



Extraction and Determination of Aliphatic Alkanes in Marine Sediment Samples from the Coast of Tripoli (Libya)

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استخلاص وتحديد الألكانات الأليفاتية في عينات الرواسب البحرية من ساحل طرابلس – ليبيا

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Abstract:

This study, conducted on sediments from the coast of Tripoli, Libya in 2025, aimed to monitor marine pollution by assessing the spatial distribution and molecular composition of PAH (normal alkanes C9–C20) in surface sediments. Total organic carbon (TOC) was measured, and hydrocarbons were analyzed using gas chromatography-mass spectrometry (GC-MS). Results showed that sediments were predominantly sandy (89.61%–99.8%), indicating a high-energy hydrodynamic environment that limits organic matter accumulation, as reflected by low TOC values (0.023%–0.079%). Statistical analysis revealed a strong negative correlation between sand and TOC ($r = -0.84$) and a positive correlation between silt and TOC ($r = 0.79$), confirming the role of fine particles in retaining organic matter. Total alkanes ($\Sigma C9-C20$) ranged from 1510.1 to 8812 ng/g, with an average of 4770 ng/g, showing high spatial variability (coefficient of variation = 60.8%), suggesting the influence of local pollution sources. The highest concentrations were recorded at stations S5, S4, and S7, indicating accumulation zones linked to marine activities. Molecular distribution was dominated by long-chain alkanes (C15–C20), reflecting terrestrial petroleum and plant inputs, while lighter compounds (e.g., C9) at some sites indicate recent contamination. Correlation analysis showed a strong relationship between hydrocarbons and clay ($r = 0.822$), but a weak relationship with TOC ($r = 0.079$), indicating that hydrocarbon distribution is mainly controlled by sediment texture and external inputs. These findings highlight the combined influence of sediment characteristics, hydrodynamics, and human activities, emphasizing the need for continuous monitoring and sustainable coastal management.

Keywords: Port of Tripoli, Libya, Sediment Analysis, Aliphatic hydrocarbons and Saturated.

الملخص

تُعدّ الرواسب البحرية على ساحل طرابلس، ليبيا، مؤشرًا مهمًا لرصد التلوث البحري نظرًا لقدرتها على تراكم الملوثات العضوية. هدفت هذه الدراسة، التي أجريت عام 2025، إلى تقييم التوزيع المكاني والتركييب الجزيئي للهيدروكربونات الأليفاتية (C9–C20) في الرواسب السطحية، إلى جانب قياس إجمالي الكربون العضوي (TOC) باستخدام تقنية كروماتوغرافيا الغاز-مطياف الكتلة (GC-MS). أظهرت النتائج أن الرواسب ذات طبيعة رملية مرتفعة (حوالي 90%–100%)، مما يعكس بيئة مائية ديناميكية تحدّ من تراكم المواد العضوية، وهو ما يتوافق مع انخفاض قيم TOC (حوالي 0.023%–0.079%). كما بيّن التحليل الإحصائي وجود علاقة سلبية قوية بين الرمل وTOC، وعلاقة إيجابية مع الطمي، مما يؤكد دور الحبيبات الدقيقة في احتجاز المواد العضوية. تراوحت تراكيز الألكانات الكلية بين 1510 و8812 نانوجرام/جرام بمتوسط يقارب 4770 نانوجرام/جرام، مع تباين مكاني واضح، حيث سُجّلت أعلى القيم في بعض المحطات المرتبطة بالأنشطة البحرية. وقد سادت الألكانات طويلة السلسلة (C15–C20)، ما يشير إلى مصادر بترولية أرضية ونباتية، في حين دلّت المركبات الخفيفة على وجود تلوث حديث في بعض المواقع. كما أظهر التحليل وجود ارتباط قوي بين

الهيدروكربونات والطين، وضعيف مع TOC، مما يدل على أن توزيعها يتأثر أساسًا بنسيج الرواسب ومصادر التلوث الخارجية. وتشير هذه النتائج إلى أهمية المراقبة المستمرة والإدارة البيئية المستدامة للمناطق الساحلية للحد من آثار التلوث البحري.

الكلمات المفتاحية: ميناء طرابلس، ليبيا، تحليل الرواسب، الهيدروكربونات الأليفاتية و المشبعة.

Introduction

These compounds are of considerable environmental concern, as they pose a serious pollution problem that requires close monitoring, particularly in coastal regions characterized by intense saturated hydrocarbons, scientifically referred to as alkanes, represent a major organic component of marine environments and constitute a substantial fraction of the hydrocarbon mixtures associated with crude oil and its various derivatives. Their widespread occurrence in soils and marine sediments, coupled with their persistence over extended periods, makes them reliable indicators of marine pollution, especially oil-related contamination. Petroleum hydrocarbon pollution has been an increasing concern in the last 40 years due to its wide usage as an energy source in most industrial and developing countries. Petroleum hydrocarbons generated from human activities and industrial processes are widespread and cause serious environmental problems due to their persistence, toxic, mutagenic, bioaccumulation and carcinogenic properties, as in [1]. PAH form a major component of crude oil and petroleum products. They belong to the group of open-chain organic hydrocarbons, and aromatic hydrocarbons enter to the environment through leaks, spills or accidents, industrial releases, or as by-products from commercial or domestic uses, as in [2]. Their chemical structure is represented by the general formula C_nH_{2n+2} , in which molecular weight increases with the number of carbon atoms. Ranging from low- to high-molecular-weight alkanes. Alkanes are composed exclusively of carbon and hydrogen atoms, with carbon atoms connected by single covalent bonds, conferring high chemical stability compared to unsaturated hydrocarbons. PAH consist of straight and saturated carbon chain starting from C6–C40 containing odd and even carbon numbers indicating anthropogenic and natural hydrocarbon sources, as in [2,3,4]. This increase directly influences their physical properties, including physical state, volatility, and solubility. Owing to their hydrophobic nature, alkanes readily adsorb onto fine-grained particles and organic matter in sediments, leading to their accumulation on the seabed and their persistence as environmental pollutants. Tripoli Coast situated along the Mediterranean coast, is one of Libya's most active maritime regions, hosting a network of strategic ports that serve as major hubs for maritime transport and international trade. This intensive activity includes the movement of large vessels, the loading and unloading of oil and petroleum products, and a variety of industrial operations closely linked to the energy sector. Human impacts on the environment can be summarized into seven broad categories, as follows: wastewater management practices, solid waste management practices, ship-based activities, ferry traffic, tourism, cruise boating, and marine aquaculture, as in [5]. The present study aims to assess the occurrence and spatial distribution of PAH in sedimentary soils along the Tripoli coast, with particular emphasis on comparing sites located near the Port of Tripoli with those situated at increasing distances from the port. Sediment samples will be analyzed using reliable and well-established analytical techniques to quantify hydrocarbon concentrations and to examine their relationship with anthropogenic activities and local environmental conditions. Additionally, the study seeks to distinguish between natural and anthropogenic sources of contamination and to provide recommendations for pollution management and mitigation. Understanding the distribution patterns and sources of PAH pollution in marine sediments is essential for the development of effective monitoring strategies and sustainable environmental protection policies, particularly in environmentally sensitive coastal and port areas where human activities are closely linked to the marine environment. Although saturated hydrocarbons are generally less toxic than other organic pollutants, such as polycyclic aromatic hydrocarbons (PAHs), their accumulation at high concentrations may lead to indirect environmental impacts. These include reduced oxygen permeability in sediments, adverse effects on benthic organisms, and disruption of ecological balance. Moreover, prolonged accumulation can hinder natural biodegradation processes and contribute to long-term environmental degradation.

Materials and methods

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 city's climate is influenced by the Mediterranean climate, resulting in hot and dry summers.

Sample taking and preparation

Surface sediment samples were collected from ten different locations along the coast of Tripoli, Libya in 2025 (Fig1). The sediments were collected using a shovel from varying depths, depending on the location and depth of the sample, by divers. After collection, the samples were placed in pre-cleaned, wide mouthed bottles and stored at 20°C for analysis. The samples were analyzed according to the techniques of the United Nations Environment Programme, as in [6]. The samples were air-dried at room temperature and then stored in a clean, sealed poly bottle for analysis. 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.



Figure 1 : Sampling locations along coast of the western city of Tripoli - Libya (study area)

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.

Grain size Analysis

About (18-32gm) of dried samples was taken for mechanical analysis. The samples were subjected to the combined technique of dry sieving and pipette analysis according to the method described, as in [7]. Grain size determination was made on the dried samples by the conventional sieving method. Dry sand was fractionated by dry sieving using sieves with openings of (2, 1, 0.5, 0.25, 0.125, 0.063 and 0.032 mm) and an electric shaker, and the pipette analysis technique was used for separation of sand, silt and clay fractions to illustrate the sediment types.

Total Organic Carbon

Total organic carbon (TOC) was determined according to the method described, as in [7-8].

Results and Discussion

Grain size and The total organic matter

Grain size provides important data about the source of sediments, depositional conditions, and transport history, as in [9-10, 11-12]. shows in the (Table1) the spatial pattern of grain size, mean, sorting, twisting, and kurtosis. The sediments in the studied areas are characterized by their nature, ranging from fine sand to coarse sand (fine sand was present in samples 1, 2, and 6, while medium sand was present in sites 5, 7, and 8, and coarse sand in sites 3, 4, 9, and 10). The presence of fine sediments may be due to the predominance of fine-grained terrestrial sediments. The variation in mean grain size may reflect differences in erosion and deposition processes, as well as the impact of human activities.

Table (1) Locations and distances of sediment samples taken from the coast of Tripoli, Libya and Distribution of grain size, total organic carbon,(study area)

Site no	Latitude (N)	Longitude (E)	Sand (%)	Silt (%)	Clay (%)	TOC %	Nomenclature
S1	32°47'52.28"	13°44'57.33"	96,09	3,91	0	0,07	Fine sand
S2	32°48'58.99"	13°37'42.13"	89,61	10,39	0	0,079	Fine sand
S3	32°51'17.08"	13°29'51.05"	99,8	0	0,2	0,023	Coarse sand
S4	32°54'42.65"	13°22'27.94"	99,69	0,19	0,12	0,057	Coarse sand
S5	32°55'26.39"	13°16'50.96"	98,41	1,31	0,28	0,072	Medium sand
S6	32°54'44.91"	13°12'24.12"	97,77	2,08	0,15	0,034	Fine sand
S7	32°54'20.01"	13°8'59.80"	98,07	1,63	0,3	0,056	Medium sand
S8	32°52'26.21"	13°4'52.08"	99,11	0,89	0	0,04	Medium sand
S9	32°50'54.30"	13°0'25.31"	99,7	0,21	0,09	0,054	Coarse sand
S10	32°49'51.30"	12°57'5.76"	99,76	0,24	0	0,033	Coarse sand

Although most of the organic carbon produced in the surface layer is recycled in water by aerobic and anaerobic decomposition, only a very small fraction is buried in the sediments. Although this percentage is small, its accumulation over geological time makes marine sediments a long-term carbon reservoir and a key pillar in regulating carbon balance and global climate. It has been estimated that only 1% of the organic matter produced may be transferred to the deep biosphere as a result of decomposition by aerobic and anaerobic remineralization processes , as in [13·14].

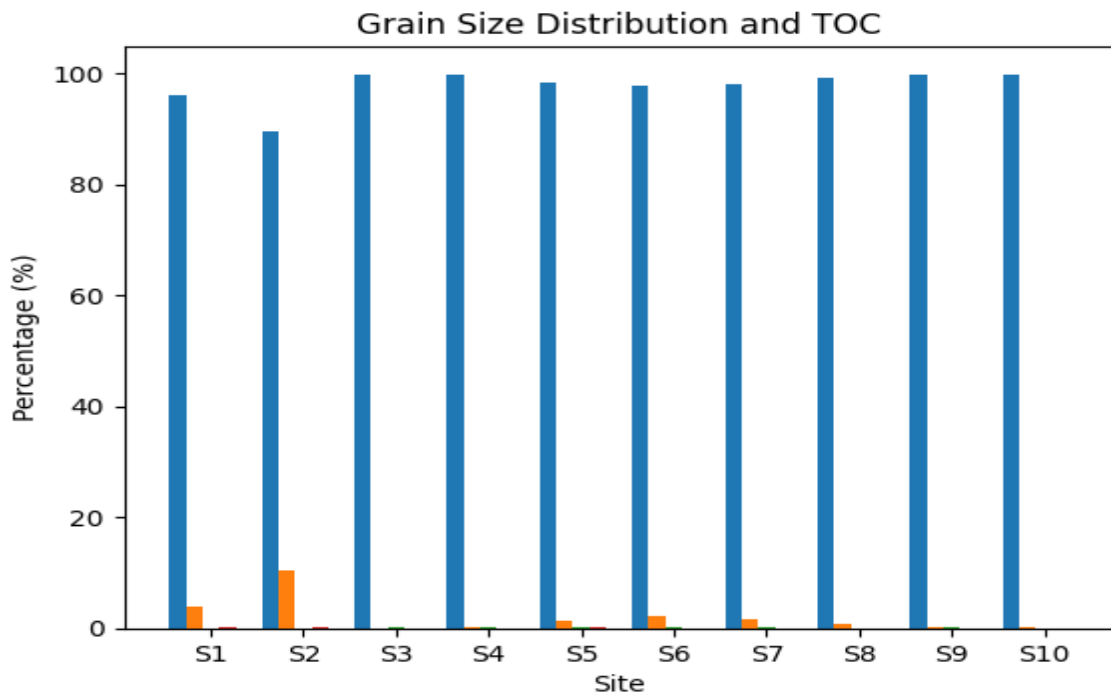


Figure 2 : The relationship between Grain size distribution and total organic carbon content (TOC%) in the study area

The composition and quantity of organic matter preserved in marine sediments vary considerably between regions and depositional environments , as in [15·16]. In the fig (2· 3)The total organic matter (TOC%) in the surface sediments of the studied areas ranged from 0.023% at site (3) to 0.079% at site (2), values reflecting a significant decrease in overall organic content (Table 1). This decrease is attributed to the prevalence of active hydrodynamic conditions that facilitated hydraulic sieving, where fine, low-density organic particles are transported and removed compared to heavier sediment components such as shells and carbonates. Furthermore, the marked decline in TOC at the sampling site near the ground-drainage zone—which is typically a major source of organic debris—may indicate the dominance of oxidizing conditions in the sedimentary environment. These conditions are often associated with continuous sediment resuspension and low sedimentation rates, which limit the accumulation and preservation of organic matter within the sedimentary column, consistent with the findings of , as in [4].

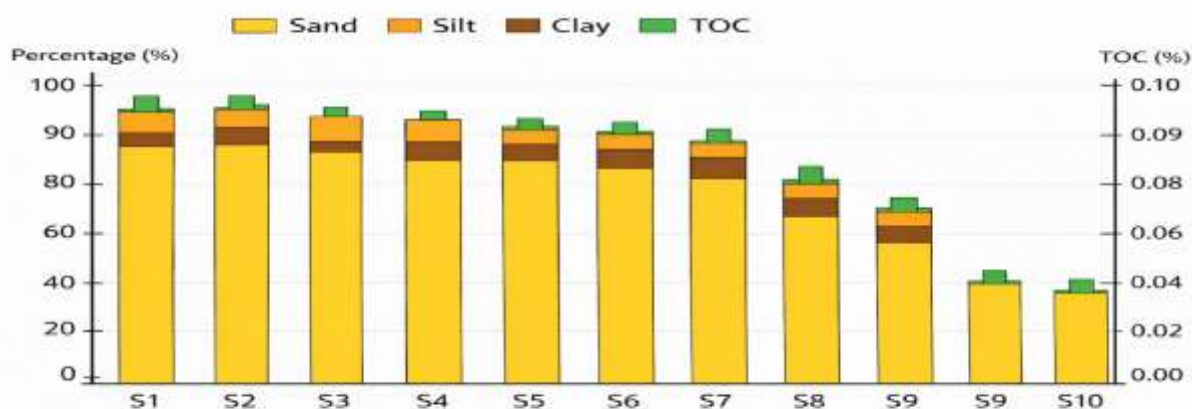


Figure 3: The relative distribution of surface sediment components (sand, silt, clay) and its relationship to the total organic carbon content (TOC%) in the studied area

The results, as shown in Table (No. 1), indicate that the sand content was generally high, ranging from 89.61% in sample S2 to 99.8% in sample S3, while the silt content ranged from 0% to 10.39%, and the clay content from 0% to 0.3%. Statistical analysis revealed a strong inverse relationship between sand and TOC, with a Pearson correlation coefficient of ≥ 0.84 ($r = -0.84$) and a p-value of 0.002. This indicates that increased sand content is associated with decreased organic matter content. For example, sample S3, with 99.8% sand, had the lowest TOC (0.023%), while sample S2, with 89.61% sand, had the highest TOC (0.079%). As for silt, a strong positive correlation was observed with TOC, with a correlation coefficient of $r = 0.79$ and a p-value of 0.006, indicating that increased silt content enhances organic matter retention. In contrast, clay showed only a moderate positive correlation ($r = 0.41$) with TOC, but this correlation was not statistically significant ($p = 0.25$) due to the low clay content in the samples. Overall, this analysis suggests that the organic content in these sediments is low ($<0.08\%$) and reflects an active marine environment where water movement sieves the sediments and causes the loss of lighter organic matter. Texture ratios also influence the sediment's ability to retain organic matter: sand reduces it, silt increases it, while clay has a limited effect.

Distribution and sources of n-alkanes (PAH)

Polycyclic PAH (n-alkanes) are important constituents of organic matter and are widely distributed in the environment, as in [17]. n-alkanes are marine environment chronic constituents and their concentrations have considerably increased due to anthropogenic activities. They are widely dispersed in the marine environment, particularly in harbors, dockyards, marinas, estuaries and other shallow coastal areas with anthropogenic inputs, as in [18,19,20]. This caused undesirable effects, especially in coastal areas adjacent to highly populated urban zones. The PAH consist of saturated and straight carbon chains of C6–C40 which contain even and odd carbon numbers that indicate anthropogenic and natural sources of hydrocarbon, as in [20,21,22]. However, the sources of n-alkanes are considerably complex, except for anthropogenic sources, such as petroleum pollution, there are several natural sources of n-alkanes, such as terrestrial plant waxes, phytoplankton, bacteria, and digenic transformation of biogenic precursors, as in [23]. Organic-rich marine sediments may contain up to 100,000 ng g⁻¹ of total PAH, but concentrations higher than these are usually associated with petroleum inputs. When concentrations of hydrocarbons are $>50,000$ ng g⁻¹, a more detailed analyses of the hydrocarbon constituents is generally required to assess the magnitude of anthropogenic contamination, as in [24]. Concerning the distribution of the resolved compounds, an elevated proportion of C15–C23 of n-alkanes indicate that unburned lubricating oils from road traffic exhaust are a significant contributor to PAH as in [25]. United Nation Environmental Program, as in [6], introduced guide lines to identify the levels of harmful ($> 10 \mu\text{g g}^{-1}$) and harmless ($<10 \mu\text{g g}^{-1}$) PAH in the marine sedimentary environment, as in [3].

Analysis of Aliphatic Hydrocarbons.

Aluminum oxide and silica gel were ultrasonically processed in normal hexane according to the methods of Erhardt (1987). After filtration, they were dried with a nitrogen stream, activated by heating, then partially deactivated by adding 5% water, and stored in sealed bottles. All solvents used were pesticide-grade and obtained from BDH or Merck. Anhydrous sodium sulfate was extracted using a Soxhlet apparatus with normal hexane for 8 hours, followed by dichloromethane or methanol for another 8 hours, after being pre-burned overnight in an oven at 400°C and then cooled in grease-free dryers. Thirty grams of the dried precipitate were taken and subjected

to ultrasonic extraction twice in 100 mL of normal hexane for 30 minutes, followed by ultrasonic processing in 100 mL of dichloromethane. The collected extracts were concentrated using a rotary evaporator at a low temperature (40 °C) and then concentrated to 1 mL using a nitrogen stream. The samples were purified and separated by extraction through a silica/aluminum oxide column (prepared by packing 10 g of silica, 10 g of alumina, and 1 g of anhydrous sodium sulfate). The alkanes (F1) were extracted using 30 mL of normal hexane. F1 was concentrated under vacuum to 5 mL and then to 1 mL using a mild nitrogen stream, and the resulting concentrates were subjected to gas chromatography-mass spectrometry (GC-MS) analysis, as in [6].

Concentrations of normal alkanes in sediment samples from the Tripoli coast - Libya

In Table 2 shows the total concentrations of normal alkanes with atomic masses ranging from C9 to C20 in sediment samples from the Tripoli coast. Concentrations below the detection limit were assigned a zero value. Sediment texture plays a role in the accumulation of normal alkanes. When analyzing the quantitative distribution of PAH in surface sediments within the C9–C20 carbonate range, a clear spatial variation is evident among the studied stations, both in terms of total concentration and molecular distribution pattern. The total values (\sum C9–C20) show that the highest concentrations were recorded at stations 5 (8812), 4 (8623), 7 (7584.33), 6 (6030.8), and 3 (5632.14), which are relatively high levels compared to the other sites. Conversely, the lowest values were recorded at stations 8 (1510.1) and 9 (1589.33), while stations 1 (2583.84), 2 (2610.51), and 10 (2727.4) fell within the category of relatively low to medium concentrations. Structurally, the stations with high values exhibit a clear predominance of longer-chain compounds (C15–C20). For example, at station 4, the concentrations of C16 (751.5), C17 (778.5), C18 (804), and C19 (844) are elevated, reflecting a significant contribution from heavier hydrocarbons with higher relative stability in the sedimentary environment.

Table (2): Concentrations of normal alkanes (ngg g⁻¹) in sediments of the Tripoli coast (Libya).

No	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	\sum C9 -C20
1	1132.6	145.4	115.8	188.9	148.3	196.9	135.4	167.8	125.3	139.5	112.7	123.6	2583.84
2	1128	149.5	105.6	176.2	148.1	183.3	124.4	153.4	112.9	131.7	102.6	94.7	2610.51
3	2532	94.5	232.5	156	145.5	285	358.6	369	351	366	367	375	5632.14
4	1968	330	240	369	495	720	690	751.5	778.5	804	844	633	8623
5	1405	726	352	355.2	727.6	998	936.2	1217	1311	634	27	123	8812
6	1872	259.7	166.5	145.5	327	360	261.5	379.4	355.9	633.2	982.1	288	6030.8
7	1384	414	214.4	198	459	452.5	559	824.5	859	878.5	851.4	490	7584.33
8	994.4	40.15	13.96	97.07	34.7	112.3	36.07	75.4	24.73	45.16	12.15	24.01	1510.1
9	1105	48.15	18.49	84.48	54.84	90.9	31.3	59.7	21.9	39.7	11.27	23.1	1589.33
10	1764	110.1	78.7	120.9	61.45	38.17	324.7	36.9	13.6	14.74	32.5	131.7	2727.4

A similar pattern is observed at station 7, where C16 (824.5), C17 (859), C18 (878.5), and C19 (851.4) register high values, indicating the accumulation of heavier petroleum fractions or advanced remnants of petroleum weathering processes. At station 5, a relatively different pattern is observed, characterized by a significant increase in C10 (726), C13 (727.6), C14 (998), C15 (936.2), C16 (1217), and C17 (1311), compared to a sharp decrease in C19 (27) and C20 (123). This contrast may reflect the influence of a relatively recent source or biological degradation and selection processes affecting the higher molecular weight compounds. Station 3, on the other hand, shows a more homogeneous distribution of the C14 (285) to C20 (375) chains, with relatively high values for C15 (358.6), C16 (369), C17 (351), C18 (366), and C19 (367), which may indicate a mixed source of petroleum contributions and long-chain organic compounds. In contrast, stations 8 and 9 show distinctly low values across most series, with the majority of compounds ranging from 11.27 to 112.3, and a total not exceeding 1589.33. This indicates either low hydrocarbon inputs or more effective dispersion and degradation processes at these sites. Stations 1 and 2 are characterized by a clear dominance of compound C9 (1132.6 and 1128, respectively) compared to the other series, while C9–C20 values remain relatively low. This may reflect a localized effect of lighter compounds or relatively recent inputs, with limited long-term accumulation in the sediments. Overall, the variation between 1510.1 and 8812 reflects the wide differences in the intensity of hydrocarbon pollution across the sites. Furthermore, the predominance of heavy chains at several stations indicates the precipitation and accumulation of more stable compounds, while lower concentrations at other locations suggest less exposed environments or higher hydrodynamics that limit pollutant accumulation. This pattern underscores the spatial heterogeneity of pollution and its connection to local factors including emission sources, water movement, and

sediment composition. In the figure 4, the linear distribution of hydrocarbon concentrations in the study area revealed a clear and systematic environmental pattern. A gradual increase was observed from station 1 to station 5, reflecting the cumulative transport and gradual accumulation of pollutants under the influence of coastal currents.

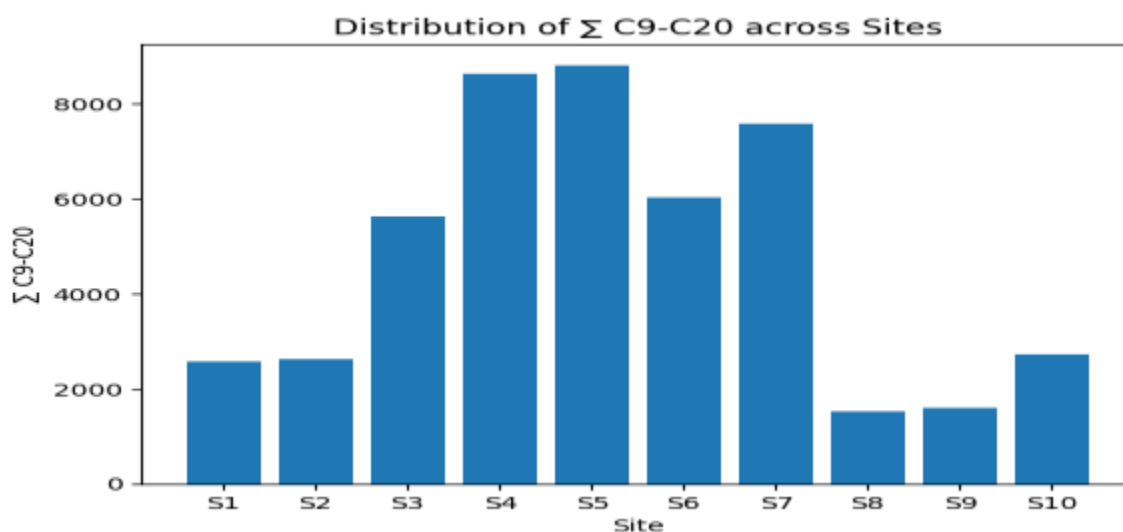


Figure 4 : linear distribution of hydrocarbon concentrations in the study area revealed .

In the figure 5, this trend indicates the presence of a sedimentation zone where hydrodynamic conditions create a favorable environment for hydrocarbon deposition and retention. Station 6, located within the port of Tripoli, recorded a concentration of 6030 ng/g, a high concentration but not the maximum. Despite the intensity of marine and industrial activities in this area, including loading, unloading, maintenance, and marine diesel fuel combustion, the recorded value suggests that hydrodynamic mixing and dispersion partially limit the final accumulation of hydrocarbons at the immediate source. This is due to the ecological behavior of semi-volatile hydrocarbons, which tend to adsorb onto fine particles and organic matter before being transported and deposited in areas with relatively low hydrodynamic energy. Stations 7–10 show a marked decrease in hydrocarbon concentrations, averaging 3353 ng/g.

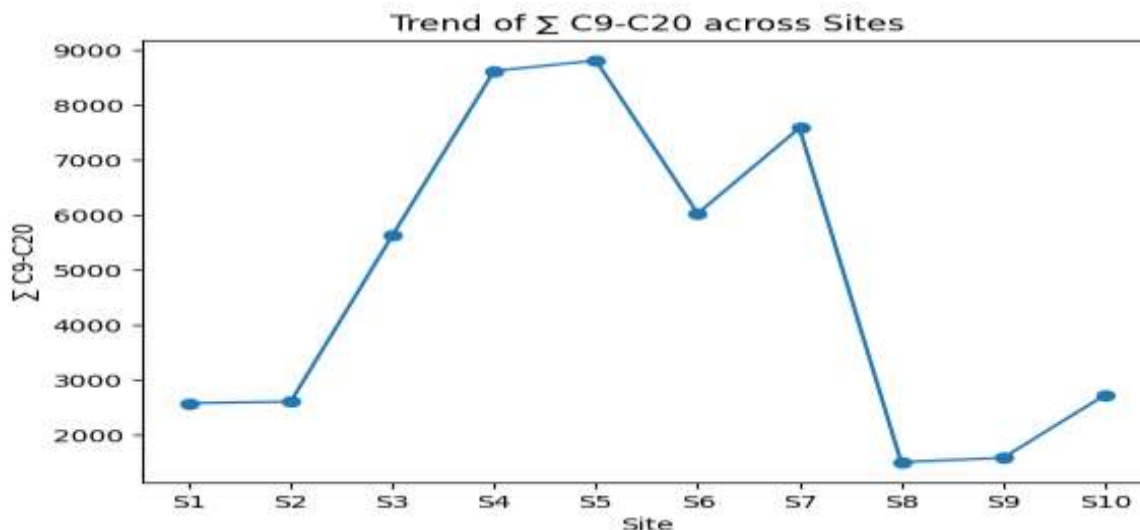


Figure 5: Trend of aliphatic hydrocarbon concentrations in the study area according to the sample results.

The lowest concentrations were recorded at stations 8 (1510 ng/g) and 9 (1589 ng/g), indicating a sharp decrease compared to the upstream accumulation zone. This decrease reflects improved dispersion conditions, increased wave and current energy, or a relative decrease in anthropogenic inputs. From an ecological perspective, this integrated pattern suggests that the coastal system is affected by relatively moderate to high levels of hydrocarbon pollution, with local hotspots controlled not only by the intensity of anthropogenic inputs but also by sediment characteristics and prevailing hydrodynamic conditions. The arithmetic mean of total hydrocarbon concentration within the C9–C20 range was 4770 ng/g, a level classified as moderate to relatively high in anthropogenic coastal

environments. However, the most significant value is not the mean itself, but rather the high standard deviation (2902 ng/g) and the coefficient of variation (CV) of 60.8%, which clearly indicates poor spatial homogeneity and strong distributional variability. In environmental sedimentary studies, a CV exceeding 50% is indicative of the dominance of point pollution sources or heterogeneous local influences, thus negating the hypothesis of uniform distribution or a homogeneous natural background.

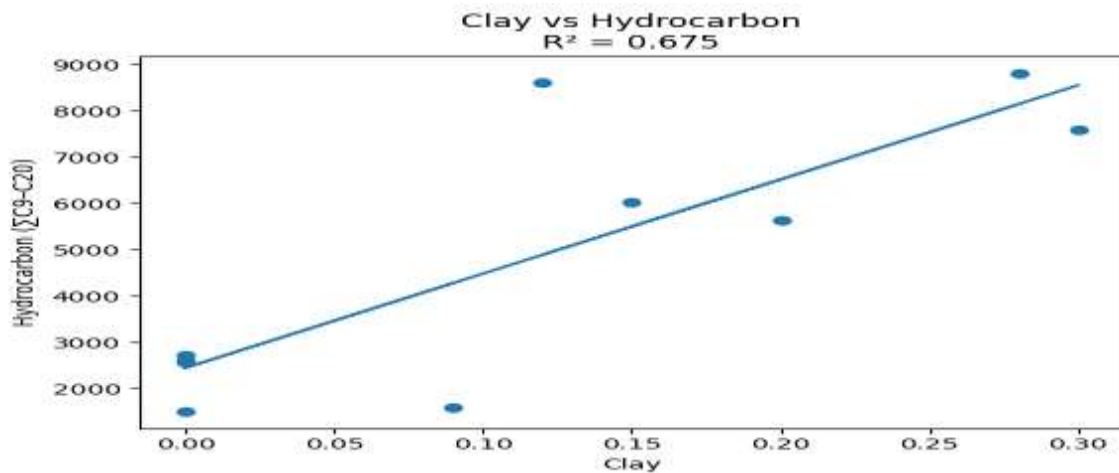


Figure 6: The relationship between aliphatic hydrocarbon concentrations and clay content in the study area.

This high variability suggests that the sedimentary system is subject to the influence of local input sources, often associated with maritime and industrial activity, in addition to hydrodynamic factors controlling the redistribution of pollutants. Therefore, the values should be interpreted within a detailed spatial context, not just the overall mean. Analysis of stations 1–5 reveals a sub-average of 5652 ng/g, significantly higher than the overall average, confirming the presence of a major accumulation zone. Two distinct peaks are observed at stations 4 and 5, indicating genuine hotspots rather than mere statistical fluctuations. Sedimentologically, these elevated values reflect one or more of the following factors: weak local current dynamics, increased micro sedimentation rates, or direct proximity to a discharge source or heavy maritime activity. Correlation analysis revealed a positive relationship between hydrocarbon concentrations and clay content ($r = 0.822$). Nevertheless, this relationship should be interpreted cautiously because the sediments of the study area are overwhelmingly sandy, with clay percentages ranging only between 0 and 0.30%, and four stations showing no detectable clay fraction. Under such conditions, the relatively high correlation coefficient may partly reflect the influence of a limited number of localized stations rather than a robust regional sedimentological control. Although the coefficient of determination ($R^2 = 0.675$) indicates that part of the hydrocarbon variability may be statistically associated with changes in the fine sediment fraction, the extremely low clay content limits the strength of this interpretation from a sedimentological perspective. Therefore, the distribution of hydrocarbons along the Tripoli coast is primarily controlled by local human inputs and hydrodynamic redistribution processes, rather than by silt accumulation alone.

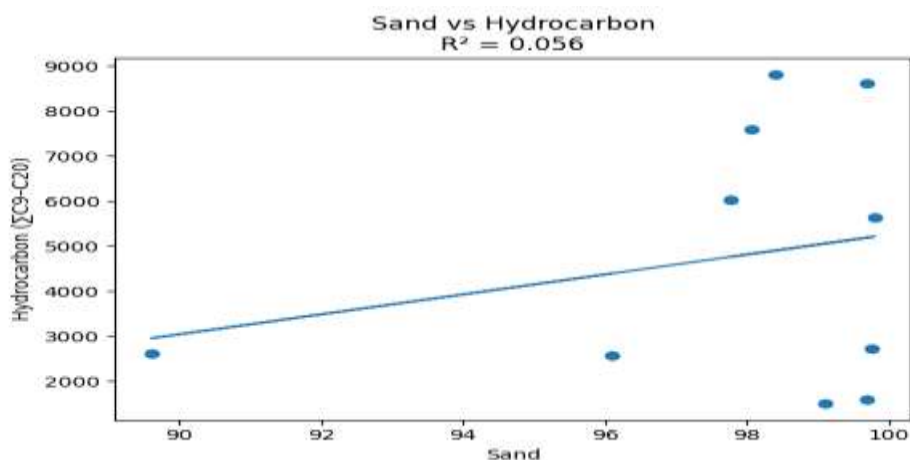


Figure 7: The relationship between aliphatic hydrocarbon concentrations and Sand content in the study area.

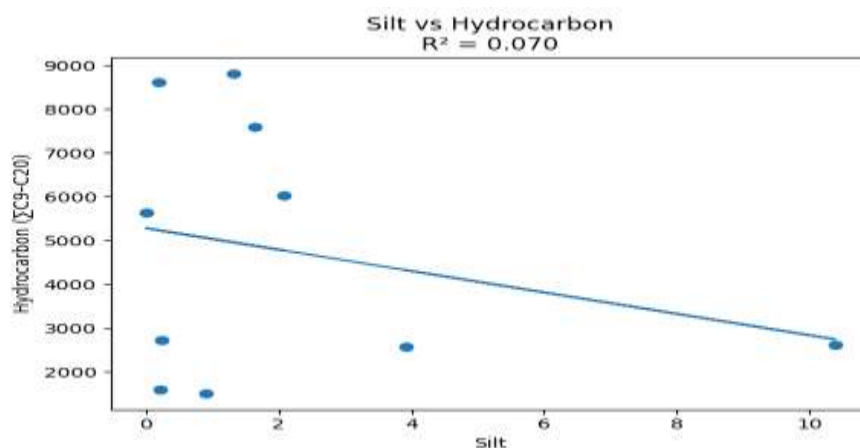


Figure 8: The relationship between aliphatic hydrocarbon concentrations and Silt content in the study area.

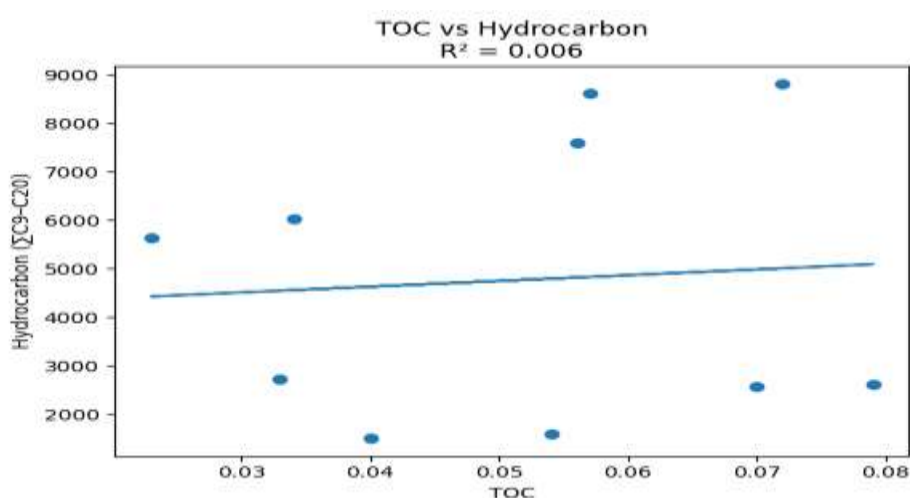


Figure 9: The relationship between aliphatic hydrocarbon concentrations and TOC content in the study area.

In contrast, sand showed a weak positive correlation ($r = 0.237$, $R^2 = 0.056$), confirming that coarse-grained sediments have a limited capacity to deposit hydrocarbons due to their small surface area and high permeability resulting from their large grain size. In the fig (8) Silt showed a weak negative correlation ($r = -0.265$, $R^2 = 0.070$), which may reflect hydrodynamic sorting processes rather than direct geochemical control . In the figure 9 The relationship between total organic carbon (TOC) and hydrocarbon concentrations was low and insignificant ($r = 0.079$, $R^2 = 0.006$), indicating that organic matter does not significantly control hydrocarbon distribution in the study area. This suggests that hydrocarbon inputs are primarily driven by external human sources rather than by in situ organic matter. Overall, the results show that while sediment texture—particularly the clay component—plays an important role in hydrocarbon accumulation, direct human inputs appear to be the dominant factor. This is particularly evident in sandy environments where high hydrocarbon concentrations are present despite unfavorable retention conditions.

Comparisons with other studies

The concentrations of PAH in surface sediments of the Tripoli coast were compared with published data from various regions in the northern and southern Mediterranean and the Middle East (Table 3). The results showed that the normal alkanes (C9–C20) concentration range in the study area was between 1510.1 and 8812 ng/g, placing it within globally recorded limits, although relatively low compared to several other locations. Compared to regional studies, the values recorded on the Tripoli coast show a significant decrease compared to those reported in the port of Zuwetina (Libya) according to Mohamed Ziada et al. (2023), as well as compared to the values recorded along the coasts of Benghazi and Daryanah (Abdel-Ati Al-Farjani et al., 2023), where much higher concentrations were recorded in $\mu\text{g/g}$, indicating that these areas are subject to greater pollution pressures, likely due to intensive oil activities

Table (3): Concentration ranges of PAH (ng - and microgram/g) in surface sediments from different regions.

Location	N-alkane (ng/g)	References
Tripoli Coast - Libya	1510.1 – 8812	This study
Western Moroccan Mediterranean Sea	128800 – 648160	Bouزيد et al., 2011
Zwitina Harbor Coast (Libya)	8690 – 684460	Mohammed Ali Zeyadah et al., 2023
El-Mex Bay, Alexandria, Egypt	4194 – 11681	Tantoush, J. A. M. (2018)
South China Sea	35600 – 1466100	Hafidz et al., 2012
Red Sea, Egypt	33.97 – 553.48	Salem, Dalia M.S. et al., 2014
Benghazi City and Dyriana Town Coasts (Libya)	8270 – 707000	Abdell -atti El-Fergani et al., 2023
Bizerte - Tunisia (Mediterranean Sea)	10670 – 211820	Zrafi-Nouira et al., 2008

Regionally and internationally, the values recorded in this study are significantly lower than those reported in the western Mediterranean off the Moroccan coast (Bouزيد et al., 2011) and in the South China Sea (Hafiz et al., 2012), where high concentrations in micrograms per gram ($\mu\text{g/g}$) were recorded, reflecting intense industrial and marine impacts in those areas. In contrast, the results of this study are consistent with values recorded in the Gulf of Mex in Alexandria (Tantoush, 2018) and with some measurements in the Red Sea (Salem et al., 2014), indicating moderate to low pollution levels. The values also partially correspond to those recorded in the sediments of Bizerte, Tunisia (Zrafi-Nouira et al., 2008), although the latter exhibit a wider range and relatively higher concentrations, which may be attributed to differences in hydrodynamic characteristics and pollution sources. In general, the variation in normal alkane concentrations between different regions can be explained by the multiplicity of their sources. These include human sources such as sewage discharge, industrial waste, oil spills, and maritime transport activities, as well as natural sources such as terrestrial and aquatic plant remains and microbial activity. Environmental factors such as the nature of the sediments (sandy or clayey), total organic carbon (TOC) content, and redox conditions also play a significant role in controlling the accumulation and distribution of these compounds. Note: In (Table 3) , all concentrations N-alkane were standardized to the unit (ng/g)

Conclusion

This study examined the distribution PAH in sediments of the in the coastal sediments of Tripoli, Libya, on the Mediterranean Sea were analyzed, and their potential sources were estimated . A geological study showed that the sediments in the studied area ranged from fine to coarse sand, with low total organic carbon content. However, the total alkanes ($\Sigma\text{C9-C20}$) concentrations ranged between 1510.1 and 8812 ng/g, with an average of 4770 ng/g. The highest alkanes concentration was recorded at station (5) at 8812 ng/g, and the lowest at station (8) at 1510.1 ng/g. The molecular structure of the normal alkanes indicates mixed sources, including both petroleum-derived inputs and biological contributions. Statistical relationships revealed that the sediment texture, particularly the proportion of fine particles (clay and silt), plays a more significant role in controlling hydrocarbon accumulation than the total organic carbon content. This highlights the importance of the physical properties of sediments in influencing pollutant distribution. These results demonstrate that combining statistical analysis with geochemical indicators is an effective approach for identifying pollution sources and assessing their levels in marine environments. The study also underscores the need for continued environmental monitoring programs, particularly in major commercial ports that are pollution hotspots. Finally, the study recommends future studies on a broader spatial and temporal scale, using advanced analytical techniques, to better understand hydrocarbon dynamics and their long-term environmental impacts on coastal ecosystems. The findings have led to a better understanding of the risks and potential sources of PAH on the coast of Tripoli, Libya, and provide further information for protecting human health and water resources.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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