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Review Article

PER AND POLYFLUOROALKYL SUBSTANCES (PFAS) IN THE ENVIRONMENT: A REVIEW

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ABSTRACT

Per and Polyfluoroalkyl substances (PFAS), a group of more than 7,800 synthetic heterogeneous organic compounds with different physicochemical properties, are chemically and thermally stable. Since 1945, these compounds have been used for innovative developments in the field of material sciences to provide numerous benefits to society. These compounds have oil and water-resistant properties and are used as refrigerants and fire suppressors, in the textile industry, paint industry, electronic industry, cookware industry etc.

This review documents the concentration of the most commonly used Per and Polyfluoroalkyl substances in the aquatic environment, milk samples, soil, plants, vegetables, fruits, fish and their impact on humans

Due to overuse and misuse of these compounds in different industries, these persistent pollutants are present in all the compartments of the environment, i.e. air, surface water, groundwater, river water, marine water, drinking water, soil, animal and breast milk, food chain, vegetables, fruits, and fish. In the 21st Century, these chemicals, along with antibiotics, are considered the most harmful persistent organic pollutants. The wastewater generated by households, industries, and armed force areas is a hotspot of the residual PFAS. Human health is adversely affected by consuming PFAS-contaminated plant produce and animal food and by drinking PFAS-contaminated water. On accumulation in humans, it affects the immune system, alters the lipid metabolism, endocrine activity, thyroid gland and mammary gland functioning.

Keywords: Per and Polyfluoroalkyl substances, Human, Environment, Milk, Vegetables, Fruits, Fish, Soil.

1. INTRODUCTION

Per- and polyfluoroalkyl substances (PFAS) are synthetic man-made organic compounds, that were accidently first formed in the DuPont company labin 1938. Since 1945, Dupont has been using this compound (Teflon) for coating cookware to make it non-stick cookware. These chemicals have numerous applications [1-4] used in adhesives, fire fighting foams, cosmetics, electronic items, stain and water repellent agents in the textile industry, resulting in the commercial use of these chemicals from the 1950s. Due to the synthesis of PFAS, innovative development in material chemistry for societal benefits became possible. Since then, these organic compounds have been prominent players in the betterment of human life and society. As per the US Environmental Protection Agency report [5], approximately 7,800 PFSA structures have been synthesized, having different physical and chemical properties. The useful major applications of PFAS for modern society are given in Table 1.

Due to the presence of many C-F bonds, which is the strongest covalent bond in per and Polyfluoroalkyl substances (PFAS), the PFAS becomes thermally stable, chemically inert, and possesses hydrophobic and oleophobic properties [6]. Due to their chemical stability, they persist in the environment for a longer period of time and have high mobility [7]. These compounds are found even in remote areas like the Arctic and Antarctic [8, 9] and are also called “forever chemicals.” When these compounds are uptaken by biota via the food chain are very easily bioaccumulated and biomagnified [10, 11]. The residues of per and polyfluoroalkyl substances and their metabolites are reported in all the compartments of the environment, viz., air, groundwater, surface water, marine water, drinking water, soil, food chain, fruits, vegetables, cereals, grains, animal feeds, carpets and upholstery; cosmetics and personal care products, food wrappers and carry-out containers. Several research studies [12-15] have found the residues of PFAS in human blood, urine, breast milk, tissues, organs and in aquatic flora and fauna. According to the finding of food scientists [16,17], the presence of PFAs in the environment adversely affects the terrestrial ecosystem.

The soil is an integral part of the environment, and the ecosystem is the natural source for plant growth and food production. As the protein part of the soil organic matter acts as a sorbent for PFAS [18], the soil acts as a sink/reservoir for per and polyfluoroalkyl substances [19]. In low and middle-income countries due to water scarcity, untreated wastewater is used by farmers for agricultural usage, which cause the accumulation of these pollutants in soils. Accumulation of these undesirable organic chemicals in soils beyond their normal concentrations not only deteriorate the soil quality but also has impact on human health, food quality, and social development [20, 21], as water-soluble PFAS pollutants are transported to surface water and/or leach to groundwater resulting accumulation in plants (via roots) and animals [22].

This work aims to provide the most up-to-date review of the PFAS applications to humans, including the amount of these persistent pollutants in various environmental compartments and their impact on humans.

Table 1: Applications of Per and Polyfluoroalkyl substances (PFAS) in different industries/for humankind

Industry	Application of PFAS
Aerospace	Corrosion protection of Phosphate ester-based brake and hydraulic fluids by altering the electrical potential at the metal surface. Used as Lubricant and elastomeric seals in Turbine-engine, Jet engine/satellite instruments. Protects wire and cables from high-temperature endurance and makes them high–stress crack resistant. Used in the propellant system as fuels and oxidizers and as aerosol propellant. PFAS are coated to protect from atomic oxygen effects.
Air-Conditioning/ Refrigerators	The Working fluid of the air conditioners and compressors contains PFAS.
Ammunition	PFAs makes them shockproof to prevent unplanned explosions and enable the ammunition for long-term storage without decay.
Automotive Industry	PFAS are used in weather resistance paint; improve the resistance of the polish to water and oil, prevent icing on the windshield in the cold countries, as sealants and bearings, engine coolants. Used in cylinder head coatings and hoses to reduce gasoline vapour emission resulting in enhanced fuel efficiency, cable and wires, andbrake pad additives.
Biotechnology	PFAS helps in cell cultivation by the enhanced supply of oxygen and other gases to microbial cells and PFAS microporous membranes prevent bacterial growth.
Building and Construction	Used in roofs of houses and Greenhouses- for protection from weathering; acts as dirt repellant and used for light. As cement additive to retard cement shrinkage. Protects wire and cables, gasket and hoses from high-temperature endurance and makes them high-stress crack resistant
Chemical Industry	Used in the production of chlorine and NaOH; in the processing of Tantalum, molybdenum, and niobium; acts as an aid in the processing of high- and linear low-density polyethene film and Fluoropolymer. These compounds act as a medium for crosslinking of resins, elastomers and adhesives and provide inert media for gaseous reactants.
Cleaning	As PFAS provides stain resistance and repels soil is used as a dry-cleaning liquid for cleaning the carpet and upholstery,is also used as a cleaning fluid for adhesives.
Effluent water treatment	Filter membranes used in the treatment plants are composed of polymeric PFAS.
Electronic Industry	PFAS acts as an inert fluid and is used for the testing electronic devices and equipment. Used for cooling of electronic and electrical equipment. These compounds dissolve the unwanted compounds deposited during the manufacturing of hard disk drives, helping in -Etching of

	piezoelectric ceramic filters. Electroluminescent lamps have the coating of PFAS. The PFAS compounds are coated on LCDs to make them moisture resistant and provide liquid crystals with polarity. The electronic razors contain polymeric PFAS. Printed circuit boards are made up of fibre-reinforced fluoropolymer. These compounds show Piezoelectric and pyroelectric properties
Electroplating	PFAS compounds helps in increasing the strength of nickel plates, preventing haze from a copper plate, in tin plating helps in uniform thickness coating. On steel, fluoropolymer particles are deposited.
Energy Sector	As PFAS are not easily vapourised, have high weather ability and dirt repellant is used in solar collectors and photovoltaic cells and wind mill blades. In the power plants of Coal-based, the fly ash from the hot smoky discharge is removed with the help of the filters prepared from these compounds and also helps in the separation of the carbon dioxide in flue gases. In the lithium batteries, these compounds act as a binder of electrodes, reduce high temperature, help in the oxygen transport of lithium-air batteries, and act as a solvent for lithium-sulphur batteries. In the polymer electrolyte fuel cells and vanadium redox batteries, the PFAS polymers act as a membrane.
Fire-fighting foam and flame retardants	Aqueous film forming foam of the PFAS class is used for firefighting and fire retardants
Food Production	To resist degradation wines and dairy products before bottling are filtered through polymeric PFAS membrane
Laboratory equipment and instrumentation	Vials, globes, caps, tape used in the laboratory, seals membranes in autoclaves, ovens, oils and grease in pumps, membranes used for filtration and solvent in LC columns contain fluorinated compounds. These compounds are also used for the estimation of phosphoamino content in proteins.
Medical field	These compounds have applications in defibrillators, pacemakers, cardiac resynchronization therapy (CRT), positron-emission tomography (PET) and magnetic resonance imaging (MRI), Video endoscope devices. These compounds are also used in X-ray films; surgical drapes and gowns; X-ray imaging; MRI imaging; Proton and 19F NMR imaging. The PFAS also have applications in retinal detachment surgery and in the manufacturing of contact lenses, eye drops. Filters, tubing, O-rings, seals and gaskets, membranes used in dialysis machines; Catheters, stents, and needles are composed of the Polymers of the fluorinated compounds. The polymeric PFAS have application in the anaesthesia as is used to dry or humidify breath. These chemicals are also used in the artificial heart pump and for wound care.
Nuclear Sector	Used as lubricants for valves and ultracentrifuge bearings in Uranium nuclear plants.
Oil and Gas Sector	PFAS are used as drilling fluid, insulating material for drilling cable and wires helps in removing heavy crude oil well polymer blockers, and helps in gas production by removing reservoir capillary forces. PFAS helps in evaporation loss of oils and safe transport. Polymeric PFAS membranes are used for oil and fuel filtration.
Metal Products	PFAs coating prevents steel corrosion, and enhances the life of the alkali bath. PFAS helps in the pickling of steel wires. Prevent cracks in the metal coating during drying.
Ore Industry	PFAS forms stable foams which help in the separation of metals from soil; improve the separation of Uranium and Vanadium from ores.
Paints	PFAS contaminated paints are antistick, durable, anti-corrosive, oil and water repellants used as all-weather coating paints on the exterior, interior walls and on ships.
Personal Care Products	PFAS are used for creams as they can penetrate the skin easily, absorbs more oxygen and skin looks brighter. Makeup by PFAS contaminated creams became more durable and weather resistant. These compounds are also used in hair conditioners.
Plastic and Rubber Industry	PFAS not only separates mould and moulded material but also retards imperfection on the moulded surface. These chemicals improve the quality of the polymer and enhance the efficiency

	of the process. PFAS acts as an anti-blocking agent in rubber production. Fluoroelastomers are used as an additive in curatives. These compounds help in the bonding of rubber to steel. Coating of PFAS on rubber and plastic makes them anantistatic agent.
Pharmaceutical Industry	Reaction vessels, stirrers, and other components used in the pharmaceutical industry are composed of PFAS polymers instead of steel, polymeric PFASs are used as a filter for the ultrapure water system and as a moisture barrier film for packaging. PFAS also helps in the manufacturing of microporous particles.
Photographic Industry	PFASs act as an antifoaming agent and prevents air bubble formation in the photographic processing solution. These compounds act as wetting agents, stabilizers, antistatic agents, emulsion additives for photographic films and papers also control uniformity at edges in multilayer coatings. These compounds also act as anti-reflective agents. Removes cured epoxy resins from integrated circuit modules, and checks the formation of the dielectric film. Provides bonding ply for the multilayer circuit board.
Sports Material	The PFAS compounds are applied in Tennis rackets; bicycles (Lubricant); boat equipment; fishing lines; climbing ropes; golf gloves.
Textile Industry	PFAS chemicals are used for dyeing and bleaching of textiles, textile treatment baths and in the finishing process of the fibre.
Tracing and Tagging	PFAs compounds are used for tracing gas and petroleum reservoirs, pollutants in the air, leaks in pipelines, and underground storage tanks.
Wood Industry	PFAS are used for the clear coating on wood, and adhesive resins used in the wood industry also contain these chemical compounds.
Other applications	Used for the preservation of the historical manuscripts, to make utensils non-sticking, to make water repellant fibres and breathable membranes, glass industry; thread and joints as household application; in the leather industry; in paper and cardboard industry; pesticide industry; printing ink; as a sealant and adhesive,

2. CLASSIFICATION OF PER AND POLY-FLUOROALKYL SUBSTANCES (PFAS)

The number of PFAS compounds ranges from 5600 to 7800 with different physical and chemical properties, they may be gases, liquids, solids or high molecular weight polymers, which can be classified as discussed below.

2.1. Classification based on the physical and chemical properties

2.1.1. Nonpolymers PFSA

The non polymers PFSA is classified into two classes

2.1.1.1. Perfluoroalkyl substances

These are the compounds in which all the hydrogens of the alkane are replaced by fluorine. These molecules have more than two carbon atoms with a charged functional group at one end of the chain. Their structure can be denoted as $C_nF_{2n+1}R$ where, R is a functional group that may be carboxylate, sulphonate or sulphonamides. A few examples are Perfluoroalkyl carboxylic acids, perfluoro alkane sulphonic acids and perfluoro alkane sulphonamides.

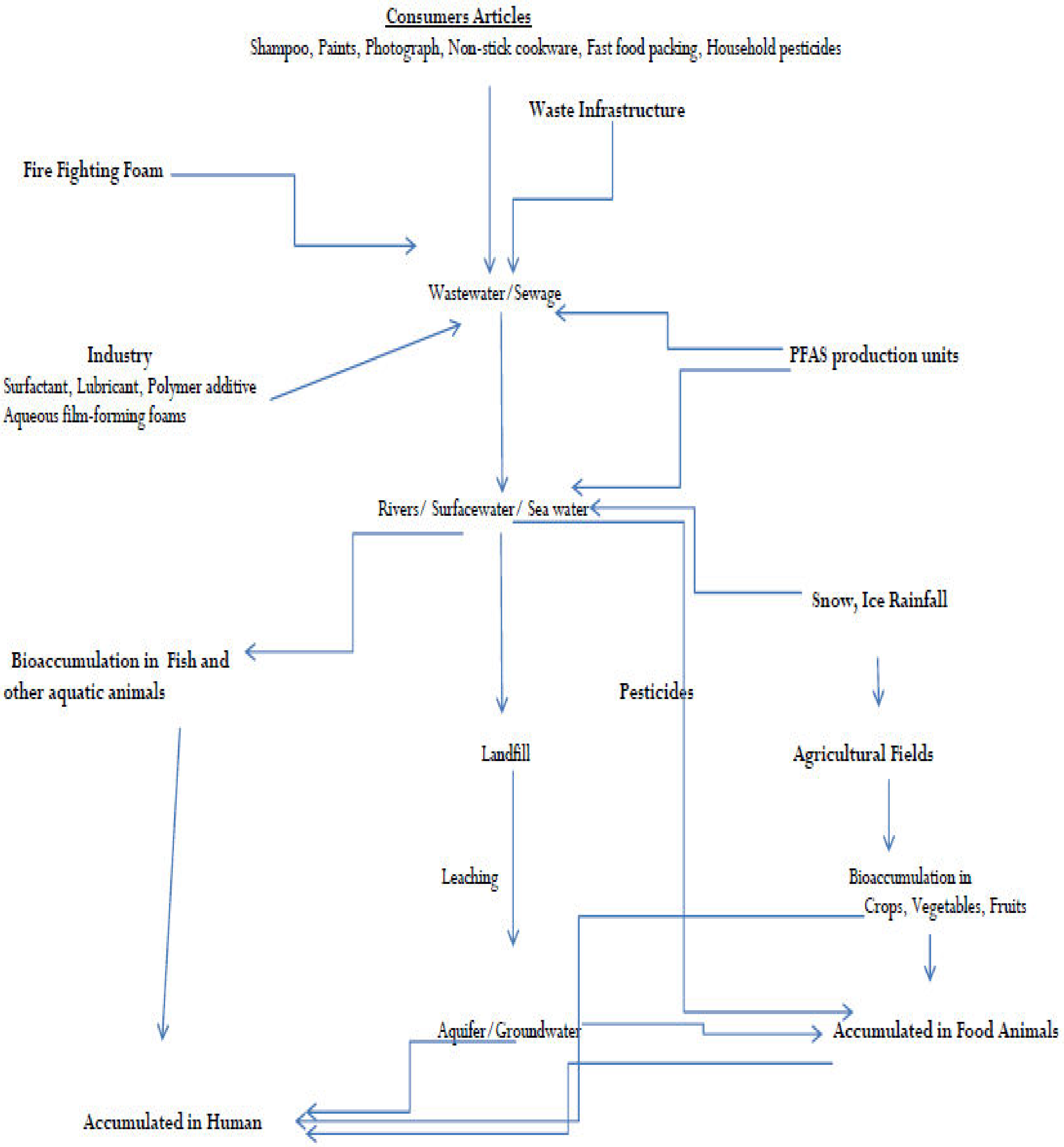
The perfluorinated alkyl substances are further divided into: (a) Perfluoroalkyl acids (PFAAs)- PFAAs includes (i) Perfluoroalkyl carboxylic acids (PFCAs) (Where R is COOH) for example perfluorooctanoic acid; (ii) Perfluoroalkyl carboxylate (where R is COO^-) e.g. perfluorooctanoate (iii) Perfluoroalkane sulphonic acid (PFSAs) (where R is SO_3H) e.g. perfluorooctane sulphonic acid (iv) Perfluoroalkane sulphonates (PFSAs) (where R is SO_3^-) example is perfluorooctane sulphonate (v) Perfluoroalkyl phosphonic acid (PFPAs) (where R is H_2PO_3) e.g. perfluoropentane phosphonic acid.

(b) Perfluoroalkyl sulphonamides (FASAs) e.g. perfluorooctane sulphonamide (where R is $-SO_2NH_2$).

(c) Perfluoroalkyl ether acids (PFEAs) (where R is O-COOH) e.g. perfluoro-2-methoxyaceticacid.

(d) Perfluoroalkyl aldehyde (PFALs) (where R is -CHO) for example perfluorooctanal

The most studied perfluoroalkyl substances are perfluorooctane carboxylate (PFOA) $[(CF_3\text{-}(CF_2)_5\text{-}CF_2\text{-}COO^-]$ and perfluorooctane sulphonate (PFOS) $[(CF_3\text{-}(CF_2)_5\text{-}CF_2\text{-}SO_3^-)]$.



Sources of the PFAS in the Environment

2.1.1.2. Polyfluoroalkyl substances

These are the compounds in which all the hydrogens are not replaced by fluorine, they have one or more non-fluorine atoms. Non-fluorine atom are usually H or O attached to at least one carbon atom in the tail. Generally, these compounds are named with n:x prefix where n denotes the number of fully fluorinated carbon atoms and x denotes the number of non-fully fluorinated carbon atom(s). Polyfluorinated PFAS can be divided in to the following classes:

(a) *Fluorotelomer Compounds:* These are those polyfluoroalkyl substances that are produced by the fluorotelomerization process. This class includes- (i) Fluorotelomer alcohols (FTOH): [(CF_3-(CF_2)$_7$-CH_2- CH_2OH)] (ii) Fluorotelomer sulfonic acids (FTSA) (iii) Fluorotelomer carboxylic acids (FTCA).

(b) *Perfluoroalkane sulfonamido compounds:* These compounds contain a fully fluorinated carbon chain with one or more CH_2 group(s) attached to the sulfonamido tail, e.g. n-ethyl perfluorooctane-sulphamido ethanol, [(CF_3-(CF_2)$_7$-CH_2-SO_2N(C_2H_5) -CH_2-CH_2OH)]. This class includes (i) perfluoroalkane sulphamido ethanols (FASEs) (ii) perfluoroalkane sulphamido acetic acid (FASAAs) (iii) N-alkyl perfluoroalkane sulphonamides (N-alkyl FASAs).

2.1.2. Polymer PFSA

These are large molecules formed by combining many of the same or identical small molecules called monomers**.** The polymeric PFAS can be divided into following:

2.1.2.1. Fluoropolymers

These are the compounds in which most of the hydrogen atoms attached to the carbon of the monomer are replaced by fluorine atoms. Common examples are Poly tetra fluoro ethylene (PTFE), polyvinylidene fluoride (PVDF).

2.1.2.2. Side chain fluorinated polymers

These compounds contain the non-fluorinated carbon chains with a side chain of the poly/perfluoroalkylic group, e.g. Fluorinated urethans, Fluorinated acrylates.

2.1.2.3. Perfluoropolyethers (PFPE)

These are the compounds in which carbon atoms are attached with oxygen besides fluorine, e.g. Perfluoro-polyether-benzophenone (PFPE-BP).

2.2. Classification based on the number of carbon atoms in the chain

2.2.1. Long-chain PFAS

These are compounds with six or more fully fluorinated carbon atoms e.g. PFSAs, PFCAs.

2.2.2. Short-chain PFAS

Those PFSAs which have six or fewer carbon atoms are called short-chain PFAS, e.g. perfluorobutanoic acid, perfluorobutane sulphonic acid.

3. ENVIRONMENTAL SOURCES OF PER AND POLYFLUOROALKYL SUBSTANCES (PFAS)

Per and Polyfluoroalkyl substances are oil and water repellent, chemical resistant and are used in the firefighting foams, textiles, electrical, non-sticking metal coatings, laundry and cleaning industries, painting, printing and paper industries, oil extraction and mining, medical devices, pharmaceuticals, pesticides, skin creams, cosmetics, photography, chrome painting etc. The short-chain PFAS are highly mobile and are more stable and are easily accumulated in the environment [23], while long-chain PFAS are easily accumulated in humans, animals, soils and sediments. The major sources of exposure to the citizenry are public water systems, drinking water wells, surface water of lakes, ponds, groundwater, food packaging, food items sold in the market, fish, indoor dust from carpets, textiles, etc.

4. ROUTES OF CONTAMINATION

4.1. Human intake of the Per and Poly-fluoroalkyl substances (PFAS)

Humans are exposed to Per and Polyfluoroalkyl substances (PFAS) either by direct exposure or indirect exposure [24, 25].

(i) *Ingestion (direct exposure):* It occurs via the gastrointestinal route, i.e. by up-taking contaminated food and other feeds, drinking contaminated water, milk and other drinks via the mouth.

(ii) *Dermal/via permeable membrane (Indirect exposure):* Dermal uptake means absorption through the skin. Skin creams and cosmetics are a few examples of dermal uptake.

(iii) *Inhalation (Indirect exposure):* Inhalation uptake occurs via inhalation of the polluted air as dust fumes or contaminated vapours.

(iv) Cleaning products, car polishing, wood, stone and floor are the other routes of human uptake of PFAS [26].

Per and Polyfluoroalkyl substances (PFAS) present in sediments are bioaccumulated in the small aquatic organisms present in the sediments. These toxic compounds become available to wildlife animals and humans who eat these aquatic organisms as food.

5. PFAS IN THE AQUATIC ENVIRONMENT

Manufacturing industrial discharges, domestic wastewater discharges, sewage sludge, sewage water, effluent from landfills and air emissions are the major entry sources of these persistent pollutants in to the aquatic environment. The concentration of these compounds in the wastewater depends on the source of effluent, the physic-chemical properties of the pollutant (i.e. the number of carbon atoms in the chain, the functional group attached) and water solubility as most of the PFAS are persistent i.e. they cannot be evaporated. These pollutants enter to surface water, river water, groundwater, drinking water, marine water and agricultural fields via wastewater [27, 28]. According to literature review, the total concentration of the PFAS in wastewater ranges from 0.0ng/L to 143ug/L, in river water ranges from a few ng/L to 496 ug/L, in surface water up to 84 ug/L and in drinking water ranges up to 8300 ng/L. The concentration of the different PFAS in water samples is given in Table 2.

6. PFAS IN THE PLANTS AND VEGETABLES/ CROPS

The major constituents of the human diet are vegetables, fruits and cereals (i.e., field crops) and meat, milk, and eggs i.e., animal origin food. Globally, due to changes in dietary habits, to reduce malnutrition, population explosion, and prosperity, the demand for vegetables and fruits has been increasing since the beginning of the 21st century. The use of treated or untreated wastewater for irrigation (the survey of literature denotes that approximately 20 million hectares of land are irrigated by raw wastewater or partially treated wastewater contaminated by PFAS), amendment of soils with sewage sludge or paper-fibre biosolids, and atmospheric deposition are the main sources of soil contamination by PFAS. From soil, these PFAS are transported to plants via roots. Globally, 10% of the world population consumes food grown on the wastewater irrigated or manure amended soils. The accumulation of the different PFAS compounds depends on number of the carbon atoms in the chain of the pollutant and the amount accumulated in soil and plant type. The accumulation of PFAS in the vegetation parts of plants was greater than in reproductive and storage parts. The accumulation of PFAs in the different parts of plants were in the order of the leaves > stem/shoot > root > fruit. Accumulation of PFAS in plants damages cell structure, and organelle functions, perturbs photosynthesis, protein synthesis, carbon and nitrogen metabolism, gene expression, etc. [29].

The accumulation of different PFAS in different parts of plants, vegetables and crops is documented in Tables 2 and 3.

7. PFAS IN FISH AND OTHER AQUATIC ORGANISMS

Food and Agriculture Organization (FAO), with 195 members, a specific agency of the UN, was established in 1945 to eliminate hunger and malnutrition. The worldwide population is increasing and is expected to be 9.1 billion by 2050. As per the FAO report, since the last decade, the number of undernourished and malnourished people in developing countries is increasing. Despite the innovative techniques, agricultural production has not been able to solve this problem. Fish and other aquatic animals are the food source for billions of people across the world. It is a general belief that fish is a healthy source of nutrients, protein, omega-3 fatty acids, vitamin D, calcium, vitamin B complex, vitamin A, iron, zinc, essential fatty acids, micronutrients, and lysine. Due to poverty, deficiency in agricultural food production, and to cope with the malnutrition, the consumption of fish and other aquatic animals is continuously increasing. The global consumption per capita has increased from 9 kg in 2013 to 21 kg per capita in 2021 and is expected to reach 40 kg per capita by 2050. The increasing concentration of PFAS in the aquatic medium affects fish and other aquatic animals. As PFAS is associates with protein-rich tissues, these organic pollutants persist for a longer period of time and are bioaccumulated in the gills, liver, lungs, muscles, and intestines of fish via protein, organic matter, and the food they consume [30]. Bioaccumulation of these pollutants (PFAS) in fish organs causes metabolism disturbance, reproduction disruption, oxidative stress, developmental toxicity, thyroid disruption, nuclear receptor activation, reactive oxygen species induction, interaction with the membrane etc. [31]. The concentrations of different PFAS in fish and other aquatic animals are given in Table 4.

Table 2: Concentration of different antibiotics in sewage wastewater, hospital effluent, ground water, aquaculture water, river water, sediments and manure/compost

Compound	Wastewater/ Sewage water/ sewage	Groundwater	Freshwater/ Surface water	River water	Drinking water	Vegetables/ fruits/Crops/ Milk	Soil	Human blood /Serum
Perfluoro-octanoic acid (PFOA)	**Sewage**-0.48-0.91 ng/g dw [51]; 0-18 ug /kg [52]; 2-900 ng/g [53]; 8-68 ng/g [54]; 1-240 ng/g dw [55]; 34 ng/g dw [56] **Landfill Chelate-** 79.5-2800 ng/g dw [53] **Sewagewater:** 0-11 ng/L [52]; 3.2-13 ng/L [57]; 103-443 ng/L [58]; 21.6 ng/L [59]; 8-68 ng/g [54]; 640 ng/L [60];0.026-0.112ug/L [61]	7-175.2 ng/L [58];0-1.76 ng/L [62]; 0-8.03 ng/L [63];1-47000 ng/L [15]; 0-5.11 ng/L[64]; 0-0.76 ng/L [65]; 64.5-4150 ng/L [66]; 1.7-74 ng/L [67]; 105-2510 ng/L [68];15-58 ng/L [69]; 0-61 ng/L [52]; 2.2 ng/L [70] **Perched groundwater:** 1930 ng/L [52]	0-223.8 ng/L [58]; 0.48-5.33 ng/L [64]; 0.08-1.18 ng/L [65]; 6.32-112 ng/L [71]; 0-800 ng/L [72]; 0-64 ng/L [52] 0.05-4.02 ng/L [73]; 53.5 ng/L [74]; 7294 ng/L [75]; 23-2752 ng/L [76]; 18250-69500 ng/L [27]; 4.06-61900 ng/L [77]; 8.5 ng/L [78]	1.8-12.2 ng/L [79]; 1590 ng/L [80]; 93 ng/L [81]; 0.09-5.2 ng/L [82]	10-34 ng/L [83]; 4.15-104 ng/L[71]; 0.2-1630.2 ng/L [84]; 2.3-84 ng/L [85]; 460 ng/L [53]; 18.4-3165 ng/L [86]; 45-268 ng/L [87]; 0.74ng/L [88]; 0.87-1.6 ng/L [89];100 ng/L [90]; 68.9 ng/L [91]	Corn-2478.4ng/g dw [37]; Wheat- 1-809 ng/g dw [37]; Maize-0-0.4 ng/g dw [37]: Rice- 0-1.9 ng/g dw [92]; Soybean-0.3-3967 ng/g dw [37]; Lettuce- 0-1038ng/g dw [93]; 540-633 ng/g [94]; Spinach- 0-6.7 ng/g dw [95]; 2.49 ng/g dw [17]; Cabbage 1.3-4ng/g dw [17];Celery- 75.4-1119.4 ng/g dw [37]; Cucumber-0.005-1.4ng/gdw[68]; 1.7ng/g dw 88]; Pumpkin- 0.05-15.1 ng/g dw [37];Pepper 0.007-39.3 ng/g dw [17]; Tomato- 0-0.5 ng/g dw [88]; 0.18ng/g dw [17]; 1.7ng/g dw [68]; Radish 0.08-1879.8ng/g dw [37];Carrot-0.005-138.6 ng/g dw [95]; 1468.1ng/g dw [37]; 0.22 ng/ g dw [17]; 470-530 ng/g [94]; Potato-0.01 ng/g dw [95]; Egg plant- 0.82 ng/g dw [17]; Cauliflower- 86.1 ng/g dw [37]; Cereal grains- 8.3-393ng/g	0.059-1.84 ng/g [99]; 0.11-1.67 ng/g dw [17]; 0.11-0.30 ng/g [93]; 0.29-0.54 ng/g [100]; 8- 68 ng/g [101]; 66.3-173.4 ng/g [37] ; 0-2 ug/kg [52]; 10-2531 ng/g [76] ;46-300ug/kg [53]; 0.1-0.8 ug/kg [102]; 2531 ng/g [103]; 5-27 ng/g[38]; 22.5-37.1 ng/g dw [104]	Blood of Human-147 ng/L [15]; Blood Serum -0.4-7.3 ug/L [15]; Blood Serum-8.6 ng/mL [90]

						[96]; Grapes-1.6ng /g dw [88]; Pear- 1 ng/g dw [88]; Peach- 1.3ng/g dw[88] ; Watermelon7.9 ng/g dw [88] **Milk-**6.2-37.4 ng/kg [97]; 0-854 ng/kg [98]; 0.0-151.8 ng/L [32]	
Perfluoro-nonanoic acid (PFNA)	**Sewage water- 0**.0-1.4 ng/L [57]; 0.05-4.9ng/L [105]	0-1-22 ng/L [58]; 0-0.2 ng/L [64]; 0-0.22 ng/L [65]; 0.2-2.2 ng/L[67]; 0-1.38 ng/L [37];0.1 ng/L [68]; 0-0.9ng/L [63]	0-4.6ng/L [58];0-06-1.0 ng/L [64]; 0-0.19 ng/L [65]; 0.86-41.4 ng/L [71] ; 58-374 ng/L [27]		0.74-38.6 ng/L [71]; 0.40ng/L [88]; 33.4 ng/L [91]	Corn- 1.13 ng/g dw [37]; Maize- 62 ng/g dw [37]; Rice- 0.21 ng/g dw [92] ;Wheat- 0.42 ng/g dw [37];Soybean- 1.63 ng/g dw [37]; Cabbage- 0.06 ng/g dw [17]; Carrot- 0.64 ng/g dw [37]; Celery 0.49 ng/g dw [37]; 0.34 ng/g dw [17]; Lettuce- 0.09 ng/g dw [37]; Pepper- 0.15 ng/g dw [37]; Radish- 0.67ng/g dw [37]; 0.03 ng/g dw [17]	0.02-0.29 ng/g dw [17]; 0.04-0.21 ng/g [37]
Perfluoro-butanoic acid (PFBA)	3.6-19 ng/L [57]; 15-23 ng/L [106]	1.13-1544 ng/L [64,66];6.1 ng/L [70]	3.05-96.8 ng/L [71]; 1400-3800 ng/L [27]; 11 ng/L [78]		3.62-104ng/L [71]	Wheat-1-1100 ng/g dw [107]; 339ng/g dw [76]; 1102.5 ng/g dw[37]; Maize- 0-1449 ng/g dw [108]; 37.4 ng/g dw[76]; Rice 0.01-2.4 ng/g dw[109]; Soybean 223-2378 ng/g [110]; 2378.3 ng/g dw[37];Lettuce-0-2365 ng/g dw [88]; Spinach- 0-6.7 ng/g dw [111]; Cabbage- 17.9 ng/g dw [17];	0.02-0.37 ng/g [17]; 0.04-13.0ng/g [93]; 0.073-0.49 ng/g [100]; 3.88-15.10ng/g [37]

					2.5-17.8 ng/g dw [112]; Celery-433.2-517.8 ng/g dw [113]; 1049.6ng/g dw [37]; Cauliflower- 194.1 ng/g dw [37];Cucumber-0.1-.63 ng/g dw [68]; Pumpkin- 0-638.1 ng/g dw [114]; Pepper-0.1-946.5 ng/g dw [37]; Eggplant- 0.5-4.5ng/gdw [68];Tomato-3.9ng/g dw [88];3.15ng/g dw [17]; 63ng/g dw [68]; 0-3.3 ng/g dw [112];Radish -1-1167.5 ng/g dw [21]; Carrot- 0.02-865.8 ng/g dw [115]; 2552.7ng/g dw [37]; Potato-0.8 ng/g dw [116]; Corn 1448.6 ng/g dw[37]; Grape-9.8ng/g dw [88];Pear- 3.7 ng/g dw [88]	
Perfluoro-pentanoic acid (PFPeA)	**Sewage water-** 4.4-15 ng/L [57]		1.95-501 ng/L [71]; 860-2820 ng/L [27]	1.78-514ng/L [71]	Corn-387.7 ng/g dw[37];Maize- 7.65 ng/g dw [37]; Wheat-495.8 ng/g dw [37]; 83.2 ng/g dw[76];Soybean-992.6 ng/g dw [37]; Cabbage- 1.79 ng/g dw [17]; Carrot-852.3 ng/g dw [37]; Cauliflower-78.3 ng/g dw [37]; Celery-324.1 ng/g dw [37]; Cucumber-	0.0-0.57ng/g [93];1.64-9.49 ng/g [37]

						0.85 ng/g dw [68]; 4.68 ng/g dw [17]; Lettuce- 281.2 ng/g dw [37];Eggplant- 0.61 ng/g dw [17]; Pepper-415.9 ng/g dw [37]; Pumpkin- 64.1 ng/g dw [37]; Radish- 426.4 ng/g dw [37]; 6.05 ng/g dw [17]; Spinach-1.79 ng/g dw [17]; Tomato-2.74 ng/g dw [17]; 1.30ng/g dw [68]	
Perfluoro-hexanoic acid (PFHxA)	**Sewage water-** 5.0-20 ng/L [57]; 165-847 ng/L [92] **Sludge-**0.2-0.5ng/g dw [51]		2.02-55.1 ng/L [71];1360-4300 ng/L [27]; 3-214000 ng/L [117]	8-193 ng/L [118]	1.43-60.8ng/L [71]; 320 ng/L [119]	Corn- 116.1ng/g dw [37]; Wheat- 0.3-135 ng/g dw [120]; 134.7 ng/g dw [37]; Maize-0-116 ng/g dw [93] 13.04ng/g dw [76]; Rice-0.02-1 ng/g dw [17]; Soybean- 5.5-212ng/g dw [21]; 211.8 ng/g dw [37]; Lettuce-0-72 ng/g dw [115]; 72.2ng/g dw [37]; Spinach- 0-1.2 ng/g dw [88];3.9ng/g [17]; Cabbage- 0.2-1.4ng/g dw [17];Celery- 18.4-19.9 ng/g dw [113]; 94.3 ng/g dw [37];Cucumber- 0.0-0.32ng/g dw [68];1.36 ng/g dw [17]; Pumpkin-0-11.7ng/g dw[37]; Pepper 0.2-74.4 ng/g dw [17]; Eggplant- 0.0.4 ng/g dw [68]; 0.22ng/g	0.02-0.29 ng/g dw[17];0.0-0.66ng/g [93]; 1.0-6.13ng/g [37]

						dw [17]; Tomato- 0-1.4 ng/g dw [88];0.56 ng/g dw[68]; Radish- 0.1-103.3ng/g dw ;4.6 ng/g dw [17];Carrot-0-32.4 ng/g dw [95];Potato-0.06ng/g dw [95]	
Perfloro-heptanoic acid (PFHpA)	**Sewage water-** 1.6-16 ng/[57];662-1143ng/L [84]		1.13-184 ng/L [71]; 1360-4030 ng/[27] ;2.2-10500 ng/L [77]		0.79-177ng/L [71];10.5 ng/L [91]	Corn- 248.8 ng/g dw [37] ;Maize- 65 ng/g dw [51]; Rice- 0.12 ng/g dw [92]; Wheat-51.2 ng/g dw [37]; 2.06 ng/g dw [37]; Soybean- 530.3 ng/g dw [37]; Lettuce-72.9 ng/g dw [37]; Cabbage-0.76 ng/g dw [17];Carrot-229.1 ng/g dw [37]; Celery- 88.3 ng/g dw [37]; Cucumber-0.26 ng/g dw [68];0.18ng/g dw [17]; Pepper- 18 ng/g dw [37]; Pumpkin-5.25 ng/g dw [37]; Radish- 251.9 ng/g dw [37]; 0.21 ng/g dw [17]; Spinch-0.47 ng/g dw [17]	0.71-4.55ng/g [37]
Perfluorobut anesulphonic acid (PFBS)	Sewage water-2.3-20 ng/L [57]; 1.29-195ng/L [79]	1.53-11016 ng/L [68,65] 4.4 ng/L [70]	1.12-11.1 ng/L [71]; 7.0 ng/[78]; 2.24-9.32 ng/L [27]		1.17-11.9 ng/L [71];130 ng/L [119];7.94 ng/L [91]	Corn- 0.29 ng/g [37]; Wheat- 0-.51ng/g dw [37]; Maize-0-100 ng /g dw [120]; Rice-0-0.03 ng/g dw [92]; Cauliflower -1.1ng/g dw [37]; Lettuce- 0-1.6 ng/g dw[93]; Spinach- 0.17 ng/g dw[17]; 0-1.7ng/g dw [95]; Cabbage 0-	0.004-0.01 ng/g [37]

						0.1 ng/g [17]; Celery- 0.05-0.07ng/g dw [93]; 0.02 ng/g dw [37]; Cucumber-0-0.15 ng/g dw [68]; 0.05 ng/g dw [17]; Pepper- 0.02 ng/g dw [37]; Pumpkin-0.02 ng/g dw [37]; Radish- - 0.02 ng/g dw [37]; Spinach-0.17 ng/g dw [17]; Tomato- 0-0.3 ng/g dw [88]; 0.25 ng/g [17]; 13ng/g dw [68]; Carrot- 0-1.0 ng/g dw [95]		
Perfluorooctanesulphonic acid (PFOS)	Sludge:1060-2150 ug /kg [52]; 0-140 ng/g [53]; 0-380ng/g [121]; 403 ng/g dw [56] **Landfill Chelate**- 0-300 ng/g dw[53]; 10-1100ng/g dw[55] **Sewage water:** 169-635 ng/L[52]; 6100.8 ng/L[122]; 662-1143 ng/L[84]; 3.8-92 ng/L[57] ; 97.5-394 ng/L[59]; 53,000ng/L [123]; 0.44-461.7	1.3-4800 ng/L [67]; 0-18 ng/L [52]; 0.1-33 ng/L [125]; 4300 ug/L [126];11 ng/L [70] **Perched groundwater**: 35300 ng/L[52]	2.28-48.3 ng/L [71]; 0-100 ng/L [72]; 0-230 ng/L [127]; 0-2060 ng/L [52]; 0.03-6.23 ng/L [73]; 40.2 ng/L [74]; 10.6-46.8 ng/L [128]; 50 ng/L [75]; 8970 ug/L [126]; 0.073-113 ng/L [76]; 650 ng/L[123]; 75 ng/L 78];19.8-93.3 ng/L 27]	20.5 ng/L [80]; 0.7-1.7 ng/L [122]; 2.6 ng/L [84]; 29 ng/L [129]; 20.2 ng/L [59]; 0.18-0.53 ng/L [82]; 4-102 ng/L [118]	1.62-36.9ng/L [71];0-70.1ng/L [84]; 0.4 ng/L [122]; 0.2-22 ng/L [85]; 20 ng/L [53];0.25ng/L [88]; 8000 ng/L [119]; 61.2 ng/L [91]	Corn- 1.07 ng/g dw [37]; Wheat- 0.2-0.93 ng/g dw [37] (; Maize- 0-0.23 ng/g dw [37] 2;Rice- 0-55.5 ng/g dw [92]; Soybean- 0-2.3ng/g dw [37]; Lettuce-0-3.5ng/g dw [93];3.46 ng/g dw [37]; 481-555ng/g [94]; Spinach- 0-0.1 ng/g dw [95]; Cabbage 0.0-0.43ng/g dw [17]; Celery- 0.07-1.62ng/g dw [37];Cucumber-0.0-0.12 ng/g dw [68]; Cauliflower-- 0.32 ng/g dw [37]; Pumpkin- 0.0-0.09ng/g dw [37]; Pepper 0-0.2 ng/g dw [17]; 0.62 ng/g dw [37]; Tomato- 0-0.2 ng/g dw [88];	0.018-2.55ng/g [99]; 0.57-12.0 ng/g [93]; 0.93-2.1ng/g[100]; 80-219 ng/g[101]; 1-172ug/kg [52]; 9700 ug/kg [126]; 3-5,500 ng/g [103]; 0.2-0.4 ug/kg [102]; 878ng/g [130] ; 41.87-622.46 ng/g dw [131] ; 6.29-13.5 ng/g dw [104]; 0.004-0.17ng/g [37]	Blood Serum -1.4-34.6ug/L [15]; Blood Serum-157ng/mL [132]

	ng/L[121]; 5-50 ng/L[124] ; 470 ng/L [60] ;0.818-1.364ug/L[61]					0.19ng/g dw [17]; Radish-0- 1.85 ng/g dw[37] ;Carrot- 0-1.73 ng/g dw [95]; 298-625 ng/g [94]; Cereal grains- 3.9-860ng/kg [96] **Milk**-0-212 ng/kg [7]; 144 ng/kg [98]; 0-9060 ng/L [32] ;1-42 ng/g [130]		
Perfluorohexanesulphonic acid (PFHxS)	Sewage water-2.7-13 ng/L [57];2.6-15 ng/L [84]	0.5-1.5ng/L [58]; 0-0.23 ng/L [64]; 0-0.08 ng/L [65]; 2.6-280 ng/ [67]; 0- 0.25 ng/ L[37]; 0.1-1140 ng/L [68]; 0-6.05ng/L [63]; 76-160 ng/L [69]	0- 41.7ng/L [58]; 0-0.18 ng/L [64] ; 0-0.30 ng/L [65]; 0.86-44.8 ng/L [71]; 0.03-3.51 ng/L [73]; 74 ng/L [75]; 42 ng/L [78]; 2.44-27.7 ng/L [27]		0.79-21.1ng/L [71]; 1700ng/L [119]; 30.5 ng/L [91]	Corn-0.02 ng/g dw [37] ; Wheat- 0-68 ng/g dw [120]; 0.37ng/g dw [37]; Maize- 0 -0.05 ng/g dw [93]; 0.04 ng/g dw [37]: Rice 0.-3.8ng/g dw [17]; Soybean- -0.02 ng/g dw [37]; Lettuce-0-0.5 ng/g dw [115]; 0.02 ng/g dw [37]; Spinach- 0-0.1 ng/g dw [88]; Cabbage- 0-0.1 ng/g dw [17]; Celery-0.05-0.09 ng/g dw [93]; Cucumber-0-0.31ng/g dw [68]; Pepper 0-0.005 ng/g dw [17]; 0.02 ng/g dw [37]; Egg plant- 0-0.001 ng/g dw [68]; Tomato- 0-0.004ng/g dw [88]; 0.29 ng/g dw [68]; Radish-0-0.1 ng /g dw [37]; Carrot- 0-0.07 ng/g dw [95]; Potato-0.0008 ng/g dw [95]; Grapes-0.10ng/g dw [88] **Milk-**0-111 ng/kg [97]	0.0-0.24ng/g [93]; 0.048-0.085 ng/g dw [104];0.004-0.07ng/g [37]	Blood serum-136 ng/mL [132]

Perfluorodecanoic acid (PFDA)	**Sewage**-26 ng/g dw [56] **Sewage water**- 0.0-3.6 ng/L [57]; 0.1-8.3ng/L [105]	0.43-31.1 ng/L [71];14.1-180 ng/L [27]	0.33-24.7ng/L [71]	Corn- 0.61 ng/g dw [37]; Maize- 0.07ng/g dw [37]; Rice- 0.13 ng/g dw [92]; Wheat- 0.81 ng/g dw [37] ; Soybean- 0.97ng/g dw[37] ; Cabbage- 0.03 ng/g dw [17]; Carrot- 057 ng/g dw [37]; Celery- 0.15 ng/g dw [37]; Eggplant- 0.28 ng/g dw [17]; Lettuce-0.21 ng/g dw [37];Pepper- 0.02 ng/g dw [37] ; Rasish- 0.84ng/g dw [37] ;Spinach- 0.10 ng/g dw[17]	0.04-0.65ng/g dw [17]; 0.02-0.27 ng/g [37]
Perfluoroundecanoic acid (PFUnDA)	**Sewage water**-0.03-2ng/[84]	0.14-2.90 ng/L [71] ;1.47-21.2 ng/L [27]	0.54-1.85ng/L [71]	Corn- 0.12 ng/g dw [37] ; Maize-0.1ng/g dw [37] ; Rice-0.09 ng/g dw [92] ; Wheat -0.14 ng/g dw [37]; Soybean- 0.3 ng/g dw [37]; Carrot- 0.04 ng/g dw [37]; Cauliflower- 0.1ng/g dw [37];Celery- 0.04 ng/g dw [37]; Eggplant-0.12 ng/g dw [17];Lettuce-0.20 ng/g dw [37]; Pepper- 0.11 ng/g dw [37]; Pumpkin- 0.12 ng/g dw [37]; Radish- 0.04ng/g dw [37]; Spinach- 0.05 ng/g dw [17];Pear- 0.20 ng/g [88]	0.03-0.11 ng/g [37]

Perflorododecanoic acid (PFDoDA)	**Sewage water**- 0.039-2ng/L[84]		0.21-0.28 ng/L[71]; 0.55-3.90 ng/L [27]		0-0.09ng/L [71]	Corn- 0.07 ng/g dw [37]; Maize- 0.06 ng/g dw [37]; Rice- 0.05 ng/g dw [92]; Wheat-0.14 ng/g dw [37]; Soybean- 0.2 ng/g dw[37]; Carrot- 0.09 ng/g dw [17]; Celery- 0.06 ng/g dw [37]; Eggplant-0.26 ng/g dw [17]; Lettuce-0.02 ng/g dw[37] ;Pepper- 0.06 ng/g dw [37]; Pumpkin- 0.06ng/g dw [37]; Radish- 0.06ng/g dw [37]; 0.09 ng/g dw [17]; Spinach-0.22 ng/g dw [17]; Tomato- 0.12 ng/g dw [17]	0.02-0.06ng/g[37]	
F-53B		0.18-0.59ng/L [133]		0-78.5 ng/[66]				0.6-4.8 ng/L [77,79]
∑ PFAS	**Sludge**- 0.6-3.0 ng/g dw [51]; 0.12-13.9 ng/g dw [92]; 1173-2358 ug /kg [52]; 80-219 ng/g [54]; 9329.9ng/g [134] ; 4.93-92.6 ng/g dw [135] ; 31.5-49.1 ng/g dw [79]; 5.6-963.2 ng/g [134]; 4.95-980 ng/g [136] **Sewage water**:,360 ng/L [52] ; 30-198 ng/L [137]; 30-150 ng/ L [124]; 220-12000 ng/L [138]	7300-8300 ng/L [105]; 0-541 ng/L [52]; 0.03-74 ng/L [70] **Perched groundwater**: 41823 ng/L [53]	2.5-2647 ng/L[52]; 230 ng/L[75];106 ng/L[29];146.2-586.2 ng/L[87]; 638 ng/L[139]; 24400-84400 ng/L[27]	0.04-83.1 ng/L[140]; 1.3-15.9 ng/L[65]; 84,000 ng/L[27] 496,000 ng/L[141];39.44-207.59 ng/L[142];46.2-157.6 ng/L[87];1700 ng/L[143];13-200 ng/L[118]	0.72-95 ng/L [85];0.1-502.9 [117,144]; 86.3 ng/L [29]; 62-4500 ng/L [83];2.4-290 ng/L [87]; 7.16-59.49 ng/L [145]; 9.08-11.63 ng/L [145]	Crops- 58.8-8085ng/g [37] ;Cauliflower- 410 ng/g [146]; Root Vegetables- 333 ng/g [146]	433 ng/g [101]; 79.9-209 ng/g [37]; 710126 ng/g [105]; 1-182ug /kg [52]; 29-14300 ng/kg [147]; 2-485 ng/ g [54]; 0.4-6.6 ng/g dw [148];79.9-200.4 ng/g [37]	**Dust**- 1.09-55.2 ng/g [149]

∑ PFCA			0.03-14.3ng/g [99]; 7-3270 ng/kg [147]
∑ PFSA			0.0-3.27ng/g [99]
∑ PFAA	Sewage water-31-142 ng/L [57]	17.87ng/L [88]	

Table 3: Average concentration of different PFAS in shoot and /or root of plants (ng/g dw)

Plant	Sampling Point	Perfluorooctanoic acid (PFOA)	Perfluorononanoic acid (PFNA)	Perfluorobutanoic acid (PFBA)	Perfluoropentanoic acid (PFPeA)	Perfluorohexanoic acid (PFHxA)	Perfluoroheptpentanoic acid (PFHpA)	Perfluorooctanesulphonicacid (PFOS)	Perfluorohexanesulphonic acid (PFHxS)	Perfluoro Decanesulphonic acid (PFDA)	Perfluoroundecanoic acid (PFUnDA)	Perfluorododecanoic acid (PFDoDA)	PFAS	Reference
Lemna minor	Shoot	3240-19600	3.5-29.7	10-280	8.36-108	15-94.6	26.1-181	4.6-18.3	0.0	9.4-34.2	7.2-18.1	7.5-15.1	3350-20400	[27]
Cetratophyllum demersum	Shoot	2390-8340	4.2-28.1	23.7-98.1	8.6-25.1	13.5-49.9	20-79.2	4-10.5	0.0-4.4	6.7-31.2	4.2-12.9	3.6-9.9	2500-8700	
Eriochloa villosa	Shoot	740-4260	1.1-4.9	19.5-242	24.2-105	19-263	12.7-69.6	2.8-4.2	0.8-3.4	2.5-3.8	1.6-3.1	1.2-2.4	840-4950	
	Root	1980-8140	3.6-19.8	16.2-109	7.1-24.6	17.8-154	29.9-126	2.6-7	0.0-2.9	6.2-18.1	3.3-13	2.4-7	2090-8630	
Alternanthera sessilis	Shoot	570-3960	0.5-2.8	50-333	14.8-135	15.1-81.5	13.2-65.1	0.7-2.6	0.0-2.6	1.1-3.4	0.0-2.2	0.0-1.4	670-4590	
	Root	800-6320	1.8-7.0	1.51-246	3.0-85.9	4.9-68.2	9.43-75.6	5.2-20.4	0.0-19	5.3-11	3.8-8.2		840-6870	
Radish (Rahanus sativus)	Root	67												[113]
		703.4-4310						212.4-723.6						[108]
		95.3	0.07	84.1	37.6	20.9	45.7	0.06	0.04	0.09	0.1	0.02	284	[37]
	Shoot	1879.7	0.67	1167.5	426.4	103.3	251.9	1.85	0.02	0.84	0.04	0.06	3832.4	
Carrot	Root	51.6	0.05	279.7	34.9	7.4	51.6	0.79	0.05	0.08	0.04	0.02	381.3	
	Leaf petiole	138.6	0.13	865.8	128.4	32.4	138.6	1.73	0.02	0.07	0.04	0.06	1189	
	Leaf blade	1468.1	0.64	2552.7	852.3	196.8	1468.1	1.31	0.02	0.57	0.04	0.02	5302.7	
Lettuce	Leaf	1038.3	0.09	2365.2	281.7	72.2	72.9	3.46	0.02	0.21	0.20	0.02	3833.7	
Celery (Apium graveolens var.dulce)	Root	218.1	0.36	517.8	84.9	18.3	21.6	0.11	0.09	0.26	0.18	0.10	862	[37]
	shoot	232												[113]
	Leaf petiole	75.4	0.10	433.2	68.4	19.9	19.3	0.07	0.05	0.07	0.10	0.02	616.5	[37]
	Leaf blade	1119.4	0.49	1049.6	324.1	94.3	88.3	1.62	0.02	0.15	0.04	0.06	2678	

Corn	Root	225.9	0.16	116.2	40.3	15.7	74.6	0.39	0.02	0.19	0.04	0.02	473.6	[37]
													254	[111]
	Leaf												23.1	
	Leaf	2478.4	1.13	1448.6	387.7	116.1	248.8	1.07	0.02	0.61	0.12	0.07	4682.8	[37]
	Stem	64.0	0.11	82.8	20.5	10.3	44.8	0.02	0.05	0.09	0.10	0.02	223	
	Husk	50.7	0.12	83.1	11.8	8.2	32.6	0.07	0.02	0.08	0.04	0.02	186.7	
Wheat	Root	108.5	0.38	209.9	37.6	6.5	7.8	0.11	0.02	0.25	0.10	0.06	371.2	[37]
	Root												332-1411	[150]
	Shoot												39.6-821	
	Stem	22	0.28	237.7	47.5	6.7	3.9	0.05	0.02	0.02	0.40	0.06		[37]
	Leaf	809.7	0.42	1102.5	495.8	134.7	51.2	0.93	0.37	0.81	0.14	0.06		
	Husk	244.5	0.42	1768.1	345.9	69.4	20.7	2	0.02	0.29	0.04	0.15		
Soybean	Root	162.8	0.05	316.3	29.4	8.9	14.1	0.39	0.02	0.07	0.04	0.06	532.2	[37]
	Stem	45	0.05	222.8	28.3	5.5	10	0.33	0.04	0.07	0.04	0.02	312.2	
	Leaf	3966.6	1.63	2378.3	992.6	211.8	530.3	2.35	0.02	0.97	0.30	0.20	8085.2	
	Pod	261	0.08	2319.1	199.8	34.8	44.2	1.73	0.02	0.25	0.10	0.02	2861.1	
Strawberry	Root					5450								[113]
	Shoot			3900										
Wheat grass		16	0.8	766	466	515	17	1070	2790	0.25				[151]
Grass		190-520	0.86-4.9				17			1.2-11	3.7-23	30		[152]
Myriophyllum spicatum			1.02								1.28		4.78	[153]
Ceratophyllum demersum			1.46								1.89		6.54	
Valisneria spiralis,			1.68								2.31		7.63	
Chironomid													6.56-355.9	[153]
Plant	Leaves	1500dw		14000 dw				930 dw						[154]

Table 4: Total concentration of PFAS in Different Species of Fish

Aquatic animal	Location	Body Part	Total concentration of PFAS in ng/g	Reference
Pagrus major	Seawater, China	Muscle	0.04-2.14	[155]
Tridentiger trigonocephalus	Seawater, China	Muscle	10.97-12.93	[156]
Gadus morhua	Seawater, Baltic sea	Liver	6.03-23.9	[157]
Isurus oxyrinchus	Seawater, Greece	Muscle, Gill, Heart	3.2-10.3	[158]
Oxynotus centrina	Seawater, Greece	Muscle, Liver	17.9-85.1	
Mobula mobular	Seawater, Greece	Muscle, Gills	1.5-4.4	
Odontaspisferox	Seawater, Greece	Gills, Liver	62.2-65.4	
Prionace glauca	Seawater, Greece	Muscle, Gills, Liver, Heart	0.3-15.5	
Hexanchus griseus	Seawater, Greece	Muscle, Gills, Liver, Heart, Gonad	1.1-66.3	
Heptranchias perlo	Seawater, Greece	Muscle, Gills, Liver, Heart, Gonad	0.0-35	
Alopias superciliosust	Seawater, Greece	Muscle, Gills, Liver, Heart	3.1-48.19	
Micropogonias undulatus	Seawater, South Carolina	Whole Fish	15.2-21.3	[159]
Sciaenops ocellatus	Seawater, South Carolina	Whole Fish	11.3-66.1	
Cynoscion nebulosus	Seawater, South Carolina	Whole Fish	17.3-85.4	
Leiostomus xanthurus	Seawater, South Carolina	Whole Fish	14.7-67.8	
Mugil cephalus	Seawater, South Carolina	Whole Fish	6.2-20.7	
Ocytopode stimpsoni	Seawater, China	Soft tissues	7.8-10.47	[156]
Clibanarius infraspinantus	Seawater, China	Soft tissues	7.73-8.06	
Ruditapes philippinarum	Seawater, China	Soft tissues	15.5-27.5	[160]
Cassostrea gigas	Seawater, China	Soft tissues	12.45-12.76	[156]
Orcinus orca	Seawater, Greenland	Liver	614	[161]
Phoca vitulina	Seawater, Sweden	Liver	640	
Phoca hispida	Seawater, Sweden	Liver	536	
Pomacea canaliculata	Freshwater, Vietnam	Soft tissues	0.22-0.6	[74]
Corbicula fluminea	Freshwater, Vietnam	Soft tissues	0.73	
Corbicula fluminea	Freshwater, Belgium	Soft tissues	0.0-126	[162]
Dreissena bugensis	Freshwater, Belgium	Soft tissues	8.56-157	
Perca fluviatilis	Freshwater, Belgium	Soft tissues	5.22-67.8	
Anguilla anguilla	Freshwater, Belgium	Soft tissues	5.73-68.8	
Charybdis japonica	Freshwater, Vietnam	Soft tissues	0.61	[74]
Macrobrachium rosenbergii	Freshwater, Vietnam	Soft tissues	0.24-0.58	
Palaemon longirostris	Estuarine, France	Whole body	4.5	[139]
Crangon crangon	Estuarine, France	Whole body	11	[139]
Mysidacea ind.	Estuarine, France	Whole body	7.2	
Copepoda, ind.	Estuarine, France	Whole body	2.9	
Copepoda cladocera	Freshwater, Italy	Whole body	7.6	[163]
Lepomis macrochirus	Freshwater, South Korea	Muscle	32.4	[31]
Hemibarbus labeo	Freshwater, South Korea	Muscle	16.7	
Micropterus salmoides	Freshwater, South Korea	Muscle	40.3	
Chanodichthys dabryid	Freshwater, South Korea	Muscle	30.5	
Carassius caassius	Freshwater, South Korea	Muscle	17.6	
Cyprinus carpio	Freshwater, South Korea	Muscle	50.6	

Ctenopharyngodon idellus	Freshwater, South Korea	Muscle	8.87-10.66	
Hemibarbus labeo	Freshwater, South Korea	Muscle	16.7	
Micropterus salmoides	Freshwater, China	Muscle	3.02	[164]
Anguilla anguilla	Freshwater, Netherlands	Muscle	4.7-172	[158]
Carassius carassius	Freshwater China	Muscle	3.15-4.09	[164]
Siniperca chuatsi	Freshwater China	Muscle, Liver	3.02-5.12	
Larimichthys polyactis	Freshwater China	Muscle, Liver	8.99-87.9	
Pungitius pungitius	Freshwater, Alaska	Whole body	3.66-15.6	[165]
Esomus danricus	Freshwater Vietnam	Whole body	0.91	[74]
Pangasius elongatus	Freshwater Vietnam	Whole body	0.3	
Eleotris fusca	Freshwater Vietnam	Whole body	0.92	
Chana striata	Freshwater Vietnam	Liver Muscle	0.18-1.01	
Oreochrommic niloticus	Freshwater Vietnam	Liver Muscle	0.5-10.6	
Perca fluviatilis	Freshwater, Amsterdam	Whole body	1500	[166]
Perca fluviatilis	Freshwater, Amsterdam	Muscle	330	[167]
Fish	Freshwater, Norway	Liver	12-300	[168]
		Muscle	5-68	
Salvelinus namaycush	Freshwater, USA		45 (PFOS)	[169]
Finfish-0.32-14.58 ng/g	Fresh water, Bangladesh	Whole body	0.32-14.58	[170]
Shell fish			1.31-8.34	
Micropterus salamoids	Freshwater, USA	Liver , Testis	3.2-834.4	[171]

8. PFAS IN THE MILK

Per capita milk consumption throughout the world (i.e., developed and developing countries) is increasing, which may be due to economic prosperity, population explosion, and changes in dietary habits. India, the top producer globally produces approximately 18% of the global milk production. Several researchers [32-34] have reported residues of PFAs in breast milk and animal milk. In the USA, more than 80% of breast milk is contaminated with PFAS. PFAS binds to the β-lactoglobulin protein present in the milk. Exposure of PFAS to infants via breastmilk affects immunity, hormonal function, development of the nervous system, vaccine response, kidney function, obesity, asthma etc. The data on the concentration of PFAS in milk is recorded in Table 2.

9. PFAS IN SOIL

Soil is the most important natural source on earth as it supports the production of the human food system, fodder for animals, fibre etc. Healthy soil is essential for human life and their well-being. Franklin D. Roosevelt correctly interpreted that "*The nation that destroys its soil destroys itself*." But for the last 60 years, due to anthropogenic activities, the health of the soil has been deteriorating. Soil is an important reservoir of pollutants, e.g. potentially toxic metals, pesticides, antibiotics, PFAS etc.

PFAS are released in agricultural soils through irrigation water, biosolids applications, AFFFs discharge, and atmospheric dispersion [35, 36]. The PFAS pollutants are either sorbed by soil particles or dissolved in the soil solution. From the soils, these pollutants are either absorbed by the roots of the cultivated plants or leached into the groundwater. Many agricultural scientists [37-39] have reported that soils globally are contaminated with PFAS. The concentration of the different PFAS compounds in soil is given in Table 2.

10. IMPACT OF PFAS ON HUMANS

The impact of these chemicals on humans depends on the route of exposure, duration of exposure and concentration of the chemical [40]. A number of studies [41-43] have reported that PFAS, mainly PFOA and PFOS, in humans affects the immune system, alter the lipid metabolism, endocrine activity, thyroid gland and mammary gland functioning. These chemicals also cause delays in the mammary gland development, obesity, increased miscarriage risk and low sperm count [44]. In their studies, Temkin [45] found that these toxic chemicals in humans increase blood cholesterol and that these chemicals are also linked to kidney diseases, testicular cancer, kidney cancer, increased uric acid concentration in the blood, and immunity/decreased response to vaccines. Zeng *et al.,* [46] reported that PFOS in humans decreases cell activities and increases ROS levels, decreases mitochondrial membrane potential with enhanced apoptosis and autophagy. Increase of endoplasmic reticulum stress by PFAS in humans has been reported by Louisse *et al.,* [47]. Redox imbalance and abnormal autophagy with decreased glutamatmine synthase activity by PFOS have been found by Li *et al.,* [48]. Borghese *et al.,* [49] discovered that exposing pregnant women to PFHxS for a longer period of time increases the chances of preeclampsia development by three fold. Blood glucose level and PFOS exposure had a positive significant correlation [50].

11. CONCLUSION

- PFAS are considered one of the the most toxic pollutants of the 21st century as they are present in all the compartments of the environment, viz., air, groundwater, surface water, river water, drinking water, house hold wastewater, soil, manure, milk, vegetables, crops fruits, and fish.
- As PFAS compounds possess the strongest covalent C-F bond, these compounds are thermally and chemically stable and possess hydrophobic and oleophobic properties. Due to their chemical stability, they persist in the environment for a longer period of time with a high mobility. These compounds are found even in remote areas like the Arctic and Antarctic and are also called "forever chemicals."
- In biosolids and manure, the concentration of these pollutants ranged from ng/g to ug/g. The concentration of these pollutants in surface water near industrial level and AFFF discharge points ranged up to mg/L. The concentration of these pollutants in soils near the AFFF discharge points ranged up to 7 mg/kg.
- In the agrosystem, PFAS are introduced via manure amendments and irrigation by contaminated water and impacts the ecological balance in soils.
- Short-chain PFAS compounds translocate very easily into plant components that are consumed by humans or animals as fodder, while long-chain PFAS compounds remain in the root part.
- As these pollutants contain functional groups such as carboxyl, sulphonyl, sulphonamide, amine groups glycosylation of the pollutants in the plants occurs.
- PFAS are bioaccumulated in the liver, muscle and fillet part of the most consumable fish (rainbow trout) worldwide.
- Ingestion of the PFAS through animal and/or plant-based foods as well as drinking of PFAS-contaminated water has impact on human health. The accumulation of these pollutants in humans affects the immune system, lipid metabolism, endocrine system, and reproductive system and alters development. These pollutants also have cancerogenicity. Health impacts on humans depend on concentration, route and duration of exposure.

Future Suggestions

- The production and utilization of these pollutants must be reduced.
- Researchers must find some alternate, less toxic, more efficient compounds.
- It is a need of the hour to develop effective technology to remove these pollutants from wastewater.
- Efforts must be made to create awareness to the citizenry regarding the negative impacts of these pollutants

Conflict of interest

The authors declare no competing intrests.

Declaration

No original data has been used in this review, all information as accessed from published work.

12. REFERENCES

1. Fredriksson F, Eriksson U, Karrman A, et al. A Pilot Study of the Fluorinated Ingredient of Scotchgard Products and Their Levels in WWTP Sludge and Landfill Leachate from Sweden, Örebro, 2020, p.38. Digitala Vetenskapliga Arkivet.
2. Hatton J, Holton C, DiGuiseppi B. *Remediation Journal*, 2018; **28 (2):** 89-99.
3. USEPA. Assessing and Managing Chemicals under TSCA - Fact Sheet: 2010/2015 PFOA Stewardship Program, 2018.
4. Herzke D, Anker-Nilssen T, Nøst TH, et al. *Environ. Sci. Technol,* 2016; **50(4)**:1924-1933.
5. US Environmental Protection Agency. Basic information about the Integrated risk information system, Washington, DC, May, 2020.

www.epa.gov/iris/basic-information-about-integrated-risk-information-system

6. Zhang Z, Sarkar D, Biswas JK, et al. *Bioresource Technology, 2021;***344(PtB):**126223.
7. Roscales JL, Vicente A, Ryan PG, et al. *Environ Sci Technol,* 219; **53**:9855-9865.
8. Xie Z, Wang Z, Magand O, et al. *Sci Total Environ*, 2020; **741**:140200.
9. MacInnis JJ, Lehnherr I, Muir DCG, et al. *Environ Sci Technol*, 2019; **53**: 10753-10762.
10. Koch A, Jonsson M, Yeung LWY, et al. *Environ Sci Technol*, 2020; **54:**11951-11960.
11. Miranda DA, Benskin JP, Awad R, et al. , *Sci. Total Environ*, 2021; **754**:142146.
12. Kotlarz N, McCord J, Collier D, et al. *Environ, Health Perspect*, 2020; **128**:77005.
13. Jin H, Mao L, Xie J, et al. *Sci Total. Environ, 2020;* **713**:136417.
14. Ruan Y, Lalwani D, Kwok KY, et al. *Chemosphere*, 2019; **229**:366-373.
15. Gebbink WA, van Leeuwen SPJ. *Environ Int,* 2020; 137:105583.
16. McCarthy CJ, S. Roark SA, Wright D. *Environmental Toxicology and Chemistry*, 2021; 40(8):2319-2333.
17. Zhang M, Wang P, Lu Y, et al. *Environment International,* 2020; **135**:105347.
18. Bolan N, Sarkar B, Yan Y, et al. *Journal of Hazardous Materials*, 2021; **401**:123892.
19. Wei Z, Xu T, Zhao D. *Environ Sci Water Res Technol,* 2019; **5**:1814-1835.
20. Brevik EC, Slaughter L, Singh BR, et al. *Air, Soil, and Water Research*,2020;**13:** 1-23.
21. Wen B, Pan Y, Shi X, et al. *Sci Total Environ*, 2018; 642:366-373.
22. Abunada Z, Alazaiza MYD, Bashir MJK. *Water,* **12**; 3590.
23. German EPA. 'PFC-Planet: Chemikalien in der Umwelt', Umweltbundesamt, accessed 2 December 2019.
24. De Silva AO, Armitage JM, Bruton TA, et al. *Environmental Toxicology and Chemistry,* 2021; **40(3):**631-657.
25. Augustsson IA, Lennqvist T, Osbeck CMG, et al. *Environmental Research,* 2021; **192:** 110284.
26. Sørli B, Lag M, Ekeren L, et al. *Toxicology in Vitro,* 2020; **62;** 104656.
27. Colomer-Vidal P, Jiang L, Mei W, et al. *Journal of Hazardous Materials,* 2022; **421**: 126768.
28. E. Barton KE, Starling AP, Higgins CP, et al. *Int J Hyg Environ Health,* 2020; **223 (1)**: 255-266.
29. Li X, Fatowe M, Cui D, et al. *Sci Total Environment*, 2022; **806 (1)**: 150393.
30. Ali AM, Higgins CP, Alarif WM, et al. *Environ Sci Pollut Res,* 2021; **28**:2791-2803.
31. Lee YM, Lee JY, Kim MK, et al. *J Hazard. Mater,* 2020; **381:** 120909.
32. Li X, Fatowe M, Cui D, et al. *Sci Total Environment*, 2022; **806 (1)**: 150393.
33. LR, Olowoyo JO, Mugivhisa LL. *Science of The Total Environment*, 2020; **755(2)**: 142697.
34. Hill NI, Becanova J, Lohmann R. *Anal Bioanal Chem*, 2022; **414 (3):**1235-1243.
35. Zheng G, Schreder E, Dempsey JC, et al. *Environ Sci Technol*, 2021; **55 (11):**7510-7520.
36. Panieri E, Baralic K, Djukic-Cosic D, et al. *Toxics,* 2022; 10(2):10020044.
37. Ghisi R, Vamerali T, Manzetti S*Environ Res,* 2019; **169**: 326-341.
38. Liu Z, Lu Y, Song X, et al. *Environment International*, 2019: 127; 671-684.
39. Galloway JE, Moreno AVP, Lindstrom AB, et al. *Environ Sci Technol*, 2020; 54:7175-7184.
40. Zhang W, Zhang D, Zagorevski DV, et al. *Chemosphere,* 2019; **233**:300-308.
41. Fenton SE, Ducatman A, Boobis A, et al. *Environ Toxicol Chem,* 2021; **40**: 606-630.
42. Conti A, Strazzeri C, Rhoden KJ., *Mol Cell Endocrinol*, 2020; **515**: 110922.
43. Croce L, Coperchini F, Tonacchera M, et al. *J Endocrinol Investig*, 2019; **42**: (1329-1335.
44. Behr AC, Kwiatkowski A, Stahlman M, et al. *ArchToxico*l, 2021; **95**: 2891.
45. National Toxicology Program (NTP), Monograph on Immunotoxicity associated with exposure to perfluorooctanoic acid (PFOA) or perfluorooctane sulphonate (PFOS), Office of Health Assessment and Translation Division of the National Toxicology Program National Institute of Environmental Health Sciences, Sep.2016.
46. Temkin AM, Hocevar BA, Andrews DQ, et al. *Int J Environ ResPublicHealth*, 2020; **17 (5)**:1668.
47. Zeng H-C, Zhu B-C,- Wang Y-Q, et al. *-Biomed Res Int,* 2021;2021: 662592.
48. Louisse J, Rijkers D, Stoopen G, et al. *Arch Toxicol,* 2020; **94:** 3137-3155.
49. Li Y, Cheng Y, Xie Z, et al. *Sci Rep,* 2017; 7: 43380.

50. Borghese MM, Walker M, Helewa ME, et al. *Environment International*, 2020; **141:**105789.
51. Preston V, Webster TF, Henn BC, et al. *Environment International*, 2020; **139**: 105728.
52. Dalahmeh S, Tirgani S, Komakech AJ, et al. *Science of The Total Environment,* 2018; **631–632**:660-667.
53. EGLE, Summary Report: Initiatives to Evaluate the Presence of PFAS in Municipal Wastewater and Associated Residuals (Sludge/Biosolids) in Michigan, June 2020.
54. Department of Environmental Conservation, Perfluoroalkyl Substances (PFAS) Contamination Status Report, Vermont, July, 2018.
55. JG, Blaine AC, Hundal LS, et al. *Environmental Science and Technology,* 2011; 45(19): 8106-12.
56. J Sheets J, Ledoux M. Addressing the impacts of PFAS in biosolids, water and waste management. Sept, 2021
57. Venkatesan AK, Halden R. *Journal of Hazardous Materials*, 2013; **252-253:**413-418.
58. Nguyen HT, Kaserzon SL, Thai PK. *Emerging Contaminants,* 2019; **5**: 211-218.
59. Chen S, Jiao XC, Gai N, et al. *Environmental Pollution,* 2016; **211**:124-131.
60. Salvidge R. EXCLUSIVE: Locations of high PFAS concentrations in wastewater and rivers revealed, Ends Report, 05 May, 2021.
61. Koch A. Fate of pharmaceuticals and perfluoroalkyl substances during source separated wasterwater treatment. Swedish University of Agricultural Sciences, Dept. of Aquatic Sciences and Assessment, Master's thesis, 2015.
62. Choi GH, Lee DY, Bruce-Vanderpuije P, et al. *Environ Geochem Health,* 2021; **439**: 347-360.
63. Liu Y, Hou X, Chen W, et al. *Sci Total Environ,* 2019; **689**:1388- 1395.
64. Sammut G, Sinagra E, Helmus R, et al. *Sci. Total Environ*, 2017; **589**:182-190.
65. Cao X, Wang C, Lu Y, et al. *Ecotoxicology and Environmental Safety Ecotoxicology and Environmental Safety*, 2019; **174**; 208-217.
66. Sharma BM, Bharat GK, Tayal S, et al. *Environ Pollut,* 2016; **208**: 704-713.
67. Wang P, Lu Y, Wang T, et al. *Journal of Hazardous Materials,* 2016; **307**; 55-63.
68. Hepburn E, Madden C, Szabo D, et al. *Environmental Pollution,* 2019; **248**: 101-113.
69. Bao J, Yu WJ, YLiu Y, et al. *Ecotoxicology and Environmental Safety,* 2019; **171**; 199-205.
70. Schaefer CE, Choyke S, Ferguson L, et al. *Environ Sci Technol*, 2018; **52(18)**: 10689–10697.
71. Szabo D, Coggan TL, Robson TC, et al. *J Sci Total Environ,* 2018; **644:**1409-1417.
72. Boone S, Vigo C, Boone T, et al. *Science of The Total Environment,* 2019; 653: 359-369.
73. Jian JM, Guo Y, Zeng L, et al. *Environment International,* 2017; **108**:51-62.
74. Baabish A, Sobhanei S, Fiedler H*Chemosphere,* 2021; **273:**129612.
75. Lam NH, Cho CR, Kannan K, et al. *Journal of Hazardous Materials*, 2017; **323A**: 116-127.
76. Tokranov AK, LeBlanc DR, Pickard HM, et al. *Environ Sci Processes Impacts,* 2021; **23**:1893-1905.
77. Liu Z, Lu Y, Wang P, et al. *Science of The Total Environment,* 2017; 580:1247-1256.
78. Chen W, Zhang X, Mamadiev M, et al. *RSC Advances*, 2017; **7:** 927.
79. Allinson M, .Yamashita N, Taniyasu S, et al*Heliyon*, 2019; **5(9)**:e02472.
80. Pan Y, Zhang H, Cui Q, et al. *Environ Sci Technol,* 2018; 52(14): 7621-7629.
81. Wang T, Wang P, Meng J, et al. *Chemosphere,* 2015; **129**: 87-99.
82. Sunantha G, Vasudevan N. *Marine Pollution Bulletin*, 2016; **109**: 612-618.
83. Duong HT, Kadokami K, Shirasaka H, et al. *Chemosphere*, 2015; **122**: 115-124.
84. Sun M, Arevalo E, Atrynar M, et al. *Environ Sci Technol Lett,* 2016; **3(12)**: 415-419.
85. Kunacheva C, Fujii S, Tanaka S, et al. *Water Sci. Technol*, 2012; **66:** 2764-2771.
86. Nishikoori H, Murakami M, Sakai H, et al. *Chemosphere*, 2011; **84**: 1125-1132.
87. Fang S, Sha B, Yin H, et al. *Journal of Hazardous Materials,* 2020; **396**:122617.
88. Tan KY, Lu GH, Yuan X, et al. *Bull Environ Contam Toxicol,* 2018; **101**: 598-603.
89. Li P, Oyang X, Zhao Y, et al. *Chemosphere,* 2019; **225**: 659-667.
90. Pignotti E, Casas G, Llorca M, et al. *Science of The Total Environment,* 2017; 607-608: 933-943.
91. Li Y, Barregard L, Xu Y, et al*Environ Health,* 2020; **19**: 12940.
92. Jiang J-J, Okvitasari AR, Huang F-Y, et al. *Chemosphere,* 2021; 264(2): 128579.
93. Kim H, Ekpe OD, Lee JH, et al. *Science of The Total Environment*, 2019; **671:** 714-721.
94. Scher DP, Kelly JE, Huset CA, et al. *Chemosphere,* 2018; 196: 548-555.

95. Bizkarguenaga E, Zabaleta I, Mijangos L, et al. *Science of The Total Environment,* 2016; **571:** 444-445.
96. Eun H, Yamazaki E, Taniyasu S, et al. *Chemosphere*, 2020; **239**:124750.
97. Vestergren R, Orata F, Berger U, et al. *Environ Sci Pollut Res,* 2013; **20**: 7959-7969.
98. Fiedler H, Sadia M. *Chemosphere,* 2021; **277**: 130287.
99. NA, Al-Qudah KM, Tahboub YR. *Environmental Sci Pollution Res Int,* 2015; **22(16)**:12415-23.
100. Vedagiri UK, Anderson RH, Loso HM, et al. *Remediat J,* 2018; **28**:9–51.
101. Riaz U, Murtaza G, Saifullah FM. *L Degrad Dev*, 2018; **29**: 1343– 1352.
102. Blaine AC, Rich CD, Hundal LS, et al. *Environ Sci Technol,* 2013; **47:**14062-14069.
103. Gottschall N, Topp E, Edwards M. *Science of The Total Environment*, 2017; 574: 1345-1359.
104. Brusseau ML, Anderson RH, Guo B. *Science of the Total Environment*, 2020; 740: 140017.
105. Zhang H, Wen B, Wen W, et al. *J Chromatogr B Anal Technol Biomed Life Sci*, 2018; **1072**: 25-33.
106. Dauchy X, Boiteux V, Bach C, et al. *Chemosphere*, 2017; **183**:53-61.
107. Houtz EF, Sutton R, Park JS, et al. *Water Res*, 2016; **95**142-149.
108. Lin Q, Zhou C, Chen L, et al. *Chemosphere,* 2020; **249**; 126447.
109. Wen B, Wu Y, Zhang H, et al. *Environmental Pollution,* 2016; 216: 682-688.
110. Yamazaki E, Taniyasu S, Ruan Y, et al. *Chemosphere*, 2019; **231:** 487-494.
111. Zhao H, Guan Y, Qu B. *Int J Phytoremediation*, 2018; **20**: 68-74.
112. Navarro I, de la Torre A, Sanz P, et al. *Environ Res,* 2017152 (2017) 199-206.
113. Felizeter S, McLachlan MS, De Voogt P. *J Agric Food Chem*, 2014; **62**:3334-3342.
114. Blaine AC,. Rich CD, Sedlacko EM, et al. *Environ Sci Technol*, 2014; **48**:14361–14368.
115. Zhao S, Liang T, Zhu L, et al, *Environ Pollut,* 2019; **252**: 804-812.
116. Lal MS, Megharaj M, Naidu R, et al. *Environ Technol Innov*, 2020; **19**:100863.
117. Lechner M, Knapp H, *J Agric Food Chem,* 2011; **59:**11011–11018.
118. Chen H, Wang X, Zhang C, et al.**,** *Environ Pollut*, 2017; **221**: 234- 243.
119. Schmidt N, Fauvelle V, JavierCastro-Jiménez J, et al. *Marine Pollution Bulletin ,* 2019; **149**:110491.
120. Li J, He J, Niu Z, et al. *Environment International*, 2020; **135**:105419.
121. Lan Z, Yao Y, Hu JY, et al. *Environmental Pollution*, 2020; **263**:114487.
122. Gallen C, Eaglesham G, Drage T, et al. *Chemosphere,* 2018; 208:975-983.
123. Boontanon S, Kunacheva C, Boontanon N, et al. *Journal of Environmental Engineering*, 2013; 139(4): 588-593.
124. UKWIR Volume 1 Part 2 (2015-2020) Monitoring of Sewage Effluents, Surface Waters and Sewage Sludge - Review of Programme Results and Conclusions. Published by UK Water Industry Research Limited, 3rd Floor, 36 Broadway, Westminster, London, SW1H 0BH, First published 2020.
125. Margot J, Ross L, Barry DA, et al. *WIREs Water*, 2015; **2(5)**:457-487.
126. Lapworth DJ, Das P, Shaw A, et al. *Environ. Pollution,* 2018; **240**:938-949.
127. Anderson AH, Long GC, Porter RC, et al. *Chemosphere,* 2016; **150**:678-685.
128. UNEP Global Monitoring Plan for Persistent Organic Pollutants Under the Stockholm Convention Article 16 on Effectiveness Evaluation 1-129, 2017.http://chm.pops.int/Portals/0/download. aspx?d=UNEP-POPS-COP.8-INF-38.English.pdf.
129. Al-Mamun MH, Ahmed MK, Raknuzzaman M, et al. *Science of The Total Environment*, 2016; 571: 1089-1104.
130. Selvaraj KK, Murugasamy M, Nikhil NP, et al. *Chemosphere,* 2021; 277:130228.
131. Maine Department of Environmental Protection: Maine's Unique PFAS Site Investigation, Protecting Maine's Air, Land and Water. www.maine.gov, 2019.
132. Chu S, Letcher RJ. *Sci Total Environ,* 2017; **607–608**: 262–270.
133. Li N, Ying GG, Hong H, et al. *Environ Pollut,* 2021; **270**:116219.
134. Wei C, Wang Q, Song S, et al. *Ecotoxicology and Environmental Safety,* 2018;**152**:141-150.
135. Semerád J, Hatasová N, Grasserová A, et al. *Chemosphere,* 2020; 261:128018.
136. Letcher RJ, Chu S, Smyth C-A. *Journal of Hazardous Materials,* 2020; 122044.

137. Na S, Hai R, Li N, et al., *Analytical Letters,* 2020;**53**:2400-2412.
138. Tavasoli E, Luek JL, Malley JP Jr, et al. *Env Sci Process Impacts*, 2021; **23 (4)**:903-913.
139. Wang TT, Ying GG, He LY, et al. *Sci Total Environ,* 2020; **733**:139383.
140. Munoz G, Budzinski H, Babut M, et al. *Chemosphere*, 2019; **233**; 319–326.
141. Campo J, Pérez F, Masiá A, et al. *Sci. Total Environ*, 2015; **503–504**: 48-57.
142. Shi Y, Vestergren R, Nost TH, et al. *Environ Sci Technol,* 2018; **52**: 4592-4600.
143. Zhou Y, Zhou Z, Lian Y, et al., *Food Chem*, 2021; **349** (**8**):129137.
144. Mussabek D, Ahrens L, Persson KM, et al., *Chemosphere,* 2017; 227: 624-629.
145. Liu L, Qu Y, Huang J, et al. *Environ Sci Eur*, 2021; 33(6):
146. Guradian MG, Boongaling EG, Ross B, et al. *Chemosphere*, 2020; **256**: 127115.
147. Sungur S., *Toxin Rev*, 2018; **37 (2)**: 106-116.
148. K. Rankin K, Mabury SA, Jekins TM, et al., *Chemosphere,* 2016; **161;** 333-341.
149. Mattias S, Kikuchi J, Wiberg K, et al. *Chemosphere,* 2022; **295:** 133944.
150. Shoeib T. *Chemosphere,* 2016; 144:1573-1581.
151. Zhao S, Zhou T, Wang B, et al. *J Hazard Mater,* 2018; **46**:191- 198.
152. Bräunig J, Baduel C, Barnes CM, et al. *Sci Total Environ,* 219; **646**: 471-479.
153. Zhu H, Kannan K. *Sci Total Environ,*2019; **647**;954-961
154. Babut M, Labadie P, Simonnet-Laprade C, et al. *Science of the Total Environment*, 2017; **605-606**:38-47.
155. Chen S, Zhou Y, Meng J, et al. *Environmental Pollution,* 2018; **242**:2059-2067.
156. Gao Y, Li X, Li X, et al. *J. Chromatography (B) Analyt. Technol. Biomed. Life Sci,* 2018; **1084:**45-52.
157. Dai Z, Zeng F. *J. Chem*, 2019; 2019:2612853.
158. Schultes L, Sandblom O, Broeg K, et al. *Environ. Toxicol. Chem*, 2020; 39: 300-309.
159. Zafeiraki E, Gebbink WA, S.P.J.van Leeuwen SPJ, et al. *Environ. Pollut,* 2019; **252**:379-387.
160. Fair PA, Wolf B, White ND, et al. *Environ. Res*, 2019; **171**:266-277.
161. Cui WJ, Peng JX, Tan ZJ, et al. *Huan Jing Ke Xue,* 2019; **40**:3990-3999.
162. Spaan KM, van Noordenburg C, Plassmann MM, et al. *Environ. Sci Technol*, 2020; **54:** 4046-4058.
163. Teunen L, Bervoets L, Belpaire C, et al. *Environ Sci Eur*, 2021; **33:**39.
164. Pascariello S, Mazzoni M, Bettinetti R, et al. *Water,* 2019;**11:** 1901.
165. He X, Dai K, Li A, et al. *Food Chem*, 2015; **174**: 180-187.
166. Zheng G, Miller P, von Hippel FA, et al. *Environ. Pollut,* 2020; **259:**113872.
167. Kwadijk CJAF, Kotterman M, Koelmans AA. *Environ Toxicol Chem,* 2014; **33**:1761-1765.
168. Ahrens L, Norström K, Viktor T, et al. *Chemosphere,* 2015; **129**:33-38.
169. Langberg HA, Hale SE, Breedveld GD, et al. *Environ Sci Processes Impacts,* 2022; **24**:330-342.
170. Ren J, Point AD, Baygi SF, et al. *Science Of The Total Environment*, 2022: **819**:152974.
171. Al- Mamun MH, Ahmed MK, Raknuzzaman M, et al. *Marine Pollution Bulletin*, 2017; **124(2)**:775-785.
172. Colli-Dula RC, Martyniuk CJ, Streets S, et al. *Comparative Biochemistry and Physiology Part D: Genomics and Proteomics,* 2016; **19**:129-139.