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Review

Trifluoroacetic Acid: A Narrative Review on Physico-Chemical Properties, Exposure Pathways, and Toxicological Concerns

Andrea Moscato [1], Maria Valentina Longo [1], Margherita Ferrante [2] and Maria Fiore [2,*]

[1] Medical Specialization School in Hygiene and Preventive Medicine, Department of Medical, Surgical Sciences and Advanced Technologies "G.F. Ingrassia", University of Catania, Via Santa Sofia, 87-95123 Catania, Italy; moscatoandrea99@gmail.com (A.M.); longomariavale@gmail.com (M.V.L.)

[2] Department of Medical, Surgical and Advanced Technologies "G.F. Ingrassia", University of Catania, Via Santa Sofia, 87-95123 Catania, Italy; marfer@unict.it

* Correspondence: maria.fiore@unict.it; Tel.: +39-3405603356

Abstract

Trifluoroacetic acid (TFA) is a persistent degradation product of widely used fluorinated compounds such as hydrofluorocarbons, hydrofluoroolefins, hydrochlorofluorocarbons (HCFCs) and hydrochlorofluoroolefins. Its chemical stability, water solubility, and environmental persistence raise concerns about potential human and ecological risks. To provide an overview of current knowledge on TFA, we conducted a literature search (PubMed and Scopus, December 2024–January 2025) focusing on its environmental fate, human exposure, toxicokinetic, ecotoxicology, and regulation. A narrative approach was applied, prioritizing recent and high-quality evidence. TFA is ubiquitous in air, water, food, and consumer products. Human exposure occurs mainly through ingestion and inhalation. It is rapidly absorbed and excreted mostly unchanged in urine, with limited metabolic transformation. Though not bioaccumulated in fat, its environmental persistence and ongoing exposure raise concerns about long-term systemic effects. Ecotoxicological data show chronic toxicity in aquatic and terrestrial species, with environmental concentrations often exceeding safety thresholds. Currently, no binding EU limit exists for TFA, although several countries have proposed drinking water guidelines. TFA represents an emerging environmental contaminant with potential human health and ecological impacts. Strengthened monitoring, long-term toxicological studies, and precautionary regulatory action are urgently needed.

Keywords: trifluoroacetic acid; TFA; PFAS; toxicokinetics; ecotoxicology; drinking water; regulation

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1. Introduction

Trifluoroacetic acid (TFA) is a perfluorinated carboxylic acid characterized by high chemical stability, high water solubility, and moderate volatility. These properties make it highly persistent in the environment and capable of global distribution [1]. It is a degradation product of numerous fluorinated industrial and commercial compounds, including hydrofluorocarbons (HFCs), hydrofluoroolefins (HFOs), and other organofluorine precursors currently used as refrigerants and propellants replacing ozone-depleting substances as well as hydrochlorofluorocarbons (HCFCs) and even some hydrochlorofluoroolefins (HCFOs), among which some can also generate TFA [2]. "Therefore, in Europe, due to climate change, leading to higher ambient temperatures, and the resulting increased use of air conditioning systems, an upward trend in environmental release and accumulation of TFA is expected in the coming decades." [3].

Numerous studies have documented the ubiquitous presence of TFA in various environmental matrices—including surface and groundwater, atmospheric precipitation, soil, and biota [3]—even in remote areas without direct emission sources, as well as in numerous foods and beverages [4]. In addition, TFA is occasionally used as a solvent or chemical intermediate in pharmaceutical manufacturing and is also a urinary metabolite derived from volatile anesthetics such as desflurane, halothane, and isoflurane [5–7].

Human exposure primarily occurs through ingestion of contaminated water, but inhalation and, to a lesser extent, dermal contact are also possible routes [4]. Although several studies have investigated the potential health effects of TFA, no conclusive results have been obtained. Possible health impacts may include both local and systemic effects. Regarding local effects, corrosive skin reactions may occur after dermal contact, and respiratory epithelial toxicity may result from inhalation [8]. For systemic effects, possible hepatic alteration such as liver parenchymal hypertrophy have been hypothesized in the literature [8].

Despite its low acute toxicity observed in animal models, the widespread distribution, environmental persistence, high chemical stability, long half-life, potential for bioaccumulation, lack of chronic toxicity data, and possible systemic effects in humans make TFA a potential global threat to human health [1,9]. In addition, recent studies have raised the possibility that natural sources of TFA, particularly in marine environments, may contribute to its global occurrence, although their role remains uncertain and not yet fully characterized [10].

Moreover, the United Nations Environmental Effects Assessment Panel has recently assessed that current and projected concentrations of TFA derived from degradation of ODS (Ozone-depleting substances) replacements do not pose a significant risk to human health or ecosystems, given the wide safety margins observed [10].

This discrepancy between certain toxicological hypotheses and more reassuring environmental risk assessments highlights the need for further research to reconcile the divergent conclusions in the current literature.

Therefore, the aim of this narrative review was to critically summarize the currently available knowledge on:

- physico-chemical properties;
- sources;
- exposure routes;
- toxicokinetic assessment;
- ecotoxicological evaluation;
- regulatory framework.

2. Materials and Methods

The literature search was conducted between December 2024 and January 2025 using major biomedical and scientific databases: PubMed (Medline) and Scopus. The search strategy included the combined use of keywords and Boolean operators (“AND”, “OR”) to maximize sensitivity and specificity. Keywords included, among others: “trifluoroacetic acid,” “TFA,” “PFAS degradation,” “human exposure,” “ecotoxicology,” “biokinetics,” “drinking water,” “volatile anesthetics,” “fluorinated compounds,” “environmental fate,” and “regulation.”

We included original research articles, reviews, technical reports from regulatory agencies, REACH documents, and national and international guidelines, published in English or Italian and relevant to the review’s topics. Selection was based on relevance, prioritizing recent studies and those with reliable quantitative data. Articles with incomplete data,

unsupported opinions, or studies focusing exclusively on fluorinated compounds unrelated to TFA formation or environmental presence were excluded.

Sources were managed using Zotero version 7.0, which was used for citation organization and bibliography generation.

As this was a narrative review, no pre-registered protocol was followed, nor was a systematic risk of bias assessment performed. However, special attention was given to the methodological quality of the included studies, the consistency of findings, and triangulation of sources.

3. Results

3.1. Physico-Chemical Characteristics of Trifluoroacetic Acid

Trifluoroacetic acid ($C_2HF_3O_2$) consists of a carboxylic group bonded to a trifluoromethyl group, which gives the compound its high water solubility and acidity [11]. TFA is a strong acid, highly soluble in water, and more aggressive/reactive than other similar organic acids. Furthermore, it is volatile and can easily diffuse into the atmosphere, particularly near industrial areas where fluorinated refrigerants such as HFC-134a or HFO-1234yf are used [12,13]. TFA has a low octanol/water partition coefficient, indicating low affinity for lipophilic phases and therefore a low potential for bioaccumulation in biological tissues. Nevertheless, its bioavailability in the body remains high due to its ability to be readily absorbed through multiple exposure routes (inhalation, ingestion, etc.) [14]. In the environment, TFA mostly exists as highly water-soluble salts that do not bioaccumulate or biomagnify in food webs due to their low affinity for lipophilic phases and lack of known biological targets. Recent assessments by the United Nations Environmental Effects Assessment Panel indicate that current and predicted environmental concentrations of TFA are well below levels of concern for human health and ecosystems, suggesting minimal risk. Nevertheless, continued environmental monitoring is recommended to track future trends, therefore not only focusing on key environmental compartments but also including biomonitoring of systemic human exposure [10].

3.2. Sources of TFA

3.2.1. Degradation of Fluorinated Refrigerants (HFC-134a, HFO-1234yf)

One of the primary sources of TFA is the atmospheric degradation of fluorinated compounds (HFCs) widely used in air conditioning and refrigeration systems [15]. For instance, air pollution from HFC-134a and its subsequent transformation into TFA via photolysis and reaction with hydroxyl radicals has been studied as a major contamination source, particularly in industrialized and high-traffic regions. HFC-134a has a half-life of about 14 years and a TFA yield of approximately 20% [16].

HFO-1234yf, developed as an alternative to HFC-134a with lower global warming potential, also degrades in the atmosphere to form TFA [16,17]. It reacts with oxygen radicals and has a TFA yield close to 100%, leading to significantly higher environmental dispersion [18]. In general, HFOs have a much higher TFA yield than HFCs; however, the expected TFA yield is much higher as it is oxidized much closer to the source and due to its short half-life it has a significantly higher surface concentration [16]. HFO-1234yf and TFA exhibit a seasonal pattern: the former shows higher mean concentrations in winter (6.06 pptv) and lower in summer (2.70 pptv), while the latter follows the opposite trend [19]. The anti-correlation simply reflects that the main oxidant of the HFO is OH radicals and these are highest in summer leading to higher conversions of HFO to TFA, reducing the HFO in summer and raising the TFA level [2].

3.2.2. Metabolism of Volatile Anesthetics

Another significant source of TFA is the metabolism of volatile anesthetics (halothane, desflurane, and isoflurane). After anesthesia, TFA and other metabolites are excreted mainly in urine, although exhaled air may also contain traces [6].

3.2.3. Industrial Pollution and Production By-Products

- Perfluorinated Compounds

TFA can be produced as a by-product during various industrial chemical processes, particularly during the synthesis of perfluorinated compounds such as perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), which may degrade or transform into TFA during production or application [20].

- Fluoropolymers

Fluoropolymers, such as PTFE (polytetrafluoroethylene), used in non-stick coatings and other industrial applications, are produced using perfluorinated precursors. During manufacturing, small amounts of TFA can form as by-products of chemical reactions or degradation of fluorinated compounds [21].

- Degradation of Perfluoroalkyl Acids (PFAAs)

PFAAs, such as PFOS and PFOA, used in non-stick and water-repellent products, may undergo chemical reactions that result in TFA as an intermediate or final degradation product [22].

3.2.4. Biological Sources

The literature suggests that microorganisms in natural environments (e.g., soils or marine waters) may metabolize fluorine-containing compounds, producing TFA as a by-product [23]. However, these natural sources are still poorly documented, and there is no solid scientific evidence supporting the widespread natural production of TFA [24]. Recent studies by the German Environment Agency (UBA, 2024) have reported the presence of TFA in surface and deep waters of the Atlantic Ocean, based on 74 samples collected between 2022 and 2023 [25]. These data, analyzed by Neale et al. [10], suggest that the estimated TFA mass in the ocean is approximately 500–1000 times higher than the total known anthropogenic emissions accumulated between 1930 and 1999. This significant discrepancy strongly indicates the possible existence of one or more natural sources of TFA in the marine environment, although these sources remain unidentified and require further investigation [10].

3.3. Exposure Routes

Exposure can occur through the inhalation of contaminated air, since TFA can be released into the atmosphere during the degradation of fluorinated refrigerants, volatile anesthetics, and industrial compounds [6,12,13]. Additionally, atmospheric deposition of TFA over long distances leads to the contamination of surface waters and soils via precipitation [26], exposing humans indirectly through soil, water, and agricultural product contamination. Indirect exposure may also result from the use of industrial products containing fluoropolymers or perfluorinated compounds, which release TFA as a by-product throughout their life cycle.

Occurrence of TFA in Food Products

Recent monitoring studies have demonstrated the presence of TFA in a wide range of environmental matrices relevant to the food chain. In precipitation, median concentrations of TFA range from 0.21 µg/L in Germany to 0.70 µg/L in China, while in drinking water,

levels of up to 12.4 µg/L have been reported in Germany, with a national average around 0.9 µg/L. In other countries, average values tend to be lower, approximately 0.23 µg/L [1]. Due to its high mobility in soil and efficient uptake through the transpiration stream, TFA has also been detected in the foliage of various plants, including tea leaves, culinary herbs, and agricultural crops. Emerging evidence suggests that TFA can also accumulate in edible crops such as wheat, maize, and leafy vegetables through root uptake from contaminated soils and irrigation water. Concentrations in some plant tissues have been reported in the range of several hundred µg/kg, particularly in areas exposed to high levels of atmospheric deposition or agricultural runoff [27–29]. Notably, vegetation in the vicinity of industrial emission sources may contain exceptionally high levels of TFA [27]. This environmental contamination is also reflected in plant-based beverages. In a multi-country survey of 104 beer samples from 23 nations, TFA concentrations reached up to 51 µg/L, with a median of 6.1 µg/L. Interestingly, malt, rather than water, was identified as the primary source of contamination. Similarly, in tea and herbal infusions, TFA concentrations ranged from 0.39 to 13 µg/L, with no substantial differences observed between conventionally and organically produced samples [4]. In addition, recent EU-wide monitoring efforts have identified substantial TFA concentrations in a variety of food products, particularly in wine, showing median values around 110–122 µg/L, with peaks exceeding 300 µg/L, as well as in cereal-based items such as bread, pasta, and breakfast cereals. These levels appear more pronounced in conventionally farmed goods compared to organic alternatives, possibly due to differences in exposure to contaminated water or soil amendments [1,4]. This suggests that atmospheric deposition and root uptake from contaminated soils and irrigation water are the predominant pathways for TFA accumulation in plants [27]. Collectively, these findings indicate that food and beverages of plant origin, particularly leaf-derived products, constitute a significant dietary exposure pathway to TFA. Regular consumption of drinking water, tea, and beer may therefore represent a non-negligible contribution to human TFA body burden [4].

3.4. Toxicokinetic Evaluation (ADME—Absorption, Distribution, Metabolism, and Excretion)

The toxicokinetic of TFA in humans is not fully characterized, but data from experimental, clinical, and animal studies provide a general overview [6].

3.4.1. Absorption and Distribution

Absorption primarily occurs via inhalation, ingestion, or dermal contact—although the latter is generally negligible. TFA ingested orally is rapidly absorbed in the gastrointestinal tract [30]. Once absorbed, it is distributed in plasma and extracellular fluids, with a tendency to remain ionized due to its strongly acidic nature (pKa $\approx$ 0.5). Studies on patients undergoing halothane anesthesia have found significant levels of TFA in plasma and urine, peaking 24–48 h after exposure [30,31]. TFA concentrations up to 8.46 ng/mL have been detected in blood samples from Chinese men [9]. It is not lipophilic and therefore does not significantly accumulate in adipose tissue.

3.4.2. Metabolism

TFA is a stable metabolite and does not undergo significant further metabolism in the body. Its formation is directly linked to CYP2E1 (Cytochrome P450 2E1) activity, as demonstrated by studies in which inhibition of this enzyme by disulfiram significantly reduced TFA production and the formation of trifluoroacetylated protein adducts in the liver [30].

3.4.3. Excretion

TFA is excreted almost exclusively via the kidneys in its unchanged form. Elimination is slow, with a plasma half-life of approximately 1–2 days in humans, though this may vary.

Renal function affects clearance: in patients with kidney dysfunction, TFA may accumulate in the blood. In a study of patients anesthetized with halothane, urinary excretion of TFA peaked on the second postoperative day, with values ranging from 317 to 1259 mg [8]. TFA is also partially excreted in bile; in a study on neonates, about 17–20% of produced TFA was eliminated through bile [31,32]. While TFA is not considered bioaccumulative according to aquatic organism criteria, its concentration in the human body could increase due to continuous exposure from drinking water, food, and plant-based beverages [33].

3.5. Ecotoxicological Evaluation

3.5.1. Toxicity to Aquatic Ecosystems

TFA is classified as "harmful to aquatic life with long lasting effects" (H412) according to the EU CLP (European Union Classification, Labelling and Packaging) Regulation. Acute and chronic toxicity studies on aquatic organisms show particular sensitivity in algae, with a NOEC (No Observed Effect Concentration) of 120 µg/L for Selenastrum capricornutum. To protect the environment, several PNEC (Predicted No Effect Concentration) values have been established. The most conservative is 0.12 µg/L, derived from the NOEC with a safety factor of 1000 due to limited data and to ensure protection of marine environments as well [9]. However, according to the REACH dossier, the PNEC for freshwater is 560 µg/L and 56 µg/L for marine environments, based on a 72 h ErC10 (Effective concentration causing 10% growth rate inhibition) value of 5600 µg/L [33–35].

A global analysis of surface waters conducted between 2010 and 2023 indicates that many mean and maximum environmental concentrations exceed the most conservative PNEC (0.12 µg/L), and in some cases even the ECHA PNEC (560 µg/L), particularly in European and Chinese basins [36]. Due to its persistence, exposure to TFA should be considered chronic and continuous for most aquatic organisms. However, available chronic ecotoxicological data are limited: studies on *Daphnia magna* last 21 days, fish studies up to 35 days, and rodent studies up to 90 days, which are insufficient for a comprehensive assessment of long-term effects [37].

3.5.2. Toxicity to Terrestrial Ecosystems

Toxicological data for terrestrial environments are even more fragmented. Studies in cluded in the REACH dossier show that TFA exhibits phytotoxic effects on cultivated plants such as maize (*Zea mays*), white poplar leaves (*Populus alba*), and black locust (*Robinia pseudoacacia*), with a shoot growth EC50 (Effective concentration for 50% response) of 4.7 mg/kg and a NOEC of 0.83 mg/kg (dry soil) [38]. Hydroponic experiments reveal exceptionally high TFA uptake in roots compared to other PFCA (perfluoroalkyl carboxylic acids), with a concentration factor exceeding 1600 L/kg—far higher than that of PFBA and PFPeA [38]. In contaminated terrestrial environments, TFA has been observed to alter soil pH, inhibit microbial respiration, and impair organic litter decomposition. In one study on temperate soils, TFA concentrations between 0.0013 and 2.4 mg/kg significantly affected organic matter decomposition and microbial activity, even at levels comparable to environmental hotspots [39].

3.6. Regulation and Limits

In 2020, Germany established a health-based guidance value for TFA in drinking water of 60 µg/L, based on a chronic toxicity study in rats. However, German authorities recommended keeping the concentration as low as possible, setting a precautionary target value of 10 µg/L [25].

In 2023, the Netherlands proposed a tentative value of 2.2 µg/L for drinking water, calculated by applying a relative potency factor based on perfluorooctanoic acid (PFOA) and its water safety threshold [40].

According to REACH, the derived no-effect level (DNEL) for the general population has been established only for oral exposure, with a value of 0.042 mg/kg body weight/day. No significant risks were identified for other exposure routes [33–35].

A recent report [41] indicates that starting in 2026, the EU is expected to adopt a standard limit of 500 ng/L for "total PFAS" in drinking water. By definition, this limit should also include TFA, although its inclusion remains under debate. Current data suggest that about half of the drinking water samples analyzed would exceed this limit if TFA were included, potentially requiring major investments—in the order of billions of euros—to upgrade European water treatment facilities.

The NGO (Non-governmental organization) "Pesticide Action Network Europe" (PAN Europe) labeled TFA as a "forever chemical," reporting its presence in 94% of surface water samples. Furthermore, 63% of bottled water samples exceeded the limits proposed by the new European Drinking Water Directive. According to PAN Europe data, tap water samples had an average TFA concentration of 740 ng/L, with values ranging from below the detection limit (<20 ng/L) to 4100 ng/L. Bottled mineral and spring waters showed concentrations between below the detection limit and 3200 ng/L, with a mean of 278 ng/L [42].

To date, no specific legal limit for TFA exists within the European Union.

3.7. Analytical Challenges in TFA Detection

The identification and quantification of trifluoroacetic acid (TFA) pose significant challenges in environmental and food analysis due to its unique physicochemical properties. TFA is a small, highly polar, and fully dissociated anion in aqueous solution, which leads to poor retention and early elution in conventional reversed-phase LC-MS/MS methods commonly used for PFAS detection. As a result, sensitivity and selectivity are often compromised, and TFA has historically been underrepresented in environmental monitoring data [43]. Standard environmental surveillance protocols frequently exclude TFA, further contributing to its underreporting [1,43]. Only through the use of dedicated anion-exchange columns combined with high-resolution mass spectrometry or selective ion chromatography has it become possible to achieve suitable limits of quantification (as low as 0.05 µg/L in water samples) and adequate analytical separation from background interferences [4]. Extraction also presents specific challenges, particularly for food and beverage matrices. Accurate assessment of TFA levels in plant-based products (e.g., tea, beer) requires matrix-specific aqueous extraction protocols that simulate real-world infusion or fermentation conditions. Conventional extraction methods, such as solvent-based or ultrasound-assisted techniques, have proven inadequate for this purpose [4,44]. Moreover, water treatment processes such as ozonation and chlorination may generate TFA from unknown precursors, complicating data interpretation by introducing uncertainty regarding whether the detected TFA was pre-existing or formed during treatment [45]. Overall, these factors underscore the need for harmonized, sensitive, and robust analytical methodologies to ensure reliable monitoring and exposure assessment of TFA on a global scale.

4. Discussion

Trifluoroacetic acid (TFA) is an emerging environmental contaminant of growing concern due to its ubiquity in environmental matrices and its chemical–physical properties, including high water solubility, chemical stability, and persistence. Its widespread occurrence, even in remote areas without direct emission sources, is primarily linked to the degradation of numerous fluorinated industrial and commercial compounds, such as HFCs, HFOs, and other refrigerant and propellant precursors. The increasing use of these substances, driven by expanding air conditioning systems and climate change, is likely to further raise environmental concentrations of TFA in the coming decades.

Findings from this narrative review confirm that human exposure to TFA occurs through multiple routes, mainly ingestion, but also inhalation and, to a lesser extent, dermal contact, and that the compound is present not only in the environment but also in food, beverages, and even pharmaceuticals. Despite its low acute toxicity, data on chronic effects, endocrine disruption, and systemic interactions of TFA in the human body remain limited and fragmented. Some studies suggest hepatic effects (such as parenchymal hypertrophy), respiratory tract alterations, and local effects on the skin and mucous membranes, but robust evidence from large-scale epidemiological studies is lacking.

Toxicokinetically, TFA is rapidly absorbed, distributed in extracellular fluids, and is not further metabolized, remaining chemically stable in the body. It is mainly excreted via the kidneys, but its slow elimination and continuous exposure from environmental and dietary sources raise concerns about potential long-term systemic accumulation.

From an ecotoxicological perspective, existing evidence indicates the particular sensitivity of aquatic organisms, especially algae and aquatic plants, to chronic TFA exposure. Environmental concentrations reported in various water basins, both European and non-European, in some cases exceed proposed safety thresholds (Predicted No-Effect Concentrations), highlighting real risks to aquatic ecosystems. Terrestrial ecosystems are also showing signs of distress: preliminary studies reveal changes in soil microflora, inhibition of litter decomposition, and phytotoxicity in several plant species.

Despite this picture, there is still no specific legal limit for TFA in the EU, although some member states have adopted guidance values or proposed provisional thresholds for drinking water. The inclusion of TFA in the PFAS category for the upcoming EU "total PFAS" limit (500 ng/L) adds further complexity, considering the high prevalence of TFA in environmental samples and the potential economic implications of upgrading water treatment systems.

- Given these findings, regulatory and scientific efforts must be strengthened. There is an urgent need to: intensify environmental and biomonitoring of TFA across different compartments;
- promote long-term toxicological studies, especially focusing on endocrine and developmental effects;
- define human exposure limits based on updated and validated evidence;
- evaluate regulatory measures for TFA precursors, in line with the precautionary principle and the goals of the EU Chemicals Strategy for Sustainability.

In conclusion, TFA is an emerging contaminant that, although not currently regulated specifically, exhibits characteristics that warrant greater attention at scientific, regulatory, and public health levels. Acting now, before contamination reaches irreversible levels, represents a crucial opportunity to prevent potentially serious and lasting impacts on human health and the environment

This narrative review presents several strengths. First, it offers an updated, comprehensive, and multidisciplinary synthesis of current knowledge on TFA, integrating aspects related to physico-chemical properties, sources, exposure routes, toxicokinetic assessment,

ecotoxicological evaluation, and regulation. The chosen approach provides a systemic view of the risks associated with TFA, highlighting the interconnections between environment, human health, and industry. Additionally, the review includes recent sources and data from technical reports and regulatory agencies, often overlooked in academic literature, enhancing the practical relevance of the content.

Nonetheless, several limitations are present. As with all narrative reviews, this analysis does not follow a predefined systematic protocol for identifying, selecting, and critically appraising studies, and may therefore be subject to selection or interpretation bias. Furthermore, the heterogeneity and fragmentation of available data, particularly regarding chronic effects in humans and long-term impacts on terrestrial ecosystems, make it difficult to draw definitive conclusions. Finally, the absence of large-scale epidemiological studies limits the ability to accurately assess health risks from chronic low-dose TFA exposure.

Despite these limitations, this review represents a useful starting point for future scientific investigations and for guiding environmental and public health policy creation in Europe and globally.

5. Conclusions

Trifluoroacetic acid (TFA) has emerged as a contaminant of increasing environmental and public health concern due to its high persistence, mobility, and global distribution. Derived primarily from the atmospheric degradation of widely used fluorinated compounds, TFA is now ubiquitously present in water, air, soil, and biota, with documented occurrences even in remote and non-industrialized regions.

Despite its low acute toxicity and limited bioaccumulation potential, continuous human exposure, mainly through drinking water and food, raises important questions about long-term systemic effects. Current toxicokinetic evidence suggests rapid absorption and renal excretion with minimal metabolic transformation; however, the lack of comprehensive data on chronic and developmental toxicity remains a critical knowledge gap. Similarly, growing ecotoxicological data underscore the vulnerability of aquatic and terrestrial organisms, particularly in regions where environmental concentrations exceed established safety thresholds.

At present, no legally binding limits for TFA exist at the EU level, although several countries have proposed precautionary guidance values. The potential inclusion of TFA within the broader PFAS regulatory framework highlights the urgent need for regulatory clarity and targeted mitigation strategies.

To address this emerging threat, the following actions are recommended: (1) enhanced environmental and human biomonitoring to assess real-world exposure scenarios; (2) rigorous long-term toxicological studies focusing on endocrine, developmental, and systemic effects; and (3) the adoption of precautionary regulatory approaches in alignment with the EU Chemicals Strategy for Sustainability. These efforts are essential to prevent irreversible environmental contamination and to safeguard human health for present and future generations.

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Abbreviations

The following abbreviations are used in this manuscript:

TFA	Trifluoroacetic Acid
HFCs	Hydrofluorocarbons
HFOs	Hydrofluoroolefins
PFAS	Polyfluoroalkyl Substances
PTFE	Polytetrafluoroethylene
PFOS	Perfluorooctane Sulfonate
PFOA	Perfluorooctanoic Acid
NOEC	No Observed Effect Concentration
PNEC	Predicted No Effect Concentration
PPTV	Parts Per Trillion by Volume
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
EU CLP	European Classification, Labelling and Packaging Regulation
PFCA	Perfluoroalkyl Carboxylic Acids
PFBA	Perfluorobutanoic Acid
PFPeA	Perfluoropentanoic Acid
PAN	Pesticide Action Network Europe

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