JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(2), 121–133
https://doi.org/10.12911/22998993/196659
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.10.21
Accepted: 2024.12.15
Published: 2025.01.01

Distribution and health risks assessment of polychlorinated biphenyls in the muscles of *Oreochromis niloticus*, *Cyprinus carpio*, and *Sander lucioperca*, in Al-Massira Dam Lake (Morocco)

Loubna Ferraj[1*], Sara Ouahb[1], Meriem Bousseba[1], Lahcen Mly Ouahidi[2], Mohamed Kabriti[2], Mohammed El Bouch[2], Mustapha Hasnaoui[1]

[1] Environmental, Ecological and Agro-Industrial Engineering Laboratory. Faculty of Sciences and Techniques, Sultan Moulay Slimane University. BP. 523, 23 000 Beni Mellal, Morocco
[2] National Laboratory for Pollution Studies and Monitoring (LNESP), Rabat, Morocco
* Corresponding author's e-mail: ferraj01.loubna@gmail.com

ABSTRACT

This study investigates the contamination levels of non-dioxin-like polychlorinated biphenyls (PCBs) in three fish species (*Oreochromis niloticus, Cyprinus carpio,* and *Sander lucioperca*) from Al-Massira Dam, Morocco. The sources of PCBs contamination include industrial activities and sewage treatment plants located in the watershed of the Oum Rbiaa river, and lubricating oils from electric transformers rich in pyralene from nearby industries and towns. Fish samples collected between July 2022 and June 2023 were analyzed using gas chromatography-mass spectrometry to determine PCB concentrations. Results show varying PCB levels across species, with Sander lucioperca (5.084 ± 0.501) exhibiting the highest concentrations, followed by Cyprinus carpio (3.329 ± 0.323) and Oreochromis niloticus (2.167 ± 0.201). Predominant congeners include PCB28, PCB52, PCB101, and PCB180, reflecting species-specific accumulation patterns influenced by metabolic rates and dietary habits. Health risk assessments indicate that while PCB levels generally comply with safety guidelines for fish consumption, lifetime cancer risk (LCR) values exceed acceptable thresholds, particularly for adult and heavy fish consumers. Children, more vulnerable due to higher exposure and dietary habits, also face elevated risks. Non-carcinogenic hazard quotients (HQs) suggest high health risks for local fish consumers, emphasizing the need for ongoing monitoring and dietary management to mitigate PCB exposure. Although fish from Al-Massira Dam generally contain PCB levels below regulatory limits, their bioaccumulative nature underscores the importance of continued environmental monitoring and dietary management to protect public health.

Keywords: polychlorinated biphenyls, PCB non-dioxine-like, *Sander lucioperca*, *Cyprinus carpio*, *Oreochromis niloticus.*

INTRODUCTION

Environmental contamination by non-dioxin-like polychlorinated biphenyls (PCBs) represents a major global issue, exacerbated by rapid industrialization and urbanization. These persistent organic pollutants, derived from various industrial and commercial applications, pose significant threats due to their widespread presence in the environment, particularly in aquatic ecosystems. Indeed, the multiple sources of occasional inputs of PCBs are remobilization of PCBs contained in polluted sediments, liquid discharges from industries and sludge from sewage treatment plants located in the watershed of the Oum Er-Rbia River, uncontrolled emptying of old electrical transformers (MEMEE, 2014), accidental or deliberate leaks and spills from electrical appliances or hydraulic circuits, and reinforcement activities. Non-dioxin-like PCBs are synthetic compounds related to dioxin-like PCBs but lacking the same toxic properties (Henry et al., 2003; Klocke et al., 2020).

Their physical and chemical characteristics make them suitable for a range of industrial uses, including lubricants, hydraulic fluids, and insulation in electrical equipment. The historical use of non-dioxin-like PCBs raises concerns about their long-term environmental impact (Mort, 2017; Mrema et al., 2014).

Human exposure primarily occurs through the food chain and drinking water (Pastorino et al., 2021), posing a potential risk to public health. PCBs accumulate in aquatic organisms, especially fish, through biomagnification: smaller fish absorb these contaminants, and as larger predators consume them, PCB concentrations increase. This process adversely affects fish health, leading to reproductive disorders, immune system impairments, and physical malformations (Morrison et al., 2019). For humans, consuming contaminated fish can result in serious health risks, including neurological disorders and an increased risk of cancer (Jansen et al., 2020).

Despite regulatory efforts, non-dioxin-like PCBs continue to challenge environmental management and public health, necessitating ongoing vigilance and effective policies to reduce their presence (Klocke and Lein, 2020; Ravanipour et al., 2022). The accumulation of these toxins in aquatic ecosystems underscores the need for monitoring fish as indicators of contamination and implementing strict regulations to manage PCB levels (Häder et al., 2020; Javed and Usmani, 2019). This study, the first of its kind in Morocco, assesses environmental contaminants in three fish species from the Almassira Dam lake: Pike perch (*Sander lucioperca*), a top predator; common carp (*Cyprinus carpio*), a benthivore; and Nile tilapia (*Oreochromis niloticus*), an omnivore. These species provide diverse insights into PCB contamination levels and associated health risks.

MATERIALS AND METHODS

Study area

The Al Massira Dam, established in February 1979, serves as the centerpiece of the Oum Rabia watershed development plan. Located in the Settat province, 120 km southeast of Casablanca (32°28’32” North, 7°32’15” West), this dam is situated at an altitude of 385 m on the Oum Er Rabia River. It stretches 30 km in length, with a maximum width of 10 km and a depth reaching up to 40 m, covering an area of 139 km^2 and having a capacity of 2,760 million m^3. The water resources of this watershed primarily originate from the surface water of three major wadis as well as groundwater.

The sources of contamination by polychlorinated biphenyls (PCBs) in this area include oils from recreational and fishing boat engines, as well as industrial activities located in the watershed of the Oum Rabia River. Lubricating oils from transformers containing pyralene, sourced from nearby industries and towns, also contribute to this pollution. Additionally, improperly disposed plastic waste represents a significant source of contaminants (MEMEE, 2014).

PCBs enter the ecosystem through several pathways. Firstly, surface runoff during rainfall can transport these pollutants from spill areas into watercourses and ultimately into the dam. Secondly, industrial discharges may release contaminated wastewater directly into the Oum Rabia River. Lastly, soil erosion and sediment resuspension can release accumulated PCBs, increasing their concentration in the water (Figure 1).

Sampling

A total of seventy-two specimens (n = 24 for each species) of Oreochromis niloticus (20.5 cm to 45.8 cm), Cyprinus carpio (21.2 cm to 44.5 cm), and Sander lucioperca (26.3 cm to 50.7 cm) were purchased from local fishermen at the Al Massira Dam between July 2022 and June 2023. Upon capture, the fish were initially transported by the fishermen in large refrigerated containers equipped with freezers, ensuring low temperatures to minimize stress and decomposition. After purchase, the fish were placed in an insulated container with sufficient ice to maintain low temperatures during transport to the laboratory. Upon arrival at the laboratory, the specimens were immediately stored in a freezer at -20 °C to preserve their integrity until analysis. At the time of dissection, the fish were washed with distilled water, then dissected from the vertebral column to the dorsal fin, and the skin was removed to expose the muscle tissues.

Extraction and instrumental analysis

The first step involves preparing the samples. After freeze-drying and pulverizing the biota to ensure maximum homogeneity, 5 g of each sample are accurately weighed. This weighing is crucial to ensure the reproducibility of the results. The samples are then placed in Teflon

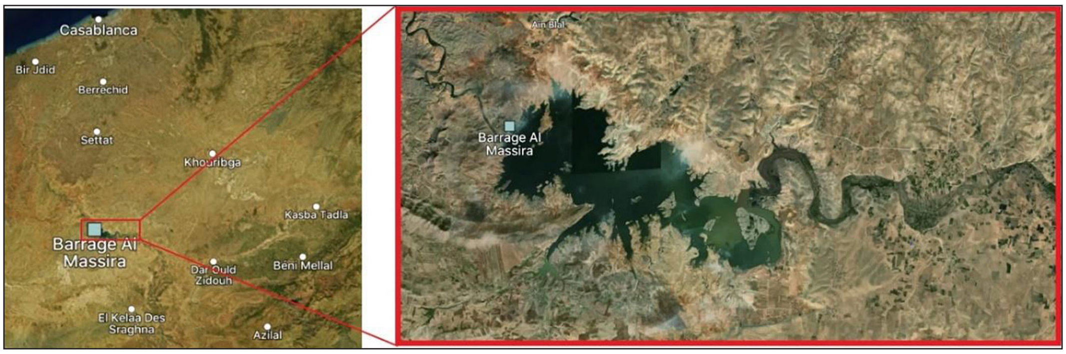

Figure 1. Location of the Al Massira Dam on the map of Morocco (Mapcarta, 2024)

tubes, and 30 mL of a mixture of hexane and acetone (27 mL of hexane and 3 mL of acetone) are added. This mixture is chosen for its ability to efficiently extract PCBs, which are organic contaminants. Each tube is supplemented with the addition of 100 µL of the internal standard. This addition allows for the verification of preparation effects, calculation of extraction yield, and compensation for variations in analysis, thereby ensuring better accuracy of the final results. After this meticulous preparation, the tubes are subjected to digestion in a microwave oven at 120 °C for 30 minutes, with a gradual heating phase. This step allows for the complete solubilization of the PCBs, facilitating their extraction. Once digestion is complete, the resulting liquid is recovered in a glass ampoule, and the tubes are rinsed with hexane to ensure that all contaminants are collected. The rinse liquid is added to the ampoule. Next, the liquid is condensed under nitrogen until a volume of 1 mL is obtained. This concentration process is essential for improving the detection of PCBs at low concentrations. Following this, 5 mL of sulfuric acid (H_2SO_4) are added and agitated. This step helps to eliminate interferences, making the hexane phase purer. Centrifugation at 4500 rpm for 5 minutes allows for the recovery of the hexane phase containing the PCBs in a flask. For fractionation, a florisil SPE cartridge is used. The column is pre-rinsed with 10 mL of hexane, and then the samples are added. After that, 10 mL of hexane are added to recover the first fraction of PCBs in a flask. The process is repeated with a mixture of hexane and dichloromethane (9 mL of hexane + 1 mL of dichloromethane) to obtain the second fraction of PCBs in the same flask. It is essential to control the drip rate at a pressure not exceeding 0.2 bar to avoid any product loss. Finally, the liquid is condensed under nitrogen until a volume of 1 mL is obtained, and then transferred to a 1 mL vial for further analysis. For the analysis of organic micropollutants, an Agilent 7890B gas chromatograph coupled with an Agilent 5977B single quadrupole mass spectrometer and equipped with an automatic sample changer was used (Cassi et al., 2019).

Statistical analysis

R software version 4.4.0 and Excel were used to perform descriptive statistics. Analysis of variance (ANOVA) and Tukey tests were conducted using R to compare concentrations of organochlorine pesticides (PCBs) among different fish muscles. Significance was defined at $p < 0.05$. When comparing multiple PCBs levels in fish tissues using ANOVA, data points below the detection limit (< BDL) were considered as zero using the method outlined by Cohen (US EPA, 2006).

The PCB concentrations initially reported in ng/g dry weight were converted to ng/g wet weight as follows: Cww = Cdw/FC Where: *Cww* represents the concentration in ng/g wet weight (ww); *Cdw* is the concentration in ng/g dry weight (Dw) and FC in the conversion factor.

NON-CARCINOGENIC RISK ASSESSMENT FOR HUMAN HEALTH

To assess the health risks associated with human exposure to contaminated food, a systematic risk assessment approach was applied (USEPA, 2006). This assessment is based on criteria adapted from USEPA (1996): (1) a standard body weight of 30 kg for children around 10 years old and 73.3 kg for adults, and (2) a fish consumption rate of 13.87 kg per year in Morocco (Kasmi *et al*., 2023; Azekour *et al*., 2020), with a higher consumption rate of 20.5 kg per year for regular consumers (FAO, 2011). The formula for calculating the Estimated Average Daily Intake (EADI) is:

$$EADI\left(\frac{\frac{ug}{Kg}}{yr}\right) = \frac{Congener\ concentration \times Food\ consumption}{Body\ weight} \quad (1)$$

This calculation allows for the comparison of the EADI to the reference dose (RfD), which indicates the exposure level below which adverse effects on sensitive populations are unlikely.

NONCARCINOGENIC HAZARD QUOTIENT

To determine the non-carcinogenic risk associated with the consumption of PCB-contaminated fish, the Hazard Quotient (HQ) is calculated as follows (Alla et al., 2013):

$$HQ = \frac{EADI}{RfD} \quad (2)$$

where: *HQ* represents the non-carcinogenic risk quotient for PCBs, *EADI* is the Estimated Average Daily Intake, and *RfD* is the reference dose.

Non-carcinogenic screening levels are set with a target *HQ* of 1; an *HQ* greater than 1 indicates a potential health risk.

CARCINOGENIC RISK TO HUMAN HEALTH

To assess oral exposure to PCBs in fish muscle, we used the formula for the average daily dose (ADD), which estimates the average PCB exposure over a lifetime in terms of carcinogenic substances (USEPA, 2000):

$$ADD(\text{mg/kg/day}) = \frac{Cp \times IR \times EF \times ED}{BW \times AT} \quad (3)$$

where: *Cp* is the concentration of PCBs in fish (mg/kg), *IR* is the ingestion rate, set at 0.038 kg/day for children and adults, and approximately 0.056 kg/day for frequent fish consumers, *EF* is the exposure frequency (365 days/year), *ED* is the exposure duration over a lifetime (70 years for both children and adults), *BW* is body weight (30 kg for children and 70 kg for adults), and *AT* is the total lifetime (70 years × 365 days/year). The formula to calculate the *ADD* for a 70-year exposure is:

$$ADD(\text{mg/kg/day}) = \frac{Cp \times IR}{BW} \quad (4)$$

LIFETIME CANCER RISK

The lifetime cancer risk (LCR) measures the probability of developing cancer due to continuous exposure over a long period. It reflects the exposure level at which the likelihood of cancer is 1 in 1 million for adults and 1 in 100,000 for children. This risk is calculated as follows:

$$LCR = ADD \times CSF \quad (5)$$

where: *CSF* is the cancer slope factor, set at 2.0 mg/kg/day for PCBs (USEPA, 2009).

For carcinogenic risk, the carcinogenic risk quotient is determined by:

$$HQ = \frac{ADD}{oral\ RfD} \quad (6)$$

where: the oral *RfD* for acceptable daily intake of PCBs is 0.00002 mg/kg/day. An *HQ* greater than 1 is considered a health risk.

RESULT AND DISCUSSION

Distribution of PCBs non dioxine like among fish muscles of *Oreochromis niloticus*, *Cyprinus carpio* and *Sander lucioperca*

The mean concentration of ΣPCBs in *O. niloticus* ranged from BDL to 9.085ng/g ww (2.167 ± 0.201) in muscles, while in *C. carpio*, it ranged from BDL to 12.169 ng/g ww (3.329 ± 0.323), and in *S. lucioperca*, it ranged from BDL to 24.532ng/g ww (5.084 ± 0.501) (Table 1). The results of the analysis of variance showed that the PCB content among the muscles of the three species was significantly different (P = 0.0472 *), and Tukey's test results indicated a significant difference between *S. lucioperca* and *O. niloticus* (Padj = 0.0396262).

A higher concentration of PCBs was observed in the muscles of *S. lucioperca*, followed by *C. carpio*, and then by *O. niloticus* (Figure 2). This is attributed to the lipophilic nature of PCBs, which promotes their accumulation along the food chain with increasing concentrations at each trophic level (Borgå *et al*., 2022). *S. lucioperca* is a top predator in aquatic ecosystems, frequently feeding on other fish and aquatic organisms that may contain high PCB concentrations. The feeding behavior of pike perch, which often includes consuming larger fish and crustaceans, significantly contributes to PCB exposure. The capacity to metabolize and eliminate contaminants varies among each species of these three fish (Brázová *et al*., 2012; Nikolić *et al*., 2023).

The muscles of these three species were analyzed for the presence of four non-dioxin-like PCBs (PCB28, PCB52, PCB101, PCB180). The percentage of samples in which these investigated NDL-PCBs were not detected (LOD%) was 17.70% for *O. niloticus*, 30.20% for *C. carpio*, and 29.16% for *S. lucioperca,* indicating widespread contamination in the study area. Non-dioxin-like PCBs (NDL-PCBs) are prevalent in the environment (Abramowicz,1985), and their accumulation in fish depends on various factors including their concentration in water, the lifespan of the fish species, and their fat content (Bartalini *et al*., 2020; Trocino *et al*., 2009).

The main contributors of ΣNDL-PCBs in the muscles of *O. niloticus* were PCB28 (35.36%), followed by PCB180 (25.62%), PCB101 (22.01%), and PCB52 (17.01%). For *C. carpio*, the order of PCB congener contributions was PCB101 (28.06%), PCB180 (28.06%), PCB28 (27.86%), and PCB52 (11.06%). In *S. lucioperca*, the contributions were PCB101 (31.3%), PCB180 (29.3%), PCB28 (23.21%), and PCB52 (16.19%) (Figure 3). These differences depend on the physicochemical properties of PCBs, environmental conditions, and the accumulation potential of each fish. The differential distribution of PCBs in fish muscle tissues provides clues about potential contamination sources and exposure pathways in the aquatic ecosystems from which these fish were sampled (Beyer and Biziuk., 2009; Shaw and Connell., 1984).

The six most commonly found congeners, namely PCB-28, PCB-52, PCB-101, PCB-138, PCB-153, and PCB-180, constitute approximately 50% of all PCB congeners found in animal-derived foods and human fats, and are referred to as PCB indicators (Arnich *et al*., 2009). Among these PCB indicators, PCB-180, which is highly persistent, has been subject to specific regulations in some European countries and has a half-life of up to 9.9 years. PCB-28, PCB-52, and PCB-101, less persistent with respective half-lives of up to 4.8 years, 5.5 years, and 5.7 years (Elabbas *et al*., 2013), are considered indicators of recent contamination (Arnich *et al*., 2009).

Carnivorous fish, occupying the highest trophic level in the ecosystem, generally have a higher lipid content compared to other fish with different feeding habits. Previous research has also demonstrated that carnivorous fish tend to accumulate higher levels of PCBs, lipophilic pollutants that accumulate extensively in adipose tissue. Recent research has demonstrated that adipocytes from various cell culture models can accumulate markedly different levels of PCB28, even when exposed to the same initial concentration in the culture medium. This accumulation was found to have a strong correlation with the quantity of triglycerides stored in the cells. (Bourez *et al*., 2013).

In our study, *S. lucioperca* exhibited higher concentrations of NDL-PCBs compared to *O. niloticus* and *C. carpio* (Table 1). Our results align with those found in Italy (Squadrone *et al*., 2015) and differ from those observed in Poland, Norway, and Scotland (Mikolajczyk *et al*., 2020; Pohořelá *et al*., 2022).

Differences and similarities observed in contamination levels result from the specific characteristics of each fish species, such as their metabolic rate, body size, and detoxification capacity. These individual factors can influence the accumulation and metabolism capacity of contaminants in fish muscle tissues, as well as pollution levels in each study area (Redondo-López *et al*., 2022).

This study, the first in Morocco to specifically focus on PCB concentrations in fish, particularly in *Oreochromis niloticus*, *Cyprinus carpio*, and *Sander lucioperca* at the Al-Massira dam, provides significant insights into local contamination levels. Other studies on Moroccan aquatic ecosystems also report elevated PCB levels. For instance, in the Oualidia lagoon, sediments exhibit PCBs concentrations reaching 18.6 ng/g (Jayed et al., 2015), indicating persistent contamination and potential exposure for benthic species. Similarly, analyses conducted by Bouchaib et al. (2007) in the Moulay Bousselham lagoon reveal PCB concentrations in mullet tissues of up to 82.39 ng/g, highlighting concerning bioaccumulation in this ecosystem. Along the Mediterranean coast, between Tangier and Al Hoceima, Kessabi et al. (1988) measured up to 500 ng/g of organochlorine contaminants, including PCBs, in industrial effluents, representing a significant pollution source in the coastal waters of the region. These findings demonstrate that PCB contamination is present across various Moroccan aquatic ecosystems, underscoring a widespread environmental issue. The PCBs present in water and sediments bioaccumulate in fish, increasing risks to ecosystem health and consumer safety. This emphasizes the importance of proactive environmental

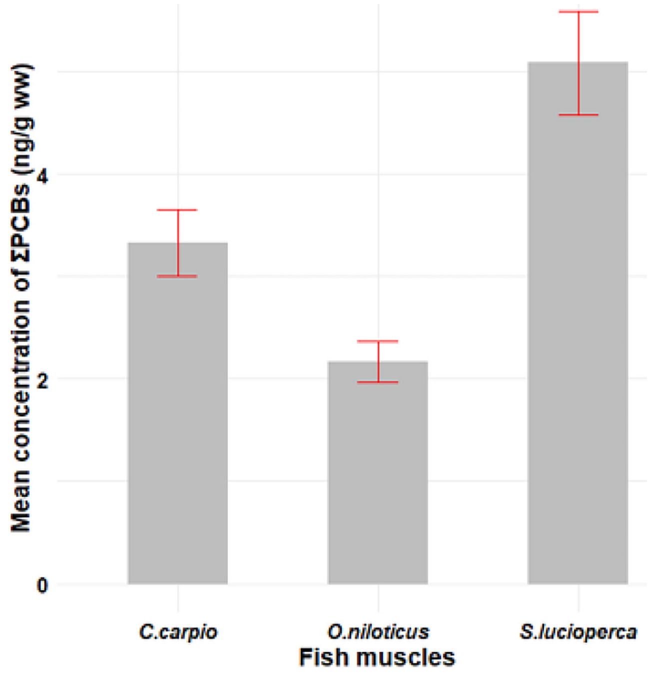

Figure 2. Mean concentration (± SE) of PCBs in fish muscles of *C.carpio*, *O.niloticus* and *S. lucioperca*

management to mitigate the impacts of these persistent pollutants.

The coefficients of determination (R^2) obtained for the four types of PCBs (PCB28, PCB52, PCB101, and PCB180) indicate that the fish body length explains only a very small portion of the variance in PCB levels in *Oreochromis niloticus* (0.32% to 2.03%), *Cyprinus carpio* (0% to 0.3%), and *Sander lucioperca* (0.18% to 3.98%), (Figure 4, 5 and 6 respectively). These results align with the findings of previous studies, suggesting that other biological factors, such as metabolic rate, detoxification capacity, and lipid content of tissues, have a more significant influence on PCB bioaccumulation in fish (Polder et al., 2014; Barakat et al., 2017). In *O. niloticus*, the negative regression coefficients for PCB52 and PCB180 indicate a slight decrease in PCB levels with increasing length, while PCB28 and PCB101 exhibit positive coefficients, albeit non-significant ($p > 0.05$). A study conducted by Polder et al. (2014) on tilapias in various African

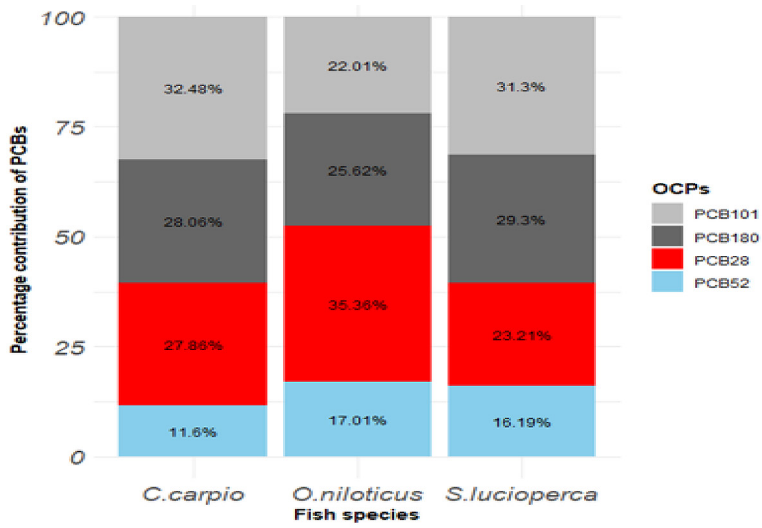

Figure 3. Percentage contributions of PCB28, PCB52, PCB101 and PCB180, in muscles of *C. carpio*, *O. niloticus* and *S. lucioperca*

lakes demonstrated that PCB bioaccumulation varies according to environmental conditions and pollution sources specific to each site. In particular, the low detoxification capacity of *O. niloticus* may contribute to the accumulation of metabolically resistant PCBs, such as PCB153 and PCB180, due to limited enzymatic degradation (Arellano-Aguilar et al., 2009).

For *S. lucioperca*, the low R^2 values, combined with the negative coefficients for PCB52 and PCB180, suggest that body length has a minimal effect on PCB bioaccumulation. The positive coefficients for PCB28 and PCB101 may reflect a trophic bioamplification effect, as this species occupies a high position in the food chain (Nikolić et al., 2021). Furthermore, detoxification capacities dependent on cytochrome P450, particularly P4501A and P4502B, play a crucial role in the metabolism of specific PCB congeners, although this enzymatic activity is limited for certain persistent congeners (Kania-Korwel et al., 2016).

For *C. carpio*, the results reveal extremely low R^2 values, suggesting that body length has virtually no influence on PCB levels. This benthic and long-lived species is often in direct contact with contaminated sediments, which could explain the increased accumulation of PCBs in its tissues (Tian et al., 2012). According to Pérez-Fuentetaja et al. (2010), PCBs preferentially accumulate in the fat tissues of *C. carpio*, a characteristic exacerbated by the limited capacity of this species to metabolize the most resistant PCBs.

These differences among species in PCB bioaccumulation may be explained by variations in metabolic rate, detoxification capacity, and feeding behavior. Madenjian et al. (2011) show that fish with a rapid metabolism tend to eliminate certain PCB congeners more efficiently, thereby reducing their accumulation. These findings suggest that while body length has a limited impact on PCBs levels, bioaccumulation is more influenced by biological and environmental factors specific to each species, as confirmed by the work of Polder et al. (2014) and Barakat et al. (2017).

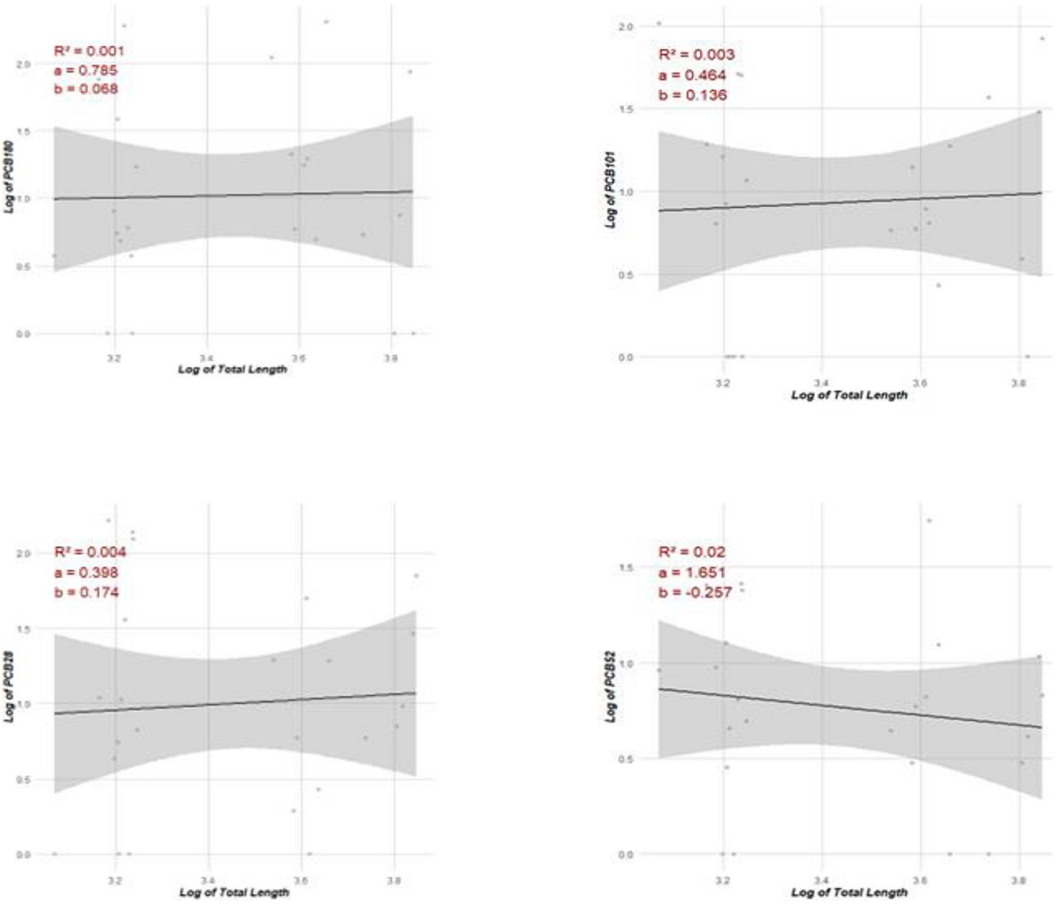

Figure 4. Relationship between total length and PCB28, PCB52, PCB101, and PCB180 concentrations in *O. niloticus*

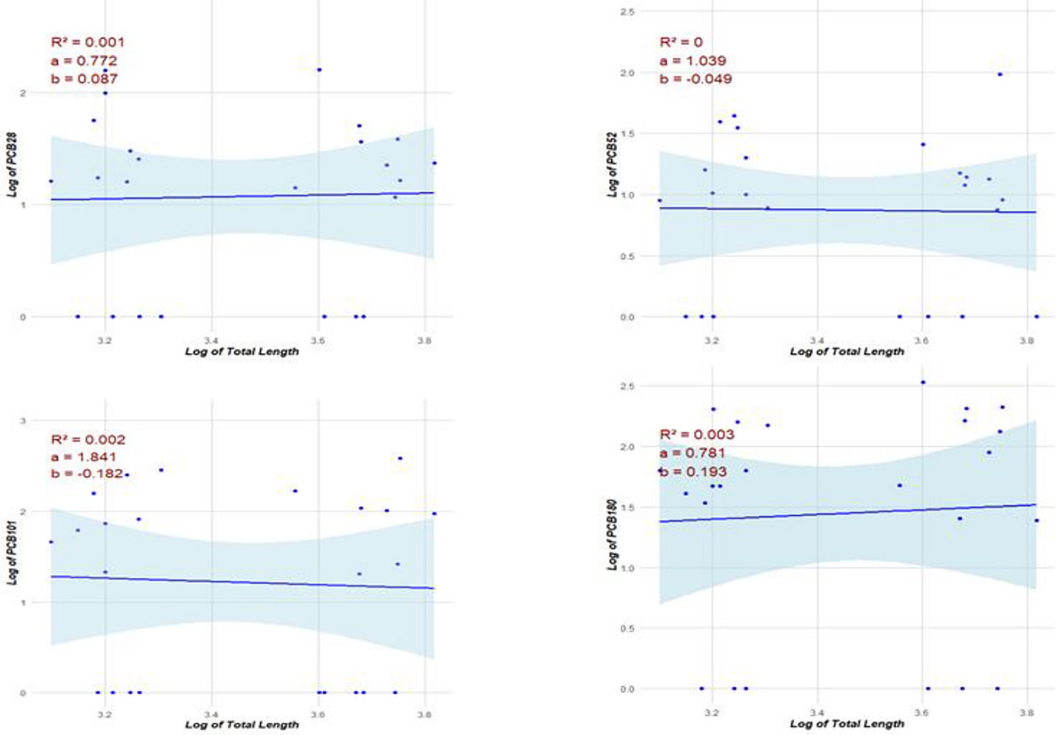

Figure 5. Relationship between total length and PCB28, PCB52, PCB101, and PCB180 concentrations in *C. carpio*

RISK ASSESSMENT OF NDL-PCBS CONGENERS IN *O. NILOTICUS*; *C. CARPIO*; *S. LUCIOPERCA*

Persistent organic pollutants (POPs), including PCBs, are particularly worrisome because of their long-lasting presence and tendency to accumulate in the food chain, leading to adverse effects on various organisms. Human exposure to PCBs is predominantly through diet, with nearly 90% of intake coming from food sources. Although fish constitutes a relatively minor component of the overall human diet compared to other food groups like meat and dairy products, it can account for up to 50% of PCB exposure (Kiviranta *et al*., 2005). Additionally, certain populations may face elevated PCB levels due to their specific eating patterns. Consequently, the aquatic environment plays a crucial role in the introduction of PCBs into the food chain.

To evaluate the effects of PCB28, PCB52, PCB101, and PCB180 concentrations on human health, the levels of these contaminants in the muscles of *O. niloticus*, *C. carpio*, and *S. lucioperca* were compared to international standards, as shown in Table 1. These concentrations were found to be below the safe threshold of 2 ppm for fish established by the United States Environmental Protection Agency (USEPA, 2000). However, PCB levels may still pose a direct health risk, particularly for low-income families and frequent fish consumers from the Al Massira dam region.

Estimated average daily intake

The EADI was based on the measured concentration of PCBs in fish from Al Massira Dam for a child weighing 30 kg and an adult weighing 73.3 kg, with a consumption rate of 13.87 kg per year for both children and adults, and a consumption of 56.164 kg per year for heavy fish consumers. At the mean concentration, the EADI ranged from 0.00062 to 0.0011 for children; from 0.00025 to 0.00048 for adults; and from 0.00038 to 0.00071 for heavy consumers of *O. niloticus*. It ranged from 0.00071 to 0.0014 for children; from 0.00029 to 0.00096 for adults; and from 0.00043 to 0.00141 for heavy consumers of *C. carpio*. For *S. lucioperca*, it ranged from 0.0016 to 0.0036 for children; from 0.00065 to 0.0014 for adults; and from 0.00096 to 0.00219 for heavy consumers (Table 2).

The non-carcinogenic hazard quotient (HQ) for humans exposed to PCBs via the ingestion of contaminated fish was evaluated. The HQ values for children, adults, and frequent fish consumers were

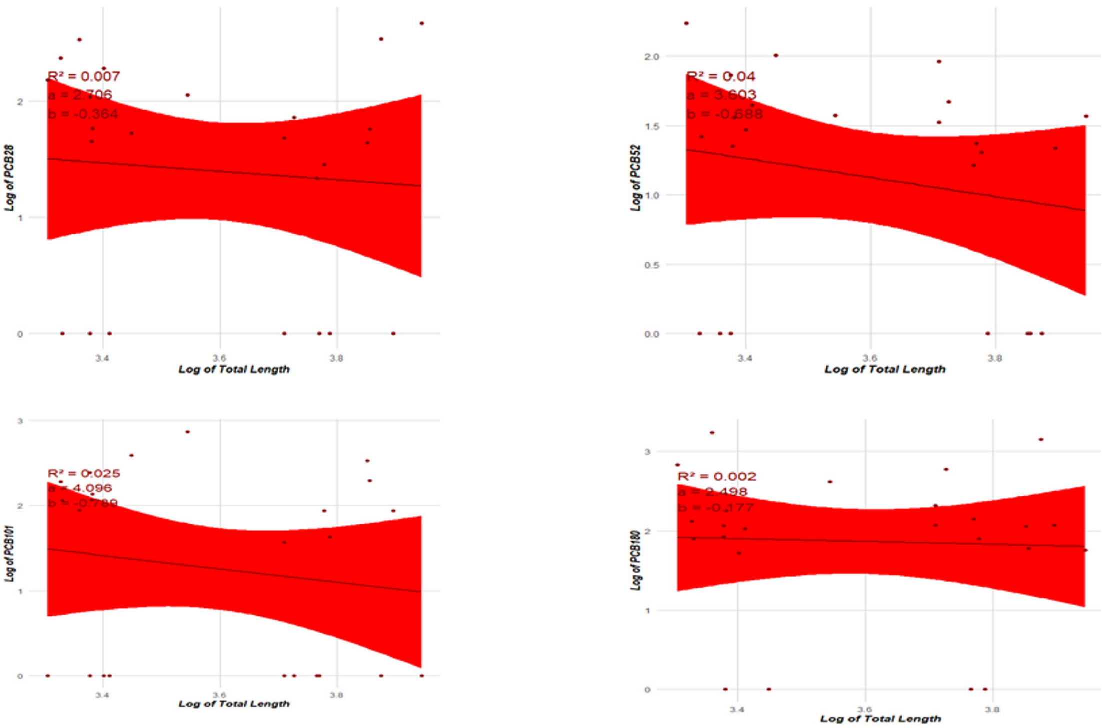

Figure 6. Relationship between total length and PCB28, PCB52, PCB101, and PCB180 concentrations in *S. lucioperca*

Table 1. Comparison of Mean concentration (± SE) NDL-PCBs (ng/g ww) reported in muscles of fish species from regions in the world (range in bold)

Region	Species	PCB28	PCB52	PCB101	PCB180	Ndl-PCBs	References
Morocco	Oreochromis niloticus	2.418 ± 0.501 BDL-8.193	1.392 ± 0.236 BDL-4.721	2.054 ± 0.381 BDL-6.531	2.554 ± 0.553 BDL-9.085	2.167 ± 0.201 BDL-9.085	This study
Morocco	Cyprinus carpio	2.714 ± 0.491 BDL- 8.073	1.834 ± 0.328 BDL- 6.256	4.055 ± 0.798 BDL- 12.169	4.712 ± 0.721 BDL- 11.582	3.329 ± 0.323 BDL-12.169	This study
Morocco	Sander lucioperca	4.774 ± 0.84 BDL-13.434	2.913 ± 0.476 BDL-8.385	4.787 ± 0.998 BDL-16.638	7.860 ± 1.295 BDL-24.532	5.084 ± 0.501 BDL-24.532	This study
Kattegat	Gadus morhua		0.2 × 10³	0.4 × 10³	0.3 × 10³		Karl *et al.*, 2009
Coast of Poland	Gadus morhua		0.1 × 10³	0.4 × 10³	0.2 × 10³		Karl et al., 2009
Poland	pike					1.17 ± 0.33 0.94-1.41	Mikolajczyk *et al.*, 2020
Poland	Blicca bjoerkna					26.81 ± 2.35 25.37-29.52	Mikolajczyk *et al.*, 2020
Italy	*Salmo trutta*	2.98	4.65	2.73	6.77		Squadrone *et al.*, 2015
Italy	Barbus barbus	1.22	1.27	1.22	5.30		Squadrone *et al.*, 2015
Italy	Anguilla anguilla	2.06	3.3	3.7	29.37		Squadrone *et al.*, 2015
Norway-Central	Atlantic salmon	0.162 ± 0.048	0.258 ± 0.089	0.448 ± 0.239	0.337 ± 0.102	3.54 ± 1.23	Pohořelá *et al* ., 2022
Scotland	Atlantic salmon			0.288 ± 0.237	0.175 ± 0.131	1.47 ± 0.685	Pohořelá *et al.*, 2022

all below 1 (Table 3). These results indicate a low non-carcinogenic health risk for populations fishing in the Al Massira Dam, suggesting that consuming fish from this dam presents a low risk to health.

LCR and hazard index

The lifetime cancer risk (LCR) values (Tables 4 and 5) for consumption of *O. niloticus*

Table 2. The estimated Average dayly intake (EADI) for NDL-PCBs concentrations in muscles of *Oreochromis niloticus*, *Cyprinus carpio* and *Sander lucioperca* from Barrage Al-Massira, Morocco

PCBs	*Oreochromis niloticus*			*Cyprinus carpio*			*Sander lucioperca*		
	Children	Adult	Heavy consumers	Children	Adult	Heavy consumers	Children	Adult	Heavy consumers
PCB28	0.0011	0.00045	0.00066	0.00145	0.00059	0.00088	0.00194	0.00079	0.00117
PCB52	0.00062	0.00026	0.00039	0.00072	0.00029	0.00043	0.00160	0.00079	0.00097
PCB101	0.00094	0.00039	0.00057	0.00234	0.00096	0.00141	0.00193	0.00079	0.00117
PCB180	0.00117	0.00048	0.00071	0.00216	0.00088	0.00130	0.00363	0.00148	0.00219

Table 3. The non- carcinogenic hazard quotient (HQ) for NDL-PCBs congeners detected in the muscles of three fish species *Oreochromis niloticus*, *Cyprinus carpio* and *Sander lucioperca* from Al Massira Reservoir Morocco

PCBs	*Oreochromis niloticus*			*Cyprinus carpio*			*Sander lucioperca*		
	Children	Adult	Heavy consumers	Children	Adult	Heavy consumers	Children	Adult	Heavy consumers
PCB28	0.005	0.00225	0.00332	0.00725	0.00297	0.00439	0.0097	0.00395	0.00587
PCB52	0.0031	0.00128	0.00193	0.00358	0.00146	0.00216	0.008	0.00328	0.00484
PCB101	0.0094	0.00194	0.00286	0.0117	0.00345	0.00705	0.00965	0.00395	0.00584
PCB180	0.00585	0.00241	0.00356	0.0108	0.0044	0.00654	0.01815	0.00742	0.01096

contaminated with 4 non-dioxin-like PCBs were between 0.00027 and 0.00051 for children, between 0.00014 and 0.00026 for adults, and between 0.0002 and 0.00038 for heavy fish consumers. The LCR for consumption of *C. carpio* contaminated ranged from 0.00031 to 0.001 for children, from 0.00016 to 0.00052 for adults, and from 0.00023 to 0.00077 for heavy fish consumers. For consumption of contaminated *S. lucioperca*, LCR values varied from 0.00083 to 0.0015 for children, from 0.00036 to 0.00081 for adults, and from 0.00052 to 0.00119 for heavy consumers of this fish. The LCR values in our study are higher than the theoretical risk threshold of 1.0E-06 or 1 in 1,000,000. This suggests that exposure to PCBs through consumption of these three species of contaminated fish may pose an increased cancer risk for adults, especially those who are heavy consumers of fish, and for children who are generally more vulnerable to the effects of toxic substances due to their metabolism and ongoing development. It may be recommended to limit consumption of these fish or implement measures to reduce PCB exposure to minimize health risks. Children are more susceptible to adverse health effects than adults due to their developing immune systems. Additionally, children are at higher trophic levels in the food web and are directly exposed to potential contaminants (Damstra, 2002). The hazard quotient (HQ) values were significantly higher than 1 for the three fish species among children, adults, and high fish consumers (Table 6). Furthermore, while the method assesses cancer risk for each individual PCB, it's important to note that fish may contain mixtures of PCBs, and the combined effects of these chemicals may differ from those of individual chemicals alone. Additionally, exposure assessment relies on measured concentrations of PCBs in fish muscles, which may not fully represent actual exposure levels due

Table 4. The average daily intake (ADD) of NDL-PCBs over a lifetime of consumption of three fish species *Oreochromis niloticus*, *Cyprinus carpio* and *Sander lucioperca* from Al Massira reservoir Morocco

PCBs	*Oreochromis niloticus*			*Cyprinus carpio*			*Sander lucioperca*		
	Children	Adult	Heavy consumers	Children	Adult	Heavy consumers	Children	Adult	Heavy consumers
PCB28	0.00024	0.00012	0.00018	0.00031	0.00016	0.00024	0.00042	0.00022	0.00032
PCB52	0.00013	0.00007	0.0001	0.00015	0.00008	0.00012	0.00034	0.00018	0.00026
PCB101	0.0002	0.00011	0.00016	0.00051	0.00026	0.00037	0.00042	0.00022	0.00032
PCB180	0.00025	0.00013	0.00019	0.00047	0.00024	0.00036	0.00079	0.00041	0.0006

Table 5. Lifetime cancer risk (LCR) for children, adult and heavy consumers of three fish species *Oreochromis niloticus*, *Cyprinus carpio* and *Sander lucioperca* from Al Massira reservoir Morocco

PCBs	*Oreochromis niloticus*			*Cyprinus carpio*			*Sander lucioperca*		
	Children	Adult	Heavy consumers	Children	Adult	Heavy consumers	Children	Adult	Heavy consumers
PCB28	0.00048	0.00024	0.00036	0.00062	0.00032	0.00048	0.00084	0.00044	0.00064
PCB52	0.00026	0.00014	0.0002	0.00030	0.00016	0.00024	0.00068	0.00032	0.00052
PCB101	0.0004	0.00022	0.00032	0.00102	0.00052	0.00074	0.00084	0.00044	0.00064
PCB180	0.00050	0.00026	0.00038	0.00094	0.00048	0.00072	0.00016	0.00082	0.0012

Table 6. Hazard index (HI) for children, adult and heavy consumers of three fish species *Oreochromis niloticus*, *Cyprinus carpio* and *Sander lucioperca* from Al Massira reservoir Morocco

PCBs	*Oreochromis niloticus*			*Cyprinus carpio*			*Sander lucioperca*		
	Children	Adult	Heavy consumers	Children	Adult	Heavy consumers	Children	Adult	Heavy consumers
PCB28	12	6	9	15.5	8	12	21	11	16
PCB52	6.5	3.5	5	7.5	4	6	17	9	13
PCB101	10	5.5	8	25.5	13	18.5	21	11	16
PCB180	12.5	6.5	9.5	23.5	12	18	39.5	20.5	30

to factors such as bioaccumulation, variability in fish consumption habits, and differences in cooking methods. Moreover, assuming that individuals are consistently exposed to PCBs at the evaluated levels throughout their lifetime may not accurately reflect real exposure scenarios, especially considering potential changes in PCB levels over time. This highlights the dynamic nature of PCB exposure across a lifetime, ignoring possible variations in exposure over time. PCB levels in the environment can vary due to factors such as agricultural practices, environmental regulations, industrial production methods, and evolving consumption patterns (Qu *et al*., 2015; Thiombane *et al*., 2018).

CONCLUSIONS

The concentrations of PCBs in the studied fish were generally below the safety levels recommended by the US Environmental Protection Agency (USEPA). However, despite these relatively low levels, the values of the Lifetime Cancer Risk (LCR) exceed the theoretical risk threshold for long-term daily exposure, indicating an increased cancer risk for adults, with a probability exceeding 1 in 1,000,000, as well as for children, whose risk exceeds 1 in 100,000. While consuming fish from the Al Massira Dam poses potential health risks, these can be mitigated through careful consumption management and rigorous monitoring of environmental contamination.

To improve the management of PCBs, it is recommended to establish regular monitoring of affected aquatic ecosystems, implement enhanced controls on industrial discharges, and conduct awareness-raising measures for the population regarding the risks associated with consuming contaminated fish. Additionally, guidelines to limit consumption in at-risk areas, along with rehabilitation actions such as sediment cleanup and the establishment of protected areas, will contribute to reducing exposure and preserving ecosystem health.

REFERENCES

1. Abramowicz D.A. (1995). Aerobic and anaerobic PCB biodegradation in the environment. *Environmental health perspectives*, *103*(5), 97–99.
2. Alla S. A. G., Ayoub M. M., Amer M. A., & Thabet, W. M. (2013). Dietary intake of pesticide residues in some Egyptian fruits. *Journal of Applied Sciences Research*, *9*(1), 965–973.
3. Arellano-Aguilar, O., Montoya, R. M., & Garcia, C. M. (2009). Endogenous functions and expression of cytochrome P450 enzymes in teleost fish: a review. *Reviews in Fisheries Science*, *17*(4), 541–556.
4. Arnich N., Tard A., Leblanc J. C., Le Bizec, B., Narbonne, J. F., & Maximilien R. (2009). Dietary intake of non-dioxin-like PCBs (NDL-PCBs) in France,

impact of maximum levels in some foodstuffs. *Regulatory Toxicology and Pharmacology*, *54*(3), 287–293.

5. Azekour K., Idir I., Lahrach, N., & El Bouhali B. (2020). Prévalence de l'obésité et du surpoids en milieu scolaire, oasis de Tafilalet, sud-est du Maroc. *Pan African Medical Journal*, *35*(1).
6. Barakat, A. O., Khairy, M., & Aukaily, I. (2017). Bioaccumulation of organochlorine contaminants in fish species from Lake Qarun, a protected area of Egypt. *Toxicological & Environmental Chemistry*, *99*(1), 117–133.
7. Bartalini A., Muñoz-Arnanz J., Baini M., Panti C., Galli M., Giani, D., & Jiménez B. (2020). Relevance of current PCB concentrations in edible fish species from the Mediterranean Sea. *Science of The Total Environment*, *737*, 139520.
8. Beyer A., & Biziuk M. (2009). Environmental fate and global distribution of polychlorinated biphenyls. *Reviews of Environmental Contamination and Toxicology, 201*, 137–158.
9. Borgå K., McKinney M. A., Routti H., Fernie K. J., Giebichenstein J., Hallanger I., & Muir D. C. (2022). The influence of global climate change on accumulation and toxicity of persistent organic pollutants and chemicals of emerging concern in Arctic food webs. *Environmental Science: Processes & Impacts*, *24*(10), 1544–1576.
10. Bouchaib, B., Mohamed, F., Larbi, I., & Pierre, L. (2007). Résidus de pesticides organochlorés chez les bivalves et les poissons de la lagune de Moulay Bousselham (Maroc). *Afrique Science: Revue Internationale des Sciences et Technologie*, *3*(1).
11. Bourez S., Van den Daelen C., Le Lay S., Poupaert J., Larondelle Y., Thomé J. P.,... & Debier C. (2013). The dynamics of accumulation of PCBs in cultured adipocytes vary with the cell lipid content and the lipophilicity of the congener. *Toxicology letters*, *216*(1), 40–46.
12. Brázová T., Hanzelová V., Miklisová D., Šalgovičová D., & Turčeková Ľ. (2012). Biomonitoring of polychlorinated biphenyls (PCBs) in heavily polluted aquatic environment in different fish species. *Environmental Monitoring and Assessment*, *184*, 6553–6561.
13. Cassi R., Choyke S., Huertas D., Tolosa I. (2019). IAEA –Environment Laboratories – Marine Environmental Studies Laboratories MEDPOL - Trace Organic Contaminants Training Course.
14. Damstra T. (2002). Potential effects of certain persistent organic pollutants and endocrine disrupting chemicals on the health of children. *Journal of Toxicology: Clinical Toxicology*, *40*(4), 457-465.
15. Elabbas L. E., Westerholm E., Roos R., Halldin K., Korkalainen M., Viluksela M., & Håkansson H. (2013). Non-dioxin-like polychlorinated biphenyls (NDL-PCBs) in foods: exposure and health hazards. In *Persistent Organic Pollutants and Toxic Metals in Foods* 215–260. Woodhead Publishing.
16. FAO, Food and Agriculture Organization. (2011). Fishery and Aquaculture Statistics, 2009. Statistics and Information Service of the Fisheries and Aquaculture Department/Service. Rome/Roma, Italy:FAO.
17. Häder D. P., Banaszak A. T., Villafañe V. E., Narvarte M. A., González R. A., & Helbling E. W. (2020). Anthropogenic pollution of aquatic ecosystems: Emerging problems with global implications. *Science of the Total environment*, *713*, 136586.
18. Henry T. R., & DeVito M. J. (2003). *Non-dioxin-like PCBs: effects and consideration in ecological risk assessment*. Washington, DC: Ecological Risk Assessment Support Center, Office of Research and Development, US Environmental Protection Agency.
19. Javed M., & Usmani N. (2019). An overview of the adverse effects of heavy metal contamination on fish health. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, *89*, 389–403.
20. Jayed, M., Benbrahim, S., Rharbi, N., Lakhlalki, H., Flower, R., Benhra, A., & Bouthir, F. Z. (2017). Contamination of shellfish by organochlorine pesticides and polychlorinated biphenyls in the lagoon of Sidi Moussa (Morocco). *Bull. Soc. zool. Fr*, *142*(1–3), 89–99.
21. Kania-Korwel, I., & Lehmler, H. J. (2016). Chiral polychlorinated biphenyls: absorption, metabolism and excretion—a review. *Environmental Science and Pollution Research*, *23*, 2042–2057.
22. Karl H., & Lahrssen-Wiederholt M. (2009). Dioxin and dioxin-like PCB levels in cod-liver and-muscle from different fishing grounds of the North-and Baltic Sea and the North Atlantic. *Journal für Verbraucherschutz und Lebensmittelsicherheit*, *4*, 247–255.
23. Kasmi K., Belhaj K., Nasri H., Slimani D., Allai L., Mansouri F., & Chafi A. (2023). Heavy Metals Concentration in Sardina pilchardus (Walbaum, 1792) from the Moroccan Mediterranean Coast and Potential Human Health Risk Assessment. *Journal of Food Quality*, *2023*(1), 1455410.
24. Kessabi, M., Elhraiki, A., & Nader, B. (1988). Contamination of urban, industrial and continental waters by chlorinated hydrocarbon pesticides along the Mediterranean coast of Morocco. *Science of the total environment*, *71*(2), 209–214.
25. Kiviranta H. 2005. Exposure and human PCDD/F and PCB body burden in Finland.
26. Klocke C., & Lein P. J. (2020). Evidence implicating non-dioxin-like congeners as the key mediators of polychlorinated biphenyl (PCB) developmental neurotoxicity. *International journal of molecular sciences*, *21*(3), 1013.
27. Klocke C., & Lein P. J. (2020). Evidence implicating non-dioxin-like congeners as the key mediators

of polychlorinated biphenyl (PCB) developmental neurotoxicity. *International journal of molecular sciences*, *21*(3), 1013.

28. Mapcarta. (2024). *Mapcarta*. Récupéré sur Mapcarta: https://mapcarta.com/
29. MEMEE (Ministre de l'énergie, des mines, de l'eau, et de l'environnement), (2014). Programme de Gestion Sécurisée des PCB au Maroc. Pilier I. PNUD/ONUDI. 123.
30. Mikolajczyk, S., Warenik-Bany, M., Maszewski, S., & Pajurek, M. (2020). Dioxins and PCBs–Environment impact on freshwater fish contamination and risk to consumers. *Environmental Pollution*, *263*, 114611.
31. Mort S. A. (2017). *Mass spectrometric methods for the determination of PCB congeners for environmental risk assessment*. North Carolina State University.
32. Mrema E. J., Rubino F. M., Mandic-Rajcevic S., Sturchio E., Turci R., Osculati A. N. T. O. N. I. O., & Colosio C. (2014). Exposure to priority organochlorine contaminants in the Italian general population. Part 2: Fifteen priority polychlorinated biphenyl congeners in blood serum. *Human & experimental toxicology*, *33*(2), 170–184.
33. Nikolić D., Poleksić V., Tasić A., Smederevac-Lalić M., Djikanović V., & Rašković B. (2023). Two Age Groups of Adult Pikeperch (*Sander lucioperca*) as Bioindicators of Aquatic Pollution. *Sustainability*, *15*(14), 11321.
34. Nikolić, D., Skorić, S., Poleksić, V., & Rašković, B. (2021). Sex-specific elemental accumulation and histopathology of pikeperch (Sander lucioperca) from Garaši reservoir (Serbia) with human health risk assessment. *Environmental Science and Pollution Research*, *28*(38), 53700–53711.
35. Pastorino P., Nocita A., Ciccotelli V., Zaccaroni A., Anselmi S., Giugliano R.,... & Prearo M. (2021). Health risk assessment of potentially toxic elements, persistence of NDL-PCB, PAHs, and microplastics in the translocated edible freshwater Sinotaia quadrata (Gasteropoda, Viviparidae): a case study from the Arno River Basin (Central Italy). *Exposure and Health*, *13*(4), 583–596.
36. Pérez-Fuentetaja, A., Lupton, S., Clapsadl, M., Samara, F., Gatto, L., Biniakewitz, R., & Aga, D. S. (2010). PCB and PBDE levels in wild common carp (*Cyprinus carpio*) from eastern Lake Erie. *Chemosphere*, *81*(4), 541–547.
37. Pohořelá B., Gramblička T., Doležal M., Dvořáková D., Pulkrabová J., Kouřimská, L.,... & Pánek J. (2022). Nutritional quality and assessment of contaminants in farmed Atlantic salmon (Salmo salar L.) of different origins. *Journal of Food Quality*, *2022*(1), 9318889.
38. Polder, A., Müller, M. B., Lyche, J. L., Mdegela, R. H., Nonga, H. E., Mabiki, F. P.,... & Lie, E. (2014). Levels and patterns of persistent organic pollutants (POPs) in tilapia (Oreochromis sp.) from four different lakes in Tanzania: Geographical differences and implications for human health. *Science of the total environment*, *488*, 252–260.
39. Qu C., Qi S., Yang D., Huang H., Zhang J., Chen W., & Xing X. (2015). Risk assessment and influence factors of organochlorine pesticides (OCPs) in agricultural soils of the hill region: A case study from Ningde, southeast China. *Journal of Geochemical Exploration*, *149*, 43–51.
40. Ravanipour M., Nabipour I., Yunesian M., Rastkari N., & Mahvi, A. H. (2022). Exposure sources of polychlorinated biphenyls (PCBs) and health risk assessment: a systematic review in Iran. *Environmental Science and Pollution Research*, *29*(37), 55437–55456.
41. Shaw G. R., & Connell D. W. (1984). Physicochemical properties controlling polychlorinated biphenyl (PCB) concentrations in aquatic organisms. *Environmental science & technology*, *18*(1), 18–23.
42. Squadrone S., Mignone W., Abete M. C., Favaro L., Scanzio T., Foglini C., & Prearo M. (2015). Non-dioxin-like polychlorinated biphenyls (NDL-PCBs) in eel, trout, and barbel from the River Roya, Northern Italy. *Food Chemistry*, *175*, 10–15.
43. Thiombane M., Petrik A., Di Bonito M., Albanese S., Zuzolo D., Cicchella D., & De Vivo B. (2018). Status, sources and contamination levels of organochlorine pesticide residues in urban and agricultural areas: a preliminary review in central–southern Italian soils. *Environmental Science and Pollution Research*, *25*, 26361–26382.
44. Tian, S., Zhu, L., Bian, J., & Fang, S. (2012). Bioaccumulation and metabolism of polybrominated diphenyl ethers in carp (*Cyprinus carpio*) in a water/sediment microcosm: important role of particulate matter exposure. *Environmental science & technology*, *46*(5), 2951–2958.
45. Trocino A., Majolini D., & Xiccato G. (2009). PCBs contamination in farmed European sea bass from different Italian rearing systems. *Chemosphere*, *76*(2), 250–254.
46. USEPA. (2000). Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories: 1: Fish Sampling and Analysis. 3rd. Washington, DC: Office of Water. EPA 823-B-00-008
47. USEPA. (2006). Fish advisories- Where you live.
48. USEPA. (2009). Polychlorinated biphenyls (PCBs) (CASRN 1336-36-3). Toxicity and exposure assessment for children's health (TEACH) chemical summary.