Environ Sci Pollut Res (2017) 24:4223–4227
DOI 10.1007/s11356-015-5225-9

EDITORIAL

Persistent organic pollutants (POPs): a global issue, a global challenge

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Received: 18 March 2015 / Accepted: 11 August 2015 / Published online: 15 September 2015

Since the Second World War, scientists have identified certain chemical contaminants that exhibit toxic characteristics and are persistent in the environment, bioaccumulative, prone to long-range atmospheric transboundary migration and deposition, and expected to impose serious health effects on humans, wildlife, and marine biota adjacent to and distant from their origin of emission. These chemical pollutants are referred to as persistent organic pollutants (POPs) (Ashraf et al. 2015).

POPs have long half-lives in soils, sediments, air and biota. No consensus exists on how long the half-life in a given medium should be for the word "persistent" to be applicable; nevertheless, the half-life of a POP might be years or decades in soil/sediment and a number of days in the atmosphere. Several thousand POP chemicals are known. Many of them are members of a definite series or "families" of chemicals. For instance, 209 diverse groups of polychlorinated biphenyls have been identified; they differ from each other by the level of chlorination and the substitution position (Jones and Voogt 1999). The carbon-chlorine bond is very stable toward hydrolysis and larger numbers of chlorine substitution and/or functional groups lead to greater resistance to biological and photolytic degradation. Because POPs break down very slowly, they will be present in the environment for a long time, even if all new sources are immediately eliminated (Chu et al. 2006).

POPs in the environment are transported at low concentrations by movement of fresh and marine waters; in addition, because they are semi-volatile, POPs are transported over long distances in the atmosphere. The result is widespread distribution of POPs across the globe, including regions where they have never been used (Buccini et al. 2003). The POP levels observed in the Arctic region are surprising to many people because some of these pollutants have been banned from the USA and Canada for many years. POPs travel toward colder areas such as Alaska and then sink because of the colder temperatures. The settled contaminants remain in the area for a long period because the temperature does not allow them to easily breakdown. Consequently, they move from the air and water to soil and plants and then to animals and humans with ease. The persistence of contaminants in the Arctic from distant sources first came to light in the late 1970s when pesticides were found in polar bear fat tissue. The reality of atmospheric POPs and their effects on wildlife and human health then became evident. In addition to the Arctic, researchers have begun to search for evidence of airborne POPs in other cold ecosystems and mountain environments (Zhao et al. 2007).

POPs are usually hydrophobic (i.e., "water-hating") and lipophilic (i.e., "fat-loving") chemicals. In marine and terrestrial systems, they bind strongly to solids, particularly organic matter, evading the aqueous segment. They also enter the lipids of organisms more easily than the inside of the aqueous medium of cells and are stockpiled in fatty tissue. This stockpiling in fatty tissue allows the compounds to persevere in biota, where the metabolism rate is low. Consequently, POPs may climb the food chain. POPs tend to move in the gas phase under environmental

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temperatures. Therefore, they may volatilize from soils, vegetation, and aquatic systems into the air and, because of their resistance to breakdown reactions in air, migrate long distances before being re-deposited. The sequence of volatilization and condensation can be repeated frequently; as a consequence, POPs are detected in regions far removed from where they were used or discharged. POPs can partition between particles and aerosols in the air and are reliant on ambient temperature and the physico-chemical characteristics of the substances. In summary, the combination of permanency and the tendency to form a gas under suitable environmental conditions causes POPs to migrate long-range atmospheric distances. The combined effects of confrontation, metabolism, and lipophilicity result in the accumulation of POPs in food chains (Jones and Voogt 1999).

Types and classification of POPs

At the UNEP Stockholm Convention 2001 (UNEP 2001), legislatures from 92 republics approved the Stockholm Convention on POPs to decrease and/or eradicate the discharge of 12 unique POP substances; these substances are referred to as the “dirty dozen” or “legacy POPs.” Although additional pollutants have been identified, the key concern is these unique 12. The group includes 10 intentionally produced pollutants: aldrin, endrin, chlordane, DDT, dieldrin, heptachlor, mirex, toxaphene, hexachlorobenzene (HCB), and polychlorinated biphenyls (PCBs) and two unintentionally generated contaminants, polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) (Ashraf et al. 2013). Polycyclic aromatic hydrocarbons (PAHs) are categorized as persistent organic pollutants as well, and combustion and burning of organic contaminants produces these substances unintentionally. Their existence is associated with man-made activities, and pollution of PAHs in river sediment is common in high-density industrial zones. Figure 1 represents the chemical structures of the most common persistent pollutants. POPs can be classified as intentionally and unintentionally produced POPs, as shown in Fig. 2.

Sources and emission

Fire is the foremost source of POPs, including natural, unintentional, and planned burning of flora (Wong and Poon

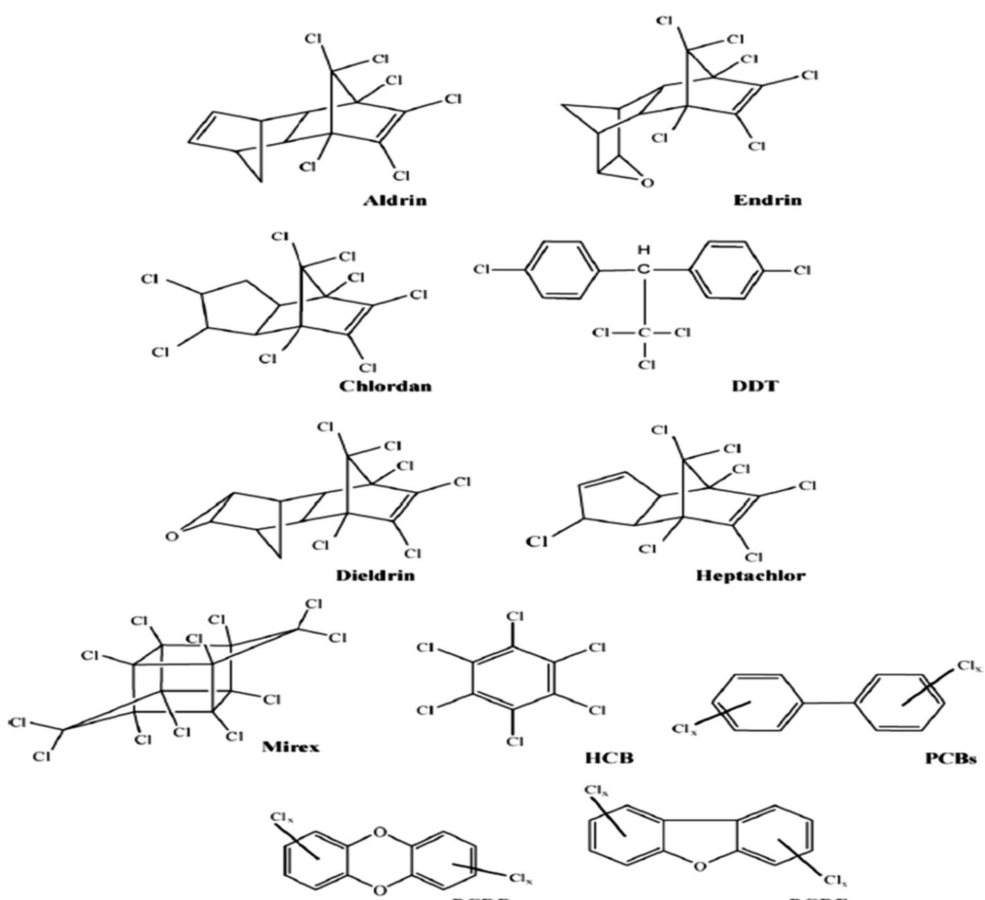

Fig. 1 The chemical structures of commonly used persistent organic pollutants

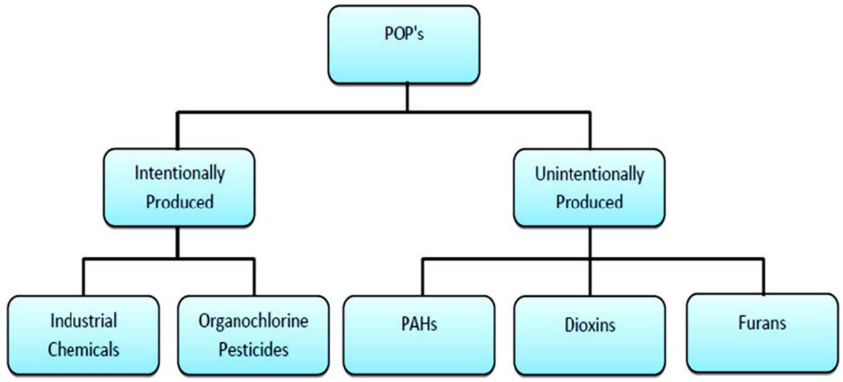

Fig. 2 Grouping of persistent organic pollutants

2003). POPs are recalcitrant in all components of the environment. They pass into the air from various industrial sources (e.g., incinerating plants, power stations, and heating stations), household furnaces, volatilization from water surfaces and soil, landfill transport, and consumption of agricultural sprays. Additional sources of POP contaminants include unpremeditated generation resulting from chemical amenities, incineration, assorted combustion processes such as forest fires, and decomposition of wastes containing PCBs. This group of wastes can result in several zones and halting from diverse activities, such as the consumption of obsolescent oil, the fixing and repair of tools, the destruction of buildings, cement manufacturing, evaporation, the burning of animal remains, coal ignition, lixiviation of dumps and reprocessing actions, municipal incineration, therapeutic waste, organochlorine pesticide plants, industrial chlor-alkali plants, aluminum secondary plants, furnace and foundry coke production plants, sewage sludge, hazardous waste/plastic waste in landfills, organochlorine pesticide stowage, and fly ash stowage (Thornton et al. 2002).

Elements, liquid fuels, oils, soil, fats, sediment, and ash in the aquatic environment originate from wastewaters from manufacturing plants or POP consumption, in consort with overflows from roads and fields and from atmospheric deposition. Seas and oceans are prevalent reservoirs where POPs collect from river sediments, by atmospheric deposition, and unintentionally. They are deposited in sediments on the beds of oceans, seas, and large lakes, where they can be discharged after a time and then withdraw into the air, as shown in Fig. 3 (Galiulin and Galiulina 1997).

Dosage and toxicity of POPs

POPs cause concern because of their potential toxicity and predominance in environmental media, even at distant topographical localities. The adverse effects of POPs on the ecosystem have triggered considerable worry in recent years, which has resulted in the monitoring and sanctioning of the consumption of these toxic compounds in several states. A large variety of organic compounds contaminate water bodies, which is a foremost concern that has thus far been focused on PCBs and organochlorine pesticides (OCPs). The continuous increase of these organic

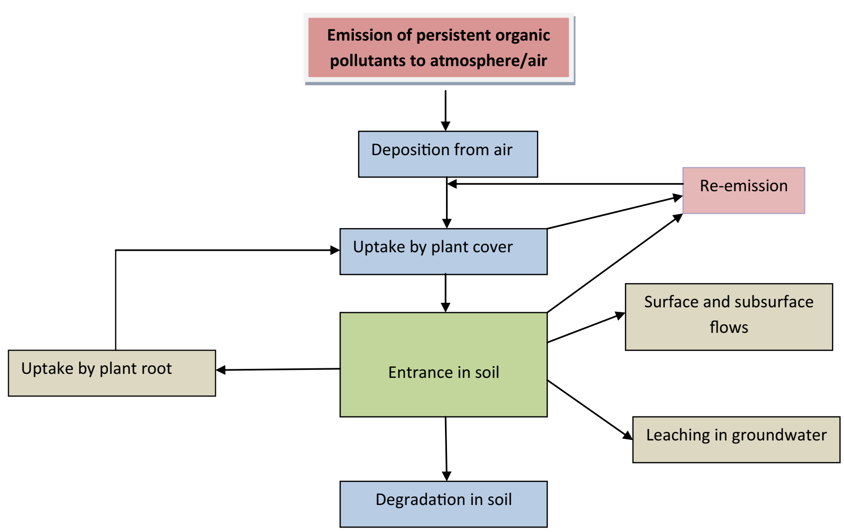

Fig. 3 Conceptual model for the behavior of persistent organic pollutants in the air–plant–soil system

contaminants in the aquatic environment is largely attributable to their high persistence and resistance to natural biodegradation.

Public concern about the toxicity by POPs has been amplified recently because a number of these chemicals are recognized as hormone disrupters, which can cause malfunctioning of the endocrine and reproductive systems in animals and humans. These chemicals impose serious health effects on our ecosystem, and none of them has any beneficial effects. After these contaminants have been introduced into the ecosystem, they continue to exist in the environment for several years, causing complications such as learning disabilities, birth defects, cancer, and behavioral, neurological, reproductive, and immunological disorders in wildlife species and humans (Sweetman et al. 2005).

Recently, certain POPs have also been implicated in immunodeficiency in infants and children and in the intensification of infection, in combination with growth deformities, neurobehavioral deficiency, and cancer and tumor generation or elevation. Several authors have reported that POPs are substantial risk factors in the etiology of human breast cancer (Roots et al. 2005). Because children are still developing, they are substantially more susceptible than adults to the effects of pollutants. Their developing cells are sensitive to contaminants and are more likely to be affected by exposure to POPs. The brain is the greatest concern because studies have shown that children exposed to POPs during infancy scored remarkably lower on assessments used to determine intelligence and the ability to shut out distractions.

POPs can have serious side effects, including birth defects, certain cancers and tumors at multiple sites, immune-system disorders, reproductive problems, reduced ability to fight diseases, stunted growth, and permanent impairment of brain function. POPs are suspected carcinogens and have been implicated in diseases such as endometriosis (a painful, chronic gynecological disorder that affects uterine tissues), increased incidence of diabetes, and neurobehavioral impairment, including learning disorders, reduced performance on standard tests, and changes in temperament (Boilt and Degen 2002). Numerous methods have been published over the past 30 years related to specific analytical techniques for the determination of PCBs and OCPs in food and environmental matrices.

Management and remediation

POPs are highly recalcitrant compounds and impose several carcinogenic and mutagenic effects on human health and the environmental ecosystem. Therefore, the existence of POPs in our environment is a global challenge and a global issue. Further studies must be conducted to elucidate and quantify the subtle effects of POPs on animal, plant, and human health. In recent times, several remedial techniques for POPs have emerged, such as thermal, chemical, and biological techniques and their combinations, such as green nanotechnology and magnetic-biochar. However, many cost effective, less time consuming, and environmentally friendly techniques are in experimental or pilot stages (Yusoff et al. 2013). In general, the research in this field concerning POPs is not plentiful, and further studies should be conducted to increase the knowledge in this field. Additionally, the health impacts and environmental issues of these techniques need to be addressed before their extensive implementation.

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