Bull. Soc. zool. Fr., 2017, 142(3) : 101-118.

Écotoxicologie

ACCUMULATION OF ORGANOCHLORINE PESTICIDES AND POLYCHLORINATED BIPHENYLS IN THE SEDIMENTS OF OUALIDIA LAGOON (MOROCCO)

par

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Levels of organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) were determined in sediment samples collected at 5 sites along Oualidia lagoon (Morocco) from spring 2015 to winter 2016. A total of 13 organochlorine compounds (OCs), namely 7 OCPs and 6 PCBs markers were searched. Target analytes include p,p'-DDT (2,2,-bis(4-chlorophenyl)-1,1,1-trichloroethane) and its metabolites (DDE and DDD), aldrin, heptachlor, lindan, hexachlorobenzene (HCB) as well as following PCBs congeners: PCB28, PCB52, PCB101, PCB138, PCB153, and PCB180. The highest levels of the total concentrations of OCPs (ΣOCPs) were 31.19 ng/g dry weight (d.w.) and that of the 6 PCBs (ΣPCBs) 9.44 ng/g d.w. In addition to spatial variation, these organochlorine compounds showed seasonal variations, with an increase of OCPs, in particular DDE compared to its metabolites, from spring to a maximum in autumn. For PCBs, the highest levels were observed in spring, with dominance of PCB153 compared to other congeners. Furthermore, a significant correlation was observed between the accumulation of DDT and DDE on the one hand and between DDT and aldrin on the other. According to the Sediment Quality Guidelines, the risk of adverse biological effects from such levels of PCBs as recorded at most of the study sites was insignificant. However, DDT levels at two sites could cause biological damage.

Keywords: Accumulation, Organochlorine pesticides, Polychlorinated biphenyls, Sediments, Oualidia Lagoon, Morocco.

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Accumulation des pesticides organochlorés et des polychlorobiphényles dans les sédiments de la lagune de Oualidia (Maroc)

Notre étude a porté sur l'analyse des pesticides organochlorés (POCs) et des polychlorobiphényles (PCBs) dans des échantillons de sédiments prélevés au niveau de 5 points de la lagune de Oualidia, du printemps 2015 à l'hiver 2016. Au total 13 composés organochlorés (OCs), à savoir 7 POCs et 6 congénères de PCBs ont été recherchés. Il s'agit du DDT et ses métabolites (DDE et DDD), l'aldrine, l'heptachlore, le lindane, l'hexachlorobenzène (HCB) ainsi que les congénères de PCBs suivants : PCB28, PCB52, PCB101, PCB138, PCB153 et PCB180. Les teneurs les plus élevées en pesticides organochlorés totaux (ΣPOCs) étudiés sont de l'ordre de 31,19 ng/g en poids sec de sédiments (p.s.) et celle en PCBs totaux (ΣPCBs) sont de l'ordre de 9,44 ng/g p.s enregistrées au Parc 1 et Parc 7 respectivement. En plus de la variation spatiale, ces composés organochlorés ont enregistrés des variations saisonnières avec une élévation des teneurs en POCs, notamment le DDE par rapport aux autres métabolites, à partir du printemps pour atteindre un maximum en automne. Quant aux PCBs, les teneurs les plus élevées sont observées au printemps avec une dominance du congénère CB153 par rapport aux autres congénères. Même si les taux d'accumulation des organochlorés dans les sédiments de la lagune de Oualidia ne sont pas négligeables dans l'ensemble de la zone d'étude, ils ne dépassent pas les seuils légalement tolérés. En outre, une corrélation significative a été observée entre l'accumulation du DDT et le DDE d'une part, et entre le DDT et l'aldrin d'autre part. Selon les lignes directrices sur la qualité des sédiments, DDT et ses métabolites peuvent avoir un effet biologique négatif potentiel sur les organismes benthiques du Parc 1 et de l'ancien parc Marost.

Mots-clés : Accumulation, Pesticides organochlorés, Polychlorobiphényls, Sédiments, Lagune de Oualidia, Maroc.

Introduction

Since the beginning of the 20th century, the world has seen great advances in technology and a rapid development of the chemical industry. These innovations were not without risk of pollution on marine and coastal habitats and the environment was invaded by toxic substances, such as organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs). These pollutants, which have been reported to cause cancer in animals and humans (BERTRAND *et al.*, 2010; KRAMER *et al.*, 2012; BRAUNER *et al.*, 2012), represent groups of compounds termed persistent organic pollutants (POPs), which have low solubility in water, high solubility in lipids, high resistance to photolytic, chemical and biological degradation, liability to bioaccumulation through the food chain, ability to travel over long distances and toxicity (CARRO *et al.*, 2010; KLJAKOVIC-GASPIC *et al.*, 2010; GUZZELLA *et al.*, 2005; WURL & OBBARD, 2005). The bioaccumulation of these xenobiotics constitutes a serious threat to filter and suspension-feeding organisms and other components of the trophic chain (CUSTER *et al.*, 2010a,b; KELLY *et al.*, 2008). To protect the environment and the human health from these chemicals, world governments have therefore established conventions, such as the Stockholm Convention that Morocco signed in 2001 and ratified in 2004.

Despite the ban on the production and use of some of these compounds, they are still present in water and sediments (TURRIO-BALDASSARRI *et al.,* 2005; DUMOULIN *et al.,* 2013; NET *et al.,* 2014). This presence may be explained by their very long persistence in the environment.

Oualidia lagoon is a site that offers abundant and varied natural riches, which are intensively exploited by the local population in the form of artisanal fishing, aquaculture, shellfish harvesting, salt extraction, agriculture, leisure activities and urbanization (INSTITUT NATIONAL DE RECHERCHE HALIEUTIQUE, 2015). This lagoon has been classified as a site of biological and ecological interest through the Protect Areas Master Plan (EL HAMMOUMI, 2000) and by the RAMSAR Convention for the conservation of wetlands of international interest (RAMSAR, 2016).

Various studies have been conducted recently on the distribution of OCPs and PCBs in the aquatic environment (BENBAKHTA *et al.,* 2007, 2014; MEHDAOUI *et al.,* 2000; JAYED *et al.,* 2010; GIULIANI *et al.,* 2015). Others have focused on the pollution by organochlorine pesticides in the Loukkous estuary (DAOUDI *et al.,* 2014; EL BAKOURI *et al.,* 2008), the Oued Souss estuary (AGNAOU *et al.,* 2014) and the Triffa plain (FEKKOUL, 2013). In Oualidia lagoon, the only data available concerning organochlorines (OCs) in sediment are those reported by JAYED *et al.,* (2015); and these data represent the first report on the levels of contamination by OCPs and PCBs. A more comprehensive study was needed to reflect the overall seasonal and special distribution of Organochlorines in superficial sediments from the Oualidia lagoon. The present study was therefore carried out on 20 surface sediment samples collected in the study area in order to identify and quantify OCP and PCB contamination levels.

Materials and methods

The study area, Oualidia lagoon (32°44’42”N–09°02’50”W), is located on the Atlantic coast of Moroccan, 76 km south of Eljadida. It is a small seaside resort where several socio-economic activities are developed, including aquaculture. It is 7 km long and 0.4 to 0.5 km wide, with a total area of about 3 km^2 (BEAUBRUN, 1976). The study area is has a Mediterranean type climate (semi-arid), but the coastal strip undergoes Atlantic influences.

Sediment samples were taken from spring 2015 to winter 2016 at 5 sites located by GPS (Global positioning system) selected to cover the whole area of the lagoon. These sampling sites were chosen due to their locations near agricultural fields and, especially, for their aquaculture potential. A sample of superficial sediment (0-5 cm) was hand-collected at each site at low tide and the pH was measured simultaneously. After collection, samples were wrapped in aluminium foil and transported in cool conditions to the laboratory, where they were stored in a freezer. Prior to analysis, samples were dried at 40°C and then ground mechanically with an electric sieve shaker to obtain the fine fraction. Details of the sampling sites and other parameters are shown in Figure 1 and Table 1.

The analyses were carried out according to the Standard Operating Procedures elaborated by CATTINI in 2013.

Each sample (4 to 5 g) was spiked with internal standards: 2,4,5-trichlorobiphenyle (TCB) and hexachlorohexane (εHCH). These standards were used to quantify the overall recovery of procedures. The samples were micro-wave extracted with 30 ml of a hexane/acetone mixture (90:10), then concentrated to almost 10 ml using a rotary evaporator in a water bath (*ca.* 30°C), and the extract was then treated with activated copper to remove sulphur. An aliquot of each sediment sample was cleaned up through florisil after evaporation to 1 ml. The clean-up and fractionation of OCPs and PCBs was performed by passing the extract through a florisil column (17 g) that had been activated at 130°C for 12 h and partially deactivated with 0.5% water. Two fractions were eluted from this column, the first fraction with 70 ml of hexane; the second with 50 ml of hexane/dichloromethane (70:30). Each fraction was concentrated to 1 ml and injected into a GC (Hewlett Packard P 6890) equipped with a 63Ni electron capture detector (ECD) and split/splitless injector. The capillary column used was an HP-5MS (phenyl-methyl poly-siloxane, 30 m length, 0.52 mm internal diameter and 0.52 µm film thickness). The initial oven temperature was 60°C (for 2 min hold), raised to 160°C at 20°C/min, then 200°C (for 10 min hold) and was maintained at 250°C for 2 min. Injector and detector temperatures were maintained at 250 and 300°C, respectively. The carrier gas was helium with a flow-rate of

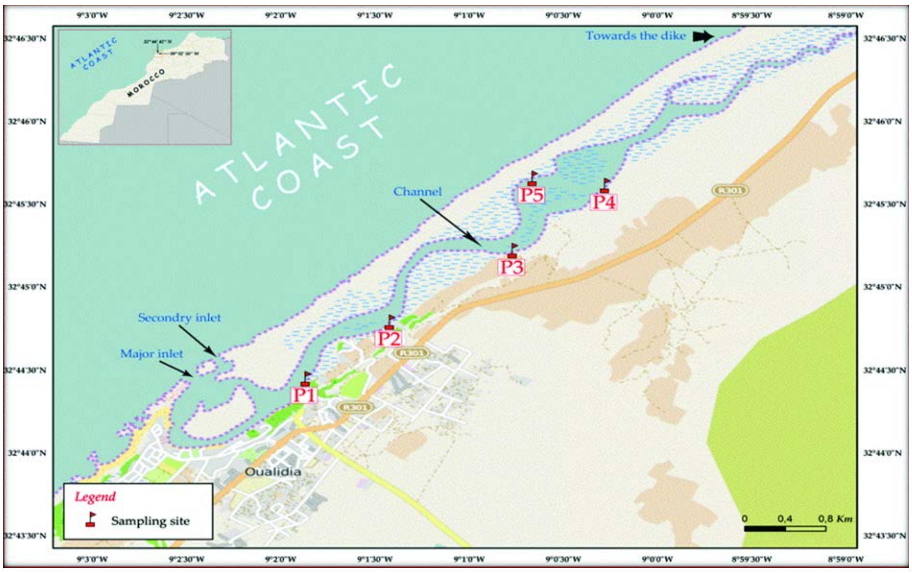

Figure 1
Location of Oualidia lagoon and the sampling sites.
Localisation de la lagune de Oualidia et les sites d'échantillonnage.

Table 1

Sampling site locations and characteristics of sediments from the Oualidia lagoon.
Localisation des sites de prélèvement et les caractéristiques du sédiment de Oualidia.

Code	Sampling site	Location	pH	% < 63 µm
P1	Annex park 7	32.74080’ N 009.03113’ W	7.98	7.48
P2	Park 7	32.74649’ N 009.02367’ W	8.06	4.37
P3	Park 1	32.75366’ N 009.01280’ W	8.08	11.73
P4	Former Marost park	32.76019’ N 009.00463’ W	7.91	6.61
P5	Annex park 1	32.76091’ N 009.01105’ W	7.96	7.84

2 ml/min and the make-up was nitrogen with a flow-rate of 60 ml/min. Concentrations of individual organochlorines were quantified from individually resolved peak areas with the corresponding peak areas of standards.

To control the analytical reliability and assure recovery efficiency and accuracy of the results, simultaneous analyses were conducted on the sediment reference material n°417 provided by IAEA/Monaco. A procedural blank was carried out to determine any contamination during analyses and the same procedures were applied to the sediment samples.

In this study, Xlstat software was used for all statistical analysis, and in all cases, the level of significant was set at 0.05. The Pearson’s correlation analysis was used to test for significant relationships between OCPs, PCBs and seasons on the one hand, and OCPs, PCBs, pH and % 63 µm in sediments on the other hand. Analysis of variance (ANOVA) was used to test variation between the analysed compounds concentrations. The homogeneity of variance was tested by the Fisher test.

Results and discussion

All OCP and PCB congeners were well resolved and eluted within a reasonable time under the optimized GC conditions. Recoveries were determined for all samples by spiking with internal standard prior to extraction and ranged from 50 to 98%. Concentrations of OCPs and PCBs are summarized in Tables 2 and 3. The detection limits of PCBs and OCPs were estimated from TOMBESI *et al.* (2017) and SCHIAVONE & COQUERY (2009), respectively.

Polychlorinated biphenyls. Individual and total concentrations of PCB congeners in sediment samples collected from Oualidia lagoon are given in Table 2. Targeted PCBs were detected in all sediment samples, demonstrating ubiquitous

Table 2

Concentrations of PCBs in superficial sediments of Oualidia lagoon (ng/g d.w.).
Concentrations des PCBs dans les sédiments superficiels de la lagune de Oualidia (ng/g p.s.).

Season	Congener	P1	P2	P3	P4	P5
Spring	CB 28	0.15	<0.008	<0.008	0.09	<0.008
	CB 52	<0.008	0.58	<0.008	<0.008	<0.008
	CB 101	0.24	<0.008	0.27	0.30	0.17
	CB 153	0.63	1.73	0.76	0.92	0.43
	CB 138	0.30	1.28	0.50	0.20	0.09
	CB 180	0.22	0.36	0.28	0.10	0.01
	∑PCB	1.54	3.95	1.81	1.61	0.7
Summer	CB 28	0.32	0.24	<0.008	0.33	0.26
	CB 52	<0.008	0.31	<0.008	<0.008	<0.008
	CB 101	<0.008	<0.008	<0.008	<0.008	<0.008
	CB 153	0.23	0.16	0.18	0.35	<0.01
	CB 138	0.19	0.72	0.16	0.31	0.09
	CB 180	0.20	0.16	0.12	0.24	0.23
	∑PCB	0.94	1.59	0.46	1.23	0.58
Autumn	CB 28	0.32	0.63	0.29	0.38	<0.008
	CB 52	<0.008	<0.008	<0.008	<0.008	<0.008
	CB 101	0.22	<0.008	0.23	0.50	<0.008
	CB 153	0.17	0.52	0.19	0.14	0.14
	CB 138	0.21	1.09	0.28	0.19	0.10
	CB 180	0.16	0.22	0.17	0.14	0.31
	∑PCB	1.08	2.46	1.16	1.35	0.55
Winter	CB 28	<0.008	<0.008	0.10	0.43	<0.008
	CB 52	<0.008	<0.008	<0.008	<0.008	<0.008
	CB 101	<0.008	0.35	0.14	0.17	0.15
	CB 153	0.38	0.50	0.25	0.15	0.05
	CB 138	0.31	0.47	0.18	0.22	0.09
	CB 180	0.25	0.12	0.14	0.12	0.03
	∑PCB	0.94	1.44	0.81	1.09	0.32

contamination by these compounds in the aquatic environment of Oualidia lagoon. All the congeners were frequently observed, except PCB52, which was detected only at P2 in spring and summer; this might be related to its lightness, which makes it more metabolizable and volatile than the other congeners. The ΣPCBs levels, defined as the sum of the concentrations of all observed congeners, varied from 0.32 to 3.95 ng/g d.w., with a mean value of 1.3 ng/g d.w. The fact that these pollutants are still detected could be explained by their persistence in the environment and the intensive industrial activities in the region of El Jadida-Safi. This is supported by the

Table 3

Concentrations of OCPs in superficial sediments of Oualidia lagoon (ng/g d.w.).
Concentrations des POCs dans le sédiment superficiel de Oualidia (ng/g p.s.).

Season	**Pesticide**	**P1**	**P2**	**P3**	**P4**	**P5**
Spring	HCB	0.12	0.26	0.20	0.08	0.09
	DDE	2.72	2.22	5.02	3.23	1.11
	Aldrin	<0.1	<0.1	<0.1	<0.1	<0.1
	Heptachlor	0.49	<0,1	0.34	0.18	0.24
	Lindan	<0.1	0.24	<0.1	0.14	<0.1
	DDD	<0.1	0.46	0.93	0.12	0.06
	DDT	<0.1	0.21	<0.1	0.14	<0.1
	∑OCP	3.33	3.39	6.49	3.92	1.5
	DDT/DDE	<0.33	0.09	<0.33	0.04	<0.33
Summer	HCB	0.54	<0.1	0.55	0.56	0.36
	DDE	2.20	2.01	2.65	7.83	1.70
	Aldrin	<0.1	<0.1	<0.1	<0.1	<0.1
	Heptachlor	0.56	0.39	0.52	0.67	<0.1
	Lindan	0.26	0.33	0.11	<0.1	<0.1
	DDD	0.59	0.51	0.70	0.78	0.54
	DDT	0.89	0.68	0.19	<0.1	0.41
	∑OCP	5.04	3.92	4.72	9.84	3.01
	DDT/DDE	0.40	0.34	0.07	<0.33	0.24
Autumn	HCB	0.29	0.94	0.48	0.15	0.28
	DDE	2.36	3.15	10.17	6.10	1.76
	Aldrin	<0.1	<0.1	<0.1	<0.1	<0.1
	Heptachlor	<0.1	<0.1	0.17	0.23	0.50
	Lindan	1.86	0.14	0.46	0.34	0.24
	DDD	0.72	1.77	0.85	0.49	0.44
	DDT	0.80	0.42	0.50	0.51	0.39
	∑OCP	6.03	6.42	12.63	7.82	3.61
	DDT/DDE	0.34	0.13	0.05	0.08	0.22
Winter	HCB	0.15	0.25	0.19	0.32	0.30
	DDE	3.15	1.63	5.37	4.81	1.13
	Aldrin	<0.1	<0.1	<0.1	<0.1	<0.1
	Heptachlor	<0.1	<0.1	0.12	0.21	0.17
	Lindan	1.01	0.63	0.36	0.34	0.22
	DDD	0.55	0.59	0.95	0.63	0.32
	DDT	0.78	0.37	0.37	0.26	0.16
	∑OCP	5.64	3.47	7.36	6.57	2.3
	DDT/DDE	0.25	0.23	0.07	0.05	0.14

studies of BARAKAT *et al.* (2012) and DIERKING *et al.* (2009), who found that the presence of tetrachloro- (PCB52), pentachloro- (PCB101 and PCB118) and hexachloro- (PCB138 and PCB153) congeners is consistent with a contribution from the commercial mixtures that have been widely used in electrical equipment (particularly transformers) and other industrial applications in several countries.

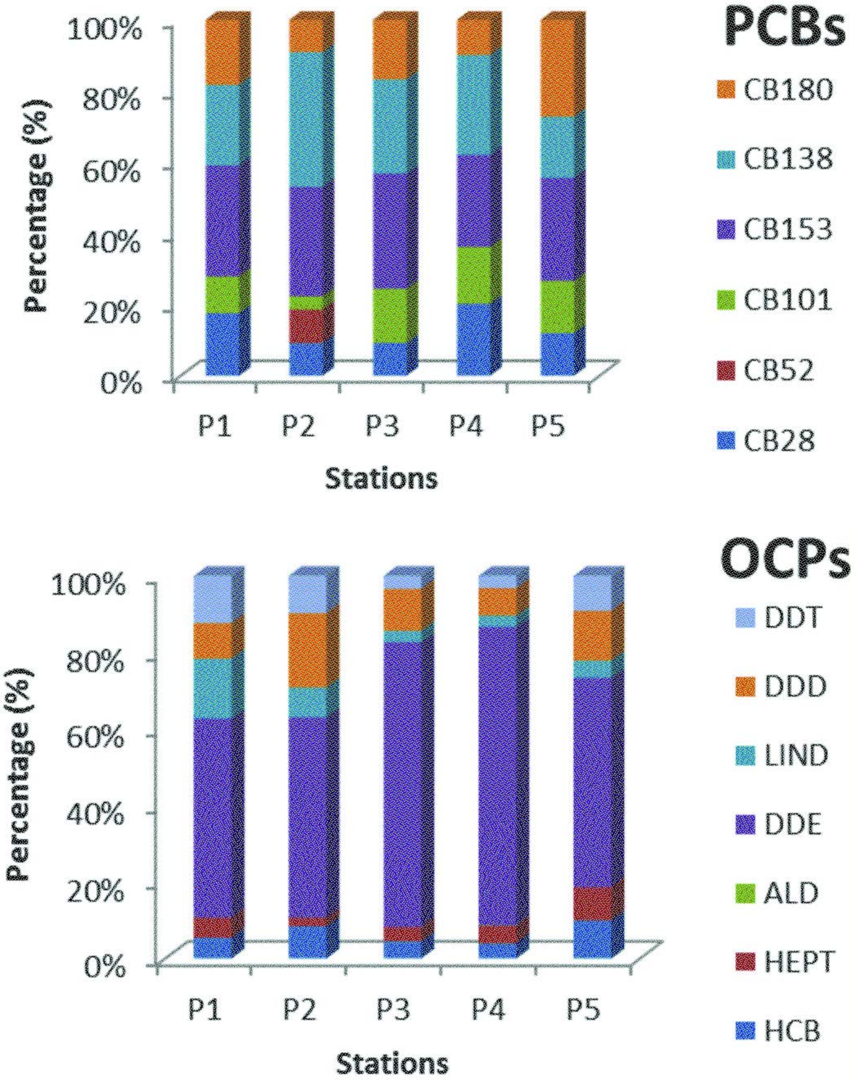

Figure 2
Percentages of individual PCBs and OCPs in the sediment of Oualidia lagoon.
Le pourcentage de contribution des PCBs et POCs dans le sédiment de la lagune de Oualidia.

As shown in Table 2, the distribution of PCBs in surface sediments from Oualidia lagoon revealed that concentrations varied slightly, depending on the station and the season. The highest levels were detected at P2, which might be related to the painting of pleasure boats concentrated at this site. In addition to P2, relatively high concentrations of PCBs were also observed at station P4. The lowest concentration was found at P5, located on the oceanic side of the lagoon with less anthropogenic activity. Several authors stated that hydrodynamic conditions are the most important factors influencing the distribution of PCBs in surface sediments (TANG *et al.,* 2000; ZHANG *et al.,* 2007). For example, the water flow and current velocity, which may influence the adsorption of contaminants and/or sediment transport, have been reported as playing an important role in various levels of PCBs in sediments from the Wuhan reach of the Yangtze River, China (YANG *et al.,* 2009).

In terms of individual congener distribution, the contribution of the six studied congeners towards the total PCBs content in the whole sediment was in the order PCB153 > PCB138 > PCB180 > PCB28 > PCB101 > PCB52. Figure 2 clearly shows that the predominant congeners were PCB153 and PCB138, which are the main constituent in Aroclor 1260 and Aroclor 1254 respectively (ATSDR, 2000; CARRO *et al.,* 2010). On average, these compounds collectively accounted for almost 65% of total PCBs, whereas the other congeners made only small individual contributions. The observed congener distribution is therefore in accordance with many recently published data in other environments worldwide, showing the preferential retention of the less volatile and more lipophilic compounds in marine sediments (TOMBESI *et al.,* 2017; RAGAB *et al.,* 2016; KANZARI *et al.,* 2014; BARHOUMI *et al.,* 2014).

Differences in congener composition in the aquatic systems may also be attributed to a decline in the proportion of less chlorinated PCBs (CB 28, CB52, and CB101) that are more susceptible to losses through volatilization, sedimentation and possibly microbial degradation (QUENSEN *et al.,* 1988; MACDONALD *et al.,* 1992). Moderately and highly chlorinated PCBs (PCB138, PCB153, and PCB180) may be more persistent in the aquatic environment because they are less volatile and more soluble in lipids, adsorbed more readily to sediments, and are more resistant to microbial degradation (CONNELL, 1988; TYLER & MILLWARD, 1996).

Organochlorine pesticides. The level of contamination by OCPs in the Oualidia lagoon sediments is relatively higher than that by PCBs, reflecting the predominance of agricultural versus industrial activities in the studied area. As shown in Table 3, all of the targeted compounds were recorded in all stations in the different seasons, except Aldrin, which was only detected in spring at station P4. The highest concentration (12.63 ng/g d.w.) was measured in autumn at P3, a zone with intensive agricultural activities. This site is also located in front of a cliff where different vegetable crops are cultivated, which means that there is drainage of field runoff towards station P3. The lowest concentration (1.5 ng/g d.w.) was found in spring at station P5, which is characterized by a low agricultural activity. The presence of pesticides that have been prohibited in Morocco since 1984 might be attributed to the persistence of those compounds in the environment due to a slow rate of degradation. DDE was the most abundant compound in the sediment samples (55 to 80% of total contribution) and, among all OCPs, concentrations of DDT and its metabolites were more important than those of the other compounds, which might indicate that these pesticides have been extensively used in the lagoon and the surrounding agricultural fields. That could be explained by the illegal use of old obsolete stocks of these phytosanitary products. The relatively high levels of DDT and its related compounds in present study are in accordance with those observed in other ecosystems like those of Moulay Bousselham lagoon, Sebou Estuary in Morocco (BENBAKHTA *et al.*, 2014), Cyprus in the eastern Mediterranean (KUCUKSEZGIN *et al.*, 2016), the Red Sea of Egypt (RAGAB *et al.*, 2016), Bizerte lagoon in Tunisia (BERHOUMI *et al.*, 2013), the Han River in Korea (KIM *et al.*, 2009), and the Gulf of Lion of France (TOLOSA *et al.*, 1995).

In the environment, DDT can be biodegraded to DDE under aerobic conditions and to DDD under anaerobic conditions (AISLABIE *et al.*, 1997). The rate of degradation depends on several factors including sediment type, temperature and organic carbon content. It can be seen from figure 2 that DDE was the predominant compound at most sampling sites, suggesting possible degradation of DDT through aerobic processes. This is consistent with active hydrodynamic conditions in the lagoon favouring water oxygenation and therefore microbial metabolisation of DDT to DDE (BARHOUMI *et al.*, 2014). Therefore, the ratio of DDT/DDE can be used as an indicator to identify a recent input of DDT (STRANDBERG *et al.*, 1998). Ratios below 0.33 generally indicate no recent input. In the present study, almost all ratio values were below 0.33 (Table 3), indicating no recent input of DDT in Oualidia lagoon. Only at stations P1 and P2 (in summer and autumn) does this ratio exceed the reference value, which might be due variations in hydrodynamic conditions.

Seasonal variation of PCBs and OCPs. Besides the spatial variation, these organochlorine compounds showed obvious seasonal variation (Table 2 and 3). The OCPs, lindan, DDT and its related compounds showed an increase in autumn, while HCB, Aldrin and Heptachlor increased in summer. As for PCBs, an increase was observed in autumn for less chlorinated congeners (PCB28, PCB52, and PCB101), whereas an increase was observed after the wet season for the heavy congeners (PCB153, PCB138, and PCB180). Previous studies of seasonal variation of OCPs and PCBs in sediment recorded different results. NOUIRA *et al.* (2013) reported that PCB concentrations increase in the wet season and decrease in the dry season. In contrast, CETIN *et al.* (2017), SHI *et al.* (2016) and FU & WU, (2006) reported a general increase in concentrations of these compounds after the wet season, which they explained by atmospheric deposition, surface runoff and an increase in temperature, which plays an important role in the volatilization of some PCBs congeners. The latter findings are in accordance with the results of the present study, especially regarding HCB, Aldrin, Heptachlor and the heavy PCB congeners.

The analysis of variance showed no significant difference between HCB, Lindan, DDD, and heptachlor. However, for DDT, DDE and Aldrin, the difference was significant. The Pearson's correlation analysis (Figure 3) also demonstrated that there is a highly significant correlation between on the one hand DDT and DDD, and on other hand, between DDT and Aldrin, while no significant correlation was found for the other pesticides and PCB congeners.

Furthermore, in the aquatic environment, it is generally accepted that the finer grain size fractions of sediments contain higher concentrations of organochlorines

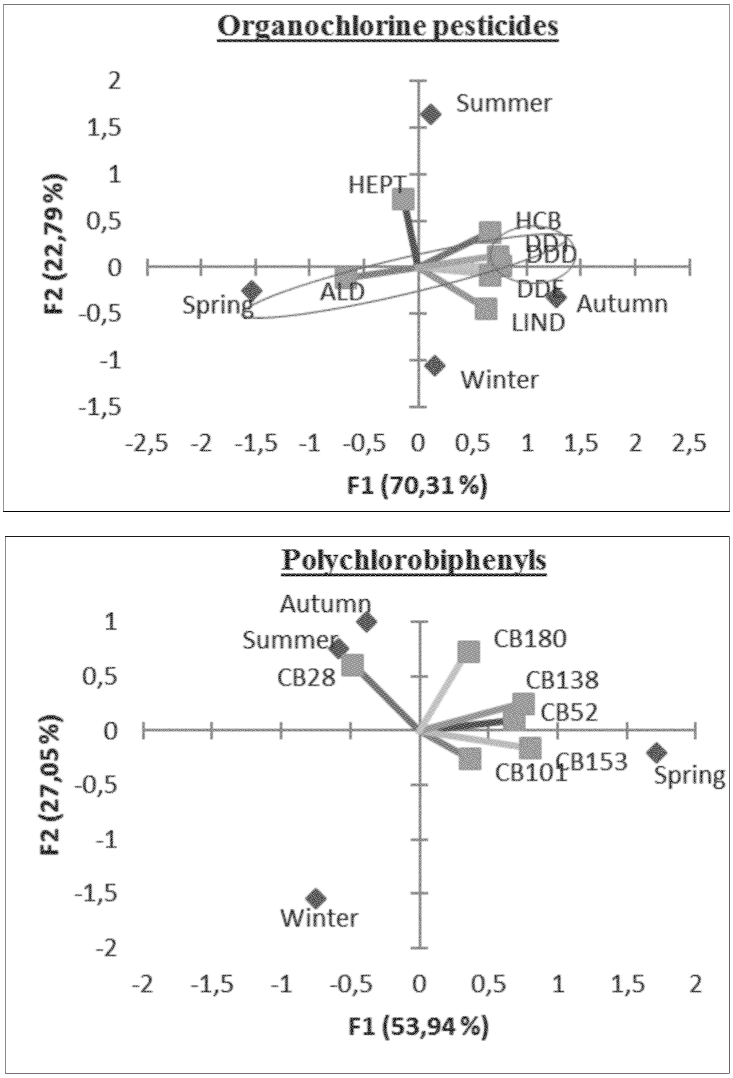

Figure 3

Correlation of organochlorine concentrations in the different seasons in Oualidia lagoon.

Corrélation des concentrations de organochlorés dans la lagune de Oualidia dans les différentes saisons.

Table 4

Correlation matrix (Pearson (n)) of OC concentrations and sediment characteristics in Oualidia lagoon (n=5 and p < 0.05).

Matrice de corrélation (Pearson (n)) entre les concentrations des organochlorés et les caractéristiques du sédiment de la lagune de Oualidia (n=5 et p < 0.05).

Variables	**∑OCPs**	**∑PCBs**	**pH**	**<63 µm (%)**
∑OCPs	1	0.087	0.164	0.499
∑PCBs	0.087	1	0.407	-0.641
pH	0.164	0.407	1	0.289
<63 µm (%)	0.499	-0.641	0.289	1

(CAMACHO-IBAR & MCEVOY, 1996). This relationship is due to the greater surface area of the smaller particles providing a larger area for the adsorption of organic matter (PEDERSEN, 1995). However, in this study, the grain size does not seem to influence the sediment adsorption of these pollutants, as highlighted by the absence of a correlation between ΣPCB, ΣOCP and the percentage of the fine fraction (Table 4) as previously reported by BARHOUMI *et al.,* (2013). The pH showed no correlation with ΣPCB and ΣOCP, which is in agreement with the results of BARHOUMI *et al.* (2013) and CAMACHO-IBAR & MCEVOY (1996).

The existence, on one hand, of stations with lowly contaminated sediments (such as P1, P3 and P5), but with a high percentage of fine fraction and, on the other hand, of stations with a low percentage of fine fraction, but highly contaminated (such as P2 and P4), can provide a possible explanation of the scarce relationship between grain size and organic pollutant concentrations. This suggests that the distribution of contaminants is mainly related to the proximity and importance of their sources (BARHOUMI *et al.*, 2013).

The comparison of OC concentrations observed in other regions of the world is difficult because of differences in the geological characteristics of the sampling areas, the analytical methods, the number of samples and the number of compounds analysed (BARHOUMI *et al.*, 2013). However, it is useful to have an idea of contamination levels in other areas around the world.

As shown in table 5, the concentrations of PCBs in the present study were lower than in almost all the compared regions, except those recorded in the Red Sea coast by RAGAB (2016). The levels OCPs were lower than those recorded for Bizerte lagoon in Tunisia (BARHOUMI *et al.,* 2013), Cyprus (KUCUKSEZGIN, 2016) and the Huveaune river in France (KANZARI *et al.*, 2014), but higher than those observed in Cantabria, Spain (GOMEZ *et al.*, 2011) and the Red Sea Coast of Egypt (RAGAB *et al.*, 2016). In terms of the contamination levels in sediment fixed by the IFREMER (ANONYMOUS, 2008), Oualidia lagoon presents a very low degree of contamination (0-10 ng/g d.w.).

Evaluation of ecotoxicological risk. Sediment constitutes an important reservoir for hydrophobic pollutants such as PCBs and OCPs and therefore represents a substantial contamination source for the associated communities. To evaluate the eco-

Table 5

Comparison of PCB and OCP concentrations (ng/g d.w.)
in sediments from various locations in the world.
Comparaison des concentrations de PCBs et POCs (ng/g p.s.)
dans le sédiment de différentes régions du monde.

Site	PCB	OCP	Reference
Oualidia lagoon (Morocco)	0.5-2.4	2.6-7.8	Present study
Oualidia lagoon (Morocco)	0.6-18.6	ND	JAYED *et al.*, 2015
Nador lagoon (Morocco)	2.5-20.7	ND	GIULIANI *et al.*, 2015
Bizerte lagoon (Tunisia)	0.8-14.6	1.1-14.0	BARHOUMI *et al.*, 2013
Red Sea coast (Egypt)	0.08-0.1	0.04-0.08	RAGAB *et al.*, 2016
Dakar (Senegal)	4.0-333.0	ND	NET *et al.*, 2015
Cyprus	15.0-325.0	2.8-306.0	KUCUKSEZGIN, 2016
Buenos Aires (Argentina)	0.6-17.6	ND	TOMBESI *et al.*, 2017
Huveaune river (France)	0.8-435.0	0.2-10.0	KANZARI *et al.*, 2014
Cantabria (Spain)	ND	1.8-3.9	GOMEZ *et al.*, 2011
Barcelona (Spain)	2.3-44.0	ND	CASTELLS *et al.*, 2008

toxicological risk of sediment contamination by PCBs and OCPs (represented by DDT, DDE, and DDD) in Oualidia lagoon, sediment quality guidelines (SQGs) specified by the UNITED STATES ENVIRONMENT PROTECTION AGENCY (1997) and by the CANADIAN COUNCIL OF MINISTERS OF THE ENVIRONMENT (2002) were applied in this study. Effects range-low (ER-L) and effects range-median (ER-M) values are used to predict potential impacts of contaminants in sediments. ER-L values correspond to the lower 10 percentile and ER-M values to median values, when the concentrations of a contaminant in marine sediments are sorted according to the degree of their effect levels. ER-L represents the value at which toxicity may begin to be observed in sensitive marine species. In addition, the threshold effect level (TEL) and the probable effect level (PEL) are used as criteria for the prediction of toxicity. TEL corresponds to the concentration below which no effects are observed; TEL corresponds to the concentration above which frequent adverse effects are expected. Sediment quality criteria and concentration ranges of PCBs and DDTs are summarized in table 6.

Table 6

Comparison of DDT (DDT, DDE and DDD) and PCB concentrations in sediments of the study area with ER-L, ER-M, TEL and PEL values (ng/g d.w.). ER-L and ER-M from LONG & MORGAN (1990) and LONG *et al.*, (1995); TEL and PEL from MACDONALD *et al.*, (1996).
Comparaison des concentrations des DDTs (DDT, DDE, et DDD) et des PCBs dans le sédiment du site d'étude avec les valeurs ER-L, ER-M, TEL et PEL (ng/g p.s.). ER-L and ER-M d'après LONG & MORGAN (1990) et LONG et al., *(1995); TEL et PEL d'après MACDONALD* et al., *(1996).*

	ER-L	ER-M	TEL	PEL
∑PCBs	22	180	21.6	188.8
∑DDTs	2	46	3.9	51.7

For ΣPCBs the levels at all sample locations do not exceed the ER-M, ER-L, PEL and TEL values, hence PCBs accumulated in sediments will not have an ecotoxicological impact on the benthic fauna of Oualidia lagoon. However, concentration levels of ΣDDTs are above ER-L at two sites (P1 and P2), equal to ER-L at one site (P5), and higher than both ER-L and TEL at two sites (P3 and P4), but significantly lower than the ER-M and PEL values. Consequently, DDT and its related compounds stored in sediments at sites P3 and P4 could have a potential ecotoxicological impact on the benthic fauna of these two stations.

Conclusions

The results of PCB and OCP concentrations detected in superficial sediments of Oualidia lagoon were consistent with the anthropogenic activities of the surrounding area. These levels varied from weakly to moderately polluted environments (by PCBs and OCPs respectively). These findings are an important contribution to our knowledge regarding levels of organochlorines in this important RAMSAR site on the Atlantic coast of Morocco. Further investigation is still needed to extend the area of study in order the better identify sources of OCPs and PCBs in this region and to assess their potential influence on all components of the marine ecosystem of Oualidia lagoon. This study provides valuable new information on ecotoxicological risks to the benthic fauna by reference to Sediment Quality Guidelines, nevertheless. However, additional studies of other elements of the trophic chain in Oualidia lagoon will be necessary to confirm these contamination levels on one hand and to understand the phenomena of bioaccumulation and biomagnification of these persistent organic pollutants.

Acknowledgments

The authors would like to thank all colleagues of the monitoring network and the safety of the Oualidia station for their useful help during sampling.

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(reçu le 28/02/2017 ; accepté le 30/09/2017)

mis en ligne le 17/10/2017