Chapter

Role and Effect of Persistent Organic Pollutants to Our Environment and Wildlife

Nisha Gaur, Dhiraj Dutta, Aman Jaiswal, Rama Dubey and Dev Vrat Kamboj

Abstract

Persistent organic pollutants (POPs) are toxic substances composed of carbon-based chemical compounds and mixtures. In the recent times, persistent organic pollutants (POPs) came as a threat for the wildlife and environmental world. POPs are chemically stable, remain intact in the environment for long periods, are recalcitrant in nature, and are lipophilic in nature. Therefore, they accumulate in fatty tissue of living organisms and reside longer period of time finally affecting the human and wildlife. It is believed that approximately 90% of human beings are exposed to POPs from their diets that contain animal products. These foods lead to bioaccumulation in fat tissues that then cause health hazard. There are many studies such that its behavior in photocatalytic oxidation reactions are available; also many research studies are going to combat from these toxic substances. In this chapter, we will take you through how persistent organic pollutants are affecting our environment and wildlife and what are its roles.

Keywords: persistent organic pollutants, food chain, grasshopper, health, environment, Stockholm convention, global warming, marine

1. Introduction

As the name implies, persistent organic pollutants (POPs) are extremely persistent in the atmosphere, with a half-life of over a decade in the soil, sediments, air, and biota [1]. The importance of research into persistent organic pollutants is illustrated by the Stockholm Convention, adopted in 2001 by conference of Plenipotentiaries and came into force on May 17, 2004. POPs have now become the focus of different growing national and international concern as they show toxic effects on animal reproduction, development, and immunological function. Some national agencies are still not taking it seriously and call it differently as "Bio accumulative chemicals of concern" (BCCs) [2]. Only those compounds that get the extreme end of the distribution in degree of persistence, mobility, and toxicity will be ranked as POPs.

Chlorinated substances stay in the environment for a long time. With the introduction of electron capture detectors, several organochlorine pesticides such as dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethane (DDE), dieldrin, and toxaphene began to be detected [3]. These have been reported at such places where never been used before such as the earth's pole.

S. No.	Class	POPs
1	Subject to elimination of production and use (A)	Aldrin, hexachlorobenzene, Decabromodiphenyl ether, Endrin, Hexachlorobenzene, Beta hexachlorocyclohexane, Polychlorinated naphthalene's, Technical, endosulfan and its related isomers, Chlordane, Dicofol, Heptachlor, Hexabromocyclododecane, Hexachlorobutadiene, Lindane, Pentachlorophenol and its salts and esters, Perfluoroctanoic acid and its salts and PFOA related compounds, Tetrabromodiphenyl ether and pentabromodiphenyl ether, Chlordecone, Dieldrin, Hexabromodiphenyl ether, Alpha hexachlorocyclohexane, Mirex, Polychloriented biphenyls, Short-chain chlorinated paraffins, Toxaphene pentachlorobenzene, hexabromobiphenyl.
2	Restricted in production and use (B)	DDT, PFOS and PFOSF.
3	Unintentionally produced (C)	Pentachlorobenzene, hexachlorobenzene, Hexachlorobutadiene, PCDDs, polychlorinated Polychlorinated naphthalenes PCDFs, PCBs.
4	Chemicals under investigation	Dechlorane Plus, Methoxychlor, UV-328.

Table 1.
POPs recognized in Stockholm convention [4].

These bio-accumulate in the food chain (animals and humans), causing a slew of well-known health and environmental problems. These pollutants are causing great concern among scientists, governments, and nongovernmental organizations (NGOs). There are different types of POPs such as heptachlor, chlordane, aldrin, dieldrin, hexachlorobenzene, endrin, mirex, chlordecone, toxaphene, lindane, hexa- and penta-bromodiphenyl ethers (commercial octabromodiphenyl ether), tetra- and penta-bromodiphenyl ethers (commercial pentabromodiphenyl ether), hexabromobiphenyl, pentachlorobenzene, polychlorinated biphenyls (PCBs), α- and β-hexachlorocyclohexane, α- and β-endosulfans (technical endosulfan and its isomers), perfluorooctane sulfonic acid and its salts (PFOS), perfluorooctane sulfonyl fluoride (PFOSF), DDT, pentachlorobenzene, hexachlorobenzene, polychlorinated dibenzofurans (PCDFs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated biphenyls (PCBs), hexachlorobutadiene, chlorinated naphthalenes, pentachlorophenol hexabromocyclododecane (HBCD), short-chained chlorinated paraffins were recognized by United Nations Environment Program (UNEP), Montreal, International POPs Elimination Network (IPEN), and Stockholm Convention. These pollutants are classified into four categories based on their toxicity and are shown in **Table 1** [4].

2. POPs: a general aspect

It is important to discuss the aspects of POPs before coming to the effects of these to understand the notorious effects of POPs.

Persistent chemicals generally have higher concentrations because they usually present in the environment for longer time and get their steady state. If emissions decline to near-zero after a particular duration of use, the amount of chemical in the environment will decrease exponentially. The overall transformation rate constant in the environment determines the rate of elimination, and persistent substances are removed more slowly [1].

The impact of POPs can be well understood by its deposition process. This innovative method combines aerosol remote sensing data with POP aerosol phase observations. By this process, POPs impact remote oceanic areas, raising environmental concerns because of their toxicity and accumulation in aquatic food webs. Because POPs are semi-volatile chemicals that can exist in both the gas and aerosol phases, precipitation scavenging will deposit POPs in both dissolved and particulate forms [5]. Persistent organic pollutants separate into gas and aerosol phases once they are released and are subject to long-range atmospheric transport (LRAT). In the transport and fate of POPS at the regional and global scale, atmospheric depositional processes play a key role. Then, by adopting any of the three primary processes such as (1) dry deposition of particulate-bound pollutants, (2) diffusive gas exchange between the atmospheric boundary layer (ABL), and (3) the surface ocean and rain scavenging (either from gas or particulate phases), transport of semi-volatile organic compounds from the atmosphere to the ocean takes place [6]. Additionally, this can be concluded that the dry aerosol and gaseous deposition contribute to aquatic ecosystems pollutant burden and finally support POP accumulation in marine food web.

Climate change has already sparked a slew of environmental issues, and there is a direct link between pollutant emissions, dispersion, and toxicity and climate change. Both the IPCC report and the annual report of the United Nations Environment Program (UNEP) stressed the importance of paying attention to the problem of environmental pollution, particularly in light of global warming [7]. The series of POPs has already been discussed above, and the transport processes for persistent organic pollutants can be seen in **Figure 1**. POPs are transported globally in two ways: atmospheric circulation and ocean currents. POPs can exist in both gaseous and particle forms in the atmosphere. As a result, POPs in the atmosphere can be distributed globally via gaseous and particulate thanks to atmospheric circulation. POPs are more likely to be deposited on the land surface when the temperature drops while they will evaporate back into the atmosphere and migrate again, when the temperature rises.

POPs are transported globally in two ways: atmospheric circulation and ocean currents. POPs can exist in both gaseous and particle forms in the atmosphere. Hence, gaseous and particulate POPs in atmosphere can be globally spread with the help of atmospheric circulation.

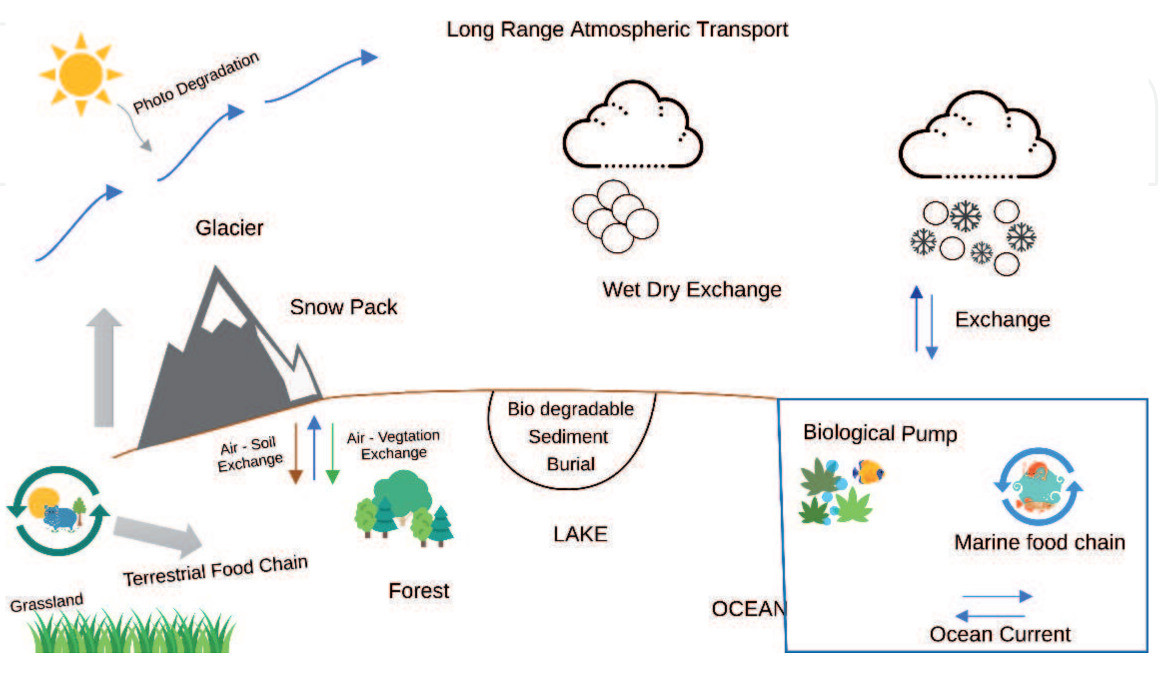

Figure 1.
Fate of persistent organic pollutants in the environment.

This cycle repeats itself, allowing POPs to be transported and deposited in far-flung locations. The grasshopper effect is what it is called. Furthermore, some POPs with a significantly higher solubility, such as hexachlorocyclohexanes (HCH) and perfluoro octane sulfonates (PFOS), can penetrate surface waters, feed into ocean currents, and travel around the world. Changes in climatic parameters such as temperature, wind speed, wind direction, and precipitation occur as a result of climate change. The intensity and pathways of POPs transported by air and ocean will undoubtedly change as these conditions change [8].

3. United Nations Stockholm convention

The text of the Stockholm Convention was adopted by the Conference of the Plenipotentiaries on May 22, 2001 and came into effect on May 17, 2004. In May 1995, the UNEP Governing Council recognized that persistent organic pollutants (POPs) pose serious and escalating dangers to human health and the environment and recommended that an international assessment process of an initial list of 12 POPs be performed in its resolution 18/32. The Intergovernmental Forum on Chemical Safety (IFCS) develops international action recommendations that must be considered by the UNEP Governing Council and the World Health Assembly by 1997. The Stockholm Convention's 12 initial POPs were divided into three categories.

- Pesticides: aldrin, dieldrin, endrin, heptachlor, chlordane, DDT, hexachlorobenzene, mirex, toxaphene;

- Industrial chemicals: hexachlorobenzene, polychlorinated biphenyls (PCBs); and

- By-products: hexachlorobenzene; polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/PCDF), and PCBs.

- POPs are organic chemical compounds, that is, carbon-based, according to the Stockholm Convention. They have a unique set of physical and chemical qualities that, once released into the environment, allow them to:

- last an incredibly long time without deterioration

- As a result of natural processes including soil, water, and most significantly, air, they have become widely disseminated across the ecosystem;

- are lethal to both humans and wildlife and;

- accumulate in the fatty tissue of living organisms, including humans, and are present at higher levels in the food chain at larger quantities.

Another mechanism known as bioaccumulation concentrates POPs in living creatures [9]. The term "bioaccumulation" has two meanings: a) to define a dynamic process in which an element or compound is passively or actively taken up and concentrated within an organism; b) to indicate a currently high concentration as a result of prior accumulation activities [10].

4. Role and effect of persistent organic pollutants

Many developed countries have taken initiatives in recent years to restrict and limit the flow of PCBs into the atmosphere. The most important element in establishing these limits was a 1973 suggestion from the Organization for Economic Co-operation and Development (OECD) (WHO, 1976; IARC, 1978; OECD, 1982). Since then, the 24 OECD member countries have set manufacture, sales, importation, exportation, and use limitations, as well as a labeling system. POPs have severe effect on wildlife as well as on environment and hence to humans also. Reproductive impairment and malformations, increased risk of tumors, altered liver enzyme function are some of the many bad effects of POPs.

In **Figure 2**, it can be seen that POPs have an anthropogenic origin and are discharged into the air, water, and land, where they deposit in water and eventually enter the food chain through sediment. These are disseminated over the world by air and ocean currents and hence, travel a long distance. They subsequently penetrate atmospheric processes, air-water exchange, and cycles such as rain, snow, and dry particles, exposing even the most remote groups of humans and animals who rely on aquatic food.

4.1 Effect of POPs on environment

As of now, we know that POPs are a global hazard since POPs discharged into the environment can travel a considerable distance through the air and water via evaporation and redeposition from their initial source. The most important factor in the transportation of global POPs is the atmosphere. Because of the semi-volatile nature of the atmosphere, these chemicals are found in atmospheric gases. Once these POPs get encountered into the gases, they go under some other processes such that degradation, soil deposition, vegetation, bioaccumulation, sedimentation, and many more (**Figure 3**). Because these POPs are temperature-dependent, the Global Distillation Effect theory predicts that gas-phase contaminants will be transported from warm regions of the planet, such as tropical or temperate source areas, to colder, higher-latitude regions, affecting vapor pressure and Henry's constant,

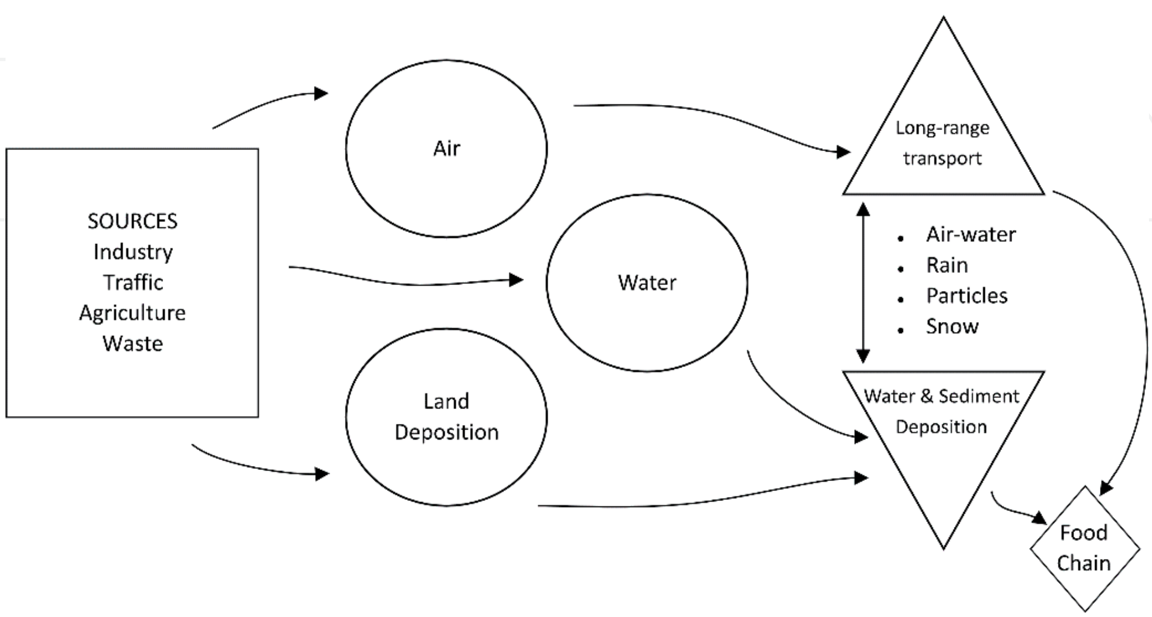

Figure 2.
POPs in the environment.

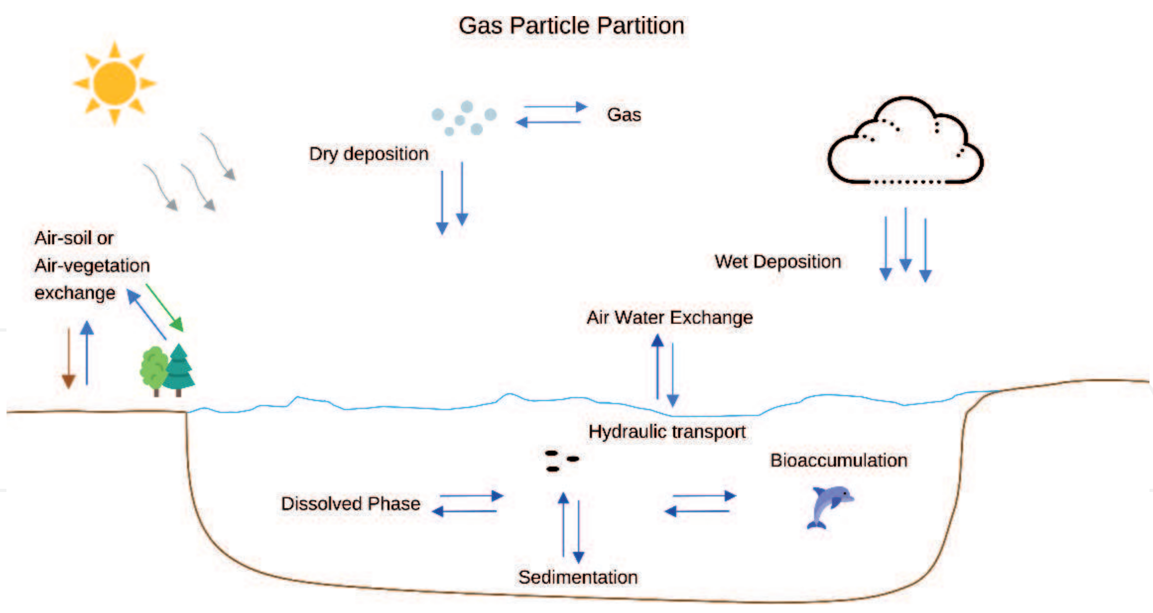

Figure 3.
Environmental progressions during long-range atmospheric transport of POPs.

resulting in condensation and accumulation of POPs in soil, vegetation, and other places, from where they can enter into the food chains [11].

Because reactivity, adsorption, and accumulation are all temperature-dependent activities, they can be influenced by climate change at any point along the transport and redistribution paths. Climate-change-related activities are predicted to modify POP exposure patterns for native and resident human populations in the long run. The majority of POPs have been produced and released in enormous quantities in the Northern Hemisphere, primarily by agriculture and industry. The emission pattern for most legacy POPs began around 1940–1950, according to published data on POPs. Following a significant increase in emissions, some countries banned or restricted the use of these compounds or found techniques to eliminate them as by-products, resulting in a period of reduction (about 1970). Variations in climate and ambient temperature have a direct impact on a number of deciding environmental elements as summarized in **Table 2** [12].

Several persistent organic pollutants (POPs), such as polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs), have been widely utilized in Asian developing countries for industry, agriculture, and vector control throughout the last few decades. Pesticide usage in India is at 85,000 metric tons per year, with DDTs, HCHs, and malathion accounting for 70% of that [13]. Due to a lack of efficient facilities in Asian developing countries, substantial amounts of municipal trash from populous regions are directly thrown into open dumping sites with poor management. The public is concerned about the potential negative consequences for local communities and the environment as a result of this behavior. When recent rigorous research revealed increased human health risk from exposure to harmful substances such as dioxins and similar compounds, as well as heavy metals in these dumping sites, these worries became more serious [14].

Since these POPs are highly volatile and resistant to photolytic, biological, and chemical degradation, they were found at high concentrations around the globe, including open oceans, deserts, the Arctic, and the Antarctic. Many studies have looked at the spread of PCBs around the world. POP levels were found to be extremely high. Many studies have looked at the spread of PCBs around the world. Few studies have discovered high levels of some organochlorines in ocean, rainfall, and wild animals. The concentration of HCB in Antarctic fish was found to be comparable to that of North Sea fish in a study [15].

Parameters	Effects and indicators to be considered
Transport and distribution	Changing matrix composition Rapid/slow distribution Change of ocean currents, pH change, rising sea levels
Bioavailability	Changing bioavailability, new exposure routs invading species Changing regional food webs
Source and emissions	Increased emissions from secondary sources Emerging new primary sources
Environmental stability (persistence)	Changing thermal stability Changing radiation regime Changing adsorption properties Changing albedo
Toxicity/ecotoxicity	Changing toxicity potential Effects on immune response Exposure routs and profiles are changing Hormone and endocrine effects
Transformation and degradation	Changing degradation/transformation properties Changing microbiology

Table 2.
Influences of climate change on environmental processes related to transport and distribution of POPs [12].

4.2 Effect of POPs on wildlife

As we previously discussed, POPs are organic molecules with high lipid solubility, allowing them to stay in the environment for long periods of time, be transported substantial distances from their source, and bio-accumulate in food chains. They are deemed to have a danger of generating negative effects on human and wildlife health because of these traits.

Multiple exposure routes can expose wildlife species living in contaminated areas to complex combinations of pollutants. Wild species can be utilized as biomonitors of environmental pollution in a place since they have varied ecological, etiological, and physiological properties. Hazardous material exposure at various organizational levels also threatens the long-term viability of wildlife populations. As a result, pollution is currently considered one of the most serious threats to biological diversity. Exposure and effect biomarkers can be examined and integrated simultaneously to provide more information about probable toxicity pathways and ecosystem component health [16].

Marine wildlife numbers, particularly megafauna species, have dropped dramatically in recent decades, according to several research studies. For example, census studies in Eastern Australian seas show that loggerhead turtle numbers have plummeted by up to 86% during the 1970s. Similarly, in the last 90 years, the global population of dugongs appears to have fallen by at least 20%. (approximately three dugong generations). These and many more marine wildlife species have been added to the Red List of Threatened Species as a result of their critical population status, which spans from endangered to vulnerable to extinct, and are high conservation priorities [17].

Disease has been highlighted as a major contributor to the loss of marine wildlife populations, among the many concerns. Chronic sickness, which can lead to mortality, has been found to be on the rise in marine wildlife populations, reaching panzootic levels in some cases [18]. POPs are distributed in the marine environment as a result of subsequent transport mechanisms and source discharges. An increasing corpus of research examines the relationship between tissue loads of dominating POP groups and functional outcomes that have been degraded (**Table 3**).

Species	Target POPs	Functional parameters	Type of correlation	Reference
Gray seal	PBDEs	Circulating thyroid hormone	+	[19]
	PCBs, DDTs	TT3, FT3	—	[20]
California sea lion	PCBs	Serum vitamin A and T3	—	[21]
Beluga whale	PCBs	AhR and cyp1A1 expression	+	[22]
Bottlenose dolphin	PCBs	TT4, FT4, T3	—	[23]
	PCBs	Lymphocyte proliferation	—	[23]
	OH-PCBs	cyp1A1 expression	+	[24]
Common dolphin (male)	PCBs, DDTs	Blubber retinoids	+	[25]
Common dolphin (female)	PCBs, DDTs	Blubber retinoids	—	[25]
Polar bear	PCBs	Plasma cortisol	+	[26]
	OCPs	Plasma cortisol	—	[26]
Green sea turtle	p,p′-	Hematocrit	+	[27]
	DDE	Total blood proteins	—	[27]
	γ-HCH			

AhR: aryl hydrocarbon receptor; p,p′-DDE: 4,4′-dichlorodiphenyldichloroethylene; DDTs: dichlorodiphenyltrichloroethane; HCHs: hexachlorocyclohexanes- hexanes; OCPs: organochlorine pesticides; PCBs: polychlorinated biphenyls; PBDEs: polybrominated diphenyl ethers. TT3: total triiodothyrine; FT3: free triiodothyrine; TT4: total thyroxine; FT4: free thyroxine; T3: triiodothyrine; cyp1A1: cytochrome P450A1.

Table 3.
Summary of correlative studies associating functional health parameters with body burdens of persistent organic pollutants in marine wildlife.

Hydrophobic (water-hating) and lipophilic (fat-loving) compounds are the most common types of POPs. They bond firmly to solids, particularly organic matter, in both marine and terrestrial environments, avoiding the aqueous section. They also enter lipids more easily than the aqueous system inside cells and accumulate in fatty tissue. Chemicals are stored in fatty tissue, allowing them to remain in biota where metabolism is slow. As a result, POPs may move up the food chain. Under ambient temperatures, POPs tend to shift into the gas phase. As a result, they may volatilize from soils, plants, and aquatic systems into the air and migrate vast distances before being re-deposited due to their resistance to breakdown reactions in air [28].

POP loads can be passed from the mother to the child not only during placental development, but also through breast feeding in placental viviparous species, which are the only placental mammals. The importance of maternal transfer in terms of early exposure should not be ignored; various studies have shown that juvenile placental mammals acquire higher amounts of PCDD/Fs or PCBs via milk than they do from prenatal exposure during placental development. According to the studies, the offspring of pregnant rats administered six PCDD/Fs, including 2,3,7,8,-TCDD/F and the non-ortho PCBs 77, 126, and 169, got 7–28% of their doses lactationally and just 0.5–3% through the placenta. Fasting mothers can increase their children's dietary exposure to POPs from milk. Although the trend in female polar bear body burdens was not consistent—DDT and HCH decreased during fasting, while chlordane and PCBs increased—the ratio of plasma/adipose tissue and milk/adipose tissue OC concentrations did not change during the fast, indicating that POPs were probably at steady state among the various tagging systems [29].

All birds, most reptiles, most amphibians, and the rare monotreme mammals, for example, will deliver POPs to their eggs via maternal transfer. The direct transfer of the contaminant burden from the female to the eggs via the reallocation of the female's lipid storage is the principal source of POP exposure to the growing embryo. Both biological processes and chemical features of the pollutants induce the deposition of lipids and proteins (together with the POPs associated with the lipids and proteins) in the developing egg. The energy required for egg production can come from the female's older body reserves, her energy consumption during the egg formation period, or a combination of both [29].

4.3 Effect of POPs on human health

Among the many POPs that are abundant in our surroundings, a "black list" of POPs has been recognized under the diplomatic signature of the Stockholm Convention in 2001. Pesticides, such as aldrin, DDT, dieldrin, endrin, heptachlor, chlordane, mirex, and toxaphene; industrial compounds, such as hexachlorobenzene and polychlorinated biphenyls (PCBs); and other chemical by-products, such as polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs)—the general name "dioxins" is used for PCDDs and PCDFs. These POPs are known to be especially hazardous, having a high proclivity for biomagnification in the food chain, and have been linked to carcinogenic and endocrine disrupting effects in a variety of biota [9].

POP residues have been found in human adipose tissue from people living in a variety of countries, including Europe, Asia, Africa, and North America, for many years. Pesticide toxicity and persistence are beneficial for killing their target organisms, but they can cause difficulties for humans and the environment. Organochlorine pesticides (OCPs) have been found in the environment and, as a result, in the food chains of humans and wildlife since the early 1960s. Dichlorodiphenyltrichloroethane (DDT) and its derivatives have already been discovered in almost all environmental media and are the most common OCPs detected in human tissues, particularly adipose tissue. DDT is an organochlorine chemical initially synthesized in 1874 in Germany. The insecticidal effects of DDT were discovered in 1939, and commercial use began in 1945. DDT is dechlorinated in the human body to tetrachlorodiphenylethane (DDD), which is water-soluble and less hazardous to humans. Dichlorodiphenyldichloroethanes (DDEs) are another class of DDT derivatives that quickly accumulate in human adipose tissue and constitute a considerable health risk due to their long half-life. DDE can be acquired through DDT metabolism in the body or from intake of DDE-tainted foodstuffs [30].

While human data analysis has raised concerns, it has yet to produce conclusive evidence of causal relationships between low-level exposure to environmental chemicals, endocrine disrupting activities, and harmful human health impacts. All relevant data, including experimental animal data and wildlife observations, must be examined. The difficulties of correlating prenatal, postnatal, and childhood exposure to adult functioning are particularly concerning [31].

Reduced semen quality (i.e., reduced numbers, motility, and altered morphology of sperm), male reproductive tract abnormalities (e.g., hypospadias and cryptorchidism), altered sex ratio, endometriosis, precocious puberty, and early menarche) have been the focus of much of the human health concerns resulting from EDC exposure. A reduction in sperm counts has been recorded in a number of research studies in a lot of countries [32].

Increased rates of some hormone-related malignancies in many regions of the world are frequently cited as proof that EDC exposure has had negative health consequences. Increases in breast cancer and testicular cancer are particularly concerning. Several human epidemiological studies and experimental laboratory investigations have been undertaken to see if organochlorine pesticides are linked to an increased risk of breast cancer [31].

Organometals that bind to protein, particularly organomercurials; lipophilic contaminants such as dioxins, PCBs, polybrominated diphenyl ethers (PBDEs), and chlorinated pesticides; and persistent non-lipophilic compounds such as per fluorinated compounds used as repellents are all sources of concern for human health. Toxicity does not necessitate the persistence of a chemical. Many volatile organic chemicals, phthalates, and bisphenol A, which are present and leach from typical industrial products, are also found throughout the food supply and in the bodies of many of the world's populations. It has recently been discovered that exposure to certain chlorinated POPs increases the likelihood of developing type 2 diabetes, an insulin-related disease [33]. Surprisingly, this increased risk appears to occur at extremely low concentrations and does not appear to follow a linear dose–response curve [34]. DDE and hexachlorobenzene appear to have the strongest links, although PCBs also greatly enhance the risk [35]. Because type 2 diabetes is an insulin receptor disease, the processes underlying this link are unknown; however, it is most likely the result of gene induction. Obesity is frequently cited as a major risk factor for diabetes. Obese people who do not have high levels of POPs, on the other hand, do not have an increased risk of diabetes, according to certain research [33].

5. Conclusion

By now it is very much clear that how severe the POPs can be in future for the upcoming generations. It is not affecting only environment but also through environment to wildlife animals and directly or indirectly to human. Because of rising industrial use, persistent organic pollutants are becoming a major concern, causing their accumulation and persistence in living beings and the environment. Its exposure has numerous deadly implications for organs and tissues, including oxidative stress and cell death, due to several mechanisms. Several international plans have been developed to reduce the use of POPs and eliminate them completely; however, many developing countries around the world continue to ignore the Aarhus and Stockholm conventions. All of the class 1 and 2 POPs listed by these conventions must be banned. There are many agencies and NGOs working to accomplish their goals, but as humans, we must also recognize how damaging a single error can be. When scientific information is unknown, decision-making on the possible detrimental effects of chemical exposure is increasingly regulated by the precautionary principle, both internationally and nationally. The impact of endocrine disruptors on negative health consequences has yet to be proven conclusively. However, it is evident that the risk of endocrine disruptors is significant at specific times (preconception, pregnancy, and postpartum), and further research and development are needed to determine the health problems that should always be prioritized.

Conflict of interest

The authors declare no conflict of interest.

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