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SUSPECTED TOXICOLOGICAL EFFECTS OF PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS) ON THE ENVIRONMENT AND HUMAN HEALTH

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Abstract: *PFAS stands for per- and polyfluoroalkyl substances, which are a group of chemicals that are commonly used in industrial and commercial production. These chemicals have been found to have significant toxicological effects on both humans and wildlife, meaning they can cause harm to living organisms. The toxicity of PFAS mixtures, which are the combinations of different PFAS chemicals that can be found in the environment, is not yet fully understood. In recent decades, there has been an increasing amount of information discovered about chemical organic pollution, which includes thousands of human-made substances that are widely used in various aspects of daily life and are emitted from many industrial processes. The purpose of the article is to review the toxicity of PFAS chemicals, their behavior and existence in the environment, their tendency to accumulate in living organisms, and the potential negative health effects they can have on the biota, which refers to all living organisms in a particular area or ecosystem.*
Keywords: *per- and polyfluoroalkyl substances (PFAS), perfluoroalkyl acids (PFAA), environmental pollution, human health.*

1. INTRODUCTION

Per- and polyfluoroalkyl substances (PFAS) are organic fluorinated chemicals, highly persistent, synthetic contaminants with tremendous health impacts on human populations such as obesity, various cancers, elevated cholesterol levels, liver damage, decreased immune and liver functionalities, and significant birth defects (Jha et al. 2021; Dickman & Aga 2022). PFASs can be referred also as PFCs (per- and polyfluorinated chemicals, or perfluorocarbons, more than 5000 substances (USEPA 2021), perfluoroalkyl acids (PFAA), perfluoroalkyl carboxylic acids (PFCA), and perfluoroalkane sulfonic acids (PFSA). Limited toxicological data are available for most PFAS yet (McCarthy et al. 2021). PFAAs exert human toxicity, high persistence, and environmental mobility, widespread presence in food of plant and animal origin, and poor removability from contaminated matrices (Sznajder-Katarzyńska 2019; Langenbach & Wilson 2021; Lyu et al. 2022; Harvard News 2023).
The purpose of the article is to review the toxicity of per- and polyfluoroalkyl substances, environmental behavior, bioaccumulation, and health effects.

2. METHODS

The review is made by searching open data sources of Google, Google Scholar, PubMed, Taylor & Francis, and others. The searches were conducted using the title of the article, titles of main sectors included in the paper, and different keywords. The articles were chosen by interest and data of publication, usually looking for the last years of publication. The keywords used in the search were numerous: “PFAS toxicity”, “PFAS in soil”, etc.

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3. RESULTS

3.1. PFAS into the environment

The majority PFASs emissions are released into the aquatic environment mainly from point sources such as manufacturing plants and firefighting activities using PFAS-containing foams (Koch et al. 2019). PFAS are released to air from a variety of sources, travel significant distances in air, depending on the physico-chemical properties, registered in Arctic, which demonstrates their long-range atmospheric transport (USEPA 2021).
Surface deposition of atmospheric emissions is followed by leaching to groundwater (de Silva et al., 2021; Jha et al. 2021). PFAS are identified in all parts of biosphere, on surface of the water and groundwater, in the rain, snow, and drinking water (Houtz et al. 2013; Hu et al. 2016; Guardian et al. 2020; Sun et al. 2016; Gobelius et al. 2019; Abunada et al. 2020; Barzen-Hanson et al. 2017; Kaserzon et al. 2019; Abunada et al. 2020; Xu et al. 2021), manufactured goods like cosmetics (Vestergren et al. 2013; Mousavi et al. 2021), food packaging (Trier et al. 2011; Zabaleta et al. 2016), agricultural foodstuffs (Vestergren et al. 2013; Blaine et al. 2013; 2014; Genualdi et al. 2017).
Once into the environment, terrestrial or aquatic, PFAS persist for long periods due to their resistance, the fate of the PFAS in different environmental conditions provides information for the mechanisms of degradation (fig.1; Dickman & Aga 2022).

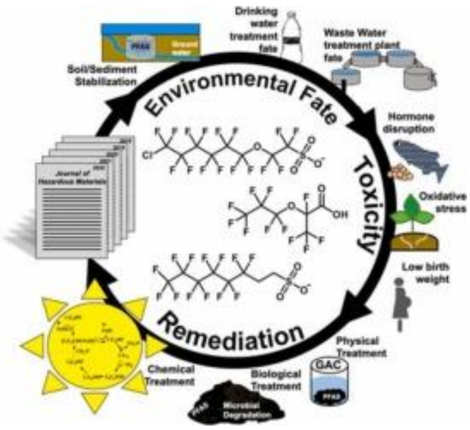

Figure 1. Fate, effects, and treatment of per- and polyfluoroalkyl substances (PFAS). Source: Dickman & Aga 2022. Open access, used with permission

PFAS consequences depend on carbon chain lengths, head groups, ether bonds, ionic state, and environmental pH, chain fluorination degree, which determines sorption and bioaccumulation, volatilization, and the potential for transformation (Dickman & Aga 2022). PFAS easily undergo bioaccumulation due to their long persistence times (Kurwadkar et al. 2022), and provoke negative health effects on humans and wildlife (Dickman & Aga 2022). Long chain PFAS are more bioaccumulative (Koch et al. 2019).
PFAS are ubiquitous and have negative health effects, leading to monitoring in drinking water, food products, and the environment, with regulatory focus on drinking water and food products, but they exist everywhere in soils, water, plants, livestock, and dairy products, and human exposure comes from various sources (fig.2; Danish Environmental Protection Agency Report, 2015; Ojo et al., 2021; Fenton et al., 2021; Jha et al. 2021; Yadav et al. 2022).

Figure 2. Sources of per-and poly-fluoroalkyl substances (PFAS; Yadav et al. 2022). Source: Yadav et al. 2022. Used with permission

3.2. PFAS toxicity

PFAS are present in a variety of mixtures in the environment, and their interactions with other chemicals can affect their toxicity. The most widely studied PFAS are PFOA and PFOS, which have been found to have toxic effects on humans and wildlife (Kang 2019; Dickman & Aga 2022). PFOA and PFOS are persistent in the environment, meaning that they do not break down easily and can accumulate in the food chain (Koch et al. 2019; Kurwadkar et al. 2022). Studies have shown that exposure to PFOA and PFOS can lead to a range of health effects, including developmental and reproductive problems, immune system dysfunction, and cancer (ATSDR 2021; Jha et al. 2021). Despite the widespread use and potential health effects of PFAS, there is still much to learn about their toxicity and how they interact with other chemicals in the environment (Lerch et al. 2023).

The concentration of pollutants, such as PFAAs, in fish is a result of two processes: uptake from the aqueous phase and intake of contaminated food (aquatic organisms). Uptake from the aqueous phase refers to the process by which fish absorb pollutants directly from the water they swim in. This can occur through their gills or skin. Intake of contaminated food refers to the process by which fish consume other organisms that have already accumulated pollutants in their tissues. This can include smaller fish, crustaceans, and other aquatic organisms. The combination of these two processes can result in high concentrations of pollutants in fish, which can then be passed up the food chain to fish-eating birds or mammals (Navarro et al. 2020). It is important to consider the entire food chain when assessing the ecological risk of pollutants in aquatic ecosystems, as pollutants can accumulate and magnify as they move up the chain. The effects of two types of per- and polyfluoroalkyl substances (PFAS), namely PFOA and PFOS, were investigated on a type of fish called Medaka (*Oryzias latipes*). The study found that PFOA and PFOS induced different effects on the fish. PFAS affect the endocrine system of fish, which can have implications for their reproductive health and the health of the ecosystems they inhabit (Kang 2019).

3.3. Human health effects of PFAS

Humans can be exposed to PFAS from air, water, food of food contact materials (FCMs). Inhalation of PFAS can occur when PFAS-containing products are used indoors or when dust containing PFAS settles on surfaces (De la Torre et al. 2019; Zhang et al. 2020). Direct contact with PFAS-containing products are also sources of toxicity, when products such as non-stick cookware or waterproof clothing are used (Trudel et al. 2008), or cosmetics (Mousavi et al.

2021). Ingestion of contaminated water occur when PFAS leach into groundwater or surface water from sources such as firefighting foam or landfills (Domingo & Nadal 2019). PFAS can migrate from food contact materials into food, contributing to human dietary exposure and risk assessment procedures should consider this pathway (Sunderland 2018; Susmann et al. 2019).
Exposure to PFAS can lead to various health problems including birth defects, developmental delays, elevated cholesterol levels, increased risk of heart disease and stroke, various cancers, decreased immune and liver functionalities (fig.3; ATSDR 2021; Beans 2021; Dickman & Aga 2022).

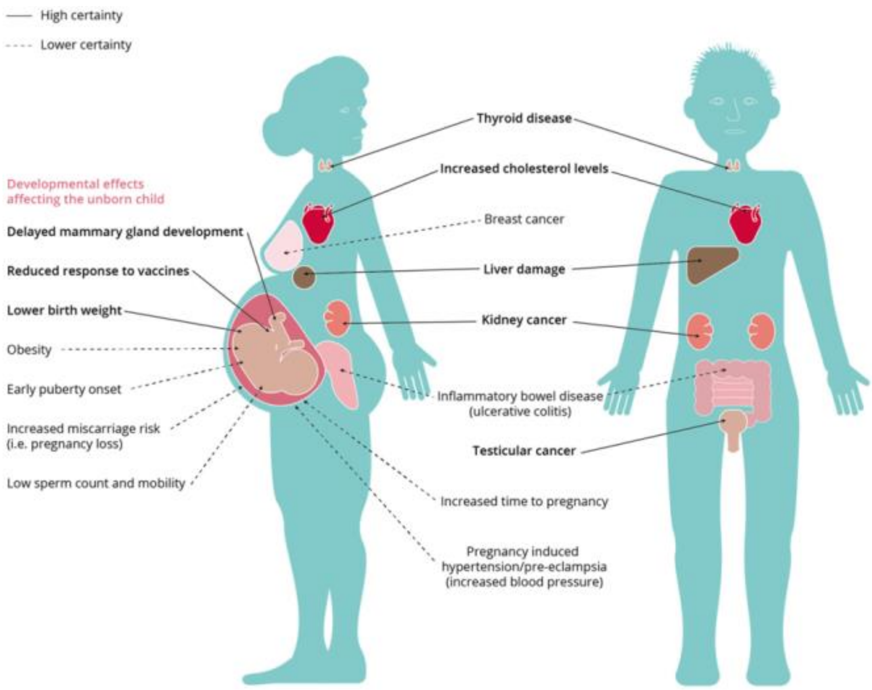

Figure 3. Effects of per- and polyfluoroalkyl substances on human health.
Used with permission from the European Environment Agency (2019)

PFAS exposure increased osteoporosis risk, kidney dysfunction, hormonal disregulation and metabolism, most frequently thyroid hormones (Jha et al. 2021). PFAS route exposure in humans is intake with food and water consumption (Sznajder-Katarzyńska et al. 2019). An FDA Total Diet Survey (TDS) confirmed that at least one type of PFAS was detected in 17 TDS samples, 14 of the samples were seafood, representing 44% (14 of 32) of TDS seafood samples. In a targeted survey of seafood in 2022, PFASs were found in 74% (60 of 81) of samples of shellfish, cod, crab, pollock, salmon, shrimp, tilapia and tuna. Data on PFAS in seafood is still limited, but testing suggests that it is likely at higher risk of environmental contamination with PFAS than other types of food (FDA 2023).
PFAS from food contact materials can contribute to dietary exposure and impact human health, but unlike other persistent organic pollutants, they do not bioaccumulate in adipose tissue and primarily distribute to the liver, blood serum, and kidney (Bischel et al. 2011; Lau 2012, 2015; Kato et al. 2015; Lerch et al. 2023). PFAS are present in 99% of the human population and have been linked to adverse health effects, prompting a national health study by ATSDR (CDC 2022; Langenbach & Wilson 2021; ATSDR 2020).

4. CONCLUSION

Overall, the accumulation of PFAS in the human body can have serious health consequences, and it is important to limit exposure to these chemicals as much as possible. This can be done by avoiding products that contain PFAS, such as non-stick cookware and stain-resistant fabrics, and by using alternative products that are safer for human health and the environment.

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