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Polychlorinated Biphenyls (PCBs) in Sediments of Khor Al-Zubair, South of Iraq: Distribution, Occurrence and Implications

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ABSTRACT

This study examined twelve polychlorinated biphenyl (PCB) congeners detected in sediment samples collected from six locations within Khor Al-Zubair, a key estuarine zone in southern Iraq recognized for both its ecological significance and industrial activity. Sediment sampling was conducted using standard grab techniques, and samples were analyzed via gas chromatography–mass spectrometry (GC–MS) for compound identification and quantification. The twelve target congeners (Σ12 PCBs) were: PCB18, PCB28, PCB31, PCB44, PCB52, PCB101, PCB138, PCB141, PCB149, PCB153, PCB189, and PCB194. Concentrations ranged from 0.01 to 2.22ng/ g dry weight (dw) in summer and from 0.01 to 1.56ng/g dw in winter, with the minimum and maximum values observed at stations 5 and 1, respectively. The highest total Σ12 PCB concentration was recorded at Station 1, reaching 7.37ng/ g dw in winter and 6.02ng/ g dw in summer. In contrast, Station 5 exhibited the lowest Σ12 PCB levels, with 0.23ng/ g dw in summer and 2.18ng/ g dw in winter. As no previous studies have assessed PCB contamination in this specific estuarine system, these results provide valuable baseline data for ongoing monitoring and environmental risk assessments. Furthermore, this dataset offers a useful reference for comparative studies on PCB contamination in sediments from other regions. Potential sources of PCBs in Khor Al-Zubair sediments are likely anthropogenic in origin, including industrial discharges and urban runoff.

INTRODUCTION

Polychlorinated biphenyls (PCBs) are synthetic organic compounds composed of biphenyl structures substituted with chlorine atoms at various positions **(Maria & Maria, 2008)**. Extensively manufactured during the 20th century, PCBs were widely used in industrial applications due to their desirable dielectric properties, chemical stability, non-flammability, and versatility. Common applications included transformer coolants, hydraulic fluids, plasticizers, adhesives, and lubricants **(Sullivan *et al.*, 1998)**.

However, due to their extreme environmental persistence, ability to bioaccumulate in food chains, and documented harmful effects on both wildlife and

humans, the production and use of PCBs were restricted or banned in many countries during the 1970s and 1980s **(Dobrzyska *et al.*, 2010)**. Despite these regulatory measures, PCBs remain a significant environmental concern. They continue to be detected in aquatic environments **(Nguyen *et al.*, 2024)** and are known to strongly adsorb to sediment particles, leading to long-term accumulation in aquatic systems **(Foreman *et al.*, 1995)**. Their persistence and bioaccumulative nature pose serious risks to aquatic organisms and humans alike. PCBs can be remobilized from sediments into the water column, becoming bioavailable to aquatic fauna. Through biomagnification, concentrations increase at higher trophic levels, threatening top predators, including humans **(Samanipour, 2015)**.

The mobility and persistence of PCBs in estuarine environments are influenced by various physicochemical interactions **(Gess & Pavlostathis, 1997)**. Major sources of PCB pollution include industrial discharges, municipal wastewater, and improper waste disposal practices, which introduce these chemicals into the air–water–sediment continuum **(Khawaja, 2003)**. In aquatic systems, PCBs readily bind to suspended particles **(Malik *et al.*, 2011)**, eventually settling into bottom sediments where they can persist for decades **(Eqani *et al.*, 2012a)**.

Chronic exposure to PCBs has been linked to a range of adverse health effects, including neurological, immune, and endocrine system dysfunction, liver damage, developmental defects, and carcinogenesis. Classified as endocrine disruptors, PCBs can impair thyroid hormone function and reduce serum hormone levels, as reported in populations exposed to PCB contamination in southern Iraq **(Wei *et al.*, 2008)**.

Khor Al-Zubair, a vital estuarine system in southern Iraq, supports diverse aquatic life and plays a critical role in the region's environmental and economic sustainability. However, it faces increasing threats from anthropogenic activities, particularly industrial discharges, urban wastewater, and agricultural runoff **(Al-Shaheen, 2021)**. Given its vulnerability to PCB contamination, monitoring the distribution, concentration, and persistence of PCBs in its sediments is of urgent importance.

The present study aimed to assess the levels and spatial distribution of selected PCB congeners in sediment samples collected from multiple stations across Khor Al-Zubair, using validated chromatographic and spectrometric techniques. The findings provide insight into the extent of contamination, potential sources of PCB inputs, and associated ecological risks. These results may also support the development of targeted regulatory measures and pollution control strategies to protect the ecological integrity of this critical estuarine environment.

MATERIALS AND METHODS

Description of the study area

Khor Al-Zubair (KAZ) is a tidal estuary located southwest of Basrah, Iraq, extending approximately 40km from the vicinity of Umm Qasr toward the northern Arabian Gulf. The estuary varies in width from 1 to 2km and has an average depth ranging between 10 and 20 meters during spring tides **(Al-Taei *et al.*, 2012)**. Its tidal

regime is semi-diurnal and partially mixed, with hydrological connectivity to the adjacent Arabian Gulf and an average tidal amplitude of about 3.2 meters **(Al-Mukhtar *et al.*, 1992)**.

KAZ functions as a vital maritime corridor, accommodating frequent cargo vessel movements to and from Umm Qasr Port, thereby facilitating both local and international trade. However, the estuary has come under increasing pressure from anthropogenic activities, including dredging, land reclamation, industrial effluents, and domestic wastewater discharges. These impacts—driven by rapid economic, social, and industrial expansion—have disrupted the ecological balance of an already stressed system and contributed significantly to its environmental degradation **(Al-Dabbas & Al-Jaberi, 2015)**.

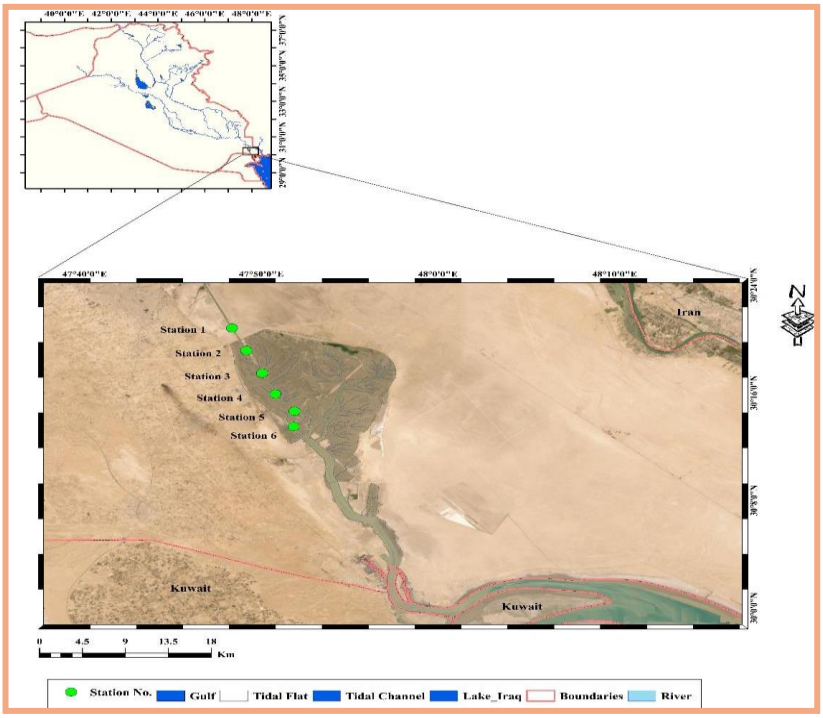

Fig. 1. Sample location

Sediment samples

Surface sediment samples were collected from selected locations using a Van Veen grab sampler. Upon retrieval, excess water was carefully decanted, and each sample was sealed in aluminum foil, labeled, and transported under refrigerated conditions to maintain sample integrity. In the laboratory, samples were oven-dried, homogenized, and sieved through a 63µm mesh to ensure uniform particle size prior to chemical analysis.

Percentage analysis of sediment grain size

Grain size distribution was determined using the pipette method for fine fractions (silt and clay), while sand-sized particles were separated using a standard 63µm sieve.

Sediment texture classifications were established using ternary diagrams, based on the relative proportions of sand, silt, and clay **(Folk, 1974)**.

PCB extraction from sediment samples

Upon arrival at the laboratory, sediment samples were freeze-dried, cleaned of non-sedimentary materials, and ground to a fine powder using a FRITSCH grinder. The homogenized material was then passed through a 63μm mesh sieve to ensure uniform particle size.

For PCB extraction, 20g of the sieved sediment were placed into cellulose thimbles and subjected to Soxhlet extraction using a 1:1 solvent mixture of hexane and methylene chloride for 48 hours at temperatures below 40°C. Following extraction, the solvent mixture was filtered and saponified with 15mL of 4 M potassium hydroxide in methanol for 2 hours.

The resulting mixture was transferred into a separatory funnel, and an additional 50mL of the hexane–methylene chloride solvent mixture was added to facilitate liquid–liquid partitioning. The organic layer was separated, evaporated, and purified using a silica gel chromatography column topped with anhydrous sodium sulfate. The purified extract was transferred to labeled glass vials, air-dried, and stored under appropriate conditions until gas chromatography–mass spectrometry (GC–MS) analysis was conducted **(Aganbi *et al.*, 2019)**.

Procedural blanks

Procedural blanks were prepared and processed in parallel with sediment samples to monitor potential contamination from laboratory solvents, glassware, or environmental exposure. Concentrations detected in blanks were subtracted from the corresponding sample values to ensure analytical accuracy, particularly at low concentration levels. Field collection and laboratory analyses followed APHA-endorsed standard procedures for the evaluation of physicochemical parameters in sediments **(APHA, 2005)**.

Statistical analysis

To determine statistically significant differences in PCB concentrations among sampling stations, a one-way analysis of variance (ANOVA) was performed using GenStat software. A significance threshold of $P \leq 0.05$ was applied. Where significant differences were observed, Least Significant Difference (LSD) tests were conducted to identify specific variations between stations.

RESULTS

Grain size

Sediments collected from Khor Al-Zubair comprised varying proportions of sand, silt, and clay. Station 1 recorded the highest sand content (73.74%), whereas Station 5 exhibited the lowest (2.76%). Silt content ranged from 2.63% at Station 1 to 30.37% at Station 3. The highest clay proportion was observed at Station 2 (71.71%), while the lowest was at Station 1 (23.64%) (Table 1, Fig. 2).

These results align with previous studies from the Shatt Al-Basrah region, where surface sediments were reported to originate from recent Tigris and Euphrates riverine deposits combined with desert-derived dust, producing a mixture of sand, silt, and clay fractions. Similar sediment textures have been recorded in adjacent marshland areas, where sandy alluvial layers up to 7cm thick have been identified **(Balasim *et al.*, 2013)**. Comparable findings were also reported by **Jabeir *et al.* (2024)**, who described surface sediments in marshes containing upper sandy alluvial layers of similar thickness.

Table 1. Size of the particle data of the present study during the summer 2024 and winter 2025

Station	% Grains size			Texture type
	Sand%	Silt%	Clay%	
St. 1	73.74	2.63	23.64	Sandy clay loam
St. 2	6.46	.83	71.71	Clay
St. 3	23.08	30.37	46.56	Clay
St. 4	19.63	27.55	52.81	Clay
St. 5	2.76	29.59	67.64	Clay
St. 6	12.33	28.67	59	Clay
Mean	23	23.44	53.56	
SD	26.0114	10.6371	17.3322	

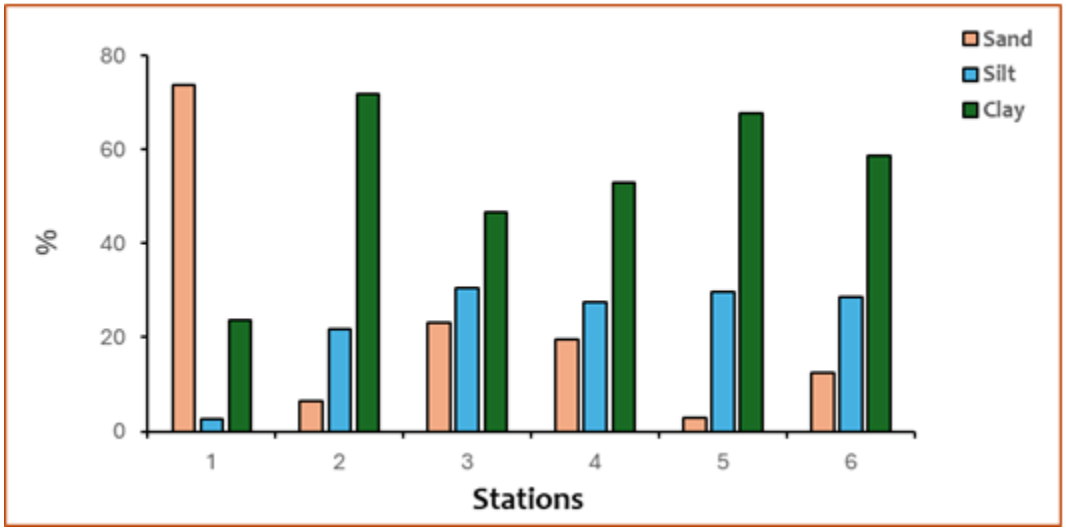

Fig. 2. Grain size (%) in the sediments of the studied stations

PCBs in the sediments

Analytical results showed that Station 1 recorded the highest average PCB concentration during winter (0.61ng/ g dry weight), whereas the lowest concentration (0.02ng/ g dw) was observed at Station 5 in summer (Table 2 & Fig. 3).

Table 2. Mean seasonal changes in PCBs (ng/g d.w.) during summer 2024 and winter 2025

Station	Summer	Winter
St. 1	0.61	0.50
St. 2	0.43	0.29
St. 3	0.28	0.16
St. 4	0.26	0.12
St. 5	0.18	0.02
St. 6	0.25	0.13

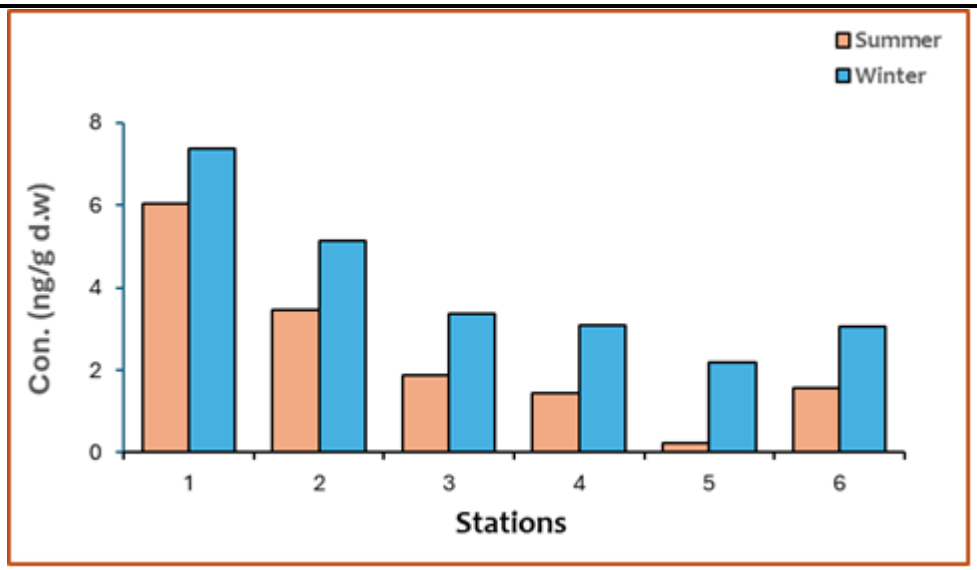

Fig. 3. Mean seasonal variations in PCBs (ng/g d.w.) during summer 2024 and winter 2025

During the winter season, PCB18 reached its peak concentration at Station 3 (1.56ng/g dry weight), while PCB141, PCB138, and PCB189 were entirely undetectable at Station 5. Station 1 recorded the highest mean PCB concentration (0.61ng/ g d.w.), whereas Station 5 presented the lowest average value (0.18ng/ g d.w.), as outlined in Table (3), and illustrated in Fig. (4a, b).

Table 3. Concentrations and types of PCBs (ng/g d.w.) during the winter season

Compound Name	St1	St2	St3	St4	St5	St6
PCB 18	0.60	1.09	1.56	1.34	1.51	1.02
PCB 31	0.01	0.01	0.15	0.03	0.04	0.01
PCB 28	1.24	0.27	0.14	0.19	0.15	0.38
PCB 44	0.53	0.04	0.04	0.04	0.03	0.04
PCB 52	0.77	0.59	0.31	0.73	0.01	0.35
PCB 101	0.52	0.53	0.04	0.25	0.10	0.34
PCB 141	0.65	0.72	0.56	0.09	0.00	0.10
PCB 149	0.07	0.13	0.06	0.04	0.03	0.09
PCB 138	0.79	0.36	0.15	0.01	0.00	0.10
PCB 153	0.91	0.02	0.18	0.28	0.20	0.10
PCB 189	0.96	0.90	0.03	0.03	0.00	0.46
PCB 194	0.32	0.49	0.15	0.04	0.11	0.04
Total	7.37	5.13	3.37	3.08	2.18	3.05
Mean	0.61	0.43	0.28	0.26	0.18	0.25
±SD	0.35942	0.35605	0.42738	0.39620	0.42351	0.28766

0=Not detected

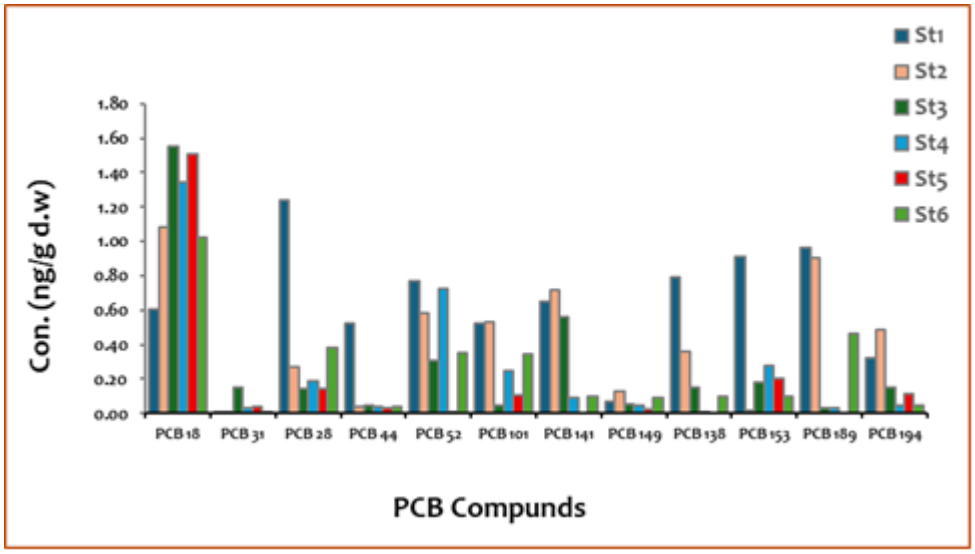

Fig. 4a. Concentrations and types of PCBs (ng/g d.w.) during the winter season

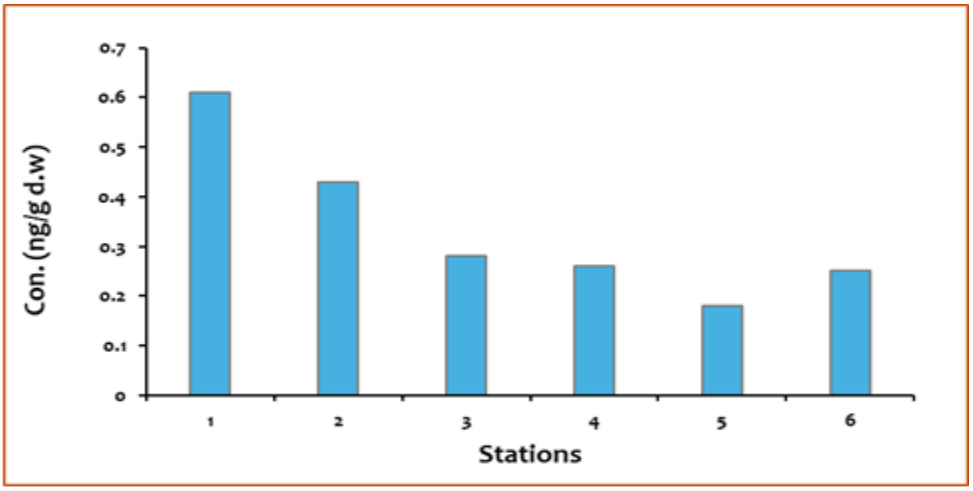

Fig. 4b. Mean concentrations of PCB (ng/g d.w.) compounds during the winter season

During the summer season, Station 1 recorded the highest concentration of PCB44 at 2.22ng/ g dry weight. In contrast, several congeners—including PCB18, PCB52, PCB141, PCB149, PCB138, PCB153, PCB189, and PCB194—were not detected at Station 5. The highest seasonal mean concentration was also observed at Station 1 (0.50ng/ g d.w.), while the lowest average value (0.02ng/ g d.w.) was recorded at Station 5, as presented in Table (4) and visualized in Fig. (5a, b).

Table 4. Concentrations and types of PCBs (ng/g d.w.) during the summer season

Compound Name	St1	St2	St3	St4	St5	St6
PCB 18	0.74	0.20	0.31	0.61	0.00	0.36
PCB 31	0.01	0.23	0.11	0.20	0.01	0.18
PCB 28	0.06	0.26	0.17	0.05	0.01	0.21
PCB 44	2.22	0.66	0.01	0.02	0.06	0.11
PCB 52	0.44	0.10	0.15	0.01	0.00	0.03
PCB 101	0.67	0.70	0.29	0.01	0.15	0.32
PCB 141	0.02	0.20	0.23	0.09	0.00	0.01
PCB 149	0.81	0.03	0.04	0.01	0.00	0.10
PCB 138	0.29	0.33	0.11	0.03	0.00	0.01
PCB 153	0.38	0.16	0.30	0.34	0.00	0.21
PCB 189	0.32	0.23	0.06	0.02	0.00	0.02
PCB 194	0.05	0.36	0.10	0.04	0.00	0.01
Total	6.02	3.46	1.87	1.43	0.23	1.57
Mean	0.50	0.29	0.16	0.12	0.02	0.13
±SD	0.61045	0.20382	0.10456	0.18407	0.04393	0.12493

0=Not detected

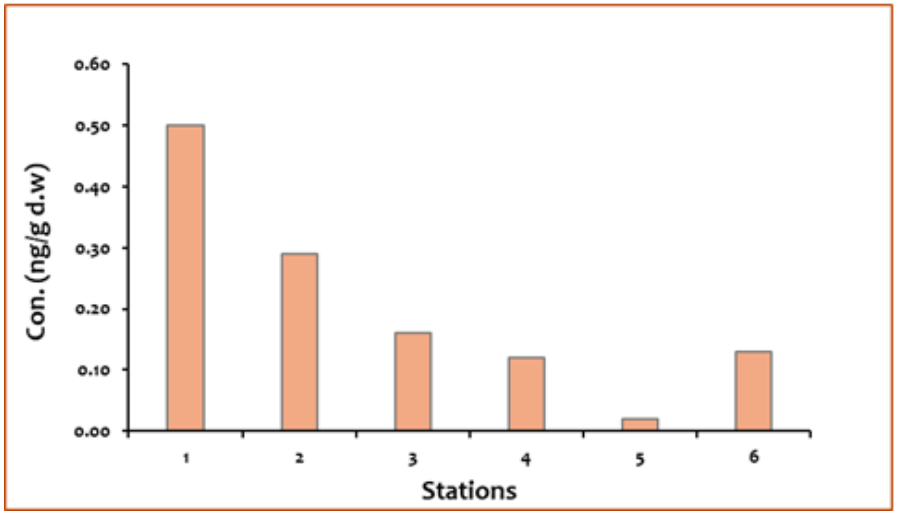

Fig. 5a. Types and levels of PCBs (ng/g dry weight) observed in the summer season

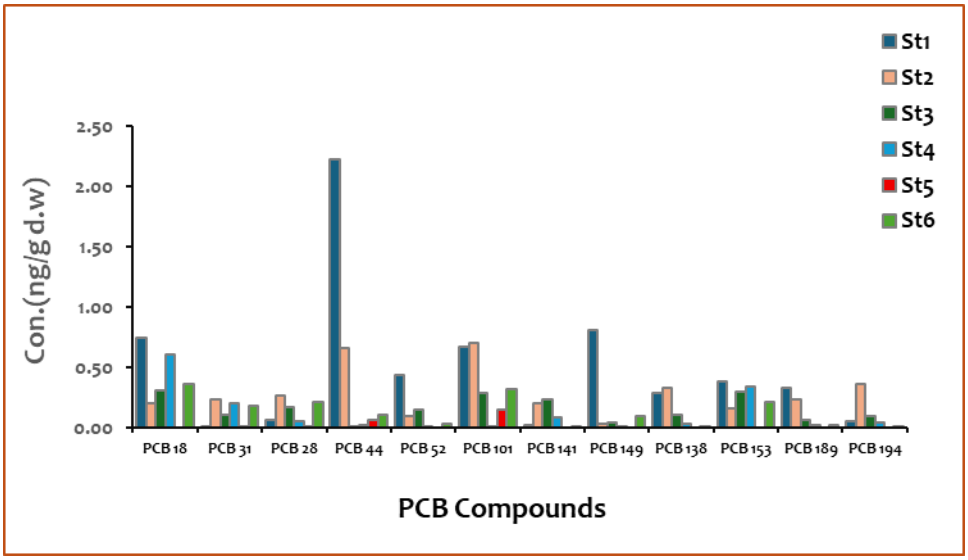

Fig. 5b. Average PCB compound levels (ng/g d.w.) in summer samples

Most PCB congeners—including PCB18, PCB28, PCB52, PCB138, PCB141, PCB153, PCB189, and PCB194—exhibited higher concentrations during the winter season. In contrast, PCB31, PCB44, and PCB149 reached their peak levels during the summer. Among all congeners, PCB18 was the most dominant, being consistently detected at all sampling stations in both seasons. Its widespread occurrence is likely attributed to its extensive use in industrial processes, as well as its low microbial degradability and high chemical stability **(Jabeir *et al.*, 2024)**. In contrast, PCB31 showed the lowest detection frequency among all analyzed congeners across the sampling sites, as illustrated in Fig. (6).

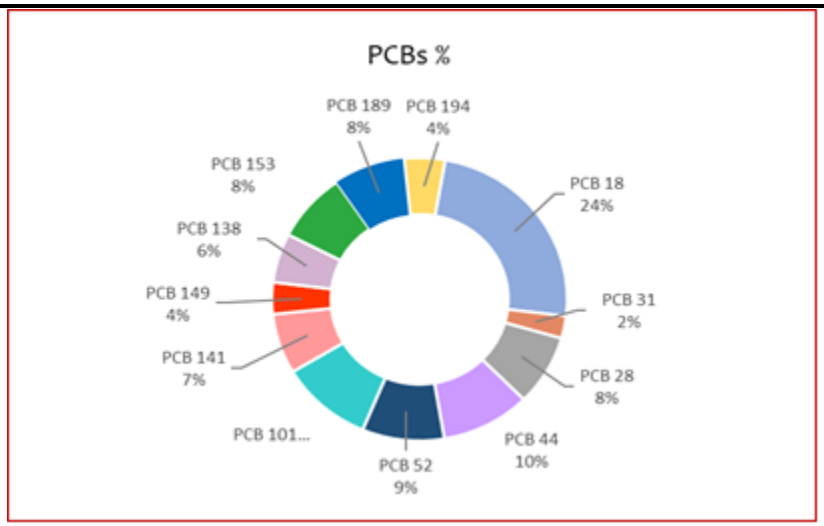

Fig. 6. Percentages of PCB (%) at the stations during the study seasons

DISCUSSION

Statistical analysis of the results revealed significant differences in PCB concentrations between sampling stations ($P< 0.05$), with Station 1 (S.1) showing the highest levels of contamination. This elevated contamination may be attributed to the sediment composition at Station 1, which is predominantly silty clay. Finer-grained sediments like silty clay have a higher capacity for chemical sorption and retention, enhancing their ability to accumulate pollutants **(Al-Zabad *et al.*, 2021)**. In general, PCBs tend to concentrate more in clay-rich sediments than in sandy ones due to their greater surface area and organic matter content.

Supporting this, **Barakat *et al.* (2013)** reported that areas located closer to urban centers tend to show higher concentrations of chemical pollutants, including PCBs. This is likely due to the presence of industrial and municipal waste in urbanized regions. Conversely, rural zones typically exhibit lower levels of PCB contamination, although exceptions can occur depending on local conditions.

Sediments play a critical role in environmental pollution studies because they serve as significant sinks for persistent organic pollutants such as PCBs. These compounds can remain in sediments for extended periods and may be gradually released into the water column **(Han *et al.*, 2023)**. Factors such as water flow and organic matter content influence PCB behavior: water dynamics affect transport and distribution, while organic matter affects adsorption and physical binding of PCBs.

Once introduced into the aquatic environment, PCBs tend to accumulate in sediments. This conclusion aligns with findings of **Sari *et al.* (2023)**, who noted that persistent organic pollutants, particularly PCNs, were the dominant compounds in sediment accumulation. When compared with the current results for PCBs, there is good agreement with previous studies, as shown in Table (5).

Table 5. Comparisons of PCBs concentrations with those in other studies worldwide

Study area	Country	Concentration	Sources
Shuaiba Port	Kuwait	926 -132 ng/g	**(Lyons *et al.*, 2015)**
Jeddah coast	Saudi Arabia	15.36 - 0.58 ng/g	**(El-Aziz El-Maradny *et al.*, 2015)**
Khor Musa	Iran	30.9 - 1.6 µg/kg	**(Hassan et *al.*, 2013)**
Bizerte lagoon	Tunisia	14.6 - 0.8 ng/g	**(Barhoumi *et al.*, 2014)**
Forcados River	Nigeria	202.3 - 2.7 µg/kg	**(Iwegbue, 2016)**
Haizhou Bay	China	6.27 - 1.33 ng/g	**(Zhang *et al.*, 2014)**
Napoleon Bay	Uganda	1848 - 362 pg/g	**(Ssebugere *et al.*, 2014)**
Shatt al-Arab	IRAQ	27.75 - 4.48 ng/g	**(Al-Zabad *et al.*, 2021)**
AL -Hamaer Marshes	IRAQ	0.14-2.84 ng/g d.w	**(Jabeir *et al.*, 2024)**
Khor Al-Zubair	IRAQ	7.37 - 0.23 ng/g d.w	**Present study**

CONCLUSION

A total of twelve PCB congeners were detected in sediment samples collected from six different sampling locations. Significant variations in PCB concentrations were observed across both sites and seasonal periods. These findings provide valuable baseline data and may serve as a useful reference for future investigations into PCB contamination and environmental monitoring.

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