The North African Journal of Scientific Publishing (NAJSP)
مجلة شمال إفريقيا للنشر العلمي (NAJSP)
E-ISSN: 2959-4820
Volume 4, Issue 3, 2026
Page No: 21-31
Website: https://najsp.com/index.php/home/index
SJIFactor 2024: 5.49 معامل التأثير العربي (AIF) 2025: 0.69 ISI 2024: 0.696

A study to assess environmental pollution by aromatic hydrocarbons (PAHs) in sediments of the coast of Tripoli City, Libya

Jumaa Al-Mansouri Tentoush*
Department of Environmental Science and Technology, Higher Institute of Science and Technology, Al-Zahraa, Libya.

دراسة لتقييم التلوث البيئي بالهيدروكربونات العطرية متعددة الحلقات في رواسب ساحل مدينة طرابلس، ليبيا

جمعة المنصوري تنتوش*
قسم علوم وتكنولوجيا البيئة، المعهد العالي للعلوم والتكنولوجيا، الزهراء، ليبيا

*Corresponding author: Tntieej@gmail.com

Received: April 18, 2026	Accepted: June 28, 2026	Published: July 10, 2026

Abstract:
This study assessed the distribution, environmental risks, and sources of sixteen priority (PAHs) in surface sediments collected from ten sites along the coast of Tripoli, Libya. Total (ΣPAHs) concentrations range from 7.569 to 12.250 ng/g dry weight, with an average of 9.696 ng/g, indicating low pollution levels. The highest concentration was recorded at Station 6 near Tripoli Seaport, while the lowest was recorded at Station 9. Environmental risk assessment, based on sediment quality criteria such as ERL, ERM, TEL, and PEL, showed that all PAHs concentrations were well below the threshold values, indicating a minimal risk to aquatic organisms and marine life. Combustion-derived ΣPAHs (ΣCOMB) range from 5.493 to 10.190 ng/g, while fossil fuel-derived ΣPAHs (ΣTFPAH) ranged from 1.251 to 1.887 ng/g, and carcinogenic ΣPAHs (ΣCARC) ranged from 5.493 to 9.627 ng/g. Principal component analysis (PCA) identified two main sources of (PAHs): combustion inputs, consisting of high molecular weight compounds (BaP, BbF, BkF, and BghiP) associated with ship emissions and industrial activities around the port of Tripoli, and petroleum-derived inputs, consisting of low molecular weight compounds (Ace, Phe, and Anth) associated with fuel spills and oilfield activities in coastal fishing areas. In general, the sediments along the Tripoli coast show low levels of (PAHs) and minimal environmental risks, but continued environmental monitoring is recommended to ensure the long-term protection of the marine ecosystem.

Keywords: Tripoli coast, Libya; sediment analysis; PAHs; sediment quality guidelines; marine pollution.

الملخص:
في هذه الدراسة تم تقييم توزيع ومخاطر ومصادر 16 مركباً من (PAHs) ذات الأولوية في الرواسب السطحية المجمعة من 10 مواقع على طول ساحل طرابلس، ليبيا. تراوحت تراكيز ΣPAHs بين 7.569 و12.250 نانوغرام/غرام من الوزن الجاف، بمتوسط 9.696 نانوغرام/غرام، مما يشير إلى مستويات تلوث منخفضة. سُجل أعلى تركيز في المحطة 6 قرب ميناء طرابلس، وأدنى تركيز في المحطة 9. أظهر تقييم المخاطر البيئية اعتماداً على معايير ERL وERM وTEL

وPEL أن جميع القيم كانت أقل بكثير من الحدود المرجعية، مما يدل على مخاطر ضئيلة على الكائنات المائية. تراوحت ΣCOMB بين 5.493 و10.190 نانوغرام/غرام، وΣTFPAH بين 1.251 و1.887 نانوغرام/غرام، بينما تراوحت ΣCARC بين 5.493 و9.627 نانوغرام/غرام. وأظهر تحليل المكونات الرئيسية (PCA) مصدرين رئيسيين: مصدر احتراقي يتكون من مركبات عالية الوزن الجزيئي (BaP، BbF،BkF ، BghiP) مرتبط بانبعاثات السفن والأنشطة الصناعية قرب ميناء طرابلس، ومصدر بترولي يتكون من مركبات منخفضة الوزن الجزيئي (Ace، Phe،Anth) مرتبط بتسربات الوقود وأنشطة حقول النفط في مناطق الصيد الساحلية. بشكل عام، تشير النتائج إلى مستويات منخفضة من PAHs ومخاطر بيئية طفيفة في رواسب ساحل طرابلس، مع التوصية بالاستمرار في الرصد البيئي لضمان حماية النظام البيئي البحري على المدى الطويل.

الكلمات المفتاحية: ساحل طرابلس، ليبيا؛ تحليل الرواسب؛ الهيدروكربونات العطرية متعددة الحلقات؛ معايير جودة الرواسب؛ التلوث البحري.

Introduction:

Environmental pollution in general and marine pollution in particular is one of the biggest problems facing the world today. It is a rapidly growing problem that poses a threat not only to the environment but also to human lives. It was found that diseases related to water and pollution are among the main causes of death in the world. Despite these severe and serious problems that developing countries suffer from, developed countries also still suffer from water problems, especially in closed areas, from water pollution problems. (Dozier, 2005).

There are many factors causing environmental pollution, the most important of which is the large increase in the world's population and the human activities resulting from it. Aquatic systems are very sensitive to pollution. Marine pollution, Water contamination caused by chemical, physical, and radioactive pollutants, which contributes to disease and premature mortality, has become a major global environmental concern. Continuous monitoring and assessment, supported by integrated water resource policies at local, national, and international levels, are essential to mitigate its impacts. Petroleum hydrocarbons are ubiquitous organic pollutants in coastal areas and can be broadly classified into aliphatic and aromatic hydrocarbons, which can be extracted from abiotic, petrogenic, and biogenic sources (Seopela et al., 2020).

Sources of hydrocarbons in sediments vary in their origin but may include incomplete combustion of fossil fuels, biosynthesis of hydrocarbons by terrestrial or marine organisms, and various petroleum processes related to the oilfield industry, i.e., drilling, extraction, transportation, accidental spills, and oil spills. and gas (Abdulla et al. (2023) ، Kucuksezgin et al., 2012). TPH undergoes significant changes in composition once in the sea due to evaporation, photochemical oxidation, biodegradation and selective dissolution. Short-chain alkanes and aromatics containing only a few carbon rings are lost quickly, while complex aromatic molecules are more stable and can be used to identify the source of contamination (Abdulla et al. (2023) ، Kucuksezgin et al., 2012).

Surface sediments are an important vehicle for the accumulation of ΣPAHs and can be transported in water and air, interfer and accumulate in marine sediments by adsorption and desorption. (Hydrophobic compounds are mostly deposited in marine sediments through association with solid particles (Wang et al., 2015a). TPH are lipophilic substances, which promote bioaccumulation in the marine food chain. Research has shown that TPH can It is easily obtained and absorbed in the digestive system (Gupta, 2016) Hydrocarbons have received increasing attention owing to the damage they inflict.serious environmental problems, due to their toxicity and carcinogenic and lethal effects to most marine organisms, especially the class of polycyclic aromatic substances (Al-Nemr et al., 2013).
Therefore, sediments are considered a reservoir for various pollutants, and the levels of polycyclic substances in sediments vary according to the analysis of proximity to the locations of activity areas. Marine sediments are a useful indicator for identifying and tracking pollution levels and sources and assessing the environmental impact and threat to the ecosystem (Shraidah et al., 2013). Assessing concentrations of aliphatic hydrocarbons (AHs) and polyaromatic hydrocarbons (PAHs) in coastal sediments provides insight into their distribution and can highlight pollution hotspots associated with oil production (Sammarco et al., 2013, Abdulla et al. 2023).

The partitioning of PAHs between water and sediments is primarily governed by sediment characteristics, particularly organic matter content and grain size. (Weber et al., 1992; Gustafsson et al., 1997. The study area is located along the northern coast of Tripoli, Libya, on the southern shore of the Mediterranean Sea. This area is considered a hotspot for human activities, transportation, and maritime traffic. Marine sediments provide a valuable archive for assessing the historical status of environmental pollution, identifying its sources, and understanding its transport and distribution pathways over time.

Surface sediments in the study area along the northern coast of Tripoli, Libya, on the southern margin of the Mediterranean Sea, exhibit varying degrees of contamination. This region is characterized by intense human activity, making it one of the most anthropogenically impacted areas in western Libya. Consequently, there is an urgent need for a more comprehensive assessment of hydrocarbon pollution in this coastal zone. Sediment samples were collected from across the study area and analyzed to determine grain size distribution, total organic carbon (TOC), polycyclic aromatic hydrocarbons (PAHs).

Materials and Methods:

Study area and sampling:

Study area:

The study area extends along the northern coast of Tripoli, Libya, located in the southern Mediterranean Sea, for a distance of approximately 90 nautical kilometers from the Garabuli fishing marina, located east of Tripoli at 32°47'43.79"N - 13°44'48.17"E, to the Sayyad marine marina, located west of Tripoli at 32°49'25.80"N - 12°57'19.83"E. The study area is considered a major attraction as a transportation, transit, and movement area for human activities (Tantoush, (2026). The city is characterized by a semi-arid climate. As is the case with the rest of the northern Libyan coast, the northerly winds blowing across the Mediterranean Sea are dominant. The climate of the city is characterized by a Mediterranean regime, which is associated with hot, dry summers. June, July, and August are the hottest months of the year. The average monthly temperatures during these months range between 32 and 34.2°C. December, January, and February are the winter months. Average temperatures range from approximately 12 to 18 degrees Celsius, with March–May and September–November being the mildest months. (Tantoush, (2026).

Sample taking and preparation:

Marine sediment samples were taken in 2025. Ten surface sediment samples were collected from 10 stations in the study area, stretching 90 kilometers off the coast of Tripoli, Libya.

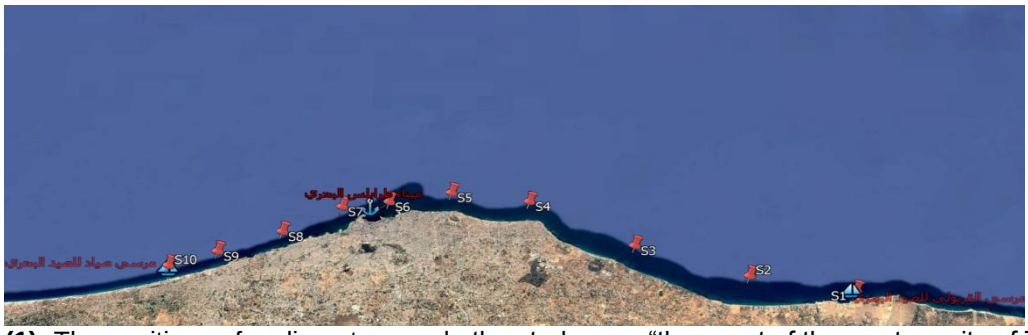

Figure (1): The positions of sediments sample the study area “the coast of the western city of Tripoli - Libya” from a satellite image (Google 2025) (Tantoush, (2026).

Samples were collected manually by diving after selecting the sampling stations. They were then coded from S1 to S10, as shown in Figure 1. Location, coordinates, and distances were determined using GPS as shown in Table 1. Sites were selected to cover the area known to be affected by marine human activities. A kilogram was weighed for each station, and samples were stored in an icebox at 4°C in the laboratory; they were kept frozen until analysis. Samples were allowed to air dry in Petri dishes at room temperature. Each sample was then divided into two subsamples. One subsample was used for grain size analysis, while the other was homogenized using agate mortar to normalize the sediment grain size variation within the sample. The dried homogenized sediment samples were sieved through a 63 µm sieve and stored in clean, sterile plastic containers, ready for TOC analysis as the original powder sample.

Table (1): Locations and associated distances of sediment sampling sites along the coast of Tripoli, Libya (study area) (Tantoush, 2026).

Site no	Latitude (N)	Longitude (E)	Distance among sample (m)	
S1	32°47'52.28 "N	13°44'57.33 " E	Marsa Al-Qarbouli Center -1	340
S2	32°48'58.99 "N	13°37'42.13 " E	1-2	11500
S3	32°51'17.08 "N	13°29'51.05 " E	2-3	13000
S4	32°54'42.65 "N	13°22'27.94 "E	3-4	13150
S5	32°55'26.39 "N	13°16'50.96" E	4-5	8900
S6	32°54'44.91 "N	13°12'24.12 " E	5-6	7100
S7	32°54'20.01 "N	13° 8'59.80" E	6-7	3500

S8	32°52'26.21 "N	13° 4'52.08" E	7-8	7350
S9	32°50'54.30"N	13° 0'25.31 E	8-9	7450
S10	32°49'51.30"N	12°57'5.76 E	9-10	5500

Extraction and Analysis (PAHs) of sediment samples.

The perform analysis (The polycyclic aromatic hydrocarbons) (PAHs). was carried out following the techniques given by UNEP (1995). Each sediment sample (30 g) was Soxhlet extracted w ith 250 mls of hexane for 8 hrs and then re-extracted for 8 hrs into 250 ml of dichloromethane. Then the two extracts were combined and concentrated down using rotary evaporation at 30°C followed by concentration with N2 gas stream down to 1 ml. The compounds were analyzed by GC/ MS. Identification of each compound in the extract was made by comparing the retention times and its spectrum with those taken from HP memory and with the EPA standard at the Laboratories of the National Institute of Marine Science. The samples were analyzed for PAHs following different steps, including extraction, cleaning up, Sulphur removal, fractionation, instrumental analysis, and Analytical quality controls.

Approximately 10 g of freeze-dried sediment samples were analyzed for PAHs using USEPA 8015D and USEPA 8275A method (USEPA, 1993), Sixteen priority polycyclic aromatic hydrocarbons (PAHs) have been identified by the United States Environmental Protection Agency (USEPA) as high-priority pollutants. These include naphthalene (NaP), acenaphthylene (Acy), acenaphthene (Ace), fluorene (Flu), phenanthrene (Phe), anthracene (Ant), fluoranthene (Fla), pyrene (Pyr), benzo(a)anthracene (BaA), chrysene (Chry), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkF), benzo(a)pyrene (BaP), indeno (1,2,3-cd) pyrene (InP), dibenzo (a, h) anthracene (DahA), and benzo (g, h, i) perylene (BghiP). In the present study, these PAH compounds are categorized based on their ring number: those containing 2–3 aromatic rings are classified as low molecular weight (LMW) PAHs, whereas compounds comprising 4–6 rings are classified as high molecular weight (HMW) PAHs.

Column chromatography:

The extracted volumes were purified using a silica–alumina column prepared by slurry packing. The column consisted of 20 mL (10 g) of silica gel, previously activated at 185 °C overnight and subsequently deactivated with 12.5% water, followed by 10 mL (10 g) of neutral alumina (90, 70–230 mesh), also activated at 185 °C overnight and deactivated with 12.5% water. A layer of 1 g anhydrous sodium sulphate was added on top. Elution was carried out sequentially using 40 mL of hexane to obtain the aliphatic fraction, followed by 40 mL of a hexane/dichloromethane mixture (90:10), and finally 20 mL of hexane/dichloromethane (50:50), the latter fractions collectively containing the PAHs. The resulting eluates were then concentrated under a gentle stream of nitrogen (N_2) to a final volume of approximately 0.2 mL.

Sulphur removal:

To eliminate sulphur interference in GC–MS analysis, copper powder was employed following the method described by Sundberg et al. (2005). Prior to use each working day, the copper powder was pre-cleaned with concentrated HCl to remove surface oxides, followed by multiple rinses with ultrapure water, methanol, and acetone. The powder was then dried under a gentle stream of nitrogen gas. The activated copper powder was subsequently added to the collected fractions, where a visible colour change from brassy red to black indicated successful sulphur removal. An excess amount of copper powder was applied to ensure complete elimination of sulphur.

Identification of PAHs:

Blanks concentrated 1000-fold were analyzed using GC–MS (Trace Ultra coupled to DSQ-II, Thermo Electron S.p.A.) equipped with an autosampler. The system was operated in full scan mode (m/z 50–650) with electron ionization at 70 eV, and 3 µL of each sample was injected in splitless mode. PAH concentrations were reported as ng g^{-1} dry weight. Fifteen USEPA priority PAHs were determined, including naphthalene, acenaphthylene, acenaphthene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b/k) fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, indeno (1, 2, 3-cd) pyrene, and dibenz (a, h) anthracene. The GC–MS system used a splitless injector and a TR-35 MS capillary column (30 m × 0.25 mm × 0.25 µm). Helium was the carrier gas at 1.5 mL min^{-1}. The oven program started at 60 °C (1 min), ramped to 100 °C at 8 °C min^{-1} (1 min hold), then to 300 °C at 5 °C min^{-1}, with final hold for ~20 min. Injector and transfer line temperatures were kept under controlled conditions.

Analytical quality controls:

To control the analytical reliability and assure recovery efficiency and accuracy of the results, 6 analyses were conducted on PAH compound reference materials, HS-5 (sediments) provided by NRC-IMB of Canada and SRM-2974 (Freeze-dried mussels tissue) (Mytilus edulis) provided by NIST of USA as well as sediment samples of known PAH levels spiked with a mixture consisting of 2 µg each of PAHs were analyzed as above to validate the analytical method used in this study. Detection Limits

(DL) are provided in Table (2). The recovery efficiency ranged from 93 to 107% for HS-5, 86to 94% for SRM-2974 and 95 to 102% for the spiked samples. The mean recovery for PAHs were as followed: Naph 89.2%, Acthy 91.2%, Ace 104.1%, Flu 96.5%, Pyr 93.5%, BaA 90.7%, Chr 108.4%, BaP 92.6%, BbF 93.5%, DBA 101.8%, BghiP 94.5% and InP 97.5%.7%. (Al-Nemr et al.,).

Table (2): Detection limits for individual PAHs recorded using - GC-MS

Component	DL, µg/ml, dry weight
Naph	0.04
Acthy	0.01
Ace	0.01
Phe	0.02
Ant	0.01
Flu	0.03
Pyr	0.03
BaA	0.04
Chr	0.05
BbF	0.05
BkF	0.05
DBA	0.06
Bghip	0.08
Inp	0.001

2. 4. 2 Concentrations of polycyclic aromatic hydrocarbons in sediment samples from the coast of Tripoli (Libya)

Table (3): Concentrations (ng g^{-1}dry wt) in sediment samples from the coast of Tripoli (study area)

Sit no	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Ace	0.4381	0.40513	0.4292	0.41275	.4548	0.5381	0.4140	0.4318	0.3886	0.4038
Flu	0.44223	0.42059	0.4103	0.41648	.4603	0.5638	0.4354	0.447	0.4068	0.3808
Phe	0.6303	0.6109	0.6516	0.6277	.7052	0.7622	0.6216	0.6311	0.6232	0.6502
Anth	0.4818	0.4712	0.4485	0.48385	.5457	0.5865	0.4669	0.4853	0.4639	0.4505
Pyre	0.1463	0.1425	0.1411	0.1387	.1676	0.1736	0.1443	0.1482	0.1459	0.1419
Chry	0.5923	0.5841	0.5867	0.5866	.6665	0.7211	0.5772	0.5988	0.576	0.582
Be (a)	0.8239	0.821	0.4866	0.8194	.9222	0.9905	0.8292	0.8255	0.8096	0.7943
Be (b) flou	0.3921	0.4037	0.4107	0.3906	.4463	0.5065	0.4073	0.4012	0.4059	0.4092
Be (k) flou	0.4222	0.433	0.4551	0.4206	.4718	0.5431	0.4498	0.4227	0.4484	0.4531
Be (a) pyrene	0.8068	0.8142	0.7735	0.805	.9002	1.02	0.8174	0.8057	0.8153	0.7716
Be (g. h. i)	0.00013	0.00315	0.0108	0.00137	.1380	0.00206	0.00946	0.0115	0.0082	0.00959
In	4.114	4.037	4.0412	4.102	4.512	5.4887	4.083	4.313	4.081	4.0392
Di (a, h)	0.23318	0.28222	0.2864	0.28178	0.9808	0.3546	0.2805	0.2822	0.2294	0.28496
∑PAHs	9.57334	9.42869	9.4319	9.48683	11.37	12،250	9،5361	9.522	7. 569	8.78921

Ace = acenaphthene, Flu = Fluoranthene, Phe = phenanthrene, Anth = anthracene, Pyre = pyrene, Chry = Chrysene, Ba (a) =Benzo(a)anthracene, Be (b) F = benzo(b)fluoranthene, Be (k) F = benzo (k) flouranthene, Be (a) P = benzo (a) pyrene, Be (ghi) = benzo (ghi) peryene, Di (a. h) = dibenzo (a, h) anthracene, In = indenopyrene,

Total (4): Concentration of (Σ TF PAHs) in sediment samples on the Tripoli coast

Sit no	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Ace	0،4381	0،40513	0،4292	0،4127	0،5457	0،5381	0،414	0،4318	0،3886	0،4038
Phe	0،6303	0،6109	0،6516	0،627	0،7052	0،7622	0،6216	0،6311	0،6232	0،6502
Anth	0،4818	0،4712	0،4485	0،4838	0،4548	0،5865	0،4669	0،4853	0،4639	0،4505
Σ TF PAHs	1،5502	1،48723	1،5293	1،5243	1،2509	1،8868	1،5025	1،5482	1،4757	1،5045

ΣTFPAH= sum of PAHs components of molecular weight < 17

Table (5): Concentration of (ΣCOMB) in sediment samples on the coast of Tripoli (Libya)

Sit no	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Flu	0،44223	0،42059	0،4103	0،41648	.4603	0،5638	0،4354	0،447	0،4068	0،3808
Chry	0،5923	0،5841	0،5867	0،5866	.6665	0،7211	0،5772	0،5988	0،576	0،582
Be(a)	0،8239	0،821	0،4866	0،8194	.9222	0،9905	0،8292	0،8255	0،8096	0،7943
Be (b) flou	0،3921	0،4037	0،4107	0،3906	.4463	0،5065	0،4073	0،4012	0،4059	0،4092
Be (k) flou	0،4222	0،433	0،4551	0،4206	.4718	0،5431	0،4498	0،4227	0،4484	0،4531

Be (a) pyrene	0،8068	0،8142	0،7735	0،805	.9002	1،02	0،8174	0،8057	0،8153	0،7716
Be (g. h. i)	0،00013	0،00315	0،0108	0،00137	.1380	0،00206	0،00946	0،0115	0،0082	0،00959
In	4،114	4،037	4،0412	4،102	4،512	5،4887	4،083	4،313	4،081	4،0392
Di (a, h)	0،23318	0،28222	0،2864	0،28178	0،9808	0،3546	0،2805	0،2822	0،2294	0،28496
Σ COMB	7،82684	7،79896	7،4613	7،82383	5،4928	10،1903	7،88926	8،1076	7،7806	7،72475

ΣTFPAH= sum of PAHs components of molecular weight < 17

Table (6): Concentration of (ΣCARC) in sediment samples on the coast of Tripoli (Libya).

Sit no	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Chry	0،5923	0،5841	0،5867	0،5866	0.6665	0،7211	0،5772	0،5988	0،576	0،582
Be (a)	0،8239	0،821	0،4866	0،8194	0.9222	0،9905	0،8292	0،8255	0،8096	0،7943
Be (b) flou	0،3921	0،4037	0،4107	0،3906	0.4463	0،5065	0،4073	0،4012	0،4059	0،4092
Be (k) flou	0،4222	0،433	0،4551	0،4206	0.4718	0،5431	0،4498	0،4227	0،4484	0،4531
Be (a) pyrene	0،8068	0،8142	0،7735	0،805	0.9002	1،02	0،8174	0،8057	0،8153	0،7716
Be (g. h. i)	0،0003	0،0035	0،0108	0،0017	0.1380	0،0026	0،0096	0،0115	0،0082	0،0099
In	4،114	4،037	4،0412	4،102	4،512	5،4887	4،083	4،313	4،081	4،0392
Di (a, h)	0،2338	0،2822	0،2864	0،2818	0،9808	0،3546	0،2805	0،2822	0،2294	0،2846
ΣCARC	7،3841	7،3787	7،051	7،4075	5،4928	9،6266	7،4536	7،6606	7،3738	7،3435

ΣCARC = sum of BaA, BbF, BkF, BaP, Chr, Di, BghiP and InP

Table (7): Concentration of (ΣPAHs), (ΣCOMB), (ΣTFPAH), (ΣCARC) and (% CARC) in sediment samples on the coast of Tripoli (Libya)

N	∑ PAHs	Σ COMB	Σ TF PAHs	Σ CARC	% CARC	Σ COMB / ∑ PAHs
1	9.57334	7.8268	1.5045	7.3439	76.7	0.817
2	9.42869	7,7989	1.4757	7.3738	78.2	0.827
3	9.4319	7.4613	1.5484	7.6606	81.27	0.791
4	9.48683	7.8238	1.5025	7.4538	78.57	0.824
5	11.37	5.4928	1.8868	9.6265	84.66	0.483
6	12،250	10.1903	1.2509	5.4928	44.83	0.831
7	9،5361	7.8892	1.5243	7.4073	77.67	0.827
8	9.522	8.1076	1.5293	7.051	74.04	0.851
9	7. 569	7.6806	1.4872	7.3783	97.48	1.01
10	8.78921	7.7247	1.5502	7.3846	84.01	0.878
Ave	9.696	7.800	1.526	7.417	77.74 %	0.814
Max	12،250	10.1903	1.8868	9.6265	97.48	1.01
Min	7. 569	5.4928	1.2509	5.4928	74.04	0.483

Table (8): LMW/HMW, Phe/Ant, Flu/Pyr and diagnostic ratios between PAHs in sediment samples on the coast of Tripoli (Libya)

N	LMW/HMW	Phe/Ant	Flu/Pyr	D-1	D-2	D-3	D-4
1	0.1922	1.3082	3.022	0.4332	0.7514	0.9999	0.4123
2	0.1892	1.2964	2.9536	0.4354	0.7470	0.9992	0.4079
3	0.2075	1.4528	2.9078	0.4480	0.7441	0.9973	0.3863
4	0.1950	1.2982	3.0050	0.4351	0.7503	0.9996	0.3990
5	0,4548	1.5505	2.7464	0.3920	0.7330	0.9703	0.3949
6	0،5865	1.2995	3.2476	0.4348	0.7645	09996	0.4251
7	0.1904	1.3313	3.0173	0.2476	0.7510	0.9977	0.4119
8	0.1909	1.3004	3.0161	0.4347	0.7510	09973	0.4146
9	0.1896	1.3436	2.7882	0.4267	0.7360	0.9979	0.3949
10	0.1947	1.4432	2.6835	0.4473	0.7285	0.9976	0.3693

Table (8): Concentrations of different PAHs (ng g^{-1}dry wt) in surface (µg) sediments from different areas**.**

Location	ΣPAHs (ng/g) range	References
coast of Tripoli (Libya)	7. 569- 12.25	This study
Med. Coast (Egypt-2010)	208 – 1,020	El Nemr et al., 2012

Damietta, Egypt (2010)	282 – 10,362	El-Gharabawy, 2013
El-Mex Bay (2017)	41 – 2555	Tantoush, J. A. M. (2018).
Gulf of Naples (Italy)	210 – 5,430	Montuori et al., 2018
Gulf of Salerno (Italy)	95 – 2,870	Montuori et al., 2018
Gulf of Gabès (Tunisia)	180 – 3,950	Fourati et al., 2018
Eastern Mediterranean Coast (Spain)	56 – 1,940	Perra et al., 2019
Aegean Sea (Greece)	0.7 – 70	Triantafyllaki et al., 2020
Marine sediments of Qatar	0.17 – 16.4	Maryam A. A et al., 2023
Piraeus Harbor (Greece)	320 – 4,850	Paraskevopoulou et al., 2023
Saronikos Gulf (Greece)	95 – 1,760	Paraskevopoulou et al., 2023
Heraklion Coast, Crete (Greece)	48 – 690	Paraskevopoulou et al., 2023
Adriatic Sea (Italy–Croatia, Mediterranean)	4 -235	Vasileiadou et al., 2024
Northeastern Mediterranean Basin	12 – 460	Stavrakakis et al., 2024

The concentrations of total polycyclic aromatic hydrocarbons (ΣPAHs) detected in the surface sediments of the coast of Tripoli (Libya) in the present study ranged from 7.569 to 12.25 ng/g dry wt, as presented in Table (8). These concentrations are considered relatively low when compared with many regional and international coastal environments reported in previous studies. The obtained levels were markedly lower than those reported for several Egyptian coastal regions, including the Mediterranean Coast of Egypt (208–1,020 ng/g) reported by Ahmed El Nemr et al. (2012), Damietta coast (282–10,362 ng/g) reported by El-Gharabawy (2013), and El-Mex Bay (41–2555 ng/g) reported by Tantoush, J. A. M. (2018).

The elevated PAHs concentrations in those areas are mainly attributed to intense industrial activities, petroleum contamination, untreated sewage discharge, shipping activities, and urban runoff associated with densely populated coastal zones. Similarly, the concentrations recorded in the present study were considerably lower than those observed in several Mediterranean coastal environments, including the Gulf of Naples (210–5,430 ng/g) and Gulf of Salerno (95–2,870 ng/g) in Italy reported by Montuori et al. (2018), Gulf of Gabès in Tunisia (180–3,950 ng/g) reported by Fourati et al. (2018), and Piraeus Harbor in Greece (320–4,850 ng/g) reported by Paraskevopoulou et al. (2023).

These highly contaminated regions are characterized by intensive maritime traffic, oil refinery activities, industrial emissions, harbor operations, and continuous anthropogenic inputs, which significantly enhance the accumulation of PAHs in marine sediments. On the other hand, the PAHs concentrations measured along the Tripoli coast were comparable to or slightly lower than those reported for relatively less polluted marine environments such as the Adriatic Sea (4–235 ng/g) reported by Vasileiadou et al. (2024), the Northeastern Mediterranean Basin (12–460 ng/g) reported by Stavrakakis et al. (2024), and the Aegean Sea in Greece (0.7–70 ng/g) reported by Triantafyllaki et al. (2020).

Furthermore, the concentrations obtained in the present study were close to those reported for marine sediments of Qatar (0.17–16.4 ng/g) by Maryam A. A. et al. (2023) indicating relatively limited PAHs contamination in both regions. Overall, the present findings suggest that the surface sediments of the Tripoli coast are subjected to relatively low PAHs contamination compared with many Mediterranean and international coastal environments. Nevertheless, continuous environmental monitoring remains essential due to the persistence, bioaccumulative nature, and potential ecological risks associated with PAHs compounds in marine ecosystems.

Evaluation of PAHs ecological risk:

Sediment chemistry data alone are insufficient for assessing the environmental risks of sediment-associated contaminants, and therefore interpretive tools such as Sediment Quality Guidelines (SQGs) are required to evaluate their potential effects on aquatic organisms. The weight-of-evidence approach, developed under the NOAA National Status and Trends Program (Long and Morgan, 1990), integrates datasets of effect and no-effect concentrations, arranged in ascending order, to derive guideline values. This approach produces ERL/ERM values, where the ERL (Effects Range Low) corresponds to the 10th percentile of effect concentrations after exclusion of no-effect data, and the ERM (Effects Range Medium) corresponds to the 50th percentile of effect concentrations. Long et al. (1995) refined the method without altering its conceptual basis.

Similarly, TEL/PEL values developed by the Florida Department of Environmental Protection (FDEP, 1994) incorporate both effect and no-effect datasets; the TEL is calculated as the geometric mean of the 15th percentile of effect data and the 50th percentile of no-effect data, while the PEL is derived from

the geometric mean of the 50th percentile of effect data and the 85th percentile of no-effect data. These guideline values classify contaminant concentrations into three categories: rarely associated effects (below TEL/ERL), occasionally associated effects (between TEL/ERL and PEL/ERM), and frequently associated effects (above PEL/ERM). Exceedance of PEL or ERM values indicates a high probability of sediment toxicity to aquatic organisms (Cardellicchio et al., 2007).

Analysis of Sediment Samples:

Polycyclic Aromatic Hydrocarbon Concentrations in Tripoli Coastal Sediment Samples Table 3 shows the individual and total concentrations of (PAHs). The total PAHs in the sediments varied considerably among the studied sites. Values ranged from 7.569 ng/g (dry weight) at site 9 to 12.250 ng/g (dry weight) at site 6. The highest PAHs concentrations were recorded in sediments sampled near the Tripoli seaport (sites 6, 5, 1, 7, and 8). The highest value was recorded in sample 6 (12.250 ng/g), which is characterized by its fine (sandy) texture and average total organic carbon content (0.034%). It has been shown that the nature of the sediments affects the distribution and concentration of (PAHs) (Kim et al., 1999), (Tantoush.J., 2026), with lower concentrations observed in samples relatively far from ports. The lowest concentration was recorded in sediments taken from sample St 9 (7.569 ng/g), which consisted of 99.7% coarse sand, with a low percentage of total organic carbon (0.054%) in sample St9. The low pollution level generally corresponds to samples taken from remote locations; while higher concentrations generally represent coastal samples close to potential pollution sources (cities, ports, and sewage estuaries) (Gomez et al., 2007).

The partitioning of the PAHs between water and sediment is controlled by the sediment characteristics. Thus, the accumulation of PAHs is not only determined by the mass flux to the sea bed, but also by the sediment characteristics (El Nemr et al., 20072006 ،). It has been reported that petroleum hydrocarbon concentrations are associated with local inputs and are strongly influenced by areas impacted by human activities (Bixiong et al., 2007). Fossil polycyclic aromatic hydrocarbon (ΣTFPAH) Concentrations fell within the range of 1.2509 to 1.8868 ng/g. Typical combustion polycyclic aromatic hydrocarbon (ΣCOMB) concentrations ranged from 5.4928 to 10.1903 ng/g (Table 5). Carbonic (PAHs) (ΣCARC) concentrations fell within the range of 5.4928 to 9.6266 ng/g (Table 6).

A comparison of polycyclic aromatic hydrocarbon (PAH) chemical concentrations with soil quality standards is summarized in Table 3. As is evident, the assessment of environmental toxicity risks may vary depending on the soil quality standards used. For PAH pollution levels, all samples had concentrations below the Reference Intake (RI) of 12.25 ng/g (as suggested by Long et al., 1995). For total PAHs, all samples had concentrations below the RI of 44,792 ng/g. Clearly, if concentrations are below the RI and RI, no adverse biological effects should be observed. Total PAH concentrations recorded in the Tripoli Coast sediments in Libya fell within the range of 7,569 to 12.25 ng/g (Table 3), which are significantly lower than the RI.

Table (10): SQGs values for PAHs and average concentrations in ediment samples on the coast of Tripoli (Libya)

Component	Ave	ERL	ERM	TEL	PEL
Ace	0.4316	16	500	6.71	88.9
Phe	0.6514	240	1500	86.7	544
Anth	0.4884	85.3	1100	46.9	245
Flu	0.4384	19	540	21.2	144
Pyr	0.1490	665	2600	153	1398
BaA	0.8122	261	1600	74.8	693
BaP	0.8330	430	1600	88.8	763
DBA	0.3496	63.4	260	6.22	135
Chr	0.6071	384	2800	108	846
BbF	0.4174	ND	ND	ND	ND
BkF	0.4520	ND	ND	ND	ND
In	4.2811	ND	ND	ND	ND
BaP	0.8330	430	1600	88.8	763
Bghip	0.0194	ND	ND	ND	ND
∑PAHs	9.6957	4022	44792	1684	16770

The mean concentrations of individual polycyclic aromatic hydrocarbons (PAHs) were below the reference exposure limits. PAH levels in the coastal sediments of Tripoli, Libya, were also lower than the national sediment quality standards proposed by the U.S. Environmental Protection Agency (EPA, 1993) for fluoranthene (3000 ng/g), phenanthrene (2400 ng/g), and acenaphthylene (2400 ng/g). In

contrast, the highest concentration of carcinogenic PAHs (ΣCARC) was 9.6266 ng/g, recorded at Station 6, whereas the maximum proportion of carcinogenic PAHs (CARC = 97.48%) was observed in sediments from Station 9 (Table 7), indicating potential adverse implications for human health. The ratio of the sum of the principal polycyclic aromatic hydrocarbons (ΣCOMB) to total 16 PAHs (ΣPAHs), according to U.S. EPA classification, ranged from 0.483 to 1.01, while total PAH concentrations varied between 5.4928 and 10.1903 ng/g of sediment (Table 7). The elevated ΣCOMB/ΣPAHs ratios suggest that combustion-derived sources have strongly influenced PAH contamination in the sediment samples along the Tripoli coast. Fossil-derived polycyclic aromatic hydrocarbon (ΣTFPAH) concentrations ranged from 1.2509 to 1.8868 ng/g (Table 4).

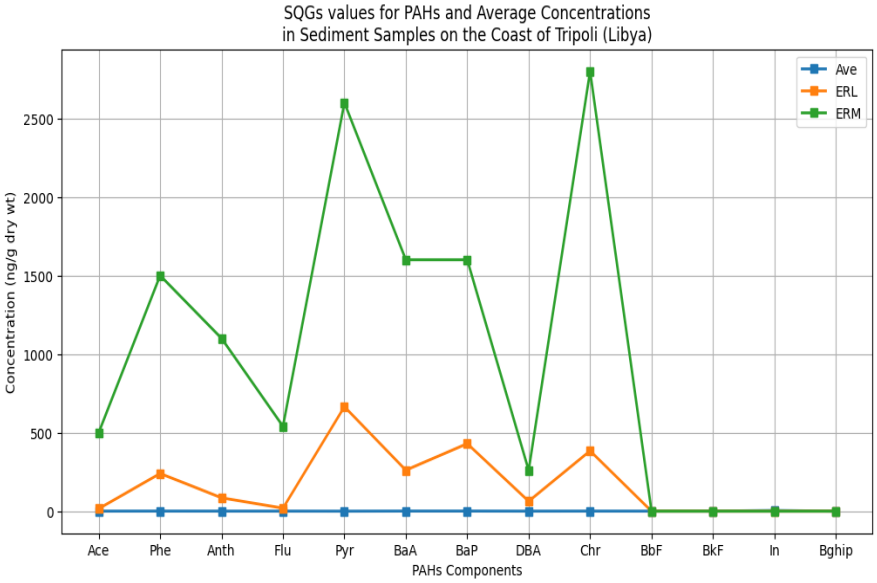

Figure (2): SQGs values for PAHs and Average Concentration.

Principal component analysis (PCA) revealed two main groups of polycyclic aromatic compounds (PACs) in Tripoli coastal sediments. High molecular weight compounds such as BaP, BbF, BkF, and BghiP were associated with the first group, suggesting combustion sources from ship emissions and industrial activity within the port of Tripoli. Low molecular weight compounds such as Ace, Phe, and Anth were associated with petroleum sources linked to fuel and oil spills in coastal fishing areas.

Conclusion:

This study examined the distribution, sources, and ecological risk of (PAHs) in surface sediments along the coast of Tripoli, Libya. The findings indicated that total PAH concentrations (ΣPAHs) ranged from 7.569 to 12.25 ng/g dry weight, reflecting generally low contamination levels when compared with other Mediterranean and global coastal environments. Spatial distribution patterns showed elevated PAH concentrations in proximity to the Tripoli seaport and urbanized coastal zones, whereas lower concentrations were observed in more distant, less disturbed sandy areas.

This distribution pattern suggests that anthropogenic activities, particularly maritime traffic, port operations, fuel combustion processes, and limited sewage discharges, represent the dominant sources influencing PAH levels in the study area. Geochemical interpretation and multivariate statistical analyses, including Principal Component Analysis (PCA), revealed mixed PAH origins. High molecular weight PAHs were predominantly associated with pyrogenic sources such as combustion-related emissions from shipping and industrial activities, while low molecular weight PAHs were mainly indicative of petrogenic inputs related to fuel leakage and oil-derived contamination.

Comparison with established Sediment Quality Guidelines (ERL/ERM and TEL/PEL) showed that all measured concentrations were well below threshold levels associated with adverse biological effects. This indicates a low ecological risk for the coastal sediments of the study area under current conditions. Overall, the results demonstrate that Tripoli coastal sediments remain relatively unpolluted by PAHs in comparison with many other Mediterranean coastal regions. Nevertheless, the evident influence of maritime and urban activities underscores the importance of continued environmental monitoring, particularly in harbor and industrial zones, to prevent potential future accumulation and ecological degradation.

Conflicts of Interest:
The author confirms the absence of any conflicts of interest.

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