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# Spatial Distribution and Ecological Risk of OCPs and PCBs in Sediments from Lake Edku, Egypt

Mohamed A. Okbah
*National Institute of Oceanography and Fisheries, NIOF, Cairo, Egypt*, m_okbah@yahoo.com

Mahmoud S. Ibrahim
*Environmental Sciences Department, Faculty of Science, Damietta University, Egypt*

Tarek O. Said
*National Institute of Oceanography and Fisheries, NIOF, Cairo, Egypt*

Mohammed E.M. Nassar
*Environmental Sciences Department, Faculty of Science, Damietta University, Egypt*

Maie I. El-Gammal
*Environmental Sciences Department, Faculty of Science, Damietta University, Egypt*



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RESEARCH ARTICLE

# Spatial Distribution and Ecological Risk of Organochlorine Pesticides and Polychlorinated Biphenyls in Sediments From Lake Edku, Egypt

Mohamed A. Okbah [a,*], Mahmoud S. Ibrahim [b], Tarek O. Said [a], Mohammed E.M. Nassar [b], Maie I. El-Gammal [b]

[a] National Institute of Oceanography and Fisheries, Cairo, Egypt
[b] Department of Environmental Sciences, Faculty of Science, Damietta University, Damietta, Egypt

**Abstract**

**Lake Edku represents one of the important sites for the environment and wildlife in Egypt. Persistent organic pollutants (POPs) hurt the environment and human health. All the samples were analyzed using gas chromatography coupled with a flame ionization detector. Hexachloro cyclohexanes (HCHs) recorded 1.83−3.68 μg/kg and 6.27−7.03 μg/kg with an average 4.69 ± 0.84 and 4.30 ± 2.01 μg/kg during spring and summer, respectively. Total cyclodienes (TC) ranged between 1.02 and 2.70 μg/kg and 12.96−16.03 μg/kg, with an average 8.58 ± 3.50 and 9.55 ± 5.10 μg/kg during spring and summer, respectively. 1,1,1-trichloro-2, 2-bis (p-chlorophenyl) ethane dichloro-diphenyl-trichloroethane (DDTs) ranged between 16.79 and 1.00 μg/kg and 19.15−16.79 μg/kg with an average of 17.69 ± 0.84 and 10.46 ± 5.26 μg/kg during spring and summer, respectively. α-HCH/γ-HCH ratio suggested the use of pure lindane for agricultural purposes. β-/(α+γ)-HCH ratio suggests recent HCH input and past usage. o,p′-DDT/p, p′-DDT, suggesting that technical DDTs were the main source, except stations IV, V, and VIII during summer that indicated dicofol-type of DDT. DDE + DDD)/∑DDTs ratio indicating past input of DDT. DDE/DDD ratios refer to anaerobic and anaerobic degradation. Sediment quality and ecological risk assessments: γ-HCH, Dieldrin, and Endrin do not represent any danger or actual threat to the environment. The concentrations of ∑DDE, ∑DDDE, and ∑polychlorinated biphenyls are indicated as safe values for the ecosystem. The results obtained from principal component analysis showed that the studied compounds could migrate into the lake from drains, leading to their accumulation and deposition in the lake.**

*Keywords:* Ecological risk, Lake edku, Organochlorine pesticides, Polychlorinated biphenyls, Sediments, Spatial distribution

## 1. Introduction

Lake Edku is one of the northern Egyptian lakes. It is located on government lands in Lower Egypt and is connected to the Mediterranean Sea through an opening known as the Maadiya Bogaz. Its area is about 62.78 $km^2$. On its northern coast are located, from west to east, Ezbet Qasim, Al-Labani, and Al-Maadiyya. Lake Edku represents one of the most important sites for the environment and wildlife in Egypt (El-Shinawi et al., 2022). The main sources responsible for transporting pollutants into the lake are (1) sub-drains such as Damanhour, El-Bousely, and Edku; (2) Barseek Drain; (3) drained water received from fish farms around the lake reached more than 300. All of these sources are responsible for transferring agricultural, industrial, and human pollutants to the lake (Okbah and El-Gohary, 2002).

The second source of the lake's water is the water of the Mediterranean Sea, as a result of the lake's connection to the sea through Boughaz El-Maadia

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* Corresponding author at: National Institute of Oceanography and Fisheries (NIOF), Cairo, Egypt.
E-mail address: m_okbah@yahoo.com (M.A. Okbah).

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from Abu Qir Bay, which is considered one of the sources of pollutant transfer and is represented in the El-Tabia Pumping Station to the lake (Badr and Hussein, 2010). Boughaz El-Maadia plays an important role in renewing water in Lake Edku (Abd El-Hamid et al., 2021). Persistent organic pollutants (POPs) are defined as chemical materials and compounds that settle down in different environments, bioaccumulate through the food chain, and can cause adverse effects on the environment and human health (Zacharia, 2019). POPs are classified into three general categories: organochlorine pesticides (OCPs), industrial compounds, and initial chemicals that are used for urban and industrial processes (El-Shahawi et al., 2010). POPs contain chlorinated chemicals such as polychlorinated biphenyls (PCBs), chlorinated pesticides, insecticides such as 1,1,1-trichloro-2, 2-bis (p-chlorophenyl) ethane dichloro-diphenyl-trichloroethane (DDT), and dioxins (Araki et al., 2022). The main environmental processes that control the persistence of POPs can be divided into three processes: (1) dilution, (2) volatilization, and (3) advection. (2) Sorption and absorption by organisms; (3) degradation (hydrolysis, photolysis, oxidation, and reduction); and (3) biodegradation (aerobic, anaerobic, and metabolic). The fate of POPs in the marine environment depends on different processes, such as air-sea exchange, which occurs through three mechanisms: gaseous exchange, particle deposition, sorption to suspended particulate solids, and sedimentation (Ilyina et al., 2006). Marine ecosystems and food chains, especially those of Benthic invertebrates, are affected by POPs, which tend to be combined with particles and then precipitate, which is taken via ingestion and bioturbation activities, thus affecting bioavailability. Indoor and outdoor environments, occupation, diet, burning of waste, and chemical fires are the main sources of POPs (Miyashita, 2020). Compounds containing hydrogen, carbon, and chlorine are collectively referred to as chlorinated hydrocarbons (CHC). A class of extremely hazardous and carcinogenic pollutants that are frequently found in the environment, chlorinated aliphatic hydrocarbons and chlorinated aromatic hydrocarbons, represent a serious threat to both human health and the ecological system (Ohura, 2007). OCPs such as DDT and industrial chemicals PCBs are considered the most important chlorinated hydrocarbons and are considered pollutants because they entered different environments in the middle of the last century and were monitored in waters, sediments, and organisms (Devi, 2020). Aquatic toxicological studies have shown the sensitivity of organisms to chlorinated hydrocarbons. These studies determined the toxicological criteria for these substances' risk assessments for chlorinated hydrocarbons, which are related to effects on human health, fish, and marine organisms (Chen et al., 2023). Although chlorinated hydrocarbon insecticides are not particularly volatile, they rapidly spread to the kidney, liver, and brain and accumulate in adipose tissues since chlorinated hydrocarbons are highly lipid-soluble and are readily absorbed through mucous membranes, and skin. A massive number of chlorinated compounds are manufactured annually. Sources vary between agricultural, industrial, and commercial, including pharmaceuticals, pesticides, and drinking water disinfectants. Due to the persistence of chlorinated organic compounds that reach high concentrations both in ecosystems and biota (Song and Carraway, 2005).

The main objective of this study was to examine the concentrations, distribution, and sources of OCPs and PCBs in the surface sediments of Lake Edku, and to assess the environmental risks of these contaminants.

## 2. Materials and methods

### *2.1. Study area and sampling*

Lake Edku is one of the northern Delta lakes of Egypt and was once considered to be among the most productive lakes of Egypt. It lies between Lat. 31°10′ and 31°18′ N and Long. 30°8′ and 30°23′E, about 30 km east of Alexandria government. Its size has shrunk, Its average depth is about 1 m, and its surface area is about 85 square kilometers, and it is a shallow, brackish coastal lagoon (Zakaria and El-Naggar, 2019).

The Lake is shallow, brackish, and subject to huge inputs of wastewater (Zakaria and El-Naggar, 2019). Indoor and outdoor environments, occupation, diet, burning of waste, and chemical fires are the main sources of POPs (Miyashita, 2020). The main sources responsible for transporting pollutants into the lake are (1) sub-drains such as Damanhour, El-Bousely, and Edku; (2) Barseek Drain; (3) drained water received from fish farms around the lake reached more than 300 fish farms. All of these sources are responsible for transferring agricultural, industrial, and human pollutants to the lake (Okbah and El-Gohary, 2002). The drainage water contains unspecified quantities of urban, industrial, and agricultural chemicals from the Beheira Governorate and beyond. Based on the diffuse sources of pollution many chemicals from human activities would be present in the drainage water. The water source of El-Khairy Drain (annual inflow $592 \times 10^6$ $m^3$) is from three drainage waters coming from El Bousely, Edku, and Damanhour subdrains, transporting domestic, agricultural, and industrial wastes, as well as the drainage water of many fish farms, while Barsik Drain (annual inflow 348 $\times$ $10^6$ $m^3$) transports mainly agricultural drainage water to the lake. The lake also receives seawater at its northwestern part through Boughaz El-Maadia from Abu Qir Bay (Farouk, 2018). The primary source of DDT in aquatic environments is its use as a pesticide in the agricultural process (Guzzardi et al., 2016). In the present study, eight points were determined for eight stations to cover most of the area of the lake. During 2022, sediment samples were taken to cover the aquatic environment of the lake during two different seasons: the winter season during March and the summer season during August.

The drawn and collected samples were used to estimate and assess the environmental impact and to assess POPs such as OCPs and PCBs in sediment samples of the lake, as well as evaluate their environmental impact. Sediment samples were collected from 8 representative sites of the lake. Stations I and II were located to cover the southern side of the lake; stations III, IV, and V cover the eastern side of the lake, which is the main estuary of the lake from the various drains. Station No. VI to cover the middle of the lake, Point No. VII to cover the connection area of the international coastal road with the lake, and finally, Station No. VIII to cover the point of contact between the sea and the lake (Al-Boughaz area). The location of the stations is illustrated in Fig. 1. Stainless steel Van-Veen grab sampler was used to collect samples from surface sediment for the lake. The labeled samples were placed in plastic bags stored in an ice pack and then kept at 4 °C in the dark before extraction and analysis. During the present study OCPs, HCHs (α-HCH, β-HCH, γ-HCH), Cyclodiene (aldrin, dieldrin, and endrin), DDTs (o,p-DDE, p,p′-DDE, o,p-DDD, p,p′-DDD,o,p-DDT, and p,p′-DDT), and PCBs (PCB 28, 52, 101, 118, 138, 153, and 180) was determined.

### 2.2. Extraction of OCPs and PCBs in sediment samples

All sediment samples were dried using a vacuum freeze-dryer. 50 g of Homogenized Lake sediment samples were extracted with a Soxhlet extraction apparatus, 200 ml dichloromethane/acetone (1 : 1, v/v) for 72 h. After extraction, a rotary evaporator apparatus was used to concentrate the sample extract to approximately 2 ml. Clean-up for the hexane extract occurred using an alumina/silica gel

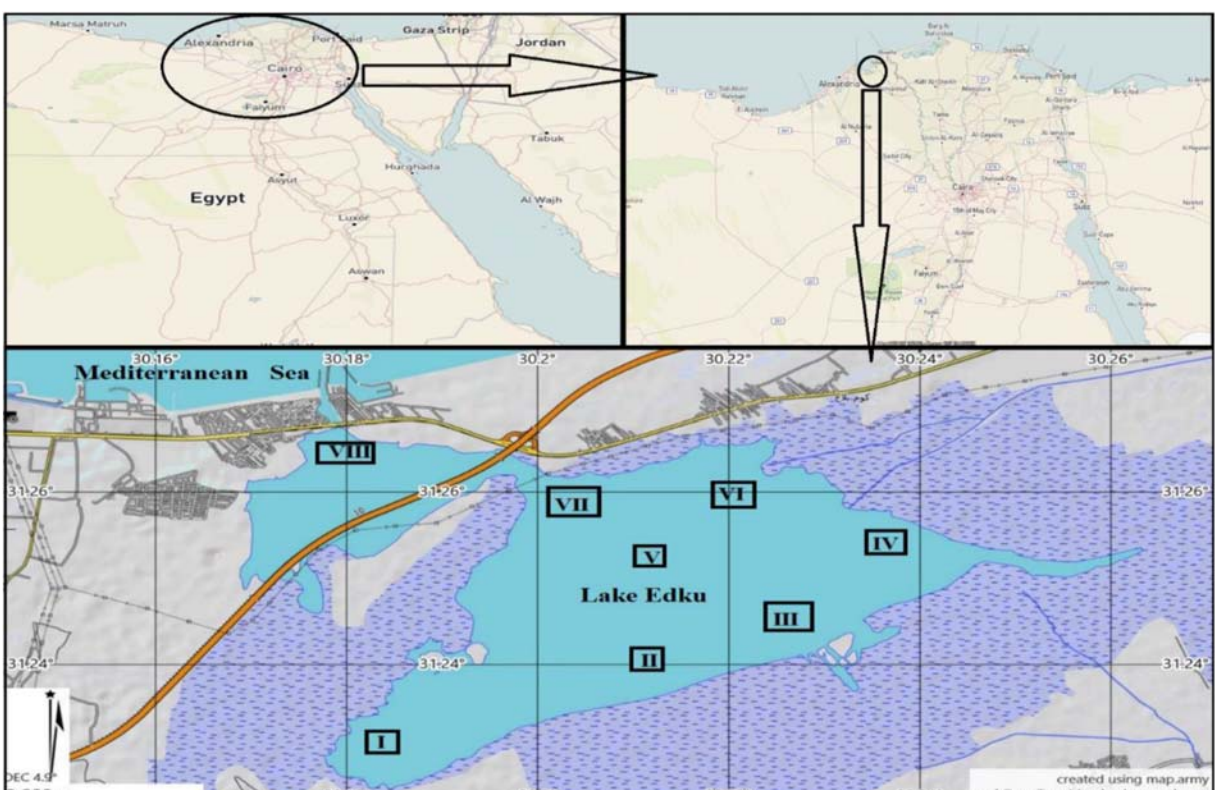


*Fig. 1. Sampling locations Lake Edku.*

glass column containing 1 cm anhydrous sodium sulphate. Dichloromethane/hexane (3 : 7, v/v) was used to elute and collect the fractions containing PCBs, and OCPs, the collected solution was evaporated to 5 mL under a gentle stream of nitrogen and lastly dissolved in 1 ml hexane and corked for gas chromatography analysis (Witt, 1995; Ezemonye, 2006). For the quantification of OCPs and PCBs in samples (water and sediment) Hewlett Packard 5890 series II GC gas chromatograph equipped, connected with Electron Capture Detector (ECD) was used; fused-silica capillary (30 × 0.32 mm × 0.52 μm) column was used. GC was programmed as follow: (1) initial temperature from 70 to 280 °C with a rate of 5 °C $min^{-1}$ and then kept at 280 °C for 20 min (2) The temperatures Detector and Injector were maintained at 300 and 270 °C, respectively. (3) carrier gas (Helium) 1.5 ml $min^{-1}$, and (nitrogen gas) with a follow rate 60 ml $min^{-1}$, was used as a make-up (El Nemr et al., 2012).

### 2.3. Quality assurance/quality control

Three analyses were conducted on standard reference materials to study the recovery efficiency that ranged from 50 to 102.1% with a coefficient of variation ranging from 6.9 to 10.2% for all studied, OCPs and PCBs. Analyzing blank samples spiked with a known quantity of each standard used for quality assurance checks, the values of PAHs in the blank samples were below the detection of the instrument. Quality control (QC) was applied by using duplicate samples. The detection limit was 0.1 μg/g for sediment.

## 3. Results and discussion

### 3.1. HCHs

HCHs recorded a minimum value 3.68 μg/kg during spring at station VI and a maximum value 6.27 μg/kg at station II with an average 4.69 ± 0.84 μg/kg; during summer recorded a minimum value 1.83 μg/kg at station VIII and a maximum value 7.03 μg/kg at station III with an average 4.30 ± 2.01 μg/kg; stations arranged as VII>III>V>II>VI>I>IV; and V>I>III>II>VII>VIII>VI>IV for α-HCH during spring and summer, respectively (Tables 1 and 2). α-HCH is a byproduct of lindane insecticide production and is classified as POPs, HCH consists of approximately 60−70% α-HCH, considered the major of HCH (Willett et al., 1998). The results fluctuated between 0.87 at station V and 2.14 at station III with an average 1.43 ± 0.42 μg/kg during spring, and from 0.65 at station VIII to 3.10 at station III with an average 1.68 ± 0.85 μg/kg, stations arranged as III>VI>VII>II>I>IV>V for β-HCH during summer; and (from 1.57 at station VI to 3.41 at station V with an average 2.54 ± 0.65 μg/kg), stations arranged as III>I>II>VII>V>IV>VI>VIII; and fluctuated (between 1.57 at station VI and 3.41 at station V with an

*Table 1. Organochlorine pesticides and polychlorinated biphenyls (μg/kg) in sediment samples collected from Lake Edku during spring 2022.*

| POPs | St.I | St.II | St.III | St.IV | St.V | St.VI | St.VII | St.VIII | Min. | Max. | Aver. | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| α-HCH | 0.34 | 0.76 | 1.09 | 0.26 | 0.84 | 0.57 | 0.68 | 1.15 | 0.26 | 1.15 | 0.71 | 0.32 |
| β-HCH | 1.25 | 1.34 | 2.14 | 0.95 | 0.87 | 1.54 | 1.65 | 1.72 | 0.87 | 2.14 | 1.43 | 0.42 |
| γ-HCH | 2.56 | 3.12 | 3.04 | 2.68 | 3.41 | 1.57 | 2.09 | 1.88 | 1.57 | 3.41 | 2.54 | 0.65 |
| HCHs | 4.15 | 5.22 | 6.27 | 3.89 | 5.12 | 3.68 | 4.42 | 4.75 | 3.68 | 6.27 | 4.69 | 0.84 |
| Aldrin | 0.21 | 0.35 | 0.29 | 2.56 | 2.14 | 2.52 | 0.65 | 1.19 | 0.21 | 2.56 | 1.24 | 1.02 |
| Dieldrin | 2.17 | 3.86 | 7.73 | 5.89 | 3.11 | 3.57 | 4.12 | 2.58 | 2.17 | 7.73 | 4.13 | 1.84 |
| Endrin | 0.32 | 1.54 | 2.55 | 4.51 | 4.87 | 5.17 | 4.95 | 1.77 | 0.32 | 5.17 | 3.21 | 1.89 |
| TC | 2.7 | 5.75 | 10.57 | 12.96 | 10.12 | 11.26 | 9.72 | 5.54 | 2.70 | 12.96 | 8.58 | 3.50 |
| o,p-DDE | 1.54 | 1.88 | 2.03 | 1.8 | 1.57 | 2.4 | 1.74 | 1.55 | 1.54 | 2.40 | 1.81 | 0.29 |
| p,p-DDE | 2.11 | 1.44 | 1.23 | 2.52 | 2.35 | 1.78 | 2.09 | 1.94 | 1.23 | 2.52 | 1.93 | 0.44 |
| o,p-DDD | 4.25 | 3.11 | 3.28 | 3.72 | 2.58 | 2.45 | 3.11 | 2.14 | 2.14 | 4.25 | 3.08 | 0.69 |
| p,p-DDD | 2.33 | 3.42 | 3.17 | 2.88 | 4.17 | 5.32 | 5.15 | 6.12 | 2.33 | 6.12 | 4.07 | 1.34 |
| o,p-DDT | 2.78 | 3.14 | 3.51 | 2.58 | 4.78 | 2.16 | 2.29 | 3.25 | 2.16 | 4.78 | 3.06 | 0.84 |
| p,p-DDT | 4.35 | 4.01 | 3.66 | 4.25 | 2.98 | 2.68 | 3.77 | 4.15 | 2.68 | 4.35 | 3.73 | 0.61 |
| DDTs | 17.36 | 17 | 16.88 | 17.75 | 18.43 | 16.79 | 18.15 | 19.15 | 16.79 | 19.15 | 17.69 | 0.84 |
| PCB 28 | 23.41 | 31.25 | 21.54 | 23.64 | 18.14 | 15.64 | 20.35 | 22.84 | 15.64 | 31.25 | 22.10 | 4.62 |
| PCB 52 | 10.23 | 12.08 | 9.41 | 9.22 | 5.71 | 14.5 | 13.81 | 10.33 | 5.71 | 14.50 | 10.66 | 2.81 |
| PCB 101 | 17.15 | 14.23 | 8.56 | 9.44 | 12.35 | 10.81 | 10.69 | 11.66 | 8.56 | 17.15 | 11.86 | 2.75 |
| PCB 118 | 8.75 | 16.32 | 16.45 | 14.87 | 15.38 | 9.11 | 12.54 | 9.42 | 8.75 | 16.45 | 12.86 | 3.34 |
| PCB 138 | 42.13 | 35.21 | 34.28 | 29.55 | 35.22 | 40.38 | 36.88 | 31.54 | 29.55 | 42.13 | 35.65 | 4.18 |
| PCB 153 | 21.35 | 14.22 | 11.81 | 11.36 | 10.47 | 9.82 | 16.35 | 17.12 | 9.82 | 21.35 | 14.06 | 3.98 |
| PCB 180 | 32.46 | 30.14 | 30.52 | 25.87 | 23.72 | 19.22 | 18.84 | 20.36 | 18.84 | 32.46 | 25.14 | 5.45 |
| Total PCBs | 155.48 | 153.45 | 132.57 | 123.95 | 120.99 | 119.48 | 129.46 | 123.27 | 119.48 | 155.48 | 132.33 | 14.32 |
| TP | 24.21 | 26.53 | 33.72 | 34.6 | 33.67 | 31.73 | 32.29 | 29.44 | 24.21 | 34.60 | 30.77 | 3.74 |

*Table 2. Organochlorine pesticides and polychlorinated biphenyls (μg/kg) in sediment samples collected from Lake Edku during Summer 2022.*

| POPs | St.I | St.II | St.III | St.IV | St.V | St.VI | St.VII | St.VIII | Min. | Max. | Aver. | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| α-HCH | 1.04 | 0.94 | 0.98 | 0.31 | 1.09 | 0.6 | 0.93 | 0.87 | 0.31 | 1.09 | 0.85 | 0.26 |
| β-HCH | 2.05 | 2.05 | 3.1 | 0.84 | 1.96 | 0.8 | 2.01 | 0.65 | 0.65 | 3.10 | 1.68 | 0.85 |
| γ-HCH | 3.01 | 2.8 | 2.95 | 0.96 | 2.06 | 0.98 | 1.09 | 0.31 | 0.31 | 3.01 | 1.77 | 1.07 |
| HCHs | 6.1 | 5.79 | 7.03 | 2.11 | 5.11 | 2.38 | 4.03 | 1.83 | 1.83 | 7.03 | 4.30 | 2.01 |
| Aldrin | 5.06 | 3.9 | 5.01 | 5.36 | 4.89 | 1.65 | 2.01 | 0.21 | 0.21 | 5.36 | 3.51 | 1.95 |
| Dieldrin | 4.55 | 5.32 | 4.5 | 8.01 | 3.69 | 2.03 | 3.3 | 0.35 | 0.35 | 8.01 | 3.97 | 2.27 |
| Endrin | 2.61 | 3.09 | 3.92 | 2.66 | 2.01 | 0.74 | 1.09 | 0.46 | 0.46 | 3.92 | 2.07 | 1.22 |
| TC | 12.22 | 12.31 | 13.43 | 16.03 | 10.59 | 4.42 | 6.4 | 1.02 | 1.02 | 16.03 | 9.55 | 5.10 |
| o,p-DDE | 2.98 | 2.22 | 2.08 | 1.85 | 0.92 | 1.98 | 1.08 | 0.12 | 0.12 | 2.98 | 1.65 | 0.90 |
| p,p-DDE | 2.06 | 3.65 | 3.01 | 3.01 | 1.06 | 0.9 | 0.99 | 0.35 | 0.35 | 3.65 | 1.88 | 1.22 |
| o,p-DDD | 4.21 | 4.44 | 2.42 | 3.06 | 2.03 | 2.01 | 0.81 | 0.41 | 0.41 | 4.44 | 2.42 | 1.45 |
| p,p-DDD | 2.77 | 0.59 | 0.64 | 2.98 | 3.19 | 1.23 | 0.57 | 0.02 | 0.02 | 3.19 | 1.50 | 1.27 |
| o,p-DDT | 2.74 | 2.03 | 3 | 0.95 | 1.98 | 0.79 | 0.88 | 0.06 | 0.06 | 3.00 | 1.55 | 1.04 |
| p,p-DDT | 2.03 | 2.09 | 3.21 | 0.64 | 0.72 | 0.68 | 2.21 | 0.04 | 0.04 | 3.21 | 1.45 | 1.08 |
| DDTs | 16.79 | 15.02 | 14.36 | 12.49 | 9.9 | 7.59 | 6.54 | 1 | 1.00 | 16.79 | 10.46 | 5.26 |
| PCB 28 | 16.88 | 16.6 | 16.31 | 15.53 | 13.4 | 11.06 | 12.02 | 10.12 | 10.12 | 16.88 | 13.99 | 2.69 |
| PCB 52 | 3.47 | 3.52 | 5.39 | 3.06 | 2.5 | 1.3 | 2.21 | 0.08 | 0.08 | 5.39 | 2.69 | 1.59 |
| PCB 101 | 13.05 | 12.52 | 15.12 | 13.4 | 13.09 | 12.01 | 11.98 | 10.03 | 10.03 | 15.12 | 12.65 | 1.45 |
| PCB 118 | 4.06 | 2.98 | 3.9 | 2.67 | 2.35 | 0.68 | 0.54 | 0.8 | 0.54 | 4.06 | 2.25 | 1.42 |
| PCB 138 | 14.22 | 14.01 | 17.08 | 11.06 | 12.01 | 11.3 | 11.65 | 10.23 | 10.23 | 17.08 | 12.70 | 2.25 |
| PCB 153 | 12.77 | 13.02 | 10.99 | 10.54 | 10.85 | 12.05 | 1.55 | 0.07 | 0.07 | 13.02 | 8.98 | 5.14 |
| PCB 180 | 11.43 | 21.95 | 21.08 | 22.01 | 22.06 | 10.06 | 11.38 | 1.01 | 1.01 | 22.06 | 15.12 | 7.84 |
| Total PCBs | 75.88 | 84.6 | 89.87 | 78.27 | 76.26 | 58.46 | 51.33 | 32.34 | 32.34 | 89.87 | 68.38 | 19.38 |
| TP | 35.11 | 33.12 | 34.82 | 30.63 | 25.6 | 14.39 | 16.98 | 3.85 | 3.85 | 35.11 | 24.31 | 11.45 |

average 2.54 ± 0.65 μg/kg) and (from 0.31 at station VIII to 3.01 at station I with an average 1.77 ± 1.07 μg/kg), stations arranged as V>II>III>I-V>I>VII>VIII>VI and I>III>II>V>VII>VI>IV>VIII during spring and summer respectively for γ-HCH (Tables 1 and 2).

Cyclodienes are strong soil insecticides due to their relative stability which is used as termite control (Meinke et al., 2021). As illustrated in Tables 1 and 2, Aldrin recorded values ranged from (0.21 at station I to 2.56 at station IV with an average 1.24 ± 1.02 μg/kg), stations (IV, VI, and V) recorded the highest value while stations (I, III, and II) during spring; and from (0.21 at station VIII to 5.36 at station IV with an average 3.51 ± 1.95 μg/kg), stations arranged as I>VI>III>V>II>VII>VI>VIII during summer, Aldrin also called 'classic organochlorines (Zitko, 2003), aldrin rapidly Degraded and converted to dieldrin when it enters the environment (Bose et al., 2021), 0.0002 mg/kg/day is considered acute oral exposure; 0.00003 mg/kg/day, is considered chronic exposure to Aldrin (Pohl and Chou, 2005); Dieldrin recorded values ranged from (2.17 at station I to 7.73 at station III with an average 4.13 ± 1.84 μg/kg) during spring, and from (0.35 at station VIII to 8.01 at station IV with an average 3.97 ± 2.27 μg/kg) during summer; during spring, 0.0001 mg/kg/day is considered acute oral exposure; 0.00005 mg/kg/day, is considered chronic exposure to Aldrin (Zitko, 2003), Aldrin is not toxic status to pesticides but when it oxidizes and is converted to dieldrin transferred to toxic status this reaction is called Diels-Alder (Jorgenson, 2001). Endrin fluctuated between (0.32 at station I and 5.17 at station VI with an average 3.21 ± 1.89 μg/kg) while during summer fluctuated between (0.46 at station VIII to 3.92 at station III with an average 2.07 ± 1.22 μg/kg). The toxicity of Cyclodienes increases with increasing ambient temperature. Cyclodienes can cause nervous disorder followed by tremors, and convulsions. Stations arranged as III>IV>VII>II>-VI>V>VIII>I during spring and I>IV>II>III>V>-VII>VI>VIII during summer for Dieldrin. Endrin recorded the highest value at stations (VI, VII, V, and IV) during spring, and (III, II, IV, and I) during summer. Kamel et al., (2015) recorded a high average value 4.70 ± 0.362 μg/kg for Aldren and 46.05 ± 3.837 μg/kg for Endrin in the sediments of Lake Manzalla during 2012 and 2013.

### 3.2. Diphenyl aliphatic (DDE, DDD, and DDT)

Diphenyl Aliphatic included o,p′-DDE, p,p′-DDE, o,p′-DDD, p,p′-DDD, o,p′-DDT, and p,p′-DDT, DDT is considered the most useful insecticide developed and still effectively used for malaria control (Sadasivaiah et al., 2007). DDT fluctuated between 2.16 at station VI and 4.78 at station V with an average of 3.06 ± 0.84 μg/kg and from 0.06 at station V and 3.00 at station III with an average 1.55 ± 1.04 μg/kg; and fluctuated between (2.68 at station VI and 4.35 at station I with an average 3.73 ± 0.61 μg/kg) and

(0.04 at station V and 3.21 at station III with an average 1.45 ± 1.08 μg/kg) for o,p′-DDT, and p,p′-DDT during spring and summer, respectively (Tables 1 and 2).

The main source of DDT in aquatic environments is its use as a pesticide (Guzzardi et al., 2016) o,p′-DDE, and p,p′-DDE during spring and summer, respectively, fluctuated between (1.54 at station I and 2.40 at station VI with an average 1.81 ± 0.29 μg/kg) and (0.12 at station VIII and 2.98 at station I with an average 1.65 ± 0.90 μg/kg); and fluctuated between (1.23 at station III and 2.52 at station IV with an average 2.00 ± 0.42 μg/kg) and (0.35 at station V and 3.65 at station II with an average 1.88 ± 1.22 μg/kg) p,p′-DDT considered the main component of insecticides containing DDT (65−80%) as an active ingredient (Battaglin and Fairchild, 2002).

DDE and DDD resulting from DDT break down, DDE, DDD, and DDT do not dissolve easily in water and take a long time (2 : 15 year) to degrade by Microorganisms (Guzzardi et al., 2016). Swallowing large amounts of DDT can lead to headaches, nausea, and seizures and can cause Type II diabetes mellitus, Scientific experiments revealed that exposure of animals to large quantities of DDT may lead to nervous system, liver, and reproductive system disorders (Peter and Cherian, 2000; Bernardes et al., 2015). o,p′-DDD ranged from (2.14−4.25 with an average 3.08 ± 0.69 μg/kg) during spring and from (0.41−4.44 with an average 2.42 ± 1.22 μg/kg) during summer; the average contributions of DDT congeners mixture detected in the sediment samples were in the order p,p′-DDT> o,p′-DDT> p,p′-DDD> o,p′-DDD> p,p′-DDE > o,p′-DDE during spring and summer. The predominance of DDTs (o,p′-DDT and p,p′-DDT) in the sediment samples was also reported by Barhoumi et al. (2014). Metcalf (1973) stated that DDT generally contains 75% p,p′-DDT, 15% o,p′-DDT, 5% p,p′-DDE, and less than 5% p,p′-DDD, he pointed out that the difference in the ratios is indications of a decrease or increase in the rate of DDTs input, If the compositional percentage of p,p′-DDT decrease with time and the metabolites p,p′-DDE + p,p′-DDD increase that is mean there was no new DDT input (Strandberg et al., 1998). p,p′-DDT can be biodegraded to p,p′-DDE in the environment under aerobic conditions in addition p,p′-DDT can be biodegraded to p,p′-DDD under anaerobic conditions, biodegraded conditions depending on many factors such as organic carbon content, temperature, and sediment type, so if the DDE more than DDD referred to oxidizing environment (Aislabie et al., 1997; Mostafa et al., 2007), stations (I, IV, V, VI, and VIII) recorded a slightly oxidation for p,p′-DDT to p,p′-DDE. p,p′-DDD recorded values fluctuated between (2.33 and 6.12 with an average 4.07 ± 1.34 μg/kg) during spring and between (0.02 and 3.19 with an average 1.50 ± 1.27 μg/kg) during summer (Tables 1 and 2).

### 3.3. PCBs

As illustrated in Tables 1 and 2, the concentration of PCB28 ranged between 15.64 μg/kg at station VI and 31.25 μg/kg at station II with an average of 22.10 ± 4.62 μg/kg during spring and ranged from 10.12 μg/kg at station VIII and 16.88 at station I with an average 13.99 ± 2.69 μg/kg during summer. PCB 52 fluctuated between 5.71 μg/kg at station V and 14.50 μg/kg at station VI with an average 10.66 ± 2.81 μg/kg during spring and between 0.08 μg/kg at station VIII to 5.39 μg/kg with an average 2.69 ± 1.59 μg/kg during summer; PCB 101 during spring recorded values ranged from 8.56 μg/kg at station III to 17.15 μg/kg at station I with an average 11.86 ± 2.75 μg/kg during spring and 10.03 μg/kg at station VIII to 15.12 μg/kg at station III with an average 12.65 ± 1.45 μg/kg during summer; PCB 118 recorded value between 8.56 μg/kg at station I to17.15 μg/kg at station III with an average 11.86 ± 2.75 μg/kg during spring and 0.54 μg/kg at station VII to 4.06 at station I with an average 2.25 ± 1.42 μg/kg during summer; values ranged between a minimum 29.55 μg/kg at station IV, 9.82 μg/kg at station VI, and 18.84 μg/kg at station VII and a maximum, 42.13 μg/kg at station I, 21.35 μg/kg at station I, and 32.46 μg/kg at station I with an average 35.65 ± 4.18 μg/kg, 14.06 ± 3.98 μg/kg, and 25.14 ± 5.45 μg/kg during spring, and a minimum values 10.23 μg/kg at station VIII, 0.07 μg/kg at station VIII, and 1.01 μg/kg at station VIII and a maximum values 17.08 μg/kg at station III, 13.02 μg/kg, and 22.06 μg/kg at station V with an average 12.70 ± 2.25 μg/kg, 8.98 ± 5.14 μg/kg and 15.12 ± 7.84 μg/kg during summer for PCB 138, PCB 153, and PCB 180 respectively in sediment during the present study. Total PCBs recorded values ranged between 119.48 μg/kg and 155.48 μg/kg with an average 132.33 ± 14.32 μg/kg, stations arranged as I>II>III>VII>IV>VIII>V>VI during spring; during summer ranged between 32.34 and 89.87 with an average 68.38 ± 19.38 μg/kg, stations arranged as III>II>IV>V>I>VIII>VI>VIII.

### 3.4. The sources of OCPs and PCBs in surface sediment

α-HCH/γ-HCH ratios are considered the most important methods used to determine of the sources of HCHs in the environment (Hao et al., 2019). As shown in Fig. 2, the α-HCH/γ-HCH ratio ranged between 0.09 and 0.61 at station IV and 0.32 and 2.80 at station VIII during spring and summer respectively, in all studied stations below 4, with β-HCH, and γ-HCH The result suggested the use of pure lindane for agricultural purposes.

β-HCH is considered the dominant isomer in different environments (water, soil, and sediment), and it has special stable chemical and physical properties than other HCH isomers (α and γ-HCH) (Willett et al., 1998). So β-/(α+γ)-HCH ratio was used to identify historical inputs. The ratio of β-/(α+γ)-HCH varied between 0.20 and 0.71 during spring, and from 0.50 to 0.99 during summer, stations I, II, IV, and VI during spring recorded values below 0.5, suggesting that the recent HCH input, while stations III, VI, VII, and VIII during spring and all stations during summer recorded value above 0.5 that referred to originated mainly from past usage (Fig. 2). Dicofol contains 3:7% of DDT, if o,p′-DDT is more major than p,p′-DDT that is referred to as dicofol source, if o,p′-DDT is less than p,p′-DDT that is indicated commercial DDT source (Qiu et al., 2005; Wang et al. 2008). As illustrated in Fig. 3, o,p′-DDT/p,p′-DDT ratio ranged between a minimum value 0.61 and 0.40 at station VII and maximum values of 1.60 and 1.50 at stations V and VIII. The study observed that all stations recorded a value below 1.3 suggesting that technical DDTs were the main source, except stations IV, V, and VIII during summer recorded a value above 1.3 indicating dicofol-type DDT. DDE + DDD)/∑DDTs ratio in the present study ranged between 0.58 at stations II, and III and 0.71 at station VI during spring; during summer recorded values ranged between 0.53 at station VII and 0.90 at station VIII. The study referred to all stations indicating past input of DDT as shown in Fig. 3. DDE/DDD ratios ranged between 0.45 at station III and 0.86 at station V during spring, and from 0.67 at station VII to 4.70 at station VIII during summer, results of ratio values greater than 1 at stations I, II, IV, VI, and VIII during spring that referred to anaerobic degradation, on other hand stations III, V, and IV during spring and all stations during summer recorded values below 1 that indicated anaerobic degradation processes (Fig. 3).

### *3.5. Risk assessment of PCBs and OCPs in surface sediments*

Numerous applications SQGs have been used in the present study, for sediment quality and ecological risk assessments, and for developing sediment quality remediation objectives; SQGs in freshwater ecosystems were grouped into different categories: threshold effect levels (TELs), effect range low values (ERLs), probable effect levels (PELs) and effect range median values (ERMs) according to EPA (1992); Menviq (1992); Smith et al. (1996); MacDonald et al. (2000) as illustrated in Table 3. γ-HCH during spring and summer recorded a value above ERL and TEL and recorded a value more than LEL and MET at stations II, III, IV, and V during spring and the lowest value during summer except for station I, all values were lower than SQAL and not recorded any severe effects level during spring and summer. On the other side, all stations during spring and summer recorded values lower than SEL, TET, ERM, and PEC, and in general, it does not represent any danger or actual threat to the environment. Dieldrin all stations recorded a high value more than Threshold Effect Concentrations during spring and summer except station I, and VIII during spring and VIII during summer for TET and lowest than SQAL, on the other hand, recorded values lowest than Probable Effect Concentrations except

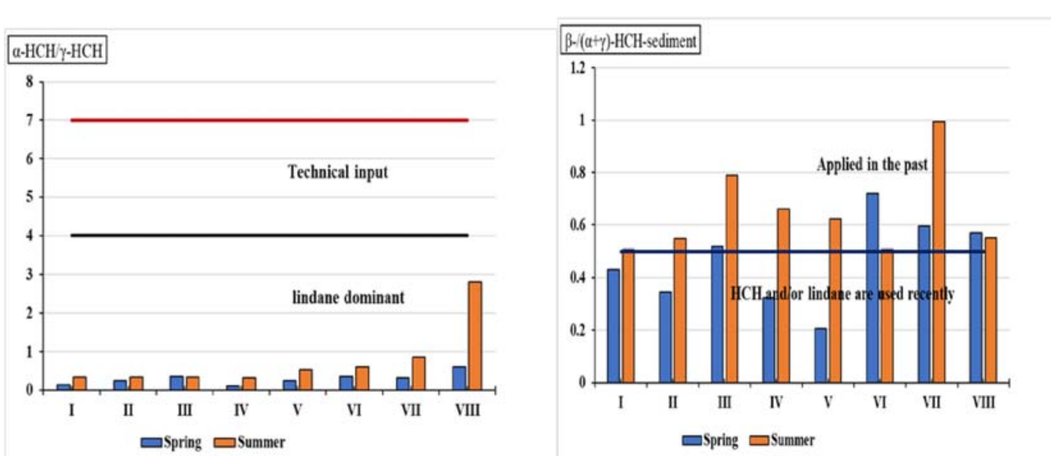


*Fig. 2. Hexachloro cyclohexanes ratios (α-HCH/γ-HCH, and β-/(α+γ)-HCH) for sediment samples of Lake Edku during spring and summer 2022.*

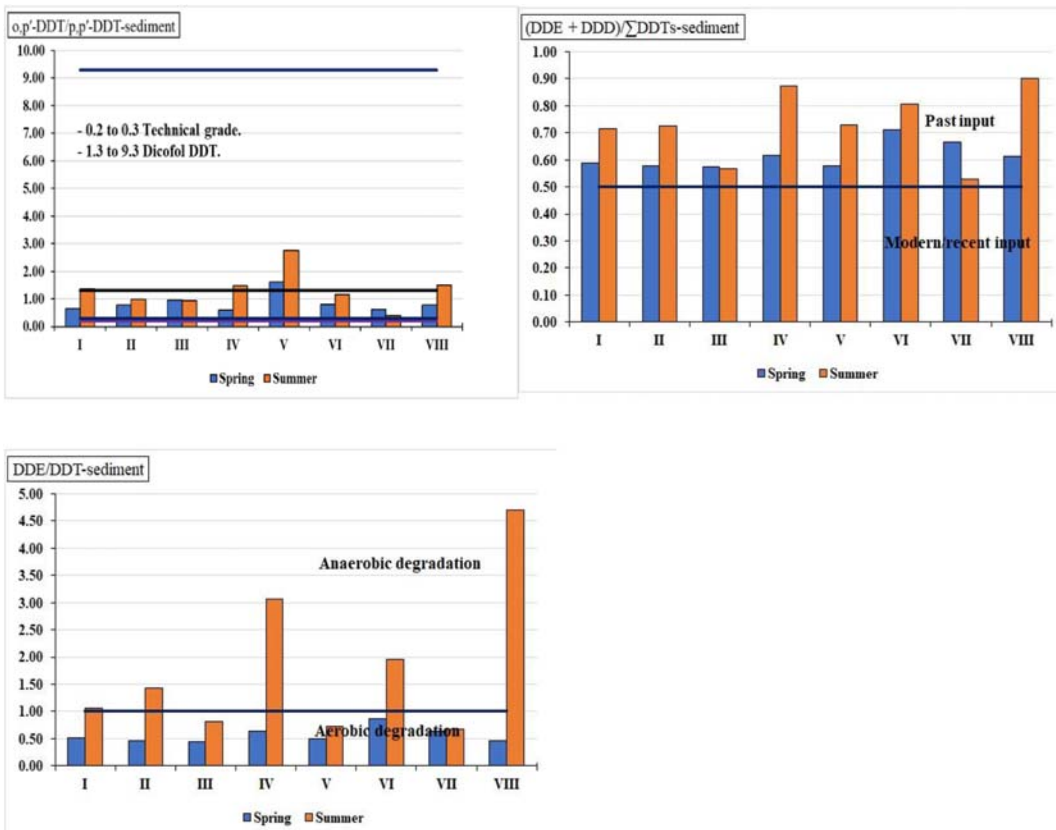


*Fig. 3. (DDE + DDD)/∑DDTs, o,p′-DDT/p,p′-DDT, and DDE/DDT ratio for sediment samples of Lake Edku during spring and summer 2022.*

*Table 3. Levels and sediment quality and ecological risk assessments values for organochlorine pesticides and polychlorinated biphenyls.*

| | St. | γ-HCH | Dieldrin | Endrin | DDE | DDD | DDT | DDTs | PCBs |
|---|---|---|---|---|---|---|---|---|---|
| Spring | I | 2.56 | 2.17 | 0.32 | 3.65 | 6.58 | 7.13 | 17.36 | 39.77 |
| | II | 3.12 | 3.86 | 1.54 | 3.32 | 6.53 | 7.15 | 17.00 | 42.52 |
| | III | 3.04 | 7.73 | 2.55 | 3.26 | 6.45 | 7.17 | 16.88 | 47.08 |
| | IV | 2.68 | 5.89 | 4.51 | 4.32 | 6.60 | 6.83 | 17.75 | 48.58 |
| | V | 3.41 | 3.11 | 4.87 | 3.92 | 6.75 | 7.76 | 18.43 | 48.25 |
| | VI | 1.57 | 3.57 | 5.17 | 4.18 | 7.77 | 4.84 | 16.79 | 43.89 |
| | VII | 2.09 | 4.12 | 4.95 | 3.83 | 8.26 | 6.06 | 18.15 | 47.46 |
| | VIII | 1.88 | 2.58 | 1.77 | 3.49 | 8.26 | 7.40 | 19.15 | 44.53 |
| | I | 3.01 | 4.55 | 2.61 | 5.04 | 6.98 | 4.77 | 16.79 | 43.75 |
| Summer | II | 2.80 | 5.32 | 3.09 | 5.87 | 5.03 | 4.12 | 15.02 | 41.25 |
| | III | 2.95 | 4.50 | 3.92 | 5.09 | 3.06 | 6.21 | 14.36 | 40.09 |
| | IV | 0.96 | 8.01 | 2.66 | 4.86 | 6.04 | 1.59 | 12.49 | 36.61 |
| | V | 2.06 | 3.69 | 2.01 | 1.98 | 5.22 | 2.70 | 9.90 | 27.56 |
| | VI | 0.98 | 2.03 | 0.74 | 2.88 | 3.24 | 1.47 | 7.59 | 18.93 |
| | VII | 1.09 | 3.30 | 1.09 | 2.07 | 1.38 | 3.09 | 6.54 | 18.56 |
| | VIII | 0.31 | 0.35 | 0.46 | 0.47 | 0.43 | 0.10 | 1.00 | 3.12 |
| Threshold effect concentration SQGs | TEL | 0.94 | 2.85 | 2.67 | 1.42 | 3.54 | NG | 7.00 | 3.41 |
| | LEL | 3.00 | 2.00 | 3.00 | 5.00 | 8.00 | 8.00 | 7.00 | 70.00 |
| | MET | 3.00 | 2.00 | 8.00 | 7.00 | 10.00 | 9.00 | NG | 200.00 |
| | ERL | NG | 0.02 | 0.02 | 2.00 | 2.00 | 1.00 | 3.00 | 50.00 |
| | SQAL | 3.70 | 110.00 | 42.00 | NG | NG | NG | NG | NG |
| | TEC | 9.97 | 1.90 | 2.22 | 3.16 | 4.88 | 4.16 | 5.26 | 59.80 |
| Probable effect concentration SQGs | PEL | 1.38 | 6.67 | 62.44 | 6.75 | 8.51 | NG | 4.45 | 277.00 |
| | SEL | 10.00 | 910.00 | 130.00 | 190.00 | 60.00 | 710.00 | 120.00 | 5300.00 |
| | TET | 9.00 | 300.00 | 500.00 | 50.00 | 60.00 | 50.00 | NG | 1000.00 |
| | ERM | NG | 8.00 | 45.00 | 15.00 | 20.00 | 7.00 | 350.00 | 400.00 |
| | PEC | 4.99 | 61.80 | 207.00 | 31.30 | 28.00 | 62.09 | 57.20 | 767.00 |

PEL at stations III, and IV during spring and IV during summer, in general, it does not represent any danger or actual threat to the environment. Endrin recorded values above ERL and low MET values during spring and summer, fluctuating through TEL and LEL. While recorded lowest value by comparing with SQAL and Probable Effect Concentrations means It does not represent any danger or actual threat to the environment. The Sum of DDE and the sum of DDDE recorded values below that of Probable Effect Concentrations except for DDT which recorded values above ERM during spring at stations I, II, III, and IV that make that Probable Effect Concentrations for the ecosystem. The sum of DDTs recorded values more than the Threshold Effect and lower than the Probable Effect make it safe for the ecosystem. The sum of PCBs recorded a value lower than the threshold and Probable Effect Based on this, all concentrations during that study are an indication of the safety of the lake from pollution with OCPs and PCBs.

### *3.6. Principal component analysis (PCA)*

PCA has been executed on the different sediment sample datasets for PCBs and OPCs. The loading matrix during spring and summer respectively as showed in (Fig. 4), The obtained results from PCA manifested that the first three principal components for OPCs show ~ 60% (PC1), 40% (PC2), and 30% (PC3) during spring and 13% (PC1) 4% (PC2), and 1% (PC3) during summer of the total variance, respectively. Considering the dominant two PCA axes, the first principal component has high positive values for both PCB (101, 118, 138, 153, and 180), γ-HCH, o,p-DDT, p,p-DDT, and o,p-DDD at stations I, II, III, and IV; PC2 was composed of remaining pollutants and stations during spring while during summer (PC1) all pollutants recorded positive values at stations I, II, III, IV, and V. The first component may be suggested due to anthropogenic activities (Aries et al., 2006; Shibamoto et al., 2007; De Rosa et al., 2022), The second component (PC2) which dominated and recorded positive values by α-HCH, γ-HCH, Aldrin, Dieldrin, Endrin, o,p-DDE, o,p-DDT, PCB 28, and PCB 180 during spring and HCHs, Endrin, o,p-DDT, p,p-DDT, and PCB52 during summer; (PC2) can be suggested that these compounds could be transferred to the lake from the drains leading to their accumulation and deposition into the lake.

### *3.7. Hierarchical cluster analysis (HCA) that*

#### *3.7.1. Single linkages*

As illustrated in Fig. 5, single linkage between stations was recorded as follow stage (1) recorded linkage between stations (III, and IV) at a distance 8.74, stage (2) between (VII and VIII) at a distance 8.74, stage (3) between (III and V) at a distance 10.81, stage (4) between (VI and VII) at a distance 12.35, between (II, and III) at a distance 14.24, between (II and VI) at distance 15.57, finally between (I and II) at a distance 19.08 during spring. And at distance 5.94 between (IV and V) at distance of 5.99 between (II and III) at distance 7.91 between (II and IV) at distance 10.22 between (I and VI) at distance 12.07 between (VII and VIII) at distance 13.49 between (I and II) at distance 19.79 between (I and VII) during summer. Station V and IV recorded most

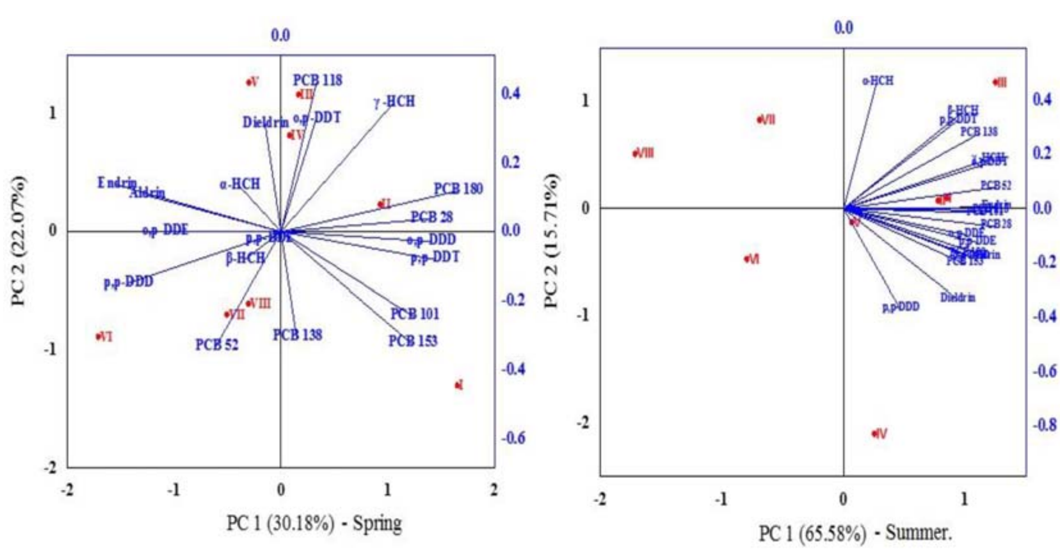


*Fig. 4. Loading matrix of the first two principal components of persistent organic pollutants in the sediment of Lake Edku during spring and summer 2022.*

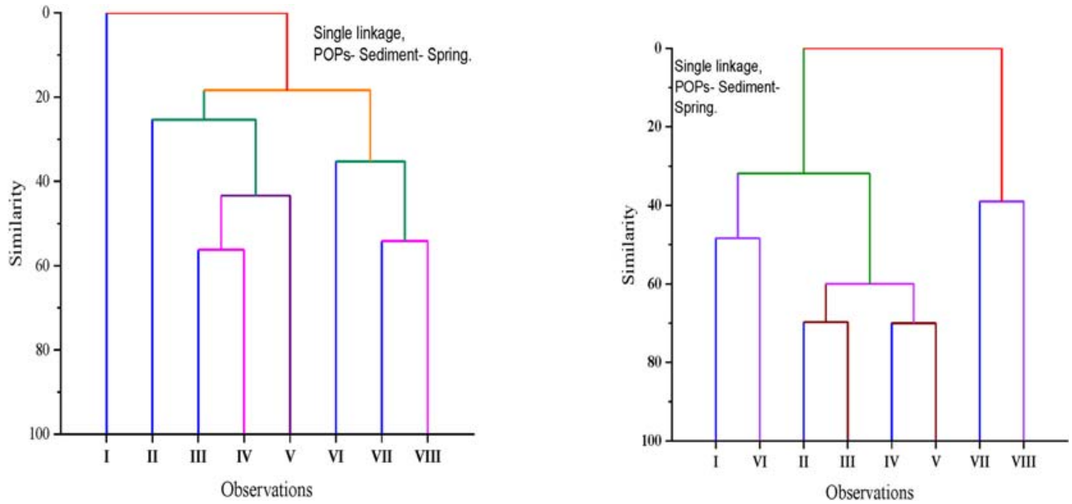


*Fig. 5. Hierarchical cluster analysis Dendrogram (single linkage) showing the spatial distribution of Persistent organic pollutants among different sampling sites in sediment from Lake Edku during the spring and summer 2022.*

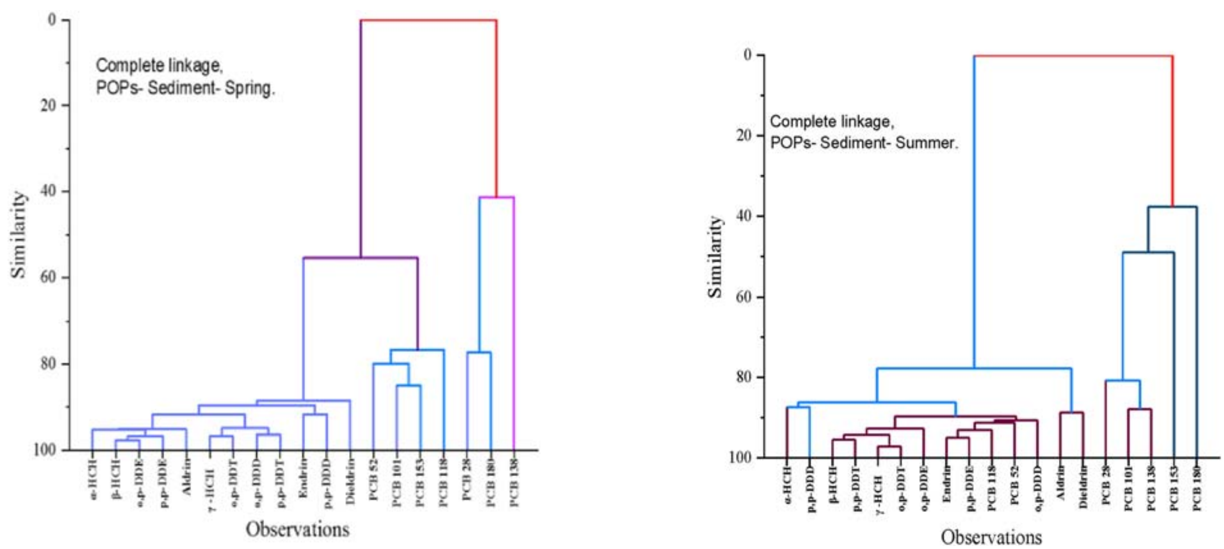


*Fig. 6. Hierarchical cluster analysis Dendrogram (complete linkage) between group for persistent organic pollutants in sediment samples from Lake Edku during the spring and summer 2022.*

representative observation, while VIII and I recorded the least representative observation during spring and summer, respectively.

### 3.8. Complete linkage

By applying the Hierarchical cluster analysis for complete linkages and similar relations between pollutants as illustrated in dendrograms (Fig. 6), the results recorded 18 stages ranged between a distance of 1.54 contained (β-HCH o,p-DDE) and 65.53 contains (α-HCH and PCB 28) during spring. During spring γ-HCH and o,p-DDT recorded linkage at a distance of 0.90 as the lowest value, and between α-HCH and PCB 28 at 11.74 as the highest value. p,p-DDT, and Endrin recorded the most representative observation while PCB 138 and PCB 180 recorded the least representative observation during spring and summer, respectively.

### 3.9. Conclusion

(a) OCPs and PCBs were studied in the Nile Delta Lake (Lake Edku) for their environmental impacts, probable sources, and ecological risk assessment.
(b) The main sources responsible for transporting pollutants into the lake are sub-drains such as

Damanhour, El-Bousely, Edku and Barseek Drain. This drains received agriculture, and industrial wastewater from the surrounding area as well as fish farms around the lake.

(c) The data obtained from the current study are important for a future database to maintain good and acceptable levels of pollutants in the lake, especially as it is an important source of fishing for the city of Alexandria.

## Ethical Clearance

Details and aims of the study were explained to all the participants.


## Funding

None.


## Author contributions to idea and protocol design

Mohamed A. Okbah: Concept, Design, Interpretation, drafting of the manuscript, Mahmoud S. Ibrahim: Interpretation, Drafting of the manuscript. Tarek O. Said: English editing and language revision. Mohammed E.M. Nassar: Sample collection, Data analyses, Maie I. El-Gammal: English editing and language revision.

### Declaration of Competing Interest

Conflicts of interest: There are no conflicts of interest.

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