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Occurrence of Selected Persistent Organic Pollutants in Bosnia and Herzegovina: A Systematic Review

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Abstract: Persistent organic pollutants (POPs) are compounds that are recognized as significant health and environmental hazards, and their use and emission have been restricted or limited by the Stockholm Convention. Despite the control measures foreseen by the international treaties, the presence in the environment is still evident. Bosnia and Herzegovina is a party to the Stockholm Convention, but regular integrative monitoring of POPs occurrence in the environment has not been established. Data on POPs concentrations reported by various research groups and institutions are scattered in the available publications, making a general assessment difficult. This paper aims to summarize data on the presence and levels of selected POPs in environmental and biological samples from Bosnia and Herzegovina, which can aid in planning further monitoring actions, the assessment of effects of already implemented control measures, and policy decision making. The main findings indicate the presence of organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) in most of the matrices (soil, air, water, sediment, and certain food). Potential ecological or health risks cannot be excluded in respect to heptachlor (Bosna river basin), dichlorodiphenyltrichloroethane (in free-range hen eggs), PCBs (in free-range hen eggs and in Modrac Lake sediment), and PAHs (in agricultural soil in Spreča valley and in sediments from Bosna and Spreča rivers).

INTRODUCTION

Persistent organic pollutants (POPs) are toxic chemicals that, upon intentional or unintentional release, tend to accumulate and persist in the environment. (Stockholm Convention on POPs, 2023) POPs are compounds of a major concern due to their physicochemical characteristics (semi-volatility, long half-lives, long-range transport, bioaccumulation, and biomagnification) and harmful effects to living organisms (acute and chronic toxicity, endocrine disruption, genotoxicity and carcinogenicity, immunotoxicity, neurotoxicity) (Guillotin, S., Delcourt, N., 2022). Since their clear recognition as significant environmental and health risk, their use and emission have been controlled. Specifically, the Stockholm Convention on POPs lists chemicals which are considered as POPs, some of which were listed for a long time, while others were added on the basis of new evidences (emerging POPs). (Stockholm Convention on POPs, 2023) Despite the control measures foreseen by the international treaties, their presence in the environment is still evident. (Matei, M., Zaharia, R., Petrescu, S. I., et al., 2023), including organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and dioxins, as well as polycyclic aromatic hydrocarbons (PAHs).

POPs are generally grouped into three main categories. The first category, intentionally synthesized for agricultural purposes, includes most organochlorine pesticides (OCPs) whose key representatives are aldrin, dieldrin and dichloro-diphenyl-trichloroethane (DDT). Intentionally synthesized substances for industrial applications, the second category includes hexachlorobenzene (HCB), polychlorinated biphenyls (PCBs), and various perfluorinated and brominated compounds (BFRs). The third category consists of chemicals unintentional produced through incomplete combustion of organic matter, such as polycyclic aromatic hydrocarbons (PAHs), dioxins/polychlorinated dibenzodioxins (PCDDs), and furans/polychlorinated dibenzofurans (PCDFs). (Matei, M., Zaharia, R., Petrescu, S. I., et al., 2023)

Organochlorine pesticides (OCPs)

Organochlorine pesticides are defined as organic compounds that contain multiple chlorine atoms. They are synthetic, chemically very stable, and hydrophobic compounds widely applied in various domains - including agriculture, industry, medicine, and domestic settings—not only for pest control but also for the management of insect-borne diseases.

Organochlorine insecticides may be divided to four distinct structural groups:

- chlorinated derivatives of ethane, namely dichlorodiphenyltrichloroethane (DDTs), and methoxychlor,
- chlorinated derivatives of benzene and cyclohexane, namely hexachlorobenzene (HCB), hexachlorocyclohexane (HCH) isomers,
- cyclodienes ("drins": aldrin, dieldrin, endrin; heptachlor, chlordanes, endosulfan) and
- chlorinated camphenes (toxaphene and chlordecone). (Hernández, F., A., 2023)

The chemical structures of key representative compounds belonging to these four major OCP structural groups are presented in Figure 1.

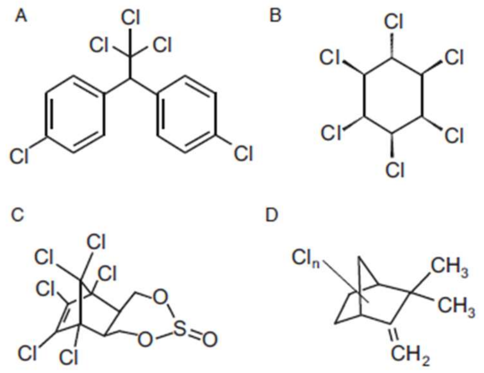

Figure 1. Chemical structures of dichlorodiphenyltrichloroethane, DDT (A); endosulfan (B); gamma-hexachlorocyclohexane, γ-HCH (lindane) (C); and toxaphene (D); (Hernández, F., A., 2023)

Since OCPs have been used worldwide in agriculture and the health sector, they can enter in all environmental compartments through various routes such as agricultural runoff, industrial wastewater, and atmospheric transport and deposition. (Ali, U., Syed, J. H., Malik, R. N., et al., 2014) Due to their ability to persist, bioaccumulate and biomagnify through the food chain, they pose a risk to human health and ecological entities. (Sparling, D. W., 2016) Human exposure to organochlorine pesticides and their metabolites is associated with an increased risk of cancer, cardiovascular diseases, diabetes, and both neurological and reproductive disorders. (Marriya, S., Naima, H., Muhammad, J., et al., 2023) They act as endocrine-disrupting chemicals (EDCs), affecting thyroid hormone balance and thereby contributing to metabolic disorders and hormone-related cancers such as breast, prostate, stomach and lung. (Jayaraj, R., Megha, P., and Sreedev, P., 2016).

Due to environmental persistence and long-term toxicity to humans and wildlife in recent decades, the agricultural use of these pesticides is banned in the European Union. However, their presence is still reported in many areas of the world, including Europe (López-Benítez, A., Guevara-Lara, A., Domínguez-Crespo, M.A., et al., 2024). Currently, their use (DDT, γ-HCH) is restricted only for very specific purpose in certain world regions.

In the Western Balkans OCPs use is currently not allowed, but the stockpiles and/or previous production (during the last two decades) were recorded in the National Implementation Plans (NIPs) for the Stockholm convention. (Stockholm Convention on POPs, NIP)

According to national regulations (Regulation of FBiH, 2022; Regulation of RS, 2016), the permissible concentration of ∑DDT, ∑HCH, and "drins" in agricultural soils is 0.1 mg/kg. In surface waters of FBiH, the maximum residue levels for OCPs are defined within the range of 0.001–0.3 µg/L (Regulation of FBiH, 2007).

Polychlorinated biphenyls (PCBs) and dioxins

Polychlorinated biphenyls (PCBs) are synthetic polyhalogenated aromatic hydrocarbons consisting of two benzene rings with up to ten chlorine substitutions, forming 209 possible isomers and congeners. General chemical structure of PCBs is shown in Figure 2.

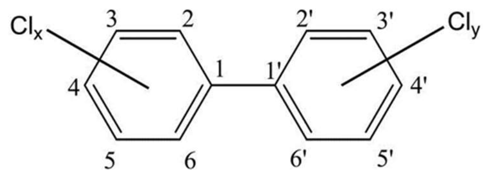

Figure 2. General chemical structure of PCBs (ATSDR, 2000)

PCB congeners are divided into two categories: dioxin-like (dl-PCBs) and non-dioxin-like (ndl-PCBs). Dioxin-like PCBs (dl-PCBs) are named due to their shared mechanism of toxicity with dioxins. They possess a planar structure that enables strong binding to the aryl hydrocarbon receptor (AhR), triggering toxic responses similar to dioxins. (Benedetto, A., Brizio, P., Guaraldo, P., et al., 2016) Thus, dl-PCBs have assigned toxic equivalency factors (TEF= Toxic Equivalency Factor) and are included in the total toxic equivalent (TEQ= Toxic Equivalent Quantity) calculation. (DeVito, M., Bokkers, B., van Duursen, M.B.M., et al., 2024). In contrast, ndl-PCBs have a non-planar configuration due to ortho-chlorine substitutions, which prevents strong AhR binding and results in lower toxicity. However, ndl-PCBs are also toxic compounds (FAO/WHO, 2016).

Physicochemical properties of PCBs, such as non-flammability, high boiling point, chemical stability, and insulating capacity, led to extensive use in industry, including applications in electrical equipment, heat transfer and hydraulic systems, as well as in paints, plastics, rubbers, pigments, dyes, and carbonless copy paper. Due to their stability and persistence, PCBs easily enter various environmental compartments, where they bioaccumulate through food chain. In humans, they are primarily stored in adipose tissue and the liver, with elimination half-lives of approximately 10–15 years.

Beyond their persistence, experimental studies demonstrate that PCBs act as endocrine disruptors, contributing to disturbances in reproductive and metabolic functions. (Gupta, R., Kumar, P., Fahmi, et al., 2020).
Dioxins, or polychlorinated dibenzodioxins (PCDDs), are also a group of organic compounds, chemically classified as halogenated aromatic hydrocarbons, which, depending on the number and position of chlorine atoms, can form 75 congeners. Structurally, they consist of two benzene rings conected by oxygen atoms at the "meta" and "para" positions. The basic structure for unsubstituted dibenzo-p-dioxin (showing the carbon numbering scheme that is used to name specific congeners) is shown in Figure 3 (ATSDR, 1998).

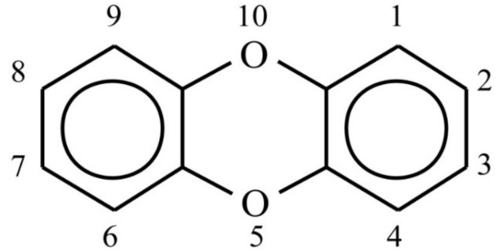

Figure 3. Basic structure for unsubstituted dibenzo-p-dioxin

The term „dioxin“ is generally used for polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (furans or PCDFs). 2,3,7,8-tetrachloro dibenzo-p-dioxin (2,3,7,8-TCDD) is the most toxic congener used as a reference for the determination of TEFs for other dioxins and dl-PCBs.
Dioxins are primarily emitted as by-products of human activities (waste incineration, vehicle emissions) or during natural disasters (volcano eruptions, wildfires). PCBs are man-made chemicals which are banned for production and use, but they can be released by improper disposal of PCB-containing products or from hazardous waste sites. (Stockholm Convention on POPs, NIP) National regulations establish permissible concentrations of PCBs and dioxins in food and environmental matrices. According to the Regulation for certain contaminants in food (Regulation of BiH, 2014), the maximum allowable level of ∑dl-PCBs, expressed as TEQ is 40 ng/g of lipid weight (l.w.), while values range from 1 to 300 ng/g for wet weight (w.w.) For dioxins, the permissible concentrations are 0.75–2.5 pg/g l.w. and 0.1–3.5 pg/g w.w. In surface waters of FBiH, maximum residue levels for total PCBs are set between 0.02 and 0.2 µg/L, and for 2,3,7,8-TCDD is 4.5x10-7 µg/L. (Regulation of FBiH, 2007)
For agricultural soils, the threshold value for ∑PCBs is 0.2 mg/kg (Regulation of FBiH, 2022; Regulation of RS, 2016).

Polycyclic aromatic hydrocarbons (PAHs)

Polycyclic aromatic compounds (PAH) are a very large group of both natural and man-made chemicals containing two or more aromatic rings, which usually occur as a complex mixture. They are lipophilic, many of them resist degradation and tend to accumulate in environment. Therefore, most of PAHs are POPs.
PAHs natural emission sources (volcanic eruptions, natural forest fire, moorland fire) are less important than the anthropogenic sources (industrial, agricultural, traffic, domestic). They are mostly produced by incomplete combustion of organic materials such as coal, gas, garbage, meat, oil, tobacco, and wood. (Patel, A.B., Shaikh, S., Jain, K.R., et al., 2020; Manousi, N., and Zachariadis, G. A., 2020) PAHs toxicity is mostly attributed to a group of 16 priority compounds which are usually monitored in the environment. (Mumtaz, M. and George, J., 1995) Well-known PAHs are benzo[a]pyrene, fluoranthene, naphthalene and anthracene whose chemical structures are shown in Figure 4.

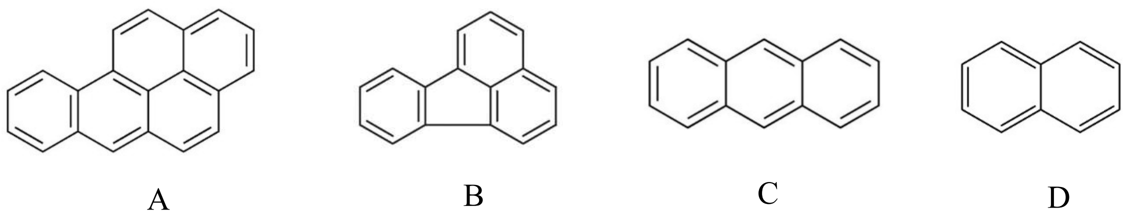

Figure 4. Chemical structures of well-known PAHs (benzo(a)pyrene (A), fluoranthene (B), anthracene (C) and napthalene (D)) (Sudip, S.K., Singh, O.V., and Jain, R.K., 2002.)

Numerous adverse health effects, including various types of cancer, respiratory and cardiovascular disorders, reproductive dysfunction, immune suppression, and endocrine disruption, have been associated with chronic exposure to PAHs. (Montano, L., Baldini, G. M., Piscopo, M., et al., 2025)
As with OCPs and PCBs, national regulatory agencies have also established maximum permissible levels for both, individual and total PAHs, in food and various environmental samples. In surface waters, the maximum allowable concentrations for total PAHs range from 0.2 to 1 µg/L. (Regulation of FBiH, 2007) In agricultural soil, the maximum permissible concentrations for individual PAHs range from 0.1 to 0.2 mg/kg, and for total PAHs the range is between 1 and 2 mg/kg. (Regulation of FBiH, 2022; Regulation of RS, 2016) In food, the maximum allowable concentrations for individual PAHs range from 1 to 6 µg/kg, while for total PAHs, the range is from 1 to 35 µg/kg. (Regulation of BiH, 2014)

Study area
Bosnia and Herzegovina is one of the Western Balkan countries with specific socio-economic, political and environmental challenges. The region’s primary economic

activities are in climate-related sectors like agriculture, forestry, and tourism.

The main industrial activities in Bosnia and Herzegovina include (Figure 5):

1. Pharmaceutical industry (Sarajevo, Tuzla, Banja Luka region, Travnik),
2. chemical industry (mostly in Tuzla region),
3. metal industry (Goražde, Zenica, Tuzla, Mostar, Sarajevo region)
4. wood industry (Sarajevo, Zenica, Tuzla, Bihać, Mostar, Banja Luka region)
5. ammunition production (Konjic, Goražde, Bugojno, Sarajevo region)
6. textile industry (Sarajevo, Tuzla, Doboj, Zenica, and Banja Luka region, Travnik, Goražde),
7. food industry (all regions)
8. Petroleum industry-refinement and delivery (Modriča and Bosanski Brod)
9. electric power industry (Tuzla, Zenica, and Mostar region)
10. coal mining (Tuzla and Zenica region)

Agricultural production is widespread in the country, but it is mainly characterized by small, inefficient family farms.

Figure 5. Map of Bosnia and Herzegovina

According to various indicators of a green transition, the entire Western Balkan region is lagging behind EU countries. (Radovanovic, N., Stevanovic Carapina, H., 2024) In order to implement the Green Agenda, Western Balkan countries are strongly encouraged to enhance monitoring and reporting on pollutants in air, water and soil. For the aforementioned reasons, this review aims to summarize published data on the presence of selected POPs in environment, including air, water, sediment, soil, and biological material. The paper can aid in planning further monitoring actions, the assessment of effects of already implemented control measures, and policy decision-making.

EXPERIMENTAL

Data research strategy

Literature search was conducted between 01.04.2025. and 16.04.2025. ScienceDirect, Web of Science and Google Scholar were searched (see Table 1), yielding 41 results in total (Figure 6). Further, a grey literature search was conducted as manual searches through reference lists of articles found, by using Google search for the key words in the Bosnian language. This additional search yields another 38 results (Figure 6). After exclusion of duplicates (n=12), records were title- and abstract-screened for eligibility (12 records excluded). One record couldn't be retrieved, and 18 records were excluded after full-text reading (Figure 6). Thus, 36 results were included in this review.

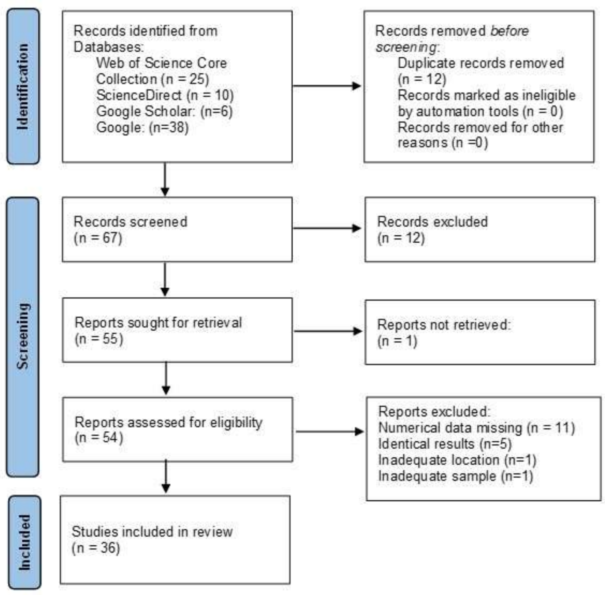

Figure 6. PRISMA flow diagram

Table 1. Search strategy used for each data source

Data source	Search strategy
Web of Science Core Collection	AB=((POPs OR persistent organic pollutants OR PCB OR PAH OR pesticide OR DDT) AND (Bosnia OR Herzegovina))
ScienceDirect	in title, abstract or keywords: (POPs OR persistent organic pollutants OR PCB OR PAH OR pesticide OR DDT) AND (Bosnia OR Herzegovina)
Google Scholar	allintitle: (Bosnia OR Herzegovina) AND (PCB OR PAH OR DDT OR "pesticides" OR "persistent organic pollutants")

RESULTS AND DISSCUSION

Organochlorine pesticides (OCPs) levels

Concentrations of OCPs in ambient air were reported in two papers. Klánová et al. (2007) reported on DDT, HCH, and HCB concentrations in air samples from Sarajevo and Tuzla and Lamell et al. (2011) from Banja Luka (Table 2). The concentrations found in soil samples from the same locations were also reported by Lamell et al. (2011) (Table 2). Concentrations for each of the OCPs reported here were within the range of the European background levels. (Helene, L. H., Pernilla, B-N., Sabine, E. et al., 2023)
Data on OCPs in soil were also found for the area of Zenica, Spreča river catchment (municipalities Lukavac, Gračanica, and Doboj Istok), and Olovo area (Table 2). None of the samples exceeded the permissible levels for the agricultural soil according to local regulations (Regulation of FBiH, 2022; Regulation of RS, 2016), although at all sites multiple pesticides were detected. In comparison with the average (0.03 mg/kg for Sum DDT, and 0.01 mg/kg for HCB) and maximum levels (0.31 mg/kg for Sum DDT, and 0.01 mg/kg for HCB) in European agricultural soil, (Silva, V., Mol, H.G.J., Zomer, P., et al., 2019) concentrations found in samples from Bosnia and Herzegovina (Table 2) were significantly lower.
OCP concentrations in air and soil samples are not sufficient for trend analysis since the measurements were temporary and spatially scattered. However, the authors (Lammel, G., Klanova, J., Erić, Lj., et al., 2011) attributed OCP in air primarily to the industrial activities (sawmill) and sporadic waste burning as a local source in the Banja Luka area.

In 2008 and 2009, sediment samples from the Bosna River (Table 2) were analyzed for OCPs (groups of HCH, DDT and its metabolites, and cyclodiene pesticides including "drins" and other: heptachlor and chlordanes). The γ-isomer of HCH (lindane) was detected at all locations. Among all analyzed OCPs, the highest concentration was recorded for heptachlor and its epoxides at all sampling sites, which also exceeded the TEL (Threshold Effect Level) or PEL (Permissible Exposure limit) (Harman, C., Grung, M., Djedjibegovic, J., et al., 2013). Ratio of parent compounds to their metabolites indicated more weathered input of heptachlor in the river Bosna at Doboj, while the opposite was recorded in other sampling sites along the river Bosna. For DDT more recent source was assumed only at the Doboj location on the river Bosna.
OCP concentrations (ng/L) obtained by passive sampling in rivers are shown in Table 2.
OCP detected in the river Neretva in 2007 were HCB (all sampling sites), heptachlor (at 2 of 3 sites), and in one location (Gabela – near delta), in addition to the previous two OCPs, pentachlorobenzene, dieldrin, and p,p'-DDE were also detected. In the river Bosna, most of the analyzed OCPs were detected, with the highest concentrations for heptachlor (among cyclodiens), followed by the sum of DDT/DDD/DDE, endrin (among „drins“), and lindane (γ-HCH). These concentrations were very similar to those reported for surface water at the Central European Biosphere Reserve Krivoklatsko (Ocí, V., Ocelka, T., Dragoun, D. et al., 2007), representing the background levels in the European region.
Concentrations found by repeated measurements in Bosna and Neretva water samples from 2007-2012 didn’t differ significantly (Table 2), suggesting that there was no new load within this time period.
In 2008, samples of honey from Bosanska Krajina were analyzed for OCPs (HCH, DDT, heptachlor, and drins). Measured concentration in all analyzed samples was below 0.001 mg/kg. (Mujić, I., Alibabić, V., Jokić, S., et al., 2011)
Concentration of HCB, Sum HCH, and Sum DDT in free range chicken eggs from Tuzla and Zenica region (2014-2015) were <1-2.65 ng/g fat, ND-3.23 ng/g fat (0.02-0.45 ng/g fresh weight), and ND-933.48 ng/g fat (ND-145.44 ng/g fresh weight), respectively. (Petrlík, J., Behnisch, P., 2016) Only DDT concentrations were higher than the EU limit (50 ng/g fresh weight). (EC, 2023; EC, 2017; EC, 2016) Since hens were from the free-range farming, DDT residues found in eggs could not be attributed to animal feed. Thus, the residues are probably accumulated from the soil. However, the soil-to-eggs bioaccumulation factor of DDT can vary greatly (Kesic, R., Elliott, J. E., Fremlin, K. M., et al., 2021) and cannot be used in a reliable assessment of a possible source of exposure. This underlines the need for regular monitoring of hen eggs used for human consumption.

Table 2. OCPs concentrations in air, soil, rivers and river sediments from different locations

AIR				
Sampling area	**Sampling year**	**Analytes**	**Range ***	**Ref**
Sarajevo (gaseous phase) Tuzla (gaseous phase)	2004	Sum DDT Sum HCH HCB	0.012-0.193* 0.025-0.054* 0.064-0.171*	Klánová *et al*. (2007) *for data from (ng/m^3) Klánová *et al*. (2007)
Sarajevo (particulate matter) Tuzla (particulate matter)	2004	Sum DDT Sum HCH HCB	0.001-0.101* 0-0.002* 0.001-0.002*	Klánová *et al*. (2007)
Banja Luka (sum of gaseous and particulate matter)	2008	Sum DDT Sum HCH HCB PeCB	27-74** 52-147** <0.1-48** 6-9.9**	Lammel, G., *et al*., 2011 **pg/ m^3 for data from Lammel *et al*., 2011
SOIL				
Sampling area	**Sampling year**	**Analytes**	**Range (mg/kg)*** **	**Ref**
Banja Luka (agricultural soil)	2008	Sum DDT Sum HCH HCB PeCB	0.112-1.222*** 0.116-0.424*** 0.124-0.526*** ND	Lammel, G., *et al*., 2011 ***ng/g for data from Lammel *et al*., 2011
Zenica (agricultural soil)	2011-2015	Sum HCH Sum DDT Drins	ND-0.0003 ND ND-0.0005	Federal Institute of Agropedology, 2016

Spreča lower flow (agricultural soil)	2017			
Lukavac		Sum HCH Sum DDT Drins	0.0046-0.08 ND 0.0114-0.0232	Federal Institute of Agropedology, 2018
Gračanica		Sum HCH Sum DDT Drins	0.006-0.0189 ND-0.005 0.0255-0.0596	
Doboj Istok		Sum HCH Sum DDT Drins	0.0057-0.009 0.0013-0.0029 0.0205-0.035	
Olovo (agricultural soil and roadside soil)	2020	Sum HCH Sum DDT Drins	ND-0.003 ND-0.001 ND-0.065	Federal Institute of Agropedology, 2021
Sarajevo (public children's playgrounds)	2016	Sum DDT	<0.001	Sapcanin, A., Cakal, M., Imamovic, B., *et al.*, 2016
RIVERS				
Sampling area	**Sampling year**	**Analytes**	**Range (ng/L)**	**Ref**
Neretva	2007	Sum 8 OCP	0.040-0.14	Djedjibegovic, J., Marjanovic, A., Sober, M. *et al.,* 2010
Bosna	2008/2009	Sum 8 OCPs	2008: 0.028-0.171 2009: 0.059-0.195	Harman, C., *et al.,* 2013

Bosna Neretva	2010	Sum 8 OCP	0.021-0.133 0.011-0.014	Harman, C., Grung, M., Djedjibegovic, J., *et al*., 2018
Bosna	2012	Sum DDT Sum HCH HCB PeCB	0.0039-0.044 0.0059-0.13 0.0018-0.02 0.0005-0.0033	Toušová, Z., Vrana, B., Smutná, M., *et al*., 2019
RIVER'S SEDIMENTS				
Sampling area	**Sampling year**	**Analytes**	**Range (ng/g)**	**Ref**
Bosna	2008/2009	Sum DDT Sum HCH Sum Drins Other cyclodienes	0.71-4.6 0.01-0.10 0.04-6.7 0.64-9.4	Harman, C., Grung, M., Djedjibegovic, J., *et al.,* 2013

Polychlorinated biphenyls (PCBs) and dioxins levels

In agricultural soils, PCB concentration (Table 3) was below the regulatory limit. (Regulation of FBiH, 2022; Regulation of RS, 2016) High concentrations of PCBs in soil were found in samples collected at locations close to industrial facilities, and most probably due to local sources (damaged capacitors, coal mines, paper production). Mean concentrations reported by Picer et al. (2005) ranged from 0.1-1.2 mg/kg dry weight, which is significantly higher than the Europe-wide mean concentration in soils (JRC, 2010)

Table 3. PCB concentrations in air, soil, rivers, and river sediments from different locations

AIR				
Sampling area	**Sampling year**	**Analytes**	**Range (ng/m^3)**	**Ref**
Sarajevo (gaseous phase) Tuzla (gaseous phase)	2003-2004	Sum 7 indicator congeners	0.059-0.172 0.06-5.645	Klánová *et al*. (2007)
Sarajevo (particulate matter) Tuzla (particulate matter)	2003-2004	Sum 7 indicator congeners	0.01-0.121 0.013-1.648	Klánová *et al*. (2007)
SOIL				
Sampling area	**Sampling year**	**Analytes**	**Range (mg/kg dry weight)**	**Ref**
Tuzla	2003-2004	Sum 7 indicator congeners	0.9 (mean)	Klánová, J., *et al*., 2007
Tuzla area Bihać Tešanj Sarajevo area	2003	Sum 7 indicator congeners	0.007-22 890 0.004-73.4 0.005-43 092 0.007-3.5	Picer, N., Čalić, V., Miošić, N., *et al*., 2005
Zenica (agricultural soil)	2011-2015	Sum 7 indicator congeners	ND-0.0012	Federal Institute of Agropedology, 2016
Spreča lower flow (agricultural soil)	2017			Federal Institute of Agropedology, 2018
Lukavac Gračanica Doboj Istok		Sum 7 indicator congeners	0.0008-0.006 ND-0.001 ND-0.002	

Olovo (agricultural soil and roadside soil)	2020	Sum 7 indicator congeners	ND-0.008	Federal Institute of Agropedology, 2021
Sarajevo (public children's playgrounds)	2016	Sum 12 congeners (18, 28, 31, 44, 52, 101, 118, 138, 149, 153, 180, 194)	<0.002	Sapcanin, A., *et al.*, 2016
Banja Luka (Incel factory)	2020	Sum 7 indicator congeners	<0.021-18.10	UNDP/BiH, 2021
RIVERS (concentrations obtained by passive sampling)				
Sampling area	**Sampling year**	**Analytes**	**Range (ng/L)**	**Ref**
Neretva	2007	Sum 10 congeners (28, 52, 101, 105, 118, 138, 153, 156, 180, 209)	ND-0.12	Djedjibegovic, J., et al., 2010
Bosna	2008/2009	Sum 7 indicator congeners	2008: 0.123-0.242 2009: 0.134-0.169	Harman, C. et al., 2013
Bosna Neretva	2010	Sum 10 congeners (28, 52, 101, 105, 118, 138, 153, 156, 180, 209)	0.06-0.294 0.024-0.195	Harman, C., et al., 2018
Bosna	2012	Sum 7 indicator congeners	0.026-0.18	Toušová, Z. et al., 2019

RIVER'S SEDIMENTS				
Sampling area	**Sampling year**	**Analytes**	**Range (ng/g)**	**Ref**
Bosna	2008/2009	Sum 7 indicator congeners	0.78-79	Harman, C. *et al.,* 2013

Una	2003-2004	Sum 7 indicator congeners	0.35-361 (fish pond Klokot 2)	Čalić, V., Miošić, N., Kodba, C., *et al.*, 2005
Usora and tributary Tešanjka			17.5-90	
Miljacka and Zujevina			<0.35-2691	
Buna and Bunica			0.35-4	
Spreča and tributaries (Gostelja, Oskova, Jala)			100-483	
River Bosna tributaries (Krivaja, Lašva, Bioštica)			12.06-24	
Vrbas near Incel	2020	Sum 7 indicator congeners	<0.021-0.528	UNDP/BiH, 2021

PCB concentrations in both river Neretva and river Bosna water samples (Table 3) were low, with slightly higher results for river Bosna. Downstream decrease of concentrations was recorded in the river Bosna, most probably due to the geographical location of the river source (vicinity of Sarajevo city). In contrast, on the river Neretva, PCB concentrations increased downstream, which can be attributed to the fact that most of the possible sources (cities Mostar and Čapljina, industrial facilities) are located in the lower river flow. (Harman et al., 2018)
Surface water was also analyzed after active sampling in Lake Modrac near Lukavac, Tuzla region (Marjanović, A., Djedjibegović, J., Omeragić, E., et al., 2021), showing Sum 7iPCBs in the range 3.23-6.19 mcg/L, and Bjelić et al. (2023), where PCBs were not detected. Except for Modrac lake, all other here reported concentrations were similar to the Europe-wide average (JRC, 2010). Sources of PCBs in Lake Modrac include industrial wastewater from nearby plants like coal mines, metal, wood, and plastic industries, as well as household wastewater from settlements lacking adequate sewage treatment.
In comparison to the Europe-wide average, PCB concentrations in sediment samples (Table 3) were similar. (JRC, 2010) The highest concentrations were found in the river Zujevina (2691 ng/g) and Spreča (483 ng/g), most probably due to the vicinity of old PCB-containing equipment, coal mines, waste waters, and damaged military relays. (Čalić et al., 2005)
PCBs in ambient air were analyzed in Tuzla and Sarajevo, 2003-2004 (Table 3). (Klánová, J., et al., 2007) These levels do not indicate higher pollution in comparison to the European average. (JRC, 2010) However, the highest concentrations were found in Tuzla near the fire station of the electrical power plant "Elektrodistribucija" due to leakage from old and damaged capacitors and transformers. (Klánová, J., et al., 2007)
In samples from Sarajevo, dominant congeners in the gaseous phase were PCB28, PCB153, and PCB138, while samples from Tuzla were dominated by PCB28, PCB52, and PCB101. In particulate matter, dominant congeners were PCB153, PCB138, and PCB180 at both locations.
PCBs were found in locally grown food, including free-range chicken eggs from Tuzla and Zenica, cow milk from the Sarajevo area, and fish samples from the Sana river and Bosnian rivers (Neretva tributaries, Una, Bosna, and its tributaries).
Sum 7iPCB in eggs ranged from ND-16.67 ng/g in fat (Petrlík, J., Behnisch, P., 2016), and didn't exceed the maximum residue level set by national regulatory (Regulation of BiH, 2014). However, the TEQ values for the sum of dioxin-like PCBs and dioxins exceed EU food standards, indicating a possible health risk. Recent studies have shown that dioxin and PCB levels in eggs from free-range chickens frequently exceed EU food standards of 2.5 pg TEQ/g fat for PCDD/Fs or 5 pg TEQ/g fat for the sum of PCDD/Fs and dl-PCBs when grazed on soil with PCDD/F or dl-PCB concentrations at levels around 2–4 ng TEQ/kg. (Weber, R., Bell, L., Watson, A. et al., 2019)
Sum 6PCB in cow milk was 10.87-187.72 ng/g in fat (Djedjibegović, J., Turalic, A., Ajdinovic, N., et al., 2019), being higher than the maximum residue level in some of the samples. (Regulation of BiH, 2014) PCB concentrations in fish from Sana River (Djedjibegovic, J., Marjanovic, A., Burnic, S., et al., 2015) and Bosnian rivers (Picer, M., Kovač, T., Picer, N., et al., 2005) expressed as Ar1254 were ND-208 mcg/kg w.w. and 2-73 mcg/kg w.w., respectively.

Polycyclic aromatic hydrocarbons (PAHs) levels

PAHs concentration in most samples from the Spreča valley was higher than the regulatory limit for agricultural soil. (Regulation of FBiH, 2022; Regulation of RS, 2016) The increase in concentrations recorded after 2014 was probably due to extreme flooding in this area (Table 4). In these samples, fluoranthene and pyrene derivatives were dominant, in some cases even critically high in comparison to the regulatory limits. (Regulation of FBiH, 2022; Regulation of RS, 2016). Benz(a)pyrene was detected in most samples, mainly in deeper layers. PAH concentrations in crops from this area were also high. (Federal Institute of Agropedology, 2014; 2015; 2016; 2017; 2018; 2019)

PAH concentrations in rivers were analyzed after passive sampling (Table 4). Surface water sampled in 2020 near powerplant Gacko did not contain detectable concentrations of PAHs. (Bjelić, S.L., Ilić, P., Nešković, M.D., et al., 2023) Most samples from Bosna river contained benz(a)pyrene in detectable concentrations.
Data for PAHs in sediment samples were found for two rivers, Bosna and Spreča. In Bosna river Sum 16 EPA PAHs was 0.2-48.973 mg/kg in 2008-2009 (Harman, C., et al., 2013). Risk assessment for 7 carcinogenic PAHs showed HI>1 for sediment from rivers Bosna and Spreča collected in 2018, Spreča beeing couple of times more polluted than Bosna. (Vijdea, A., Alexe, V., Balan, L., et al., 2022)
Benz(a)pyrene was detected in all air samples (table 4). Sum of eight carcinogenic PAHs ranged from 1.02-5.94 ng/m3 (1-2% benz(a)pyrene) in air samples from Sarajevo, and 8.44-22.37 ng/m3 (2-3% benz(a)pyrene) in samples from Tuzla.
The analyzed studies were not designed to determine a specific PAH source(s), and the available data are insufficient for such conclusions. However, known local possible sources of PAH include: traffic emission, industrial sources, household heating in all of the locations (Sarajevo, Tuzla, Zenica, Banja Luka), as well as mining and electricity production in Tuzla region.
Sum 16 PAH concentration in honey from Mostar region collected in 2019 ranged from ND-12.58 mcg/kg. In one sample from location by the road benz(a)pyrene was dominant PAH. In general, samples were safe for consumption. (Kazazic, M., Djapo-Lavic, M., Mehic, E., et al., 2020)

Table 4. Sum 16 EPA PAHs concentrations in soil, rivers, and air samples from different locations

SOIL (*mg/L in percolates)			
Sampling area	**Sampling year**	**Range (mg/kg)***	**Ref**
Sarajevo and Tuzla	2003-2004	0.036-3.9	Klánová, J., *et al*., 2007
Sarajevo Canton	2009-2015		Rešidović, N., Filipović, H., Mrković, A., *et al*., 2016
Urban soil		0.314-0.461	
Agricultural soil		0.119-0.216	
Zenica agricultural soil	2010	ND-0.67 MRL<2	Federal Institute of Agropedology, 2010
Zenica agricultural soil	2011	ND	Federal Institute of Agropedology, 2016
	2012	0.84-2.62	
	2013	ND	
	2014	0.03-1.4	
	2015	0.1-0.7	
	2011-2015 average	0.41-1.03	
Soil percolate	2013	ND-0.237	
	2014	0.003-0.098	
	2015	0.001-0.041	
	2013-2015 average	0.019-0.092	
Spreča lower flow (agricultural soil)			Federal Institute of Agropedology, 2014; 2015; 2016; 2017; 2018; 2019
Lukavac	2014	ND-0.14	
	2015	0,06-37.45	
	2016	0.49-102.64	
	2017	0.159-9.773	
	2018	1.196-13.301	
Gračanica	2014	0.03-4.42	
	2015	ND-9.72	
	2016	0.30-52.12	
	2017	0.333-11.734	
	2018	0.348-21.116	
Doboj Istok	2014	0.01-0.16	
	2015	0.04-3.19	
	2016	0.76-8.07	
	2017	0.272-1.136	
	2018	0.454-0.757	

Olovo (agricultural soil and road side soil)	2020	0.24-0.73	Federal Institute of Agropedology, 2021
Sarajevo (public children's playgrounds)	2016	0.184-7.983	Sapcanin, A, Cakal, M, Jacimovic, Z, *et al*., 2017)
Banja Luka (Incel factory)	2019	0.13-2.848	Ilić, P., Markic, D., Stojanović, Lj. 2020; Stojanović Bjelić, L., Nešković Markić, D., Ilić, P., Farooqi, Z. U. R., 2022)

RIVERS (concentrations obtained by passive sampling)

Sampling area	Sampling year	Range (ng/L)	Ref
Neretva	2007	0.16-4.0	Djedjibegovic, J., *et al.,* 2010
Bosna	2008/2009	2008: 17.456-480.444 2009: 19.571-98.525	Harman, C. *et al.,* 2013
Bosna Neretva	2010	6.527-67.558 0.447-6.956	Harman, C. *et al*., 2018
Bosna	2012	1.2-57	Toušová, Z. *et al*., 2019

AIR SAMPLES (ng/m^3)

Sampling area	Sampling year	Analytes	Concentration (ng/m^3)	Ref
Lukavac Zavidovići	2024	BaP	16.29-22.50 (PM10) 0.16-1.14 (PM10)	OSCE & Ekoforum Zenica, 2024
Sarajevo Tuzla	2004	Sum 16 EPA PAHs	15.15-50.44 58.17-121.24	Skarek, M., Cupr, P., Bartos, T., *et al*., 2007
Sarajevo	2017-2018	Sum 10 PAHs BaP	64.8 (PM10) 7.28 (11% total PAH)	Pehnec, G., Jakovljević, I., Godec, R., *et al*., 2020
Banja Luka	2008	Sum 28 PAHs	14.5-40.8	Lammel, G., Klanova, J., Ilić, P., *et al*., 2010

CONCLUSION

This paper presents data on selected POPs in environmental samples from Bosnia and Herzegovina summarized by thorough literature review. The main conclusions are:

- Although Bosnia and Herzegovina ratified the Stockholm convention in 2010, regular monitoring and other obligations in this respect are inadequate. Most of the available data are from individual studies conducted by research groups and institutions, while official monitoring is insufficient. Thus, spatial or temporal trends cannot be assessed.
- OCP levels in surface water samples are mostly in accordance with the European background levels. Concentrations in agricultural soil samples were within the regulatory limits. Heptachlor concentrations in samples from most sites on Bosna river were higher than the action levels and it is of environmental concern.
- DDT (and PCB/dioxins) levels in free-range chicken eggs were high indicating possible health risk.
- PCB concentration in agricultural soils was acceptable, and higher concentrations are recorded in industrial zones. Concentrations in air, surface water and sediment were similar to the European average. The exception is sediment from Lake Modrac, which can be marked as a local „hot spot".
- PAH concentrations were critical in agricultural soil in Spreča valley. Benz(a) pyrene was detected in river water, and concentrations in sediments from Bosna and Spreča rivers indicated ecological risk.

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Summary/Sažetak

Postojani organski polutanti (POP) su supstance prepoznate kao značajne opasnosti za zdravlje ljudi i okoliša pa je njihova upotreba i emisija zabranjena ili ograničena odredbama Štokholmske konvencije. Unatoč kontrolnim mjerama predviđenim međunarodnim ugovorima, prisustvo POP u okolišu i dalje je evidentno. Bosna i Hercegovina je članica Štokholmske konvencije, ali redovan integrativan monitoring prisustva POP u okolišu nije uspostavljen. Podaci o koncentraciji POP publicirani od različitih istraživačkih grupa ili institucija su rasuti u dostupnoj literaturi što otežava generalnu procjenu stanja. Cilj ovog preglednog rada je da sistematizira dostupne podatke o prisustvu i nivoima odabranih POP u biološkim i uzorcima iz okoliša u Bosni i Hercegovini, što može biti od koristi u planiranju budućih aktivnosti praćenja, procjene efekata implementiranih kontrolnih mjera i donošenju regulatornih odluka. Glavni rezultati ukazuju na prisutnost organohloriranih pesticida (OCP), polihloriranih bifenila (PCB) i policikličkih aromatskih ugljikovodika (PAH) u većini uzoraka (tlo, zrak, voda, sediment, određena hrana). Potencijalni ekološki ili zdravstveni rizici ne mogu se isključiti u odnosu na heptahlor (sliv rijeke Bosne), dihlorodifeniltrihloroetan (DDT) (u jajima kokoši iz slobodnog uzgoja), PCB (u jajima kokoši iz slobodnog uzgoja i u sedimentima Modračkog jezera) te PAH (u poljoprivrednom tlu u dolini Spreče i u sedimentima rijeka Bosne i Spreče).