Environmental and Spatial Analysis of Soil Contamination by Polycyclic Aromatic Hydrocarbons (PAHs) Near Maysan Refinery Using GIS Techniques, Southern Iraq

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https://doi.org/10.29072/basjs.20260214

ARTICLE INFO

Received: 25 January 2026
Accepted: 24 May 2026
Published: 31 August 2026

***Keywords*:**
PAHs, Total Organic Carbon, Industrial soil pollution, GC–MS, Maysan Refinery, Acenaphthylene

ABSTRACT

This study aimed to determine and evaluate the distribution and concentration of polycyclic aromatic hydrocarbons (PAHs), total organic carbon (TOC), pH, and electrical conductivity (EC) in selected industrial soils from several facilities within the Maysan Refinery and in soils collected from urban areas surrounding the refinery in southern Iraq. Ten soil samples were collected from a depth of 15 cm. PAH concentrations were determined using GC–MS analysis, while extraction was performed using a Soxhlet apparatus. TOC values were calculated according to the Walkley and Black method. The analyses showed variations in the concentrations of hydrocarbon compounds among the samples. The highest concentration of PAHs was recorded inside the Maysan Refinery, particularly in Sample 3 collected near the oil tanks, where the total concentration reached 10.73093 ppm. This high concentration of aromatic compounds was attributed to the presence of carcinogenic aromatic hydrocarbons, especially Acenaphthylene, which showed a significant concentration of

4.2959 ppm, indicating potential environmental contamination in the refinery soils. In contrast, the lowest total concentration of aromatic compounds was approximately 0.004911 ppm in Sample 7, collected near the refinery garage. Chemical analyses revealed that TOC concentrations varied among the samples. The highest TOC value was recorded near the oil pumps at approximately 8.59%, whereas the lowest value was observed in agricultural land outside the refinery at approximately 1.09%. These variations were attributed to differences in pollutant distribution and the locations of oil spills. In general, the highest pollutant levels were recorded near the oil tanks, and soil type had a significant effect on the distribution of hydrocarbon concentrations. These hydrocarbons contained carcinogenic pollutants such as Acenaphthylene, whereas the agricultural soils were free from such contaminants.

1. Introduction

Petroleum hydrocarbon contamination is considered one of the most serious environmental problems associated with oil production, transportation, refining, and storage activities **[1]**. Accidental spills of crude oil and refined petroleum products frequently lead to the release of hazardous organic and inorganic compounds into surrounding ecosystems, causing long-term environmental degradation **[2]**. Among these contaminants, polycyclic aromatic hydrocarbons (PAHs) are of particular concern because of their toxicity, persistence, mutagenic properties, and potential carcinogenic effects on living organisms **[3]**.

Soil represents one of the primary environmental sinks for hydrocarbon pollutants due to its ability to adsorb and accumulate organic compounds over long periods **[4]**. The continuous expansion of petroleum industries worldwide has substantially increased the risk of soil contamination, especially in areas surrounding refineries, oil fields, drilling sites, and storage facilities **[5]**. Hydrocarbon pollutants can alter the physical and chemical properties of soils, reduce soil quality, and pose significant threats to groundwater resources, vegetation, and human health **[6]**.

In oil-producing regions, contamination commonly results from drilling operations, leakage from storage tanks, pipeline failures, refinery emissions, and improper disposal of petroleum wastes **[7]**.

These activities release large quantities of hydrocarbons, trace metals, and other pollutants into the environment, particularly in surface soils near industrial facilities **[8]**. The persistence and accumulation of these contaminants at the soil surface contribute to increased ecological and environmental risks in surrounding areas **[9]**.

Southern Iraq contains some of the largest oil-producing regions in the Middle East and has experienced extensive industrial and petroleum-related activities for several decades. The Maysan Refinery is considered one of the most strategically important industrial facilities in Maysan Governorate because of its role in petroleum production and refining. The refinery has a production capacity of approximately 40,000 barrels per day and produces gasoline, gas oil, and other petroleum derivatives **[6]**. However, continuous industrial operations and historical oil spills in the refinery area have likely contributed to the accumulation of hydrocarbon contaminants in surrounding soils.

Despite the environmental importance of the refinery, only limited studies have investigated soil contamination and hydrocarbon pollution in the Maysan Refinery area **[6,7]**. Although several previous studies have examined petroleum contamination in other oil-producing regions **[3,5,8–14]**, detailed investigations focusing on the distribution and concentration of PAHs in soils surrounding the Maysan Refinery remain scarce. Therefore, evaluating hydrocarbon contamination in this area is important for understanding the environmental impacts of refinery activities and identifying potential ecological risks.

Accordingly, the present study aimed to determine and evaluate the distribution and concentration of polycyclic aromatic hydrocarbons (PAHs) in soils collected from selected industrial locations within the Maysan Refinery and surrounding urban areas in southern Iraq. In addition, selected physicochemical properties of the soils, including total organic carbon (TOC), pH, and electrical conductivity (EC), were analyzed to assess their relationship with hydrocarbon contamination and pollutant distribution.

3. Materials and Methods

Soil samples were collected from different locations within and around the Maysan Oil Refinery to evaluate the extent of environmental pollution caused by oil spills and refinery activities. Some samples were collected from inside the refinery, including areas affected by oil spills and industrial waste disposal, whereas other samples were collected from locations at varying distances from the refinery, including nearby urban areas. The geographic coordinates of all sampling locations were determined using the GPS function of a mobile phone, as shown in Figures 1 and 2.

The soil samples were collected from a depth of approximately 15 cm using a shovel. After collection, some samples were stored in nylon bags, while others were placed in small plastic containers. Each sample was carefully labeled with its corresponding number and location before being transported to the laboratory for analysis. The collected soil samples were air-dried at room temperature and manually disaggregated without crushing the small gravel particles. Subsequently, the samples were sent to Al-Wesal Scientific Laboratory in Basrah City for laboratory analyses (Figure 3 and Table 1). The analytical procedure for polycyclic aromatic hydrocarbons (PAHs) followed the method described by **[18]**. Approximately 6 g of sieved soil sample was placed in a cellulose thimble and subjected to Soxhlet intermittent extraction using a mixed solvent system. About 120 mL of methanol and benzene (1:1 v/v) was used as the extraction solvent, and the extraction process continued for 48 hours to ensure efficient recovery of hydrocarbon compounds. The combined extracts were subsequently saponified for 2 hours by adding 15 mL of 4 M methanolic potassium hydroxide (KOH) at the same extraction temperature, after which the solution was allowed to cool to room temperature. Meanwhile, total organic carbon (TOC) analysis was carried out according to the procedure described by **[19]**.

3. Results

3.1. Chemical Analysis – Total Organic Carbon (TOC)

Total organic carbon (TOC) was determined for ten soil samples using the method described by **[20]** at Al-Wesal Scientific Laboratory in Basrah, Iraq (Figure 3). Organic matter and soil sediments are naturally present in most terrestrial and aquatic environments **[2]**. However, their concentrations may increase significantly in areas affected by petroleum contamination and industrial activities.

The results revealed considerable variation in TOC concentrations among the analyzed samples. The highest TOC value (8.59%) was recorded in soil collected near the oil pumps within the Maysan Refinery. This elevated concentration was attributed to the accumulation and widespread diffusion of petroleum pollutants and organic materials in the surrounding area. The result reflects the strong influence of industrial and environmental conditions on the distribution of organic compounds within the refinery zone.

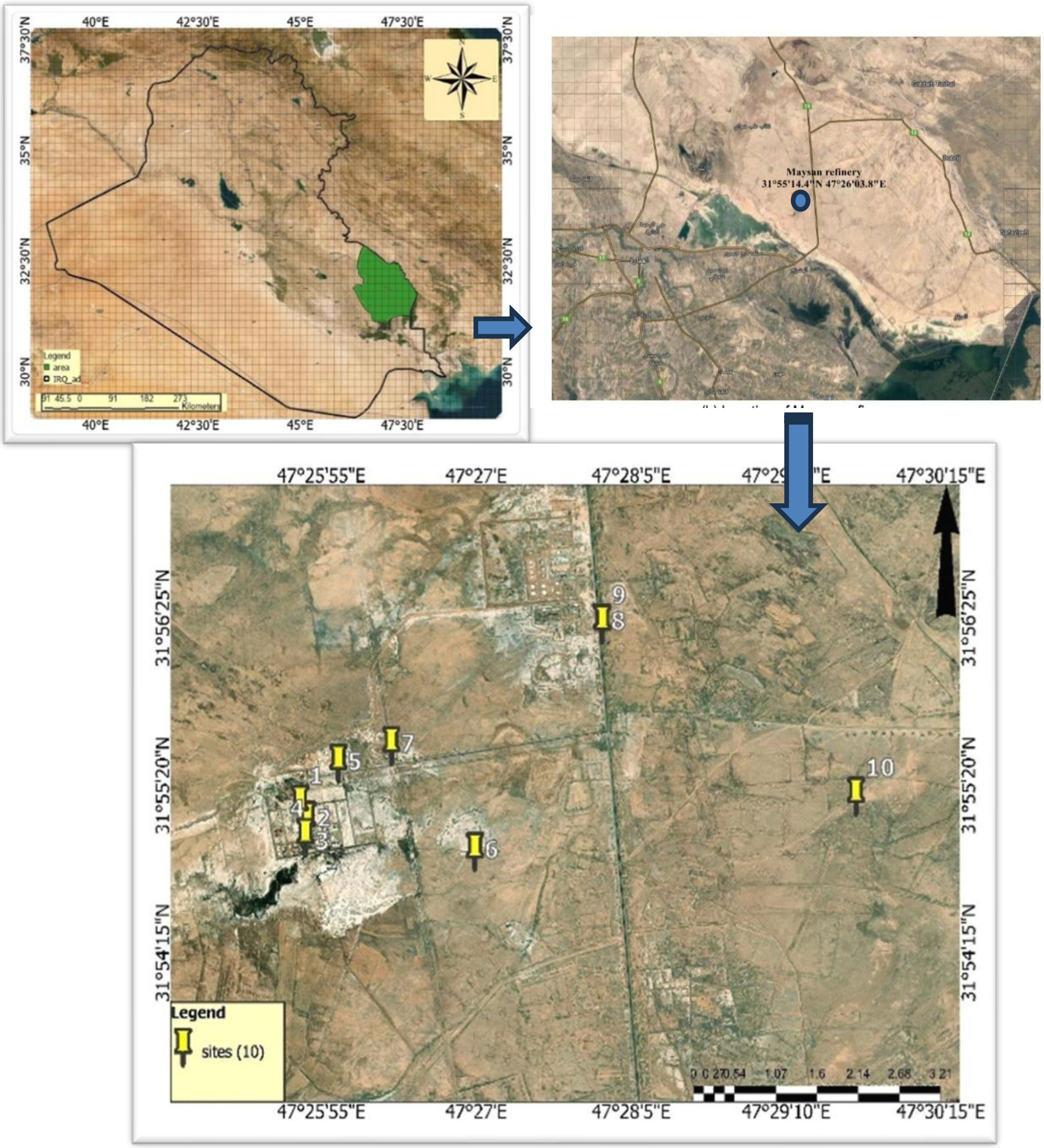

Figure 1. Earth Google map of the study area (Maysan Refinery), 1 to 10 the sites of the sample locations.

Figure 2. Photos of Maysan Refinery and soil sampling stations

Table 1. The physical measurements of the studied samples.

Sample	EC (ms/cm)	pH	°%O.M
1	48.4	8.24	5.95
2	30.4	8.03	2.83
3	105.1	7.64	10.04
4	10.4	8.32	8.31
5	27.3	7.60	4.91
6	37.7	7.77	14.81
7	76.6	7.84	2.11
8	55.8	7.78	2.47
9	6.7	8.16	5.44
10	10.1	7.93	1.88

Figure 3. Preparation of the samples at Al-Wesal Scientific Laboratory, Basrah.

In contrast, the lowest TOC concentration (1.09%) was observed in agricultural land located outside the refinery area, indicating relatively lower levels of hydrocarbon contamination. Intermediate TOC concentrations were recorded in samples collected from areas affected by oil leakage beneath industrial equipment (4.82%) and near oil storage tanks (5.82%). As shown in Table 2, the observed spatial variation in TOC concentrations suggests that localized industrial activities and specific pollution sources play an important role in controlling the accumulation and distribution of organic compounds in the study area.

Table 2. TOC Levels at different locations

sample	Location	TOC %
1	Near the buried oil waste pit	3.45%
2	Near the oil pipeline	164%
3	Near oil tanks	582%
4	Oil penetrations under the equipment	482%
5	Near a new oil well	285%
6	Near oil pumps	859%
7	Near the refinery garage	122%
8	Out of the refinery	143%
9	Out of the refinery	3165
10	Outside the refinery agricultural Land	109%

3.2. Polycyclic Aromatic Hydrocarbons (PAHs)

The total concentrations of polycyclic aromatic hydrocarbons (PAHs) varied considerably among the investigated soil samples. The recorded concentrations ranged from approximately 0.004911 ppb at the refinery garage station to 10.7349766 ppb in the sample collected near the oil storage tanks. The results demonstrated clear spatial variations in PAH distribution within the study area, reflecting differences in pollution sources and industrial activities.

High-molecular-weight (HMW) PAH compounds were dominant in three sampling stations within the study area. These compounds mainly included Chrysene, 2,2-dimethylnaphthalene, and 1-methylnaphthalene (Table 2). In contrast, low-molecular-weight (LMW) PAHs containing two to three fused aromatic rings, such as fluorene, phenanthrene, and acenaphthylene, were more common in several other soil samples.

The highest total PAH concentration was recorded at Sample 3, located near the oil tanks. This sample showed elevated concentrations of several hazardous compounds, including 2-methylnaphthalene, 1-methylnaphthalene, acenaphthylene, fluorene, phenanthrene, anthracene, and chrysene. The presence of acenaphthylene and chrysene is of particular environmental concern because these compounds are recognized as potentially carcinogenic pollutants.

The elevated PAH concentrations observed near the oil tanks were likely associated with intensive industrial activities within the refinery area. Potential sources of contamination include crude oil spills, leakage from industrial equipment, improper waste disposal, oil residues, atmospheric emissions from refinery operations, and insufficient spill prevention measures. Continuous industrial activities and long-term petroleum handling may have enhanced the accumulation of hydrocarbon pollutants in surrounding soils.

Long-term exposure to carcinogenic PAH compounds, particularly high-molecular-weight hydrocarbons such as chrysene, may pose serious environmental and human health risks, including increased probabilities of cancer development and other toxic effects (Table 3).

4. Discussion

Figures 4–9, derived from the GC–MS analysis results (Figure 10), revealed the presence of numerous hydrocarbon compounds that were unevenly distributed across the investigated sampling stations. The ten sampling locations showed considerable variation in the concentrations of aromatic hydrocarbons, reflecting differences in pollution intensity and proximity to contamination sources within the study area.

The highest concentrations of aromatic compounds were recorded at Stations 3, 4, and 6, which were located near the oil pipeline, oil storage tanks, and oil pumps, respectively. These elevated concentrations were primarily attributed to the dispersion of industrial pollutants associated with refinery activities, crude oil spills, and gaseous emissions released from the Maysan Oil Refinery. Compounds such as naphthalene, 1-methylphenol, and acenaphthylene represented major contamination indicators, with particularly high concentrations observed at Site 8, where some values exceeded 4.0. Such elevated levels strongly indicate severe polycyclic aromatic hydrocarbon (PAH) contamination resulting from the proximity to industrial facilities and environmental conditions that favor pollutant accumulation.

In contrast, the lowest concentrations of aromatic compounds were recorded at stations located farther from the primary oil pollution sources. The obtained curves also demonstrated clear differences between carcinogenic and non-carcinogenic aromatic compounds. Higher concentrations were associated with carcinogenic compounds such as 2-methylnaphthalene, 1-methylnaphthalene, and acenaphthylene, whereas lower concentrations were observed for relatively less hazardous compounds including Indeno[1,2,3-cd] pyrene, Dibenz[a,h]anthracene, and Benzo[ghi]perylene.

The spatial distribution of PAHs across the study area appeared irregular and heterogeneous. Some sampling locations exhibited very low or nearly absent concentrations of compounds such as anthracene, pyrene, and dibenz[a,h]anthracene, whereas other sites showed relatively high concentrations of the same compounds. This pronounced spatial variability emphasizes the importance of detailed spatial analysis to better understand pollution distribution patterns and identify the potential sources and transport pathways of hydrocarbon contaminants.

For total polycyclic aromatic hydrocarbons (PAHs), the highest concentrations were generally observed in the central and northern parts of the study area, whereas relatively lower concentrations were recorded at peripheral locations, particularly at Sites 1, 4, and 5. This spatial trend suggests that proximity to pollution sources and environmental transport mechanisms played a major role in controlling contaminant accumulation within the investigated soils.

Table 3. The concentration of PAHs in ten stations

Naphthalene	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Naphthalene, 2-meth	0.021611	0.140909	0.099537	0.000982	0.002114	0.222222	1.005291	2.707048	0.003221	0.741551
Naphthalene, 1-metf	0.356582	0.879545	0.890046	0.000982	0.006342	1.387097	1.881834	2.629956	0.041868	2.079S23
Acenaphthylene	0.001965	0.7375	0.756944	0.000982	0.006342	1.163082	1.474427	4.299559	0.043478	2.26839
Acenaphthene	0.018664	0.002273	0.002315	0	0	0.003584	0.003527	0.193833	0.003221	0.003976
Fluorene	0.008841	0.004545	0.006944	0	0	0.007168	0.026455	0.385463	0.006441	0.071571
Phenanthrene	0.008841	0.020455	0.011574	0	0.004228	0.032258	0.021164	0.409692	0.008052	0.139165
Anthracene	0	0.0125	0.018519	0.001965	0.029598	0.019713	0.005291	0.0837	0.004831	0.067594
Fluoranthene	0	0	0	0	0	0	0.001764	0.006608	0.00161	0.003976
Pyrene	0	0	0.001157	0	0	0	0	0	0	0
Benz[a]anthracene	0	0.001136	0.001157	0	0.004228	0.001792	0.001764	0.013216	0	0.001988
Chrysene	0	0	0	0	0.004228	0	0	0.002203	0	0
Benzo[b]fluoranthen	0	0.001136	0	0	0.038055	0.001792	0	0	0.003221	0
Benzo(k)fluoranthen	0	0	0	0	0.002114	0	0	0.004405	0	0
Benzo[a]pyrene	0	0	0	0	0.002114	0	0.0017	0.002203	0	0
lndeno[1,2.3-cd]pyre	0	0	0	0	0	01.47442	0	0	0	0
Dibenz[a,h]anthracen	0	0	0	0	0	0	0	0	0	0
Benzo[ghi]perylene	0	0	0	0	0	0	0	0	0	0

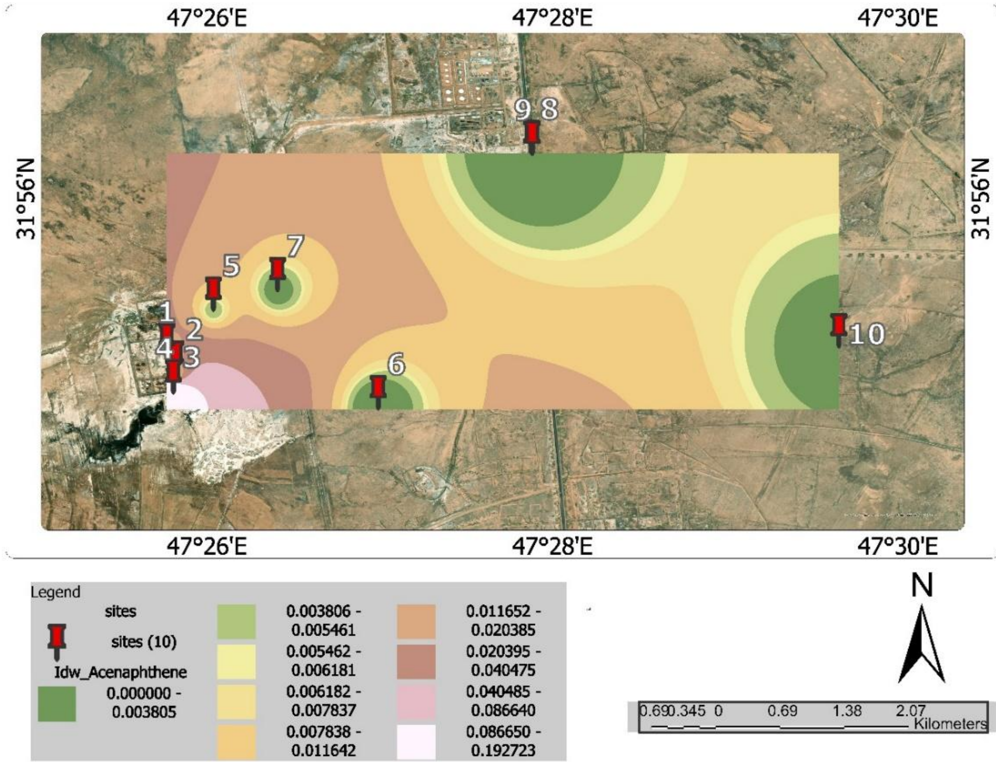

Figure 4. The spatial distribution of concentrations of **Acenaphthene** in the study area

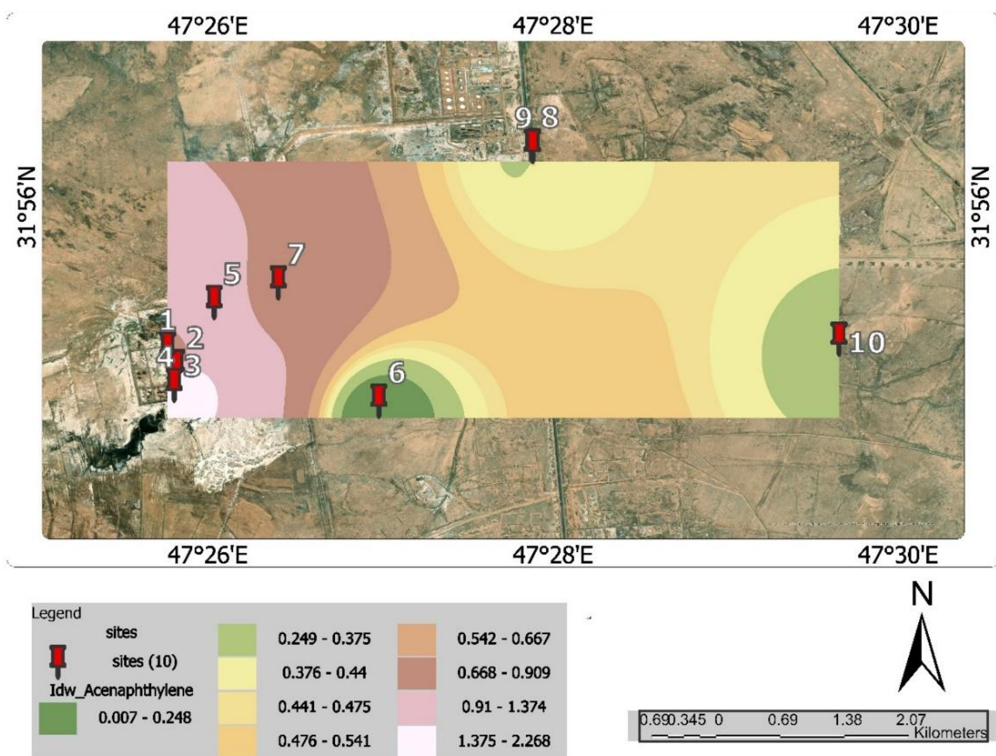

Figure 5. The spatial distribution of concentrations of **Acenaphthylene** in the study area

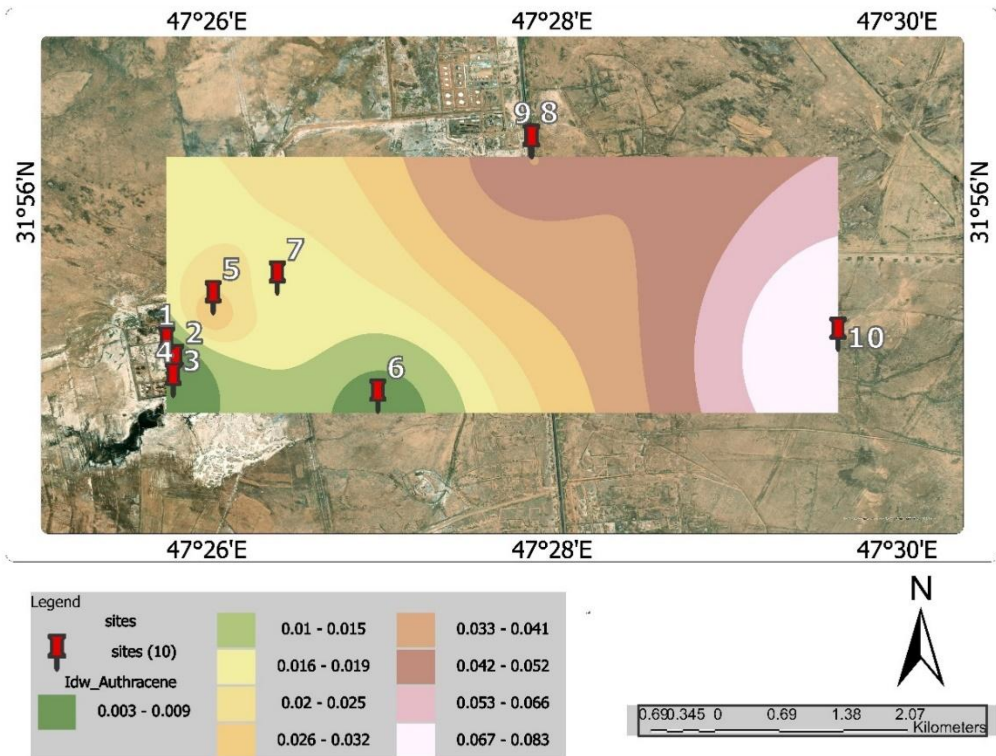

Figure 6. The spatial distribution of concentrations of **Anthracene** in the study area

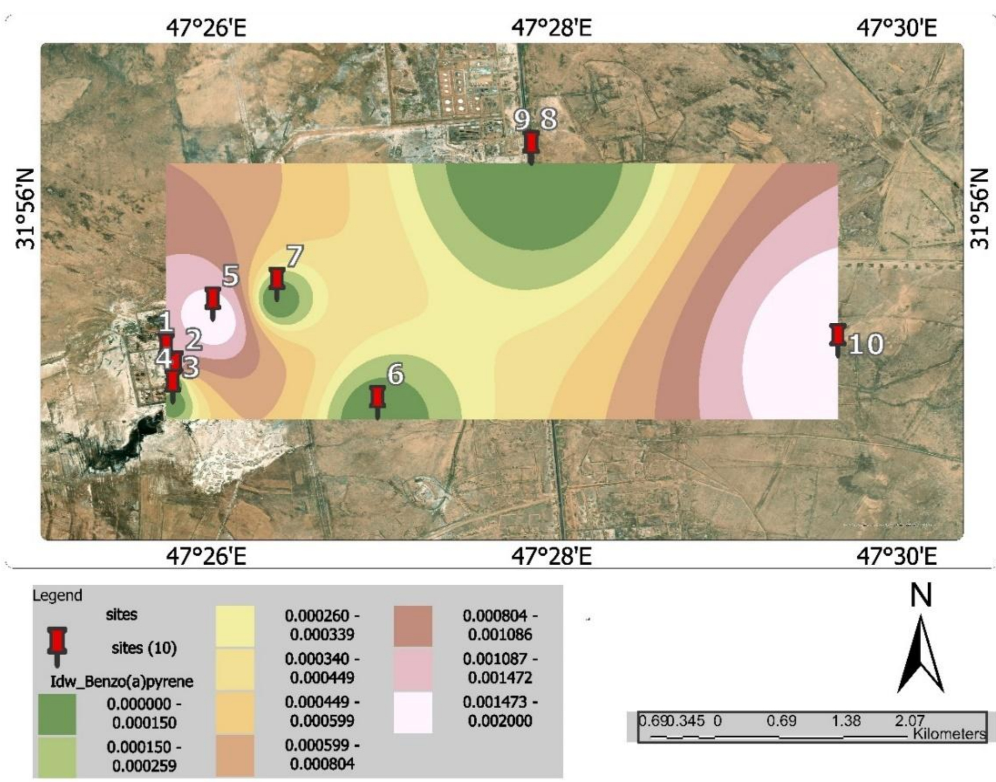

Figure 7. The spatial distribution of concentrations of **Benzo[a]pyrene** in the study area

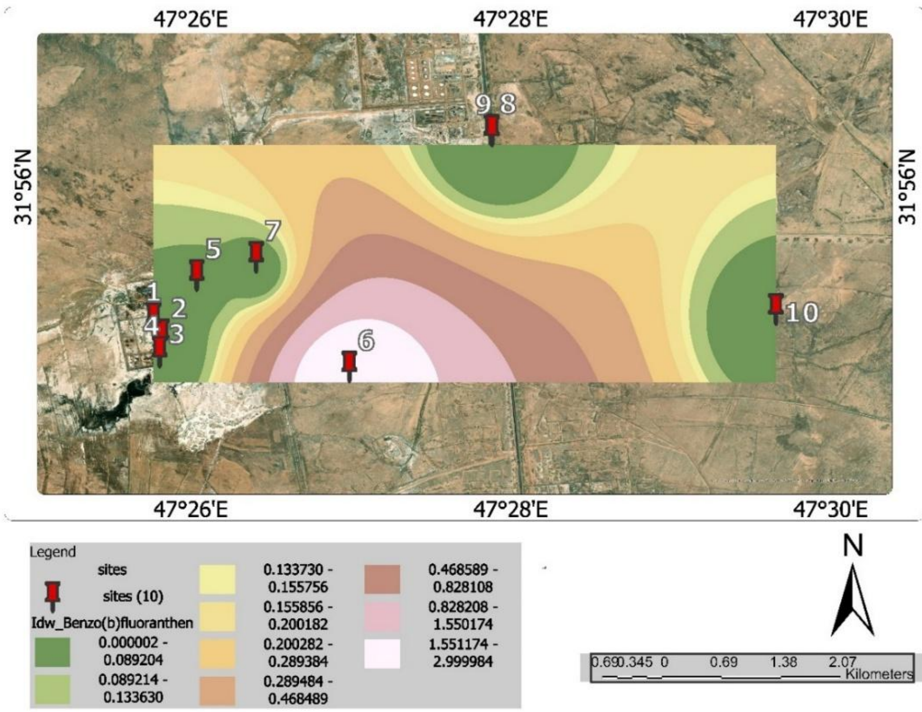

Figure 8. The spatial distribution of concentrations of **Benzo[b]fluoranthen** in the study area

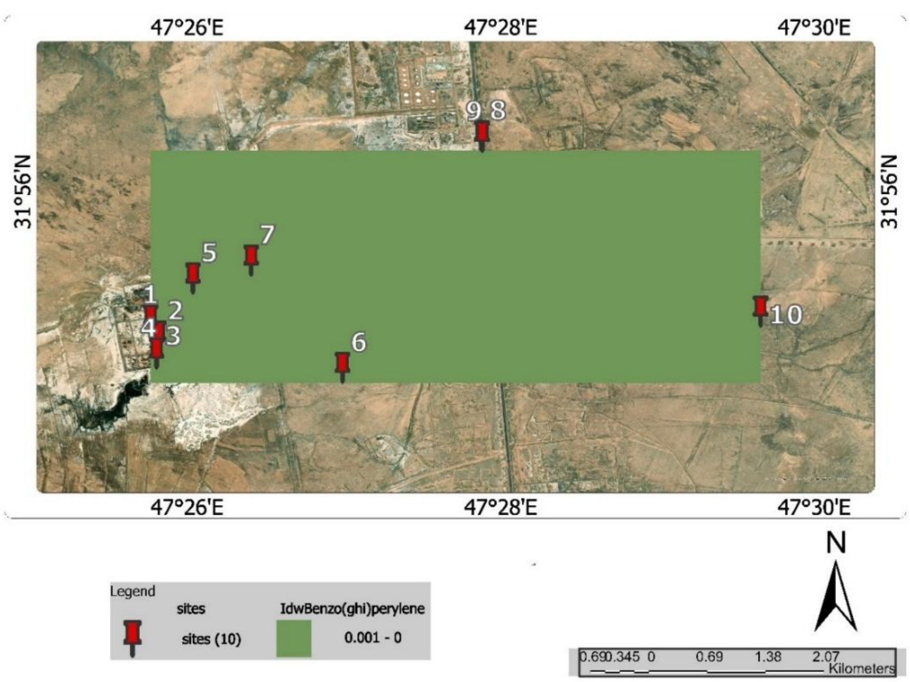

Figure 9. The spatial distribution of concentrations of **Benzo[ghi]perylene** in the study area

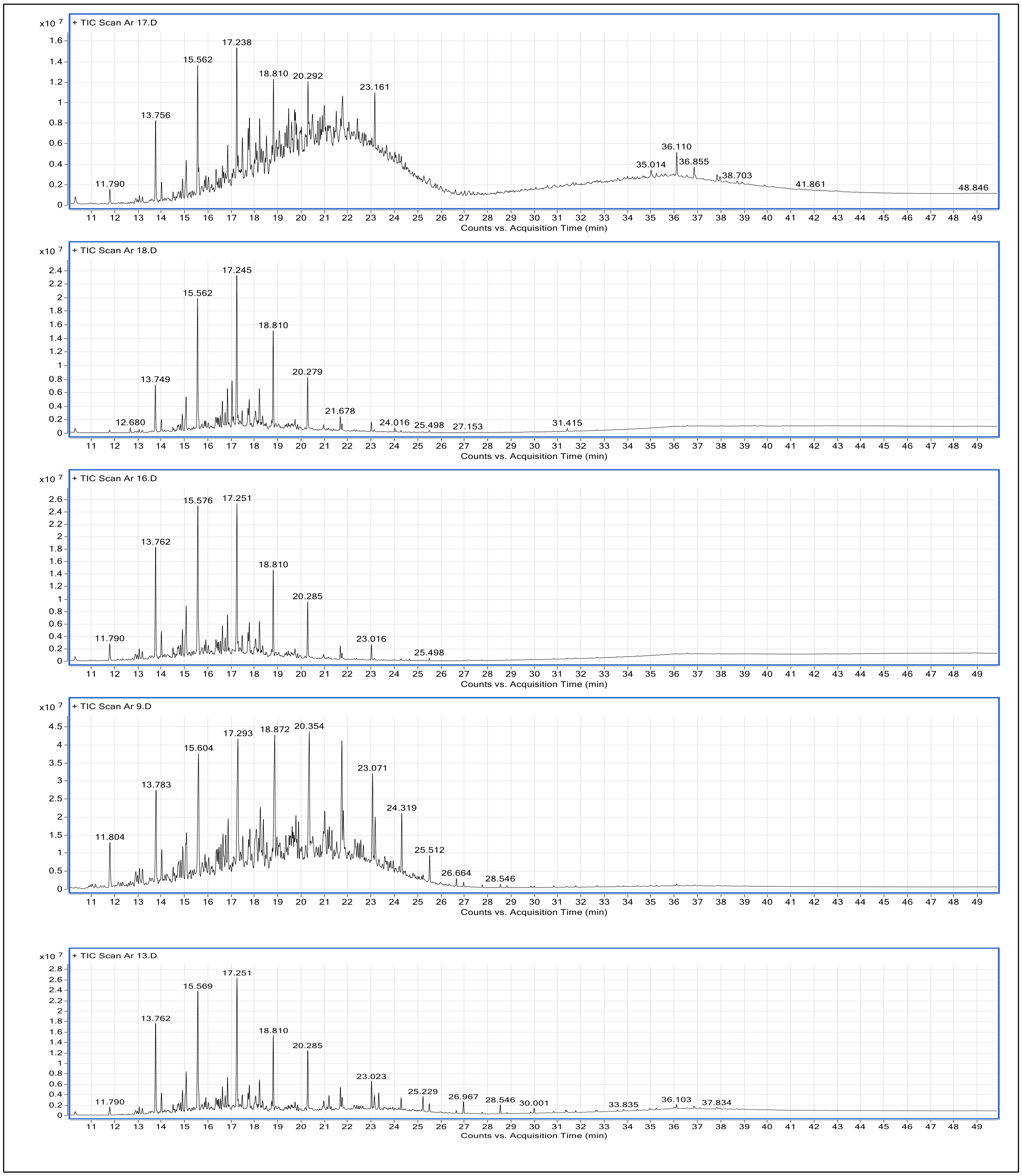

Figure 10. Polycyclic aromatic hydrocarbon concentrations in the stations

The results also provide evidence that refinery-related waste and industrial activities significantly contributed to the widespread distribution of hydrocarbon contaminants throughout the region. Most PAHs present in the environment are generated as byproducts of pyrolysis or the incomplete combustion of fossil fuels **[21]**. More than 97% of PAH emissions originate from stationary fuel combustion sources **[22]**. Additional important sources include oil spills associated with industrial activities, as well as emissions from vehicles and transportation systems **[23]**. At the local scale, hazardous waste disposal sites near industrial facilities may also act as concentrated sources of PAH contamination.

The widespread occurrence and carcinogenic nature of PAHs, particularly in surface soils, are among the primary reasons for continued environmental investigations of these compounds. The detection of PAHs even in soils located relatively far from industrial facilities suggests that atmospheric deposition following both local and long-range transport represents a major pathway for introducing these contaminants into the soil environment **[24]**.

5. Conclusions

The highest polycyclic aromatic hydrocarbon (PAH) concentrations were detected at the Maysan Refinery, particularly near the oil storage tanks. Across all investigated sites, PAH distributions and concentrations varied significantly in relation to local soil characteristics. Elevated levels of PAHs, specifically carcinogenic compounds like acenaphthylene, signal critical environmental contamination and public health risks near the refinery. This localized pollution is further evidenced by elevated total organic carbon (TOC) levels in soils surrounding oil infrastructure, such as pumps, contrasted against lower TOC levels in nearby agricultural zones. Ultimately, these fluctuating hydrocarbon concentrations are driven by proximity to spill sites, infrastructure, and soil properties, highlighting the severe impact of industrial activity on soil quality. Consequently, continuous monitoring is essential for effective environmental management and pollution mitigation in the region.

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التحليل البيئي والمكاني لتلوث التربة بالهيدروكربونات العطرية متعددة الحلقات بالقرب من مصفاة ميسان باستخدام تقنيات نظم المعلومات الجغرافية، جنوب العراق

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المستخلص

تهدف هذه الدراسة إلى تحديد وتقييم توزيع وتركيز الهيدروكربونات العطرية متعددة الحلقات (PAHs) والكربون العضوي الكلي (TOC) ودرجة الحامضية (PH) والتوصيل الكهربائي (EC) في عينات مختارة من التربة الصناعية في بعض المنشآت الصناعية بمصفاة ميسان، بالإضافة إلى عينات مختارة من التربة من المناطق الحضرية المحيطة بالمصفاة، جنوب العراق. تكتسب هذه الدراسات أهمية بالغة لارتباطها بصحة الإنسان والتلوث البيئي. جُمعت عشر عينات من التربة على عمق 15 سم. تم تحديد تركيزات الهيدروكربونات العطرية متعددة الحلقات باستخدام تقنية كروماتوغرافيا الغاز-مطياف الكتلة(GC-MS) ، واستُخلصت المركبات باستخدام جهاز سكسوليت. حُسبت التركيزات وفقًا لطريقة . Walkley and Black أظهرت التحليلات تباينات في تركيزات مركبات الهيدروكربون بين العينات. سُجِّل أعلى تركيز للهيدروكربونات العطرية متعددة الحلقات في مصفاة ميسان، وتحديدًا داخل المصفاة، حيث بلغ التركيز الإجمالي 10.73093 جزءًا في المليون في العينة رقم 3 (بالقرب من خزانات النفط). ويعود سبب هذا التركيز العالي للمركبات العطرية إلى وجود مركبات عطرية مسرطنة (مع تركيز ملحوظ من الأسينفثيلين (4.29959)، مما يشير إلى تلوث بيئي محتمل) بنسب عالية في تربة محطة المصفاة. أما أدنى تركيز للمركبات العطرية الكلية فكان حوالي 0.004911 جزءًا في المليون في الموقع رقم 7 (بالقرب من مرآب المصفاة). وكشف التحليل الكيميائي عن تباين في تركيزات الكربون العضوي الكلي، حيث سُجِّل أعلى تركيز بالقرب من مضخات النفط، بنسبة 8.59% تقريبًا، وأدنى تركيز في الأراضي الزراعية خارج المصفاة، بنسبة 1.09% تقريبًا، وذلك نتيجةً لاختلاف توزيع الملوثات ومواقع التسربات النفطية. وبشكل عام، سُجِّلت أعلى مستويات الملوثات بالقرب من خزانات النفط، وكان لنوع التربة تأثير كبير على توزيع مستويات هذه الهيدروكربونات. حملت هذه الهيدروكربونات ملوثات مسرطنة مثل الأسينفيلين ولكن الأراضي الزراعية كانت خالية من هذه الملوثات.

الكلمات المفتاحية: الهيدروكربونات العطرية متعددة الحلقات؛ الكربون العضوي الكلي؛ تلوث التربة الصناعية؛ GC–MS؛ مصفى ميسان؛ الأسينفثيلين.