Chapter 9
Toxic Organic Micropollutants and Associated Health Impacts

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Abstract Toxic organic micropollutants (TOMPs) are produced during any incombustion process e.g., industrial plants and road transport. These chemicals are highly toxic and some of these are carcinogens. These include poly aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins (dioxins), polychlorinated dibenzofurans (furans), and polybrominated diphenyl ethers (PBDEs). PAHs are emitted from municipal incinerators, coal gasification plants, aluminum industries, and coal tar and asphalt production facilities. PCBs have been used as a coolant in electric transformers and capacitors. Other uses include as a plasticizer in plastics, paints, dyes, carbonless copy papers and during heat transfer. The main sources of dioxins and furans are incinerators, industrial processes, incomplete combustion, and volcanic eruption. PBDEs are flame retardants and have been used in plastics, electronic enclosures, cell phones, personal computers, textiles, foam-based packaging, adhesives, and paint products.

There is no threshold limit for these pollutants as these can cause health damages even in small quantities. PCBs have been declared as Group I carcinogens by the International Agency for Research on Cancer (IARC). PCBs are also linked with adverse effects on kidney, liver, endocrine, and neurological systems. PAHs are genotoxins with irreversible genetic damage to humans. Exposure to PAHs leads to risk of lung, bladder, and skin cancers. Dioxins and furans cause cancer, endocrine disruption, effects on reproductive systems, and impairment of immune system.

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PBDEs are associated with neurodevelopment, liver and thyroid dysfunction, and endocrine disruption.

Once released into the environment, these micropollutants undergo physical, chemical, and biological processes such as atmospheric transport, volatilization, deposition, partitioning, and bioaccumulation. There is a need to implement regulatory measures for safe handling, transport, and use of organic micropollutants and to reduce the health impacts through appropriate treatment.

9.1 Introduction

Advances in evolution occur day by day. Chemical constituents are used in modern culture to furnish the requirements of humans. Some of these substances are dangerous and are detectable in various matrices such as food, soil, water, and air. Over time, organic micropollutants (OMPs) have become significant sources of pollution and pose threats to ecosystems, human health, and safety. OMPs include various classes such as microplastics, endocrine-disrupting compounds (EDCs), polycyclic aromatic hydrocarbons (PAHs), pharmaceuticals, personal care products (PCPs), agricultural products, flame retardants, and industrial chemicals (La Farre et al. 2008).

Air contamination and its unfavorable consequences for humans have become issues of great concern. There are significant sources of air poisons—for example, inorganic gases, natural impurities, and particulate matter. Even nonindustrialized nations have recognized problems with air contamination caused by traffic, development outflows, inappropriate garbage disposal and reuse, and modern and horticultural manufacturing practices (Anh et al. 2019; Bi et al. 2002).

There is an established relationship between everyday clinical manifestations of severe respiratory illnesses and concentrations of common air toxins (for example, SO_2 and NO_2), such as those seen in the metropolitan spaces of Hanoi and Ho Chi Minh City (Bohlin et al. 2008; Birgul et al. 2017). Nonetheless, more hazardous concentrates, including exceptionally harmful steady natural contaminations (POPs), in air are moderately restricted in most part because of the absence of appropriate inspecting strategies and savvy evaluation apparatuses (Bi et al. 2002; Jaward et al. 2004).

Some legacy POPs (for example, dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyls (PCBs)) are highly concentrated in the atmosphere in Vietnam and several other Asian nations (Akutsu et al. 2001). Raised concentrations of PCBs and polybrominated diphenyl ethers (PBDEs) have been measured in the air and around the people using part of the waste as recycling material in some parts of the world especially in Southeast Asia (Alaee et al. 2001). Similarly, a study reporting OMP pollution in groundwater in China screened about 1300 micropollutants in 13 samples from rural areas, although the carcinogenic risk was low, as only two samples had high micropollutant concentrations (Li et al. 2016).

9.2 Types and Sources of Atmospheric Toxic Organic Micropollutants

Harmful natural micropollutants are formed during incomplete combustion cycles, operation of chemical plants, and operation of road transport vehicles. These synthetic compounds are exceptionally harmful, and some (such as PCBs, polychlorinated dibenzodioxins (PCDDs, or dioxins), PAHs, polychlorinated dibenzofurans (PCDFs, or furans), and PBDEs) are cancer-causing agents (Li et al. 2016).

PAHs are emitted from metropolitan incinerators, coal gasification plants, aluminum smelters, and coal tar and asphalt production facilities. In industry, PCBs have been utilized as coolants in electric transformers and capacitors. Their different utilizations include plasticizers in plastics, paints, dyes, carbonless copy paper, and heat transfer (Huang et al. 2006).

The main sources of dioxins and furans are incinerators, industrial processes, incomplete combustion, and volcanic eruptions. PBDEs are flame retardants and are used in plastics, electronic equipment, cell phones, personal computers, textiles, foam-based packaging, adhesives, and paint products (Gouin et al. 2005).

During thermal and combustion processes, dangerous OMPs (such as PAHs, PCBs, furans, and dioxins) are formed (Gevao et al. 2006). Because they are semivolatile, they occur in gaseous form or are associated with particulate matter in the atmosphere. When these compounds are released in atmosphere, they can be transferred or accumulated to the terrestrial as well as aquatic environment through deposition (wet and dry) (Chen et al. 2017b).

The zone of influence is a major issue associated with emission of the compounds mentioned above, and this determines whether such emissions have mainly local or regional impacts, or whether they influence global background pollution levels. The existence of these compounds (PCBs, PAHs, dioxins, and furans) was recently investigated in the Eordaia basin in northwest Greece, where intensive coal burning takes place for power generation (Chen et al. 2017b; Hien et al. 2007).

Toxic organic compounds were formed by the burning of materials such as quantities of transformer oil, mineral oil and plastic wires etc. in a closed room. Similarly, indoor concentrations of semivolatile organic compounds in gas phase, settled dust, and airborne particles has been detected (Blanchard et al. 2014; Schröder et al. 1997).

Plastics play significant roles in overall advancement of human well-being—for example, by enabling creation of disposable clinical equipment and expansion of food handling. However, plastic waste entering the environment may have the opposite impact—for example, by creating conditions conducive to disease transmission, encouraging breeding of mosquitoes, obstructing water drainage, and causing flooding. Lack of appropriate waste management is believed to have resulted in accumulation of over 250,000 tons of floating plastic pieces in the seas (Rappe et al. 1986).

It was estimated that coastal nations discarded 4.8–12.7 million metric tons of plastic into seas in 2010 (Eriksen et al. 2014). In the environment, plastic waste (which frequently originates as consumer goods waste that has been disposed of

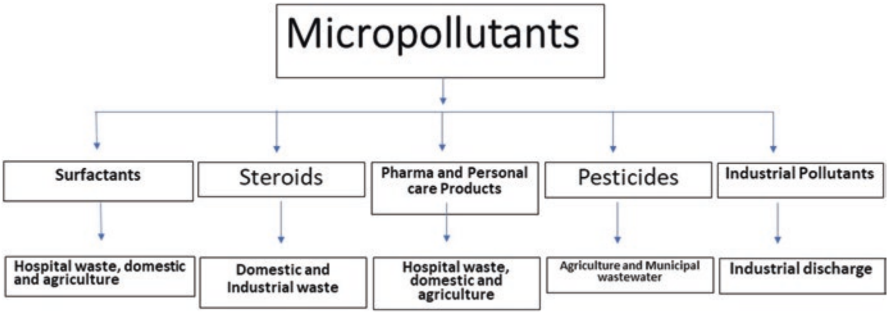

Fig. 9.1 Types of toxic organic micropollutants and their sources

inappropriately) undergoes slow degradation via photodegradation, thermo-oxidation, and (to a lesser degree) biodegradation, degrading the integrity of the materials and causing them to disintegrate into parts less than 5 mm in size, which are known as secondary micropollutants (Brown et al. 2001; Rappe et al. 1986). When plastic particles of small sizes are purposely created to be utilized in consumer goods (such as makeup, exfoliants, or toothpaste) or commercial applications (such as air blasting), they are called essential microplastics.

Microplastics are now found in seawater in concentrations of up to 102,000 particles per cubic meter and are additionally responsible for contaminating freshwater (Vickers 2017; Zagorski et al. 2003) and even staple commodities such as beer, sea salt, and tap water (Sakurai et al. 2000).

The pervasive presence of microplastics in the environment and in consumer goods prompts inevitable human exposure to these particles. The results of this exposure are not yet fully known. The current evidence regarding the impacts of environmental exposure to microplastics on human well-being has been explored to some extent, giving rise to theories regarding the mechanisms of exposure and the extent of microplastic toxicity, and providing a basis for additional research. However, the available data on the effects of microplastics on humans are limited because of ethical issues, the strict biosecurity measures required when performing research involving human subjects, and restrictions on the locations where such research can be conducted (Birnbaum and DeVito 1995).

Different types of toxic OMPs and their sources are shown in Fig. 9.1.

9.3 Health Effects of Toxic Organic Micropollutants

There is no known safe concentration of these toxins, as they can damage human health even in small quantities. PCBs are classified as group 1 carcinogens by the International Agency for Research on Cancer (IARC) and are associated with harmful effects on the kidneys, liver, endocrine system, and neurological system. PAHs are genotoxins and cause irreversible genetic damage in humans. Exposure to PAHs poses risks of lung, bladder, and skin cancers (Kouimtzis et al. 2002).

Dioxins and furans cause malignancies, endocrine dysfunction, effects on reproductive systems, and immune system impairment. PBDEs are associated with endocrine, neurodevelopmental, liver, and thyroid dysfunction (Lee et al. 1999).

After these micropollutants are delivered into the environment, they go through physical, chemical, and organic processes such as volatilization, atmospheric transport, distribution, and bioaccumulation. There is a need for appropriate measures to manage transport and utilization of natural micropollutants safely and to decrease their impacts on health through suitable treatment (Mandalakis et al. 2002). Different types of toxic OMPs, their transport media, and their associated health influences are listed in Table 9.1.

Table 9.1 Types of organic micropollutants, their transport media, and associated health impacts

Organic micropollutants	Transport media	Adverse health impacts	References
Microplastics	Water, soil, air	Disruption of photosynthesis in primary producers; reduced food intake and energy levels; disturbances producing inflammation and oxidative stress in higher vertebrates; cell damage and inflammatory and immune reactions	Revel et al. (2018) and Vethaak and Legler (2021)
Pharmaceuticals (β-blockers, anti-inflammatory drugs, antibiotics, neuroactive compounds)	Water, soil	Toxic effects on biota, harming aquatic and terrestrial environments	Larsson et al. (2007) and Manzetti and Ghisi (2014)
PCPs (e.g., antiseptics, fragrances)	Water, soil	Breast cancer; asthma; autism; reproductive problems; other health issues	Paulsen (2015)
EDCs	Water, soil, air	Endocrine disorders (e.g., adrenal disorders); neurodevelopmental dysfunction in children; endocrine-related cancers; bone and metabolic disorders; male and female reproductive disorders	Meek et al. (1994), International Agency for Research on Cancer %J Lyon (2010), Grob, (2015), and Chávez-Mejía et al. (2019)
PAHs	Water, soil, air	Effects on reproduction, development, and immunity in terrestrial invertebrates; carcinogenic effects (e.g., benzo[*a*]pyrene is a group 1 carcinogen); mutagenic effects, posing serious threats to human health; increased risks of lung cancer	humans (2010), Latimer and Zheng (2003), and Kim et al. (2013)

(continued)

Table 9.1 (continued)

Organic micropollutants	Transport media	Adverse health impacts	References
Agricultural waste (pesticides)	Water, soil, air	Harmful effects through antagonism or mimicking of natural hormones in the body, as well as hormone disruption; immune suppression; diminished intelligence; cancers; reproductive abnormalities in humans; adverse health effects of pyrethroid pesticides (e.g., immunotoxicity, teratogenicity, carcinogenesis, mutagenicity)	Aktar et al. (2009) and Zhou et al. (2019)
Flame retardants	Air, dermal contact, dust ingestion	Ripple effects on wildlife and the environment; minor respiratory irritation; BFRs affect the endocrine, neural, reproductive, immune, and cardiovascular systems	Feiteiro et al. (2021)
PCBs	Water, soil, air	Skin and eye irritation; decreased pulmonary function; decreased birth weight in offspring of occupationally exposed mothers; variable effects on cancer formation; altered reproductive and thyroid function in both males and females	Safe (1994), Ross (2004), and Carpenter (2006)
PCDDs, PCDFs	Air, soil, food	Adverse effects on the immune, nervous, and endocrine systems with long-term exposure; impaired reproductive function; high TCDD levels cause dermal problems with acne-like lesions (chloracne) on the face or upper body; reduced motility, abnormal morphology, and reduced capacity of sperm to penetrate oocytes, resulting from ingestion of PCDDs or PCDFs in food	Guo et al. (2000) and Zheng et al. (2008)

BFR brominated flame retardant, *EDC* endocrine-disrupting compound, *PAH* polyaromatic hydrocarbon, *PCB* polychlorinated biphenyl, *PCDD* polychlorinated dibenzodioxin, *PCDF* polychlorinated dibenzofuran, *PCP* personal care product, *TCDD* 2,3,7,8-tetrachlorodibenzodioxin

9.4 Toxic Organic Micropollutant Exposure

Micropollutants are far-reaching foreign substances. Exposure of the human body to micropollutants occurs through ingestion of food containing toxic substances, inhalation of micropollutants in the surrounding air, and also skin contact with particles contained in items, materials, or dust (Nakao et al. 2002). Possible effects of exposure to toxic OMPs on human health are shown in Fig. 9.2.

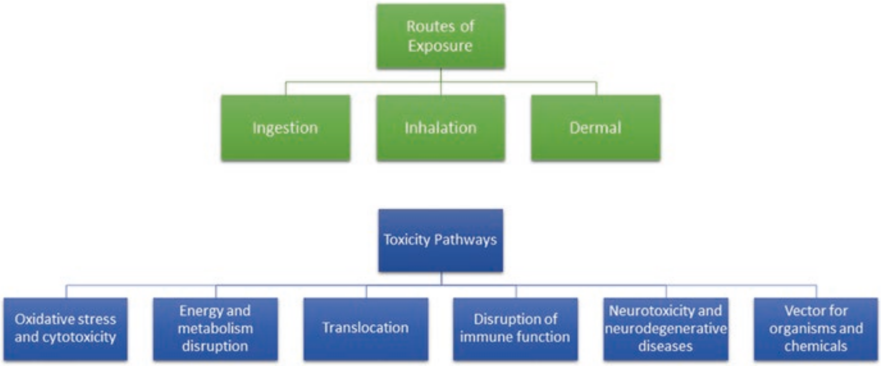

Fig. 9.2 Routes and effects of exposure to toxic organic micropollutants on human health. (Revel et al. 2018)

9.4.1 Inhalation Exposure

Micropollutants are delivered into the air by various sources, including manufactured materials, scraping of materials (for example, vehicle tires and structures), and resuspension of micropollutants from surfaces. One study of atmospheric micropollutants measured outdoor concentrations of 0.3–1.5 particles per cubic meter and indoor concentrations of 0.4–56.5 particles per cubic meter (33% from polymers), including particles of inhalable sizes. It has been estimated that, on average, an individual person inhales 26–130 airborne micropollutant particles per day (Dayan and Koch 2002).

According to an atmospheric examination utilizing a life-sized model, it is common for a male individual performing light movements to inhale 272 micropollutants during each day. Various assessments have focused on the influences of variations in aspects such as space use factors, cleaning processes, furniture materials, exercise, and seasons. The properties of molecules, such as their size and thickness, influence their effects on the respiratory system; smaller and thinner particles are breathed into deeper parts of the lungs than larger or thicker particles (Carroll 2001).

There is evidence that macrophage activation or movement of particles into the circulation or the lymphatic system may lead to transport of microparticles within the body. The huge surface areas of tiny particles in the respiratory system may elicit major chemotactic responses, inhibiting macrophage movement and increasing the ability of particles to penetrate different tissues and cause persistent irritation, known as residue overburden (Wobst et al. 1999).

In one study, the presence of polystyrene nanospheres (64 nm in size) prompted neutrophil convergence and aggravation in the lungs of rodents. Moreover, proinflammatory responses were observed in epithelial cells as a result of greater oxidant activity brought about by the huge surface area of the nanospheres (Brown et al.

2001). In an in vitro study, polyvinyl chloride (PVC) particles (2 μm in size) created by emulsion polymerization caused hemolysis and critical cytotoxicity in rodent and human airway cells (Su and Christensen 1997).

Respiratory symptoms that have previously been linked to increases in aviation and interstitial lung disease have also been associated with exposure to airborne micropollutants in factory workers, workers managing livestock, and workers in PVC production facilities, with the same effects being replicated (Barboza et al. 2018; Agarwal et al. 1978).

Filaments 205 nm in size have additionally been identified in human lung biopsies and associated with malignant growths, although causation has not yet been demonstrated. All things considered, under conditions of high fixation or individual susceptibility, airborne micropollutants can injure the respiratory system (Donaldson et al. 2000).

9.4.2 Dermal Exposure

Dermal contact with micropollutants is considered a less critical means of exposure, although it has been postulated that nanoparticles (<100 nm in size) could cross the dermal barrier (Barboza et al. 2018).

This route is regularly associated with exposure to monomers and plastic substances such as bisphenol A, phthalates, and EDCs via daily utilization of common equipment. The likelihood that nanoparticles do cross the dermal barrier and cause harm should not be discounted without confirmation. The presence of plastics in medications can cause minor inflammatory responses, as well as less common reactions such as fibrosis. However, in one study, sutures utilizing interlaced polyester and monofilament polypropylene were found to cause more minor reactions and fibrosis than silk after 21 days (Vickers 2017; Eriksen et al. 2013). In a study using mice, different types of plastic plates 10 mm in size were implanted subcutaneously and then removed after 98 days. Polyethylene plates were found to cause the least aggravation, but PVC plates stabilized with organo-tin or plasticizers caused toxic effects, with moderate degeneration and rot, perhaps due to leachate toxicity (Canesi et al. 2015). Although microparticles and nanoparticles may cause aggravation and unusual bodily reactions, differences in surface properties could elicit particular results. Human epithelial cells have been shown to exhibit harmful effects with exposure to micromaterials and nanomaterials (Frias et al. 2010).

Accordingly, the known adverse effects of nanoparticles and inevitable dermal exposure to plastic particles (for example, from engineered strands, dust, and microbeads in cosmetic products) support the requirement for further research in this area.

9.4.3 Oral Exposure

Ingestion is viewed as one of the most significant routes of human exposure to micropollutants. In view of the widespread utilization of these substances (for example, in food packaging), it has been estimated that each person ingests 39,000–52,000 micropollutant particles per year (Cole et al. 2013).

Particles may enter the gastrointestinal system through mucociliary clearance after inhalation, and they may cause major inflammation, increased tissue penetrability, and changes in gut microorganism populations and digestion (Karami et al. 2017). The presence of micropollutants has been documented in food items such as mussels, fish, table salt, sugar, and filtered water. In Europeans, exposure to micropollutants via bivalve consumption has been estimated to be 11,000 particles per year (Saravia et al. 2014). Moreover, it has been estimated that each year, Europeans ingest 37–100 micropollutant particles per capita through consumption of table salt.

However, some researchers have suggested that settling of micropollutant residue on dinner plates may be a more significant source of micropollutant consumption than the presence of these pollutants in the food itself (Furukuma and Fujii 2016). Incidence of dementia are higher while living near highways as compared to Parkinson's disease and multiple sclerosis (Chen et al. 2017a).

Particles of insoluble substances may infiltrate digestive fluid through an increase in their dissolvability via adsorption of a "crown" of intestinal substance or because of their small sizes, so it was observed that particles present in rodent intestinal segments are of polystyrene latex with a size range of 14 nm to 415 nm (Sternschuss et al. 2012).

Another possible means of infiltration of these particles is persorption, with paracellular movement of particles through a single layer of intestinal epithelium. Micropollutants would be exposed to these equivalent systems according to their toxic nature especially in circulatory system. This has been demonstrated in vivo after oral administration. For example, in a study of rodents, 6% of polystyrene particles (0.87 mm in size) entered the circulation within 15 min of oral administration. In another study, oral administration of 1.25 mg kg of polystyrene particles 50 nm in size resulted in 34% absorption, perhaps via transport through the mesentery lymph system into the circulatory system prior to accumulation in the liver (MohanKumar et al. 2008).

Polystyrene nanospheres were delivered by human colon fibroblasts across the cell layer. After disguising by human gastric adenocarcinoma cells, these polystyrene particles influence the quality of articulation, hinder cell viability and initiate provocative reactions (Li et al. 2016).

Humans are exposed to micropollutants through inhalation and ingestion because our environment is now significantly contaminated with micropollutants. However, the dangers associated with bodily contamination by micropollutants are not yet adequately understood, because of a lack of research assessing general human exposure and its consequences (Saravia et al. 2014).

9.5 Conclusion

Polyaromatic hydrocarbons, polychlorinated dibenzodioxins, polychlorinated biphenyls, polychlorinated dibenzofurans, and polybrominated diphenyl ethers are highly toxic substances emitted from incinerators, coal gasification plants, the aluminum industry, and coal tar and asphalt production facilities. There is an urgent need to reduce the presence of these toxic pollutants in the atmosphere and in the environment. The following are important recommendations to help achieve this goal:

1. Open burning of garbage should be limited (especially in periurban areas), and emissions from chimneys and brick kilns should be permitted only under strictly controlled conditions.
2. Use of older vehicles should be banned, especially those that have been running for more than 20 years and those with outdated engine, because road traffic emits toxic lead and other pollutants, which can impact not only human health but also the health of plants and trees growing along roadsides.
3. Industries should be required to limit their waste, and there should be appropriate mechanisms for waste management, especially in the steel and plastic industries.
4. Policies regarding emissions should be enforced strictly, and action should be taken against anyone violating these policies or polluting the environment.
5. Activities should be undertaken to increase awareness of environmental pollution and discourage it at all levels.

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