Emerging Pollutants

Miss: the biology teacher told us that our body activities are controlled by hormones but that there are pollutants which interfere with this. What are these pollutants and where do they come from?

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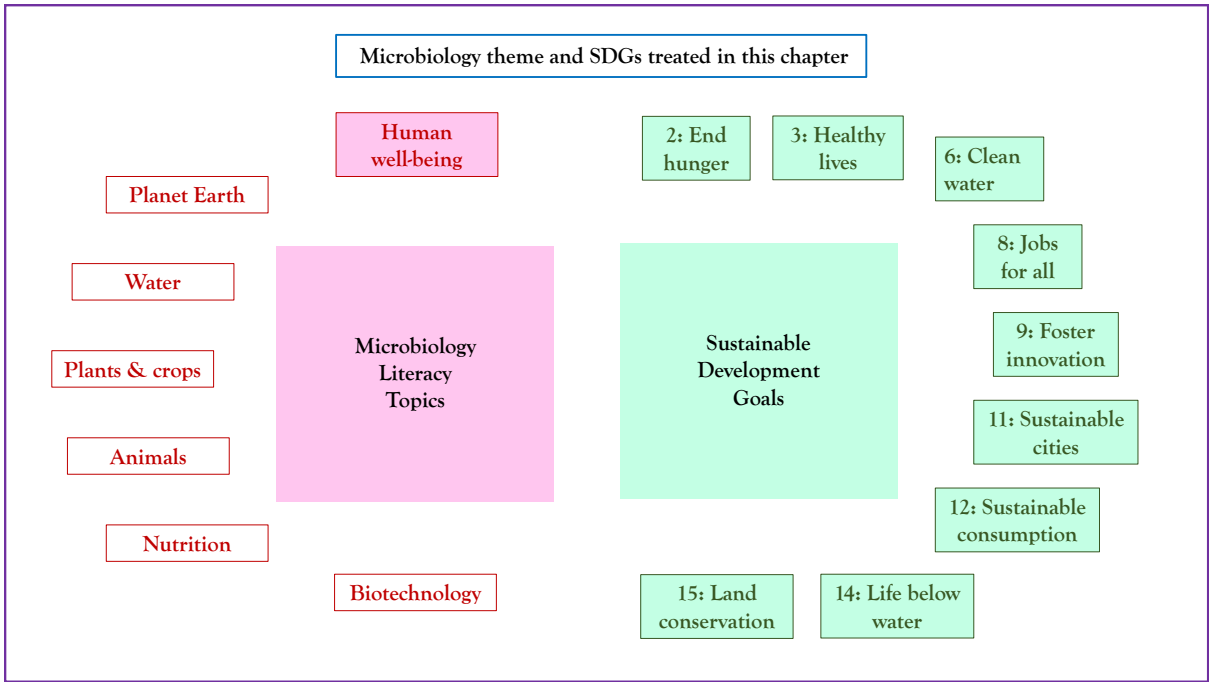
Storyline

Can you imagine life without personal-care products (shampoo, toothpaste, perfume, body milk, shower gel, soap, deodorants, sunscreens…) or medicines? Or even without detergents for cleaning the house or our clothes, or without disinfectants to ensure the safety of drinking water, or even in swimming pools? These products, and many others such as pesticides employed in agriculture and other contexts, are used in our daily routine and are considered essential to our lifestyle and health. However, after we use them they end up in the environment by different routes that we are not able to control. Most of these products contain compounds that become environmental pollutants: even at the low concentrations found in the environment, over long periods of time they can cause problems for human health and also affect the health and behaviour of other animals, plants, or environmental microorganisms, which may affect the equilibrium of ecosystems. Such compounds are the emerging pollutants. Fortunately, many of them can be degraded by microbes, but unfortunately in many cases not fast enough to reduce their environmental impact, The presence of emerging pollutants in the environment may have a significant impact on the implementation of diverse Sustainable Development Goals.

The Microbiology and Societal Context

The microbiology: wastewater treatment; biodegradation; food webs; biogeochemical cycling; microbial ecotoxicology effects; antimicrobial resistance spread in different environmental ecosystems; . *Sustainability issues:* environmental pollution; health; food and energy; economy and employment.



Emerging Pollutants: the Microbiology

1. ***What are emerging pollutants/contaminants?*** Modern life is highly dependent upon a diverse range of chemicals that are used to create indispensable products that we use daily, such as personal-care products, medicines, detergents, pesticides, etc. All of these products are composed of a set of compounds (chemicals/molecules) that constitute their active ingredients, preservatives, dyes, stabilizers, fragrances, etc., some of which may be environmental pollutants, i.e. they may harm members of the biosphere. Such compounds are emerging pollutants: chemicals/molecules commonly found in products of daily use that are found in the environment (in water bodies, soil, air…) at very low concentrations (in the order of nanograms (ng) or micrograms (µg) per liter).

To get an idea of such concentrations, consider that a nanogram (ng) is a million times smaller than a gram. For example, one grain of sugar weighs 625000 ng which corresponds to 625 µg. Therefore, the amount of an emerging contaminant in water can be compared to the dissolution of a single grain of sugar (or even less) in 1 litre of water.

Economic growth, current lifestyles, and the increase in the global population all drive an increase in the use of such products, the creation of new ones, and the number of ecosystems contaminated. It is impossible to avoid the daily use of these products, and their discharge into the environment so, even though emerging pollutants are found in water bodies in such small quantities, they are major cause of global concern.

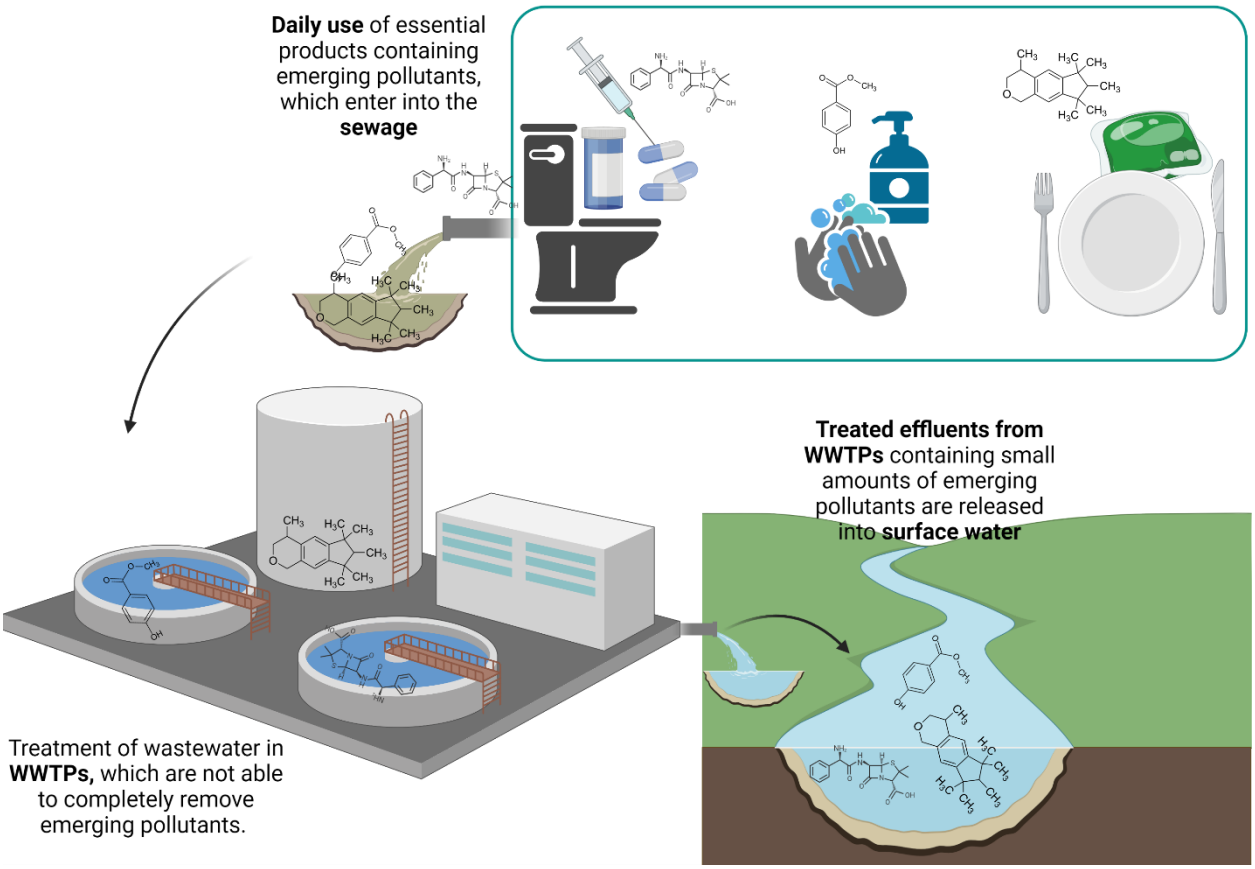
2. ***How do emerging pollutants reach water bodies and drinking water?*** The entry of emerging pollutants into the environment may follow different routes, depending on the product that is the source of the pollutant, and how this product is used and disposed of. The main sources of emerging pollutants are wastewater treatment plants (WWTPs) which are designed to treat sewage water so that it can be safely returned to surface waters (rivers, lakes, etc.). In WWTPs, the treatments are applied to reduce the chemical and microbial contamination load.

Current treatments in WWTPs are primarily based on the exploitation of biodegradative activities of microbes to use wastewater as food, and thereby digest in particular most of the organic matter in sewage, including pathogens and toxic chemicals. They do not, however, remove all contaminants. One reason is that many emerging pollutants are present at such low concentrations that they are not 'seen' as food by the WWTP microbes. Another reason is the wide variety of molecules present in wastewater, some of which cannot be degraded by microbes or, if they can be, are degraded too slowly to be removed. And yet another reason is also the complexity of their mixtures, which may present a particular challenge to the metabolic activities of the WWTP microbes. In addition, the high cost often associated with the identification and quantification of emerging pollutants, which is essential for monitoring their degradation, is a problem. These are the main challenges in the removal of emerging pollutants today. To better understand how emerging pollutants reach the environment and ecosystems, representative examples are presented:

a. *Example 1: WWTPs.* Why do we have pharmaceuticals in our water resources? When we take some pharmaceuticals (pills, syrup, injections, or vaccines…), their ingredients are not completely used in our bodies and, in some cases, only a small part is used up in our bodies in the process of combatting illness. The other part is excreted in our faeces or urine and delivered into sewage, which is mostly treated in WWTPs. As mentioned before, WWTPs do not completely

remove pharmaceuticals from wastewater. Consequently, treated water, which is delivered into water bodies, will contaminate them with pharmaceuticals.

Also, house-care products, clothes-care products, and personal-care products are washed into our wastewater, are transported to WWTPs, and ingredients that are not completely removed are then released into surface waters.

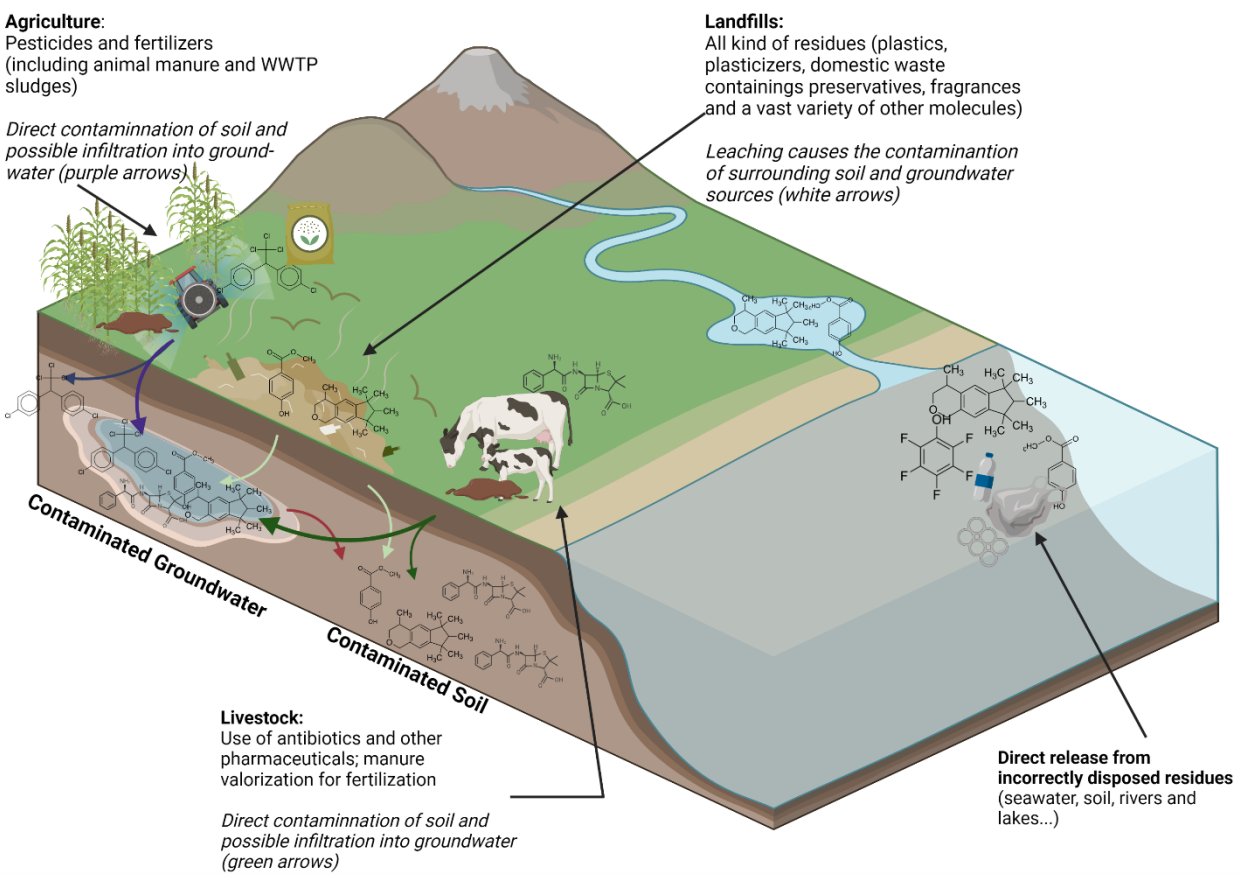


Illustrative scheme of the release of emerging pollutants into the environment through WWTPs.

b. *Example 2: Soil and leachates.* Another route of entry of medicines into ecosystems is the incorrect disposal of unused pharmaceutical products or their containers in the common trash, which usually ends up in landfills. Rain falling on landfills leaches out many chemicals, producing so-called 'landfill leachates', which can transport such medicines to underlying and surrounding soils. Rain can further transport pollutants from the soils to underlying groundwaters, some of which may be used as a sources of drinking water. Because leachates can carry significant quantities of toxic chemicals, modern landfills have a sealed base and leachates are channeled to a treatment facility to remove pollutants. But, once again, emerging pollutants are not effectively removed.

Agricultural activities are also a significant source of emerging pollutants. The use of pesticides and fertilizers directly on the soil is responsible for soil contamination and also for the contamination of groundwater sources. The same happens when animal manure or sludge from WWTPs is used for soil fertilization. The manure may contain some of the pharmaceuticals given to animals, such as antibiotics, which will contaminate the soil and, consequently, groundwater.

Sludge from WWTPs also contains emerging pollutants that may be adsorbed during treatment in WWTPs.



Illustrative scheme of the transport of emerging pollutants into the environment through leaching, soil penetration, and incorrect disposal of residues.

c. *Example 3: Direct disposal into the environment.* The worrying accumulation of plastics in water and soils also contributes to the accumulation of emerging pollutants in surface waters and also in groundwaters, as illustrated above.

3. ***What are the problems of emerging pollutants in ecosystems?*** The presence of emerging pollutants in water bodies may have toxic consequences for ecosystems. These effects can be classified as acute toxicity (often resulting in death or sickness of living organisms after a short period of exposure or even a single exposure), or chronic toxicity (resulting from prolonged and repeated exposure causing adverse and non-lethal effects). Exposure to pharmaceuticals, which are present at very low concentrations in water bodies, causes mainly chronic toxicity, resulting in alterations in the behaviour of aquatic animals.

For example, several studies have reported that the presence of antidepressants (pharmaceuticals used to treat depression in humans) in water alters the behaviour of aquatic animals. Exposure to fluoxetine, a pharmaceutical used by humans to treat anxiety and depression, lowers the swimming velocity of Arabian toad tadpoles (tailed aquatic larva of an amphibian, an

early stage of life after egg hatching) and reduces their ability to escape from their predators. The social behaviour of some fishes, such as the European perch, is also altered when these fishes are exposed to oxazepam, a pharmaceutical used to treat anxiety symptoms. Such fishes are also more active and eat more than fish that were not exposed to this pharmaceutical. The presence of antidepressants in water thus changes the behaviour of aquatic animals, including their responses to predators, which, as a consequence, may affect food webs and ecological balance in ecosystems.

Moreover, there is a wide variety of pollutants known as endocrine disruptor compounds (EDCs), that interact with animal endocrine systems. The endocrine system is composed of all the glands that produce hormones responsible for the regulation of biological processes in the body. The hormones are important messengers that inform body cells what they should do (for example, some hormones inform the bones that they need to grow, and others regulate the reproductive cycle). Hormones act by binding to receptors on the surfaces of target cells of specific tissues and organs, triggering a metabolic change in the cells.

EDCs have a structure similar to natural hormones and can bind to the hormone receptors and trigger the metabolic response in the absence of the natural hormone, thereby perturbing our natural hormonal controls of body functions. Examples of EDCs are some herbicides and pesticides, plastic contaminants, heavy metals, biocides, heat stabilizers, chemical catalysts, pharmaceuticals and dietary components, flame retardants, and others. The presence of these compounds in water may result in alterations in the growth of aquatic animals as well as in their reproduction ability.

Microbial communities are also important living organisms with a relevant role in ecosystems. They are essential to the equilibrium of ecosystems: they are the base of some food webs and crucial to the nutrient biogeochemical cycles in soil and aquatic environments, i.e. microorganisms play key roles in the transfer of biologically essential elements (nitrogen, carbon, phosphorous…, which have huge importance for all living organisms) between biotic and abiotic compartments of ecosystems. However, the presence of emerging pollutants in water bodies or soil may also affect microbial diversity and their functions in the ecosystem, resulting in alterations in water characteristics and soil composition.

Some pollutants can accumulate in the tissues of living organisms in a process called *bioaccumulation*, which is frequently described for fragrances, pesticides, biocides, perfluorinated compounds, and so on. Bioaccumulation has been reported in sea animals, such as mussels and sea urchins, as well as terrestrial and aquatic plants. Such pollutants are then transferred into the food web and pass to the immediate predators, which thereby become affected by the pollutant. Because of the pyramid structure of food webs, with one level consuming more than lower levels, pollutants that bioaccumulate increase in quantity up the food web, a phenomenon called *biomagnification*. This affects the entire ecosystem, but the most severe effects of biomagnification are experienced by the top predators, including humans.

Although these worrying consequences for aquatic animals have been proven, information about the consequences of emerging pollutants on other organisms, such as plants, terrestrial mammals, birds, microorganisms etc., remains underexplored. Nonetheless, we must do our best in terms of residue discharge and treatment, as well as reduce the use of products containing chemicals with known ecotoxic effects.

Relevance for Sustainable Development Goals and Grand Challenges

The microbial dimension of emerging pollutants relates to several SDGs including

- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture**. Intensive agriculture and the wide use of pesticides directly contribute to the presence of emerging pollutants in soil and water resources
- **Goal 3. Ensure healthy lives and promote well-being for all at all ages**. The use of antibiotics and other antimicrobial agents is essential for infection control and public health. However, residues from their use have been found in water resources and soil. These pollutants have a worrying impact on the *dissemination of antimicrobial resistance* through the ecosystems, endangering public health. Moreover, the chronic exposure of humans to emerging pollutants, for example through drinking water extracted from contaminated aquifers, is likely to result in long term adverse health consequences.
- **Goal 6. Ensure availability and sustainable management of water and sanitation for all**. Emerging pollutants are present in several water sources (surface water, seawater, groundwater, soil) causing pressure in different ecosystems and organisms. However, emerging contaminants are also present in drinking water and treated wastewater. *The incomplete removal of emerging pollutants in treatment plants by chemical, physical and microbial processes* contributes to the circularity of emerging pollutants among water sources and drinking water.
- **Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.** Rapid economic growth has created a demand for several products which have become/are becoming indispensable for the population, which translates into increasing environmental pollution by emerging pollutants.
- **Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.** Industrialization is responsible for the pollution of the environment, and emerging pollutants come from industrialized products and processes that use different molecules that improve product performance, shelf-life, etc. Innovation is the key to sustainable industrialization and the development of new products to replace compounds of concern and reduction in emissions of toxic and emerging pollutants.
- **Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable.** Safe cities have efficient sanitation programs and efficient programs of waste management as well as reduced air pollution. The adequate management of liquid and solid wastes is essential to prevent avoidable release of contaminants into water sources and soils.
- **Goal 12. Ensure sustainable consumption and production patterns**. The burden of emerging pollutants in water sources and the environment is highly dependent on prevailing policies of sustainable production and consumption practices. Reducing waste, using only the amount of product that we need, choosing ecological and natural products and avoiding products containing toxic and concerning molecules result in reduced emissions of emerging pollutants into the environment.
- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development**. Emerging pollutants are present in several water sources (surface water, seawater, groundwater, soil) causing pressure on different ecosystems and organisms. The presence of emerging pollutants in water bodies may have a significant impact on the natural *microbial*

communities, altering their *diversity and function* which may compromise the biogeochemical cycles, which may be translated into alterations in water characteristics.

- **Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.** The presence of emerging pollutants in soil may have a significant impact on the natural *microbial communities*, altering their *diversity and function* which may compromise the biogeochemical cycles, which may be translated into alterations in the nutritive composition of the soil.

Potential Implications for Decisions

1. ***Individual***
   - **a.** Adoption of sustainable consumption practices (Am I using more products than I need? Do I choose reusable products instead of disposable products? Do I pay attention to the chemical molecules (such as parabens) present in the products I usually buy?
   - b. Waste disposal practices (Recycling, correct disposal of pharmaceuticals and respective containers)
   - **c.** Antibiotic use only with medical prescription and responsible use and disposal of wastes (avoiding the promotion of antimicrobial resistance spread)

2. ***Community policies***
   - **a.** Sustainable production and consumption policies (agriculture and industry)
   - **b.** Waste and water management
   - c. Public perception of emerging pollutants impact in ecosystems and public health
   - d. Unknown consequences for ecosystems and public health

3. ***National policies***
   - **a.** Environmental pollution
   - b. Legislation regarding the concentration of concerning molecules in treated wastewater and drinking water
   - *c.* Ensuring safe drinking water supplies
   - *d.* Ensuring adequate waste and water management policies
   - *e.* New technologies for the removal of emerging pollutants of concern
   - *f.* Education and public engagement on emerging pollutants and their associated problems

Pupil Participation

1. Class discussion about emerging pollutants

a. Is it possible to completely stop our contribution to the emission of emerging pollutants in our daily routine?

b. How can we reduce the emissions of emerging pollutants into the environment?

c. Should people be warned about the presence of emerging pollutants in water sources?

2. ***Pupil stakeholder awareness***

a. Responsible and sustainable consumption practices. Ecological products are usually more expensive, however, ecological conscience in acquisition processes should also play role. Do you choose some products according to their environmental impact?

b. Can you think of anything you might personally do to reduce your contribution for the emission of emerging pollutants?

3. ***Exercises***

a. Correct waste disposal may be helpful to avoid the entrance of unnecessary emerging pollutants into water sources. However, most of the emerging pollutants will enter the environment through their direct use. Do you think that it is possible to improve waste disposal to avoid emissions of some emerging pollutants?

b. The efficient use of products without waste and the use of just the amount needed may be important practices to avoid unnecessary emissions of emerging pollutants. How do you think it is possible to promote the efficient use of products? For example, when shampoos, detergents, body creams, and toothpaste… are finished, some product remains in the package that we are not able to use. It means that the package containing some product will be discarded incorrectly in landfills or will be recycled, passing through a washing process that will result in wastewater containing the pollutants. How do you imagine packaging can be to avoid product waste at the bottom and walls of the package?

c. Wastewater treatment is essential to ensure the safety and quality of water when delivered into the environment (in water bodies). How do you think emerging pollutants may be removed from wastewater?

The Evidence Base, Further Reading and Teaching Aids

Gomes, I.B., et al., Emerging contaminants affect the microbiome of water systems—strategies for their mitigation. npj Clean Water, 2020. 3(1): p. 39.

Tang, Y., et al., Emerging pollutants in water environment: Occurrence, monitoring, fate, and risk assessment. Water Environment Research, 2019. 91(10): p. 984-991.

Souza, H. O. et a., Bacteria and Chemicals in My Bottled Water?! Frontiers For Young Minds, 2021, https://kids.frontiersin.org/articles/10.3389/frym.2021.608273

Bednarz, V., et al. The Invisible Threat: How Microplastics Endanger Corals, Frontiers For Young Minds, 2021, https://kids.frontiersin.org/articles/10.3389/frym.2021.574637

Glossary

Bioaccumulation – accumulation of pollutants in tissues of living organisms.

Biodegradation – the ability of living organisms to degrade/transform pollutants into less dangerous compounds

Biogeochemical cycles – cycles of chemical elements (nitrogen, carbon, phosphorous…, which have huge importance for all living organisms) between biotic and abiotic compartments in ecosystems

Biomagnification – Transfer of pollutants accumulated in organisms along the trophic chain, from prey to predators, increasing their concentration along the trophic levels
Pollutant - substance introduced into the environment that has undesired effects, firstly to the environment and putatively to animal and human health
Treatment plant – installation/facilities used to reduce the negative impact of a particular product (such as wastewater or solid waste) and eventually improve the quality for further reuse
Wastewater – water that has been affected by domestic, industrial and commercial activities, which has no quality for consumption