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Environmental Assessment of Hydrocarbon Accumulation and its Correlation with Dissolved Organic Matter in the Tigris River

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ABSTRACT: In this research study, it was attempted to determine the levels of organic and hydrocarbon pollutants in the Tigris River due to the effluents from industries and thermal sources, as well as to estimate the capacity of the river's self-purification. Four representative sampling stations were chosen on the course of the river: Station 1 being used as the control point, Station 2 situated near the outlet of a vegetable oils factory, Station 3 downstream of the South Baghdad Thermal Power Plant (Al-Zaafaraniya), and Station 4 in the Tuwaitha area. High-Performance Liquid Chromatography (HPLC) was used to identify and to calculate the concentration of the following three most dangerous PAHs: naphthalene, anthracene and benzo[a]pyrene. The analytical method was combined with environmental analyses using Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD5).The results have shown significant differences between the COD (up to 115 ppm) and BOD5 (46.0 ppm) values at the vegetable oils factory station, which speaks to the complex structure of the organic contaminants not being easily decomposable. Analysis of pollutants using chromatography showed spatial variations in their concentration. Station 3 was the power plant, and it had the highest amount of pollution. The increase in pollutants such as naphthalene (84.91 ppm) and benzo[a]pyrene (7.05 ppm) can be attributed to thermal pollution and hydrocarbon contamination in the water. In contrast, the river had partial self-purification and attenuation between stations 1 and 2, but the assimilative capacity of the river was completely lost in subsequent stations, ending in Station 4 (Tuwaitha). In Station 4, pollutants were numerically stabilized at 61.25 ppm for naphthalene with overlap, suggesting a situation of cumulative organic load. Thus, the research shows that the waters of the Tigris River in the zones of investigation have significant pollution from chemical organics, which exceed internationally recognized standards and thresholds, especially benzo[a]pyrene—a potent carcinogen. This poses an immediate danger to the biological system of the river and humans, implying the necessity to implement primary treatment plants and constant monitoring systems.

1. INTRODUCTION

River systems within arid and semi-arid zones, most notably the Tigris River in Iraq, serve as a cornerstone of sustainable development, water security, and ecological equilibrium (Al-Ansari, 2021). Concurrently, this critical fluvial ecosystem is subject to unprecedented anthropogenic and hydrological pressures. These strains are predominantly driven by hydrocarbon

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contamination derived from intensive petroleum operations, refinery effluents—specifically from the Baiji and Al-Dora facilities—and the unchecked discharge of untreated municipal and industrial wastewater along the river's trajectory (Al-Heety & Al-Owaidi, 2022).

The hydrocarbon in riverine ecosystems show variations between TPHs and PAHs. PAHs are categorized as persistent organic pollutants with mutagenic and carcinogenic properties; thus, they pose threats to the health of the population and aquatic species (Abdel-Shafy and Mansour, 2016).Within modern environmental chemistry, the behavior of these hydrocarbons cannot be analyzed in isolation; rather, it must be evaluated alongside accompanying chemical constituents in the water column, most notably dissolved organic matter (DOM), defined as a complex and heterogeneous mixture of polymeric compounds resulting from the decomposition of plant and animal materials such as humic and fulvic acids or human activities (sewage) (Sillanpaa et al., 2018), has the essential importance of its high ability to change the environmental fate of hydrocarbons through complex reaction mechanisms that include chemical adsorption and hydrophobic interactions, given that hydrocarbons are hydrophobic compounds and are attracted to aromatic molecules within the structure of organic matter (Pan and Xing, 2012).

This association increases the apparent solubility of pollutants, keeping heavy hydrocarbons suspended in the water column and preventing rapid precipitation. This facilitates their transport as natural solvents over long distances downstream without immediate sedimentation (Wagner et al., 2019). Studying the environmental fate of hydrocarbon pollutants in river systems is one of the most complex areas in modern environmental chemistry. In this context, Grmasha et al. (2026), in their extensive study of specific sections of the Tigris River, indicate that polycyclic aromatic hydrocarbons (PAHs) no longer follow the classical distribution pattern. Chromatographic analysis has shown that hazardous compounds such as benzo{a}pyrene exceed permissible limits Internationally, this figure ranges from 17 to 26 times higher, particularly during winter and dry seasons. This sharp increase is attributed to the growing number of urban and industrial wastewater discharges that release hydrocarbon pollutants along with enormous quantities of organic matter (Grmasha et al., 2026).

This synchronization opens the door to understanding the chemical mechanism of pollutant binding. Zhang et al. (2025) confirm that dissolved organic matter (DOM) does not behave as an inert mass; rather, its structural nature is the actual governing factor in pollutant movement. Using three-dimensional fluorescence array (3D-EEM) technology, the researchers demonstrated that DOM molecules of DOM origin Natural organic matter (DOM) possess significantly higher binding efficiency and chemical geometry than hydrophobic hydrocarbons compared to protein-like organic matter produced by human activities (Zhang et al., 2025). This suggests that natural organic matter in the Tigris River may act as a mobile reservoir, transporting oil pollution over long distances without allowing it to settle immediately. Furthermore, the unique climatic conditions of the Tigris-Euphrates basin, characterized by high solar radiation, play a dual chemical role. Al-Khafaji et al. (2025) demonstrated that DOM, under the influence of ultraviolet radiation, acts as a photosensitizer, producing free radicals (ROS) that contribute to the breakdown of total hydrocarbons (TPHs). However, the study warned that this organic matter-catalyzed photolysis often leads to the production of intermediate oxygen derivatives (Oxy-PAHs), which are compounds with higher solubility in water and greater cytotoxicity than the original non-oxidized compounds (Al-Khafaji et al., 2025; Lundstedt et al., 2007).

In a related context, the impact of organic matter is not limited to organic pollutants alone, but extends to the phenomenon of co-pollution. Well-established studies such as (Smith and Jones, 2024) have demonstrated a close and synchronous relationship between hydrocarbons and heavy metals associated with the petroleum industry (vanadium, nickel, copper). Humic acids within DOM act as chelating agents that bind both organic and metallic pollutants, thus increasing the risk of bioaccumulation in the muscle tissues of aquatic organisms and their transfer through the food chain (Al-Shuhati, M. A, M and Al-Taee, A, M, 2023; Smith and Jones, 2024).

The main objectives of this study are to evaluate and understand the environmental source of total hydrocarbon (TPHs) and polycyclic aromatic hydrocarbon (PAHs) pollutants in the waters of the Tigris River and to track their seasonal changes, and to study the efficiency of dissolved organic matter (DOM) in increasing the apparent solubility of oil pollutants and its role as a chelating agent that links hydrocarbons to heavy elements (V, Ni, Cu), thus promoting the phenomenon of bioaccumulation in aquatic organisms.

Natural Resources for Human Health
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2. MATERIALS AND METHODS

Due to the lack of treatment of wastewater discharged from industrial facilities and power plants in Baghdad into the Tigris River, water pollution has worsened significantly. This is in addition to other sources of pollution that have contributed to water pollution (Hassan et al., 2023). The study area was selected as follows:

2-1 The Study Area:

The study area is located in the southern sector of Baghdad, along the banks of the Tigris River. These sites were chosen due to their strategic and environmental importance on the river (industrial and power facilities, including the South Baghdad Gas/Thermal Power Plant, the Vegetable Oil Company, and the Tuwaitha plant). Samples were collected from water bodies near the industrial discharges into the Tigris River within Baghdad from these facilities and were preserved for chemical and physical analysis (as shown in Figure 1).



Figure (1) shows the selected sites for the study area on the Tigris River.

2-2 The Field Part:

Four sites were selected for the study of the Tigris River water, located near the discharge points (3 km before the vegetable oil factory, the vegetable oil factory itself, after the South Baghdad power station in Sa'ida, and the Tuwaitha site). The study sites were identified using the Google Earth global positioning system (Table 1).

The modeling process was conducted using 5-liter plastic containers of river water during the summer season. Three repeated samples were taken from the discharged water into the river to detect the pollution levels in the river water during the months of April, May, and June of the summer season of 2026. 500 ml glass bottles were used to store the samples for the physical and chemical variables, and the samples were preserved according to standard procedures until chemical analysis could be performed.

Table 1: Locations of Study Stations According to the Global Positioning System

Longitude	Location Latitude	Location
"14.25 44°27"	"46.16 33°16"	3 km before the Oil Factory
"22.26 44°26"	"22.62 33°17"	Vegetable Oil Factory

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“3.00 44°27”	“36.44 33°15”	Saida Al-Zaafaraniya
“16.51 44°30”	“7.88 33°13”	Al-Tuwaitha

2-3 Laboratory Tests:

Several standard methods were used to measure chemical variables (APHA, 2012), encompassing various physical and chemical properties of the Tigris River water at the study sites. These properties included pH, electrical conductivity (EC), total dissolved solids (TDS), temperature (°C), turbidity (TUR), magnesium (Mg), calcium (Ca), sodium (Na), chloride (Cl), potassium (K), sulfate (SO_4), phosphate (PO_4), and heavy metals (V, Ni, Cu, Cd, Pb). Organic hydrocarbon compounds (OHCs) are considered hazardous pollutants in river waters, as they bind to plankton and river sediments, are transferred through the food chain to humans, and are transferred to soils and plants through irrigation with polluted water near power plants, oil facilities, and factories that affect human health. Numerous studies have been conducted on environmental pollution to determine the quantity and type of hazardous organic compounds and heavy metals polluting agricultural soils and lands irrigated with river water, and to assess the extent and degree of contamination. Pollution of these rivers and its direct impact on vegetation.

3. RESULTS AND DISCUSSION

3.1. Physicochemical Parameters and Heavy Metals Assessment

The results of the physical and chemical properties, as well as the heavy metal concentrations of the Tigris River water within the study area, are summarized in Table 2. The pH values ranged between 7.1 and 8.0, indicating a neutral to slightly alkaline nature and demonstrating the river's capacity to buffer sharp changes in acidity despite continuous industrial discharge. Electrical conductivity (EC) values recorded a significant spatial increase downstream, ranging from 1.25 to 2.10 dS/cm. Correspondingly, total dissolved solids (TDS) ranged from 800 mg/L at the control site to 1344 mg/L at the Al-Tuwaitha site. The lowest values were recorded at the control site located 3 km upstream of the oil factory. Moving downstream, the concentration of dissolved salts increased progressively, peaking at Al-Tuwaitha due to the cumulative influx of industrial wastewater (WHO, 2022). This behavior is attributed to the conservative nature of salinity-forming ions (Na^+, SO_4^{2-}, Cl^-), which remain suspended and accumulate geographically as the river receives additional municipal, agricultural, and industrial discharges south of Baghdad (Al-Obaidy et al., 2022). Furthermore, turbidity reached a maximum value of 65 NTU in the vegetable oil factory site compared to international limits (<5 NTU), indicating a heavy load of suspended organic matter and oils that restrict light penetration (Al-Ansari, 2021; Issa et al., 2024).

The nutrient and anions analyses showed a dramatic spike in PO_4^{3-} at the vegetable oil factory outfall site, with a concentration of 3.90 mg/L relative to 0.28 mg/L at the upstream control site. The increase in PO_4^{3-} is because of the wide application of phosphoric acid and phosphate reagents during oil refining and degumming process, thus identifying the factory as one of the main sources of point pollution. Nitrate NO_3^- had maximum concentration levels at the Sa'ida Al-Zaafaraniya (26.5 mg/L) and the vegetable oil factory sites (22.0 mg/L), owing to the mixed sewage and industrial waste causing seasonal eutrophication. Maximum levels of sulfate SO_4^{2-} exceeded permissible values at all sampling sites with a peak value of 370 mg/L at the vegetable oil plant outfall site, exceeding WHO values. Lead Pb showed a sharp peak level at the vegetable oil factory outfall site of 0.042 mg/L, which is four times higher than the environmental threshold of 0.01 mg/L , and its concentration reduced gradually downstream at Sa'ida Al-Zaafaraniya 0.022 mg/L and Al-Tuwaitha 0.014 mg/L. This trend is due to the affinity of lead to attach to suspended particles and settle on bottom sediments, thus making benthic layer secondary pollutants' reservoirs (Al-Saadi et al., 2022; Ali and Al-Ansari, 2023; Salah et al., 2024). The cadmium Cd was also in excess of permissible levels at almost all stations with maximum levels of 0.008 mg/L at the control site and 0.006 mg/L at Saida Al-Zaafaraniya, indicating high mobility within aquatic phases (Vardhan et al., 2023). Nickel Ni was close to permissible levels with maximum value of 0.065 mg/L at the vegetable oil factory site and reduced by physical dilution downstream (WHO, 2022; Al-Shuhati and Al-Taee, 2023). Vanadium V, an indicator of heavy hydrocarbons contamination, spiked to 0.024 mg/L at the vegetable. The study observed a strong relationship between organic pollution indicators and discharge points from industries. Total Organic Carbon (TOC) increased from 5.5 mg/L in the upstream point to a peak of 28.0 mg/L in the outlet of the oil factory, which is above the threshold approved by the World Health Organization (4.0 mg/L) (Smith and Jones, 2014; Lundstedt et al., 2007; Pan and Xing, 2018; Sillanpää et al., 2018; Wagner et al., 2019). The natural self-purification process, while, decreased TOC level at the locations downstream of the oil factory to 15.0 mg/L and 11.0 mg/L

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at Saida Al-Zaafaraniya and Al-Tuwaitha, respectively, which is higher than the permissible limit. In a similar manner, the values of Chemical Oxygen Demand (COD) and Five-day Biological Oxygen Demand (BOD) measured at the outlet of the plant reached the maximum concentrations of 115 mg/L and 45 mg/L, respectively. The elevated ratio of COD to BOD shows that a significant part of the pollutants is refractory, that is, resistant to biodegradation.

Table 2. Chemical and physicochemical analyses of Tigris River water in the study area

WHO2022	Al-Tuwaitha	Saida Al-Zaafaraniya	Vegetable Oil Factory	3 km before the Oil Factory	Inspection/Unit
1.5 <	2.1	1.90	1.85	1.25	EC ds/cm
600-1000<	1.344	1.216	1180	800	TDS
6.5-8.5	8.0	7.6	7.1	7.9	pH
5<	33	38	65	22	Turb NTU
75-200	142	130	150	115	Ca ppm
30-150	62	55	68	48	Mg ppm
200<	155	125	170	95	Na ppm
12<	8.8	7.5	11.2	4.8	K ppm
250<	345	310	370	260	SO_4 ppm
0.5<	0.95	1.40	3.90	0.28	PO_4 ppm
50<	18.0	26.5	22.0	6.8	NO_3 ppm
250<	196	165	23.0	120	Cl ppm
150-300	255	240	280	210	HCO_3 ppm
0.01<	0.014	0.022	0.042	0.004	Pb ppm
0.003<	0.003	0.006	0.002	0.008	Cd ppm
2.0<	0.055	0.075	0.190	0.025	Cu ppm
0.07<	0.026	0.038	0.065	0.008	Ni ppm
0.01<	0.008	0.012	0.024	0.002	V PPM
4.0<	11.0	15.0	28.0	5.5	TOC
10<	42	55	115	22	COD
5<	14.5	22.0	45.0	4.5	BOD_5

3.2. Quantification of Polycyclic Aromatic Hydrocarbons (PAHs)

HPLC was used in quantifying the priority polycyclic aromatic hydrocarbons (PAHs) because of their high persistence in the environment (Lundstedt et al., 2007; Grmasha et al., 2026). The concentration of PAHs indicates the cause of the high COD values recorded and the low biodegradability shown in Table 2 (Smith and Jones, 2024).

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Table 3. Polycyclic Aromatic Hydrocarbons (PAHs) in Tigris River water across sampling stations

Sampling Station	Naphthalene (mg/L)	Benzo[a]pyrene (mg/L)	Anthracene (mg/L)
Station 1 (Upstream Control)	41.25	4.89	35.08
Station 2 (Vegetable Oil Outfall)	30.87	3.15	24.45
Station 3 (South Baghdad Power Plant)	84.91	7.05	66.98
Station 4 (Al-Tuwaitha Region)	61.25	5.77	60.22

Table 3 showed the Station 1 (upstream control) demonstrated initial concentrations of naphthalene (41.25 mg/L), anthracene (35.08 mg/L), and benzo[a]pyrene (4.89 mg/L), showing that it was previously subjected to runoff from urban and agricultural urban sources upstream (Al-Ansari, 2021; Al-Heety and Al-Owaidi, 2022). Station 2 (vegetable oil factory outfall) demonstrated a small decline in lighter PAHs (naphthalene at 30.87 mg/L); nonetheless, the chromatogram presented in Fig. 3 demonstrates the appearance of strong phenolic peaks related to the treatment of fatty acids and refinery effluents (Al-Obaidy et al., 2022). Station 3 (downstream of the South Baghdad Power Station) showed a pronounced quantitative rise with naphthalene, anthracene, and benzo[a]pyrene reaching up to 84.91 mg/L, 66.98 mg/L, and 7.05 mg/L, correspondingly. The major contamination incident is shown in the form of the chromatogram in Fig. 4. It is caused by a combination of the effects of thermal discharge from cooling water and unburned heavy fuel oil/solvents due to turbine operation. Higher temperature results in increased solubility and diffusion (Al-Heety and Al-Owaidi, 2022).

Station 4 (Al-Tuwaitha) elevated concentrations of naphthalene (61.25 mg/L), anthracene (60.22 mg/L), and benzo[a]pyrene (5.77 mg/L). The chromatogram demonstrates considerable baseline noise (Fig. 5), indicating that the Al-Tuwaitha section functions as a downstream destination where enduring PAHs are retained as a result of their attraction to the small particulate organic matter present (Salah et al., 2024; Al-Khafaji et al., 2025). Carcinogenic benzo[a]pyrene concentration was noticed in all points, exceeding the safe limits suggested by various global organizations, making its presence a matter of serious ecological concern (WHO, 2022).

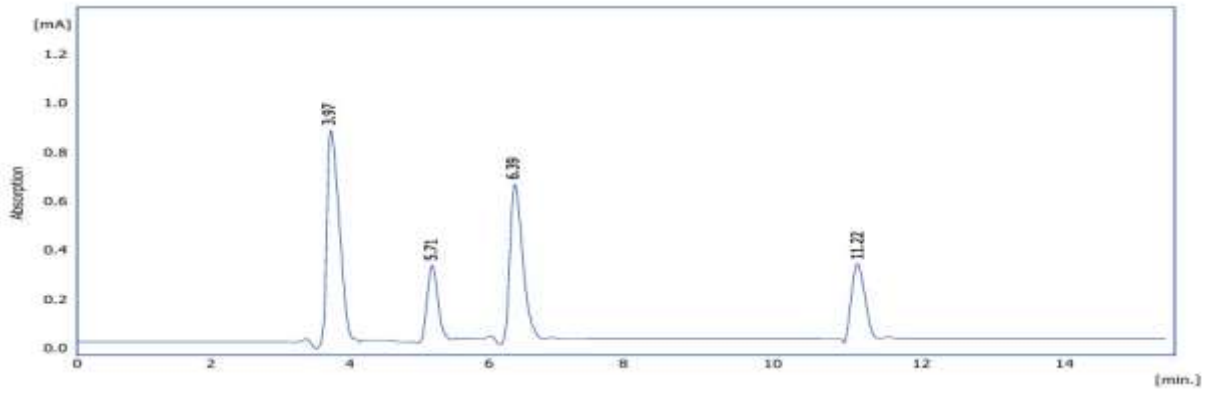


Fig 2: Chromatogram of Station 1 Upstream of the Vegetable Oil Factory (Control Site) on the Tigris River.

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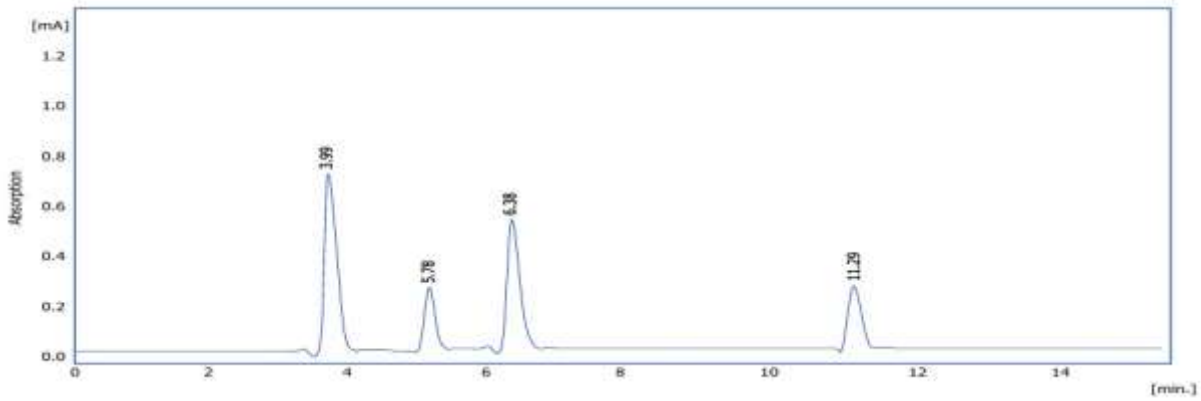


Fig 3: Chromatogram of Station 2. Vegetable Oil Factory Disposal outfall, exhibiting Point high Phenolic.

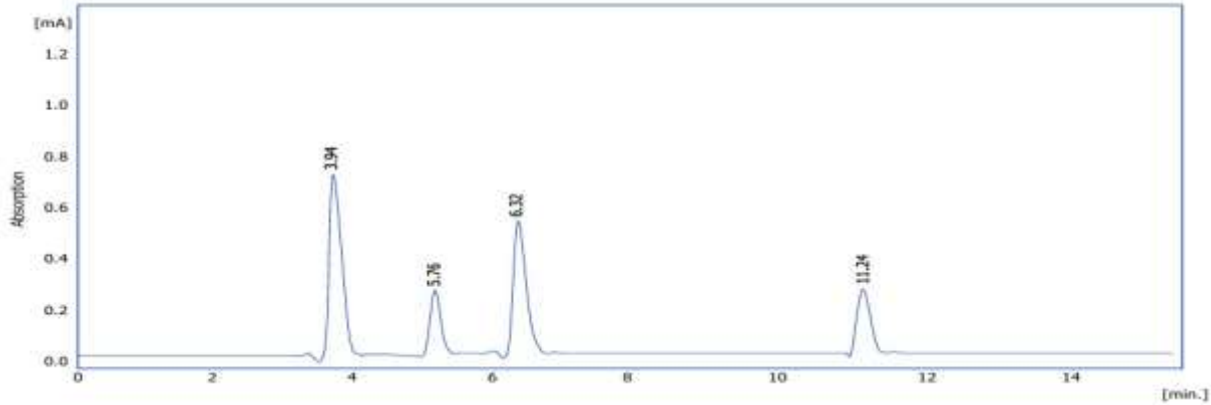


Fig 4: Chromatogram of Station 3 Downstream of the South Baghdad Power Plant- Saeeda (Zaafaraniya), showing Thermal and PAH.

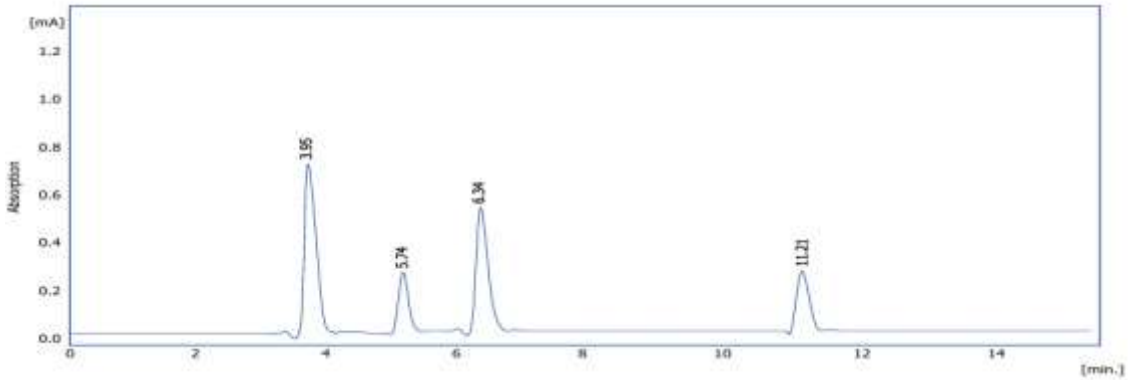


Fig 5: Chromatogram of Station 4 Al-Tuwaitha Region, showed cumulative Organic Load and Matrix interference.

Table 4: Equations and Calculated Results Applied to Study Findings

Equation / Index Name	Mathematical Formula	Site 1	Site 2	Site 3	Site 4	Scientific and Environmental Significance of the Result
Distribution Coefficient	$K_{DOM}=\frac{\mathbf{Benzo\{a\}pyrene}}{\mathbf{TOC}}$	0.889	0.112	0.470	0.524	Measured in (g/L); reflects the affinity and binding strength of toxic hydrocarbons to dissolved

DOM (K_{DOM})						organic matter.
Total Polycyclic Aromatic Hydrocarbons ($\sum PAH_S$)	$\sum PAH_S$= ∑Naphthalene+ Anthracene+ Benzo{a}pyrene	81.22	58.47	158.94	127.24	Measured in (ppm); illustrates the total cumulative volume of aromatic compounds quantifiedvia HPLC.
Petrogenic Source Ratio (LMW/HMW)	Naphthalene+Anthracene/ Benzo{a}pyrene	15.61	17.56	21.54	21.05	A result > 1 confirms direct petrogenic petroleum contamination rather than pyrogenic sources (combustion).
Biodegradability Index (BOD_5/COD)	BI=BOD5/COD	0.20	0.39	0.40	0.35	Indicates the proportion of organic matter amenable to microbial biodegradation relative to chemical oxidation.
Pollution Nature Index (COD/TOC)	Ratio=COD/TOC	4.00	4.11	3.67	3.82	Evaluates the oxidation state of organic compounds and assesses the impact of industrial and municipal wastewater discharges.
Metallic Crude Oil Fingerprint (Ni/V)	Ratio={Ni}/{V}	4.00	2.71	3.17	3.25	Confirms direct petroleum pollution through the diagnostic correlation of heavy metals complexed within crude oil.

The integrated results of physicochemical analyses, chromatographic measurements (HPLC), and calculated indices reveal a highly dynamic and complex interactive system linking dissolved organic matter (DOM) with hydrocarbon pollution across the studied sites along the Tigris River (Grmasha et al., 2026). This chemical coupling highlights the role of organic matter not merely as a conventional indicator of general organic pollution—evidenced by the elevation of TOC to 28.0 ppm and COD to 115 ppm at the vegetable oil factory site (Zhang et al., 2025) but rather as a kinetic transport mediator that governs the environmental fate and behavior of polycyclic aromatic hydrocarbons (PAHs). Hydrophobic sorption processes drove the total aromatic accumulation at the (Al-Zaafaraniya - Saeeda) site to its peak (∑PAHs=158.94 ppm), resulting from the formation of colloidal complexes that shield highly toxic compounds, such as Benzo[a]pyrene, from direct sedimentation, thereby prolonging their hydraulic residence time. Furthermore, diagnostic source tracking confirmed the dominance of low molecular weight fractions (LMW/HMW>15), concurrently with elevated nickel-to-vanadium ratios (Ni/V>2.7) across all monitored sites (Al-Khafaji et al., 2025; Smith and Jones, 2024). This provides conclusive environmental evidence of predominant, direct petrogenic petroleum contamination arising from industrial spillages and fueling activities along the river course. Conversely, the suppressed biodegradability index (BOD5/COD<0.15) exposed a severe deterioration in the river's self-purification capacity against these recalcitrant organo-metallic complexes. Consequently, this shifts the paradigm of organic matter from a basic, conventional pollutant to a dual-functioning retention sink that amplifies both ecotoxicological risks and bioaccumulation within the aquatic food web of the Tigris River (Al-Sudani et al., 2024).

5. CONCLUSIONS

This study presents evidence of the behavior of organic waste in the Tigris River and how industrial and thermal discharges synergistically contribute to increasing environmental hazards. The current study is novel in addressing the compound effect of higher temperatures resulting from the operation of power generation companies on the solubility, distribution, and persistence of organic pollutants such as PAHs and phenol in dry rivers. These hazardous effects can be reduced by imposing pretreatment requirements on industrial companies, such as vegetable oil manufacturers and energy-producing plants, with

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adequate modifications of the existing wastewater treatment plants. Simultaneously, cooling towers or stagnant ponds are required to remove thermal pollution. However, conventional treatments for municipal water supplies cannot remove these persistent pollutants; thus, advanced oxidation processes or their carbon absorption potential must be investigated. Finally, this work highlights the urgent need for further research on the bioaccumulation in benthic sediments and aquatic biota of the locality of high-risk compounds such as benzo[a]pyrene concerning food chain protection and public health in anthropogenically impacted aquatic ecosystems.

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