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Organic Compounds as Environmental Pollutants

By Anita Rakić[±]

Various substances pollute and contaminate the environment, such as improper waste disposal, oil spills from ships, discarded scrap metal, harmful gases, etc. Pollutant particles can contaminate air and soil and enter water systems. Air can be contaminated by particles (gases, heavy metals...) that result from the combustion of fossil fuels in motor vehicles or heating systems, as well as from technological industrial processes [1]. In today's world, with industrial development, the synthesis of numerous chemical substances and various chemical preparations—such as organic compounds—increases the risk of pollutants in key environmental components. Pollutants can degrade water quality in rivers, lakes, groundwater, coastal, and marine waters, endangering plant and animal species and, consequently, human health. Alongside organic substances, many chemical compounds used for various purposes (e.g., crop protection or as by-products in industrial processes like polycyclic aromatic hydrocarbons, pharmaceuticals, brominated flame retardants, naphthalene, etc.) can also cause pollution. As a result, numerous individual substances that harm the environment can be found in surface waters. Nevertheless, using different methods, it is possible to determine their origin and reduce or eliminate their presence, thus preserving both the environment and human health. Water, air, and soil pollution represents a quantitative and qualitative deviation from the natural chemical, biological, and physical composition. Chemically polluted water contains numerous compounds and toxins that impair water quality indicators such as pH, osmotic value, mineral content, dissolved oxygen, smell, taste, etc. Based on their chemical nature, pollution can be inorganic, organic, or radioactive. Biological water pollution refers to contamination by pathogenic bacteria, viruses, fungi, and other organisms that directly cause disease or act as vectors of pathogenic microorganisms, posing risks to human and animal health. These pathogens typically enter surface waters from wastewater or agricultural runoff, while in groundwater, they may enter via leaky sewage systems or poorly built septic tanks. Physical pollution denotes harmful changes in water properties, such as increased temperature, turbidity, color, and unpleasant taste and smell. Today, with the growing population, various types of pollution are increasing. Hydrocarbons are a group of organic compounds commonly found in nature. Based on molecular structure, they are divided into acyclic or aliphatic (carbon atoms arranged in chains) and cyclic or ring-shaped (carbon atoms arranged in rings).

Natural Organic Compounds

Natural organic compounds are found in surface and groundwater and result from natural environmental processes such as plant material decay and biological activity of algae, protozoa, and microorganisms. They are complex

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mixtures of compounds whose molecules consist of aliphatic chains and aromatic rings with functional groups such as amide, carboxyl, ketone, hydroxyl, etc. Examples include proteins, amino acids, polysaccharides, humic substances, fulvic acids, etc.

Persistent Organic Pollutants (POPs)

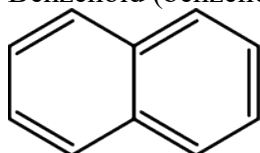
Persistent organic pollutants are hazardous to humans and the environment due to their long-term stability, allowing them to travel long distances and accumulate in human and animal tissue. Some examples include dioxins, furans, pesticides, halogenated hydrocarbons (used as cleaning and degreasing agents in the metal and textile industries), and polycyclic aromatic hydrocarbons released into the atmosphere from fuel combustion [1]. These compounds evaporate in warmer regions and condense in colder ones, making them widespread globally. The most common sources of POPs are pesticides, industrial products, and by-products [3,4].

Dioxins and furans, as part of this group, pose a severe threat to living organisms and the environment. Their primary sources are combustion processes, especially incineration of municipal, medical, and industrial waste. Due to the severe risk of environmental accumulation, many countries have implemented plans to monitor their emissions.

Aromatic Compounds

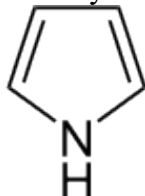
Aromatic compounds are a large group of cyclic organic compounds with high chemical stability. They can be:

- Benzenoid (benzene, naphthalene, anthracene),



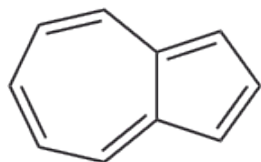
naphthalene

- Heterocyclic (pyrrole, pyridine, thiophene),



pyrrole

- Non-benzenoid (ferrocene, azulene).



azulene

Heterocyclic aromatic compounds contain atoms other than carbon (e.g., nitrogen, oxygen, sulfur) within their rings. They are essential in biological systems. Carbohydrates, chlorophyll (green pigment in leaves), and heme (red pigment in blood) are heterocyclic compounds. These rings are often reactive centers in enzymes and coenzymes and bind to long nucleic acid chains, playing vital biological roles.

Pharmaceuticals

Organic chemistry in pharmaceuticals is the intricate science behind the medicines that improve and save lives. It plays a fundamental role in developing, synthesising, and understanding pharmaceutical compounds. Pharmaceuticals are a broad group of substances used to treat, prevent, or alleviate diseases. Today, they are considered "emerging environmental pollutants." They are typically classified based on therapeutic purpose: antibiotics, antiparasitics, anesthetics, analgesics, antihistamines, etc. The active pharmaceutical ingredient (API) is the component responsible for the drug's pharmacological effect. After use, a large portion is released into wastewater unchanged or as metabolites. They also enter the environment through agricultural runoff, potentially breaking down into even more harmful compounds.

Long-term pharmaceutical release negatively impacts aquatic ecosystems, especially surface and groundwater. High concentrations in wastewater can pollute drinking water. For example, the presence of estrogen in water leads to the feminization of fish and is toxic to other organisms. The three most commonly detected pharmaceuticals in water are clotrimazole, tamoxifen, and diclofenac. Clotrimazole and tamoxifen pose high risks to marine organisms, while diclofenac—used in Voltaren, Cataflam, Zipsor, Zorvolex, etc.—is the most frequently detected due to its widespread use (global consumption: 940 t/year) [5].

The removal process includes active sludge treatments involving biotransformation, aeration, adsorption, and phototransformation, with effectiveness ranging between 20–40% [1,8].

Conventional wastewater treatment plants struggle to remove pharmaceuticals, allowing them to enter aquatic ecosystems. A large study found that 80% of 32 tested drugs were detected in at least one treatment plant, while 20 different drugs and 4 metabolites were found in rivers [12]. Pharmaceuticals have been found in treated wastewater, surface and groundwater, and soil. Although concentrations are generally low, concerns remain over long-term

exposure effects on both humans and aquatic ecosystems. Their concentration is expected to rise with growing pharmaceutical use.

Landfills and Organic Contamination

Many global landfills lack systems for collecting leachate, posing significant threats to the environment, especially groundwater. Studies assess the presence of specific organic pollutants in landfilled waste and their penetration into deeper soil layers and groundwater. Using chromatographic and spectrometric techniques, many individual components in waste can be identified. These are generally grouped into:

- Substances from biological waste and microbial transformation,
- Substances typical of anthropogenic waste.

It has been observed that polar organic pollutants are transported effectively through leachate, leading to significant groundwater contamination near landfills.

Basic physical-chemical analysis shows that the average organic content in landfill waste is about 21%, with high humus content (6–22%), indicating mostly transformed organic matter of natural origin. However, given that over 5 million tons of waste are stored at some sites, landfills serve as massive reservoirs of organic pollutant release. Fortunately, research shows that only 1–3% of the organic matter fraction is readily mobilized by water [7,8].

Impact on human health

As mentioned, hydrocarbons—released from various anthropogenic sources—enter wastewater and watercourses and cause environmental harm, including oil slicks, harm to flora and fauna, photosynthesis inhibition, and serious health risks such as mutagenicity and carcinogenicity. Ingestion can cause nausea, vomiting, diarrhea. Benzene and toluene irritate skin and eyes, causing redness, and via inhalation can lead to lung damage and vomiting [7].

The World Health Organization (WHO) assesses health and environmental risks, particularly from volatile organic compounds. Exposure may cause acute and chronic health issues, including:

- Respiratory and eye irritation,
- Headaches,
- Dizziness,
- Vomiting,
- Kidney damage.

According to WHO, lifelong exposure to benzene at 1 $\mu\text{g}/\text{m}^3$ concentration causes leukemia in 6 out of 1 million people [6].

Environmental cleanliness directly impacts human health, as pollution contributes to:

- Allergies,
- Asthma,
- Hypersensitivities,
- Cancers,
- Cardiovascular diseases,
- Diabetes, etc.

Many effects of pollution become more pronounced after long-term exposure.

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