POLLUTANTS PRESENT IN THE ENVIRONMENT AND THEIR INFLUENCE ON LIVING BEINGS

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Abstract. A healthy environment is a basic prerequisite for preserving the health of people, animals and plants. Land, water, air are common natural resources that do not know state borders and represent the common concern of all humanity. That is why environmental pollution cannot be observed only at the local level or at the level of one country, but it is to be considered at regional and global level. In order to understand the potential dangers and the impact of environmental pollution on the living world, it is necessary to know the characteristics of the most environmental important pollutants and their sources. In the 21st century, humanity is facing increasing levels of pollution of the Earth and its components. The effects of pollution manifest in the reduction of biodiversity, climate change, changes in precipitation patterns, increasing deserts, rising sea levels and oceans due to the melting of glaciers and the emergence of new diseases that are difficult to cure. Programs for reducing contamination are based on reducing the production of polluting substances, applying good agricultural and good production practices, as well as applying efficient and sustainable methods for their removal.
Keywords: *sources of pollution, living world, diseases, pesticides, decontamination*

Abbreviations. OCP - organochlorine pesticides; PM - particulate matter; PAHs - Polycyclic aromatic hydrocarbons; POPs - Persistent organic pollutants; PCBs - Polychlorinated biphenyls; PCDD - polychlorinated dibenzo-p-dioxins; PCDF - polychlorinated dibenzofurans

Introduction

In the 21st century, humanity is facing with increasing pollution of the Earth. Indicators of pollution are: reduction of biodiversity, climate change, changes in precipitation dynamics, increase in deserts, rise in sea levels and oceans due to the melting of glaciers and the emergence of new and incurable diseases (Mimura, 2013; Ristić and Komatina, 2014; Đorđević, 2019; Al-Blooshi et al., 2020; Shetty et al., 2023; Kleespies et al., 2024). A healthy environment is a basic prerequisite for preserving the health of people, animals and plants (Benson et al., 2024; Leonardi et al., 2024). Land, water, air are common natural resources that do not know state borders and represent the common concern of all humanity. That is why environmental pollution cannot be observed only at the local level or at the level of one country, but it should be examined at the level of the region and the whole world (Brunekreef, 2010; Ristić and Komatina, 2014; Đorđević, 2019; Bojanić Rašović, 2020a,b; Nahar et al., 2021). In order to understand the potential dangers and the impact of environmental pollution on the living world, it is necessary to know the characteristics of the most important environmental pollutants and their sources. The goal of the paper was to consider the most important types and sources of chemical environmental pollutants, the dangers they have for human and animal health, as well as the technologies and strategies used to remove pollution.

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The most significant environmental pollutants

In order to improve living conditions, people developed industrial production and agriculture, which caused an excessive load on the environment with pollutants. The number of pollutants that enter the environment every day is very large, and the most significant are inorganic pollutants, organic pollutants, organometallic compounds and radioactive substances (Mirić and Šobajić, 2002; Liu et al., 2022; Majumdar et al., 2024). Pollution of land, water and air has a harmful effect on all living beings on Earth: people, animals, plants, microorganisms (Weldeslassie et al., 2018; Shetty et al., 2023; Awewomom et al., 2024). Industrial and exhaust gases of numerous pollutants, means used to protect plants and other pollutants have an adverse effect on the living world. Substances dangerous to health are those that cause: acute toxicity, skin corrosion and irritation, severe eye damage, hypersensitivity of the respiratory tract or skin, mutagenicity, carcinogenicity, teratogenicity, reproductive toxicity, immunosuppression, cardiovascular diseases (Bhat, 2013; Suzuki et al., 2020; Münzel et al., 2022; Shetty et al., 2023). When assessing the reproductive toxicity of a substance, it should be borne in mind that the harmful effect does not have to be manifested in the fetus whose mother was exposed to a dangerous substance during pregnancy, but changes can occur in a subsequent, second, or third generation. Pollutants affect both animal and human behavior. They affect their memory, learning, reproductive behavior, sociability, aggression, danger avoidance, nutrition (Fairbrother and Hope, 2005; Ružić and Poznanović, 2009; Bagi and Bodnar, 2012; Ma et al., 2019; Alex et al., 2021; Liu et al., 2022; Shetty et al., 2023; Yesildemir et al., 2024).

Inorganic pollutants

Heavy metals

In recent years, environmental contamination with heavy metals has increased dramatically due to unsustainable agricultural practices and improper waste disposal. Bioaccumulation of arsenic, lead, mercury and cadmium has been observed in crops grown in areas irrigated with wastewater. Exposure of animals and humans to heavy metals leads to a number of health problems, such as neurotoxicity, carcinogenicity, cardiovascular diseases, developmental disorders, causes liver, kidney and thyroid gland function disorders. Dietary intake is the primary route of exposure (Mirić and Šobajić, 2002; Mahurpawar, 2015; Lamas et al., 2016; Dash et al., 2019; Singh et al., 2021; Shetty et al., 2025; Jomova et al., 2025). Metals are present in food as a result of pollution from human activities such as agriculture, industry or transport, or due to contamination during food processing and storage. Heavy metals can enter the environment and food through industrial activities, acid rain, chemical fertilizers, pesticides and sewage. Metal accumulation mainly occurs in plant roots (Neisi et al., 2024). Agriculture can lead to increased concentrations of heavy metals as a result of the use of various fertilizers and pesticides. Atmospheric deposition is known as the main way lead enters leafy vegetables. Accumulation of heavy metals in soil and plants is a serious health problem (Tóth et al., 2026). Heavy metals are dangerous to health because they tend to bioaccumulate. The consumption of seaweed and halophytes that bioaccumulate heavy metals both in the form of organic and inorganic compounds can especially lead to a negative effect on health (Dujardin et al., 2023). Traces of various heavy metals were found in food as vegetables, meat, fish, milk, etc. due to their bioaccumulation. Organic compounds of heavy metals can be particularly toxic to living organisms (Olayiwola et al., 2017;

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Scutarașu and Trincă, 2023; Neisi et al., 2024; Shetty et al., 2025; Ondrasek et al., 2025). When heavy metals enter the body, they oxidize and form stable bonds with enzymes or protein molecules. Heavy metals can cause disorders in the cardiovascular system by creating free radicals, DNA damage, lipid peroxidation and oxidative stress. The presence of heavy metals in the organism of bees can be an indicator of the degree of pollution of the human environment (Burden et al., 2019). Bee products can be successfully used in environmental pollution testing (Formicki et al., 2013). Heavy metals, which are ubiquitous in water, are very strong neurotoxins for fish. They cause deformities in fish that can serve as biomarkers of environmental pollution by heavy metals (Ali et al., 2019). Methods for the removal of heavy metals from different substrates are chemical precipitation, electrodialysis, coagulation and flocculation, photocatalytic removal and processes based on adsorption. However, these procedures are expensive and difficult to implement, so it is necessary to find new methods for their elimination. Preventing environmental contamination and reducing the content of heavy metals in the environment requires sustainable agricultural practices (FAO/WHO, 2001, 2017, 2022; Neisi et al., 2024).

Nonmetals and their compounds

In addition to metals, non-metals are also important for environmental pollution, whose large distribution also poses a danger to life on Earth. They can originate from natural sources, from which they are released spontaneously, or come from human sources. Water pollution with phosphorus from non-point sources of soil is increasing dramatically, leading to eutrophication of water bodies (Akinnawo, 2023; Ge et al., 2023). Phosphorus and its compounds are used as fumigation agents, for the production of bombs, phosphate mineral fertilizers. Together with nitrogen compounds they are found in industrial wastewater, mining, additives, organic fertilizers, etc. (Liu et al., 2024; Wang and Tang, 2024; Karasa et al., 2024). Organic and inorganic forms of phosphorus compounds in waste water can convert into each other (Kuznietsov et al., 2023). The enrichment of streams, lakes, and rivers with phosphorus is increasing and leading to eutrophication, i.e. algae blooms (Ge et al., 2023). Algae blooms lead to increased consumption of oxygen, which is needed by aquatic organisms. The number of bacteria in the water is also increasing, primarily faecal bacteria, which leads to an increased health risk when consuming shellfish and fish from such water. This leads to the death of aquatic animals and the reduction of aquatic biodiversity (Mallin and Cahoon, 2020). Increased nitrogen input through the use of fertilizers has a detrimental effect on terrestrial and aquatic ecosystems, as well as on human health. The detrimental effect is manifested by the loss of plant diversity in terrestrial ecosystems and excessive algae growth in aquatic ecosystems. Excessive algae growth leads to the appearance of so-called dead zones where there is no oxygen, eutrophication and acidification (Mirić and Šobajić, 2002; de Vries, 2021). Nitrogen oxides are released in industrial processes. Nitrogen oxide is considered to be the third most important greenhouse gas after carbon dioxide and methane. Nitrogen oxide emissions play a very significant role in the formation of O_3, which is one of the most important air pollutants affecting human health. N_2O is a very important factor that leads to damage to the stratospheric ozone layer, which increases the risk of skin cancer. Nitrites and nitrates are found in nitrogen fertilizers, fecal waters from septic tanks, manure - especially liquid manure. They are also found in tobacco smoke (Martínez-Dalmau et al., 2021; Berger et al., 2022). Nitrates and nitrites are most commonly ingested through water and dietary sources. Nitrates and nitrites are

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completely resorbed from the digestive tract. Part of the ingested nitrates is reduced to nitrites in the mouth by the action of microorganisms, and then in the cecum and small intestine. Nitrites that reach the blood convert hemoglobin into methemoglobin, which does not transport oxygen to the cells. Nitrates and nitrites also have a teratogenic effect, leading to congenital malformations. They also lead to disorders of the thyroid gland, because they inhibit the binding of iodine. They cause a change in the composition of phospholipids in the body, headaches, reduce the concentration of B group vitamins and interact with vitamin A. When reacting with amines, nitrites form nitroso compounds that are carcinogenic (Mirić and Šobajić, 2002; Karwowska and Kononiuk, 2020; Picetti et al., 2022; Membrino et al., 2025). The use of chemical coagulants such as lime, magnesium sulfate, and iron sulfate has been found to remove more than 95% of nitrates and phosphates from polluted water (Akinnawo, 2023). Hypochlorites and chlorites are used as bleaching agents, disifectants, and chlorates and perchlorates for the production of matches, explosives, as non-selective herbicides. Many disinfection byproducts are carcinogenic to humans, cytotoxic, genotoxic, and mutagenic. Elevated concentrations of chlorine in the soil and water can cause toxicity in plants. They are harmful to the flora and fauna of a water body and can have negative effects on microorganisms and plankton present in these ecosystems. Sodium chlorate and potassium perchlorate lead to hemolysis and death (Mirić and Šobajić, 2002; Svensson et al., 2021; Parveen et al., 2022; Valentukeviciene et al., 2023).

Organic pollutants in the environment

Polycyclic aromatic hydrocarbons

These compounds are widely distributed in the environment. Anthropogenic sources of PAHs are processes in which organic carbon is exposed to high temperatures. They are created by incomplete combustion or pyrolysis of organic matter, wood and fossil fuels. Forest fires and all types of fires, burning of agricultural waste, burning of fossil fuels, contribute the most to increasing the content of PAHs, above all in the atmosphere. The most important industrial sources of PAHs are the coke, hydrocarbon fuel, aluminum, iron, and steel production industry. In the atmosphere, PAHs can be present in the form of gas (PAHs of lower molecular weight, e.g. phenanthrene), or they can be adsorbed on the surface of particles (PAHs of higher molecular weight, e.g. benzo-(a)pyrene), with which they can be transported over long distances. Most of these compounds decompose slowly in the atmosphere, so they remain unchanged in it for a long time. They can be transported from the atmosphere by wind over long distances (Mirić and Šobajić, 2002; Spasojević, 2015; Patel et al., 2020). Polycyclic aromatic hydrocarbons are carcinogenic. The most toxic is benzopyrene, which is most often used as an indicator of the presence of these compounds in the environment. In addition to the sources mentioned, benzopyrene is also produced during the burning of plastics, the production of gasoline and other fuels, heavy and light metals, in the exhaust gases of motor vehicles, the burning of waste, etc. Polycyclic aromatic compounds have a harmful effect on the body by having the ability to bind to lipids, DNA, RNA and proteins (enzymes) of cells and thus destroy it. The most significant pathological effect of PAHs is causing cancer. They also cause damage to the skin, liver, cataracts in fish, etc. PAHs are found in the environment in an inactive form - only after entering the body are they transformed into carcinogenic forms. Some microorganisms have the ability to degrade PAHs, so the possibility of biodegradation of PAHs in soil depends on the activity of soil microorganisms (Abdel-

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Shafy and Mansour, 2016; Patel et al., 2020; Hishamuddin et al., 2023; Shetty et al., 2023; Yemele et al., 2024).

Persistent organic pollutants

A special group of organic pollutants consists of the group of organochlorine compounds, the so-called persistent - long-lasting pollutants (Persistent Organic Pollutions, POPs). These compounds are poorly soluble in water, and dissolve very well in fats, which results in their bioaccumulation in the fatty tissues of living organisms. They are toxic to living organisms. They are transported over long distances by water and air, which is why they are widely distributed even where they have never been used. They are carcinogenic. This is why they are the most researched compounds today. The most widespread from this group are: polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and organochlorine pesticides (Bogdal et al., 2014; Mortimer and Reichelt-Brushett, 2023). The sources of these compounds are numerous and in the environment they usually appear in cultivated land as residues of mineral fertilizers and plant protection agents, by deposition from the air as a result of emissions from the textile and pharmaceutical industry, the cement and construction material industry, waste processing and incineration plants, etc. They remain unchanged in the environment for a long period of time (Pariatamby and Kee, 2016; Mandal et al., 2024). The Stockholm Convention on POPs aims to protect human health and the environment from very dangerous, long-lasting chemicals by limiting and ending their production, use, trade, release into circulation and storage. Montenegro is also a signatory to the Stockholm Convention on POPs (Anon, 2013a, 2014a,b, 2015a,b, 2016).

Polychlorinated biphenyls

These organochlorine compounds were widely used at the end of the 20th century. Polychlorinated biphenyls (pyralenes) are a group of chlorinated aromatic hydrocarbons that have a biphenyl structure and at least one chlorine atom that replaced the hydrogen. Depending on the number of chlorine atoms in their molecules, they differ in physical, chemical and toxicological properties. Chlorinated industrial chemicals are extremely toxic, they are classified as POPs substances, which are one of the most toxic chemicals synthesized by man. They are very stable compounds with low vapor pressure, low inflammability, good electrical insulators, high heat capacity and dielectric constant. They originate from building materials and electrical equipment. They were used as dielectric liquids in transformers and as impregnations in capacitors, as additives to lubricants, in the paint industry, etc. (Dave et al., 2021). They are very toxic and dangerous for nature, people and animals. In soil and water, they lag up to 10 years. They are poorly soluble in water. Their burning produces the very toxic compound dioxin (2,3,7,8-tetrachloro-dibenzo-dioxide) (Montano et al., 2022; Shetty et al., 2023; Cosentino et al., 2025). In poisoned birds, lethargy, a bristling appearance, loss of feathers, enlargement of the liver, kidneys, reduction of the spleen, etc. occur. They accumulate in lake fish. A number of countries have stopped producing these compounds since the mid-1970s, but PCBs are still significant pollutants. The reason is that significant amounts of PCBs are still in use, due to the long life of equipment, such as transformers, and due to their longevity, they are still present in the environment. The signatory countries of the Stockholm Convention have undertaken to phase out the use of equipment with polychlorinated biphenyls, and by the end of 2028 they are obliged to completely remove such equipment (Kumari et al., 2024). PCBs are transferred from the

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environment to humans through various routes, most commonly through contaminated food - fish, seafood, dairy products. Exposure to high concentrations of PCBs is associated with various health conditions, such as neuropsychological and neurobehavioral disorders, dementia, immune system dysfunction, cardiovascular disease, cancer, and reduced fertility. Endocrine dysfunctions, type 2 diabetes, obesity, cardiovascular disease, liver disorders have been associated with PCBs exposure (Stajkovac et al., 2009; Anon, 2013a; Bogdal et al., 2014; Kaw et al., 2017; Scheringer, 2017; Ryzhenko et al., 2020; Singh et al., 2021; Montano et al., 2022; Radosavljevic, 2025).

Polychlorinated -p-dibenzodioxins and dibenzofurans

These compounds are not produced intentionally, except for research purposes, and are produced as side products in various chemical processes in the industry of chlorinated compounds, pulp and paper industry, waste incineration, in ferrous and non-ferrous metallurgy, cement production, etc. (Picone et al., 2020; Vernez et al., 2023). The optimal temperature for their synthesis is 400-700 ^{0}C. Due to their high toxicity and danger of accumulation in nature, many countries have made a list of industrial sources and their emissions into the environment in order to better understand the participation of individual sources in their total emissions and to reduce their emissions. In Europe, the processes of burning municipal and medical waste, synthesis of iron ore, forest fires, production of non-ferrous metals, wood and coal-fired furnaces in households, steel production processes using the electric furnace process, etc., account for the largest share of the total emission of these compounds into the air (Bogdal et al., 2014; Yu et al., 2019; Pan et al., 2024.). They damage the liver, peripheral nerves, have a toxic effect on development, reproduction and the immune system, lead to diabetes and cancer (Vernez et al., 2023).

Pesticides

Extensive use of pesticides in order to increase yields in agriculture has drastically increased the amount of agrochemicals in the environment. Pesticides are chemical agents that are used against the causative agents of plant diseases, against harmful insects, nematodes, rodents, birds, to control weeds and regulate plant growth. However, the consequence of inadequate use of pesticides leads to the emergence of resistance of harmful organisms, which leads to even greater use of pesticides. This leads to a reduction in the biological diversity of agricultural land, loss of land fertility, and food contamination (Stojić and Pucarević, 2019; FAO, 2022; Tourinho et al., 2025). By seeping through the soil, pesticides reach groundwater and marine systems. Hormonal system disorders, nervous disorders, and fetal development disorders occur in people exposed to pesticides. As the use of pesticides in Europe has been continuously increasing since 1996, measures are being taken to ensure that agricultural producers use pesticides with the least risk to human health and the environment. Different pesticides are usually used in different phases of the plant's vegetation, so sometimes up to ten different preparations are used. By using groundwater contaminated with pesticides, humans are most often exposed to pesticides. The extent to which groundwater contamination will occur depends on many factors such as: the rate of leaching, type of land, depth of the aquifer, the amount of pesticide used and its physical and chemical properties. Pesticides enter the air during the application itself, by evaporation from the soil and plants and carried away by the wind. Pesticide particles and vapors easily travel long distances

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through the air, where they eventually settle. That is why pesticide treatments should never be carried out in windy weather. Particles and vapors of pesticides that reach the air represent a direct risk to the health of people, plants and animals (Aktar et al., 2009; Weldeslassie et al., 2018; Anon, 2019a,b; Stojić and Pucarević, 2019). The use of pesticides and their appearance in the environment has as a result not only a harmful effect on harmful insects and other pests, but also a reduction in the number and types of beneficial insects, birds that feed on them and a change in the entire biocenosis. Pesticides destroy bees and other beneficial insects that pollinate plants, then ants, fish, invertebrates, as well as other types of animals and humans. Pesticide poisoning in humans causes the cessation of vital center function, paralysis of the respiratory center, heart failure, and pulmonary edema (Kristiforović-Ilić, 2004; Lazić et al., 2009; Čolović et al., 2013; Jayaraj et al., 2016; Stojić and Pucarević, 2019). Pesticide residues are most often introduced into the body of humans and animals through food and drinking water. Food of animal origin may contain residues if the animals are fed with contaminated plant food or the animals themselves are treated with pesticides in order to destroy parasites and insects. Pesticides are easily deposited in organs. Organochlorine pesticides are easily deposited in fatty tissue due to their liposolubility (Stajkovac et al., 2009; Bagi and Bodnar, 2012). The maximum residue level permitted in food is the smallest quantity that can be detected and determined by analytical methods and is 0.01 mg/kg of food (Ockleford et al., 2018).

Organochlorine pesticides

After the Second World War, organochlorine pesticides were intensively used as insecticides and fungicides in agriculture to protect timber, and in healthcare to combat malaria and typhus. They persists longer in the environment and bioaccumulates in plants and animals, leading to contamination of food consumed by humans. They enter the body of humans and animals in three ways: inhalation, ingestion and through the skin. Due to their good solubility in fats and great stability, they easily enter the food chain, which represents a great danger. Gradually accumulated in one organism, they reach other organisms through food. Acute endrin poisoning is characterized by nausea, vomiting, irritability, coma. Chronic poisoning is manifested by damage to the nervous, digestive and cardiovascular systems and blood-forming organs (Kristiforović-Ilić, 2004; Stajkovac et al., 2009; Bagi and Bodnar, 2012; Čolović et al., 2013; Jayaraj et al., 2016; Stojić and Pucarević, 2019). Many organochlorine molecules are carcinogenic and neurotoxic. They affect blood pressure disorders, liver dysfunction, increase the risk of Parkinson's disease, of type 2 diabetes, lead to changes in lipids, especially LDL-cholesterol, increase oxidative stress, affect the complement system, disrupt the endocrine system (Jayaraj et al., 2016). Various methods are used to remove organochlorine pesticides. These are conventional water purification procedures, such as adsorption and filtration, adsorption, chemical treatments (oxidation and reduction reactions), biological treatments, application of ultrasonic waves, photocatalytic decomposition. Biological treatments that use microorganisms to decompose these pesticides give good results in removing pollutants from water systems contaminated with organochlorine pesticides. Control of environmental conditions is very important for the performance of bioremediation (da Silva Júnior et al., 2023). Both phytoremediation and ozonization can be used to remove organochlorine pesticides (Ajiboye et al., 2020). Burning at a very high temperature, usually above 500 ◦C in the presence of oxygen, can also be used. The chemical dechlorination method is based on the removal of chlorine from organochlorine

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pesticides using reducing radicals that have hydrogen to donate (Ajiboye et al., 2020). Considering the persistence of organochlorine pesticides in the environment, advanced technologies are needed that can successfully degrade these pollutants. The strategy to prevent contamination of the environment with these pesticides implies the use of biopesticides and agrochemicals with gradual release, research into mechanisms of interaction with soil, plants, microbiota, development of new methods of pesticide removal (Anon, 2016b; Tzanetou et al., 2022; da Silva Júnior et al., 2023).

Organophosphorus pesticides

Organophosphorus compounds are derivatives of phosphoric, phosphonic or phosphinic acid in which the oxygen atoms attached directly to the phosphorus atom can be replaced by sulfur or nitrogen atoms. These compounds form a large group of organic compounds that are used primarily as pesticides, some as medicines, and the most dangerous as nerve warfare agents. Due to their effectiveness and low price, they are still used in large quantities to control pests. Organophosphorus pesticides are less dangerous than organochlorine pesticides, because they are less stable. Of the organophosphorus pesticides, one of the most dangerous is parathion (Camacho-Pérez et al., 2022; Ore et al., 2023). The toxicological effect of organophosphorus compounds consists in lowering the activity of the enzyme acetylcholinesterase, as a result of which acetylcholine accumulates in the synapses of nerve cells. An increase in the content of acetylcholine first stimulates and then blocks the transmission of nerve impulses in the nervous system. In the case of chronic poisoning in humans, there is a narrowing of vision, increased activity of the endocrine glands, difficult and irregular breathing, cessation of breathing, nausea, diarrhea, increased blood pressure, general physical weakness, rapid fatigue, dizziness, nervousness, irritability, memory loss, coma, cessation of breathing, allergies, immunosuppressive phenomena, chronic degenerative changes (Coronado et al., 2004; Stajkovac et al., 2009; Bagi and Bodnar, 2012; Ghorab and Khalil, 2015; Stojić and Pucarević, 2019; Camacho-Pérez et al., 2022).

Neonicotinoids

Neonicotinoids such as imidacloprid, clothianidin, acetamiprid, thiamethoxam, thiacloprid, nitenpyram, dinotefuran are a relatively new generation of insecticides derived from nicotine. Their use increased in the early nineties. They act on the central nervous system of insects, leading to their paralysis and death. These pesticides permanently bind to nicotinic acetylcholine receptors and thus block the passage of nerve impulses. Imidacloprid is particularly toxic to bees - damages the memory and metabolism of the brain of bees (Johnson et al., 2010; Laurino et al., 2011; Anon, 2013a; Rişcu et al., 2013; Sanchez-Bayo et al., 2016; Kiljanek et al., 2016; Plavša and Pavlović, 2017; Stojić and Pucarević, 2019; Bojanić Rašović, 2022; Zhang and Lu, 2022). Imidacloprid, clothianidin and thiamethoxam are prohibited due to their toxicity to bees and other pollinators in the European Union (Laurino et al., 2011; Anon, 2013b; Yáñez et al., 2014; Brandt et al., 2016). In order to improve the efficiency of the pesticide, the small amount of pesticide that remains in the packaging can lead to poisoning. That is why it is necessary to dispose of unwashed packaging in special containers (Ružić and Poznanović, 2009; Anon, 2014b, 2015). The persistence and degradation of pesticides in the environment depend on a large number of factors such as: temperature, relative humidity, amount of light, pH value of the environment, the presence of living things, etc. (Stajkovac et al., 2009; Bursić et al., 2010; Stojić and Pucarević, 2019).

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Other pesticides

Pyrethroids are synthetic compounds similar to pyrethrin, which are obtained from the feverfew plant *Pyrethrum cinerariaefolium*. Natural pyrethroids break down under the influence of light, while synthesized ones are more stable. Pyrethroids act on nervous tissue. They are very toxic to aquatic organisms (Zgomba, 2014; Stojić and Pucarević, 2019). Carbamates are derivatives of carbamic acid. They act on the nervous system by inhibiting the enzyme acetylcholine esterase. This inhibition is a reversible process. They are particularly toxic to bees and fish. They are subject to biodegradation processes, so their concentration in the environment decreases rapidly (Bagi and Bodnar, 2012; Zgomba, 2014; Stojić and Pucarević, 2019). Phenoxy herbicides are derivatives of phenoxy acid. They act on living organisms by preventing their growth. They have a short half-life, but can still be found in underground and surface waters (Zgomba, 2014; Stojić and Pucarević, 2019). Triazines are herbicides based on the triazine ring. They are used to destroy broad-leaved weeds. They pass through the soil very easily and since they are persistent, they are often found in underground and surface waters. They lead to the appearance of congenital anomalies and cancer. The use of atrazine is prohibited. Imidazolinones are also used to destroy broadleaf weeds, and the basis of their structure is the imidazoline ring. These pesticides easily reach groundwater, are highly persistent and toxic to plants (Bagi and Bodnar, 2012; Čolović et al., 2013; Zgomba, 2014; Stojić and Pucarević, 2019).

Phenols

Phenols are aromatic compounds that are formed by replacing one or more hydrogen atoms with OH groups. All OH groups are attached directly to the aromatic ring. They are used as starting raw materials in the synthesis of various products such as resins, medicines, polyurethanes, pesticides, explosives, paints, antioxidants, oil and petroleum additives; they are released during the hydrolysis of organophosphorus insecticides, herbicides, fungicides and thus end up in wastewater and waterways, having a toxic effect on living things. During the water disinfection process with chlorine, chlorinated phenols are formed. In this way, chlorinated phenols enter the food production process. That is why chlorinated phenols are removed from water before the chlorination process. Chlorinated phenols can be found in waste water, because they are also formed during the dry distillation of wood, production of varnishes, paints, in the petrochemical industry. They are non-biodegradable, carcinogenic and embryotoxic (Said et al., 2021; Panigrahy et al., 2022; Mhlongo et al., 2024).

Organometallic compounds in the environment

Organometallic compounds are a type of compound in which a metal atom is bonded to a carbon atom that is in the structure of an organic radical or molecule. Organometallic compounds are widely used in agriculture (as herbicides and fungicides), in the chemical industry (as catalysts), in the oil industry, in the pharmaceutical industry, in medicine, in the automotive industry (gasoline production), in the form of silicone and silicone resins (as an insulating material), in the production of paints. In the environment, most organometallic compounds are found to be persistent, not readily degraded, but readily concentrated and highly toxic, often more toxic than their elemental form (Mirić and Šobajić, 2002; Majumdar et al., 2024). Soil plays a particularly important role in the distribution of organometallic compounds, as it is the main reservoir of these pollutants

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and has a high absorption capacity. Organometallic compounds are very toxic, especially compounds of mercury, lead, thallium, arsenic. Methylmercury, being liposoluble, damages the nervous system, has a mutagenic and carcinogenic effect, and negatively affects cholesterol metabolism. It leads to kidney disease. Alkyl-mercury compounds are also embryotoxic and teratogenic. The basic principle of the toxic effect of mercury, as well as other toxic elements, consists in binding to SH groups of enzymes and proteins. Compounds of lead prevents the normal formation of hemoglobin, which causes anemia (Mirić and Šobajić, 2002; Craig and Jenkins, 2004; Dopp et al., 2004; Haydee and Dalma, 2017; Majumdar et al., 2024).

Pharmaceutical and hormones

Discharging inadequately treated pharmaceutical wastewater into waterways leads to environmental pollution. Pharmaceutical compounds have been detected even in remote areas such as the Arctic. Lakes are more sensitive to pollutants than rivers, because rivers have self-purification mechanisms. Pharmaceutical wastewater contains organic and inorganic compounds, which can lead to eutrophication. Pharmaceutical drugs such as beta-blockers, antibiotics, anti-cancer drugs, hormones, antidepressants, analgesics, have a devastating effect on the ecosystem, increasing mortality and impairing the physiological and reproductive functions of aquatic species and other animals and humans (Gworek et al., 2021; Kusturica et al., 2022). The appearance of antibiotics in the ecosystem affects microbial communities by promoting the reproduction of microorganisms that are resistant to antibiotics. In water and soil, antibiotics are dangerous for plants, aquatic organisms, humans, and sensitive microorganisms. If polluted water from the pharmaceutical industry is used for irrigation, the drugs reach aquatic organisms, and thus food. Water contamination with pharmaceuticals can lead to illness and death in humans and animals. Expired pharmaceuticals and their residues are a significant source of contamination. Methods used for their degradation include the application of UV light, sorption, hydrolysis, sediment solubility, direct and indirect photolysis. Before they are excreted from the body in urine, medicinal compounds are metabolized. Sometimes these metabolites are more dangerous and harmful than the parent compound. Steroid drugs, progestins, glucocorticoids and estrogens have been found in the aquatic environment. Continuous exposure to synthetic estrogen results in endocrine and hormonal disruption in fish. Methods currently used for wastewater treatment are bioremediation methods. One of these methods is based on the use of microalgae biomass. Microalgae enable the renewal of nutrients while simultaneously reducing greenhouse gas emissions (Shola et al., 2022). Pharmaceuticals from wastewater lead to changes in the physiology, behavior, reproduction, and death of aquatic species. The presence of estrogens in the environment is a serious contamination problem. It is excreted into the environment annually by the human population, but a larger source is livestock production. These types of hormones are capable of disrupting the physiology of humans and animals and affecting normal reproduction. Estrogens as pollutants are also associated with a higher incidence of breast cancer in women and prostate cancer in men. Anticancer drugs stop the growth and division of cells, and when released into the environment, these drugs affect the ecosystem by disrupting fertility and causing significant genetic changes in living organisms (Gworek et al., 2021; Kusturica et al., 2022).

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Microplastics

The use of plastic is increasing every year due to its widespread use. Plastic poses a serious environmental problem, as it takes over 500 years to decompose. During this long time, it decomposes into tiny particles, known as microplastics. Microplastics are plastic particles smaller than 5 mm, present everywhere and affecting terrestrial and aquatic ecosystems. Microplastics are formed by the crushing and decomposition of plastic into small fragments. The synthetic textile industry, as well as the plastics industry, produce a large amount of microplastics. Plants, mosses and lichens are most often used to examine the presence and impact of microplastics on living things (Li et al., 2023; Jahedi et al., 2025). People are exposed to microplastics through oral ingestion, inhalation and through the skin. Microplastics lead to oxidative stress, DNA damage, organ function disorders, metabolic disorders, immune response disorders, neurotoxicity, as well as reproduction and growth disorders. It is believed that the occurrence of several chronic diseases is related to exposure to microplastics. It can get into food via contaminated sewage sludge, compost, etc. Microplastics can accumulate in microalgae. In addition to being toxic itself, microplastics absorb and transport many pollutants into biological tissues and organs (Li et al., 2023). Microplastics are difficult to decompose and difficult to recycle. Cancer, intestinal, pulmonary, cardiovascular, infectious and inflammatory diseases are caused or mediated by microplastics. Nanoplastics, whose particles are less than 1 μm in diameter, pose an even greater risk to living organisms than microplastics due to their greater abundance and reactivity. Due to their small size, they can easily reach living cells and distant places. The main focus of microplastic treatment strategies is to remove it from aquatic ecosystems, where it often ends up. There are two groups of techniques for removing microplastics: conventional and innovative. Conventional strategies include coagulation, membrane bioreactor technology, rapid sand filtration, and adsorption. Innovative techniques for removing microplastics include electrocoagulation, photocatalytic degradation, electrochemical oxidation and magnetic separation. Each of these techniques has both positive and negative sides. One of the most effective strategies for controlling environmental contamination with microplastics is to reduce their use and production. It is very important to develop society's awareness of the importance of microplastics in causing diseases in humans and animals (Osman et al., 2023).

Radionuclides in the environment

In addition to natural radionuclides of geogenic origin, radionuclides of anthropogenic origin also occur in the environment, which mainly arrive from various industrial processes, waste disposal sites or nuclear activities. In order to suppress the pollution of the environment with radionuclides, including land, more and more attention is paid to the control of polluting substances in industrial emissions. This especially applies to the chemical industry, cement production, production of construction materials, steel, etc. from which radionuclides most often reach the environment by emission into the air or directly on land by dumping waste on unprotected surfaces. The harmfulness of usual levels of radioactivity of natural origin has not been proven, while chronic exposure to higher doses of radionuclides leads to unwanted adverse effects on health - i.e. carcinogenic, mutagenic and teratogenic effects (Sofilić, 2014; Li et al., 2024). High doses cause a toxic effect on the kidneys. Radionuclide poisoning can occur in three ways: by inhalation, through the skin and through the mouth. Cesium 134 (Cs-134), Cs-137 (cesium-137), Co-58 (cobalt-58), Co-60 (cobalt-60), Sb-125 (antimony-125), Ba-133

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(barium-133), Ce-144 (cerium 144), Sr-90 occupy a special place among radioactive substances that endanger the environment. Radionuclides Cs-134 and Cs-137 behave analogously to potassium in the body and are found in every cell of the body. Radionuclides Sr-89 and Sr-90 behave analogously to calcium in the body and are deposited in the bone system. The deposition of J-131 in the human thyroid varies depending on the age of the organism, and is the highest in newborns. Due to their very strong carcinogenic effect, plutonium radionuclides are one of the greatest threats to human survival (Narayana et al., 1995; Sofilić, 2014; Eke et al., 2024; Huang et al., 2025).

Pollutants in air

According to the World Health Organization (WHO), almost seven million people die each year as a result of air pollution, from respiratory diseases, heart disease, cancer and stroke (Giordano et al., 2021). The spread of air pollutants is influenced by meteorological conditions, such as wind speed and direction, temperature and relative humidity, global solar radiation, atmospheric stability (turbulence), the altitude at which emissions occur (for example, whether there are high emission sources such as factory smokestacks or ground-level emission sources such as vehicles in traffic), local and regional relief, the type of source (whether it is a stationary or mobile source, etc.). In the atmosphere, due to complex photochemical reactions, pollutants are transformed into new chemical compounds, which are often even more toxic. Industrial activities and fuel combustion are the main contributors to air pollution (Maji et al., 2023; Vilcin et al., 2024; Yu et al., 2025). The gas released during coke production contains gaseous and liquid pollutants, such as tar, ammonia water, benzene, naphthalene, ammonia, sulfate, sulfur dioxide, nitrogen oxides, carbon oxides, hydrogen cyanide compounds, and dust particles. Solid waste contains benzenes and polycyclic aromatic hydrocarbons. During iron ore synthesis, the gases produced contain solid dust particles and heavy metals, chloric acid, hydrofluoric acid, nitrogen oxides, sulfur dioxide, carbon oxides, volatile organic compounds, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, dioxins, dibenzofurans. Particulate matter and ground-level ozone are considered the most dangerous to human health today. The concentration of particulate matter with a diameter of less than 2.5 μm (PM 2.5), due to its significant impact on human health, is one of the most important indicators of air pollution. They penetrate through the respiratory system into the alveoli, and through them into the bloodstream. Inhalation of PM particles causes difficulty breathing, and the heart is under strain to compensate for the reduced oxygen intake; resistance to allergies and infections decreases, and inflammation occurs in the lower respiratory tract. Depending on the time of exposure and the concentration of PM particles, suffocation and asthma attacks, high blood pressure, heart attack, stroke and death can occur (Weldeslassie et al., 2018). These particles are mostly emitted as a result of the combustion of solid and liquid fuels. PM particles make lakes and streams more acidic, change the nutritional value of coastal waters and river basins, deplete soil of nutrients, damage forests and agricultural crops, and affect the biodiversity of ecosystems. Ground-level ozone (O3) also has a harmful effect on human health. Inhaling higher concentrations of ground-level ozone can cause irritation of the respiratory tract, difficulty breathing and bronchitis. It also affects the worsening of cardiovascular diseases and arteriosclerosis. In higher doses, it can be fatal. Recently, it has been created in the atmosphere near the ground by photochemical reactions rich in nitrogen oxides, which are the result of human activity (traffic, etc.). Increased ozone concentrations affect

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photosynthesis processes and slow down plant growth. It also acts as a greenhouse gas, which makes it even more harmful (Manisalidis et al., 2020; Münzel et al., 2023). Exposure to air pollutants is closely linked to chronic obstructive pulmonary disease, cough, shortness of breath, asthma, respiratory diseases, cardiovascular diseases and cardiovascular mortality, diabetes, and cancer (Manisalidis et al., 2020). After entering the body, the toxic substance undergoes biological transformation processes, during which one chemical substance is converted into another. The role of biotransformation is detoxification and faster removal of toxins; however, in some cases the toxicity of the substance increases, as toxic intermediates and metabolites are formed (Sofilić, 2014; Puri et al., 2017; Weldeslassie et al., 2018; Turner et al., 2020; Manisalidis et al., 2020; Münzel et al., 2022; Maji et al., 2023).

Pollutants in water

Pollution of water from non-point sources is reflected in the creation of sediment and nutrients. Sediment consists of soil particles formed by erosion from construction sites, stream banks, agricultural lands, etc. Sediment that gets into the water makes it cloudy, making it difficult for fish to find food, and can damage their gills, making it difficult for them to breathe. Sediment can also cover spawning habitats affecting the reproduction of fish populations. Non-point sources of nutrients are manure, pet excrement, contents of defective septic tanks, etc. Nutrients increase the growth of aquatic plants (weeds and algae) in lakes and rivers. Factories and power plants can be a source of point pollution that affects both air and water. Smokestacks can release carbon monoxide, heavy metals, sulfur dioxide, nitrogen dioxide, or "particulate matter" into the air. Oil refineries, paper mills, and automotive plants that use water as part of their manufacturing processes can discharge wastewater - wastewater containing harmful chemical pollutants - into rivers, lakes, or oceans (Xie et al., 2022; Hou et al., 2022; Liu et al., 2023). Sediment plays a significant role in aquatic ecosystems, as it is a source of organic and inorganic matter and pollutant of anthropogenic origin ends up in it. This indicates that even small concentrations of pollutants that constantly reach the lake can represent a significant problem. These pollutants are constantly deposited in the sediment, increasing their concentration. Sediment plays an important role in water pollution because pollutants can accumulate in sediment and it can function as a long-term reservoir of pollutants. Suspended sediment absorbs pollutants from water flowing in rivers and settles at the bottom. Pollutants accumulated in the sediment of the river bed affect the living world. The concentration of heavy metals is 100-10,000 times higher in sediment than in water. Benthic invertebrates have high concentrations of heavy metals in their tissues due to proximity to contaminated sediments (Yi et al., 2008; Bełdowska et al., 2021; Wieringa et al., 2022; Alfee and Bloor, 2024; Hossain et al., 2024).

Agricultural practices, such as fertilization with mineral and organic fertilizers and the application of chemical protective agents - which are usually easily soluble in water, have a detrimental effect on the quality of surface and groundwater. Large amounts of pesticide residues enter the environment from agricultural land through erosion. Residues of mineral fertilizers - phosphates and nitrates, various toxic liquids from silos, manure from pig and poultry farms, residues of pharmaceutical products - antibiotics, hormones, growth inhibitors and disinfectants end up in water, from where they can spread into the environment in several ways and be found in living organisms, where they lead to health impairment. It is necessary for all production entities to treat wastewater before discharge,

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in order to remove toxic and persistent pollutants and prevent their deposition in living organisms (Aydinalp and Porca, 2004; Sofilić, 2014; Haseena et al., 2017; Weldeslassie et al., 2018; López-Pacheco et al., 2019; Manisalidis et al., 2020; Arias-Pérez et al., 2020; Shah et al., 2021; Lin et al., 2022; Misman et al., 2023; Sun et al., 2025).

Pollutants in soil

Soil pollution with various toxic substances can result in negative impacts on water, air, diversity of flora and fauna, and human health. A healthy environment, and thus clean soil, is a basic condition for preserving human health and the quality of life in an area. Pollutants can enter the soil directly - by dumping waste, spilling from tanks or conveyors, using pesticides in agriculture, etc., or indirectly - by dry or wet deposition from the air or polluted wastewater (Faraj et al., 2024). The ability of plants to accumulate heavy metals present in the soil is used to clean the soil of heavy metals. Given the toxicity of these metals to plants, excessive accumulation in plants can be phytotoxic and cause disturbances in plant nutrition. In addition to heavy metals, the introduction of pesticides into the environment as pollutants is of great importance. Pesticides that enter the soil can change the composition of the soil microflora. They enter the food chain and accumulate in certain tissues of living beings. They first accumulate in plants, where they enter mainly through the roots, via water from the soil in which they are dissolved. After entering the plant, pesticides are distributed throughout its organs, so that the concentration in individual plant organs is different. In addition to the roots, pesticides can also enter the plant through the leaves (Sofilić, 2014; Sures et al., 2014; Weldeslassie et al., 2018; Lull et al., 2022; Münzel et al., 2022).

Biomonitoring of environmental pollution

Biomonitoring provides data on the total impact of all pollutants on the environment, their genotoxicity for living organisms, as well as the changes they cause at the population level. Bioindicators are living organisms such as plants, planktons, animals, microorganisms, which are used to check the health of natural ecosystems in the environment (Parmar et al., 2016). Biomonitoring uses bioindicators such as lichens, mosses, algae, shells, fish, higher plants (poplars, ash, beech, willows, sorghum, tobacco, etc.), vegetation, birds, insects, bacteria, etc. Lichens have the longest use as bioindicators. Macroinvertebrates, periphyton, and fish are most commonly used as bioindicators for assessing water quality in freshwater ecosystems (Aguilar et al., 2022). Higher plants, in addition to air pollution monitoring, can also be used for land pollution monitoring (Gautam et al., 2022). Birds are used as indicators of harmful effects on the ecosystem, especially as indicators of increased concentrations of pesticides, heavy metals, oil, etc. Rodents are also very good bioindicators - forest mouse, forest vole, meadow vole. The degree of environmental pollution can be determined based on the concentration of heavy metals in the organs of these animals. Mosses are good bioindicators of air pollution, as their pollution is directly influenced by air, due to the lack of contact with the soil (Baczewska-Dąbrowska et al., 2023). Planktons respond quickly to changes in the environment and are considered excellent indicators of water pollution due to their rapid reproduction. Microorganisms are often used as indicators of the health of aquatic and terrestrial ecosystems. Because of their rapid reproduction, they are easy to study. Some microorganisms, when exposed to contaminants such as cadmium

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and benzene, produce stress proteins that can be used as early warning signs. Microorganisms respond even to low levels of contaminants and other physicochemical and biological changes. Bioluminescent bacteria are also often used as microbial indicators. The presence of toxins in water alters the metabolism of microorganisms, which leads to changes in the amount of light emitted by the bacteria (Parmar et al., 2016; Jahedi et al., 2025). Human biomonitoring determines the degree of human exposure to pollution by testing for the presence of toxic substances in their tissues (blood, urine, nails, breast milk). Biomarkers are also used to determine the presence of pollutants in living organisms. Biomarkers are molecules that are produced in the body as a result of changes in tissues due to their damage by toxic substances. Biomarkers can be retinol, the enzyme acetylcholinesterase, porphyrins, stress protein vitellogenin, eggshell thickness, etc. (Valavanidis et al., 2006; Sofilić, 2014; Hamza-Chaffai, 2014; Giordano et al., 2021; Baak et al., 2024; da Silva Alves, 2024).

Possibilities for reducing environmental pollution in the future

The protection of natural resources and the environment is becoming increasingly important as people's awareness of the dangers they pose increases with increasing levels of pollution. The main risk factors leading to environmental pollution are industrial and agricultural production. Accordingly, it is necessary to work on reducing the health risks of using plant protection products, encouraging the use of non-chemical plant protection measures, applying the principles of good agricultural practice and integrated pest management, decontamination of the environment, bioremediation of soil and water, improving the dissemination of information and advice on the safe use of plant protection products, risks to human health and risks to nature and the environment (Awewomom et al., 2024). There are numerous conventional technologies for the remediation of polluted sites, but phytoremediation and bioremediation are recommended, as they are cost-effective and sustainable methods. The use of plants in community with microorganisms leads the way compared to other methods and is promising in the decontamination of stubborn pollutants in soil and water. Therefore, it is necessary to further research and improve phytoremediation techniques, in order to improve and speed up waste management in different environmental conditions (Gautam et al., 2021). Sustainability and climate change are closely related phenomena that affect ecological conditions (Lynch and Schepers, 2008). Sustainability of natural resources implies that their use or consumption does not decrease over time and that minimum conditions for ecosystem stability are ensured. Sustainable development is based on establishing a balance between the exploitation of natural resources and the preservation of biodiversity. In addition, sustainable development is possible only if a balance is achieved between ecological and economic requirements. Reducing the use of pesticides is one of the foundations of sustainable agriculture and sustainable development. Integrated protection is a plant protection system that includes the use of all available methods of controlling harmful organisms, such as the cultivation of resistant varieties, the application of adequate agrotechnical measures, crop rotation, mechanical and biological control measures, etc. This protection system reduces the number of chemical treatments and thus prevents environmental pollution and endangering human health. One of the basic things is to strengthen the ecological awareness of the population and ways to protect the environment and flora and fauna (Ugrinov and Stojanov, 2010; Bogdal et al., 2014; Scheringer, 2017; Weldeslassie et al., 2018; Martinović, 2019; Mihajlović and Blagojev,

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2019; Petrović and Petrović, 2019; Anon, 2019a,b; Ryzhenko et al., 2020; van den Berg et al., 2020; Singh et al., 2021; Awewomom et al., 2024; Sauvé, 2024).

Conclusion

Industrial production and agriculture are the main sources of environmental pollution. The most significant pollution factors are: inorganic pollutants, organic pollutants, organometallic compounds and radioactive substances. Acute and chronic exposure of animals and humans to pollutants can lead to a number of consequences, such as mutagenic, teratogenic and carcinogenic changes, immunosuppression, reproductive toxicity, etc. In order to reduce the level of environmental pollution, it is necessary to work on preventing the harmful effects of industrial production, reducing the use of chemical plant protection products, encouraging the use of non-chemical plant protection measures, applying the principles of good agricultural practice and integrated plant protection, improving information to producers about the safe use of plant protection products and their risks to human health, nature and the environment, improving and implementing decontamination procedures, especially soil and water bioremediation, etc. It is necessary to further research and improve phytoremediation techniques, in order to improve and speed up waste management in different environmental conditions. Industrial and agricultural production should be based on the principle of sustainability. One of the basic measures is to strengthen the ecological awareness of the population about the importance and measures for protecting the environment and flora and fauna.

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