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PFAS in drinking water in India - A review

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Abstract
PFAS, or per- and polyfluoroalkyl substances, are a large group of chemicals used in a wide range of consumer products, including firefighting foam, textiles, food packaging, and personal care products. Because PFAS are highly persistent and can accumulate in humans to toxic levels, there are concerns about the long-term effects of exposure. PFAS in drinking water is an emerging environmental and public health concern in India, and information on concentrations in drinking water, including surface and groundwater, is limited. As India continues its path towards sustainable development, regulations are needed to prevent further PFAS contamination of drinking water and to set safe limits for drinking water. A nationwide monitoring network for PFAS in drinking water is needed, and infrastructure and technology investments for water treatment should be prioritized, especially in vulnerable communities.
Research should focus on generating key data, highlighting factual inaccuracies, and suggesting safe substitutes for PFAS, in order to support evidence-based policy making. Multisectoral action is needed to reduce the risks of PFAS exposure through drinking water consumption in India, including technical developments, improved public knowledge, and community engagement.

Keywords: PFAS, drinking water, regulations, human health
Emneord: PFAS, drikkevann, reguleringer, human helse

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Preface

Access to clean and safe drinking water is a fundamental human right and a cornerstone of public health. However, the presence of per- and polyfluoroalkyl substances (PFAS) in drinking water sources presents a pressing challenge that demands urgent attention. PFAS, often referred to as “forever chemicals” pose significant risks to human health and ecosystems. Despite growing global concerns and regulatory advancements, the issue remains largely underexamined in India, where gaps in monitoring and public awareness persist.

This report seeks to bridge these knowledge gaps by providing a comprehensive analysis of PFAS contamination in drinking water in India. It traces the historical context of PFAS usage, identifies their sources, and examines their transport and accumulation in water systems. It also highlights the human health risks associated with PFAS exposure, drawing from scientific evidence and risk assessment studies worldwide. It focuses on the status of PFAS monitoring and regulatory frameworks both globally and in India. While international organizations such as the WHO and regulatory bodies in North America, Europe, and the Asia-Pacific have established guidelines for management of PFAS in drinking water, India lacks a robust framework to address this emerging contaminant. This report critically evaluates the limitations in India's current approach and underscores the need for targeted interventions.

To address these challenges, this report proposes a set of policy recommendations aimed at strengthening PFAS management in India. These recommendations include establishing national guidelines for PFAS in drinking water, launching a nationwide PFAS monitoring program, investing in advanced water treatment technologies, and fostering collaboration among government agencies, industries, and civil society. Moreover, it advocates greater public engagement, capacity building efforts, public education campaigns, and targeted protection measures for vulnerable communities

The insights presented in this report are intended to inform policymakers, researchers, and stakeholders working towards enhancing water quality and public health in India. By addressing PFAS contamination through science-based policies, regulatory enhancements, and community-driven solutions, India can take decisive steps toward safeguarding its drinking water sources and ensuring a healthier future for its citizens.

We hope this report of the INOPOL project, funded by the Royal Norwegian Embassy in New Delhi (IND-3025, IND-22/0004) serves as a valuable resource for all stakeholders and institutions committed to mitigating PFAS pollution and advancing sustainable water management in India.

From the Indian side (Mu Gamma Consultants), Avanti Roy-Basu was primary responsible for writing the report. Merete Grung from NIVA has contributed to text covering European regulations and fate of PFAS in the environment. The other authors have contributed to smaller parts of the text, revision, and editing. Hans Adam is the main project leader of INOPOL at NIVA.

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Oslo, 22.04.2025

Summary

This report explores the presence, risks, and management of per- and polyfluoroalkyl substances (PFAS) in India's drinking water. It covers the history, sources, uses and applications of PFAS, emphasizing their widespread occurrence and persistence in the environment. It takes a close look at the fate and transport mechanisms of PFAS in the water systems, including how they accumulate in water treatment plants. The public health risks and impacts of PFAS exposure are discussed, backed by strong scientific evidence and risk assessment results. A review of global and regional monitoring efforts follows, along with a discussion on the challenges of detecting PFAS. Next, the report critically discusses the PFAS regulations around the world, including frameworks from the WHO, EFSA, and various other regions like North America, Europe, and the Asia-Pacific. The paper then shifts focus to India, assessing the extent of PFAS contamination, potential sources, and pinpoint the gaps in current regulations. It highlights the challenges of funding and technical resources for PFAS monitoring and the urgent need for better wastewater treatment regulations. The opportunities for improvement are also explored, including the need in setting up real-time monitoring systems, raising public awareness, and training stakeholders on how to manage PFAS.

The envisaged output of the report is a set of policy recommendations that emphasize the need for stronger regulations, better stakeholder engagement, clearer risk communication, and environmental justice. Specifically, it calls for incorporating PFAS standards into the BIS drinking water quality standards (IS-10500). A quick rundown of the key recommendations is as follows:

- Develop clear national guidelines for PFAS in drinking water, based on international standards.
- Create a national PFAS monitoring programme for drinking water sources.
- Invest in water treatment technologies and research to pinpoint the sources of PFAS pollution.
- Develop a real-time map on PFAS contamination in public and private water systems, pollution hotspots, and affected population groups.
- Regulate industrial discharge and encourage industries to adopt PFAS alternatives.
- Promote public-private partnerships to effectively manage PFAS risks.
- Ensure equitable access to clean water, especially in vulnerable communities, through technical assistance and capacity-building initiatives.
- Run education campaigns to raise public awareness about PFAS risks and how to reduce them.
- Work with government ministries and engage with stakeholders like industries, NGOs, and local communities.
- Make targeted efforts to ensure that vulnerable, low-income communities have access to clean water and are involved in decision-making processes related to water quality.

In short, this report calls for stronger policies, better monitoring, improved infrastructure, community engagement, and collaborative efforts to manage PFAS contamination in India's drinking water and ensure safe drinking water for everyone.

Sammendrag

Denne rapporten undersøker forekomst, risiko og håndtering av per- og polyfluoralkylstoffer (PFAS) i drikkevann i India. Rapporten tar for seg PFAS-stoffenes historie, kilder, bruksområder og forbruk, og legger vekt på stoffenes utbredte forekomst og persistens i miljøet. Videre ses det nærmere på PFAS-stoffenes skjebne og mobilitet i vannmiljøet, og rapporten har økt oppmerksomhet på hvordan konsentrasjonene til stoffene vil øke i råvann før det behandles videre i vannbehandlingsanlegg. Risiko for folkehelse og konsekvensene av PFAS-eksponering diskuteres med henvisninger fra publiserte artikler, rapporter og risikovurderinger. En oversikt over globale og regionale overvåkingsstrategier presenteres, samt tiltak dersom PFAS påvises i drikkevann. Rapporten diskuterer PFAS-regelverket fra WHO, EFSA og ulike andre regioner som Nord-Amerika, Europa og Asia-Stillehavsregionen. Videre omhandler rapporten tilstanden i India, der omfanget av PFAS-forurensning og mulige kilder vurderes, og mangler i dagens regelverk kartlegges. Til slutt fremheves utfordringene knyttet til finansiering og tekniske ressurser for PFAS-overvåking og det økte behovet for bedre reguleringer for rensing av avløpsvann. Mulighetene for forbedringer, blant annet behovet for å etablere overvåkingssystemer i sanntid, øke bevisstheten i befolkningen og gi interessenter opplæring i hvordan de skal håndtere PFAS er undersøkt.

Et mål med rapporten er å komme fram til fremtidige politiske anbefalinger, som understreker behovet for strengere reguleringer, bedre interessentengasjement, tydeligere risikokommunikasjon og miljørettferdighet. Det oppfordres til å innlemme PFAS-standarder i BIS drikkevannskvalitetsstandarder (IS-10500). En kort oversikt over de viktigste anbefalingene er som følger:

- Utvikle klare nasjonale retningslinjer for håndtering av PFAS i drikkevann, basert på internasjonale standarder.
- Utforme et nasjonalt PFAS-overvåkingsprogram for drikkevannskilder.
- Investere i vannbehandlingsteknologier og forskning for å finne kildene til PFAS-forurensning.
- Utvikle et sanntidskart over PFAS-forurensning i offentlige og private vannsystemer, forurensningskilder og berørte befolkningsgrupper.
- Regulere industriutslipp og oppmuntre industrier til å ta i bruk PFAS-alternativer.
- Fremme offentlig-private partnerskap for effektivt å håndtere PFAS-risikoer.
- Sikre rettferdig tilgang til rent vann, spesielt i sårbare samfunn, gjennom teknisk assistanse og kapasitetsbyggingsinitiativer.
- Gjennomføre utdanningskampanjer for å øke offentlig bevissthet om PFAS-risiko og hvordan den kan reduseres.
- Samarbeide med offentlige departementer og engasjere interessenter som industri, frivillige organisasjoner og lokalsamfunn.
- Gjøre en målrettet innsats for å sikre at sårbare lavinntektssamfunn har tilgang til rent vann og er involvert i beslutningsprosesser knyttet til vannkvalitet.

Oppsummert etterlyser denne rapporten strengere retningslinjer, bedre overvåking, forbedret infrastruktur, samfunnsengasjement og samarbeid for å håndtere PFAS-forurensning i Indias drikkevann og sikre trygt drikkevann for alle.

1 Introduction

PFAS, or per- and polyfluoroalkyl substances, are a large class of more than 38,000 chemicals, commonly found in various consumer products owing to their unique properties—such as resistance to heat, grease, water, and oil. They are also known as "forever chemicals" (Wee & Aris, 2023) because they don't break down easily in the environment. In 2021, a definition of PFAS was published by Wang et al., (2021):

"PFAS are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H, Cl, Br or I atom attached to it), i.e., with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS". The "noted exceptions" refer to a carbon atom with a H, Cl, Br or I atom attached to it". Many PFAS function as surfactants, containing an ionic head (often carboxylic- or sulfonic acid) and a lipophilic chain (C6-C18) Sharma et al., (2024). This amphiphilic structure, comprising a hydrophobic tail and a hydrophilic head allows them to accumulate at fluid-fluid interfaces, aligning along the air-water boundary with their hydrophilic heads in the water and hydrophobic tails in the air (ITRC, 2023).Most PFAS are therefore both hydrophobic and lipophobic, and they are extremely persistent in the environment due to the strength of the carbon-fluorine bond (Sharma et al., 2024). PFAS can contaminate drinking water sources through industrial discharges, firefighting foams, consumer products, and other pathways. Notably, PFAS have also been detected in rainwater (Cousins et al., 2022).

The extreme persistence of PFAS and the fact that several PFAS can accumulate in human bodies, raise concerns about long-term exposure effects, including potential links to serious human health issues (Wang et al., 2017; EFSA Panel on Contaminants in the Food Chain (EFSA CONTAM Panel, 2020; EFSA CONTAM Panel., 2020). Research has linked PFAS exposure to a variety of human health challenges, that are discussed in greater detail in Section 4. EFSA's CONTAM Panel (2020), however, made some specific observations about health outcomes of PFAS. Limited or no evidence of PFOS/PFOA exposure was linked to carcinogenic incidence or mortality. It also observed that drinking water, either directly through consumption or using water for cooking, contributes significantly to total exposure to PFASs for various population groups and locations. The exposure to PFAS may vary by age, gender, and socioeconomic level. The greatest concern is for vulnerable groups, such as children and fetuses, who may be more susceptible to the adverse effects of these chemicals (National Institute of Environmental Health Sciences (NIEHS), 2022).

Despite extensive research over the past 20 years, critical knowledge gaps persist in detection methods, risk quantification, and long-term health outcomes. Additionally, industries lack transparency regarding PFAS production and usage. As society seeks effective regulatory measures to manage PFAS exposure, significant challenges remain in understanding and addressing the "PFAS problem." While PFAS pollution has been extensively studied in developed nations, Indian perspectives remain underexplored, necessitating a localized approach to risk assessment, policy action, and mitigation strategies. This report provides a comprehensive overview of PFAS contamination in India's drinking water, focusing on its sources, environmental and public health implications, and regulatory landscape. The report examines India's challenges in managing PFAS contamination, highlights monitoring and regulation gaps, and proposes science-based solutions to safeguard drinking water quality. By drawing insights from international best practices and tailoring them to India's unique socio-environmental context, this report seeks to inform policymakers, researchers, water managers, and regulatory bodies working toward a sustainable and effective response to PFAS pollution. This report serves as a resource to advance India's water safety goals, promote collaboration, and ensure safe and accessible drinking water for current and future generations.

2 History, sources, and uses of PFAS

PFAS were first developed in the 1940s due to their chemical stability and resistance to heat and water. One of the earliest and most well-known PFAS is polytetrafluoroethylene (PTFE), commonly known as Teflon, which was introduced in 1941. PTFE belongs to the group of fluorinated polymers and has quite different properties from “chemical PFAS” (PFOS and PFOA). PTFE is considered stable at low temperatures, but at elevated temperatures it breaks down to smaller PFAS, which poses risks to human health and the environment. Over the following decades, PFAS were increasingly used in various applications, including non-stick coatings, water-repellent fabrics, and food packaging. By the late 20th century, concerns about the environmental persistence and potential health effects of PFAS began to surface. Studies showed that these chemicals persist in the environment, contaminating soil and water on a wide scale. They are widely distributed in the global environment due to their extensive use, low/moderate sorption to soils and sediments, and are therefore resistant to biological and chemical degradation. In the early 2000s, major manufacturers started phasing out certain PFAS compounds, particularly perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), due to regulatory pressure and growing public concern (USEPA, 2015).

2.1 Sources of PFAS

As noted earlier, PFAS are hydrophilic due to their polar functional groups, but also have hydrophobic fluorinated carbon chains. This amphiphilic nature enhances their environmental mobility and potential to contaminate drinking water through the following sources (Trobisch et al., 2024 ; Post, 2021):

Industrial discharges: Facilities that manufacture or use PFAS (like chemical manufacturing plants, textile mills, and paper mills) can release these chemicals into the air, soil as well as surface water bodies that may serve as drinking water sources. PFAS can also volatilize from industrial emissions, travel through the air, and deposit onto water bodies via precipitation (Yamazaki et al., 2025).

Firefighting foam: Aqueous film-forming foams (AFFF), used in firefighting, particularly at airports and military bases, contain high levels of PFAS. Runoff from training exercises and incidents can contaminate nearby groundwater and surface water sources. Communities near industrial sites or military bases often face higher risks of PFAS exposure (McGarr et al., 2023).

Landfills and WWTP (wastewater treatment plants): PFAS from waste, consumer products, and biosolids in landfills can leach into groundwater or be discharged into water bodies via WWTPs as conventional treatment methods are often ineffective at removing them (Randazzo et al., 2025). Common consumer items like non-stick cookware, stain-resistant carpets, and certain food packaging, when discarded, can also be sources of PFAS contamination.

Agricultural runoff: PFAS can be present in fertilizers and biosolids used in agriculture, leading to contamination of crops and nearby groundwater and surface water sources. Wastewater collected by treatment plants from upstream sources, such as houses, landfills, and industrial facilities, may have PFAS in the biosolid (USEPA, 2024d; USEPA, 2024).

Leaching from plumbing materials: PFAS can migrate from certain plumbing materials, including pipes, coatings, and outdated infrastructure into drinking water systems during firefighting or at industrial sites (Szabo et al., 2023).

2.2 Uses of PFAS

PFAS have been utilized in a wide range of applications due to their thermal and chemical resistance (USEPA, 2021; Cousins et al., 2020), some of the uses of PFAS are mentioned below:

Firefighting foam: Firefighting foam (Class B) is used to put out flames caused by flammable liquids (liquid hydrocarbon fuels). They include AFFF (aqueous film forming foam), fluoroprotein foams (FP), or film-forming fluoroprotein foams (FFFP), all of which are fluorosurfactants, (that contain PFAS), and used to put out large fuel fires (Cousins et al., 2019).

Food packaging: PFAS are used in food wrappers, microwave popcorn bags, and pizza boxes to repel grease and oil (Dueñas-Mas et al., 2023). Paper-based food packaging may contain high levels of PFAS, which are used to increase water and fat resistance (Carney Almroth et al., 2023).

Textiles: Many outdoor and performance fabrics (carpets, rugs, upholstery, curtains, tablecloths, bedding, canvas, rope, and sails) are treated with PFAS to make them water- and stain-resistant (Schellenberger et al., 2022).

Cleaning products: Some cleaning agents and surface protectants contain PFAS for their stain-resistant properties (Green Science Policy Institute, 2025).

Aerospace and automotive: PFAS are used in certain parts in the aerospace crafts and automobiles for their chemical stability and resistance to high temperatures (Acquisition & Sustainment (ACQ) Office of the Under Secretary of Defense, 2023).

Cosmetics and personal care products (PCP): PFAS are found in cosmetics, shampoos, nail polish, eye makeup, denture cleaners, eye drops, contact lenses, and others (Harris et al., 2022).

Biocides: PFAS are used as inert enhancing components in pesticides; perfluoroalkyl phosphonic and phosphinic acids (PFPAs and PFPiAs) as anti-foaming agents in solutions; EtFOSA (sulfluramid) in ant and termite baits; and short-chain sulfonamides in plant growth regulators and herbicides.

Lithium-ion batteries: They are a key component of sustainable energy technologies, but their production and disposal may lead to the release of PFAS into the environment (Guelfo et al., 2024).

Laboratory supplies and equipment: Products that contain PFAS, especially fluoropolymers, are widely used in laboratories, analytical equipment, and laboratory supplies (Cousins et al., 2019).

Medical devices: To lower friction and improve clot resistance, fluoropolymers are applied as coatings to catheters, stents, and needles. They are also used to provide protein resistance in filters, tubing, O-rings, seals, and gaskets used in kidney dialysis machines and immunodiagnostic devices (Cousins et al., 2019).

Pharmaceuticals: A wide range of pharmaceuticals contain fluorine constituents including fluoroalkyl groups (some of which qualify as PFAS depending on their structure), which is used to enhance biological half-life, bioabsorption, and pharmacological efficacy (Cousins et al., 2019).

3 Fate and transport of PFAS in drinking water

PFAS are persistent chemicals of growing concern in drinking water and potential health risks (Wee & Aris, 2023b). Compounds like perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) are transported in water systems based on their chemical properties, environmental conditions, and interactions with soils and sediments. These characteristics make managing PFAS contamination particularly difficult.

Several environmental factors influence the transport and fate of PFAS in water systems, primarily through their interactions with soil, sediments, and water (ITRC, 2023). In addition, the inherent properties of the PFAS can be described by the following parameters/terms (European Parliament and Council, 2006):

log Kow refers to the logarithm of the octanol-water partition coefficient (Kow), a measure of a substance's tendency to dissolve in an organic solvent (octanol) versus water, which is useful for predicting its environmental fate and bioaccumulation potential.

Kd (soil-water distribution coefficient) and **Koc** (organic carbon-water distribution coefficient) are distribution coefficients used to assess how a substance partitions between soil/sediment (or the organic carbon in soil/sediment) and water, helping estimate leaching and mobility in the environment.

Volatility, indicated by vapor pressure, affects how PFAS enter the air; higher vapor pressure means a substance is more volatile.

pKa is the acid dissociation constant, expressed as a negative logarithm, which indicates the acidity or strength of an acid, specifically in relation to its ability to donate a proton (H+) in an aqueous solution.

Persistence (P): PFAS are highly resistant to degradation, meaning they don't break down easily in the environment (water, soil, air, or in the human body). **Very persistent (vP):** The European Union's chemical regulation REACH (Regulation (EC)1907/2006 REACH, 2006) states the criteria for the classifications of P/vP. Many PFAS are classified as vP[1] due to their high resistance to degradation.

Soil composition: Soil rich in organic matter and clay promotes sorption, particularly for long-chain PFAS, which reduces their mobility, and results in soil becoming a persistent environmental reservoir for PFAS contamination. In contrast, sandy or soils with low organic content allow PFAS to move more freely into groundwater, increasing their spread.

Water chemistry: The pH, salinity, and ion content of water affect how PFAS interacts with soil and sediments. Salinity can influence the fate of PFASs in aquatic or marine environment. In a study on the sorption kinetics of long-chain and emerging PFASs on sediment at various salinities, it was found that the increase in salinity resulted in the decrease of desorption rate of PFASs from marine sediment (Yin et al., 2022).

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[1]*A substance fulfils the 'very persistent' criterion (vP) in any of the following situations:*

a) *The degradation half-life in marine, fresh or estuarine water is higher than 60 days.*
b) *The degradation half-life in marine, fresh or estuarine water sediment is higher than 180 days.*
c) *The degradation half-life in soil is higher than 180 days.*

Hydrological factors: Water flow rates and patterns play a critical role in PFAS transport. Fast-moving water can speed up the spread of PFAS, while stagnant or slow-moving waters allow more accumulation in sediments, where long-chain PFAS can remain bound for long periods.

Sorption and mobility: Long-chain PFAS are more likely to adsorb to organic matter and sediments, reducing their mobility but leading to long-term contamination. Short-chain PFAS, being more water-soluble, remain dissolved in water, spreading more easily and potentially affecting larger areas, including drinking water sources. Different types of PFAS behave differently in water. For example, PFAS with carboxylic acid end-groups dissolve more easily in water than those with sulphonic acid end-groups, even if they have the same chain length. This affects how PFAS attaches to or detaches from sediments, which is measured using partitioning coefficients like Kd (distribution coefficient) or Koc (organic carbon-water partition coefficient; described above). These values help determine how strongly PFAS bind to sediments versus how easily it moves through water (ITRC, 2023).

Partitioning: PFAS can transition between air, water, and solids. Long-chain PFAS tend to partition to sediments, while short-chain PFAS are more likely to remain dissolved in the water column, allowing them to travel farther.

Long-range transport: Certain PFAS can undergo long-range atmospheric transport, leading to their accumulation in remote regions such as Arctic snow and ice (Hartz et al., 2024) as well as air, aquatic environments (fresh and salt water) and wildlife including polar bears, whales, seals, and birds (Muir et al., 2019).

Bioaccumulation: Certain PFAS do not break down and can bioaccumulate over time in the environment and in human or animal body, which may result in negative health effects. PFAS elimination rates differ depending on chemical structure, chain length, and the organism involved. In rodents, half-lives range from a few hours to several weeks, generally much shorter than in humans. In humans, the half-lives of short-chain PFAS (PFBA, PFBS, PFHxA) range from a few days to about one month, while long-chain PFAS (PFOA, PFNA, PFDA, PFHxS, PFOS) can persist for several years. The prolonged elimination of long-chain PFASs is primarily due to their interaction with transporters involved in reabsorption processes in the liver, intestines, and kidneys (EFSA CONTAM Panel, 2020).

Biomagnification: PFAS can biomagnify in food webs wherein their concentration rises as they make their way up the food chain. Research shows the unique bioaccumulation properties of PFAS, indicating that most PFAS function as surfactants, meaning they have both water-soluble and fat-soluble characteristics, particularly in longer-chain compounds. Unlike persistent organic pollutants (such as PCBs and PBDEs), which primarily accumulate in fatty tissues, PFAS exhibit a different bioaccumulation mechanism due to their strong affinity for proteins. This difference influences how PFAS behave in aquatic food webs. Specifically, PFOS has been observed to biomagnify in fish, binding to proteins rather than lipids, which distinguishes its environmental behavior from that of traditional lipophilic contaminants (Conder et al., 2008; Liang et al., 2023).

Microbial degradation occurs when microorganisms transform PFAS (to derive energy and nutrients for growth) into shorter-chained compounds. In general, the strong C-F bonds in PFAS enhance their resistance to degradation and heat, making them extremely persistent and not susceptible to microbial degradation. However, during biological treatment, it is seen that microbial species may cleave the C-F bond in PFAS compound either by oxidation (oxygen addition across C-F bond) or reduction (electron addition across C-F bond). Non-fluorinated carbons and the position of functional groups can influence biotransformation pathways. Bacterial species such as *Gordonia, Acidimicrobium,* and *Pseudomonas* can degrade PFAS under both anaerobic and aerobic conditions, though primarily through aerobic degradation. Microalgae such as *Scenedesmus*, *Chlorella*, and *Chlamydomonas* as well as some fungi are capable of degrading PFAS (Bhattacharya et al., 2025). These combined factors determine how PFAS behave in water systems and influence the complexity of their removal and containment (Guelfo et al., 2021).

3.1 Transport mechanisms in water systems

Building on the previous section, PFAS can move through water systems via the following routes:

Groundwater transport: PFAS can leach into groundwater, and this is observed especially near airports, military sites, industrial sites or landfills. Short-chain PFAS move faster than long-chain PFAS, spreading over large areas and entering drinking water wells (Li & MacDonald Gibson, 2022).

Surface water transport: PFAS can enter rivers, lakes, and reservoirs via industrial discharges, runoff, or wastewater. They may adsorb to sediments or remain in the water column, traveling downstream (ITRC, 2023).

Sea spray transport: PFAS enter the ocean through wastewater discharges, runoff, and atmospheric deposition. Once in the ocean, PFAS can concentrate at the sea surface microlayer, which interacts directly with the atmosphere. Wave breaking and air bubble bursting create sea spray aerosols that are enriched with PFAS. These aerosols can then be transported by wind back onto land, leading to re-deposition of PFAS in coastal and even inland areas (Sha et al., 2024).

Sorption and desorption: Long-chain PFAS comprise perfluoroalkyl carboxylic acids (PFCAs) containing not less than seven perfluorinated C atoms and perfluoroalkyl sulfonates (PFSAs) containing not less than six perfluorinated C atoms. Long-chain PFAS tend to bind to soil and sediment, slowing their movement. However, environmental changes can release them back into the water (ITRC, 2023) .

3.2 Fate of PFAS in drinking water

Understanding the fate of PFAS in drinking water involves several factors:

Persistence and bioaccumulation - PFAS exhibit exceptional stability, allowing them to persist in water for extended periods. Once PFAS enter drinking water sources, they can persist for extended periods, bioaccumulating in wildlife and moving up the food chain, posing ongoing risks to ecosystems and humans who consume contaminated water or species (Sadia et al., 2023).

Chemical degradation: The strong carbon-fluorine bonds make PFAS resistant to hydrolysis, photolysis, or oxidation.

Biodegradation: Their chemical structure hinders microbial processes from effectively breaking them down.

3.3 Accumulation in water treatment systems

PFAS can accumulate in drinking water systems over time due to their persistence. Conventional water treatment processes are generally ineffective at removing PFAS, allowing these chemicals to persist in treated water supplies. A study by Kang et al., (2025) highlights the persistence of PFAS in treated drinking water, indicating the limitations of conventional water treatment processes in effectively removing PFAS. While certain methods like granular activated carbon (GAC) and coagulation/sedimentation showed some efficiency in reducing high-molecular-weight PFAS, other commonly used treatments (preozonation, ozonation, and chlorination) were largely ineffective. The detection of short-chain PFAS in both raw and treated water, likely due to industrial sources and precursor breakdown, further underscores the challenge of eliminating these chemicals from drinking water supplies.

Coagulation and sedimentation: These processes remove particulate matter but not dissolved PFAS. Coagulation and sedimentation can remove parts of the PFAS that bind strongly to the particulate matter. The removal efficiency by coagulation and sedimentation increases with hydrophobicity, similar to the trend observed with GAC (Kang et al., 2025).

Filtration and disinfection: Conventional methods (e.g., chlorine treatment) do not break down or remove PFAS.

Activated carbon: Significant removal of long chain PFAS such as PFOS was found from water treatment works involving activated carbon in addition to coagulation and sedimentation (Grung et al., 2024). GAC and powder activated carbon (PAC) showed significant effectiveness in removing PFAS in drinking water treatment plants. According to Pan et al., (2016), PFAS detected in tap water are not expected to pose immediate health risks from short-term exposure. In wastewater treatment plants, conventional activated sludge treatment was largely ineffective in eliminating most PFAS. In contrast, advanced treatment methods such as membrane bioreactors (MBR) and Unitank showed moderate efficiency, removing approximately 50% of long-chain ($C \geq 8$) perfluorocarboxylic acids (PFCAs) (Pan et al., 2016).

The fate and transport of PFAS in drinking water are largely defined by their chemical stability, environmental persistence, and water solubility. Very short-chained PFAS tend to “accumulate” in water since current water treatment systems are unable to remove them. Since they are very persistent, the concentration in water will increase with time. Once introduced into water systems, PFAS persists due to their resistance to degradation and limited removal by conventional treatment methods. In a 2024 study, the concentrations of all eight target PFAS increased in the water treatment plant's processed water compared to raw water that the authors reasoned with unknown precursors that changed into more stable PFAS end-products during the treatment process (Koulini et al., 2024). The “accumulation” of PFAS in drinking water raise potential health risks. This necessitates the adoption of advanced treatment technologies and strict regulations to mitigate their impact on human health and the environment. The EU has recently introduced a new hazard class to mitigate risk from such substances under the REACH regulation (Hale et al., 2020). "Persistent, Mobile and Toxic (PMT)" and "Very Persistent and Very Mobile (vPvM)" substances are considered to be of similar environmental concern as "Persistent, Bioaccumulative and Toxic (PBT)" and "Very Persistent and Very Bioaccumulative (vPvB)".

4 Impacts on human health

PFAS are widely used in industrial and consumer applications due to their durability and resistance to degradation. However, their persistence in the environment and potential for bioaccumulation have raised major concerns about their effects on human health. The key concerns relate to the consumption of contaminated drinking water and food, which is considered the major exposure route for humans. Various factors related to people’s exposure (dosage, frequency, route, and duration); individual response (sensitivity and disease burden); and other external determinants of health (access to safe water and good healthcare facilities) determine the associated risks and level of health impacts. PFAS can be present in the water, household products, workplace materials, and the surrounding environment, and can enter and affect the human system through the following routes:

- Consumption of PFAS-contaminated public drinking water systems as well as private drinking water wells **(Figure 1**; USEPA, 2024b).
- Water bodies at or close to hazardous waste facilities, landfills, and disposal sites can be sources of PFAS exposure. Landfilling and wastewater treatment do not eliminate PFAS but redistribute them across environmental media. PFAS leach from consumer products in landfills into leachate, which is transferred to wastewater treatment plants. PFAS persist in sludge and effluent, contaminating soil, water, and crops when biosolids are landfilled, incinerated, or used as agricultural applications. Incineration of PFAS-containing waste can release fluorinated greenhouse gases and products of incomplete combustion. PFAS may also remain in in incinerator ash, contributing to residual contamination. Such sources and pathways of PFAS discharges can affect human health near disposal sites (Stoiber et al., 2020) .
- Aqueous film-forming foams (AFFFs) containing PFAS are used to extinguish flammable liquid fires and are widely applied in training and emergency response at airports, shipyards, military bases, firefighting training facilities, etc., leading to significant human exposure (Sunderland et al., 2018).
- Consumption of PFAS contaminated food (seafood, fish, meat, egg, dairy products, etc). Fish caught from PFAS contaminated water and dairy products from livestock exposed to PFAS, can affect human health (USEPA, 2024b).
- Ground and surface water, as well as grazing animals on the land can be exposed to PFAS contamination when biosolids from wastewater treatment plants are applied as fertilizer on agricultural land (USEPA, 2024b).
- Manufacturing and chemical production facilities that produce or use PFAS, such as chrome plating, electronics, and certain textile and paper manufacturers, are significant sources (USEPA, 2024b).
- Food packaging, including grease-resistant paper, fast food containers, microwave popcorn bags, pizza boxes, and candy wrappers, is a significant source of PFAS exposure (USEPA, 2024b).
- Personal care products, such as certain shampoos, dental floss, and cosmetics, can contain PFAS, contributing to human exposure (USEPA, 2024b).

In India, major routes of PFAS exposure include contaminated drinking water, food, and via inhalation of PFAS-laden particles. PFAS chemicals are found in rivers, groundwater, and tap water, often due to industrial discharges, such as those from textile factories and other manufacturing facilities. These substances are detected in several Indian rivers, including the Ganges, Noyyal, and Cooum, as well as in groundwater used for drinking and irrigation. Additionally, PFAS contamination extends to food, with studies showing PFAS in fish and agricultural products from affected areas. Studies have detected elevated PFAS levels in the breast milk samples of women in Chidambaram, Kolkata, and Chennai. PFAS is also present in particulate air pollution, contributing to public health risks (International Pollutants Elimination Network (IPEN), 2019).

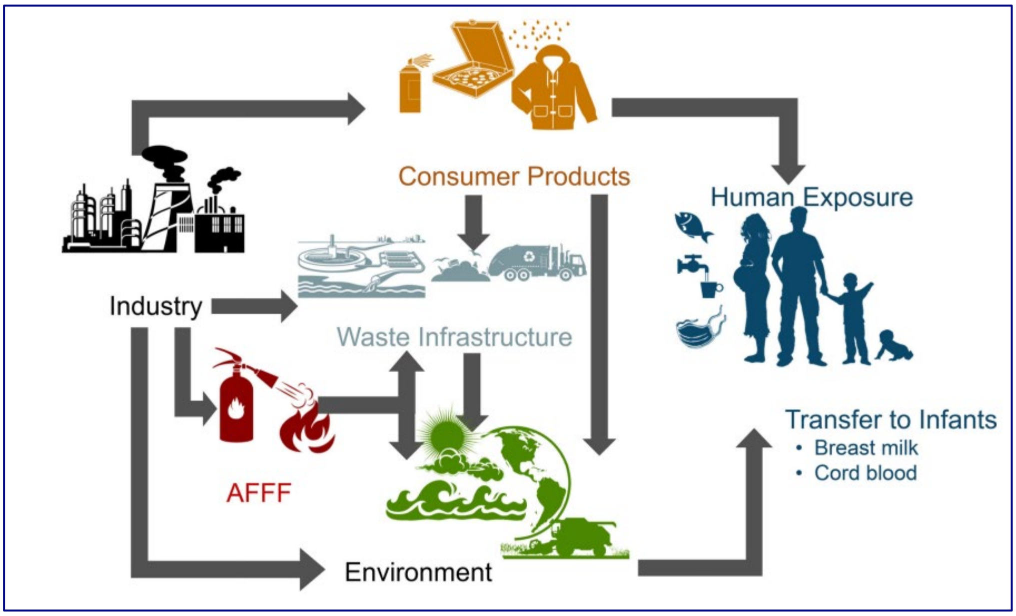

Figure 1. Overview of PFAS exposure for different human population groups (other than occupational exposure).

4.1 Human health risks and vulnerabilities

Reproductive and developmental effects: Preterm births, reduced birth weights, stunted fetal growth, and delayed fetal development have all been related to exposure to PFAS during pregnancy. Studies suggest that PFAS can cross the placental wall and may impact fetal development. Specific PFAS such as PFOA and PFOS have been associated with small reductions in birth weight. Exposure to PFAS has also been linked to lower fertility in both men and women, possibly due to effects on reproductive hormones, thereby leading to longer times to pregnancy (EFSA Panel on Contaminants in the Food Chain (EFSA CONTAM Panel), 2020). PFOA and PFOS causes pregnancy-induced hypertension and preeclampsia in women. Human breast milk samples from Chidambaram, Kolkata, and Chennai in India showed significant PFAS levels for PFOS, PFOA, PFHxS, and PFBS wherein the average PFOS levels averaged 46 pg/ml (Tao et al., 2008). Various studies on PFOS and PFOA since 2018 substantiate the causal association between PFOS and PFOA and birth weight (EFSA Panel on Contaminants in the Food Chain (EFSA CONTAM Panel), 2020) .

Reduced vaccine response: PFAS has the potential to impair immunity, lessening the body's capacity to react favourably to vaccinations (EFSA Panel on Contaminants in the Food Chain (EFSA CONTAM Panel), 2020). Specific PFAS, such as PFOA, PFOS, perfluorohexane sulfonate (PFHxS), and perfluorodecanoic acid (PFDA), are accountable for reducing the antibody response to certain immunizations. This raises particular concern for children since it can make them more susceptible to illnesses and infections that vaccinations are meant to prevent.

Enhanced risks of cancers: Research has linked exposure to PFAS to a higher risk of developing specific malignancies, including kidney and testicular cancer (International Pollutants Elimination Network (IPEN), 2019), primarily because of PFOA exposure. The risk is associated with PFAS-induced oxidative stress and cellular damage; however, physiological mechanisms are still being researched. It should be noted here that the International Agency for Research on Cancer (IARC) has classified PFOA as carcinogenic (Group 1) and PFOS as possibly carcinogenic (Group 2b) for humans (International Agency for Research on Cancer (IARC), 2025).

Modifications in liver enzymes: Changes in liver enzymes have been linked to elevated blood levels of PFAS, which may be a sign of inflammation or liver injury (Fenton et al., 2021). Researchers have linked persistent exposure to PFAS to severe liver diseases, such as non-alcoholic fatty liver disease (NAFLD)(Fenton et al., 2021). The occurrence of NAFLD cannot be entirely explained by the risk factors that are commonly known, such as diet, genetics, and sedentary lifestyle, and are linked to PFAS exposure. The common PFAS responsible for liver diseases are PFOA, PFOS, and PFHxS (Agency for Toxic Substances and Disease Registry (ATSDR), 2024b).

Interference with endocrine system: PFAS can interfere with the endocrine system's regular ability to regulate hormones. Hormonal disruption can result in thyroid disorders, change in the onset of puberty, and other potential effects on metabolic systems (International Pollutants Elimination Network (IPEN), 2019).

Other potential health impacts: Elevated cholesterol levels have been connected to PFAS exposure (mostly from PFOA, PFOS, PFNA, and PFDA), which may raise the risk of cardiovascular disorders (Agency for Toxic Substances and Disease Registry (ATSDR), 2024b). Serum concentrations of cholesterol are positively correlated with exposure to PFOA and PFOS in humans. This means exposure to these chemicals may be a likely factor in elevated blood cholesterol levels (EFSA Panel on Contaminants in the Food Chain (EFSA CONTAM Panel), 2020) . Scientific evidence also suggests that there may be a link between PFAS exposure and a higher risk of ulcerative colitis, an inflammatory bowel condition.

Summary of EFSA CONTAM Panel's assessment of human health outcomes related to the presence of PFAS in food

To accurately assess the potential health risks associated with PFAS exposure through food intake, the EFSA CONTAM Panel states that the limited amount of data available on PFAS occurrence — including a lack of comprehensive data on various PFAS types and their concentrations in different food sources— contributes significantly to the high uncertainty in current exposure assessments. EFSA CONTAM Panel notes that more comprehensive occurrence data are needed. The various health outcomes are summarized below:

Immune outcome: PFOS and PFOA are associated with reduced antibody response to vaccination, observed in several studies. Combined serum levels of PFOS, PFHxS, and PFOA during pregnancy and at age 5 years pre-booster vaccination showed a strong inverse association with serum antibody titres to diphtheria and/or tetanus at age 7.5 years.

Metabolic outcome: There is an association between exposure to PFOS, PFOA, and PFNA, and increased serum levels of cholesterol.

Fertility and pregnancy outcome: There may well be a causal association between PFOS and PFOA and birth weight.

Developmental outcome: Associations between prenatal exposure to PFOS or PFOA and early life neurobehavioral development or being overweight was considered insufficient.

Neurotoxic outcome: Consistent adverse associations were not found with serum levels of PFOS or PFOA. For other PFAS, there is insufficient evidence to conclude that its exposure may adversely affect neurobehavioral, neuropsychiatric and cognitive outcomes.

Carcinogenic outcome: While some studies found no evidence for carcinogenicity, the IARC classifies PFOA as a known carcinogen

4.2 Risk assessment: Evidence and scale of impact

4.2.1. Scientific evidence

Findings from epidemiological studies show links between exposure to PFAS and various health consequences, including impacts on immune, thyroid, kidney and liver function, negative reproductive and developmental outcomes, lipid and insulin dysregulation, and some cancers (Du et al., 2024). To establish these links, studies often measure PFAS levels in blood serum and monitor health outcomes over time. However, the long-term effects of chronic, low-level exposure through drinking water are not entirely understood, despite research showing the bioaccumulation of certain PFAS through drinking water sources.

Laboratory research on animals has demonstrated toxic effects of PFAS, corroborating results from human studies. These investigations frequently identify the mechanisms of toxicity, such as endocrine disruption and oxidative damage (Fenton et al., 2021). In laboratory animals, PFAS have been linked to immune system and liver damage, low birth weight, birth abnormalities, delayed development, and newborn mortality. Systematic reviews support a relationship between in-utero exposure to PFOA and PFOS and reduced fetal growth in animals (mice) and humans. Animal developmental toxicity studies involving maternal oral exposures during pregnancy and lactation and resulting in adverse effects in the offspring, are observed to be occurring at blood concentration levels nearly 1000 times higher than the general human population. These effects result from repeated oral doses of PFAS, **often used to simulate exposure through contaminated** drinking water (Rodriguez, 2021). However, humans and animal **responses to PFAS exposure vary** though most animal studies use PFAS doses significantly higher than typical environmental exposure **levels in humans** (Agency for Toxic Substances and Disease Registry (ATSDR), 2024b).

4.2.2. Scale of impact

PFAS pollution in drinking water affects millions of people worldwide and is a serious public health concern. PFAS in firefighting foam, consumer goods and industrial processes has led to widespread environmental contamination. According to estimates from the U.S. Geological Survey, at least 45% of tap water in the United States contained one or more PFAS types in 2023 (USGS, 2023). It tested for the presence of 32 PFAS types out of the over 12,000 types, most of which remain outside the scope of current routine monitoring methods (USGS, 2023). In India, human exposure to PFAS from drinking water has been found to be lower than in many developed countries (Sharma et al., 2016). Drinking water is typically not the primary contributor to human PFAS body burden, except in areas with highly contaminated sources. Food products like fish, meat, fruits, eggs, etc. are the primary contributors to PFAS xposure. In a Norwegian study (Grung et al., 2024), drinking water near known sources had higher levels of PFAS, and only one of 142 drinking water samples exceeded the limit.

Communities residing close to PFAS-contaminated sites, expectant mothers, infants, and young children are among the vulnerable and high-risk population groups. The risk of negative health impacts rises with cumulative exposure over time. When higher concentrations of PFAS are found in their drinking water, pregnant and lactating women may experience greater exposure to PFAS than other population groups since they typically drink more water per pound of body weight than normal people. It is possible for the fetus to be exposed to PFAS in utero during pregnancy, as well as infants to be exposed through formula food manufactured with water containing PFAS or through breast milk from mothers who have PFAS in their blood. Compared to adults, children consume more water per pound of body weight, which may increase their chance of PFAS exposure. Additionally, those who live or work close to PFAS-producing locations, as well as industrial workers engaged in the production or processing of PFAS, may be at greater risk of PFAS exposure.

5 Status of PFAS monitoring in drinking water sources

5.1 Widespread contamination and monitoring initiatives

Contamination extent: PFAS are widely detected in drinking water across various regions, including the United States and Europe. As of November 2024, PFAS were detected in 8,865 public water sites; this affects 143 million people in communities throughout the US having drinking water that tested positive for these chemicals (EWG, 2024).

Monitoring programmes: Countries such as the United States, members of the EU, and Australia, have initiated or enhanced PFAS monitoring programs. In the U.S., the Environmental Protection Agency (USEPA) has been actively working to address PFAS contamination through various programs and regulations. Under the US National Primary Drinking Water Regulation (NPDWR) 2024, it is mandated that 'Public water systems must monitor specific PFAS and complete initial monitoring by 2027, followed by ongoing compliance monitoring; and by 2029, must implement solutions that reduce PFAS that exceeds limits.' Similarly, the European countries have also ramped up monitoring efforts as part of the European Union's broader environmental health initiatives.

5.2 Analytical methods and technologies

Sampling techniques: Following standard PFAS sampling guidelines such as those recommended by the USEPA or ISO, water samples are collected at various points in the water distribution system to assess potential contamination sources, including surface water (lakes, rivers), groundwater (wells, aquifers), and treated drinking water (post-filtration).

Analytical techniques: Advances in analytical methods, such as high-resolution mass spectrometry (HRMS) and liquid chromatography-tandem mass spectrometry (LC-MS/MS), have significantly improved the sensitivity and accuracy of PFAS detection in drinking water. These methods can help in trace-level detection and analysis of PFAS. Time-of-flight mass spectrometry (TOF-MS) allows for the detection of unknown PFAS compounds, providing a broader scope of analysis (Zahra et al., 2025).

Emerging technologies: New technologies and methodologies are being developed to enhance detection capabilities, including novel sorbents for sample preparation and innovative sensors for real-time monitoring. The emerging treatment technologies for PFAS removal include ion exchange resins, adsorption, advanced oxidation processes, and membrane-based separation (Zahra et al., 2025). Also, comprehensive characterization of PFAS is needed for effective risk assessment at contaminated sites. The total oxidizable precursor (TOP) assay helps in this process by converting unknown PFAS precursors into measurable stable PFAS. The TOP assay, however, presents technical challenges for laboratories that need to be resolved (Ateia et al., 2023). Studies indicate that a significant fraction of total fluorine (a method used to estimate total PFAS) remains unaccounted for across studies, underscoring the need for non-targeted screening to identify unknown PFAS (Idowu et al., 2025).

5.3 Challenges in PFAS monitoring

Complexity of PFAS: The wide range of PFAS compounds complicates monitoring and regulation, due to their diverse structures, functional groups, and differing detection challenges. Standard methods may not detect all relevant PFAS, and comprehensive testing can be costly and time-consuming. Due to their complex chemical structures, PFAS behave differently in environmental and biological matrices, requiring varied analytical approaches.

Data gaps: Data gaps persist regarding the geographic extent and concentration ranges of PFAS contamination in drinking water. Regulatory gaps are of course, a great concern, which has been covered comprehensively in this report.

Analytical challenges: Various analytical methods are available for sampling, testing, and analyzing PFAS, but ensuring accuracy and reliability is crucial; it would otherwise lead to inconsistent results. Participation in international interlaboratory proficiency testing programmes, such as those by WEPAL-QUASIMEME, helps laboratories validate their analytical procedures. These programs assess whether methods fall within acceptable limits, ensuring consistency and comparability of PFAS data across different studies and regulatory assessments. Using results from such proficiency tests improves analytical consistency and supports regulatory compliance.

Other challenges: Monitoring PFAS in drinking water presents other unique challenges, such as lack of infrastructure, limited access to high-end analytical equipment and trained personnel, and high costs associated with sampling, analysis, and data management, which hinder regular monitoring efforts.

6 Legislations on PFAS in drinking water

PFAS regulations in drinking water have evolved alongside growing awareness of their public health risks. The complexity of regulating PFAS have prompted the development of diverse standards, regulations, and guidelines for managing their presence in drinking water sources across different countries and regions worldwide.

6.1 PFAS regulatory history

6.1.1. Early actions (in general)

PFAS chemicals were first discovered in the 1930s. Numerous consumer products have been manufactured with or containing PFAS since the 1950s. The discovery of some PFAS in the blood of exposed individuals during occupational studies in the 1970s and subsequent research in the 1990s reporting detections in the blood of the general human population are responsible for raising awareness of the presence of PFAS (Interstate Technology Regulatory Council (ITRC), 2020). Early regulations were minimal, due to limited understanding of PFAS-related risks at the time growing evidence of PFAS contamination was discovered in the 2000s, especially in drinking water close to industrial areas and airports, which prompted more investigation. Two of the most researched PFAS compounds, PFOA and PFOS, were the focus of the U.S. EPA's initial PFAS monitoring program. Since 3M and other major U.S. manufacturers began phasing out perfluorooctanyl chemicals on a voluntary basis, the amounts of PFAS, particularly PFOS, in human blood have decreased steadily. Since 2002, the production and use of PFOS and PFOA in the U.S. have significantly declined, leading to a reduction in blood PFAS levels. From 1999-2000 to 2018-2019, blood PFOS levels decreased by over 85%, and blood PFOA levels dropped by more than 70%. As PFOS and PFOA have been phased out, they have been replaced by other PFAS, potentially exposing individuals to different types of these chemicals (Agency for Toxic Substances and Disease Registry (ATSDR), 2024a).

6.1.2. Earlier regulatory milestones (PFAS in drinking water)

6.1.2.1. United States:

In 2009, the US EPA included PFOS and PFOA in its Contaminant Candidate List (CCL), emphasizing their need to be regulated under the Safe Drinking Water Act. In 2016, the EPA released a health advisory for PFOS and PFOA, setting a combined lifetime exposure limit of 70 ppt in drinking water (USEPA, 2024c). This marked a significant milestone in acknowledging PFAS-related risks. The 2020s saw a rise in legislative activity globally, with several countries and regions starting to set their own drinking water regulations and thresholds for PFAS (Post, 2021). The US EPA released a regulation in December 2021 mandating that utilities provide drinking water tests for 29 PFAS chemicals.

Several class action lawsuits have been filed against 3M, DuPont, and other chemical companies in recent years over alleged PFAS contamination. 3M and DuPont have and will settle claims over PFAS contamination in public water systems (Mindock, 2023).

6.1.2.2. Canada

In 2018 and 2019, Health Canada established drinking water guidelines for PFOS and PFOA, as well as screening values for nine other PFAS, including PFBA, PFPeA, PFHxA, PFHpA, PFNA, PFBS, PFHxS, 6:2 FTS, and 8:2 FTS. These guidelines apply to water intended for human consumption. In 2021, the Government of Canada published a notice of intent to address PFAS as a chemical class, rather than regulating individual compounds. Subsequently, in 2023, Canada released the draft state of PFAS report, assessing the sources, fate, occurrence, and potential impacts of PFAS on the environment and human health, to guide future decision-making (Health Canada, 2024).

6.2 Current thresholds, standards, and guidelines

6.2.1. WHO guidelines

The World Health Organization (WHO) developed a background document for developing the Guidelines for Drinking-Water Quality (GDWQ) on PFAS in drinking-water, focusing on PFOS and PFOA. WHO suggested in 2022 that the respective provisional guideline values (pGVs) for PFOS and PFOA be set at 100 ppt or 0.1 μg/L, though these values are not legally binding for national adoption. In addition, the WHO suggested a pGV of 500 ppt, or 0.5 μg/L, for all 30 different PFAS that can currently be measured using current techniques (Association of State Drinking Water Administrators (ASDWA), 2022).

6.2.2. EFSA guidelines

In July 2020, the European Food Safety Authority (EFSA) established a tolerable weekly intake (TWI) limit of 4.4 nanograms per kilogram of bodyweight, based on the risk assessment on human health (EFSA Panel on Contaminants in the Food Chain (EFSA CONTAM Panel), 2020). The exposure depends on body weight and food intake. EFSA adopted this safety threshold for a group of four PFAS that accumulate in the body (PFOA, PFOS, PFNA, and PFHxS), and thus follows EFSA's guidance for assessing combined exposure to multiple chemicals. These four PFAS were selected as they accounted for half of the lower bound exposure to the PFAS with available occurrence data (not because of their bioaccumulation capacity). Notably, there has been a rapid decline in the TDI (tolerable daily intake), and TWI (tolerable weekly intake) considered by EFSA. In the first risk assessment, the TDI (daily) was 150 ng/kg body weight (bw) for PFOS and 1500 ng/kg bw for PFOA (EFSA CONTAM Panel, 2008; EFSA CONTAM Panel, 2008).

6.2.3. Regulations in North America

6.2.3.1. United States

PFAS National Primary Drinking Water Regulation (NPDWR), 2024: The first-ever National Primary Drinking Water Regulation (NPDWR) for six PFAS was announced by the EPA in April 2024. Legally enforceable levels, called maximum contaminant level (MCLs) were set for six PFAS in drinking water: PFOA, PFOS, PFHxS, PFNA, and HFPO-DA as contaminants with individual MCLs, and PFAS mixtures containing two or more of PFHxS, PFNA, HFPO-DA, and PFBS using a hazard index MCL to account for the combined and co-occurring levels of these PFAS in drinking water. US EPA also finalized health-based, non-enforceable Maximum Contaminant Level Goals (MCLGs) for these PFAS (US Federal Register, 2024), as presented in **Table1**. MCLGs represent ideal health-based targets with no known or anticipated adverse effects, while MCLs are enforceable thresholds.

Table 1. Drinking water PFAS limits in the United States under NPDWR, 2024.

PFAS	Final MCL* (ng/L)	Final MCL* (enforceable levels in ng/L)
PFOA	Zero	4.0
PFOS	Zero	4.0
PFHxS	10	10
PFNA	10	10
HFPO-DA (commonly known as GenX Chemicals)	10	10
Mixtures containing two or more PFHxS, PFNA, HFPO-DA, and PFBS	1 (unitless) Hazard Index	1 (unitless) Hazard Index

** MCL or maximum contaminant level, is the maximum level of a contaminant allowed in water that is delivered to a public water system user.*

Through the Bipartisan Infrastructure Law, the EPA is also providing US states and territories $1 billion to help them test for and treat PFAS in public water systems and to assist private well owners in dealing with PFAS contamination.

Mandatory requirements under NPDWR

The following are some of the NPDWR's necessary requirements for public water systems:

Public water systems are required to monitor the specified PFAS. They need to complete the initial monitoring by 2027, followed by ongoing compliance monitoring. Public water systems must also provide the public with information on the levels of these PFAS in their drinking water starting in 2027.

Public water systems must implement solutions that reduce these PFAS by 2029 if monitoring results indicate that drinking water levels exceed the MCLs (as specified in **Table 1**).

Public water systems that have PFAS in their drinking water that exceed one or more of these MCLs will need to take steps to lower the levels of these PFAS and notify the public of the infraction, starting in 2029.

State-Level Standards: Eleven US states, namely Maine, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Washington, and Wisconsin, have set specific standards (MCLs) for certain PFAS in drinking water.

6.2.3.2. Canada

In Canada, the current limit is set at 30 nanograms per litre (ng/L) for a sum of 25 specific PFAS[2] measured in drinking water (Health Canada, 2024). The 30 ng/L target is based on a precautionary approach, concentrations that can be consistently tested using current techniques, and concentrations that can be attained by drinking water treatment. The key factors considered when defining the limits were: PFAS levels found in Canadian waters, available removal technology, lowest measurable PFAS levels, and the concentration that can be consistently obtained from a technical treatment perspective.

6.2.4. European regulations

6.2.4.1. European Union (EU)

The total amount of PFAS in drinking water is limited to 500 ng/L by the recast Drinking Water Directive (DWD) (EU) 2020/2184. Additionally, it specifies that the sum of the 20 individual PFAS levels must be less than 100 ng/L. It also states that the sum of all PFAS should be less than 500 ng/L (European Environmental Agency, 2024) . Beginning in 2026, Member States will have to comply with these levels.

In 2023, a dossier for PFAS regulation, which restricts about 10,000 PFAS for the EU, was submitted to the European Chemicals Agency (ECHA) by five EU Member States: Germany, Denmark, Norway, Sweden, and the Netherlands (3E, 2024) .

Some EU Member States have set specific limits, as discussed below.

- Sweden: The Swedish Food Agency's regulations have limit values for four PFAS (PFOA, PFNA, PFOS and PFHxS, as per EFSA's health-based guidelines) at 4 ng/l, and for PFAS-21 (20 PFAS specified in EU) at 100 ng/l. The limit values for PFAS are required to be implemented as of 1 January 2026. Up to that point, there is a transitional period in which the limit values can serve as benchmarks for when action is required (Swedish National Food Agency, 2025; Life Source, 2023).
- Denmark: In 2021, the Danish Environmental Protection Agency limit values of not more than 2 ng/L of the total sum of four PFAS (PFOA, PFOS, PFNA and PFHxS), which is based on EFSA's recommended tolerable intake levels (Retsinformation, 2024; DHI, 2021).
- Germany: The Drinking Water Ordinance (TrinkwV) amendment incorporates EU regulations for drinking water protection into national law and sets a PFAS limit value for Germany. The cumulative limit value for 20 PFAS in drinking water will be 100 ng/L, as of January 12, 2026. Moreover, it sets a limit of 20 ng/L for the sum of four PFAS (PFHxS, PFOS, PFOA, and PFNA) beginning in 2028 (Umwelt Bundesamt, 2023).

6.2.4.2. United Kingdom (UK)

Currently, the UK has no regulatory standard for PFAS in tap water, and the country's Water Supply Regulations make no reference for PFAS (ZeroWater, 2022). However, 100 ng/L (of PFAS) is the guideline threshold set by the Drinking Water Inspectorate.

6.2.5. Regulations in the Asia-Pacific (APAC) region

Japan: In 2024, Japan set a target value of 50 ng/L for PFOS and PFOA for drinking water, as well as for public water bodies and groundwater (ChemRadar, 2024).

[2] The 25 PFAS include: PFBA, PFNA, PFPeS, 6:2 FTS, PFMBA, PFPeA, PFDA, PFHxS, 8:2 FTS, NFDHA, PFHxA, PFUnA, PFHpS, HFPO-DA, 9Cl-PF3ONS, PFHpA, PFDoA, PFOS, ADONA, 11Cl-PF3OUdS, PFOA, PFBS, 4:2 FTS, PFMPA, and PFEESA.

China: The Standards for Drinking Water Quality of China (GB5749-2022) established for PFASs are limited to PFOS and PFOA, with limit values of 40 and 80 ng/L, respectively (Guo et al., 2023).

South Korea: In 2017, the Republic of Korea developed PFAS limits in drinking water and set it as 70 ng/L for PFOS and PFOA as a sum, and 480 ng/L for PFHxS (Republic of Korea, 2019).

Australia: The Australian Drinking Water Guidelines (2011, updated 2018) has set the limits for PFOS as 70 ng/L, and PFOA as 560 ng/L in drinking water (National Health and Medical Research Council (NHMRC), 2024).

The summary of 'Regulatory Thresholds of PFAS in Drinking Water' in different countries across the globe are presented in **Table 2**.

Table 2. Summary of 'Regulatory thresholds of PFAS in drinking water' in different countries across the globe.

Country	PFAS	MCL* (ng/L)
North America		
USA	PFOA	4
	PFOS	4
	PFHxS	10
	PFNA	10
Canada	Sum of 25 specific PFAS	30
European Union (EU)/Member States		
EU	PFAS	500
	Sum of 20 PFAS	100
Sweden	PFAS-4 (PFOA, PFNA, PFOS and PFHxS)	4
	PFAS-21 (20 PFAS specified in EU)	100
Denmark	Sum of four PFAS (PFOA, PFOS, PFNA and PFHxS)	2
Germany	Sum of 20 PFAS	100
	Sum of four PFAS (PFHxS, PFOS, PFOA, and PFNA)	20
United Kingdom (UK)	PFAS	100
Asia-Pacific (APAC) Region		
Japan	PFOS and PFOA	50
China	PFOS	40
	PFOA	80
South Korea	Sum of PFOS and PFOA	70
	PFHxS	480
Australia	PFOA	560
	PFOS	70

** MCL or maximum contaminant level, is the maximum level of a contaminant allowed in water that is delivered to a public water system user*

7 Opportunities and limitations in management of PFAS

Globally, the regulatory environment for PFAS in drinking water is complex and evolving rapidly. There has been significant progress in setting PFAS standards, especially in North America and Europe, but there are still obstacles to be overcome in the areas of regulatory harmonization, resolving scientific uncertainty, and removing economic impediments. Long-term research, technical advancement, and global cooperation offer promising opportunities to improve drinking water safety and PFAS risk management.

7.1 Opportunities

Many regions across the world are currently undergoing regulatory reforms on PFAS management. The EU, the US, and the APAC region are all addressing the challenge of PFAS in drinking water, each using distinct regulatory approaches. There is potential for global harmonization of PFAS standards, though differing national priorities and analytical capacities remain barriers. Research collaborations and international data sharing may result in more efficient regulatory strategies.

Innovation is now essential for improving PFAS detection and remediation. Opportunities to effectively manage and minimize PFAS pollution are presented by developments in water treatment techniques and detection technologies. Greater investment in R&D could lead to more effective PFAS removal technologies.

Raising public knowledge and awareness of the risks associated with PFAS can lead to stronger regulations and improved compliance. Campaigning can result in stringent laws and greater corporate accountability for polluters for controlling PFAS contamination in drinking water sources.

7.2 Limitations

Scientific uncertainty surrounding the entire spectrum of human health consequences from various PFAS and the long-term impact of low-level exposure makes it difficult to establish universally recognized standards.

Some technological and economic challenges are commonplace. Implementing stricter PFAS regulations can be expensive for water utilities, especially in areas where contamination is widespread. Significant funding is also needed for the development and implementation of efficient treatment and removal methods for PFAS in drinking water. Research on the associated health effects must be done to understand the effectiveness of treatment methods and justify the related resources spent on them.

Industries across the US, EU, and APAC regions may face emerging regulatory challenges that can be solved by staying abreast of new laws and ban orders. They also need to constantly ensure transparency from their suppliers and across their supply chains, to avoid non-compliance risks.

A known challenge may be to find a suitable alternative to PFAS to be used in products. This challenge may be addressed through increased investment in research and development and establishing corresponding regulatory standards for the development and adoption of less harmful substitutes. Companies like ChemSec help with the process of identifying, assessing, and comparing PFAS substitutes.

The process of developing and updating regulations can be cumbersome and time-consuming and may often fall behind advances made in scientific discoveries as well as emerging threats. In the absence of updated regulations, populations (especially the vulnerable ones) are subjected to continuous exposure, and this results in various health hazards.

PFAS regulations vary greatly between countries and regions, and several of these countries lack dedicated or enforceable PFAS regulatory frameworks. International trade can meet this challenge by developing regulations in different countries and regions ensuring companies to change their processes of including PFAS in products where they are not needed. PFAS should only be used in products where it is essential and where alternatives are not available. In many cases good alternatives already exist, which should be explored by companies.

PFAS monitoring entails significant financial costs. For the United States, the US EPA estimates the annual costs for public water systems to implement NPDWR regulation is approximately USD 1.5 billion that includes: water system monitoring (USD 36 million), water system treatment and disposal (USD 1.5 million), water system administrative (USD 1 million), and primacy agency implementation and administration (USD 5 million) (USEPA, 2024a). Nonetheless, the costs of inaction may outweigh those of intervention. The socioeconomic analysis of environmental and health impacts due to exposure to PFAS reveals significant costs. For the Nordic countries, annual health-related costs are estimated between 2.8 and 4.6 billion EUR, while for all EEA countries, these costs range from 52 to 84 billion EUR. Depending on assumptions about environmental, legal, and economic impacts, the overall non-health costs for the Nordic countries are estimated between 46 million and 11 billion EUR, underscoring the substantial economic burden of PFAS contamination on public health and the environment (Goldenman et al., 2019).

8 The India perspective

PFAS contamination in drinking water is an emerging concern in India, given rapid industrialization and dependence on vulnerable water sources. While India currently lacks specific regulations for managing PFAS in drinking water, there is a scope for regulatory enhancement by including PFAS limits into existing water quality standards, improving laws governing industrial discharge, and conducting nationwide monitoring programs. Addressing the current roadblocks (e.g., lack of data, weak enforcement) will require coordinated efforts from the government, industry, and civil society to ensure safe drinking water for all. This section discusses the relevance and current scope for regulatory enhancement for managing PFAS in drinking water sources in India.

8.1 Relevance for India

8.1.1. Potential PFAS sources

India's rapid industrial growth is projected to expand further in the coming decades, especially in the sectors of textiles, leather, electronics, and chemicals. All these sectors have the potential to utilize and produce PFAS chemicals. PFAS are known to be present in military bases, airports, and fire-training grounds (Koulini et al., 2024) . Rapid urbanization has increased demand for consumer goods, straining waste management systems and resulting in unscientific disposal of industrial waste contaminated with PFAS. Significant PFAS contamination sources in open landfills and wastewater treatment facilities cause these chemicals to leak into water sources, greatly endangering drinking water supplies. Open drains carrying untreated industrial and domestic wastewater are another source of these trace level contaminants in water bodies, and conventional wastewater treatment techniques lack the removal capacity (Pavithra et al., 2024). The manufacturing, usage, import, and export of PFAS are mostly unregulated in India, and specific data on the quantities involved are not available.

8.1.2. PFAS drinking water contamination

India is dependent on both surface water and groundwater for drinking purposes. PFAS are persistent in the environment and resistant to natural degradation, leading to their accumulation in surface water bodies, soil, and groundwater. Indian water supplies are hence especially susceptible to PFAS pollution. A limited number of studies have examined PFAS pollution in India, as discussed below.

In a 2009 study, seven PFAS chemicals were found in Indian tap water: PFOS, PFHxS, PFBS, PFOA, PFHxA, PFPeA, and PBFA. Samples from Goa, Coimbatore, and Chennai contained shorter chain PFAS such as PFHxS (81 ng/l), rather than PFOS or PFOA. This study (Yim et al., 2009) reflected a shift in India toward the use of short-chain PFAS.

A 2016 study found 15 PFAS in several locations in surface water and groundwater of River Ganga, the latter being primarily used for drinking water and irrigation in most of Ganga basin (Sharma et al., 2016). These PFAS were frequently detected in the river with the highest concentrations observed for PFHxA (0.4–4.7 ng/l) and PFBS (< Limit of quantification (LOQ) – 10.2 ng/l) among PFCAs and PFSAs, respectively.

A 2018 study in Varanasi (Uttar Pradesh, India) showed high concentrations of PFAS, pharmaceuticals and pesticides contaminated aquifers deeper than 100 meters (Lapworth et al., 2018).

A 2024 PFAS quantification study in Tamil Nadu revealed that drinking water sources in Chennai as well as surface water samples from the Buckingham Canal, Adyar River, and Chembarambakkam contained elevated levels of PFAS (Koulini & Nambi, 2024). PFAS concentrations ranged from 0.10 ng/L to 136.27 ng/L, with groundwater showing the highest levels. The study found L-PFBS (up to 136.27 ng/L) and PFOA (up to 77.61 ng/L) in all samples. Notably, PFAS concentrations increased by 5 to 103% in the treated water compared to raw water (which is distributed as drinking water), suggesting transformation of precursors during treatment processes.

Research has indicated the presence of PFOA and PFOS in Cauvery River and lakes close to Chennai. PFOS was not reported in the Cauvery River, but PFOA was found in all sites (5 ng/L). The Noyyal River had the highest levels (93 ng/L of PFOA and 29 ng/L of PFOS) because to the region's considerable industrial activity, which includes textile manufacturers directly discharge their waste into the river (International Pollutants Elimination Network (IPEN), 2019) .

8.2 Public health implications

Long-chain PFAS exposure is linked to cancer, impaired immunity, and infertility. In contrast, short-chain PFAS, which are commonly used substitutes, particularly impact the health of vulnerable populations (pregnant women, infants, and communities living near contamination hotspots), who may be exposed to these newer PFAS for extended periods (Koulini et al., 2024; USEPA, 2024b). Rural communities and low-income urban population groups, who depend on untreated water sources, are also susceptible to PFAS contamination. The risk in these populations is increased by limited awareness about PFAS-related risks and inadequate access to safe drinking water. The following examples from susceptible demographics in India show the public health implications of PFAS contamination in drinking water.

A 2008 study showed high PFAS levels (PFOS, PFOA, PFHxS, and PFBS) in women from Chidambaram, Kolkata, and Chennai; however, the PFAS sources are not well understood. The PFOS levels in human breast milk samples from Indian women averaged higher than the US national drinking water health advisory limit at that time but were lowest among other Asian countries. However, it must be noted that breastfeeding has unique advantages that outweigh the risks associated with PFAS intake (Tao et al., 2008).

The 2016 study mentioned earlier, estimated human exposure to PFAS using groundwater pollution data. The highest exposure was found in PFHxA and PFHpA; and PFPA were higher than intakes of PFOS and PFOA. Children had the highest PFAS intake per kg of body weight (Sharma et al., 2016).

8.3 Current scope for regulatory enhancement

India's regulatory framework for managing PFAS in drinking water is underdeveloped, with no specific laws or standards in place. While international initiatives like the Stockholm Convention have aimed to limit certain PFAS, the existing national environmental laws do not directly regulate these chemicals, leaving policies inadequate. This section examines the existing gaps in regulatory measures, explores opportunities for enhancing the framework, and highlights the challenges India faces in improving PFAS regulation and monitoring to protect public health.

8.3.1. Existing Framework and Gaps

Currently, India does not have specific legislations that regulate PFAS in general or its presence in drinking water (International Pollutants Elimination Network (IPEN), 2019). The existing environmental laws such as the Water (Prevention and Control of Pollution) Act, 1974, and the Environment (Protection) Act, 1986, do not directly regulate PFAS. In 2006, India became a Party to the Stockholm Convention, which in 2009 included PFOS to Annex B, restricting its production and use. PFOA was proposed for listing in 2015. However, India has not accepted the amendment listing for this chemical. Hence, PFOS, along with other PFAS, remains unregulated in India.

To address the widespread and largely unregulated use of PFAS in consumer products, such as single-use plastics, personal care and cosmetics, processed food, and packaging, the Bureau of Indian Standards (BIS) adopted the International Standards Organizations (ISO) criterion for sampling and testing of PFOA and PFOS in 2020. However, these standards do not currently address PFAS in drinking water.

8.3.2. Opportunities and challenges for regulatory enhancement

8.3.2.1. Opportunities

PFAS are not regulated or regularly monitored in India. By incorporating PFAS into the Bureau of Indian Standards/BIS drinking water quality standards (IS-10500), India can improve its regulatory framework. Establishing permissible limits for PFAS in drinking water would be a big advancement.

It is essential to strictly regulate industrial discharge by mandating wastewater treatment to remove PFAS prior to environmental release. This could be accomplished by updating the industrial wastewater discharge standards to include specific PFAS limits.

As discussed previously, nationwide monitoring systems are essential to evaluate PFAS contamination in drinking water sources, especially near airports, military bases, fire-fighting sites as well as industrial areas. Creating real-time, interactive maps (similar to the PFAS contamination map developed by the United States) is crucial. Results of such live dataset will help to identify hotspots and prioritize regulatory interventions. It is essential to map military training grounds, airports etc., the potential hotspots for PFAS-contamination, for assessing the PFAS usage in firefighting foam.

It is essential to raise awareness among stakeholders, including government organizations, business associations, and the general public—about PFAS contamination in drinking water. To improve compliance and lower the risk of contamination, regulatory agencies and industry sectors should receive training and capacity building on PFAS management, safe disposal, and use of substitutes.

8.3.2.2. Challenges

It will take a quantum of financial and physical resources to establish and enforce PFAS regulations, including the development of infrastructure for testing and monitoring. India may need to invest or allocate funds for setting up technical facilities and labs that can detect PFAS at low concentrations. The USEPA estimates that $1.5 billion is the annual cost of PFAS monitoring, communicating with customers, and if needed, obtaining additional sources of water or installing and maintaining PFAS treatment technologies (USEPA, 2024a). Finding a balance between environmental protection and industrial growth is a complex but necessary trade-off in the pursuit of sustainable development.

8.4 Policy recommendations

8.4.1. General recommendations

- Clear, stringent, and legally binding national legislation and guidelines must be developed to control PFAS levels in drinking water, using regional or other national standards (EU/USEPA) as a reference. These guidelines must apply to both public and private water utilities to ensure compliance.
- India can benefit from collaborating with other countries and international organizations to adopt best practices, access technological innovations, and participate in global efforts to manage PFAS pollution in drinking water sources.
- Municipal and privately-owned water treatment systems should be mandated to conduct regular PFAS testing in drinking water sources and publicly report the findings, fostering transparency and building public trust. A national PFAS monitoring program for drinking water sources could help track drinking water quality trends and identify pollution hotspots.
- It is crucial to conduct comprehensive research for identification and characterisation of PFAS pollution source(s) in lakes and rivers as well as different environmental matrices.
- At the national level, a real-time contamination map showing PFAS in drinking water sources needs to be developed. The map will help to provide data on the spread of PFAS contamination in public and private water systems, point out pollution hotspots, and the population groups affected by it.
- Investments in cutting-edge water treatment technologies (granular activated carbon, ion exchange, and reverse osmosis) and innovations must be encouraged to remove PFAS contaminants from drinking water sources. It is essential to enhance technical capacity at the local and regional levels to test for and mitigate PFAS in drinking water sources.
- To facilitate wider access and analysis of PFAS pollution trends across various regions and sources in India, a PFAS data sharing registry can be a centralized online platform where different stakeholders, such as government agencies, research institutions, and citizen monitoring groups, can upload and share their PFAS data in different environmental matrices including rivers and lakes.
- A national action plan for PFAS regulation and remediation should be developed. It should focus on reducing emissions from possible sources such as agriculture and industry.
- Stringent regulations must be imposed for industries on PFAS industrial discharge, focusing on reducing contamination at the source. Prohibitions or restrictions on the manufacture and importing of items containing PFAS should also be part of stricter industrial discharge

regulations. Transparent disclosure of PFAS use and constituent chemicals should be mandated for industries who manufacture, import, or use PFAS to make consumer goods.

- Industries may oppose new stringent regulations; therefore, a phased approach with incentives for compliance might be required. This might prevent India from repeating the mistakes made by the Western nations. Industries need to keep up with the emerging laws, restrictions, and ban orders, and find ways to solve new regulatory challenges. India should carefully consider the environmentally sound alternatives to PFAS in industrial applications.
- It is essential to provide financial incentives and support for PFAS mitigation. To assist communities impacted by PFAS pollution in drinking water sources, especially marginalized and vulnerable populations, a funding mechanism must be put in place. Grants or subsidies for improving water systems and carrying out corrective measures, particularly for small or underfunded utilities, fall under this category.

8.4.2. Stakeholder engagement

Policymakers need to establish a strong legislative framework and give PFAS top priority as a public health concern. Stakeholder involvement and scientific research should inform policy, guaranteeing that sufficient funds are allotted to uphold rules and aid in remediation initiatives.

Convergence and regular coordination between policy makers from the Ministry of Environment, Forest & Climate Change (MoEFCC), Ministry of Jal Shakti (Drinking Water and Sanitation Department), Ministry of Health and Family Welfare (MoHFW), Ministry of Agriculture and Farmers Welfare (MoAFW), and Ministry of Chemicals and Fertilizers should be established and a joint task force to oversee the action on ground on monitoring PFAS in drinking water should be undertaken.

The different stakeholders (managers and owners) of municipal and privately-owned water treatment systems must be equipped to monitor and implement PFAS reduction technologies. They must ensure their infrastructure satisfies the ever-evolving regulatory requirements and seek advice on PFAS treatment technology. Initiatives aimed at exchanging information and mobilising financial resources may benefit greatly from public-private cooperation.

Other Stakeholders - Industries should collaborate with the government to regulate PFAS-containing consumer products, cookware, laundered clothing, and food packaging, that may otherwise transfer or leach into the drinking water sources. NGOs can raise public awareness and advocate for environmental justice, whereas civil society should participate in decision-making processes to ensure transparency and accountability.

8.4.3. Environmental justice perspective: Inclusion of vulnerable communities

Vulnerable and underserved communities in rural, disadvantaged, and low-income areas should have equitable access to clean drinking water. A dedicated technical assistance program should be established to help these communities access national-level resources by working directly with water systems to identify challenges and work towards solutions, such as development of plans, building technical, managerial, and financial capacities, and applying for water infrastructure funding. For these vulnerable communities, decentralised or stand-alone water supply systems may not be sustainable and need to be integrated with the city water supply system. The goal should be a zero-exclusion service.

Specific efforts are required to **involve and include** these marginalized groups (who are disproportionately affected by PFAS contamination) in the decision-making process and ensure the delivery of resources through community-led initiatives for drinking water quality improvement in these high-risk communities.

8.4.4. Risk communication and public awareness

Transparent and timely risk communication is crucial to educate the public on the risks of PFAS exposure and its mitigation measures. Risk communication can be challenging when dealing with rapidly evolving knowledge on PFAS and therefore must focus on cautious dissemination of sensitive information. Communicators must balance conflicting interpretations of emerging scientific evidence and risk management strategies, while earning community trust and encouraging meaningful public engagement. The government (with the help of other stakeholders) must develop and disseminate clear and effective messaging tailored to different audiences, focusing on public health impacts as well as doable steps that communities may take to safeguard themselves.

National and state-wide public awareness campaigns should be implemented to educate citizens about PFAS contamination and the importance of safe drinking water practices via social media, traditional outlets, and community-based campaigns.

8.4.5. Partnerships and community engagement

To coordinate efforts for PFAS mitigation, a platform for multistakeholder collaboration comprising government agencies, commercial businesses, researchers, and NGOs must be established. These collaborations can improve the distribution of best practices, technology transfer, and resource allocation.

To address PFAS pollution, India should engage in international cooperation and leverage existing global initiatives. Collaborations with nations in the forefront of PFAS mitigation and agencies such as the USEPA and the United Nations Environment Programme (UNEP) will be essential for information exchange, technical assistance, and capacity building.

Community involvement in monitoring and remediation efforts is a must. Community science programs, where residents collect water samples, can empower citizens and increase their trust in water quality management.

9 Conclusion and way forward

9.1 Conclusion

PFAS contamination in drinking water is an emerging environmental and public health concern in India, especially when it is linked to either a contaminated site (groundwater or waterways) or a contaminated community water system. The persistent nature of PFAS necessitates immediate and focused responses, even though India has made great progress in reducing water contamination from conventional contaminants. These 'forever chemicals' are prevalent in water sources may have long-term negative impacts on ecosystems, human health, and agricultural output. Since many affected populations may not be aware of the potential hazards, efforts to reduce risks are further complicated by India's lack of defined regulatory standards for PFAS in drinking water.

As India moves further on its path to sustainable development, addressing PFAS pollution in drinking water sources, needs to be one of the top priorities in larger water and chemical management plans. To protect human health and the environment, it will be crucial to advance scientific knowledge, implement the international best-practices for PFAS regulation and management, enhance technical and management capacities, and raise public awareness.

9.2 Way forward

PFAS regulations and health advisories have been established in many countries and regions, as an outcome of research and efforts made to evaluate the risks related to PFAS. To establish safe exposure limits and standards, additional research is necessary and there is still uncertainty, as evidenced by the differences in guidelines between regions and countries. Therefore, policymakers must focus on developing universal regulations and guidelines that address key regulatory gaps, monitoring capacity, and stakeholder engagement. Meanwhile, researchers should focus on generating key data and new scientific evidence, point out factual inaccuracies, and suggest safe substitutes for PFAS, to support evidence-based policy making.

To address PFAS pollution in drinking water, multisectoral collaboration and inclusivity are needed. The following is a summary of the ways to proceed:

- The development of specific regulatory guidelines for PFAS in drinking water need to be India's one of the top priorities.
- A joint task force comprising of policy makers and experts from different line ministries such as MoEFCC, MoHFW, MoJS, MoAFW etc should oversee the PFAS monitoring and management plans of India.
- Real-time data supporting policy decisions can be obtained from a nationwide monitoring network for PFAS in drinking water, especially in high-risk locations.
- Infrastructure and technological investments for water treatment must be prioritized, especially in communities that are at risk.
- To foster trust and promote preventative actions at the community level, public awareness and risk communication strategies should be in place.
- Therefore, a combination of stricter regulations, technical developments, improved public knowledge, and community engagement will be essential, to lower the risks of PFAS exposure in drinking water sources and safeguard public health in India.

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