. 2.** Concentrations of PAHs in Burullus Lake drains.

contamination around Burullus Lake. El-Shakhloubah and El Hox were related to petrogenic due to several electric boats for fishing.

3.2. Principal component analysis (PCA)

Principal component analysis (PCA) is crucial for applying similarities and differences between additional data and facilitating better visualization (Doong R and Lin Y 2004). The sediment sample PCA analysis was carried out in this study. Sediment samples that comprised more than 40% and 35% of the sediment were used to extract the two

principal components (PCs-PC1 and PC2). The PAHs load at PC-1 and PC-2 was described by the PCA biplot of the sediments in Fig. 5. Based on diagnostic ratios and principal component analysis (PCA), sites 1 and 4 are positively correlated with one another and negatively correlated with sites 3 and 7. Additionally, PC1 is linked to the PAHs Phenanthrene and Anthracene, the main contributors to the contamination of PAHs in Burullus Lake sediments. On the other hand, Naphthalene and fluoranthene do not affect the contamination of PAHs. Finally, PC4 does not represent a contamination interface for PAHs. Site 5 strongly correlates with PC1 according to a site's PCA.

3.3. Risk assessment of PAHs in Burullus Lake

3.3.1. Non- carcinogenic effect

Because of the presence of organic pollutants like PAHs, particularly in lakes connected to the marine environment, lakes do not have a carcinogenic effect from PAHs according to selected indices in the study area. The results of the non-carcinogenic hazard test are shown in Table 7. HI, which is the total of the HQs in each category, typically ranged

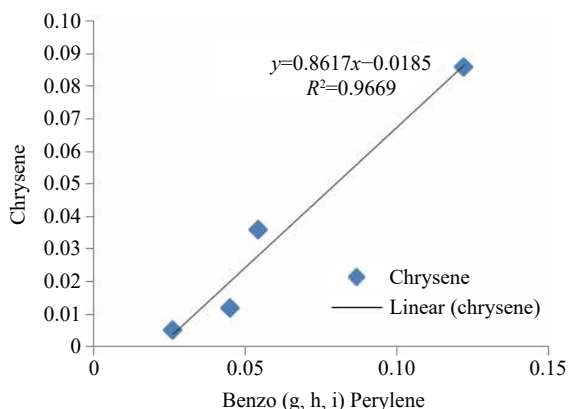


Fig. 3. Linear regression between chrysene and Benzo (g, h, i) in Burullus Lake drains.

Table 6. Extracted principal components (PC-1, PC-2, PC-3, and PC-4) analysis of sediments samples.

	PC-1 (40.08%)	PC-2 (35.71%)	PC-3 (20.66%)	PC-4 (3.54%)
Nap	0.43	5.13	33.98	1.92
Ace	0.37	22.72	0.09	22.87
Phe	19.85	2.8	0.1	3.17
Ant	19.59	2.68	0.53	4.81
Flu	5.2	18.01	1.12	9.74
Pyr	13.4	1.11	13.48	15.25
Acenap	1.43	21.33	0.56	22.19
B.ghi.P	15.22	3.43	7.49	6.14
Flun	0.38	6.7	31.68	0
Chr	18.08	0.96	7.26	0.02
Total	6.05	15.14	3.71	13.89

between 0.0025 and 0.014 for adults and children.

3.3.2. Carcinogenic effect

Some indices were used to estimate the carcinogenic risk. The RI is the most significant index for measuring the carcinogenic potential of sediments. RI is the total of the ILCRs, which, as shown in Table 8, are 0.00076 for adults and 0.0017 for children. The study's overall TEQ and MEQ values for Chrysene were 0.00139 and 0.002363, respectively. Additionally, as shown in Table 9, the TEQ and MEQ for Benzo (g, h, I perylene were 0.00247 and 0.04693, respectively.

4. Discussion

Contamination of PAHs in sediments in the present study was compared with sediment quality guidelines (SQG). Brinbal Canal may have low levels of PAHs because it receives a lot of fresh water, in contrast to El-Khashah drain, which receives a lot of domestic and agricultural waste and allows people to avoid fishing there. So, it is extremely uncommon for ships to sail in this location. Additionally, the findings indicate that Drain 8 (Damro) receives many industrial pollutants, such as oil, grease, and other hydrocarbon sources. Burullus Lake has low severe pollution based on previous data. Additionally, there are relatively few studies on PAHs in Burullus Lake, and the collected data is limited, so it is necessary to strengthen the monitoring of PAHs pollution. El-Zeiny A and El-Kafrawy S (2017) mentioned that high levels of organic matter were recorded at the lake's edges, mainly on the southern borders. These levels reflect the high load of organic matter discharge in sectors that receive high amounts of agricultural and sewage wastes from different sources. It was shown that Fluoranthene has the highest compound in sediment samples along the study area. This PAHs predominance may be attributed to preferential degradation occurring during PAHs transport and burial into sediments (Guo W et al., 2007). Different sources of PAHs have specific composition ratios (De Almeida M et al., 2018). Primary sources of PAHs produced from petrogenic

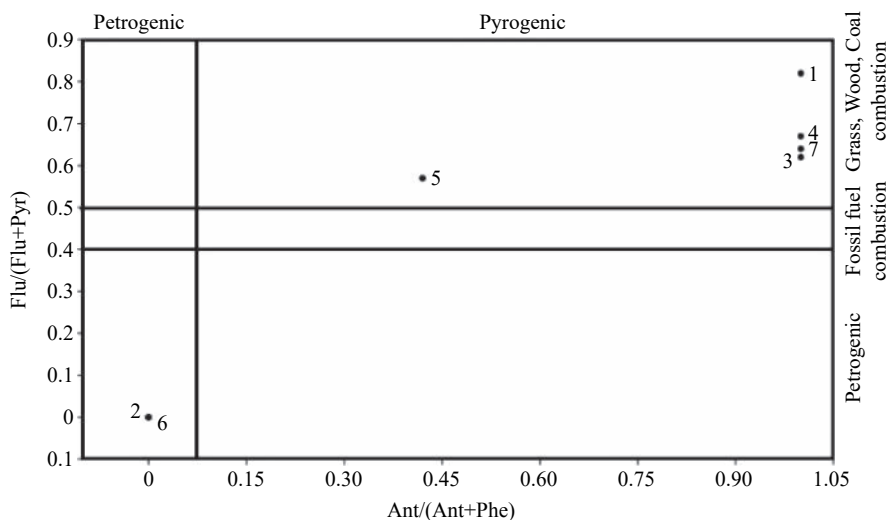


Fig. 4. Cross plots indicate the diagnostic ratios for the sources of PAHs.

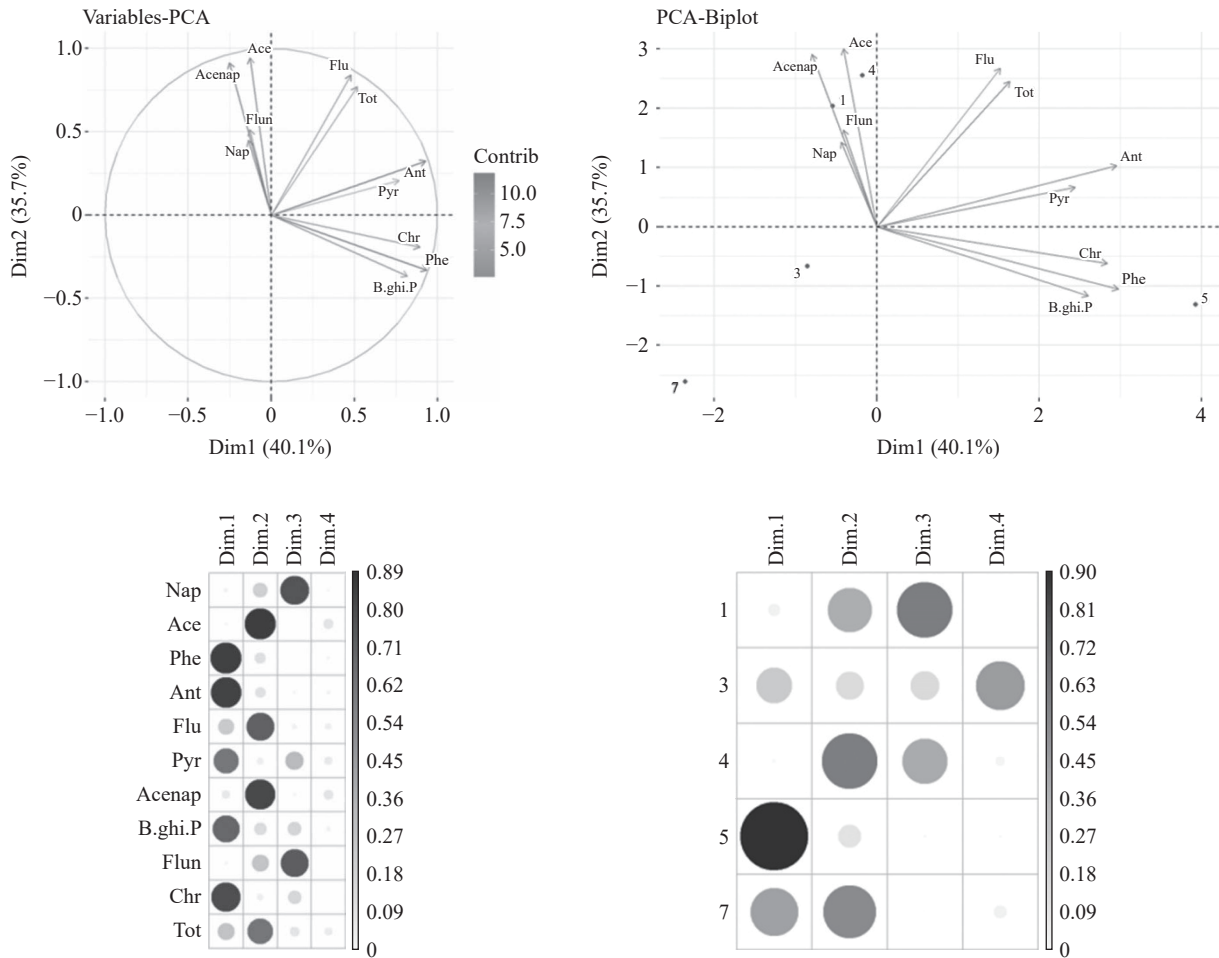


Fig. 5. The PCA biplot showing loads on PC-1 and PC-2 in sediments of Burullus Lake.

Table 7. Hazard quotients (HQs) of PAHs in sediment samples in Burullus Lake.

PAHs	RFD	Dermal absorption	
		Adult	Child
Naphthalene	0.02	0.00257	0.0059
Phenanthrene	0.04	9.88×10^{-7}	0.00069
Anthracene	0.04	3.22×10^{-6}	0.0014
Fluoranthene	0.04	1.48×10^{-6}	0.0046
Benzo (g, h, i) perylene	0.04	8.7×10^{-7}	0.002337
Fluorene	0.04	–	–
HI	–	0.00257	0.014927

Table 8. Incremental lifetime carcinogenic risk (ILCR) of PAHs in sediment samples of Burullus Lake.

PAHs	CSF	Dermal absorption	
		Adult	Child
Naphthalene	0.73	3.75926×10^{-5}	8.61772×10^{-5}
Phenanthrene	7.3	0	0
Anthracene	0.73	8.79269×10^{-5}	0.000201564
Fluoranthene	7.3	1.80482×10^{-5}	4.13736×10^{-5}
Benzo (a) pyrene	0.73	0.000587722	0.001347293
Fluorene	0.73	2.97718×10^{-5}	6.82487×10^{-5}
Chrysene	0.073	0	3.64229×10^{-6}
RI	–	0.00076265	0.001748298

Table 9. TEQ and MEQ of PAHs in the sediment samples of Burullus Lake.

PAHs	TEF	Calculated TEQ (mg/kg)	MEF	Calculated MEQ (mg/kg)
Benzo (a) anthracene	0.1	–	0.082	–
Chrysene	0.01	0.00139	0.017	0.002363
Benzo (b) fluoranthene	0.1	–	0.25	–
Benzo (k) fluoranthene	0.1	–	0.11	–
Benzo (a) pyrene	1	–	1	–
Dibenzo (a, h) anthracene	1	–	0.29	–
Indeno (1, 2, 3-cd) pyrene	0.1	–	0.31	–
Benzo (g, h, i) perylene	0.1	0.00247	0.19	0.04693

(exploration, tanker processing, and accidents of oil spills), pyrolytic (incomplete combustion of organic matter components such as fossil and coal), and biogenic (Shen H et al., 2013). According to Anifowose AJ et al. (2021), there are two main routes of PAHs sources in a marine environment: petrogenic or pyrolytic processes such as coal and or wood burnings and emissions from gasoline and diesel engines. To identify potential sources of PAHs in the soil, Phe/Ant,

Flu/Pyr, and Pyr/Bap are combined with the environmental characteristics of the study area, such as industrial layout and type of pollution discharge (Qu YJ et al., 2020). Other potential sources include sporadic oil spills, vehicle deposits, and engine leaks on asphalt-tarred roads, which, when they build up in the surficial sediment, are toxic to benthic fauna and can cause developmental malformations, loss of reproductive ability and many diseases in marine mammals (Klages N et al., 2011). The atmospheric deposition of dust containing PAHs into the marine environment could be another reason for high PAHs levels. Sources of PAHs resulting from incomplete fuel combustion and wood burning are described in PC-1.

Some PAHs like Fluoranthene and Dibenzo (a, h) Anthracene are mainly related to vehicular emissions (Tavakoly SS et al., 2014). PAHs were exactly associated with oil spills, shipping, drainage water inputs, and industrial activities (Farid NA et al., 2015). It is clear from PCA and diagnostic ratio that the sources of PAHs in Burullus Lake are coal combustion and pyrolysis. As a result, PC-1 outlines the sources of PAHs from incomplete fuel combustions and wood burning, which are real-world occurrences in the region because crude oil refiners use wood for heating without considering the environmental impact (Howard IC et al., 2021). Grmasha RA et al. (2023) mentioned that PC1 accounted for 26.60% of the variance, and its representative PAHs were Nap, Acy, Ace, FI, BaA, Chr, BbF, BaP, BghiP, and IND. PC2 accounted for 18.55% of the variance, with Flu, Pyr, BaP, and DBA representative PAHs. The PC3 was responsible for 15.83% of the variance in PAHs.

Additionally, these values fell below the advised limit set by the US Environmental Pollution Agency (Benson NU et al., 2017). Results and studies showed that adults with the highest risks are more susceptible than children to non-carcinogenic risks (Karyab H et al., 2016). *HQ* or *HI* 1 indicates no detectable non-carcinogenic risk, while a value greater than 1 indicates a significant effect (Titilawo Y et al., 2018). There is no chance of any non-carcinogenic effects from dermal contact, according to the *HQs* obtained in this study concerning human exposure to the contaminants, which were all less than 1. The *TEQs* indicated no cancer risk to those exposed to the marine sediment, and the *MEQ* revealed that the congener could, to some extent, cause a number of other health issues in humans besides cancer after exposure (Hussein RA et al., 2016). Low intelligence quotient, lung conditions, congenital disabilities, impotence, and many other issues are examples of such issues (Hsu H et al., 2014). As previously reported in comparable studies, this study's exposure to PAHs is considerably less than that from other sources of exposure (Wang L et al., 2018). Grmasha RA et al. (2023) showed a possible effect range with occasional biological effects of most measured PAHs in all sediment samples. Studying such relationships in the future might provide helpful and deeper insights into the dynamics of these compounds.

5. Conclusion

The environmental pollutants known as polycyclic

aromatic hydrocarbons (PAHs) are pervasive and pose hazardous effects on the environment and human health. The second-largest lake in Egypt's Delta, Burullus Lake, primarily supports food security. All PAHs concentrations were below ER-M values, but those of benzo (g, h, I) perylene, acenaphthylene, fluoranthene, and naphthalene were above ER-L values, indicating a potential ecological risk. According to diagnostic ratios analysis, the pyrolytic origin and fuel combustion were attributed to the PAHs in sediment samples. According to PCA, PC-1, and PC-2 account for more than 75% of the data in the study area. Burullus Lake's sediments are primarily contaminated by phenanthrene and anthracene, which are linked to PC1. The non-carcinogenic indices support the low-risk status of all data for adults and children. The values of HI in the study area are lower than 1 indicating no significant adverse risk. The present study shows that all carcinogenic and non-carcinogenic effect of PAHs has no negligible risk to human health. This study emphasizes the need for the local population to exercise caution when fishing or otherwise using the water in this area. This research is the first comprehensive study to evaluate human and ecological health risks due to exposure to PAHs in this location's sediment samples. Given that, hydrocarbon contamination has no impact on Burullus Lake. For Burullus Lake to have a healthy environment and produce fish, proactive measures must be taken.

CRedit authorship contribution statement

Hanan E. Osman, Mohamed H. El-Morsy and Hazem T. Abd El-Hamid conceived, designed, and performed the experiments. Hanan E. Osman, Mohamed H. El-Morsy, and Hazem T. Abd El-Hamid analyzed interpreted the data and contributed reagents, materials, analysis tools, or data. All authors provided critical feedback and helped shape the research, analysis and manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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