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Screening and Ecological Risk Assessment of Organochlorine and Synthetic Pyrethroid Pesticides in Kufa River using GC-MS

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ABSTRACT

The Kufa River (Shatt Al-Kufa) in Najaf Governorate, Iraq, faces escalating environmental degradation driven by agricultural runoff, untreated municipal wastewater, and industrial discharges. To evaluate the presence and ecotoxicological risks of persistent and current-use agrochemicals, surface water samples were collected across five representative sites (S1–S5) from August to December 2025 and analyzed for organochlorine pesticides (OCPs) and synthetic pyrethroids (SPs) using Gas Chromatography-Mass Spectrometry (GC-MS) following dichloromethane extraction. Quantitative screening revealed severe multi-pesticide contamination exceeding US EPA water quality criteria across all sampling stations. Extremely high concentrations of legacy contaminants were recorded at S1, notably Endrin (85.000ng/L) and P,P-DDT (67.000ng/L), while S5 exhibited severe pollution dominated by O,P-Methoxychlor (198.000ng/L), Dieldrin (0.970ng/L), and Aldrin (1.060ng/L). Furthermore, active agricultural applications were confirmed by the ubiquitous presence of the synthetic pyrethroid Lambda-cyhalothrin, which reached up to 4.001ng/L at S1. The co-occurrence of legacy organochlorines and active pyrethroids creates complex chemical mixtures in the aquatic environment, posing severe toxic hazards to aquatic biodiversity, threatening planktonic community stability, and impairing ecosystem self-purification capacity along the Euphrates River basin.

1. Introduction

The Kufa River in Al-Najaf Al-Ashraf Governorate a vital hydrological branch of the Euphrates River faces escalating environmental degradation driven by rapid population growth, industrialization, and untreated agricultural and domestic wastewater discharges (Al-Dahmoshi et al., 2020; Al Sharifi et al., 2024). Comprehensive monitoring of basic physical-chemical parameters alongside complex organic pollutants is essential for protecting river health and supporting sustainable development (Al-Tabatabai & Al-Haidarey, 2026; Mohammed et al., 2021; Sharqi et al., 2024). A major concern in riverine systems is

the co-occurrence of persistent organic contaminants such as bioaccumulative chlorinated pesticides and pharmaceutical pollutants like antibiotics (Muturi et al., 2017; Pérez-González et al., 2023). These chemical mixtures directly threaten foundational photosynthetic organisms, including cyanobacteria and microalgae, which regulate carbon and nitrogen biogeochemical cycles (Singh et al., 2020; Nadudvari et al., 2025). While alkaline, nutrient-rich conditions promote harmful algal blooms (HABs) dominated by opportunistic genera such as *Microcystis* and *Oscillatoria* (Huisman et al., 2018), Simultaneously, chlorinated pesticides disrupt photosynthetic pathways, impair growth, and reduce microbial biodiversity (Delorenzo et al., 2001; Menezes-Sousa et al., 2018). Ultimately, these chemical-biological perturbations induce severe chronic sublethal hazards across aquatic food webs, compromising fish and invertebrate communities while endangering human populations reliant on the Kufa River for domestic and agricultural water supplies (Fawzy et al., 2020).

Riverine ecosystems in semi-arid regions face mounting ecotoxicological pressures from intensified agricultural practices, urban runoff, and municipal discharges. As a major branch of the Euphrates River system in central Iraq, the Kufa River serves as a critical hydrological lifeline, sustaining aquatic biodiversity, agricultural irrigation, and municipal water supplies. However, continuous anthropogenic activities along its stretch expose this vital aquatic ecosystem to persistent organic and synthetic contaminants, jeopardizing riverine food webs and downstream water safety (Grmasha et al., 2023).

Agrochemical residues represent a primary stressor in freshwater ecosystems. Organochlorine pesticides (OCPs), despite global regulatory restrictions, remain persistent threats in aquatic environments due to historical usage, high lipophilicity, environmental recalcitrance, and strong sediment partitioning. Concurrently, agricultural practices have increasingly adopted synthetic pyrethroids (SPs) as modern chemical alternatives. While pyrethroids generally exhibit shorter environmental half-lives than legacy OCPs, their extreme acute toxicity toward non-target aquatic organisms (specifically freshwater macroinvertebrates, crustaceans, and fish) presents severe sub-lethal and toxicological hazards (López-Benítez et al., 2024). The simultaneous presence of legacy OCPs and current-use SPs creates complex chemical mixtures that complicate risk trajectories for freshwater communities.

Recent water quality evaluations across the Middle Euphrates basin highlight pronounced hydrochemical degradation driven by reduced upstream discharge, high evaporation rates, and unmitigated agricultural return flows in Najaf Governorate. In the Al-Kufa stretch, recent hydrochemical reviews document elevated Electrical Conductivity (EC) values spanning 900 to 1,860 $\mu\text{S}/\text{cm}$ and Total Dissolved Solids (TDS) concentrations routinely exceeding 1,000–1,500 mg/L, indicating acute salinization and ionic imbalance in surface waters (Grmasha et al., 2023). Water chemistry assessments in Al-Najaf over the past five years identify key agricultural and municipal drainage channels including the Northern/Southern Al-Kufa, Albuhadari, and Albushkhair drains as continuous conduits of organic and chemical loading into the main channel. Agricultural returns along these outfalls deliver high concentrations of dissolved nutrients and synthetic chemical residues, pushing Biological Oxygen Demand (BOD₅) past 5 mg/L in urban-agricultural mixing zones and signaling compromised self-purification capacity across the aquatic habitat (Ghazal et al., 2022).

Ecotoxicological Profile: Agrochemical and Heavy Metal Pressures While recent Iraqi monitoring has documented accumulating trace element levels (Cd, Pb, Zn) and aromatic hydrocarbons in the Euphrates, systematic quantification of organic pesticide residues remains a critical monitoring gap (Grmasha et al., 2022). Microbial and riverbank filtration (RBF) assessments along the Kufa River demonstrate that natural soil and sediment filtration cannot fully attenuate persistent synthetic pollutants,

underscoring the necessity of high-precision GC-MS screening for organochlorines and synthetic pyrethroids (Ghazal et al., 2022).

Environmental monitoring of the Middle Euphrates and Kufa River stretches underscores seasonal deterioration in surface water quality within Najaf Governorate. Investigations near Najaf recorded Total Dissolved Solids (TDS) concentrations peaking at $924.19 \pm 44.26 \text{ mg/L}$ during winter, alongside marked seasonal surges in toxic trace metals—most notably lead (Pb), which increased from $0.05 \pm 0.02 \text{ mg/L}$ in spring to $1.47 \pm 0.31 \text{ mg/L}$ in autumn (Zwain & Al-Haidarey, 2025). Furthermore, evaluations across adjacent Euphrates tributaries demonstrate that severe ionic imbalances and heavy metal contamination repeatedly surpass international health standards (Alkam et al., 2014). Beyond inorganic chemical stressors, biological assessments link hydrochemical fluctuations directly to aquatic community structure. Baseline studies on zooplankton dynamics along the Kufa River reveal that seasonal variations in water temperature, electrical conductivity, and nutrient ratios directly regulate zooplankton density and species distribution (Al-Ameen et al., 2017). Because planktonic assemblages serve as the foundation of the riverine food web, the unquantified influx of hydrophobic agrochemicals (specifically organochlorine pesticides, OCPs and synthetic pyrethroids, SPs) threatens to disrupt lower trophic levels vital to ecosystem stability. Al-Haidarey's investigations into sediment-water interactions show that unmitigated municipal and agricultural discharges alter sediment microbial dynamics, impairing natural river self-purification processes.

Evaluating dual-generation pesticide contamination in dynamic river systems requires precise analytical instrumentation. Gas Chromatography-Mass Spectrometry (GC-MS) offers the chromatographic resolution and selectivity necessary to screen, identify, and quantify trace concentrations of hydrophobic pesticide residues in surface waters and sediments (Rehman et al., 2022). Integrating GC-MS quantitative screening with formal Ecological Risk Assessment (ERA) framework models (such as the Risk Quotient method) translates environmental concentration data into actionable ecotoxicological risk tiers across multiple aquatic trophic levels.

This study systematically screens and quantifies organochlorine and synthetic pyrethroid pesticide residues along the Kufa River using GC-MS and evaluates their ecological risk profiles. By establishing spatial distribution patterns and baseline ecotoxicological hazard indices, this research provides vital empirical data to inform catchment-scale water quality management, preserve riverine biodiversity, and guide environmental policy across the Euphrates River basin

2. Materials and Methods

The Euphrates River enters Kufa district after branching off and is called the Shatt al-Kufa. Its length within the governorate is 75,200 km. The Shatt al-Kufa flows through the city of Kufa and is also called the Shatt al-Kufa, which is the study area. The Kufa River flows through the northeastern part of Najaf Governorate at the center of the Kufa district (Al-Dabbas *et al.*, 2024). The current study was conducted along Al-Kufa, Najaf / Iraq. Samples were collected from five specific sites as shown as in Table 1, (Fig. 1). The first site was located about 6 km away north of Al-Kufa city center, near Al-Zarqa water filtering station. Site (2) was near Albuhdari drainage. This drain is located approximately 1.2 km south of the northern Kufa drainage. It is a drain in which agricultural lands in the areas it passes through have been transformed into residential slums. (Site 3) was the Al-Kufa Northern Drainage, where various. It is 12 km

long and its discharge rate is 0.5-1 m³/s. The drain was designed to collect agricultural waste adjacent to the northern part of the Kufa River (Abdul Abbas, 2012). Site (4) was near Albarakeya Drainage, wastewater was discharged into the river without completely treatment. Site (5) was Southern Al-Kufa drainage, it is near the Kufa cement plant and consisted of a drainage channel surrounded by industrial waste and a large amount of agricultural waste, making it difficult to access. It is 8 km long and its discharge rate is 0.5-1 m³/s.

Table (1) : Geographic sites with their coordinates of study sites along Al-Kufa River

Site s	Name	East	North
S1	Near Al-Zarqa water filtering	44.354496	32.117233
S2	Near Al-Albuhdari	44.388145	32.081398
S3	Al-Kufa Northern Drainage	44.3923459	32.059494
S4	Near Albarakeya Drainage	44.428760	32.014101
S5	Southern Al-Kufa drainage	44. 4546804	31.4815544

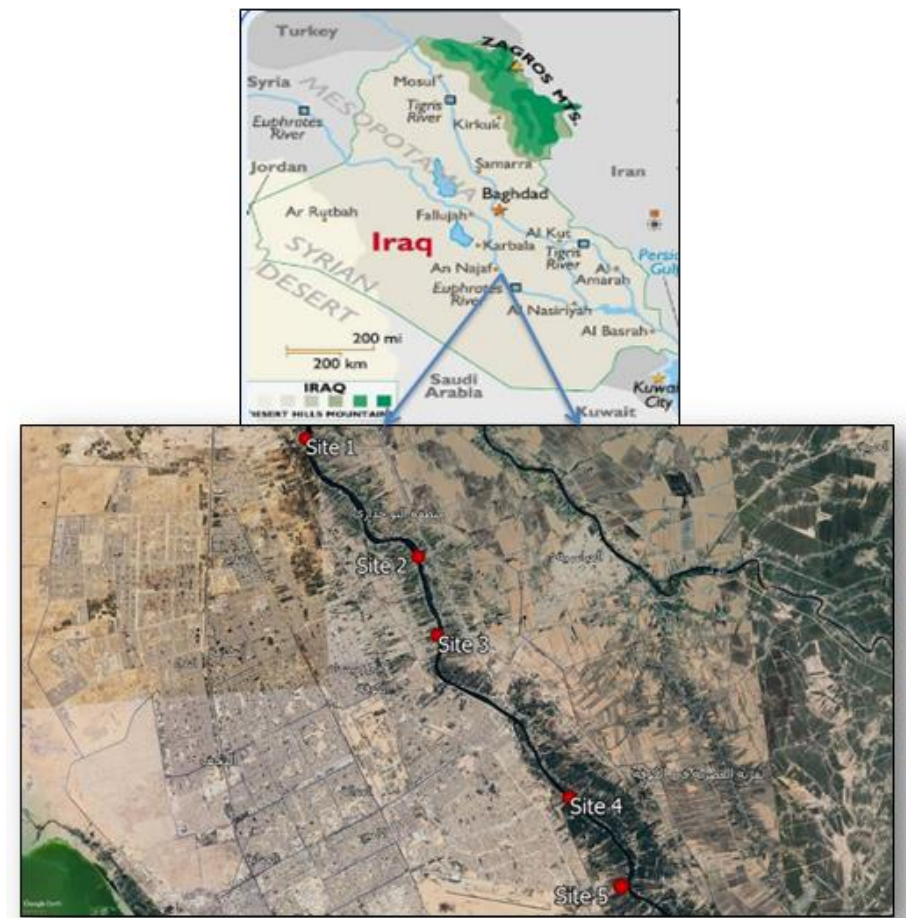


Fig. 1: The map of Samples Collection Sites in Current Study.

Samples were collected during period at Aug. – Dec. 2025. The samples were taken from five sites of the study area (Fig.1), triplicate five dark (brown) bottles for water sample was kept to analyze and identify pesticides and antibiotics residues.

Gas Chromatography/Mass Spectrometer (GC/MS) using Dichloromethane (DCM) for extracting certain Organochlorine pesticide compounds from water as the following steps (Meng *et al.*, 2011) (Fig. 2)

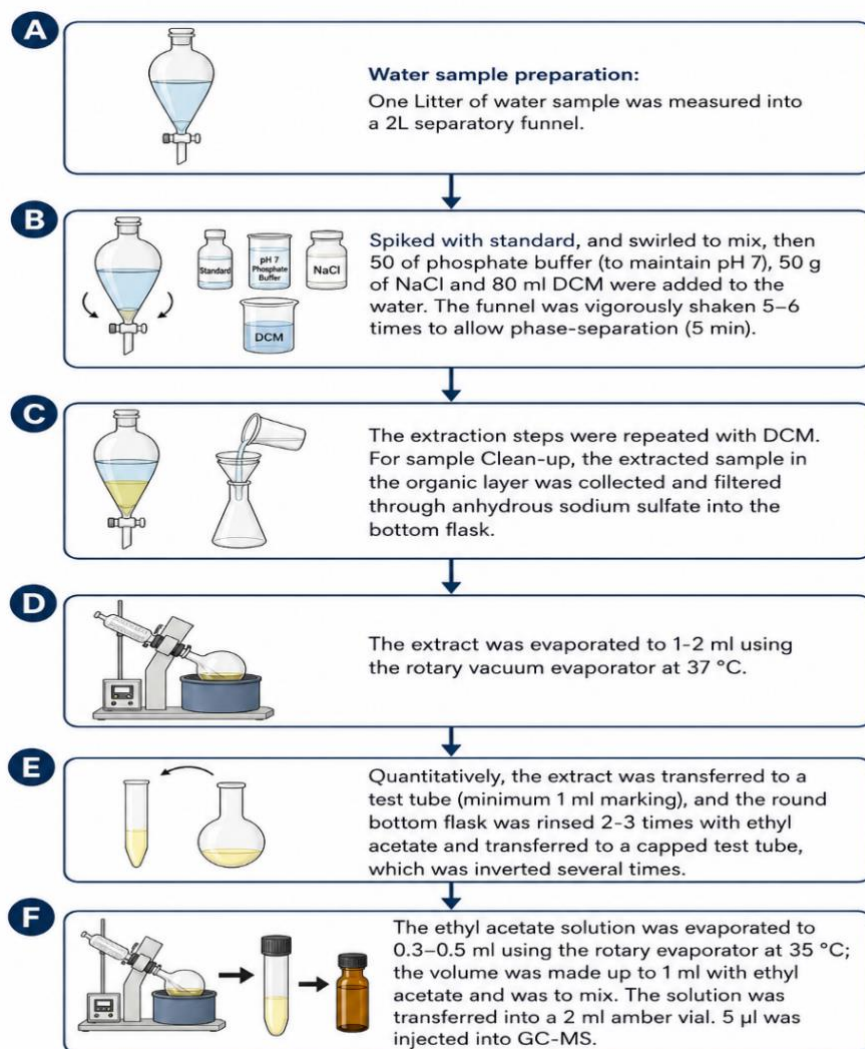


Fig 2: pesticide extraction steps

3. Results and Discussion

Results from sampling sites S1-S5 demonstrate significant surface water contamination along the Shatt Al-Kufa with multiple organochlorine pesticides and a synthetic pyrethroid. Concentrations often far exceed the US EPA allowable limits. A combination of historic pesticide residues as seen with DDT and its metabolites and more contemporary pesticide application to agriculture are observed along the river (Table 2, Fig. 2).

The water at S1 is extremely contaminated with Endrin (85.0 μ g/L) and P,P-DDT (67.0 μ g/L), both of which are several orders of magnitude above the EPA limits (Endrin limit = 0.0023 μ g/L; P,P-DDT =

0.001 µg/L). The contamination at S1 is further evidenced by Dieldrin (2.1 µg/L) and O,P-methoxychlor (42.8 µg/L). Concentrations of pesticides at S1 signify strong pesticide use by humans either through the application of agriculture pesticides and/or poor pesticide management practices. Given the level and types of contaminants, Endrin in particular, strong negative, toxic, irreversible and long term effects to the aquatic ecosystem are virtually guaranteed.

The absence of Endrin, Aldrin and Dieldrin at S2 is noteworthy, however, O,P-methoxychlor (64.0 µg/L) and P,P-DDT (42.9 µg/L) are present at concentrations which exceed allowable limits. The detection of lindane (0.100 µg/L) and lambda-cyhalothrin (1.031 µg/L) also shows mixed pesticide pollution. While legacy pesticides have been removed, the persistent agricultural contamination is clear. The presence of toxic P,P-DDT and O,P-methoxychlor suggests considerable damaging effects to the aquatic environment which are likely irreversible.

At S3, there are reductions in some pesticide levels, especially when compared to levels at S1 and S2. There are still concerns, however. The levels of O,P-methoxychlor and P,P-DDT are 17.27 and 34.9 µg/L respectively. These levels are extremely high when assessed against EPA thresholds. Endrin is present at a detectable but low level of 0.335 µg/L. Aldrin and dieldrin were not detected. It is possible that these have been partially degraded or diluted. DDT related compounds constantly present do indicate that DDT will be released from sediment for a long time and this will have an ecological effect, particularly with regard to affecting .

At S4, P,P-DDT was almost totally removed at a level of 0.55 µg/L and several other compounds were absent, indicating that there may be some localized dilution. There are still concerns with O,P-methoxychlor (> 22.8 µg/L), O,P-DDT, and λ-cyhalothrin (> 2.762 µg/L). It is obvious that the ecosystem in this zone is still under considerable chemical stress, particularly since it is still comparatively more contaminated than other zones. It is very likely that in this zone, as well as in other zones, there will continue to be an adverse ecological effect of chemical stress, including the impairment of plankton .

The greatest level of overall contamination at S5 is caused by O,P-methoxychlor, which has a concentration of 198.0 µg/L. Compared to the EPA criterion of 0.03 µg/L, this concentration is several thousand times higher. Dieldrin and P,P-methoxychlor are also present at elevated levels. While O,P-DDT was not found, the significant levels of methoxychlor suggest that this location most likely has one of the most severe pollution impacts. This location most likely is a toxic ecological zone. There will most likely be severe and chronic impacts on the fish and other organisms that dwell within the sediment, as well as the microbial sediment organisms. There will most likely be severe impacts on the organisms that are more sensitive, including the collapse of these organisms, as well as mortality and reproductive impairment.

When screening all sites as a whole, it is apparent that none of the sampling sites fall within the US EPA water quality criteria for most pesticides, especially for DDT derivatives, methoxychlor, and lambda-cyhalothrin. The pesticide impacts on the environment point to the presence of pollution from older pesticides (DDT, aldrin, dieldrin) and newer pesticides that are most likely from active farming (methoxychlor, lambda-cyhalothrin). From the standpoint of the environment, having several different pesticides will lead to greater than additive toxicity (Mesnage & Antonioum, 2018).

This will likely reduce fish population along with diminished invertebrate diversity, altered algal communities, and the potential for biomagnification (Schäfer et al., 2011).

Table (2): The multiple organochlorine pesticides and a synthetic pyrethroid concentrations in five sampling sites (S1–S5) along the Shatt Al-Kufa

Sampl ID	S1	S2	S3	S4	S5	US EPA Permissible limits
ENDrin	85.000	ND	0.335	ND	1.800	0.0023
Aldrin	ND	ND	ND	ND	1.060	0.056
Dieldrin	2.100	ND	ND	ND	0.970	0.056
O,P –Methoxychlor	42.800	64.000	17.270	22.800	198.000	0.03
P,P –Methoxychlor	ND	ND	ND	ND	1.630	0.03
O,P –DDT	1.330	ND	ND	0.800	ND	0.001
P,P –DDT	67.000	42.900	34.900	0.550	0.500	0.001
liNDane (γ -HCH)	0.010	0.100	ND	ND	ND	0.08
Lambda-cyhalothrin	4.001	1.031	1.943	2.762	3.992	0.0016

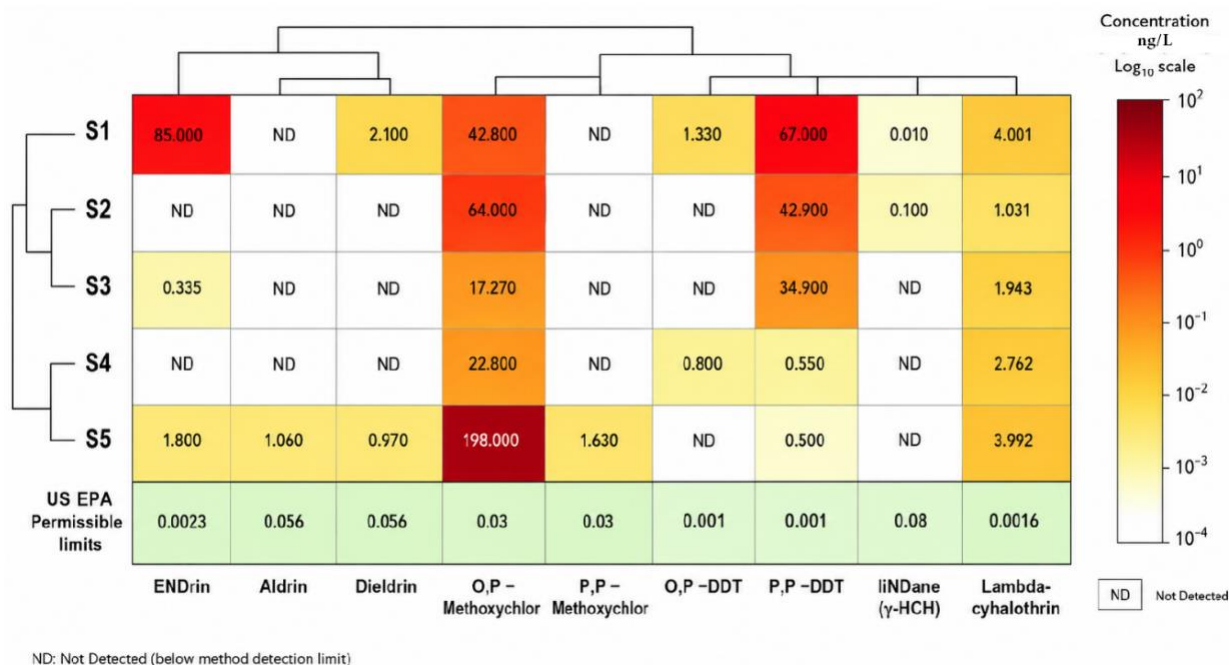


Fig. 3: Heatmap Analysis of Pesticide Concentrations (ng/L) Across Sampling Sites (S1–S5) on the Shatt Al-Kufa River Relative to Ecological Permissible Limits.

4. Conclusions

Surface waters have become toxic, and the absolute absence of US EPA safety standards can be attributed to legacy organochlorine and modern agricultural chemical contamination.

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