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Biotechnological Interventions in the Removal of Emerging Pollutants

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We dedicate this book to our parents, family, and teachers for their guidance and motivation

Preface

Emergent pollutants are broadly categorized as a range of inorganic and organic compounds, which have detrimental effects on the well-being of living things. Different kinds of pollutants are produced by different human activities, and consequently, these pollutants have impacted public health and degraded biodiversity in different levels. The examples of emergent pollutants are pharmaceuticals, endocrine disruptors, heavy metals, antibiotics, personal care items produced by various sectors, etc. The majority of these emerging pollutants are released into surface water, where they contaminate ground water, soil, sediments, and seas. Both inorganic and biological treatments can be used to remove or degrade these pollutants from terrestrial and aquatic environments. Numerous microorganisms can be utilized effectively in bioremediation of emergent contaminants, through the processes of removal, breakdown, detoxification, and immobilization of contaminants. Simultaneously, enzyme biotechnology has also evolved as cost-effective low-energy requiring and eco-friendly technology, which can be used for remediation of various pollutants. However, bioremediation is not always adequate to treat emergent pollutants completely. Rather, a combination of both physical and chemical treatment, especially the applications of nanotechnology, can be effective in sustainable removal of the pollutants.

This book comprises 26 chapters, which address different perspectives related to emergent pollutants, the health hazard caused by them, and their bioremediation mechanisms. This book not only deals with the various health issues caused by emergent pollutants and their regulatory approaches, it also highlights the latest advancements in bioremediation techniques, exploring how microorganisms can break down various pollutants and examines the future potential of bioremediation to reduce global pollution. It will be a valuable resource for policymakers, educators, researchers, scientists, as well as undergraduate and graduate students in agriculture, forestry, ecology, soil science, and environmental sciences.

We extend our heartfelt gratitude to all the contributing authors and reviewers whose invaluable support has been instrumental in shaping this book. We sincerely thank the authors for their outstanding efforts in writing the informative chapters. Our appreciation also goes to the reviewers for their crucial inputs that have

significantly improved the chapters. We would like to convey our sincere thanks to the entire team of Springer Nature for giving us the opportunity to edit this book. We also express our gratitude to our mentors, teachers, and students for their motivation. Their support has provided us with the assurance and strength to complete this project.

Finally, we thank our colleagues, family, and friends for their encouragement and support throughout the preparation of this book.

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We thank and express our sincere gratitude to all the authors and reviewers for their valuable contributions to this book. We appreciate their timely submissions and necessary corrections. We express our gratitude to the publishing team of Springer Nature for providing us the opportunity to edit this book. We convey our thanks to our colleagues for giving us the confidence and strength to accomplish this task. Finally, we would like to convey our gratitude to our family members for their constant support and encouragement.

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Contents

Chapter 1
An Overview and Impact of Emerging Pollutants on Human Health and Environment

Vishal Das, Kongkana Goswami, Sangeeta Biswas, Sosanka P. Sandilya, and Pobi Gogoi

Abstract Emerging pollutants (EPs) have been identified and quantified in living things and various environmental substances in recent years. Basically, chemicals that are either man-made or naturally occurring and have the potential to enter the environment and have a negative influence on both the ecosystem and human health are referred to as emerging pollutants. However, the harmful effects of environmental exposure on the general population are largely unknown and less covered. They are not currently being monitored and analyzed in the environment, although they contribute a major threat to the ecosystem and to human health, as well as causing environmental harm. Perfluorinated chemicals, by-products of water treatment, gasoline additives, pesticides, pharmaceuticals and personal care products, nanomaterials, human and veterinary medications, and UV filters, are some of the most common developing toxins. Numerous pollutants have been also reported and considered to increase the risk of cancer. Moreover, the EPs, also referred to as micropollutants, cause major harm to the environment and to human health and have made them a significant concern for the entire world's population in recent years. The existence of EP in the environment, its toxicological effects on health, and future perspectives regarding potential removal and treatment options including practical considerations, recent novel processes, new avenues, and solution strate-

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gies will be comprehensively discussed in this book chapter. Well, EPs are constantly being reported all over the world and considered as a major threat to the mankind and environment that needs to be addressed immediately on a global scale. The current study summarizes the overall impact and effect on emerging pollutants on human health and environment.

Keywords Emerging pollutants (EPs) · Human health · Toxicological effects

1.1 Introduction

The term "emerging pollutants" describes compounds that have just recently been discovered or have gained attention because of their environmental presence and their effects on ecosystems and human health. Numerous sources, including as industrial operations, farming practices, medications, personal care items, and more, can produce these contaminants (Gavrilescu et al. 2015). Research and regulatory efforts have focused on the effects of new contaminants on human health and the environment, as this is an increasingly pressing concern. Emerging pollutants are defined as naturally occurring or man-made substances that are not typically seen in the environment, but have the potential to do so and may have negative effects on the environment and human health that are either suspected or confirmed. It consists of items that are regularly used in homes, businesses, and other human endeavors (such as personal care and medications, plasticizers and gasoline additives, and degradation products and surfactants) (Fig. 1.1) (Arvaniti and Stasinakis 2015; Vasilachi et al. 2021).

These chemicals are being used in greater quantities in industry, transportation, agriculture, and urbanization, which are causing an increase in their hazardous waste and nonbiodegradable material levels in the environment. Furthermore, there is a lack of comprehensive and reliable epidemiological data regarding human exposure, serum and tissue concentrations, hazards to human and ecological health, and their behavior and fate in the global environment (Gavrilescu et al. 2015).

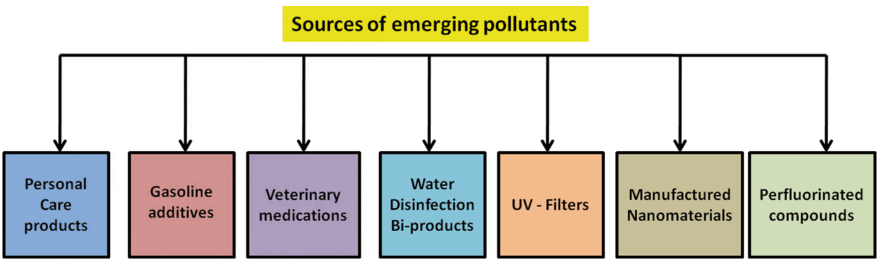

Fig. 1.1 Some of the emerging pollutants that have gained attention because of their environmental presence and their effects on ecosystems and human health

Environmental pollution ranks among the most difficult issues that face people on a daily basis. Concerning developments occurred in the quality of the environment as a result of industrialization and urbanization. Different forms of pollutants, such as persistent organic (pharmaceuticals, endocrine disrupting agents, personal care products, pesticides) and inorganic (e.g., heavy metals) are severe concerns globally that effects both the plants and animals (Bunke et al. 2019). "EPs" are chemicals that have the ability to bioaccumulate, persist in the environment, and pose a threat to human health and safety. Some of the effects of these substances include inappropriate growth, decreased fertility and reproductive health, delayed neurological development, deterioration of wildlife species, degradation of aquatic ecosystems, and possibly even immune system damage. It is crucial to emphasize that most toxins that are emerging are not newly created or have only recently entered the environment (Rodriguez-Narvaez et al. 2017). Emerging pollutants are coming from nowhere; rather, they are already here in detectable quantities, posing an irreversible threat to both human health and the ecosystem. It was previously present in extremely low concentrations, but as public knowledge of its adverse impact on the environment grows, the term "emerging pollutant" has been employed by the researchers.

This chapter summarizes and emphasizes the information on EPs and its impact on environment, a topic that has gotten a lot of attention lately. A study on emerging pollutants or emerging contaminants was examined in this work, paying particular attention to the materials' occurrence, environmental fate, and toxicity evaluation. Emerging pollutants are the threat to human health and the environment, and as a result, the study offers helpful insights to know and study about its impact on human and environment based on some thorough reports and comprehensive studies.

1.2 Perfluorinated Compounds

PFCs are aliphatic compounds with one or more carbon (C) atoms on which fluorine (F) atoms have completely replaced all hydrogen (H) atoms. The CnF2n+1− moiety is connected to a variety of functional groups in PFCs. Sulfonic acid (SO3H), carboxylic acid (−COOH), and sulfonamides (−SO2NH2) are the three main functional groups (). Produced since the late 1940s, perfluorinated compounds (PFCs) consist of a hydrophobic alkyl chain that is fully fluorinated and connected to a hydrophilic end group. The most important representative PFCs are perfluorooctanesulfonate (PFOS), perfluorooctanoic acid (PFOA), and their salts. PFCs pile up in the environment and are biomagnified by the food chain since they are incredibly stable and do not biodegrade (Morikawa et al. 2006). Compared to other environmental pollutants, PFCs are ubiquitous and can be found in blood samples from both industry employees and the general public at comparatively high concentrations. More significantly, their presence in breast milk and umbilical cord blood suggests that fetal development may be the beginning of a lifetime exposure to PFCs (Lee et al. 2013). PFC exposure is attributed to the existence of these species in blood, food, consumer products, indoor chemicals, and occupational exposure, per a study on PFCs (Wu et al. 2015).

Numerous studies have demonstrated that long-chain PFCs—that is, PFOA and PFOS—have longer elimination half-lives and are more bioaccumulative than short-chain PFCs, such as CnF2n+1COOH, where $n \geq 7$, and CnF2n+1−SO3H, where $n \geq 6$ (D'Hollander et al. 2010). The major manufacturer of PFOA and PFOS, the 3M Company, phased out production of these chemicals in 2000 due to widespread concern about the potential health and environmental effects of long-chain PFCs. This concern also facilitated regulatory initiatives in many countries to reduce the environmental release of these PFCs (Olsen et al. 2009).

Numerous toxicological consequences, such as altered thyroid hormone, hepatotoxicity, changes in glucose and cholesterol, toxicity to the reproductive and developmental systems, and carcinogenic effects, have been linked to PFAS exposure in epidemiological and experimental investigations (Rodriguez-Jorquera et al. 2019; Lau et al. 2007). The most prevalent malignancy among Chinese women is breast cancer. In the world, China is the country that accounts for 9.6% of all breast cancer fatalities and 12.2% of new diagnoses. Breast cancer risk factors include early menarche, late menopause, postmenopausal obesity, smoking, alcohol consumption, and excessive fat intake, in addition to genetic variables including mutations in BRCA-1/2. Fan L et al. in the year 2014 reported that less than one-third of cases are explained by known risk factors, and environmental exposure and lifestyle choices can significantly affect a person's risk of developing breast cancer (Fan et al. 2014). Numerous epidemiological studies have been conducted in Europe and the United States to evaluate the dangers of PFAS exposure and breast cancer (Fan et al. 2014). According to a recent study, perfluoro-n-tridecanoic acid (PFTrDA) was adversely related with breast cancer in Chinese women, but the plasma concentrations of Perfluorooctanoic acid (PFOA) and perfluoro-n-decanoic acid (PFDA) were positively associated with breast cancer. Breast cancer that was ER-, PR-, and HER2-positive was more likely to be linked to PFOA (Li et al. 2022). In their investigation, Seyyedsalehi MS et al. found a link between kidney cancer and total PFAS exposure, as well as a link between high PFAS concentrations and testicular cancer (Seyyedsalehi and Boffetta 2023). Many studies on human infertility, lactation, and semen quality have examined the relationship between the blood level of PFCs and reproductive failure in the general population. Fei et al. looked at the possibility that PFC exposure and related hormone disruptors may make infertility more likely (Fei et al. 2009). A study conducted by Joensen et al. suggested that, with the exception of primipara, PFOS may reduce the women's ability to lactate. Because multiparous women had previously breastfed and because excretion could lower PFOS serum levels, the connection between the PFOS serum level and multiparous women was not as strong. Joensen et al. looked at a possible relationship between testicular function, semen quality, and perfluoroalkyl acids (PFAAs) (Joensen et al. 2009).

The possible links between the levels of PFOA and PFOS in the serum and the prevalence of thyroid disease have been highlighted by other research. In order to determine whether there was a significant correlation between the serum and tissue concentrations of PFCs, Pirali et al. measured the PFOS and PFOA levels among 28 participants who underwent thyroid surgery for benign diseases (7 for Graves' disease and 15 for multinodular goiters) and malignant thyroid diseases (5 for papillary carcinoma and 1 for follicular carcinoma) (Pirali et al. 2009). The Northeastern states with the highest prevalence of thyroid cancer were the main locations where the higher PFAS levels were found. These findings support closer monitoring of PFAS exposure among local populations and provide guidance for future research on the possible consequences of exposure on the thyroid gland (Alsen et al. 2003).

1.3 Gasoline Additives

Chemical compounds or substances known as gasoline additives are added to gasoline in order to improve performance, lower emissions, increase fuel efficiency, and prevent engine deposits. These additives have multiple uses and are specifically designed to meet the needs of contemporary combustion engines.

From the 1920s to the late 1980s, lead-based antiknock additive mixes were widely employed to raise the octane ratings of gasoline. These mixtures contained the volatile organic compounds 1,2-dichloroethane (DCA) and 1,2-dibromoethane (ethylene dibromide; EDB). With federal maximum contaminant levels (MCLs) of 0.05 and 5 μg/L, respectively, EDB and DCA are likely human carcinogens. In the United States, lead is no longer used in gasoline, although EDB and DCA are still present in the environment (Falta et al. 2005).

In groundwater-dependent public drinking water systems in the United States, EDB and DCA are two of the most frequently found contaminants (EPA-815-R-03-006; U.S. EPA 2003). Generally, discharges from industries (DCA) or agriculture (EDB) are blamed for groundwater pollution by these chemicals. However, more than 80% of the EDB was consumed as an additive for gasoline in the 1970s. Often utilized as a solvent, DCA is a common industrial chemical feedstock (Falta et al. 2005).

In many nations, using leaded gasoline is still standard procedure. Tetraethyl lead (Pb (C2H5)4) is the most widely used lead compound, and it is used to increase the gasoline's octane level. Greater thermodynamic efficiency is achieved by using engines with higher compression ratios, which are made possible by higher octane fuel. Manufacturers are able to obtain more power and fuel efficiency out of lighter, smaller engines thanks to this increased efficiency. However, using this gasoline results in a lot of undesired emissions of particulates, carbon monoxide, and lead. For these reasons, a number of nations have worked to alter the usage of leaded gasoline in an effort to lessen or completely prevent the unintended pollution emissions that come with the rising use of gasoline (Bravo et al. 2006).

This substance is present in gasoline and is a member of the aromatic family. It is also utilized as a solvent. Exposure to toluene, whether acute (short-term) or chronic (long-term), can be hazardous to humans and animals. Following inhalation, symptoms include headaches, nausea, exhaustion, headaches, dizziness, and upper respiratory tract irritation (ATSDR 2017) (WHO 2016).

There are over 500 components in gasoline, including methyl tert-butyl ether (MTBE), 1,3-butadiene, and benzene, all of which are known or suspected carcinogens. Due to their high volatility and solubility, methyl tertiary butyl ether (MTBE) and ethyl tertiary butyl ether (ETBE) rapidly disperse in the environment and have low biodegradability. Consequently, their presence in surface waters is widespread even at low quantities of μg/L (Apetroaei et al. 2020). The most popular oxygenated bunker, MTBE, is being sporadically employed as a new unleaded gasoline additive, especially in developing areas (Mennear 1997). Tetraethyl lead as an antiknock species can be replaced by MTBE, which also improves the octane additive used in gasoline to increase its burning efficiency and reduce carbon monoxide and other dangerous chemicals, such benzene and ozone, in vehicle exhaust (McGregor 2006). According to research on animals, MTBE can damage the kidney, liver, immune system, and central nervous system in addition to causing cancer of the testicles, uterus, and kidneys (Mennear 1997). In an analytical study, Joseph and Weiner found a correlation between the levels of MTBE in the air and the following symptoms: skin rash, palpitations, allergy, otitis media, cough, headache, throat stimulation, hypersensitive rhinitis, upper respiratory transmissible illness, sicchasia, dizziness, wheezing, anxiety, and insomnia (Joseph and Weiner 2002).

Strong alkylating chemicals like chloroethane are utilized as industrial refrigerant, topical anesthetics, polymers, pigments, and gasoline additives (Fishbein 1979). Naturally occurring and extremely lipophilic, bromoethane finds usage in both industrial and pharmacological settings. Its ability to cross the blood–brain barrier is noteworthy (Klassen 1996). According to research conducted by the National Toxicology Program (NTP), uterine tumor incidence increased in B6C3F1 mice exposed to these chemicals for several weeks of inhalation (NTP 1989a, b). Aoyama et al. (2005) recently investigated the direct estrogenic effects of bromoethane in human Ishikawa cells and in ovariectomized B6C3F1 mice. For a duration of 3 days, mice were administered 0, 100, 500, or 1000 mg kg^{-1} of bromoethane.

1.4 Personal Care Products and UV Filters

Personal care products (PCPs) are a broad category of everyday home chemicals used for cleaning, cosmetics, and wellness. Products that easily expose people include those for hair and skin care, baby care, UV blocking lotions, facial cleansers, insect repellents, perfumes, fragrances, soap, detergents, shampoos, conditioners, toothpaste, and more.

These consist of, among other things, UV filters, scents, disinfectants, and insect repellents. Due to their existence and detrimental effects on aquatic ecosystems, particularly in relation to endocrine disruption and reproductive diseases, several of them are regarded as chemicals of growing concern. Studies done in 2017 has reported that, 72 PCPs that have been identified as emerging contaminants in 30 different nations back then, with concentrations ranging from 0.029 ng/L to 7.811×10^6 ng/L. The most often reported categories were sunscreens, antiseptics, and fragrances. As anticipated, wastewater treatment plant effluents included 64 PCPs total—more than twice as much as those identified in surface water and groundwater combined—than any other source. This finding provides proof of the anthropological input of PCPs to water bodies (Montes-Grajales et al. 2017).

Oxybenzone is widely used as a photo-stabilizer to reduce color and odor changes in sunscreen preparations at doses up to 6% and primarily as a short-wave UVA light absorber (320–340 nm) at concentrations up to 290–320 nm. According to the reviewed data, oxybenzone is present worldwide in human urine, serum, and breast milk in addition to being present in water, soil, sediments, sludge, and biota. It is not as effective as avobenzone, titanium dioxide, and/or zinc oxide as a sunscreen active in preventing UVA rays. This substance is a known contact and photocontact allergen that can cause contact urticaria and, to a lesser extent, contact-mediated anaphylaxis in people. It has also been connected to Hirschsprung's illness (DiNardo et al. 2018).

PCPs are present in human bodies at all stages of life, including intrauterine development. Inhalation, cutaneous contact, ingestion, and absorption are the direct routes of exposure; product use and environmental contamination are the indirect pathways (Heudorf et al. 2007). The estimated daily cutaneous route of exposure to titanium dioxide (TiO2) is between 2.8 and 21.4 mg/person/day, with toothpaste and sunscreen being major contributors to this exposure. In addition, it was calculated that the toothpaste caused ingestion of 0.15–3.9 mg TiO2/day. An estimated 35% of produced TiO2 is utilized in PCPs as UV shielding agents or to stop yellowing of the product (Wu and Hicks 2019).

Triclosan is the most common biocide ingredient in consumer liquid hand soaps. It is an antibacterial and antifungal agent that has been used as a biocide in personal hygiene products since the 1960s. It was originally used in the medical field in 1972 as a 1% component of surgical scrub and as toothpaste for dental care in Europe in 1985. Under the Federal Insecticide, Fungicide, and Rodenticide Act, triclosan has also been approved by the USEPA for use as an antimicrobial pesticide in bacteriostat and fungicide/fungistat applications (Jones et al. 2000).

A class of p-hydroxybenzoic acid ester derivatives (methyl, ethyl, propyl, isopropyl butyl, isobutyl, or benzyl) are known as parabens. Since parabens and their chlorinated derivatives are often detected in the aquatic compartment at low ng L^{-1} levels, they could be regarded as emerging pollutants. Because of their antibacterial properties as well as their durability at various pH and temperature ranges, parabens are frequently found in cosmetic products (Haman et al. 2015).

Due to their ability to scatter UV radiation with wavelengths ranging from 290 to 400 nm, sunscreens are a popular choice for protection against UV radiation risks, early skin aging, and skin cancer. Among the organic sunscreens that absorb new UV photons are benzophenone-3 (BP-3), 2-ethylhexyl 4-methoxycinnamate (OMC), 2-ethylhexyl 4-dimethylaminobenzoate (OD-PABA), homosalate (HMS), 3-(4-methylbenzylidene)camphor (4-MBC), and 3-benzylidene camphor (3-BC). Moreover, swimming, laundry, and bathing can introduce highly generated lipophilic sunscreens into the aquatic environment. Numerous investigations conducted on laboratory animals, both in vitro and in vivo, have demonstrated the endocrine disruptive effects of sunscreen, encompassing disturbances to the hypothalamic-pituitary-thyroid axis (HPT) as well as reproductive and developmental functions. Through the food chain, human and animal exposure patterns may overlap (Lei et al. 2015). The study conducted by Johnson et al. revealed that formaldehyde releasers, cyclosiloxanes, and parabens were the most commonly used compounds. Additional chemicals of concern (CoCs) detected by gas chromatography time-of-flight mass spectrometry (GCxGC-TOFMS) included pollutants, perfumes, solvents, and preservatives. Their findings supplement research on health disparities caused by chemical exposures from several sources, increase awareness of potentially harmful compounds in PCPs, and aid in estimating disparities in chemical exposure.

Because UV filters are found worldwide in sediments, seas, and biota, they have recently gained attention as pollutants. These substances are widely utilized in commercial items to stop photodegradation and in personal care products to stop UV spectrum infiltration. These pollutants are being found in the aquatic environment more frequently as consumption rises, most likely as a result of being rinsed off after application and then seeping into the ecosystem (Coleman et al. 2023). In the cosmetics fields, octyl-methoxycinnamate (OMC) is widely used as a UV-B filter. Although OMC was first created to lessen the harmful photobiological impacts of UV radiation, its safety has come under scrutiny after certain research revealed harmful effects on the environment (Lorigo et al. 2024).

1.5 Water Disinfection By-Products

A type of secondary pollutant called disinfection by-products (DBPs) is often found in the urban water cycle and has been shown to have (eco) toxicological effects on aquatic systems as well as human health. As a result, DBPs are already commonplace environmental pollutants that should raise alarm. The chemical disinfectants that are most frequently used in public water sources are chlorine, ozone, chloramine (chlorine + ammonia), and chlorine dioxide. According to recent research, relatively modest iodine intakes raise thyroid stimulating hormone levels (Robison et al. 1998).

Analytical chemists found in 1974 that consumed waters contained amounts of up to ~160 μg/L of trihalomethanes (THM4; chloroform, bromodichloromethane, dibromochloromethane, and bromoform), which form as byproducts of chlorine interactions with natural organic matter (NOM) (Rook 1974).

The list of harmful health effects linked to chemical disinfectants keeps getting longer. As of right now, the only significant risk that seems to be connected to drinking water chlorination is a higher risk of bladder cancer in men. It is crucial to identify the substances generating this effect in order to define alternatives that lower or eliminate the risk, not just to satiate scientific curiosity (Bellar et al. 1974). By the 1940s, widespread outbreaks of cholera, typhoid, and other waterborne illnesses had been mostly contained in the industrialized world because to chlorine cleaning of municipal drinking supplies, which had begun shortly after 1900. Ever since, epidemiological research has indicated links between drinking chlorinated tap water with high THM4 levels and unfavorable health consequences, such as bladder cancer (Costet et al. 2011).

Several halogenated organic compounds, such as haloacetic acids (HAAs), haloacetonitriles (HANs), and trihalomethanes (THMs), are included in DBPs. Of the previously listed DBPs, THMs are the most prevalent, followed by HAAs, which can be detected in finished water at quantities of around μg/L, and HANs, which can be found in finished water at values as low as ng/L and as high as μg/L. Chloroform, bromodichloromethane (BDCM), chlorodibromomethane (CDBM), and bromoform are examples of volatile compounds that belong to the THMs group. On the other hand, HANs, such as dichloroacetonitrile (DBAN) and monochloroacetic acid (MCAA), and HAAs, such as dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), monobromoacetic acid (MBAA), and dibromoacetic acid (MBAA), are composed of volatile compounds (Kwarciak-Kozlowska 2020). Exposure to HOCs has been linked to a wide range of health consequences in both humans and wildlife, including neurological, immunological, endocrine, behavioral, and carcinogenic impacts. Furthermore, current research suggests that type 2 diabetes and obesity are influenced by exposure to HOCs (Kodavanti et al. 2023).

1.6 Veterinary Medications

Veterinarian medicines are one of the newly discovered toxins that have attracted a lot of interest because they have been found in water supplies and may be harmful to aquatic biota, which includes humans who use these water sources for purification. Anthelmintics make up an important portion of the animal pharmaceutical market. They are used to treat helminthic illnesses, or infections brought on by parasitic worms, and are administered to a variety of significant veterinary animals in aquaculture and agriculture (Horvat et al. 2012). Due to their widespread use as biocides, fungicides in agriculture, and antifungal agents in veterinary medicine, azole compounds have the potential to leave significant environmental residues due to their extensive use. It is believed that azoles may have an impact on aquatic species' endocrine systems (Peng et al. 2012). The pollution of soil, surface water, and groundwater caused major concerns because antibiotics, even at low concentrations, encourage the emergence and growth of antibiotic-resistant microbes because of their constant exposure to these substances. The authors report a rise in the development of harmful bacterial strains that are resistant, which can have detrimental effects on human health. A study by Vidhamaly et al. underline the necessity for additional thorough research with a solid methodology in order to better inform policy and put policies in place that ensure the quality of veterinary pharmaceuticals in supply chains. They suggested that transdisciplinary study is needed to understand the mechanism and effects of (substandard and fraudulent) SF veterinary products on human and animal health, agricultural output, their economies, and antimicrobial resistance (AMR) (Vidhamaly et al. 2022). Recent reports have linked the bicyclic nonsteroidal anti-inflammatory drug ketoprofen—which is frequently used in both human and veterinary medicine—to environmental contaminants that pose a threat to ecological health. Because of its sporadic mixture, enantiomers, and transformation products—which have ecotoxicological impacts on a variety of taxa, including plants, microbes, and vertebrates—it is becoming a more serious danger. Moreover, ketoprofen endangers the ecosystem's ability to operate by being bioaccumulated and biomagnified throughout the food chain (Tyumina et al. 2023).

1.7 Manufactured Nanomaterials

Nanomaterials (NMs) are ultrafine particles with a size range of 1–100 nm; however, size alone does not provide a valid criterion for NM classification. Materials may be incidental, man-made, or natural. Neural networks (NMs) display a variety of structural dimensions, such as zero-, one-, two-, and three-dimensional configurations (Cheriyamundath and Vavilala 2021). Because of their unique features and their applicability in a wide range of consumer and commercial applications, nanomaterials have sparked questions regarding possible environmental effects. Nanomaterials' small size may increase their bioavailability, or the ease with which living things can absorb them. Potentially negative consequences for ecological systems and creatures at various trophic levels may result from this. Because of their greater mobility, they may have a role in the environmental dispersion of nanomaterials. Additionally, they have the capacity to interact with other environmental contaminants in ways that have unclear antagonistic or synergistic effects (El-Kalliny et al. 2023).

According to the reports, NPs have the ability to damage DNA and trigger cell death since they can be found inside the cell in a variety of places, including the cytoplasm, nucleus, lipid vesicles, and cell membrane. An essential stage prior to cellular absorption is the interaction of NPs with cell membranes. It is believed that adhesive contact caused by steric interactions, electrostatic charges, Van der Waals forces, or interfacial tension effects is the mechanism of NP uptake by cells. These could consist of inflammation, oxidative stress, toxicity, and DNA damage. The transfer of NPs across tissue barriers into the bloodstream, where they can circulate and ultimately lodge in other organs, causes secondary NP exposure. These might include organ damage in the liver, spleen, or kidneys, as well as toxicity at the location of NP deposition (El-Kalliny et al. 2023).

Car exhaust is the primary source of atmospheric NPs. While gasoline engines release NPs between 20 and 60 nm, diesel engines release NPs between 20 and 130 nm. It has been discovered that CNTs and fibers are released as byproducts during the burning of gas and diesel. Since diesel-generated particles account for over 90% of all carbon nanoparticles (NPs) in the atmosphere, automobile pollution is a primary source of nanoparticulate contamination in metropolitan environments (Jeevanandam et al. 2018). In their study, Stefani et al. (2005) noted that lead, glass, respirable asbestos fibers, and other hazardous particles from everyday items could be present in the released particulates near the site of building destruction. The benthic organisms in freshwater were adversely impacted by the NPs aggregates that settled to the bottom and gradually accumulated in the silt. While NPs may build up in the marine ecology between warm and cold currents (Hyseni 2016), it has been reported that TiO2 NP exposure has been linked to negative effects on aquatic organisms, including "trout," according to certain study findings (Federici et al. 2007). Another nanoparticle Amorphous silicon dioxide particles (A-SiO2) inhalation exposure in animal has been reported partially linked to reversible inflammation in the respiratory system and alterations in blood parameters; however, these studies do not show evidence of lung fibrosis progression (Shin et al. 2017). Carbon nanotubes (CNTs), which can absorb nanomaterials by skin contact or oral ingestion through the gastrointestinal tract, have been the subject of several studies reporting possible effects on both aquatic and terrestrial creatures. According to tests on mammals, CNTs are both cytotoxic and genotoxic to various cell types, including macrophages. Exposure to CNTs can cause chromosomal aberrations, necrosis, apoptosis, and the release of reactive oxygen species (ROS), as well as the expression of inflammatory cytokines like IL-8 (Girardello et al. 2015) (Table 1.1).

1.8 Impacts of Emerging Pollutants on Human and Environment

Human health is seriously and increasingly at risk from pollution. It is now thought to be the primary environmental cause of health issues worldwide, causing over nine million preventable deaths every year. It causes the economy to suffer enormous losses, undermines efforts for economic improvement, and causes the Sustainable Development Goals (SDGs) to take longer to achieve. Pollution poses a threat to both the long-term survival of human populations and the integrity of the earth's support systems, much as climate change and the depletion of freshwater resources worldwide. The persistent challenge is the emerging pollutant. It is known that some EPs may affect aquatic ecosystems and creatures biochemically. Daphnia fish have been found to be susceptible to four distinct classes of EPs (antibiotics, antineoplastics, cardiac medications, and sex hormones) when these medicinal compounds are tested for aquatic toxicity; on the other hand, estrogens and antibiotics have been identified as the most toxic products for both public health and marine life (Rodriguez-Narvaez et al. 2017).

Chemicals are created and used by industries in over 100,000 distinct ways, making them an essential element of daily life. The employment and economic growth of nations are significantly impacted by the global chemical market. On the other hand, a lot of chemicals are released into the environment, and chemical contamination is becoming commonplace in both land and water. These environmental contaminants affect human health and the environment in a wide range of acute and

Table 1.1 Emerging pollutants, its sources, and their effects on human health and environment

S. no.	Emerging pollutants	Effect on human health and environment	Chemicals and sources	References
1	Perfluorinated compounds	Altered thyroid hormone, hepatotoxicity, changes in glucose and cholesterol, toxicity to the reproductive and developmental systems, and carcinogenic effects	Perfluoroalkyl acids	Rodriguez-Jorquera et al. (2019), Lau et al. (2007)
		Breast cancer, kidney cancer, and testicular cancer	PFAS	Fan et al. (2014), Seyyedsalehi and Boffetta (2023)
		Increased pregnancy losses and disruption in sex hormone homeostasis and sexual maturation	PFOA & PFOS	Potera (2009)
		Reduces women's ability to lactate	PFOS	Joensen et al. (2009)
2	Gasoline additives	Damages kidney, liver, immune system, and central nervous system in addition to causing cancer of the testicles, uterus, and kidneys	MTBE	Mennear (1997)
		Uterine tumor incidence.	Bromoethane	NTP (1989a, b)
		Following inhalation, symptoms include headaches, nausea, exhaustion, headaches, dizziness, and upper respiratory tract irritation	Toluene	ATSDR (2017)
		Suspected carcinogen	ETBE	Apetroaei et al. (2020)
3	Veterinary medications	Frequently used in both human and veterinary medicine has reported to have ecotoxicological impacts on a variety of taxa, including plants, microbes, and vertebrates	Ketoprofen	Tyumina et al. (2023)
		Impact on aquatic species' endocrine systems	Azole	Peng et al. (2012)
4	Water disinfection by-products	Widespread outbreaks of cholera, typhoid, and other waterborne illnesses had been mostly contained in the industrialized world because of chlorine cleaning of municipal drinking supplies.	Water chlorination	Costet et al. (2011)
		Linked to a wide range of health consequences in both humans and wildlife, including neurological, immunological, endocrine, behavioral, and carcinogenic impacts. Type 2 diabetes and obesity are influenced by exposure to HOCs	Halogenated organic compounds	Kodavanti et al. (2023)

5	Personal care products and UV filters	Oxybenzone is present worldwide in human urine, serum, and breast milk in addition to being present in water, soil, sediments, sludge, and biota. This substance is a known contact and photocontact allergen that can cause contact urticaria and, to a lesser extent, contact-mediated anaphylaxis in people. It has also been connected to Hirschsprung's illness	Oxybenzone	DiNardo et al. (2018)
		Harmful effects on the environment	Octyl-methoxycinnamate (OMC) is widely used as a UV-B filter	Lorigo et al. (2024)
		Early skin aging, and skin cancer.	Among the organic sunscreens that absorb new UV photons are benzophenone-3 (BP-3), 2-ethylhexyl 4-methoxycinnamate (OMC), 2-ethylhexyl 4-dimethylaminobenzoate (OD-PABA), homosalate (HMS), 3-(4-methylbenzylidene)camphor (4-MBC), and 3-benzylidene camphor (3-BC)	Lei et al. (2015)
6.	Manufactured nanomaterials	Negative effects on aquatic organisms	TiO2	Federici et al. (2007)
		Partially linked to reversible inflammation in the respiratory system and alterations in blood parameters	A-SiO2	Shin et al. (2017)
		CNTs are both cytotoxic and genotoxic to various cell types, including macrophages. Exposure to CNTs can cause chromosomal aberrations, necrosis, apoptosis, and the release of reactive oxygen species (ROS), as well as the expression of inflammatory cytokines like IL-8	Carbon nanotubes (CNTs)	Girardello et al. (2015)

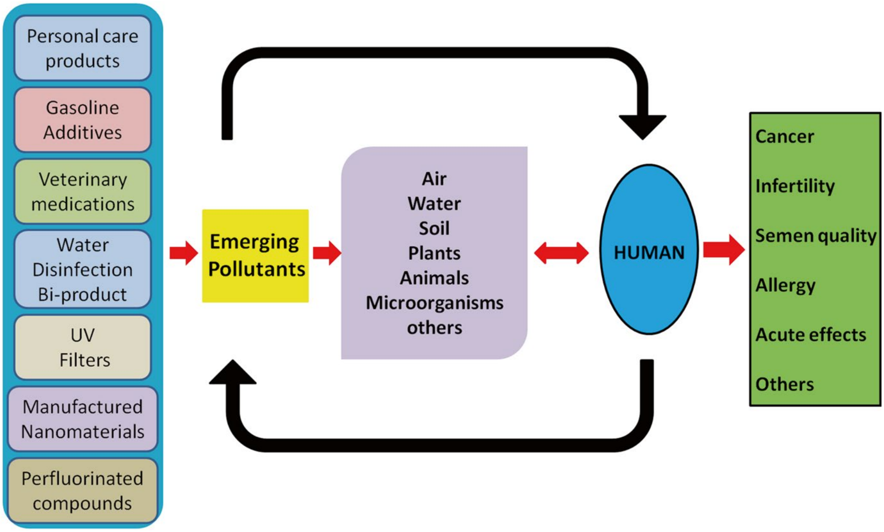

Fig. 1.2 Schematic diagram displaying the impact of some emerging pollutants on human and environment. It is also showcasing the interaction among air, water, soil, animals, microorganisms, and EPs that have harmful effects on humans upon exposure

long-term ways (e.g., immunotoxicity, neurological diseases, malignancies, endocrine disruption, etc.) (Sanchez and Egea 2018).

Chemicals and substances that have lately been determined to pose a threat to ecosystems, the environment, and human health are known as emerging pollutants, or EPs (Fig. 1.2). Furthermore, a large number of these newly discovered toxins are not covered by international or national regulations, which increases the risk to our way of life. Numerous substances, such as pharmaceuticals, steroids, endocrine disruptors, hormones, industrial additives, chemicals, microbeads, and microplastics are among the contaminants (Krishnakumar et al. 2022). Some of the emerging pollutants are discussed in this chapter that has gained attention lately.

Numerous investigations conducted on laboratory animals, both in vitro and in vivo, have demonstrated the endocrine disruptive effects of sunscreen, encompassing disturbances to the hypothalamic-pituitary-thyroid axis (HPT) as well as reproductive and developmental functions (Krause et al. 2012). Long-term exposure to particulate matter has been linked to a number of new concerns, including diabetes, prenatal mortality, neurodevelopment, and cognitive functions. Ultrafine particulate matter, secondary inorganic aerosols, organic and black carbons, and other newly discovered air pollutants have detrimental impacts on human health. Black carbon has been shown to raise mortality from all causes, as well as from cardiovascular and cardiopulmonary diseases (Yadav et al. 2021).

1.9 Conclusion and Future Recommendations

Through a variety of known and unknown routes, humans and the ecosystem are exposed to a wide range of new pollutants. Our chapter explores that these pollutants consistently create new and pressing problems for the air, water, soil, and ecosystems—especially for human health. Furthermore, novel chemical outputs proliferate and typically surpass the capabilities of risk assessment techniques, safety remediation strategies, monitoring methodologies, and existing preventative measures. The developing pollutants are suspected to be carcinogenic, teratogenic, and mutagenic to humans and other animals, according to ongoing research and studies. On the one hand, there isn't enough substantial data to establish a link between newly discovered pollutants and harmful impacts on human health and environment. However, we cannot discount the negative consequences suggested by animal tests, even though the exposure levels in animal trials could not accurately reflect human exposure levels and long-term chronic exposure is rarely used in animal models. We still don't fully understand the long-term impacts of EPs, though. The limited and sparse nature of EPs' fate and detrimental effects on aquatic life and human health demands for more research and understanding.

Therefore, in order to facilitate integrated research to reduce pollution inputs while maximizing available resources, future research endeavors should focus on the pollutants that have the most effects on both human health and environment.

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