Soil pollution: pollutants, causes and effects

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Abstract: *Soil is a complex heterogeneous system composed of solid, liquid and gaseous matrix, which is a key factor for terrestrial ecosystems. As an open system, it is a source or sink of many substances, including pollutants. Pollutants in soils can be of natural or anthropogenic origin, which are generally divided into two main groups: organic and inorganic pollutants. The report is prepared on the basis of scientific literature and is entirely aimed at clarifying the sources, impact and effects of persistent organic compounds. For this purpose, 32 scientific articles available in ResearchGate, Scholar and ScienceDirect were studied. Attention is focused on them, as they are considered a global environmental problem due to their persistence, potential for bioaccumulation, toxicity, carcinogenic and mutagenic potential.*

Keywords: *SOILS, ORGANIC POLLUTANTS, PERSISTENT ORGANIC POLLUTANTS, ORGANOCHLORINE PESTICIDES, POLYCHLORINATED BIPHENYLS, POLYAROMATIC HYDROCARBONS, BIOACCUMULATION.*

1. Introduction

Soil is a natural entity that is a very complex heterogeneous system, composed of solid, liquid and gaseous matrix, which is a key factor for terrestrial ecosystems [1-3]. Soil is defined as a dynamic natural formation on the Earth's surface, as it is a result of a change in the underlying rocks, caused by meteorological agents and living organisms, and determined by topography [1]. The abiotic component includes mineral particles (sand, silt, and clay) and organic matter. It is a habitat for a wide variety of organisms, a physical and chemical support for plants, biomass production, carbon storage, nutrient cycling and water source for organisms, living and growing in the soil, etc. [1]. For this reason, soil is considered a non-renewable resource, but of extreme importance in in terms of the range of ecosystem services it provides [1]. IIn fact, soil is a key factor in providing several ecosystem services (key functions), which can be classified into four general categories: productivity and sustainability, environmental quality, biodiversity, and human well-being.[4, 5].

Anthropogenic impacts put pressure on soils. These are soil degradation and pollution. Pollution can be point or diffuse. As an open system, soil is either a source or sink of many substances, including pollutants [3]. Soil degradation can have direct impacts on water and air quality, biodiversity and climate change [4-6]. It can thus lead to a reduction in the capacity of soil to support human communities and ecosystems, as well as desertification. It can also harm human health and threaten food and feed safety [4, 5].

Soil pollution is the result of the introduction of pollutants into it. Pollutants are compounds/substances that, above certain concentrations, cause adverse effects on soils. According to their origin, they can be natural or anthropogenic. Natural sources are the weathering of ore bodies (inorganic pollutants), volcanic activity or forest fires (inorganic and organic pollutants). The main pressure on the soil is the result of human activity (intentional or accidental). Anthropogenic sources include: domestic, urban and industrial activities, urban influence, wet and dry atmospheric deposition, animal husbandry and manure storage, plan protection practices [4]. They are depicted in Fig. 1.

Soil pollution refers to the presence of compounds/substances in concentrations that cause adverse effects on soil ecosystem services [4]. There are a variety of chemicals that can contaminate soils, ranging from simple inorganic ions to complex organic molecules, and two main groups of pollutants can be defined: organic and inorganic [1, 4, 5]. Inorganic pollutants include metals (e.g. Cd, Cr, Cu, Hg, Mn, Ni, Pb, V and Zn), metalloids (e.g. As, Bo and Sb), nonmetals (e.g. Se), actinides (e.g. U) and halogens (e.g. I and F). Some of these elements are essential for life and are considered trace elements (beneficial in small amounts but toxic above certain thresholds (e.g. B, Cl, Cu, Fe, Mn, Mo and Zn), while others are considered toxic elements (toxic at all concentrations, e.g. Hg, As and Tl). Another important group of inorganic pollutants are radionuclides, which are unstable isotopes that can undergo radioactive decay (e.g., Cs, Sr, Eu, and Th). Therefore, they emit radiation that can be harmful. Radionuclides that occur naturally usually emit low levels of radiation that are harmless, while man-made radionuclides are very dangerous. They exhibit toxic and bioaccumulative properties, but POPs are considered a global environmental problem due to their persistence, potential for bioaccumulation, toxicity, carcinogenic and/or mutagenic potential, their widespread use or continued emissions, persistence and mobility in the environment [4 , 10].

Persistent organic pollutant (POPs) refers to compounds that contain carbon in their structure and includes several groups, such as pesticides, hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polybrominated biphenyls (PBBs), polybrominated diphenyl ethers (PBDEs), surfactants or pharmaceuticals. Therefore, this term includes thousands of compounds, as each of these groups can contain tens or hundreds of different compounds (for example, the PCB group includes 209 representatives). Persistent organic pollutants (POPs) are perhaps the most important group of organic pollutants [4].

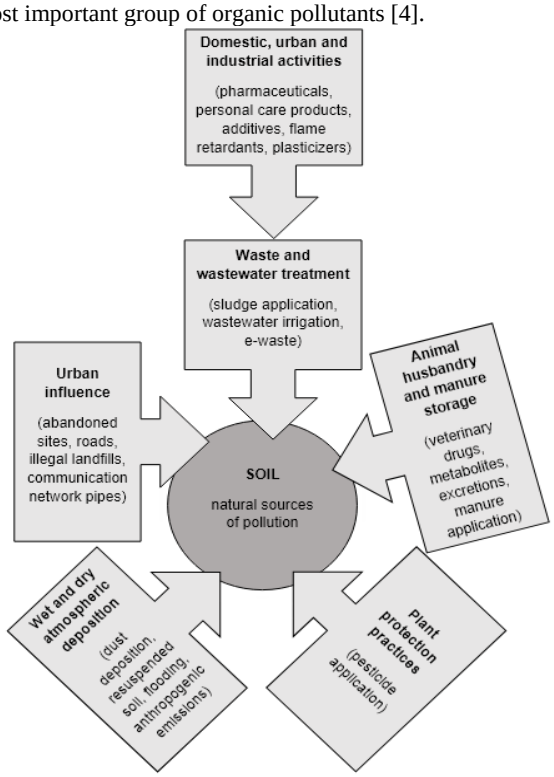

Fig.1 *Anthropogenic sources of organic soil pollutants*

Due to the demands of rapid economic growth and being located at the interface between the geosphere, the atmosphere and the hydrosphere, soils are subject to varying degrees of direct and indirect anthropogenic disturbances, which are a major driver of global change

The purpose of this report is to investigate the most common POPs contaminating soils, their characteristics, sources and impacts on humans and the environment.

2. Results and discussion

This study has several limitations. First, the small sample size (32) and second, despite the availability of a large body of scientific literature on PAHs, PCBs and OCPs, the continuous development of the pharmaceutical industry leads to the generation of new substances for which there is a lack of sufficient studies and scientific literature on their impact on the environment and human health. Nevertheless, this report can serve to conduct further observations in the field of pharmaceutical contaminants, outlining the main future directions of research for the collection of objective and valid data.

2.1. Characteristics of POPs

The list of OPs in soil research is extensive and is usually divided into different classes, although each OSs is unique in terms of its physicochemical properties and toxicological mode of action. The most common OPs found in soils include: petroleum hydrocarbons (e.g. alkanes, alkenes, cycloalkanes), chlorinated compounds (e.g. PCBs, PCDDs and PCDFs), monomeric aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene and xylene, collectively known as BTEX). Also PAHs (e.g. benzo[a]pyrene, chrysene and fluoranthene) and several pesticides, including herbicides such as atrazine, alachlor, acetochlor and bifenox, fungicides such as lindane, metalaxyl, procymidone and penconazole, and insecticides such as captan, benomyl, endosulfan, heptachlor and endrin, as well as their degradation products [6]. These compounds have a wide range of values of their properties (polarity, solubility, volatility), even within the same group, which leads to different environmental behavior and toxicity to organisms. Many organic chemicals are readily biotransformed or degraded, but others are very resistant to both chemical and biochemical transformation and have long half-lives (e.g., polyhalogenated compounds) [4].Some of these OPs are among the most hazardous, as they are toxic, persistent, bioaccumulative, and prone to long-range transport, and as such are included in the Stockholm Convention on Persistent Organic Pollutants, which mandates the elimination or reduction of their releases to the environment [6, 8].

When first described in 2001, 12 POPs were recognized as causing adverse effects on humans and ecosystems (known as the "dirty dozen") [4, 9]. The group includes 10 intentionally produced pollutants: aldrin, endrin, chlordane, DDT, dieldrin, heptachlor, mirax, toxaphene, hexachlorobenzene (HCB), and PCBs, as well as two unintentionally generated pollutants, PCDD and PCDF. PAHs are also categorized as POPs, and the combustion and incineration of organic pollutants produce these substances unintentionally [9].

Currently, the list includes 22 POPs grouped into three groups: 15 pesticides, 7 industrial chemicals and 4 by-products. Although several of these compounds have been banned or their emissions have been reduced in recent years, most of them or their degradation products are still found in soils at high levels. [4, 8]. The Convention has been signed by 151 countries, including the European Community (EC) as a regional organization.The widespread production and use of POPs in industrialized regions, together with their environmental persistence, have led to intensive soil contamination, posing potential environmental and human health risks [4].

2.2. PCBs

Polychlorinated biphenyls (PCBs) are a class of 209 congeners that are among the twelve initial POPs listed in the Stockholm Convention due to their relatively long half-lives and their tendency to remain in soil for long periods of time [4, 9-11]. They are highly hydrophobic and lipophilic and tend to accumulate in the tissues of organisms, including plants and animals, and are 100% derived from anthropogenic sources. They consist of a biphenyl base with a varying number of chlorine atoms (Fig. 2) [11-14].

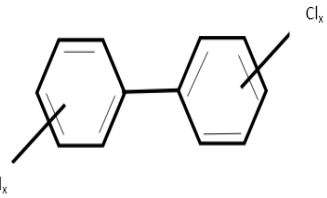

***Fig.2** Chemical structure of PCBs*

The European Union Reference Bureau has recommended monitoring of seven PCBs (PCBs 28, 52, 101, 118, 138, 153 and 180). They were chosen as indicators because of their high concentrations in technical mixtures, their wide range of chlorination (3–7 chlorine atoms per molecule) and their inclusion in the OSPAR Coordinated Environmental Monitoring Programme (CEMP) since 1998 [12, 13]. They are toxic environmental pollutants that have been produced for half a century and have been used for various industrial applications, such as lubricants, dielectric fluids and plasticizers, in ship painting, in transformers and capacitors. It is generally believed that over 1.5 million tons of PCBs have been produced worldwide [10, 14, 15]. Industrially produced commercial PCBs are usually mixtures that involve chlorination of biphenyl in the presence of a catalyst. Large quantities of these products have been released into the environment due to intentional uses and uncontrolled disposal activities [10]. Landfills for solid waste (MSW) is also a source of PCBs. As a result of waste disposal, hazardous compounds are released into the environment through landfill gases and leachates [16]. Landfills and decommissioning sites are the main sources of pollution today. They can be generated and released unintentionally from various sources, such as: open burning of waste, including landfill burning, thermal processes in the metallurgical industry, waste oil refineries, and others. Although their global production was discontinued in 1977, these toxic compounds are distributed globally through atmospheric transport and can be found in various components of the environment, including air, water, sediments, fish, and mammals [10, 12-14].

PCBs are highly lipophilic and their bioaccumulation through the food chain makes low concentrations in the environment a threat to wildlife and human health. Although acute toxicity to adults is relatively low, chronic exposure to PCBs causes neurobehavioral and immunological disorders in children. According to the Department of Health and Human Services (DHHS), the U.S. Environmental Protection Agency (EPA), and the International Agency for Research on Cancer (IARC), PCBs are now considered carcinogenic to animals and humans. Unlike many other organic compounds, the chemical stability of PCBs allows them to resist microbial biodegradation and persist in the environment [14].

2.3. OCPs

The majority (>80%) of pesticides used worldwide, even when sprayed on crop and weed foliage, make soils their ultimate sink. Once in the soil system, a number of physical, chemical and biological processes (including degradation, accumulation by organisms, sorption-desorption, volatilization, runoff or leaching to surface and groundwater) determine the behavior of pesticides. The widespread use of pesticides to improve agricultural productivity has played an important role in the last century. OCPs have been applied for decades to prevent, repel or mitigate the effects of pests. [6, 17].

Inefficient application of pesticides and fertilizers is associated with huge losses of materials through evaporation, runoff or leaching into groundwater, as well as with the accumulation of agrochemical residues in soils [7]. The use of POPs as pesticides also leads to their long-term accumulation in soils and harmful effects on animal and human health. The organochlorine pesticide dichlorodiphenyltrichloroethane (DDT), shown in Fig. 3, is widely

used in agriculture and domestic use. It was banned for use in 1972 in many countries due to its well-known toxicity to wild and domestic animals and humans, its persistence in the environment (up to 15 years in soil) and its bioaccumulation in food chains. However, DDT and its metabolites are still found in soils, which is an indication that its properties and effects are not well understood, as it should have been eliminated by now [7, 18]. The use of DDT, which is banned in many countries, is related to the high stability of DDT and its metabolites against physical, chemical and biological factors [7]. A serious threat to human health and the environment is the persistence of DDT and its metabolites (such as DDE) in soil. In the environment, approximately 85% and 5% of DDT are found as p,p′-DDT and o,p′-DDT, respectively [11].

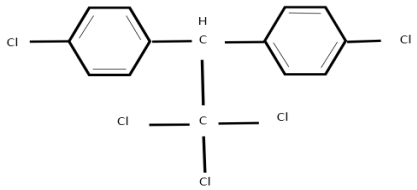

Fig.3 *Chemical structure of DDT*

The dangerous effects range from dizziness to various types of cancer, reproductive problems, lung damage, birth defects, nervous system damage, and immune and endocrine system dysfunctions [19]. Several diseases of the skin, nervous system, respiratory system and other organs of the body have been found in humans with long-term exposure to pesticides, and they can even lead to cancer, Parkinson's, Alzheimer's, etc. [20]. OCPs can be the cause of changes in feeding behavior and reproduction in birds of prey, leading to a decrease in their population. The high toxicity of OCPs can have an impact on bird mortality [19].

2.4. PAHs

Polycyclic aromatic hydrocarbons (PAHs) are a large group of organic compounds that are mostly colorless, white, or pale yellow solids. PAHs have two or more single or fused aromatic rings with a pair of carbon atoms shared between the rings in their molecules (Fig. 4). They are a ubiquitous group of several hundred chemical compounds that are persistent in the environment with different structures and different toxicity have carcinogenic and mutagenic properties. PAHs usually enter the environment by various routes and are usually found as a mixture containing two or more of these compounds [13, 21].

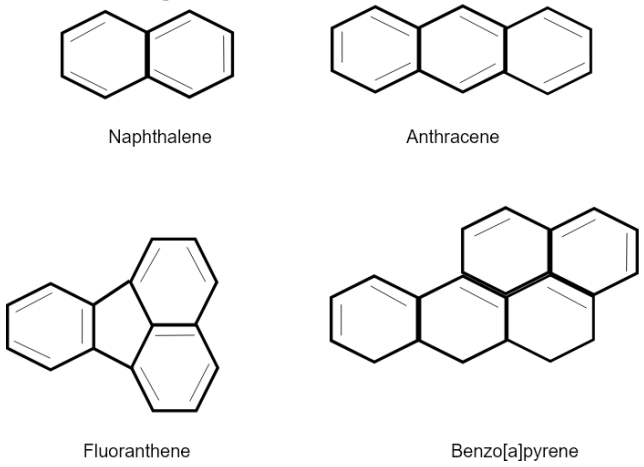

Fig.4 *Chemical structure of some PAHs*

PAHs can be formed during biological processes, the incomplete combustion of organic materials from industry, which are widely distributed through atmospheric deposition. Another important source of pollution is the use of petroleum products [13, 21]. PAHs are contained in road debris and in atmospheric air. They are used in pharmaceuticals, agricultural products, photographic products, thermosetting plastics, lubricants and other chemical industries. For example, Acenaphthene is used in the production of pigments, dyes, plastics, pesticides and pharmaceuticals, Anthracene as a diluent for wood preservatives and the production of dyes and pigments, Fluoranthene in the production of agrochemicals, dyes and pharmaceuticals, Fluorene in the production of pharmaceuticals, pigments, dyes, pesticides and thermosetting plastics, Phenanthrene for the production of resins and pesticides, other PAHs can be contained in asphalt, etc. [21].

Atmospheric deposition is a major source of widespread soil pollution by PAHs. Anthropogenic emissions of PAHs result from the incomplete combustion of coal, oil, gasoline, or wood in residential heating, coal gasification and liquefaction plants, the production of carbon black, coal tar, and asphalt, the production of coke and aluminum, catalytic cracking towers and related activities in petroleum refineries, and in motor vehicle exhaust. Atmospheric PAHs are continuously deposited on the ground by dry or wet deposition processes. Some of these PAHs are from nearby sources, such as automobile exhaust from adjacent roads. Other PAHs are from more distant sources and have been transported over varying distances by air [7, 21].

The main route of exposure of the population to PAHs is through breathing, eating food containing PAHs, smoking cigarettes, or inhaling smoke from open fireplaces. Acute effects include eye irritation, nausea, vomiting, diarrhea, and confusion. Health effects of long-term or chronic exposure to PAHs can include reduced immune function, cataracts, kidney and liver damage (e.g., jaundice), breathing problems, asthma-like symptoms, and impaired lung function. Meanwhile, frequent skin contact can cause redness and inflammation of the skin. Naphthalene a specific polycyclic aromatic hydrocarbon, can cause the breakdown of red blood cells if inhaled or ingested in large quantities. Evidence suggests that mixtures of PAHs are carcinogenic to humans. Teratogenic and embryotoxic effects of PAHs have been described in experimental animals exposed to PAHs such as benzo(a)anthracene, benzo(a)pyrene, and naphthalene [21].

The toxicity of surfactants to aquatic organisms is influenced by metabolism and photooxidation. They are generally more toxic in the presence of ultraviolet light. PAHs have moderate to high acute toxicity to aquatic organisms and birds. The presence of PAHs in soil is unlikely to have toxic effects on terrestrial invertebrates, except when the soil is heavily contaminated. Adverse effects on these organisms include effects on reproduction, development, immunity, including tumor formation. Mammals can absorb PAHs by various routes, such as inhalation, dermal contact, and ingestion. On the other hand, plants can absorb PAHs from the soil through their roots and translocate them to other parts of the plant . Phytotoxic effects caused by PAHs are rare [21].

2.5. Pharmaceutical contaminants

The human pharmaceutical industry is one of the fastest growing industries in the world. [22] Drugs play an important role in the treatment and prevention of diseases in animals and humans. The production and use of pharmaceuticals worldwide is increasing due to advances in healthcare. The reasons are obvious: first, the world population is growing by 1.24% per year and will continue to do so until 2030; second, during the same period, the proportion of people aged 65 to 80 years will increase to 28%, compared to 22% in 2000; and last but not least, increasing urbanization and a growing middle class mean that medicines are accessible and affordable to more people. However, pharmaceutical residues can have undesirable effects on animals and microorganisms in the environment [22, 23]. A wide variety of human medicines, including antibiotics, statins or cytotoxins used to treat cancer, as well as large quantities of veterinary medicines, such as antibacterials, antifungals and antiseptics, reach the environment via various routes and lead to contamination of soil, surface water and agricultural land [23].

Pharmaceuticals are a class of biologically active compounds used in human and veterinary medicine, some of which

can be applied to feed production and plant growth promotion [24]. The presence of human and veterinary pharmaceuticals in the environment has been recognized as a potential environmental threat [25].

Pharmaceuticals are typically reintroduced into the environment through two main pathways: the discharge of treated wastewater from WWTPs or through the disposal of sewage sludge. Other sources of exposure may include the disposal of expired or surplus PPCPs and animal excreta in landfills. The number of unused and/or expired pharmaceuticals has increased in recent decades, but due to the lack of comprehensive recycling strategies, they may enter municipal sewage systems and landfills [6, 22, 24-26]. Pharmaceutical residues in the environment usually occur as complex compounds and therefore, even if the concentration of a given compound is low, it may be important for ecological toxicity. In a study by Mishik et al. investigating the genotoxic properties of anticancer drugs, it was found that even low concentrations of these drugs have toxic effects on the ecosystem [23].

The fate and behavior of pharmaceuticals in soil, including their mobility and availability to plants, depends on the physical, chemical and biological properties of the soil, as well as on the properties of the substance itself [24]. The detection of pharmaceuticals in soils and biosolids has raised concerns due to their potential to be bioactive at both high and low doses. Some drugs cause microbial resistance (e.g. antibiotics), exhibit acute toxicity (e.g. diclofenac) and lead to endocrine disruption (e.g. 17β-estradiol). Nonsteroidal anti-inflammatory drugs, antibiotics, cardiovascular pharmaceuticals (β-blockers/diuretics), psychostimulants, antihypertensives, estrogens and other hormones, as well as antiepileptic drugs are the main pharmaceuticals introduced into the soil environment, some of which are presented in Fig. 5 [25]

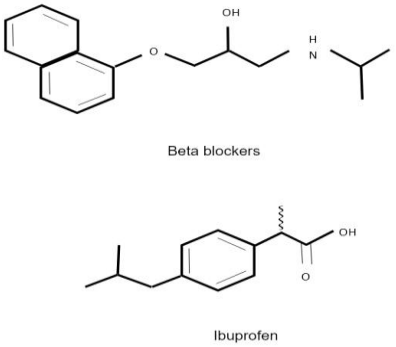

Fig.5 *Chemical structure of beta-blockers and ibuprofen*

Contamination with pharmaceutical active compounds directly affects humans through respiratory disorders, loss of reproductive capacity, cancer, skin allergies and congenital problems. Overuse of antibiotics creates resistance leading to incurable superbug infections [24, 26]. A wide range of harmful effects of pharmaceutical residues have been identified, including physiological effects, inhibition or stimulation of the growth of aquatic plants and algal species, and effects on the fertility and growth of fish, reptiles and aquatic invertebrates [23].

2.6. Bisphenol A

Bisphenols are called "priority substances" [27]. Bisphenol A or 2,2-(4,4′-dihydroxydiphenyl)propane (BPA) is a high-volume chemical intermediate, BPA is a monomer (illustrated in Fig. 6) first synthesized by Dianin in 1891, and its estrogenic activity was discovered in 1936. It is therefore one of the oldest synthetic compounds known to have endocrine activity and with confirmed endocrine potential. BPA binds strongly to estrogen receptors and to a lesser extent to androgen receptors [27-29]. It is an endocrine disrupting compound that can act like estrogen [30].

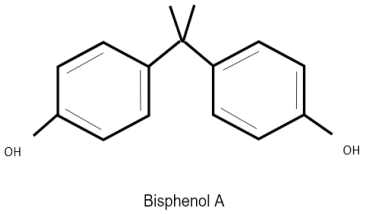

Fig.6 *Chemical structure of Bisphenol A*

It is widely used in the industrial production of plastic products and epoxy resins, as well as many consumer products, including plastics (such as polycarbonate), PVC, food packaging, dental sealants , etc. [29, 30].

Trace amounts of BPA released into the environment can reach soil through the application of wastewater sludge from municipal and industrial wastewater treatment systems that receive wastewater containing BPA, or from leachate from uncontrolled landfills [29] . The rate of degradation of bisphenol A in soil is influenced by abiotic and biotic factors, molecular characteristics and diversity of microorganisms, physicochemical properties of the soil, its pH, and redox potential [27].

BPA affects the developing central nervous system, pancreas, and immune system [31]. BPA has been linked to many human diseases, including diabetes, obesity, cardiovascular, chronic respiratory, and kidney diseases, breast cancer, behavioral problems, dental defects, and reproductive disorders in both sexes [28]. BPA has been shown to be associated with thyroid receptors and has both agonist and antagonist effects on thyroid function gland [31]. It also exhibits phytotoxicity in plants through various mechanisms, such as impairment of photosynthesis, generation of reactive oxygen species, and alteration of plant hormone levels [32].

3. Conclusions

From the review, it is clearly seen that the considered groups of POPs are characterized by wide application, multiple sources of their emission into the environment, and diverse effects on humans, flora and fauna.

Soil contamination with POPs is of paramount importance. Although they are found in small quantities, the negative effects they have on ecosystems are immeasurable. Based on these effects (phytotoxicity, bioavailability, etc.), their ability to migrate between environmental components and to be included in the food chain, it is extremely important to minimize their impact.

The main sources of POPs are anthropogenic activities. Therefore, it is necessary to take action to modernize technologies, use safer alternative substances, dispose of accumulated, obsolete pesticides and equipment containing POPs, manage waste streams, etc.

And last but not least, it is necessary to unite the efforts of institutions, organizations and industry to achieve a future without POPs.

4. References

1. Duraes, N., L.A.B. Novo, C. Candeias, E.F. Silva. Distribution, Chapter 2 - Distribution, Transport and Fate of Pollutants, *Soil Pollution*, (2018), 29-57
2. R.G.Morgado, S. Loureiro, M.N. González-Alcaraz. Chapter 3 - Changes in soil ecosystem structure and functions due to soil contamination, *Soil Pollution*, **2** (2026), 65-102
3. Patinha C., A. Armienta, A. Argyraki, N. Duarte. Chapter 6 - Inorganic Pollutants in Soils, *Soil Pollution*, (2018), 127-159
4. Cachada A., T. Rocha-Santos, A.C. Duarte. Chapter 1 - Soil and Pollution: An Introduction to the Main Issues, *Soil Pollution*, (2018), 1-28
5. Plamenov D., P. Naskova. Soil science, soil pollution and remediation technologies, *Technical University of Varna*, (2017), 121-123

6. Duarte R.M.B.O., J.T.V. Matos, N. Senesi. Chapter 5 - Organic Pollutants in Soils, *Soil Pollution*, (2018), 103-126
7. Rodrigues S.M., P.F.A.M. Römkens. Chapter 10 - Human health risks and soil pollution, *Soil Pollution*, **2** (2026), 271-306
8. Litynska M. Persistent organic pollutants: sources, migration in ecosystems, removal methods in wastewater treatment and remediation of soils and natural water , National Water and Water Purification Technologies. Scientific and Technical News, (2024), 40-48
9. Ashraf M.A. Persistent organic pollutants (POPs): a global issue, a global challenge, *Environ Sci Pollut Res*, **24** (2017), 4223-4227
10. Mao S., S. Liu, Y. Zhou, Q. An, X. Zhou, Z. Mao, Y. Wu, W. Liu. The occurrence and sources of polychlorinated biphenyls (PCBs) in agricultural soils across China with an emphasis on unintentionally produced PCBs, *Environmental Pollution*, **271** (2021), 116171
11. Anjum N.A., K.F. Mendes, M.R. dos Reis, V.L. Tornisielo, A.C. Duarte, E. Pereira. Chapter 4 - Pollutant transformation and metabolite accumulation in soils, *Soil Pollution*, **2** (2026), 103-116
12. Nenin T., T. Mitrović, A. Petković, J. Čolić. Validation of the GCMS method for the determination of polychlorinated biphenyls congeners in soil and sediment samples, *Microchemical Journal*, **207** (2024), 111761
13. Kalbe U., P. Lehnik-Habrink, N. Bandow, A. Sauer. Validation of European horizontal methods for the analysis of PAH, PCB and dioxins in sludge, treated biowaste and soil, *Environmental Sciences Europe*, **31** (2019), 29
14. P.A. Correa P.A., L.S. Lin, C.L. Just, D. Hu, K.C. Hornbuckle, J.L. Schnoor, B.V. Aken. The effects of individual PCB congeners on the soil bacterial community structure and the abundance of biphenyl dioxygenase genes, *Environment International*, **8** (2010), 901-906
15. Zhang H. B., Y. M. Luo, M. H.Wong, Q. G. Zhao, G. L. Zhang. Concentrations and possible sources of polychlorinated biphenyls in the soils of Hong Kong, *Geoderma*, **138**, (2007), 244-251
16. Mel A., A. Dettlaff, K. Kuklińska, J. Namieśnik, L. Wolska. Concentration and sources of polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) in surface soil near a municipal solid waste (MSW) landfill, *Science of The Total Environment*, **530-531**, (2015), 18-27
17. Tor A., M.E. Aydin, S. Ozcan. Ultrasonic solvent extraction of organochlorine pesticides from soil, *Analytica Chimica Acta*, **559** (2006), 173-180
18. Lesueura C., M. Gartnera, A. Mentlerc, M. Fuerhackerb. Comparison of four extraction methods for the analysis of 24 pesticides in soil samples with gas chromatography–mass spectrometry and liquid chromatography–ion trap–mass spectrometry, *Talanta*, **75** (2008), 284-293
19. Gnanaprakasam P.D., A.J. Vanisree. Recurring detrimental impact of agrochemicals on the ecosystem, and a glimpse of organic farming as a possible rescue, *Environmental Science and Pollution Research*, **29**, (2022), 75103-75112
20 Sarkar, Deepranjan, S.S. Rakesh, S. Ganguly, A. Rakshit. Management of Increasing Soil Pollution in the Ecosystem. *Advances in Research*, **12** (2017), 1–9
21. Abdel-Shafy H.I. , M.S.M. Mansour. A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation, *Egyptian Journal of Petroleum*, **25**, (2016), 107-123
22. Kumirska J., P. Łukaszewicz, M. Caban, N. Migowska, A. Plenis, A. Białk-Bielińska, M. Czerwicka, F., Qi, S. Piotr. Determination of twenty pharmaceutical contaminants in soil using ultrasound-assisted extraction with gas chromatography-mass spectrometric detection, *Chemosphere*, **232**, (2019), 232-242
23. F. Manole , P. Marian, G.M. Mekeres, A.N. Csep. A Review of the Effects of Pharmaceutical Waste on the Environment and Human Health, *Pharmacophore*, **14**, (2023), 106-110
24. G. Barbara, M. K., J. Wrzosek, M. Graniewska. Pharmaceuticals in the Soil and Plant Environment: a Review, Water, *Air, & Soil Pollution*, **232**, (2021), 145
25. K. Radka, R. Grabic, M. Kočárek, A. Klement, O. Golovko, M. Fér, A. Nikodem, O. Jakšík. Pharmaceuticals' sorptions relative to properties of thirteen different soils, *Science of The Total Environment*, **511**, (2015), 435-443
26. A. Subramanian, M.S. Mumtaz, M.H.A.K. Mohideen, A. Radha, N. Sasirekha, B. Sawicka, V. Tamizhazhagan. Pharmaceutical Pollution Crisis in the World: A Menace to Ecosystem, *Entomology and Applied Science Letters*, **8**, (2021), 77-89
27. Zaborowska M., J. Wyszkowska, A. Borowik. Soil Microbiome Response to Contamination with Bisphenol A, Bisphenol F and Bisphenol S, *International Journal of Molecular Sciences*, **21**, (2020), 3529
28. E. Soria, T. Grisin, D. Moison, M.J. Guerquin, T. Thierry, S. Pozzi-Gaudin, A. Benachi, G. Livera, V. Rouiller-Fabre, R. Habert. A new chapter in the bisphenol A story: bisphenol S and bisphenol F are not safe alternatives to this compound, *Fertility and Sterility*, **103**, (2015), 11-21
29. Careghini A., A.F. Mastorgio, S. Saponaro, E. Sezenna. Bisphenol A, nonylphenols, benzophenones, and benzotriazoles in soils, groundwater, surface water, sediments, and food: a review, *Environmental Science and Pollution Research*, **22**, (2015), 5711-5741
30. Costa H.E., E. Cairrao. Effect of bisphenol A on the neurological system: a review update, *Archives of Toxicology*, **98**, (2024), 1-73
31. Rochester Johanna R. Bisphenol A and human health: A review of the literature, *Reproductive Toxicology*, **42**, (2013), 132-155
32. Zhang Z., R. Lu, L. Li, Y. Chen, J. Lan, R. Chen, Y. Zhou, H. Han. Phytotoxic Effects of Bisphenol A on Growth and Physiology of Capsicum annuum L., *Horticulturae*, **11**, (2025), 788