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Distributions of organochlorine pesticides and polychlorinated biphenyl in surface water from Bizerte Lagoon, Tunisia

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ABSTRACT

The contamination of the marine environment by organic pollutants is a matter of great concern. Bizerte Lagoon is the second largest lagoon in Tunisia, and is known for different industry and fishing activities. The objective of this work is to investigate the distribution of seven polychlorinated biphenyls (PCBs) and nine organochlorine (OCPs) pesticides in water samples collected from the Lagoon of Bizerte. Extraction of water samples was performed by liquid–liquid extraction with hexane. Gas chromatography with ^{63}Ni electron capture detector was used to perform qualitative and quantitative determinations. The average concentrations of OCPs were 0.42 and 14.92 ng L^{-1}. For PCBs the concntrations range between 3 and 10.4 ng L^{-1}. The predominant PCB congeners in the surface water were PCB 28 (0.2–1.4 ng L^{-1}) and PCB 52 (0.8–3.5 ng L^{-1}). The most widespread OCPs were DDTs with a concentration varied between ND and 8.51 ng L^{-1}, heptachlor (ND and 7.83 ng L^{-1}), and endrin (ND and 1.51 ng L^{-1}). These concentrations are generally similar to the background levels from the Mediterranean Sea.

Keywords: Pesticides; Surface seawater; Bizerte lagoon; Marine environment

1. Introduction

The widespread contamination of the marine environment by micropolluants has become a public concern, since it may have a harmful effect on aquatic life and on human health [1]. The pollution of surface water by pesticide can be the results mostly from water run-off, agricultural storm water discharges, and return flows from irrigated agriculture. As the run-off moves, it picks up and carries away pesticides,

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finally depositing them into surface water lagoons, rivers, coastal waters, and ground waters [2].

For this reason, the European Directive 98/83/EC regulated the standard limits of pesticides in water reserved for human consumption. The maximum allowed concentration of each pesticide in water was set at 0.1 $ng\,mL^{-1}$ for individual pesticides and at 0.5 $ng\,mL^{-1}$ for the total amount of pesticides. The maximum individual concentration for aldrin, dieldrin, and heptachlor must not exceed 0.03 $ng\,mL^{-1}$ [3].

The Bizerte Lagoon is the second largest lagoon in Tunisia. This lagoon is known a fishery and aquaculture park related to the presence of three mytiliculture sectors. The human population around the lagoon is estimated at 163,000 inhabitants (2004 census) with an important percentage in the city of Bizerte. The other main important towns in the region are Menzel Bourguiba, Menzel Abderrahman, and Menzel Jemil. This lagoon is one of the most economically important areas in Tunisia. It is subject to intensive anthropogenic influence like oil refineries, ceramic industries, metallurgy, naval construction and tire production [4]. Organochlorine pesticides (OCPs) are one of the most important persistent organic pollutants (POPs) and it is well known by its chronic toxicity, persistence, and bioaccumulation [5]. The OCPs were used extensively in Tunisia between 1940s and 1980s for several applications including insect control, sanitary purposes, agricultural, and building protection [6]. The polychlorinated biphenyls (PCBs) were produced in the world from 1930 to 1983 and because of their general chemical inertness insulating capacity, heat stability, and low burning capacity they were extensively used as dielectric fluids in transformers and capacitors, as plasticizers in paint and rubber sealants [7,8]. The PCBs have been extensively used in Tunisia since the 1970s broad range of application electrical transformers, industries, hospitals, and public or private buildings, as well as for the national electricity company [6]. Tunisia became a party to the Stockholm Convention in 17 June 2004. The chemicals restricted by the Stockholm Convention are the pesticides aldrin, chlordane, dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), mirex, and toxaphene, as well as the industrial chemical PCBs [6]. However, the use of PCB and OCPs has been prohibited in Tunisia since 1980s, thus many investigations confirm the presence of pesticides in human milk [9,10], sediment [11], and biota [12] in the region of Bizerte. Previous studies also investigate the levels of inorganic mercury, methylmercury [13] organotin [14], and polycyclic aromatic hydrocarbons [15] in surface sediments and mussel tissues from Bizerte Lagoon.

The main objectives of this study is to report the first data for OCPs and PCBs concentrations in surface water collected from 14 stations in the Bizerte Lagoon and to discuss the spatial distribution and possible sources of PCBs, and OCPs in this region.

2. Materials and methods

2.1. Study area

The Bizerte Lagoon is located in the northern most part of Tunisia, between latitude 37˚08´N and 37˚14 in the north and longitude 9˚48´E and 9˚56 in the east. The surface area is 128 km^2 and the sea depth is between 3 and 12 m. The lagoon is connected to the Mediterranean Sea and to the Lake Ichkeul by straight channels. The exchanges of water between the Mediterranean and the lake determine the salinity of the lagoon, which varies between 32.5 and 38.5. The water temperature is between 10˚C during winter and 29˚C during summer. There are four main zones of anthropogenic influence (Fig. 1): Zone A: oil refineries, food and ceramic industries. Zone B: Factories of cement productions, treatment of metals (copper craft, asbestos) and sprinkling beverages. Zone C: ceramics and metallurgy activities. Zone D: metallurgy activities (Fe, Zn, Cd, Sn, and Hg), naval constructions and tire productions. The selection of the sampling sites was based on different criteria related to the geomorphology of the lagoon, the hydrological regime, and the localization of the urban and industrial discharges. Stations S1, S2, S3, S4, S5, and S6 are located along the channel connecting the lagoon to the Mediterranean Sea. This channel includes zone A and B which are highly populated and characterized by industrial activities including cement and metal treatments manufacturing. Sampling stations S7, S8, S11, and S12 were near the mouth of Tinja, Ben Hassine, Rharek, and Guenniche rivers, respectively, which are used as dumping sites for waste outdoors and agricultural inputs. In addition, the Eastern side of the Bizerte Lagoon is known by its agricultural activities and by the use of fertilizers containing pesticides and insecticides. S10 is located in the Zone D known by its intensive metallurgy and naval construction activities. S13 is near ceramics and metallurgy activities and S14 is located near the urban area of Menzel Abderrahman city and receives direct inputs of untreated urban sewage.

2.2. Sampling and storage

Surface water was collected during a sampling campaign in July 2013 with the aid of a global positioning system (Table 1). Surface water samples were taken from 14 stations (Fig. 1). Two liters of surface

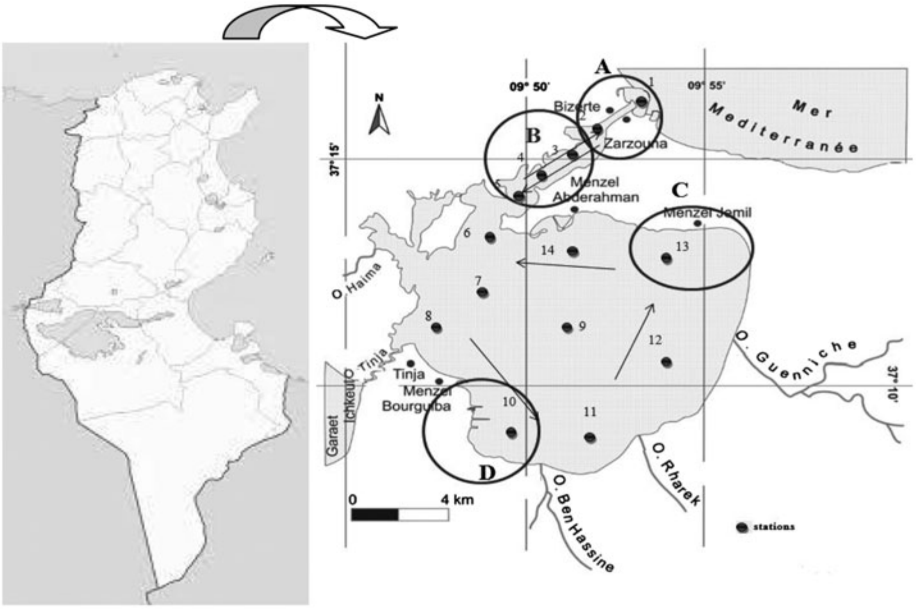

Fig. 1. Study areas with sampling locations and different types of industrial areas (A, B, C, and D) in the Bizerte Lagoon.

Table 1
Description of samples collected from Bizerte Lagoon

Sites	Latitude (N)	Longitude (E)	Water depth (m)
S1	37°17°10	09°54°03	23
S2	37°16°33	09°53°00	9
S3	37°15°52	09°52°05	12
S4	37°15°17	09°51°24	11
S5	37°15°11	09°51°00	4
S6	37°13°37	09°48°56	11
S7	37°11°01	09°48°01	5
S8	37°11°41	09°49°01	7
S9	37°10°52	09°51°00	10
S10	37°09°06	09°49°37	6.5
S11	37°10°10	09°53°05	6
S12	37°11°10	09°54°00	5
S13	37°13°09	09°54°46	5
S14	37°13°04	09°52°00	5

water were collected from each sampling sites in precleaned 2 L amber glass bottles rinsed twice with water samples. Surface water samples were acidified immediately with 4 M to $pH < 1$ to depress microbial growth and stored in the dark at a temperature of 4°C until extraction in a sealed bottles.

2.3. Reagents and standards

All chemicals, reagents were of analytical grade and the highest purity possible. Hexane and dichloromethane, used for the extraction of PCBs and OCPs, were obtained from SIGMA-ALDRICH (France), Florisil used in the cleaning was supplied by MERCK (Germany). Two external standards mixtures, the first containing (hexachlorobenzene, Lindane, pp´DDT, pp´DDE, pp´DDD) and the second standards mixture containing (Heptachlor, Aldrin, Dieldrin, Endrin) and a mixture of internal standards (PCB 29, PCB198, εHCH and Endosulfane Id4) were provided by the International Atomic Energy Agency (IAEA) for chromatography analysis.

2.4. Analytical procedures

Analysis of water samples was performed according to the technique proposed by UNEP/IAEA-EL/MELS [16]. Appropriate blanks were analyzed with set of analyses; internal standards were analyzed for quality control purposes. In more, quality control is assured by the annual participation of our laboratory to the pesticides intercomparison exercises elaborated by IAEA. Quantification was performed by calculation of response factors of individual OCPs and PCBs external standards. The reported results were corrected with recoveries of surrogate internal standards. Recoveries ranged from 72 to 93%.

Furthermore, average recoveries and relative standard deviations of PCBs and OCPs were first obtained to evaluate the method performance by multiple analyses of three replicates spiked water samples with 1 mL of internal standard solution. The standard deviation was below 1.8% for all pesticides which reveals a good repeatability of the method.

A method detection limits were calculated for each internal standards PCB 29, PCB 198, εHCH, and Endosulfane Id4 and were 0.018; 0.014; 0.006; and 0.017 ng L^{-1}, respectively.

2.4.1. Extraction

One liter of water sample and 1 mL of internal standards were introduced into two liters separating funnel and extracted three times with hexane. Extracts were concentrated with a rotavapor and then evaporated under a gentle flow of nitrogen gas.

2.4.2. Column chromatography

The final extracts were purified following a clean-up procedure on a glass column filled with florisil (pre-baked at 130°C for 8 h) with the bottom and plugged with cleaned glass wool. The extract was added on the top of column and eluted with hexane to obtain fraction F1 containing PCBs, HCB, heptachlor, pp´DDT, and Aldrin. This was then further eluted with a mixture of hexane and dichloromethane (70:10 v/v) to obtain fraction F2 containing lindane and DDTs followed by 100% dichloromethane to obtain fraction F3 containing dieldrin and endrin.

2.4.3. Gas chromatography

Analysis of OCPs and PCBs was performed by the GC–MS Varian 4000 equipped with a^{63}Ni electron capture detector, CP-8400 auto sampler, and CP-8410 autoinjector and a HP5 fused-silica capillary column (30 m × 0.32 mm × 0.25 μm). Helium was used as the carrier gas with a flow rate of 1 mL min^{-1}. The column temperature was initially held at 50°C ramped to 140°C at a rate of 20°C min^{-1} then ramped to 260°C at the rate of 3°C min^{-1}. The make-up gas used was nitrogen at a flow rate of 25 mL min^{-1}. The injector and detector were maintained at 280 and 300°C, respectively. Injection volumes were 1 μL in the splitless mode.

2.5. Statistical analysis

The statistical analysis was made by the well-known techniques of principal component analysis (PCA). All statistical analyses were performed using XLSTAT software package.

3. Results and discussion

3.1. Concentration of PCBs

Total PCBs (∑PCB) concentrations varied between 3 and 10.4 ng L^{-1} (Table 2). The highest ∑PCB was observed for station S14 and S9 with a concentration of 10.4 ng L^{-1} in the two stations and the lowest levels of ∑PCB were found at station S3 (3 ng L^{-1}) and S13 (2.4 ng L^{-1}). The concentration of PCB 101 in the surface water ranged from ND to 2.8 ng L^{-1}. PCB 28, PCB 180, and PCB 52 were the most predominant congeners, with concentrations varying from 0.2 to 1.4 ng L^{-1}, ND to 6.7 ng L^{-1}, and 0.1 to 3.5 ng L^{-1}, respectively. The highest concentration of PCB 153 was 3.3 ng L^{-1} obtained for S2. The levels of PCB 138 varied between 0.5 and 5.7 ng L^{-1}. Except station 12, PCB 209 is under detection limits in all sample sites. PCB 180 was detected in the majority stations except S1 an S13. The most detectable PCBs were PCB 180 obtained at station nine with a concentration of 6.7 ng L^{-1} representing 64.4% of total PCBs. As shown in Figs. 2(a) and 3(a), PCB 52 was the most abundant congeners detected in S1, S7, and S8 it accounted 80, 54, and 30%, respectively, of the ∑PCBs. The highest percentages of PCB 101 with respect of ∑PCBs were found in station 12 (37%). Stations 9 and 14 appear as the most contaminated with ∑PCBs concentrations around 10.4 ng L^{-1}. Due to the location of these two stations, the contamination can be explained by the anthropogenic sources (industrial areas C and D). Considering the water flow until the lagoon, it is interesting to notice the PCBs diffusion to station 10 and 11, where a concentration gradient appears. Generally, potential sources of PCBs in marine environment are due to the waste of electrical transformers, oil spillage, and any historical use of PCB [17]. Low PCBs concentrations found are probably due to their low solubility in water and high octanol–water partition coefficients, once arrived to the marine environment, PCBs can be associated with suspended particulate matter and ultimate by accumulated in bottom sediments [18]. The total PCBs reported in this study were higher than those found in the Lake of Thau (France) with concentration of ∑nPCBs ($n = 7$) ranged from 0.137 to 0.708 ng L^{-1} [19], and than those found in Venice Lagoon (Italy) with concentrations of ∑nPCBs ($n = 45$) ranged from 0.25 to 0.79 ng L^{-1} [20]. Results shows that total PCBs found in this study are lower than those in the Ebro river (Spain) with a ∑nPCBs ($n = 9$) ranged between 3.0 and 19.5 ng L^{-1} [21] but higher than those found in the Seine river (France) with a ∑nPCBs ($n = 7$) ranged between 0.4 and 3.6 ng L^{-1} [22].

Table 2
Limit of detections and concentrations of organochlorine pesticides and polychlorinated biphenyls (ng L^{-1}) in surface water collected from Bizerte Lagoon

Compounds	Limit of detection	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
HCB	0.018	0.19	0.59	2.18	0.34	0.13	0.34	0.24	0.10	1.27	0.48	0.08	0.12	0.12	0.63
Heptacolor	0.018	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.35	4.58	7.83	ND	ND
Lindane	0.006	0.02	ND	ND	0.04	0.05	ND	ND	ND	ND	ND	0.06	ND	0.02	0.03
Aldrin	0.016	0.3	0.54	ND	ND	ND	ND	ND	ND	0.76	0.60	0.29	ND	0.18	2.02
Dieldrin	0.017	ND	ND	ND	ND	0.06	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endrin	0.017	ND	ND	ND	0.17	0.18	0.25	0.21	0.35	0.22	1.51	ND	0.23	0.15	0.26
pp´DD	0.006	ND	ND	ND	ND	ND	2.26	2.39	ND	ND	1.23	ND	ND	ND	1.10
pp´DDE	0.006	ND	3.67	ND	ND	ND	6.25	ND	ND	ND	ND	ND	ND	ND	ND
pp´DDT	0.006	ND	ND	ND	ND	ND	ND	3.83	ND	ND	5.75	ND	2.01	ND	1.10
∑DDTs	–	ND	3.67	ND	ND	ND	8.51	6.22	ND	ND	6.98	ND	2.01	ND	2.20
∑OCPs	–	0.51	4.8	2.18	0.55	0.42	9.1	6.67	0.45	2.25	14.92	5.01	10.19	0.47	5.14
PCB 28	0.018	0.9	1.4	0.6	1.2	0.2	0.4	0.8	1.2	1.1	0.7	0.9	1.0	0.4	1.3
PCB 52	0.018	3.5	0.1	0.8	0.6	0.5	2.0	3.5	3.1	1.8	0.4	1.8	0.4	1.8	0.8
PCB 101	0.014	ND	ND	ND	ND	0.8	0.9	ND	2.5	ND	ND	ND	2.0	0.2	2.8
PCB 138	0.014	ND	ND	ND	ND	1.5	0.5	ND	1.4	ND	5.7	ND	ND	ND	1.6
PCB 153	0.014	ND	3.3	0.8	0.6	2.8	2.1	1.6	0.2	0.8	0.2	1.3	ND	ND	1.5
PCB 180	0.014	ND	2.3	0.8	2.5	2.5	1.2	0.5	1.9	6.7	1.5	5.1	0.8	ND	2.4
PCB 209	0.014	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.1	ND	ND
∑PCBs	–	4.4	7.1	3	4.9	8.3	7.1	6.4	10.3	10.4	8.5	9.1	5.3	2.4	10.4

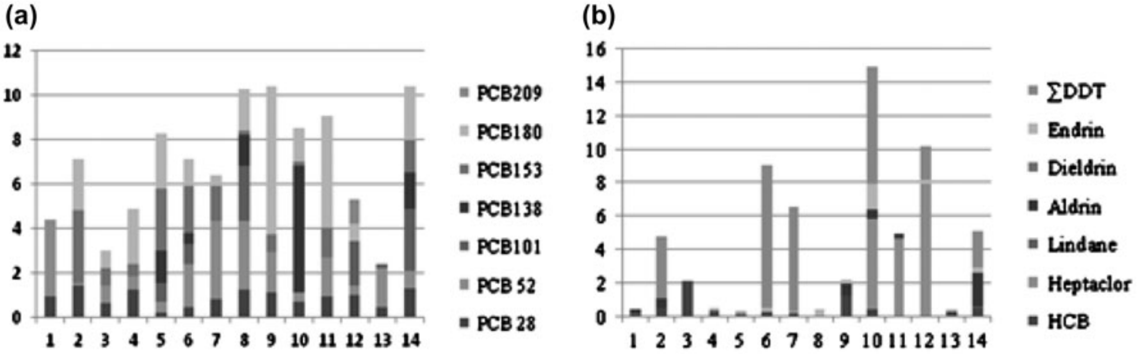

Fig. 2. Distribution of PCBs (a) and OCPs (b) in surface water samples collected from Bizerte Lagoon.

3.2. Concentrations of OCPs

Levels of OCPs compounds in surface water samples are represented in Table 2. Concentration of total OCPs ranged from 0.42 to 14.92 ng L^{-1}. The less contaminated stations in the lagoon were S5, S8, and S13 with ∑OCPs concentration 0.42, 0.45, and 0.47 ng L^{-1}, respectively. It can probably be attributed to water flow, especially for S8 situated in the mouth of Tinja river connecting the lagoon to lac Ichkeul. The most polluted stations were 6, 10, and 12 with ∑OCPs concentrations 9.1, 14.92, and 10.19 ng L^{-1}, respectively. Due to the location of these three sampling points, the contamination can be attributed to activities from area D and possibly to drain water from agriculture area near to Guenniche and Ben Hassine rivers. The pollution for the rest of stations is medium with total pesticides concentration ranging between 0.51 ng L^{-1} for station 1 and 6.67 ng L^{-1} for station 7. The most abundant OCPs detected in this survey of Bizerte Lagoon surface water were DDT and its metabolites, heptachlor, and HCB with a percentage of 47.23, 28.33, and 11% of ∑OCPs, respectively. The other OCPs accounted less than 14% of ∑OCPs, endrin (5.63%), aldrin (0.35%), dieldrin (0.1%), and lindane (0.35%). Because of their lipophilic and hydrophobic nature, OCPs tend to accumulate more in organic phase of sediment and organisms [23]. At the same time, several physical and chemical processes that include volatilization, migration, photolysis, hydrolysis, aquatic animal metabolism, and absorption also occur [24]. Sediments represent a source from which OCPs are reintroduced into the water column, and therefore contribute to measurable concentration in the water and biota of many surface water systems [25]. The concentration of OCPs in this study was lower than those found in Lagos Lagoon in Nigeria with a ∑nOCPs ($n = 6$) = 5,123 ng L^{-1} [26] and in surface waters of Jinzhou Bay in China with a ∑nOCPs ($n = 19$) ranging between 4.165 and 136.8 ng L^{-1} [7].

3.2.1. Concentration of HCB, heptachlor and lindane

HCB is an interesting chemical to study because of its prior use history, persistence, and physicochemical properties. HCB is currently formed unintentionally byproduct of several industrial sectors where both chlorine and carbon are present [27].

The HCB are detectable in all sampling sites. The levels of HCB ranged between 0.08 and 2.18 ng L^{-1}. The highest concentration of HCB was found in station 3 (2.18 ng L^{-1}) located in the Channel of Bizerte suggesting that anthropogenic (urban and industrial) inputs other than atmospheric deposition were the dominant sources. HCB may be removed from water by photolysis with a half life of about 70 d. In the water column, HCB is rapidly sorbs to particulate matter, making it unavailable for photolysis [28].

Heptachlor was detected in station 10, 11, and 12 with a concentration ranged between 4.58 and 7.83 ng L^{-1}. Lindane was detected in station 1, 4, 5, 11, 13, and 14 with a concentration varied between 0.02 and 0.06 ng L^{-1} (Table 2). The highest concentrations of heptachlor and lindane were observed for S12 (7.83 ng L^{-1}) and S11 (0.06 ng L^{-1}), respectively. These stations are situated near cultivated fields connected to the lagoon by straight channels (Genniche and Rharek). Indeed, lindane is used on fruit and vegetable crops and domestic uses [29]. While the main use of heptachlor by farmers is to kill termites, ants, and soil insects [30]. Heptachlor released into the environment can be transformed by abiotic processes, such as the transformation by photochemically produced hydroxyl radicals, and it is transformed in the presence of water to compounds such as 1-hydroxychlordene or heptachlor epoxide, the latter is known to be more toxic and persistent than heptachlor [30]. HCB was classified by the World Health Organization (WHO) as an extremely hazardous compound while lindane was classified as moderately hazardous [31]. The levels of HCB, lindane, and heptachlor were under concentration limits fixed by WHO, Australian guideline, and the European directives [3–32] (Table 3).

3.2.2. Concentration of aldrin, dieldrin and endrin

Concentration of aldrin varied between 0.18 and 2.02 ng L^{-1}. It represents 59, 34, 38, and 39% of ∑OCPs obtained for stations S1, S9, S13, and S14, respectively. All these stations are situated in channel of Bizerte and in the northeast of the lagoon influenced by industrial areas A, B, and C and by agricultural activities. Except station S5 dieldrin is below the detection limits in all stations. The long exposure to dieldrin and aldrin could lead to chronic convulsions [23]. Endrin is an organochlorine alicyclic insecticide that closely related to dieldrin and aldrin [33]. Results show that levels of endrin varied between ND and 1.51 ng L^{-1}. The percentage of endrin varied from 2.25 to 77.77% of total OCPs in station 12 and station 8, respectively. Low concentration of endrin can be explained by its adsorption to the bottom sediments and bioaccumulation in aquatic organisms. Exposure to endrin can cause death and severe central nervous system injury [34]. The comparison between the levels of aldrin and its metabolites with limit concentrations indicates that no pollution was observed with those compounds.

3.2.3. Concentration of DDTs

DDTs were widely used in World War II to protect soldiers and civilian from malaria. From 1981 to 1984, it was estimated that about 311,000 tons of DDTs were consumed in 103 countries annually [7]. DDT with the percentage of 42.88% is the most abundant of the DDT compounds, DDE and DDD represent 33.52 and 23.58% of ∑DDTs. The ∑DDTs obtained ranged between 2.01 and 8.51 ng L^{-1}. The levels of pp´ DDT, pp´ DDD, and pp´ DDE water samples varied between ND and 5.75 ng L^{-1}, ND and 2.39 ng L^{-1}, and between ND and 6.25 ng L^{-1}, respectively. Stations 6 and 7 were affluent by ∑DDT their percentages were, respectively, 93.5 and 93.3% of the total OCPs. The concentrations of DDT and its metabolites varied in the order: DDT > DDE > DDD. The DDT was found in four stations S6, S12, S13, and S14. The highest level of DDT (5.75 ng L^{-1}) was detected in station S10 near the industrial zone of Menzel Bourguiba area (D). ∑DDTs sources can be identified from their compositions. The portion of DDT degradation metabolites (DDD and DDE) indicates whether they result from new inputs or historical usage because DDT can be degraded gradually to

Table 3
Concentration limits of OCPs in water matrix (ng L^{-1})

Compounds	Classification	Concentration range	WHO	Australia guidelines	European directive
HCB	Ia[a]	0.08–2.18	1,000	–	100
Lindane	II[b]	0.02–0.06	2,000	50	100
Heptachlor	O[c]	ND-7.83	30	50	30
Aldrin	O[c]	ND-2.02	30	10	30
Dieldrin	O[c]	ND-0.06	30	10	30
Endrin	O[c]	ND-1.51	–	–	100
pp´ DDT	II[b]	ND-5.75	2,000	60	100
pp´ DDD	II[b]	ND-2.39	2,000	60	100
pp´ DDE	II[b]	ND-6.25	2,000	60	100

[a] Extremely hazardous.

[b] Moderately hazardous.

[c] Obsolete as pesticide, not classified.

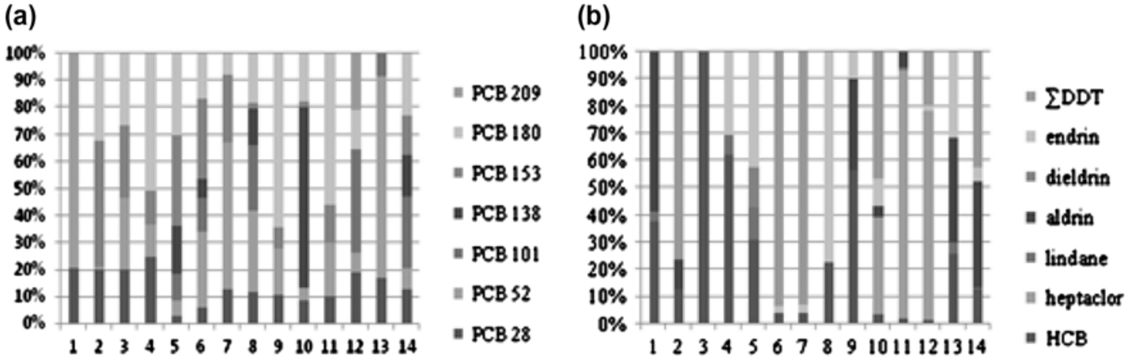

Fig. 3. Percentage of individual PCB (a) and OCPs (b) in surface water samples collected from of Bizerte Lagoon.

DDD under anaerobic condition and to DDE under aerobic condition. If the DDT/(DDD + DDE) ratio is greater than 1, it indicates that there is a new input of DDT in a given sample, whereas if this ratio is not greater than 1, the DDT is due to historical inputs [35]. In this study, the rations DDT/(DDD + DDE) obtained for station S7 and S10 were 1.6 and 4.6, respectively, which prove the recent input of DDTs in these stations. DDT was classified as a moderate hazard compound (Table 3) [31]. The Australian guideline fixed a concentration of 60 ng L^{-1}. The DDTs levels found in this work pose no health risk. In comparison with other study the residue of ∑DDT was higher than those found in Terminos Lagoon in Mexic (0.073–0.605 ng L^{-1}) [36] but similar to those found in Ebro river in Espagne (1.3–7.2 ng L^{-1}) [21].

3.3. Principal component analysis

The purpose of PCA is to evaluate the distribution model and determine groups with similar characteristics among sampling stations. The principal component scores for each site are displayed in Fig. 4. In the case of OCPs, the first principal component (PC1) accounted for 20.76% of the variability in the data, while the second principal component (PC2) accounted for 29.92%. For the PCBs, (PC´1) represent 23.38% and (PC´2) represent 27.27%. The sampling sites were divided into two groups based on their component scores: G1 include S2, S3, S6, S9, and S14, G2 include S1, S4, S13, and S8. Stations of group 2 were the less contaminated sites and group 1 contained the most contaminated sites. The sampling sites of PCBs are divided into three the first group G´1 includes S1, S13, S7, S3, and S6, the second G′2 includes S11, S5, S2, S4, and S6, the third G´3 includes S10 and S14.

The contamination by OCPs in all groups can be attributed mainly to agricultural activities while common sources for OCPs and PCBs can be produced by activities from areas A and B, except group G´3 which can be attributed to areas C and D. Contribution of water flow is considered for groups G1, G2, and G´2

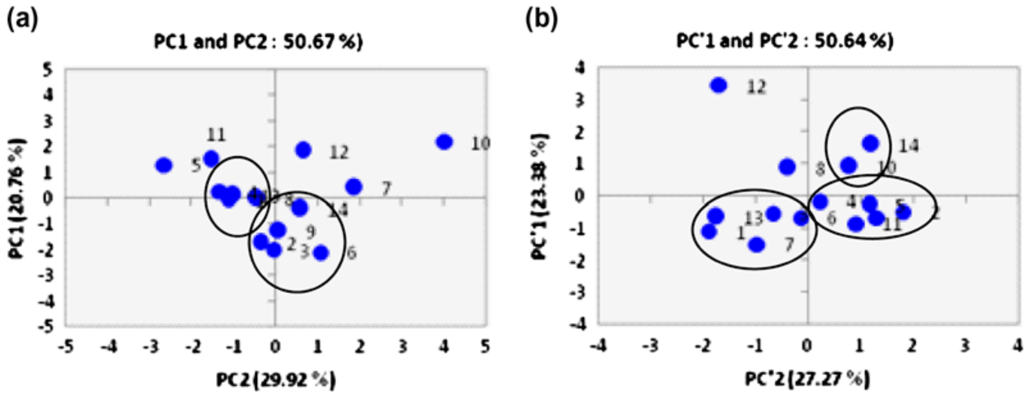

Fig. 4. PCA for individual OCPs (a) and PCBs (b) in the Bizerte Lagoon.

which explains the diffusion and the gradient of contamination by OCPs and PCBs. Industrial sources of the area C can appear in G´1 and of area D in G2 and G´3 with the consideration that G2 contains the less contaminated sampling stations.

4. Conclusion

In this study, levels of concentration by OCPs and PCBs have been assessed in the Lagoon of Bizerte which is known for many decades as a fishing and industrial area. Despite the fact that OCPs and PCBs were banned in Tunis in the latter 1980s these micropolluants still existed in the aquatic system of Bizerte Lagoon. In this study, we have demonstrated the predominance of DDTs and PCBs, DDT still predominates over its metabolites DDD and DDE which indicate recent inputs of these pesticides. Their persistence could be explained by their long half-life and atmospheric deposition as well as illegal or historical use in several areas. The highest levels of contamination were observed in sites close or far from urban zones, agricultural and industrial activities. Quite high contamination with OCPs was found to be in the South of the lagoon (S10 and S12). With regard to the water flow, this contamination can be explained by the drain waters coming from agriculture activities through rivers and activities of area D and possibly C. The North of the lagoon is more contaminated by PCBs (S14) than OCPs, it can be attributed to their use in industrial activities as dielectric fluids in transformers and capacitors, as plasticizers in paint and rubber sealants. An efficient control must take into account of urban and industrial discharges. Results shows that levels of OCPs and PCBs obtained in this study pose no threat to human and aquatic living species.

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