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Organochlorine Contaminants in Water, Sediment and Fish of Lake Burullus, Egyptian Mediterranean Sea

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Abstract Lake Burullus is one of the Delta lakes, connected with the Mediterranean Sea through El Boughaz opening. Concentrations of organochlorine contaminants were measured in water, sediments and biota of the lake because of concerns about their effects on its productivity. The concentrations of chlorinated hydrocarbons decreased in the order of PCBs > DDTs > TC > HCHs for all water samples collected from Lake Burullus during 2006. Higher concentrations were recorded during summer season, this clearly affected by higher agricultural and sewage activities. The concentrations of DDTs in water were ranged from 0.07 to 221.9 ng L^{-1}; 46.3–656.5 ng L^{-1}; 94.3–882.6 ng L^{-1} and 24.8–233 ng L^{-1} during winter, spring, summer and autumn, respectively. Among DDTs metabolites p,p-DDE was the most dominant with a maximum of 520.13 ng L^{-1} recorded at station 10 (El Boughaz opening). In sediment samples, PCBs concentrations were ranged from 4.6 to 213.9 ng g^{-1} with an average 47.2 ng g^{-1}; dry weight. Total pesticides were higher than PCBs for mostly all sediment samples of Lake Burullus. Concentrations of DDTs in fish tissues were ranged from 2.76 to 24.23 ng g^{-1} and from 14.16 to 45.13 ng g^{-1}; wet weight for *Oresochromus niloticus* and *Clarries* sp., respectively.

Keywords Pesticides · PCBs · Lake Burullus · Mediterranean · Egypt

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Chlorinated organic compounds have a wide range of industrial and agricultural applications. They include pesticides such as DDT (dichlorodiphenyltrichloroethane) and Lindane (γ-HCH or gamma-hexachloro-cyclohexane) and polychlorinated biphenyls (PCBs) which are used in a range of industrial applications including dielectrics in electrical transformers. Organochlorines have been implicated in reproductive and immunological abnormalities observed in birds and marine mammals (Livingston 1976). Man-made organochlorines have been considered a serious threat to the long-term health of the marine environment for many years. The main reasons are their strong accumulation in lipid tissues of marine biota as well as the high toxicity to marine organisms and the slow degradation of several members of this group. The highest concentrations of organochlorines have been associated with centers of urbanization in most of studies elsewhere, such as estuarine and marine sediments near major metropolitan areas along the eastern coast of the USA (NRC 1989) and at a wide range of locations in Europe, Asia and Africa associated with human settlement (Alvaerz-Pineiro et al. 1995; Agnihotri et al. 1996; Thompson et al. 1996; Abd-Allah et al. 1998; Said and Hamed 2005, 2006; El Nemr et al. 2006).

Lake Burullus is shallow slightly brackish water situated along the Egyptian Mediterranean Sea coasts. It is one of the Nile delta lakes located between the two main delta promontories; Rosetta and Damietta.

It lies on the eastern side of the Rosetta branch of the River Nile, Egypt and occupies a central position along the Mediterranean coast of the Nile. It lies between Longitude 30°30′ and 31°10′ E and latitude 31°21′ and 31°35′ N. It has an irregular elongated shape and is connected to the sea through a narrow (50 m width) passage called Al-Burg Inlet or Boughaz Al-Burullus (Fig. 1). The present area of Lake Burullus is about 420 km^2 (100,000 feddan) of which

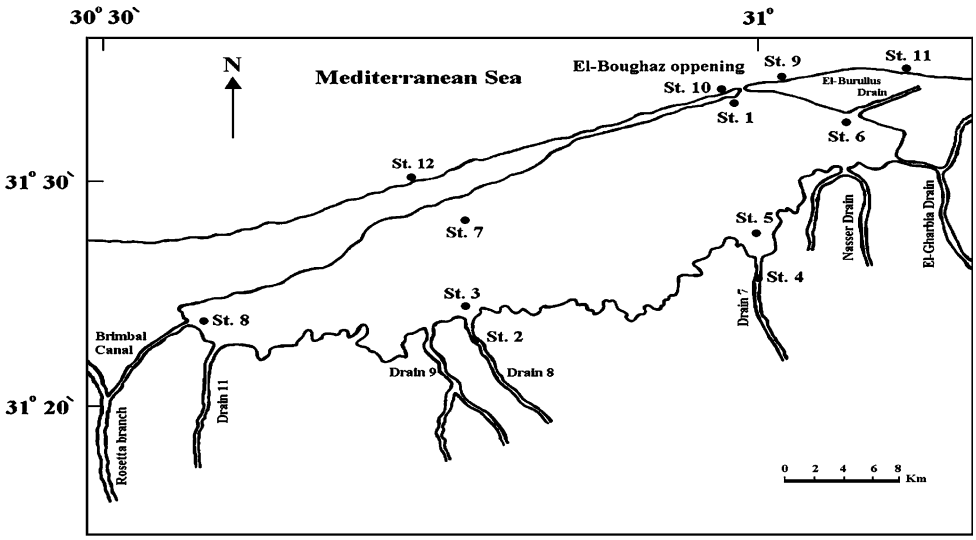

Fig. 1 Lake Burullus showing the sampling stations

370 km^2 is open water. Former estimates of the area are 588 km^2 (140,000 feddan) in 1956 and 462 km^2 (110,000 feddan) in 1974 (Okbah 2005). It seems that during the last 10 years there has been a reduction in the lake area by 30%. This decrease is due to continuous land reclamation projects along the southern and eastern shores of the lake and fish farming processes. The length of the lake is about 47 km, and the width varied between 6 and 16 km, with an average of about 11 km. The depth of the lake ranges between 0.42 and 2.07 m. It is the second largest natural lake in Egypt with respect to area and production. It is the main source of fish production in Kafr El-Shekh Governorate. Fish catch from the lake has been dropped from about 52.5 thousands tons in 1990 to about 43.6 thousands tons in 1993 or dropped by about 17% (Okbah and Hussein 2006). Huge amounts of brackish drainage water (about 2.46×10^9 m^3 year^{-1}) enter the lake from several drains including: (1) El Burullus drain at the eastern side of the lake; (2) drains 7, 8, 9 and 11 in the southern side of the lake; (3) Brembal canal in the western extremity of the lake which receives fresh water directly from Rosetta branch during the flood periods; (4) western Burullus and (5) El Nasser and El Gharbia drains. The lake receives also about 100×106 m^3 year^{-1} of precipitation. Given the present size of the lake, the residence time of water takes about 2.5 months (Okbah 2005). The existing environmental problems of Burullus lake are mainly related to natural and man-made influences. The direct effect of the increased wind speed on the lake is manifested by the introduction of the seawater into the lake through El-Boughaz channel by the northern wind, the magnitude of which depends on the wind velocity and duration. Depending on the shallowness of the lake, the increased wind velocity also causes water turbulence by stirring up surface sediments. In addition, the wind movements play an important role in the distribution of salinity in the lake. When there are easterly winds, the drains freshwater covers most of the lake and decreases the salinity to a large extent. The northerly winds drive water southerly and the salinity increases even next to drains. The objective of this paper is to study the distribution of chlorinated pesticides and polychlorinated biphenyls in water, sediment and two of the most common fishes in Lake Burullus. The effect of different drains water on the distribution of different organic pollutants was studied. We also calculated the annual inputs of pollutants from the lake into the Mediterranean Sea.

Materials and Methods

Twelve surface water samples (1 m depth) were collected seasonally from Lake Burullus on R/V Salsabil during 2006. The studied area as represented by four regions inside the lake: the Eastern region (stations 4–6), the Western region (station 8), the northern region (station 7) and southern region (2 and 3). In addition to stations 9–12, lie outside the lake (Fig. 1). Surface sediment (0–3 cm) samples were collected using a stainless steel grab sampler from 12 sites during August 2006 and stored in pre-cleaned aluminum containers and frozen in a deep freezer at −20°C until analysis. The samples were analyzed for organochlorines following well-established techniques (UNEP/IOC/IAEA 1991; IOC 1993).

In addition, two types of fish species; *Oresochromus niloticus* and *Clarries* sp., were collected during the same period to study the accumulation of organic pollutants. All the samples were collected fresh from the fishermen working in the area of study, not more than 2 h after catching, they kept frozen in the laboratory. Biological specimens were dissected and their tissues were kept frozen until

extraction. Water samples were extracted in the field, stored at 4°C and transported to the laboratory for chlorinated pesticides and polychlorinated biphenyls analysis using GC/ECD. One liter of each water sample was extracted three times with 200 mL of dichloromethane in a separating funnel after adding pentachlorobenzene as internal standard. Sample extracts were combined and concentrated by rotary evaporation to 2 mL. Finally, samples were concentrated under a gentle stream of pure nitrogen to a final volume of 1 mL. The sediments were freeze-dried, and their dry/wet ratios were determined. Sediments were then sieved through a stainless steel mesh (250 μm). Each sediment sample (30 g) was Soxhlet extracted with 250 mL of hexane for 8 h and then re-extracted for 8 h into 250 mL of dichloromethane (Villeneuve et al. 1999). Then the extracts were combined and concentrated down using rotary evaporation at 35°C followed by concentration with pure nitrogen gas stream down to a volume of 1 mL. Sulphur was removed by shaking the extracts with mercury. Ten gram of wet weight of Muscle tissue (a composite of samples from each fish) was placed in a blender and 30 g anhydrous sodium sulfate was added. The tissues were manually homogenized to determine whether the samples were adequately dried. Samples were then blended at high speed until the mixture was well-homogenized (2–3 min). The mixture was transferred to a pre-cleaned extraction thimble and the dehydrated tissue was extracted with 200 mL (1:1) n-hexane-dichloromethane for 8 h in a soxhelt apparatus cycling 5–6 times per hour. Anhydrous sodium sulfate (30 g) was extracted in the same fashion as the sample and used as the blank. The extracted solvents were concentrated with a rotary evaporator down to 2 mL (maximum temperature: 35°C), followed by concentration with a pure nitrogen gas stream down to a volume of 1 mL.

The final extracted volume (1 mL) for each of the water, sediment and biota samples was transferred to the top of a glass column. This column was prepared by slurry packing 20 g of florisil, followed by 10 g of alumina and finally 1 g of anhydrous sodium sulfate. Elution was performed using 70 mL of n-hexane for PCB fractions, then a 50 mL mixture (70% hexane and 30% dichloromethane) for pesticide fractions. Finally, eluted samples were concentrated under a gentle stream of purified nitrogen to about 0.3 mL, prior to being injected into the GC/ECD. Each fraction was concentrated and injected into a Hewlett Packard 5890 series II GC gas chromatograph equipped with ^{63}Ni-electron capture detector (ECD). The instrument was operated in split less mode (3 μL split less injection) with the injection port maintained at 290°C and the detector maintained at 300°C. A fused silica capillary column (50 m length × 0.32 mm i.d × 0.52 μm film thickness) coated with DB-1 (5% diphenyl and 95% dimethyl polysiloxae) was used for quantification. The oven temperature was programmed to increase from 90 to 140°C at rate of 5°C min^{-1}, to be maintained at 140°C for 1 min, then to increase from 140 to 250°C at rate of 3°C min^{-1}, maintained at 250°C for 1 min, then to increase from 250 to 300°C at rate of 20°C min^{-1} and then maintained at 300°C for 1 min. The carrier gas was nitrogen flowing at 1.5 mL min^{-1}. Concentrations of individually resolved peaks were summed to obtain the total PCB concentration. An equivalent mixture provided by Dr. Ehrenstorfer Laboratories (Augsburg, Germany) with known PCB composition and content was used as the standard.

Organochlorine pesticides were quantified from individually resolved peak areas with the corresponding peak areas of the external standards (POC mixture provided by IAEA). They included: α, β and γ-HCHs, Aldrin, Dieldrin, and DDT with their isomers. In addition to the following PCBs congeners were quantified: 28 (2,4,4-Trichlorobiphenyl); 52 (2,2,5,5-tetrachlorobiphenyl); 101 (2,2,4,5,-tetrachloro biphenyl); 118 (2,3,4,4,5-pentachlorobiphen-yl); 138 (2,2,3,4,4,5-hexachlorobiphenyl); 153 (2,2,4,4,5,5-hexachlorobiphenyl) and 180 (2,2,3,4,4,5,5-Heptachlorobiphenyl). To control the analytical reliability and assure recovery efficiency and accuracy of the results, seven analyses were conducted on reference material, freeze-dried mussel tissue (*Mytilus edulis*) No 2974 provided by EIMP-IAEA. The laboratory results showed recovery efficiencies ranging from 96% to 106% for PCBs with coefficient of variation of 12–18%. All solvents were pesticide grade purchased from Merck and appropriate blanks (1,000 fold concentrates) were analyzed. The limit of detection in the present study was estimated to be 0.2 ng/g for PCB and 0.3 ng/g for pesticides based on the minimum quantity of sample required for a discernible peak appeared on the chromatogram.

Results and Discussion

Tables (1–4) and Fig. 2 indicates that, the concentrations of chlorinated hydrocarbons decreased in the order of PCBs > DDTs > TC (aldrin, endrin and dieldrin) > HCHs for all water samples collected from Lake Burullus during 2006. Higher concentrations were recorded during summer season, which was clearly affected by higher agricultural and sewage activities with highest pesticide application (especially lindane and DDTs are still in use). The concentrations of DDTs in water ranged from 0.07 to 221.9 ng L^{-1}; 46.3–656.5 ng L^{-1}; 94.3–882.6 ng L^{-1} and 24.8–233 ng L^{-1} during winter, spring, summer and autumn, respectively. Among the DDTs metabolites p,p-DDE was the most dominant with a maximum of 520.13 ng L^{-1} recorded at station 10 (El Boughaz opening; outlet of the Lake to the open Mediterranean Sea). DDT (2,2-bis (p-chlorophenyl)-1,1,1-trichloroethane) is generally used against a wide variety of

Table 1 Concentrations of chlorinated hydrocarbons in water samples collected from Lake Burullus during winter 2006

Name	Concentration ng L^{-1}									
	1	2	3	4	5	6	7	8	9	10
α-HCH	0.052	0.805	n.d	0.452	0.009	0.209	0.181	0.443	0.098	0.293
B-HCH	0.095	4.448	268.498	0.878	0.018	0.575	1.052	19.616	0.386	0.464
Lindane	0.925	23.154	8.569	3.188	0.010	0.080	5.093	58.698	0.682	0.801
HCHs	1.072	28.408	277.067	4.519	0.037	0.864	6.326	78.756	1.166	1.558
Aldrin	0.262	8.438	1.961	1.189	0.002	2.409	1.694	37.891	0.358	1.164
Dieldrin	1.671	3.105	5.005	4.956	0.001	2.362	19.849	255.320	0.699	1.037
Endrin	0.814	50.995	14.710	1.686	0.067	1.409	5.884	87.583	0.766	0.364
TC	2.748	62.537	21.675	7.830	0.068	6.180	27.427	380.794	1.823	2.565
o,p-DDE	0.325	5.377	2.567	5.831	0.027	0.460	6.452	13.748	0.153	0.931
p,p-DDE	0.233	77.656	19.326	1.396	0.002	0.914	2.228	32.816	0.800	0.295
o,p-DDD	0.090	15.119	3.800	0.888	0.012	0.983	3.570	59.494	0.357	0.149
p,p-DDD	0.111	12.574	5.480	0.704	0.012	0.903	4.589	96.051	0.453	0.247
o,p-DDT	0.951	50.934	3.190	0.252	0.001	0.645	3.285	14.920	0.464	0.299
p,p-DDT	0.079	2.412	1.277	0.120	0.012	1.287	3.285	4.829	0.349	0.151
DDTs	1.789	164.072	35.641	9.192	0.066	5.192	23.409	221.859	2.576	2.072
PCB 28	2.317	49.782	10.213	11.330	0.542	23.277	33.911	663.870	0.286	1.290
PCB 52	0.817	15.794	21.360	3.216	0.002	2.962	4.532	62.288	1.134	1.930
PCB 101	0.796	2.177	5.824	1.118	0.022	0.561	6.149	10.154	0.280	0.471
PCB 118	0.451	7.163	4.185	1.930	0.012	1.108	1.969	78.080	0.565	0.365
PCB 138	13.723	62.662	83.958	12.494	0.303	15.549	65.055	696.600	1.685	2.180
PCB 153	1.382	23.559	3.554	0.279	0.097	0.940	11.939	141.300	0.199	0.482
PCB 180	2.608	22.809	5.721	6.789	0.051	0.751	8.391	28.280	0.218	0.587
TP	5.609	255.017	334.383	21.541	0.172	12.236	57.162	681.410	5.564	6.196
Total PCBs	22.095	183.946	134.814	37.155	1.029	45.148	131.947	1680.572	4.368	7.303

HCHs, Sum (α-HCH, B-HCH and lindane); TC, Sum (Aldrin, Dieldrin and Endrin); DDTs, Sum DDTs and their isomers; TP, Sum (HCHS + TC + DDTs); PCBs, Sum (PCB28-PCB180)

agricultural and forest pests and against inset pests including vectors such as mosquito and tse-tse fly. The technical product of p,p-DDT contains usually up to 30% of its isomer; o,p-DDT (UNEP 1990). Our results indicated that o,p-DDT was higher than p,p-DDT in almost all water samples of Lake Burullus. This may be because of the GC technique failing in some cases to differentiate among DDT isomers and DDE isomers and/or because of unknown environmental changes resulting in such unreasonable phenomena. In the environment, DDT can be degraded by solar radiation or metabolized in organisms. Dehydrochlorination of DDT gives the metabolite DDE under oxidative conditions. While the metabolic transformation of DDT under anaerobic conditions gives the metabolite p,p-DDD (UNEP 1990). This explains the presence of high concentrations of p,p-DDE compared to p,p-DDD recorded in all water samples of Lake Burullus compared to their original source of DDT.

Aldrin is an alicyclic chlorinated hydrocarbon and is therefore less resistant to oxidation than the aromatics. In the environment, it is being rapidly converted to the epoxide form (Dieldrin). The presence of an average concentration of 23.57 ng L^{-1} of Aldrin with an average of 27.9 ng L^{-1} of Dieldrin accounted for all water samples in Lake Burullus. This clearly reflects rapid conversion of Aldrin to its epoxide form (Dieldrin). HCH (hexachlorocyclohexane) is a fully chlorinated alicyclic compound. The most common isomers are α, β and γ-HCH. The γ isomer known as Lindane is the one normally used as an agricultural pesticide. HCH is a reasonably stable compound and only under alkaline condition decomposes to yield trichlorobenzene. It is considered as one of the less persistent organochlorine pesticide. A maximum concentration of 224.1 ng L^{-1} was recorded at station 9 (Mediterranean Sea water) during summer season. The discovery of DDT and other chlorinated hydrocarbons in parts of the world's oceans, shows that the mechanisms of global dispersion of some of these pollutants had to be by a more rapid mode than was possible by oceanic turbulence and current systems. The trans-Atlantic atmospheric transport of DDT by the northeastern trade wind system was first deduced from observations by Risebrough et al. (2000). The presence of chlorinated compounds in the Sargasso Sea atmosphere and surface

Table 2 Concentration of chlorinated hydrocarbons in water samples collected from Lake Burullus during spring 2006

Name	Concentration ng L^{-1}											
	1	2	3	4	5	6	7	8	9	10	11	12
α-HCH	n.d	16.96	n.d	10.83	19.21	1.42	6.98	5.91	49.68	3.83	35.08	n.r
B-HCH	24.78	16.67	n.d	22.42	19.78	4.55	5.70	n.d	n.d	1.98	20.62	n.r
Lindane	79.29	66.62	n.d	n.d	n.d	17.22	23.32	44.68	64.98	11.04	15.11	n.r
HCHs	104.07	100.24	n.d	33.25	38.98	23.19	35.99	50.59	114.65	16.85	70.81	n.r
Aldrin	12.44	60.31	10.90	11.55	7.20	5.07	5.74	8.08	18.76	1.13	20.24	42.60
Dieldrin	n.d	52.71	28.48	31.49	41.12	47.78	36.27	45.20	15.14	11.44	21.80	101.11
Endrin	38.02	6.74	4.81	16.28	18.42	7.19	16.90	n.d	124.74	2.35	20.11	39.54
TC	50.46	119.76	44.20	59.32	66.75	60.04	58.91	53.28	158.64	14.92	62.15	183.25
o,p-DDE	187.22	83.87	35.77	44.47	10.69	31.27	13.42	200.36	20.52	96.49	85.71	76.42
p,p-DDE	27.97	21.42	6.58	8.65	10.81	6.05	10.04	64.77	43.67	5.73	34.15	26.95
o,p-DDD	27.51	10.84	7.77	4.81	6.13	2.38	5.81	174.81	n.d	0.87	10.60	7.11
p,p-DDD	44.14	7.20	23.01	40.01	26.32	31.98	2.23	22.62	144.71	4.71	30.79	45.73
o,p-DDT	59.52	47.07	37.19	12.22	10.39	20.52	8.12	3.63	24.97	0.64	33.12	8.28
p,p-DDT	310.15	25.59	12.75	1.09	0.61	1.18	6.65	2.03	3.73	0.02	75.18	0.65
DDTs	656.51	195.99	123.07	111.25	64.96	93.38	46.28	468.22	237.59	108.46	269.55	165.14
TP	811.04	415.99	167.27	203.82	170.69	176.61	141.18	572.09	510.88	140.23	402.51	348.39
PCB 28	169.50	114.81	91.41	30.25	32.17	4.23	30.27	113.28	n.d	1.22	146.61	n.d
PCB 52	116.78	632.06	19.51	20.73	15.19	14.78	13.43	16.91	18.76	1.06	n.d	n.d
PCB 101	188.10	97.77	58.32	35.19	20.69	15.47	18.21	20.25	165.04	29.23	79.06	20.21
PCB 118	37.02	12.55	1.88	9.77	21.33	4.18	20.87	n.d	69.55	0.14	43.70	23.83
PCB 138	129.19	527.63	414.71	549.03	490.89	44.46	499.89	2471.3	941.09	230.11	n.d	16.11
PCB 153	76.97	46.62	30.20	9.72	10.71	28.39	8.61	8.00	33.26	0.27	n.d	7.82
PCB 180	109.01	11.94	7.03	12.17	6.02	9.70	11.22	686.11	45.30	3.03	45.64	17.17
Total PCBs	826.56	1443.4	623.05	666.86	597.01	121.20	602.50	3315.8	1273.0	265.05	315.01	85.13

n.d, below detection limit; n.r, not recorded

waters has been investigated more intensively (Bidleman and Olney 1974, 1975). Besides atmospheric deposition, organochlorine compounds reach the marine environment through agricultural run-off, rivers and discharge of industrial and municipal wastes. Comparison of atmospheric and river input rates of organochlorine compounds to the world's oceans was made recently (GESAMP 1993). They showed that pollution of the marine environment by these substances through the atmosphere is more important than river discharge. From another study, the potential effect of pesticide pollutants carried by the River Nile and its associated canals and drainage systems were investigated (EL Sabae and Abo EL Amayem 1979). Their results indicated the presence of some chlorinated pesticides in concentrations ranging from 340 to 950 ng L^{-1} in Mahmoudieh canal water and from 190 to 950 ng L^{-1} in slaughter wastewater. From the above discussion, we can conclude that in open seas atmospheric fallout (rainwater) is the major source of pollution by organochlrine compounds. However, in our investigated area, Lake Burullus, which is considered as semi enclosed water body, is affected mainly by municipal and/or agricultural wastes coming predominantly from Kafr El Sheikh Governorate.

PCBs form a class of 209 chemical compounds consisting of a biphenyl nucleus with one to ten chlorine atoms (UNEP 1990). They have been used as transformers oils, dielectric fluids and flame-retardants. Due to their chemical stability and their lipophilic character, PCBs persist in the environment and accumulate in organisms, especially in top predators of the food chain. PCBs are included in the black list of EC directive 76/464/EEC (ISO Guide 35 1989). Although their use is presently severely restricted, the large quantities still being discharged and their low mobility and persistence leave PCBs as a serious environmental problem in the coming years. PCBs 28, 52, 101, 118, 138, 153 and 180 were selected for analysis in the present study because they are frequently show a high occurrence in environmental and waste samples. The average concentrations of PCBs were 224.8, 844.6, 791.1 and 354.12 ng L^{-1} during winter, spring, summer and autumn, respectively in Lake Burullus (Tables 1–4). The maximum concentration of PCBs was recorded at station 8

Table 3 Concentrations of chlorinated hydrocarbons in water samples collected from Lake Burullus during summer 2006

Name	Concentration ng L^{-1}											
	1	2	3	4	5	6	7	8	9	10	11	12
α-HCH	25.69	71.02	61.71	27.02	46.14	48.88	17.77	59.58	137.31	152.42	5.57	42.34
B-HCH	48.20	41.94	84.67	33.42	121.94	50.50	5.95	122.89	127.20	192.81	7.95	23.52
Lindane	48.08	40.54	82.18	17.44	161.62	75.62	4.83	74.58	224.06	150.31	12.32	53.66
HCHs	121.97	153.50	228.56	77.88	329.70	175.00	28.55	257.05	488.58	495.55	25.84	119.52
Aldrin	15.72	48.02	29.96	82.04	87.28	71.14	1.61	39.73	108.42	99.79	16.80	66.18
Dieldrin	3.64	24.90	18.51	9.92	34.44	35.32	0.12	11.75	95.65	61.64	16.83	39.56
Endrin	13.28	12.20	29.09	9.68	55.27	34.18	3.81	17.82	108.70	84.86	13.45	62.76
TC	32.64	85.12	77.56	101.64	176.99	140.64	5.54	69.30	312.77	246.30	47.09	168.50
o,p-DDE	64.84	38.90	103.24	22.34	130.37	56.22	1.48	71.85	146.18	105.13	14.80	39.94
p,p-DDE	383.50	168.76	241.70	148.58	473.09	237.66	81.65	352.79	11.42	520.13	57.96	261.94
o,p-DDD	1.43	20.40	64.85	17.76	0.00	47.96	1.99	3.75	515.49	56.17	13.66	26.42
p,p-DDD	4.29	6.28	31.78	13.46	22.76	16.76	2.51	15.53	56.77	77.52	8.68	46.68
o,p-DDT	16.53	2.92	30.30	1.60	128.24	60.60	2.41	12.45	45.98	73.17	13.47	22.74
p,p-DDT	1.76	4.92	17.30	0.66	102.68	64.72	4.24	3.51	72.03	50.49	12.92	50.68
DDTs	472.35	242.18	489.16	204.40	857.14	483.92	94.28	459.88	847.87	882.61	121.48	448.40
TP	626.97	480.80	795.28	383.92	1363.8	799.56	128.36	786.23	1649.2	1624.5	194.41	736.42
PCB 28	74.76	81.40	74.23	36.44	183.96	133.10	14.87	75.59	265.47	140.66	27.11	114.20
PCB 52	29.81	61.58	70.62	31.76	88.42	62.70	1.81	45.76	158.08	104.79	13.62	44.72
PCB 101	65.02	231.26	160.38	113.94	237.05	114.94	71.67	121.70	665.57	223.86	91.12	231.42
PCB 118	9.69	34.64	75.54	30.32	205.41	138.10	11.77	47.78	188.54	213.59	29.28	125.64
PCB 138	19.26	10.30	232.90	16.06	33.55	248.48	8.22	32.96	418.85	255.14	57.59	159.52
PCB 153	2.82	10.12	62.22	2.96	96.96	54.74	3.21	7.30	72.90	148.14	18.79	24.04
PCB 180	18.27	127.88	55.66	668.00	78.88	43.46	41.47	21.34	166.46	616.90	252.09	31.94
Total PCBs	219.63	557.18	731.56	899.48	924.23	795.52	153.01	352.44	1935.9	1703.1	489.6	731.48

with annual average concentration of 1756.7 ng L^{-1}. This station is located nearer to Brembal canal and attached to Rasheed branch of the River Nile. It is famous for fish farming activity. The PCB congeners recorded in Lake Burullus during 2006, in decreasing order, were PCB 138 (31%) > PCB180 (23%) > PCB28 (16%) > PCB101 (12%) > PCB52 (7%) > PCB 118 (5%) > PCB 153 (4%). The maximum concentration value of 2471.3 ng L^{-1} of PCB138 was recorded at station 8 during spring 2006 (Table 2).

Table 5 presents the monthly inflows of drainage discharges to Lake Burullus (10^6 m^3) during 2006. The maximum content of drainage water was 423.7 × 10^6 m^3 recorded during July 2006 (summer season), however the lowest content of 241.2 × 10^6 m^3 was recorded during February 2006 (winter season). The annual average was ranged from 5.49 to 65 × 10^6 m^3 with a maximum of 20% and 18.5% recorded at Drains 9 and 11, respectively. Thus, the total annual average of drainage water is 32.5 × 10^6 m^3 (i.e. 32.5 × 10^9 L $year^{-1}$) from all drainage sources of Lake Burullus. From Tables 1–4, the average annual concentrations of TP and PCBs were 378.3 and 553.6 ng L^{-1}, respectively. Therefore, the total annual inputs of TP and PCBs from all sources of drainage waters of the Lake were 12.29 and 17.99 kg $year^{-1}$, respectively during 2006. These annual inputs may affect the Mediterranean Sea by exchanging the water through El-Boughaz opening.

PCBs concentrations in sediments ranged from 4.6 to 213.9 ng g^{-1} with an average 47.2 ng g^{-1}; dry weight (Table 6). In addition, PCBs concentrations were highest at stations 3 and 4 with 213.89 and 143.67 ng g^{-1}, respectively. Figure 3 declared that TP > PCBs for all sediment samples of Lake Burullus. The maximum concentration of both TP and PCBs was recorded at station 3 with 112 and 214 ng g^{-1}, respectively. This station was affected by Drain 8, which discharge about 426 × 10^6 m^3wage and agricultural wastes to the Lake annually.

The concentrations of organochlorines in fish species (*Oresochromus niloticus* and *Clarries* sp.) were decreased in the following order: PCBs > DDTs > TC > HCHs (Fig.4). The concentrations of total HCHs ranged from 0.42 to 4.2 ng g^{-1} and from 2.82 to 16.68 ng g^{-1} for *Oresochromus niloticus* and *Clarries* sp., respectively. The concentrations of TC were ranged from 0.86 to 11.3 ng g^{-1}

Table 4 Concentrations of chlorinated hydrocarbons in water samples collected from Lake Burullus during autumn 2006

Name	Concentration ng L^{-1}											
	1	2	3	4	5	6	7	8	9	10	11	12
α-HCH	2.33	0.13	52.33	55.24	2.12	4.37	16.94	7.07	68.26	118.71	38.04	22.80
B-HCH	3.46	0.50	105.03	12.44	3.18	2.77	7.61	3.84	29.30	179.60	48.98	22.73
Lindane	4.49	0.46	n.d	18.94	2.41	4.22	14.34	3.73	25.59	0.00	41.41	23.80
HCHs	10.27	1.09	157.36	86.62	7.70	11.36	38.89	14.63	123.14	298.31	128.43	69.33
Aldrin	1.82	0.47	18.78	12.71	1.06	3.21	11.43	5.93	42.10	48.39	35.59	12.57
Dieldrin	2.46	n.d	74.22	12.88	0.43	1.88	9.01	3.78	13.79	54.43	26.82	6.01
Endrin	11.56	1.42	33.98	33.39	0.96	5.36	40.43	12.93	34.90	45.91	68.90	8.05
TC	15.83	1.89	126.97	58.99	2.45	10.44	60.87	22.64	90.79	148.73	131.32	26.62
o,p-DDE	5.78	0.50	16.88	19.68	1.15	3.18	18.22	5.04	23.38	19.90	41.36	20.07
p,p-DDE	34.87	0.14	100.79	68.12	10.25	21.44	115.36	0.44	31.26	43.64	63.79	9.68
o,p-DDD	n.d	20.95	20.95	20.95	4.24	1.16	0.00	45.80	15.64	45.32	22.65	5.02
p,p-DDD	2.12	0.30	9.75	11.00	1.34	0.68	13.21	2.42	10.40	12.97	43.62	5.31
o,p-DDT	4.82	0.27	7.61	7.86	2.64	1.60	21.48	7.67	12.57	17.82	27.47	4.18
p,p-DDT	3.83	0.28	18.01	12.15	5.12	1.44	11.47	5.55	18.61	18.93	34.12	4.35
DDTs	51.42	22.45	173.99	139.77	24.75	29.50	179.73	66.92	111.86	158.58	233.00	48.61
TP	77.53	25.44	458.32	285.37	34.90	51.30	279.49	104.18	325.79	605.62	492.75	144.56
PCB 28	8.01	1.28	42.39	28.72	2.61	6.93	29.04	19.36	44.22	41.64	70.07	31.35
PCB 52	5.86	0.54	22.83	38.97	1.73	3.21	25.07	9.10	28.66	36.10	61.08	14.83
PCB 101	18.19	2.46	74.22	47.91	4.80	10.28	71.98	24.20	87.56	104.82	138.74	32.38
PCB 118	3.90	0.42	13.85	17.02	0.50	1.71	18.56	6.65	16.08	15.35	17.29	15.10
PCB 138	9.39	0.66	20.66	48.96	3.60	3.85	68.56	20.48	39.46	42.07	55.63	5.96
PCB 153	4.46	0.29	35.97	12.57	1.42	0.95	12.61	6.71	22.96	17.32	36.70	3.60
PCB 180	4.81	2.47	43.66	580.29	0.70	0.84	35.27	7.96	883.18	736.50	155.94	5.35
Total PCBs	54.61	8.10	253.58	774.44	15.36	27.76	261.10	94.47	1122.12	993.80	535.47	108.57

n.d, below detection limit

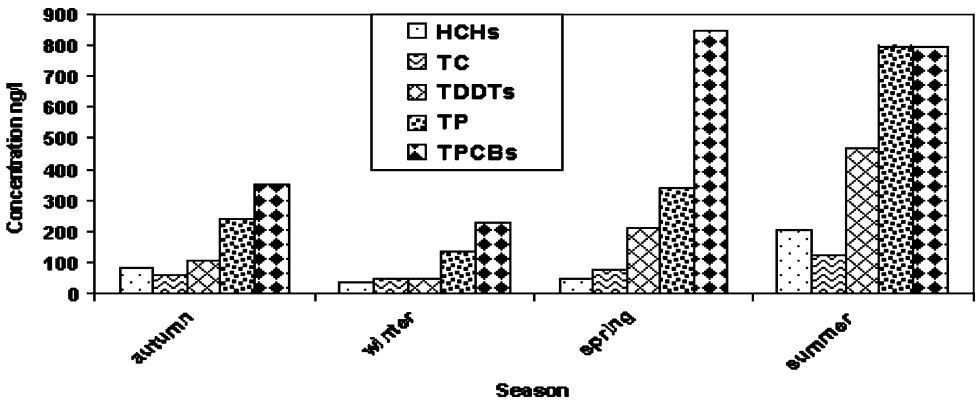

Fig. 2 Seasonal distribution of average concentrations (ng L^{-1}) of chlorinated hydrocarbons in surface water collected from Lake Burullus during 2006

and from 6.38 to 18.34 ng g^{-1}; wet weight for *Oresochromus niloticus* and *Clarries* sp., respectively. The higher contamination in *Clarries* sp. as compared to *Oresochromus niloticus* was due to difference in life history and feeding of the two fish. Although the use of HCHs in agriculture has been greater than cyclodienes and DDTs, the relatively low concentrations of HCHs in fish tissues reflect lower potential for bioaccumulation. Furthermore, higher vapour pressures for HCHs than DDTs facilitate relatively rapid atmospheric dissipation in the tropics, leaving fewer residues in sediment (Kannan et al. 1995). This was lower HCHs concentrations in comparison to DDTs concentrations recorded in Tables 6 and 7. Concentrations of DDTs in fish tissues were ranged from 2.76 to 24.23 ng g^{-1} and from 14.16 to 45.13 ng g^{-1}; wet weight for *Oresochromus niloticus* and *Clarries* sp., respectively. These values were

Table 5 Monthly inflows of drainage discharges to Lake Burullus (million m^3) during 2006

Month	Tera	Burullus (east)	Drain 7	Drain 8	Drain 9	Drain 11	Burullus (west)	Gharbia drain	Brembal canal
Jan	32.9	4.9	27.8	29.8	65	45.1	7.4	32.2	13.7
Feb	36.8	4.6	31.8	28.6	65	39.9	7.4	21.4	5.7
March	40.1	5.7	32.2	29.6	65	56.7	10.5	36.4	16.8
April	41.8	4.9	39.1	28.6	65	51.2	9	33.1	14.4
May	55.6	5	36.6	32.7	65	65.5	12.7	31.5	16.4
June	60.6	4.4	44.5	37.3	65	78.2	16.6	48.5	15.5
July	72.6	5.9	51.3	48.5	65	85	18.2	60.2	17
Aug	72.3	6.3	52	49.6	65	77.6	17.4	52.4	18
Sep	64.1	6.8	48.2	41.9	65	71.9	14.1	60	23.3
Oct	46.7	5.8	39.5	33.1	65	56.7	9.8	44	19.1
Nov	42.9	5.6	36.6	33.2	65	53.8	9.9	32.4	20.3
Dec	43.1	6	36.5	33	65	41.5	6.8	33.6	18.8
Annual	609	65.9	476.1	425.9	780	723.1	139.8	485.7	199
Av	50.8	5.49	39.68	35.49	65.00	60.26	11.65	40.48	16.58
%	15.6	1.69	12.19	10.91	20.0	18.52	3.58	12.44	5.10

Table 6 Concentrations of chlorinated hydrocarbons in sediment samples collected from Lake Burullus during 2006

Name	Concentrations ng g^{-1}											
	1	2	3	4	5	6	7	8	9	10	11	12
α-HCH	3.08	25.29	4.22	28.40	0.78	5.59	0.24	6.25	0.29	0.65	0.58	3.71
B-HCH	7.40	109.70	n.d	85.53	20.87	21.08	2.10	11.35	0.35	0.48	0.39	4.44
Lindane	3.06	n.d	22.84	n.d	n.d	n.d	1.10	2.43	0.55	0.99	0.68	1.43
HCHs	13.55	134.99	27.07	113.94	21.65	26.68	3.44	20.03	1.19	2.12	1.65	9.58
Aldrin	2.73	3.09	30.59	14.28	1.07	2.05	0.72	2.46	0.65	1.61	2.29	1.06
Dieldrin	n.d	n.d	39.99	9.61	n.d	n.d	0.29	n.d	0.30	0.96	0.43	n.d
Endrin	2.98	2.25	0.71	3.06	1.14	1.53	0.53	1.67	0.62	1.39	1.30	1.40
TC	5.71	5.34	71.29	26.95	2.21	3.58	1.55	4.12	1.57	3.96	4.02	2.46
o,p-DDE	1.76	3.65	11.79	4.93	1.10	1.70	0.31	1.59	0.34	0.77	0.68	0.66
p,p-DDE	2.44	2.42	0.19	3.08	1.61	1.08	0.30	0.97	0.60	1.28	1.08	0.83
o,p-DDD	1.43	2.18	0.59	2.89	1.59	0.80	0.40	1.95	0.31	1.11	0.96	0.45
p,p-DDD	2.04	1.63	0.21	2.27	0.67	0.75	0.29	1.14	0.70	0.64	1.01	0.76
o,p-DDT	1.26	1.57	0.27	1.86	0.37	0.94	0.29	0.87	0.23	1.34	0.44	0.68
p,p-DDT	2.04	2.69	0.32	2.35	n.d	0.92	0.35	0.94	0.67	1.24	0.80	0.49
DDTs	10.99	14.14	13.37	17.39	5.34	6.19	1.95	7.45	2.86	6.38	4.98	3.88
TP	30.24	154.47	111.72	158.27	29.20	36.44	6.93	31.61	5.62	12.45	10.65	15.92
PCB 28	3.84	5.22	178.83	12.05	4.31	2.94	0.77	4.42	0.75	1.62	1.21	2.30
PCB 52	1.42	2.07	2.30	2.59	1.18	1.48	0.18	2.12	0.33	0.64	0.39	0.74
PCB 101	5.01	36.44	31.01	25.07	10.12	8.87	1.90	7.59	1.11	1.94	2.32	2.93
PCB 118	1.20	5.82	0.50	3.00	2.58	1.55	0.21	1.59	0.47	0.62	0.41	1.82
PCB 138	6.68	4.84	0.73	6.10	1.90	3.44	0.95	2.52	1.78	2.49	1.99	2.52
PCB 153	2.27	6.36	0.29	2.22	17.50	0.89	0.13	1.29	0.33	1.42	0.51	0.98
PCB 180	1.34	1.53	0.24	92.63	5.83	1.23	0.45	1.80	0.52	1.00	0.97	1.03
Total PCBs	21.75	62.28	213.89	143.67	43.41	20.40	4.60	21.32	5.29	9.72	7.80	12.31

n.d, below detection limit

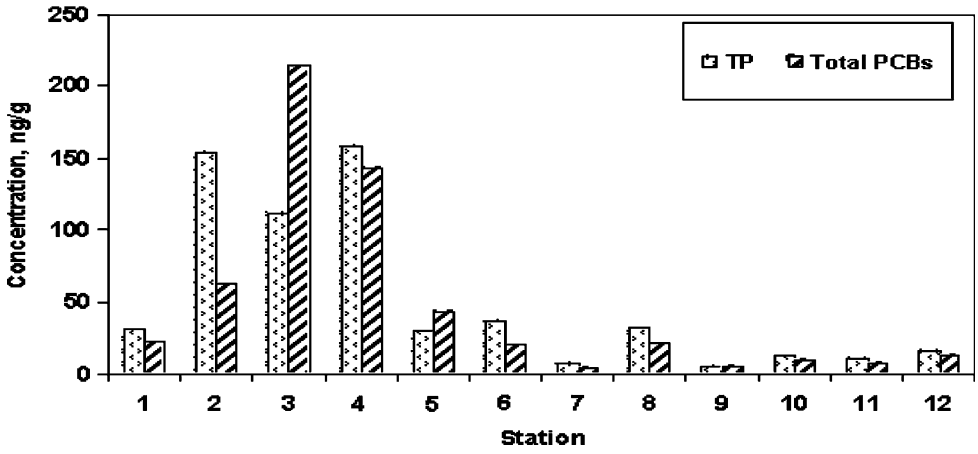

Fig. 3 Distribution of TP and PCBs in sediment samples collected from Lake Burullus during 2006

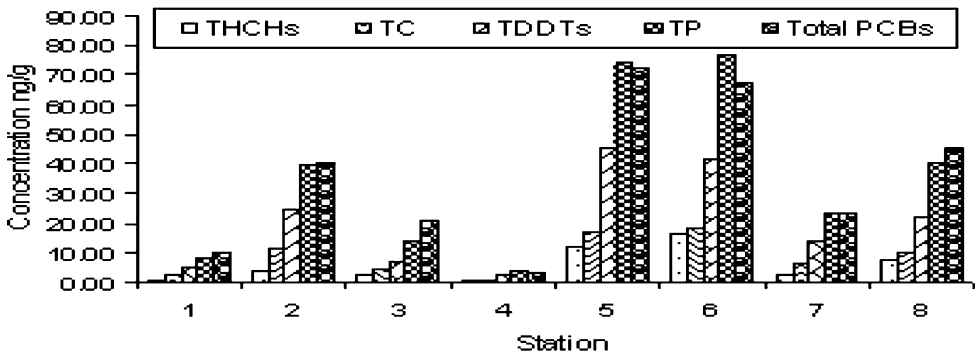

Fig. 4 Distribution of the residual concentrations of chlorinated hydrocarbons in fish samples collected from Lake Burullus during 2006: *Oresochromus niloticus* collected from sites 1–4 and *Clarries* sp. collected from sites 5–8. Sites from 1–8 are represented in Table 6

much lower than that recorded in fish samples collected from the Suez Canal with total DDTs ranged from 161 to 3,100 ng g^{-1}; wet weight (Said and Hamed 2005), and also lower levels that recorded in mussels of the Egyptian Red Sea coasts, which ranged between 125 and 722 ng g^{-1}; wet weight of Total DDTs (Khaled et al. 2004). The metabolic transformation of DDT under oxidative conditions which lead to p,p-DDE was detected clearly for sediment samples (Table 5). The same was true for p,p-DDE detected in fish tissues (Table 7).

The persistent half-life ($T_{0.5}$ = 5 years) of DDT in marine systems (GESAMP 1993) and recent work on the dechlorination of DDE in anaerobic sediments $T_{0.5}$ = 6 years are similar (Quensen et al. 1998). Assuming that after 1974 there have been no further releases of DDT, these half-life values would allow for an estimated reduction of DDT in the coastal environment. Nevertheless, despite the ban of DDT there are still continuous inputs into the coastal environment, mainly by atmospheric deposition of DDT (Villeneuve and Cattini 1986) and DDT leaching from agricultural soils followed by discharges into estuarine areas (Claisse 1989). These inputs would help maintain DDT presence in the coastal environment, as the concentrations of total DDTs were the major component of TP (Tables 1–7). Other chlorinated pesticides results indicate either a more rapid disappearance from the coastal environment than DDT (ILMR 1975) or a lower use there in comparison with DDT. The acceptable daily intake for PCBs is 10–30 µg/person/day, for DDT is 1.4 pg/person/day (FAO/WHO 1985) and for HCHs is 1.8 mg/person/day (EPA 1988).

The PCB congeners and pesticides can cause toxic symptoms similar to those caused by dioxin exposure, including developmental abnormalities and growth suppression, disruption of the endocrine system, impairment of immune function and cancer promotion. The maximum permissible levels of toxic DDTs, PCBs and cyclodienes recommended by the National Academy of Sciences and National Academy of Engineering (NAS-NAE 1972), for the protection of aquatic biota are 1,000–5,000 ng g^{-1} for PCBs and 100 ng g^{-1} for cyclodienes (all as weight concentrations in muscle tissue). In Sweden, the recommendations are 5,000 ng g^{-1} for DDTs, 2,000 ng g^{-1} for PCBs and 20 ng g^{-1} for HCH (SFR 1983). In comparing our data with that of tolerable levels, we can conclude that PCBs, DDTs and TC were lower than the permissible levels for both of sediment and biota samples of Lake Burullus. However, for HCHs stations 2, 3, 4, 5, 6 and 8 exceeded 20 ng g^{-1} in their sediments. Data from the current study indicates that the average concentration of both of pesticides and PCBs recorded in different fish species of the study area were lower than acceptable levels for the protection of human health and aquatic life. This study provides a preliminary assessment

Table 7 Concentrations (ng g^{-1}) of chlorinated hydrocarbons in fish samples collected from Lake Burullus during 2006

Name	*Oresochromus niloticus*				*Clarries* sp.			
	(1) Mastro Northern part	(2) El Berka Eastern part	(3) Brembal Western part	(4) Shkaloba Southern part	(5) Mastro Northern part	(6) El Berka Eastern part	(7) Brembal Western part	(8) Shkaloba Southern part
α-HCH	0.26	1.08	0.65	0.06	2.94	5.84	0.77	2.58
B-HCH	0.06	1.02	0.79	0.48	0.62	4.05	0.44	1.36
Lindane	0.10	2.10	0.90	0.03	8.59	6.78	1.61	3.75
HCHs	0.42	4.20	2.35	0.57	12.14	16.68	2.82	7.70
Aldrin	0.30	3.85	1.37	0.13	4.86	5.64	1.28	2.42
Dieldrin	1.24	3.07	1.53	0.01	2.37	3.85	2.06	2.27
Endrin	0.80	4.38	1.80	0.72	9.85	8.86	3.04	5.62
TC	2.35	11.30	4.70	0.86	17.09	18.34	6.38	10.31
o,p-DDE	0.55	2.09	0.77	0.12	6.22	7.02	0.98	3.05
p,p-DDE	1.12	3.13	0.81	1.11	7.02	3.27	2.37	3.75
o,p-DDD	1.57	7.09	1.07	0.24	6.66	10.64	2.13	5.62
p,p-DDD	0.47	2.35	1.65	0.33	5.76	8.66	1.58	n.d
o,p-DDT	0.54	3.39	1.37	0.11	10.01	4.01	2.38	4.26
p,p-DDT	1.07	6.19	1.44	0.85	9.46	7.95	4.73	5.32
DDTs	5.31	24.23	7.10	2.76	45.13	41.55	14.16	22.00
TP	8.08	39.73	14.16	4.18	74.36	76.56	23.36	40.00
PCB 28	0.31	4.79	2.15	0.18	9.53	14.08	1.98	7.90
PCB 52	0.21	1.27	1.21	0.10	2.69	3.56	1.36	2.11
PCB 101	1.20	7.93	4.81	0.27	13.19	9.55	5.81	n.d
PCB 118	0.96	4.08	3.31	0.50	8.87	5.75	2.01	5.17
PCB 138	1.35	10.92	3.94	2.02	23.20	12.39	5.66	11.95
PCB 153	4.04	4.55	0.84	0.01	7.73	5.64	2.95	5.27
PCB 180	2.05	6.51	4.74	0.23	6.85	16.24	3.42	12.45
Total PCBs	10.13	40.04	20.99	3.32	72.06	67.21	23.20	44.84

n.d, below detection limit

of the level of persistence organic pollutants, in a semi-closed area of the Egyptian Mediterranean coast; Lake Burullus, and serves as a baseline study for future comparisons. Repeating this study on a large scale in the near future may be useful as a quantitative integration of pollution by the most persistent organic pollutants and their possible sources.

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