Master Thesis
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Trifluoroacetic Acid (TFA) in Groundwater and Surface Water: Mapping, Trends and Regulatory Perspectives

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Abstract

Trifluoroacetic acid (TFA), an ultra-short chain PFAS, is highly persistent, mobile in water, and currently not explicitly regulated in Swedish- or other European water legislation apart from in Denmark. This thesis investigates the occurrence, trends, and potential pesticide-derived formation of TFA in Swedish ground- and surface waters along with regulatory implications on a national and international level. A dataset of 437 Swedish TFA measurements from 2023-2026 was analysed, covering 19 of 21 counties and 111 of 290 municipalities in Sweden. Results show that TFA is widespread across Sweden, with a national mean concentration of approximately 360 ng/l with indications of a southward concentration gradient. Skåne County had both the highest mean and highest maximum concentration measuring 600 ng/l and 2700 ng/l respectively. Trend analyses from 29 monitoring stations and 128 observations indicated increasing concentrations, with Linear Mixed Model and Robust Linear Model estimates showing annual increases in Sweden of 19.65% and 16.86%, respectively. Swedish pesticide sales data from 2000-2024 showed increasing input of TFA-precursor substances, with 2024 reaching the highest studied level. Mass-balance modelling suggests potential pesticide-derived TFA accumulation in Swedish waters of 130-150 tonnes by 2025 since year 2000. The conclusion is that expanded monitoring, improved knowledge of pesticide degradation pathways, and precautionary regulation are needed due to TFA's persistence and uncertain long-term effects on human health and the ecosystem.

Sammanfattning

Trifluorättiksyra (TFA), en ultrakortkedjig PFAS, är mycket ihärdig, rörlig i vatten och för närvarande inte uttryckligen reglerad i svensk eller annan europeisk vattenlagstiftning med undantag för Danmark. Denna avhandling undersöker förekomst, trender och potentiell pesticidbildad TFA i svenska grund- och ytvatten samt regulatoriska implikationer på nationell och internationell nivå. Ett dataset med 437 svenska TFA-mätningar från 2023–2026 analyserades, vilket omfattade 19 av 21 län och 111 av 290 kommuner i Sverige. Resultaten visar att TFA är utbrett i Sverige, med en nationell medelkoncentration på cirka 360 ng/l och indikationer på en sydlig koncentrationsgradient. Skåne län hade både den högsta medelkoncentrationen och den högsta maximala koncentrationen på 600 ng/l respektive 2700 ng/l. Trendanalyser från 29 mätstationer och 128 observationer indikerade ökande koncentrationer, där skattningar från en Linear Mixed Model och Robust Linear Model visade årliga ökningar på 19,65 % respektive 16,86 %. Svenska försäljningsdata för pesticider från år 2000–2024 visade en ökande tillförsel av TFA-bildande ämnen, där 2024 nådde den högsta nivån under den studerade perioden. Massbalansmodellering antyder en potentiell ackumulering av pesticidbildad TFA i svenska vatten på 130–150 ton år 2025, räknat från år 2000. Slutsatsen är att utökad övervakning, förbättrad kunskap om pesticiders nedbrytningsprocesser och förebyggande regleringsåtgärder behövs på grund av TFA:s ihärdighet och osäkerheter kring dess långtidseffekter på ekosystem och människors hälsa.

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1. Introduction

1.1. Background

Safe and readily available water is an important cornerstone in a functioning society and it serves as one of the major contributing factors to public health (WHO, 2023). When groundwater and surface water is extracted for public use, it is generally treated to reduce the amount of toxic content. As for Sweden, roughly 900 million cubic metres of water are treated each year in municipal drinking water plants (Svenskt Vatten, 2026). Amongst the toxic materials present in Swedish drinking water, only 21 out of several thousand PFAS are subject to regulation according to The Swedish Drinking Water Directive LIVSFS 2022:12. One PFAS that is so far neglected by the authorities in relation to analyses and regulation is trifluoroacetic acid, commonly referred to as TFA. This is not unique for Sweden though, as seemingly no country has yet to implement legislation setting permissible levels of TFA in any form of water with the exception for Denmark.

The effects of TFA on the human health and on ecosystems is an understudied field compared to many other PFAS, especially when evaluating long-term effects. Sources of TFA are generally known, but the exact mechanisms by which TFA is formed as a product of degradation from precursor substances has yet to be fully understood. Furthermore, point sources and major contributors that lead to the accumulation of TFA in ground- and surface waters is not well studied or mapped (Scheurer et al., 2019; Arp et al., 2024).

A potential major source of TFA is the use of certain pesticides, but how much TFA that can be formed from these pesticides is not yet fully known (Joerss, et al., 2024).

1.2. Objectives

The overall objective of this thesis is to assess the occurrence, sources, potential impacts, and regulatory status of TFA in Swedish and European waters. The study also aims to highlight the knowledge gaps regarding TFA formation, environmental behaviour, toxicity, and regulation.

The thesis addresses the following research questions:

- What is the dispersion of TFA in Sweden and are concentrations of TFA in Swedish waters stable, decreasing or increasing?
- Where does TFA come from and how harmful is it to human health and the ecosystem?
- How much TFA from pesticide use could have potentially been formed in Sweden since the year 2000?
- Are concentrations of TFA, in European waters, regulated in national- and/or EU-legislation? If not, could it be, and should it be?

2. Theory

This chapter presents the theoretical background to understand the occurrence, behaviour, and regulatory relevance of TFA. Firstly, PFAS is introduced and defined, along with TFA, as well as their sources of formation. The toxicity and ecotoxicity of TFA is looked at, and finally the current regulation and legislation from several European countries with regards to TFA is examined.

2.1. Active Substances (PFAS)

PFAS stands for per- and polyfluoroalkyl substances and is a complex group of chemical compounds that contains well over ten thousand identified substances according to KEMI, the Swedish Chemical Agency (KEMI, 2025a). All PFAS are synthetical substances that do not occur naturally and have been in production since the 1950s. The range in which PFAS substances are used is wide, stretching from water, fat and dirt repellents in textiles, to smoothing in cosmetics and efficiency enhancement in firefighting foam (KEMI, 2025a). Some PFAS are also present in several pesticides used in agricultural practices globally (Joerss, et al., 2024).

2.1.1. General Structure of PFAS

Per- and polyfluoroalkyl substances consist in essence of a carbon chain with its hydrogen atoms fully or partly replaced by fluorine atoms as seen in *Figure 1.* The definition of PFAS According to KEMI (2025a) is "[…] a molecule that contains one or more fragments consisting of a perfluorinated carbon chain of at least two carbon atoms (C2) with a bond to any atoms or group of atoms.”. Furthermore, PFAS are sometimes divided into two sub-groups, namely long-chain and short-chain PFAS. Long-chain PFAS are characterised by at least eight carbon atoms in the fluorinated carbon chain. Short-chain PFAS are characterised by at least six carbon atoms in the fluorinated carbon chain according to KEMI (2025a). Short-chain PFAS could be defined as having as little as four carbon atoms in their chain according to Eurofins (2025).

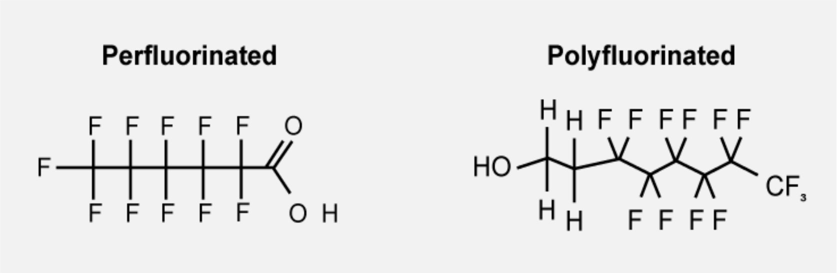


Figure 1:General molecular structure of PFAS (KEMI, 2025a).

2.1.2. Trifluoroacetic Acid (TFA)

Most of PFAS can be categorised as long- or short-chain PFAS, but an additional subcategory is sometimes used to describe PFAS with only one to three carbon atoms in their fluorinated carbon chain, so called ultrashort-chain PFAS (Eurofins, 2025). Amongst these ultrashort-chain PFAS we find TFA, short for trifluoroacetic acid. This PFAS consists of two carbon atoms, where one carbon atom forms a fully fluorinated methyl group, and the other carbon atom carries a carboxylic acid group as illustrated in *Figure 2* (KEMI, 2025b).

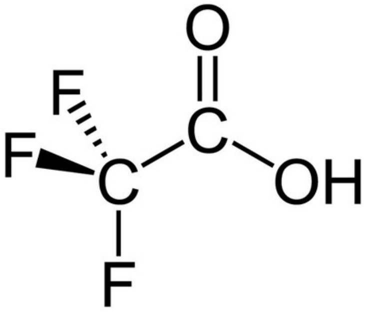


Figure 2: Molecular structure of TFA (KEMI, 2025b).

Due to the molecular structure and integrity of TFA, it is highly soluble in water (>10g/l) and travels easily through ground water while at the same time being practically impossible to break down under natural circumstances (Eurofins, 2025; BAuA 2025; KEMI, 2025b). TFA has an estimated half-life under natural circumstances of several hundreds of years (Dorgerloh et al., 2019). TFA is also strong acid, with sources claiming it to having a pK_a of between 0.23 to 0.52 (Solomon et al., 2016; NCBI, n.d.).

2.2. Sources and Formation of TFA

TFA found in groundwater and surface water has several contamination sources. While some sources contribute more than others depending on site specific properties, the main contaminators are refrigerants, pesticides and human pharmaceuticals (Scheurer et al., 2019; Arp et al., 2024). Even though mainly attributed to the marine environment rather than ground water hydro morphology, TFA is assumed by some scholars to have natural deep water oceanic sources of formation. However, the validity of this hypothesis has been criticised (Joudan et al., 2021).

2.2.1. General Mechanism

For TFA to enter the natural environment, it usually comes as a product of degradation from a precursor compound that contains the fluorinated methyl group (Freeling & Björnsdotter, 2023). As illustrated in *Figure 3*, the potential TFA precursors Nirmatrelvir, Fluopyram and HFO-1234yf that are constituents of pharmaceuticals, pesticides and refrigerants respectively, all contain said methyl group. However, the yield of TFA as a product of degradation from these compounds is dependent on the specific molecule, as TFA competes with other potential products of degradation depending on the prevalence of factors such as UV-radiation and nitrogen oxides (Burkholder et al., 2015, cited in Solomon et al., 2016).

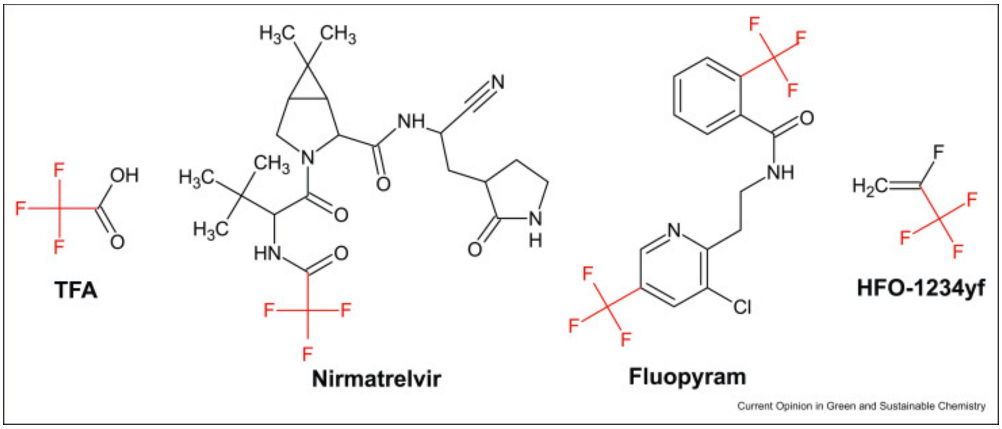


Figure 3: Examples for precursors of TFA through (bio)chemical degradation (Freeling & Björnsdotter, 2023)

TFA behaves in many ways as hydrochloric or nitric acid, as due to the low pK_a, it easily forms salts when released into the environment (Solomon et al., 2016).

Currently, the molecular structure of TFA prevents it from being removed by conventional water treatment plants according to standard practices used. High temperature thermal removal and reverse osmosis are generally seen as the two possible ways of significantly decreasing the concentration of TFA in water treatment plants, with both methods being highly energy intensive (Austin et al., 2024). Even if these methods were applied to potentially separate TFA from drinking water in water treatment plants, proper disposal is still needed since the molecules are still in existence. High-temperature combustion of residual TFA could potentially be applied, but it becomes clear that stopping TFA from entering sources of water is less energy intensive than removal and disposal.

2.2.2. Atmospheric Deposition

Much of TFA found in groundwaters come from the atmospheric deposition of TFA, formed as a product of degradation from perfluoroalkyl-containing substances. These substances include hydrofluorocarbons, hydrochlorofluorocarbons, hydrofluoroolefins, and hydrochlorofluoroolefins, all found in refrigerants, fire extinguishing agents, and physical blowing agents (Behringer et al., 2021 cited in Freeling & Björnsdotter 2023). The molar yield of TFA from atmospherically present perfluoroalkyl-containing substances differ from molecule to molecule. Studies found that some refrigerants, such as HFO-1234yf, also illustrated in *Figure 3*, showed a molar TFA yield of 100%, while other refrigerants only amounted to a molar TFA yield of 21% (Leucken et al., 2010 cited in Solomon et al., 2016). The atmospheric presence of TFA leads to deposition through precipitation and has been noted globally, with highly varying measurements ranging from roughly 3ng/l to 4µg/l in different parts of the world with Solomon et al. stating that rainfall, fog and snow are the major routes of TFA input into the natural environment (2016).

2.2.3. Pesticides

Atmospheric deposition of TFA is the result of a wide spread of TFA precursors from several sources stemming mainly from refrigerants, but there are more locally bound sources of precursors to TFA, namely pesticides. The specific pesticides connected to the degradation into TFA all include at least one fluorinated methyl group, with an approximate 80 known pesticides fulfilling this demand (Solomon et al., 2016). In Sweden there are approximately 30 pesticides containing 18 different TFA precursor substances approved for agricultural use (KEMI, 2026) as noted by Häggqvist & Rosenquist (2025). The active substances in pesticides found on the Swedish market with respective CAS-nr are presented in Table 1.

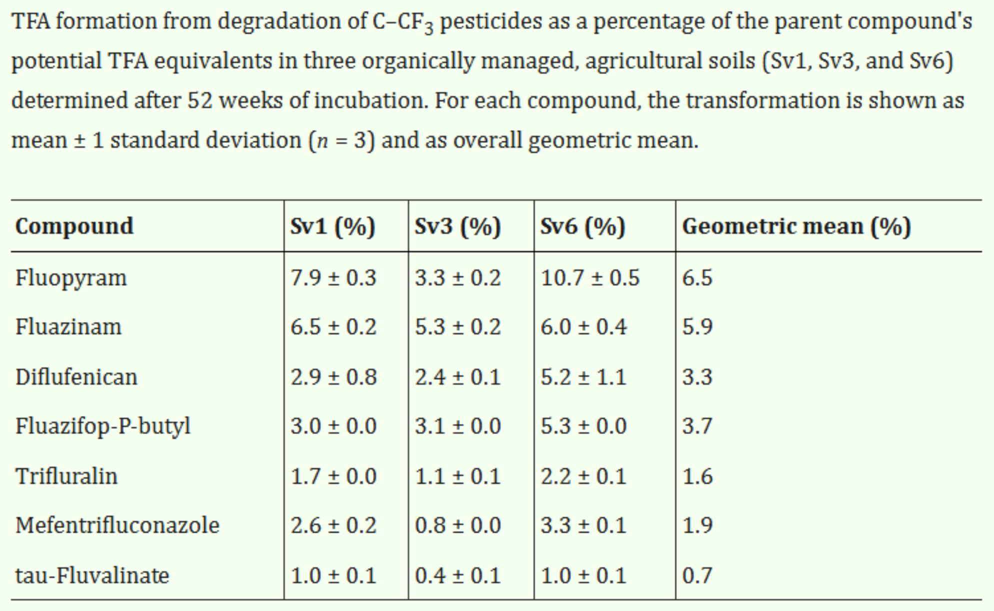
Table 1: Active substances with at least one fluorinated methyl group, present in pesticides. All have been sold on the Swedish market between 2000-2024.

Active Substance	CAS-nr	Active Substance	CAS-nr
Beflubutamid	113614-08-7	Gamma-cyhalothrin	76703-62-3
Cyflufenamid	180409-60-3	Mefentrifluconazole	1417782-03-6
Diflufenican	83164-33-4	Oxathiapiprolin	76703-62-3
Flonikamid	158062-67-0	Pikolinafen	137641-05-5
Fluazifop-P	83066-88-0	Pyroxsulam	422556-08-9
Fluazinam	79622-59-6	Tau-fluvalinate	102851-06-9
Flufenacet	142459-58-3	Tefluthrin	79538-32-2
Fluopikolid	239110-15-7	Trifloxistrobin	141517-21-7
Fluopyram	658066-35-4	Tritosulfuron	142469-14-5

Out of these active substances in Table 1, Flufenacet, Gamma-cyhalothrin and Tritosulfuron have had their approvals for being sold, ceased on the Swedish market as of 2025 (Sigma-Aldrich, n.d.; KEMI, 2026).

There are few individual studies that showcase the pathways of degradation for all individual substances listed above, but one study by Johnsen et al. (2026) has looked at the yield of TFA from degradation of seven different pesticides. The pesticides investigated in the study are Fluopyram, Fluazinam, Diflufenican, Fluazifop-P, Mefentrifluconazole, Tau-Fluvalinate and Trifluralin. Of these seven pesticides, Trifluralin has not been approved for sale on the Swedish market since 1990 (SLU, 2002) while the other six, as listed prior, are still in use for Swedish agricultural practices.

The study conducted by Johnsen et al. (2026) showed that all seven substances had TFA as a product of degradation with varying yields for each substance and soil type, as shown in *Figure 4*.



TFA formation from degradation of C–CF$_3$ pesticides as a percentage of the parent compound's potential TFA equivalents in three organically managed, agricultural soils (Sv1, Sv3, and Sv6) determined after 52 weeks of incubation. For each compound, the transformation is shown as mean ± 1 standard deviation (n = 3) and as overall geometric mean.

Compound	**Sv1 (%)**	**Sv3 (%)**	**Sv6 (%)**	**Geometric mean (%)**
Fluopyram	7.9 ± 0.3	3.3 ± 0.2	10.7 ± 0.5	6.5
Fluazinam	6.5 ± 0.2	5.3 ± 0.2	6.0 ± 0.4	5.9
Diflufenican	2.9 ± 0.8	2.4 ± 0.1	5.2 ± 1.1	3.3
Fluazifop-P-butyl	3.0 ± 0.0	3.1 ± 0.0	5.3 ± 0.0	3.7
Trifluralin	1.7 ± 0.0	1.1 ± 0.1	2.2 ± 0.1	1.6
Mefentrifluconazole	2.6 ± 0.2	0.8 ± 0.0	3.3 ± 0.1	1.9
tau-Fluvalinate	1.0 ± 0.1	0.4 ± 0.1	1.0 ± 0.1	0.7

Figure 4:TFA formation from degradation of pesticides as a percentage of the parent compound's potential TFA equivalents (Johnsen et al., 2026)

Due to the potential production of TFA from pesticides, KEMI has decided to re-evaluate 38 pesticides that contain Diflufenican, Flonikamid, Fluazinam, Fluopyram, Mefentrifluconazole and Tau-Fluvinate (KEMI, 2025 cited in Häggqvist & Rosenqvist, 2025). A decision on these 38 pesticides will be made prior to the deadline of late April 2028.

2.3. Scientific Studies of Toxicity and Ecotoxicity of TFA

TFA is a strong acid, but as present in the natural environment the concentrations are too low for any acute corrosive effects as well as having little to no bioaccumulate properties (Dekant & Dekant, 2023). Reported toxicities in animals is rather low, and conducted studies on test animals has showed little to no toxic effects. This is especially notable since the concentrations tested, very much exceed overall concentrations found in the natural environment (Freeling & Björnsdotter, 2023). One study found that inhalation of high concentration TFA in rats and guineapigs showed dystrophy of the liver and kidneys as well as loss of body weight and irritation of the respiratory pathways. However, the validity of the study was not assessed (ECHA, 2022 cited in Dekant et al., 2023). Furthermore, Dekant et al. (2023) means that the studies on TFA toxicity in animals were conducted over periods not spanning longer than weeks at most, giving little information on the effects of long-time exposure of TFA.

The effect of TFA on the reproductivity has also been studied. As one study looked at the generational effect in rats due to TFA in their diet, it was found that the highest dose administered to the rats, 250 mg/kg/day, had no adverse effects (ECHA, 2022 cited in Dekant et al., 2023). However, some changes such as increased liver weight were observed, but no impact on development or reproductivity.

In one study, the genotoxicity of TFA in bacterial colonies was conducted. TFA was added to colonies of five strains of *Salmonella typhimurium*, with upper limit concentrations of 5 mg/plate to look at reverse bacterial mutation. The conclusion drawn from the study was that TFA could not be considered as mutagenic in the bacterial colonies (ECHA, 2022 cited in Dekant et al., 2023).

The toxicity of TFA in humans has been studied, and as concluded in the report *The Effects of Trifluoroacetic Acid (TFA) in Humans: A Rapid Review* by Wipplinger et al. (2025), "The present work supports the view that TFA exhibits minimal acute toxicity. Its health effects in humans are primarily associated with its role as a metabolite in halothane-induced hepatitis and with chemical burns that may occur in accidents involving TFA in its form as a strong acid.*"*. However, it is claimed in the report that conclusions regarding potential effects on human health due to long term exposure of low concentrations of TFA cannot be made (Wipplinger et al., 2025). Due to the unknown effects of long-term exposure of TFA, The European Food Safety Authority (EFSA) has derived a human acceptable intake of 0.05 mg TFA/kg bw/day (EFSA 2014 cited in Solomon et al., 2016). This limit is based on a safety factor of 200 from a 90-day study where rats ingested with TFA showed changes in blood chemistry, liver weight and liver hypotrophy at a No-Adverse-Effect-Level (NOAEL) of 10 mg/kg bw/day (Bayer 2014 cited in Solomon et al., 2016).

Due to the former 90-day studies conducted on rats, the chemical company Solvay, on behalf of the German Federal Environment Agency (UBA), conducted their own one-year study in 2018/2019 on the effects of TFA in rat populations through ingestion of drinking water (UBA, 2020a). The study found that the main effect of concern through ingestion of TFA was the increase of the enzyme alanine aminotransferase (ALT) in the rat's blood, and increased levels of ALT in blood can relate to liver damage. Based on the study, UBA (2020a) derived a Tolerable Daily Intake (TDI) of 0.018 mg TFA /kg bw for humans based on the NOAEL in the rat population. The TDI in rats was 1.8 mg TFA /kg bw, and a safety factor of 100 was used for the human TDI.

2.4. Current Recommendations of Permissible Levels of TFA in Drinking Water and Nature Waters

At the end of July 2026, the World Health Organization (WHO) is set to have collected global data on 18 key PFAS, including TFA, to develop harmonised health-based guideline values for drinking water and food exposure by 2027 (WHO, 2026). Globally, TFA is rarely explicitly regulated in drinking water, and only a few countries, mainly in Europe, have set guidelines for permissible levels of TFA in drinking water and the environment.

2.4.1. Dutch Regulations

Dutch authorities have proposed a maximum concentration of TFA in drinking water to 2200 ng/l (RIVM, 2023). This concentration is based on a relative potency factor of the PFAS PFOA. Previous guidelines for concentrations of PFOA in Dutch drinking water has been set to 4.4 ng/L by RIVM (2021) as cited by RIVM (2023). RIVM (2023) has through the collection of data from several studies on PFAS, looked at how different concentrations of PFAS affect liver weight in rat populations. With the gathered data on liver weights, a quantitative dose–response modelling approach was used to fit liver weight versus dosage of PFAS. The curves were forced to be parallel for each PFAS, meaning differences between PFAS are captured purely as a horizontal shift in the curve. A potency factor was then extracted that eliminates the lag between a selected PFAS and the indexed PFOA. In the case of TFA, it was given a potency factor of 0.002 relative to PFOA (RIVM, 2023) meaning that according to their model, TFA would need a dose 500 times higher than PFOA to have the same negative effect on liver weights in rat populations. By dividing the guideline maximum concentration of PFOA in Dutch drinking water, 4.4 ng/L, with TFA's attained potency factor, 0.002, the proposed maximum concentration of 2200 ng/L for TFA in drinking water was established.

2.4.2. German Regulations

Germany has set TFA concentration regulations and proposals for several types of water. According to a report by UBA (2020b), the proposed maximum concentration of TFA in German groundwaters is 10 000 ng/L, based on general EU pesticide framework. For surface waters, an environmental quality standard (EQS) concentration of 2100 ng/L has been proposed in the report, referring to an internal assessment regarding the pelagic community. For German drinking water, a health-based guideline value for TFA of 60 000 ng/L and a precautionary limit of 10 000 ng/L has been proposed by UBA (2020b). The maximum value of 60 000 ng/L is derived from the TDI of 0.018 mg TFA /kg bw that was found in the Solvay Hannover study (2.3). By taking into account the average human body weight, water consumption and an allocation factor of 10%, meaning that drinking water should only amount to 10% of daily intake of TFA amongst others such as food, they derived it so that 60 000 ng/L is the threshold of which human consumption of TFA is harmless in theory (UBA, 2020a). The following equation below shows how the calculated value was made assuming a standard body weight of 70 kg and daily water consumption of 2 litres. However, the true limit by which UBA (2020a) wants TFA concentrations in drinking water to be held at is 10 000 ng/L, arguing that it is a safety margin as well as being in-line with the maximum concentration for pesticides in groundwater.

$$Max. Concentration\ of\ TFA = \frac{TDI * Body\ weight * Allocation\ factor}{Drinking\ water\ consumption} \quad \textbf{(eq. 2.1)}$$

2.4.3. Danish Regulations

Danish regulations on maximum TFA concentrations in drinking water has been set to 9000 ng/L. Denmark is seemingly the only country in Europe with an explicit limit to TFA that is legally binding according to the Danish Drinking Water Directive (BEK nr 810 af 18/06/2024). This limit has been set dependent on German rather than Danish institutions. A recommended maximum concentration of TFA in Danish drinking water was suggested by the Danish National Food Institute at DTU to 100 000 ng/L (Miljøministeriet, 2021) while the reasoning for this value was "based on available data" and no further explanation as to the origin could be found. However, Danish authorities chose to dismiss their own assessment and opted to align with the German recommendations. Furthermore, Miljøministeriet (2021) has stated that "In Germany, it is recommended that the concentration of TFA in drinking water is held under 10 μg/L". This suggests that a safety factor of 10% may have been applied by Danish authorities to the German guidelines, resulting in their final value of 9000 ng/L. Furthermore, the Ministry of Environment of Denmark has, much like in Germany, proposed maximum values for concentrations of TFA in natural waters with regards to the pelagic community (Miljøstyrelsen, 2024). These values are based on toxicologic assessments from several individual studies summarized by, amongst other, ECHA (2022) as cited my Miljøstyrelsen (2024). The proposed maximum concentrations are intended to protect fresh- and saltwater organisms from short-term and long-term exposure of TFA. The proposed long-term maximum concentrations for fresh- and saltwater are 560 000 and 56 000 ng/l respectively. Finally, the proposed short-term maximum concentrations for fresh- and saltwater organisms are 2 370 000 and 237 000 ng/l respectively.

2.4.4. EU Perspectives

In 2020, the EU adopted the recast Drinking Water Directive (EU) 2020/2184 (DWD) with the directive having entered force within EU member states in January 2021. Member states have had to transpose the directive into national law by January 2023 (European Commission, n.d.). According to the European Commission (n.d.), some key features of the revised directive are “reinforced water quality standards, in line or, in some cases, even more stringent than the WHO recommendations” as well as “tackling emerging pollutants, such as endocrine disruptors and PFAs, as well as microplastics” and “harmonisation of the quality standards for materials and products in contact with water”.

As of the 12th of January 2026, members states have to ensure compliance with Annex I in the DWD that defines minimum requirements for parametric values used to assess the quality of water intended for human consumption. Amongst the many parameters, two of them define parametric values for PFAS. The first parameter is “Sum of PFAS” and is defined as “[…] the sum of per- and polyfluoroalkyl substances considered a concern as regards water intended for human consumption listed in point 3 of Part B of Annex III. This is a subset of ‘PFAS Total’ substances that contain a perfluoroalkyl moiety with three or more carbons (i.e. –CnF2n–, n ≥ 3) or a perfluoroalkylether moiety with two or more carbons (i. e. –CnF2nOCmF2m–, n and m ≥ 1).” With a parametric value of 0.1 µg/l. However, from Part B of Annex III, TFA is clearly excluded from the defined “Sum of PFAS”. The second parameter, “PFAS Total”, is defined as “[…] the totality of per- and polyfluoroalkyl substances. This parametric value shall only apply once technical guidelines for monitoring this parameter are developed in accordance with Article 13(7). Member States may then decide to use either one or both of the parameters ‘PFAS Total’ or ‘Sum of PFAS’.”. The parametric value is set to 0.5 µg/l.

It is stated in Article 13(7) of the DWD (2020) that “By 12 January 2024, the Commission shall establish technical guidelines regarding methods of analysis for monitoring of per- and polyfluoroalkyl substances under the parameters ‘PFAS Total’ and ‘Sum of PFAS’, including detection limits, parametric values and frequency of sampling.” These technical guidelines are defined in Commission notice C/2024/4910 (2024), and it is stated that after the OECD technical definition of PFAS from 2018 was revised in 2021, TFA would now be classified as a substance under “PFAS Total”. According to the Commission notice (2024) the addition of TFA to the definition of “PFAS Total” should be evaluated since TFA concentrations in waters could significantly exceed the

Directive parametric value of 0.5 µg/l and this could lead to a separate parametric value for TFA having to be implemented.

In October 2025, EFSA (2026) held a workshop on the latest advancements of PFAS risk assessment. A summary of this workshop was published in march 2026, with conclusions stating that TFA is an important, unresolved PFAS-related issue still in need of coordinated toxicology, monitoring, method development, and cross-agency work before the science is considered mature. From the workshop, it was noted that dietary TFA exposure from edible plants may rival or even exceed exposure from drinking water due to degradation of pesticides. However, the source of TFA present in both edible plants and drinking water is likely the same. EFSA had already launched a targeted data call, collected 170 studies plus a position paper, and set up a working group to examine genotoxicity, the basis for an acceptable daily intake, and whether an acute reference dose is needed for TFA. A draft statement from the working group had gathered 177 comments from several stake holders and public consultation that will result in a final statement on TFA from the EFSA with a deadline on the 31st of July 2026. The working group's draft statement proposed an Acceptable Daily Intake (ADI) for TFA of 0.03 mg/kg bw per day, and an Acute Reference Dose (ARfD) of 0.6 mg/kg bw (EFSA, 2026).

2.4.5. Swedish State-of-the-Art

Unlike its European neighbours, Sweden does not have current recommended or enforced permissible levels of TFA in drinking water or nature waters. In accordance with EUs DWD (2020), the Swedish National Food Agency introduced a new national directive LIVSFS 2022:12 (2022) with regulations regarding water. Amongst other, new regulations regarding PFAS were introduced with permissible levels for PFAS21 and PFAS4 introduced. According to LIVSFS 2022:12, PFAS21 covers all PFAS listed under DWD's (2020) parameter Sum of PFAS with the addition of 6:2 Fluorotelomersulfonic acid. PFAS4 covers four PFAS, namely PFOS, PFOA, PFHxS and PFNA. According to the Swedish National Food Agency (Personal communication, 8th of April 2026a), PFAS21 and PFAS4 have been implemented in accordance to the DWD (2020) as separate parameters based on the Commission's "Sum of PFAS".

Neither PFAS21 nor PFAS4 cover TFA, and the Swedish National Food Agency (2026b) has stated that "Based on what we know today, the amount of TFA we consume through food and drinking water poses no health risk.". However, they also state that they will follow the evaluations of TFA conducted by ECHA and EFSA to assess whether a maximum amount of TFA allowed in drinking water should be set. The Swedish National Food Agency (2026a) has also noted that even if EU does not implement a regulatory limit for TFA concentrations in waters, Sweden could, if thought necessary, set their own legal limits.

2.4.6. Compilation of Regulatory TFA Limits

The combined proposed and enforced limits of TFA concentrations for different exposure types is presented in Table 2 below.

Table 2: Proposed or enforced regulatory limits of TFA from different authorities.

Authority / country	**Water or exposure type**	**TFA (ng/L)**	**Regulatory status / comment**
Netherlands – RIVM	Drinking water	2,200	Proposed maximum concentration for TFA in drinking water
Germany – UBA	Groundwater	10,000	Proposed maximum concentration based on the EU pesticide framework
Germany – UBA	Surface water	2,100	Proposed environmental quality standard, EQS, with regard to the pelagic community
Germany – UBA	Drinking water	60,000	Health-based guideline value derived from TDI
Germany – UBA	Drinking water	10,000	Precautionary limit / preferred target value
Denmark – Danish Drinking Water Directive	Drinking water	9,000	Legally binding explicit TFA limit
Denmark – Danish National Food Institute at DTU	Drinking water	100,000	Recommended maximum concentration. Not adopted
Denmark – Ministry of Environment / Miljøstyrelsen	Freshwater organisms, long-term exposure	560,000	Proposed environmental maximum concentration
Denmark – Ministry of Environment / Miljøstyrelsen	Saltwater organisms, long-term exposure	56,000	Proposed environmental maximum concentration

Authority / country	**Water or exposure type**	**TFA (ng/L)**	**Regulatory status / comment**
Denmark – Ministry of Environment / Miljøstyrelsen	Freshwater organisms, short-term exposure	2,370,000	Proposed environmental maximum concentration
Denmark – Ministry of Environment / Miljøstyrelsen	Saltwater organisms, short-term exposure	237,000	Proposed environmental maximum concentration
EU – Drinking Water Directive	"Sum of PFAS" in drinking water	100	Parametric value of 0.1 µg/L; TFA is excluded from "Sum of PFAS"
EU – Drinking Water Directive	"PFAS Total" in drinking water	500	Parametric value of 0.5 µg/L; TFA may fall under "PFAS Total", but no separate TFA value exists
Sweden – Swedish National Food Agency	Drinking water / natural waters	No value set	No current recommended or enforced permissible TFA level
WHO	Drinking water / food exposure	No value set	Harmonised health-based guideline values are expected to be developed by 2027

3. Materials and Methods

3.1. Study Design

The aim is to look at available data of measured concentrations of TFA in Swedish groundwaters. With the gathered data, the concentrations will be presented as differences between regions on a county and municipal level. The data on TFA will also be presented through boxplots, showing the mean, median, minimum, maximum, 25- and 75-percentiles as well as plots showing changes in concentrations over time.

Data on sold quantities of pesticides in Sweden ranging from the year 2000 to 2024 is gathered. The pesticides in question all have at least one fluorinated methyl group and several of the pesticides have been proven to produce TFA as a product of degradation. The data will be presented as accumulation of pesticides in the natural environment over time, as well as annual input to the natural environment through agricultural practices, including the potential production of TFA.

3.2. Data Sources

The main sources of data used in this study come from the Geological Survey of Sweden (SGU) and KEMI. SGU has available data on measured TFA concentrations while KEMI has data on sold quantities of pesticides. Additional data on TFA concentrations in drinking water from lake Mälaren has been acquired through Norrvatten.

3.2.1. Groundwater Data from SGU

SGU has hundreds of groundwater measuring stations covering all of the Swedish regions. The stations provide information on numerous parameters regarding concentrations of several substances present in the groundwater. The data is available to the public and can be downloaded as .JSON- or .CSV-files with compiled station data for each county. The relevant data for this study has been downloaded as .CSV-files from https://resource.sgu.se/oppnadata/grundvatten/api/miljoovervakning/lan/LANSKOD?format=csv and later converted to .XLSX-files to be handled in Excel. By changing “LANSKOD” in the URL to the specific county code, e.g., “01” for Stockholm County, a national compilation has been made from all counties.

3.2.2. Pesticide Sales Data from the Swedish Chemical Agency

KEMI releases yearly reports on the sold quantities of pesticides on a national level. Through each yearly report, the active substances in pesticides measured in tonnes per year and area of agricultural practice is reported. KEMI (2024) has released these reports since 1976, with online access available for reports 1986 and onward.

3.3. Data Preparation and Cleaning

The raw data available has first and foremost been either downloaded, as for the measurements from SGU, and compiled in Excel, or manually entered into Excel as for the data from KEMI.

From SGU, the raw data includes several parameters not relevant for this study i.e., data not covering measurements regarding TFA. These other data have been filtered out and removed. The remaining data measuring TFA is left. A total of 407 individual measurements of TFA concentrations in Sweden have been gathered from SGU’s public database. The earliest measurement available was made in late October 2023, while majority of measurements have been made in 2024. Through personal communication with SGU (12th of February, 2026), publicly unreleased measurements were received. Many of the new measurements were taken in 2025, while most lacking critical information needed for analysis, 20 additional measurements with sufficient parameter information was added. Additionally, Norrvatten supplemented with data on extracted surface water from lake Mälaren, adding an additional 12 measurements. The resulting compilation ended with a total of 437 individual measurements of TFA concentrations in groundwater and surface water from 2023 to 2026. A few measurements initially gathered were removed due to insufficient number of parameter values.

Each line of data from SGU contains information on the date of measurement, location through coordinates, county code, station name and a national station ID. Several measurements lack complete data on location of measuring station regarding coordinates. Through the Swedish Water Information System (VISS), coordinates for several stations have been added through matching of the national station ID available, but information on the exact coordinates could not be found for all stations. To further complete lacking station location, estimated coordinates were made for some stations with the use of the station name. The station name is attributed to the geographical area by which the station is located, and by matching the name of the area along with the county code, estimated coordinates were made using Google Maps and added to the data set.

3.4. Data Processing and Analysis

3.4.1. Groundwater TFA Metrics

The data from TFA measurements has been divided into two subgroups. The purpose of this is to be able to look at overall gradients in concentrations by national level, county, and somewhat on a municipal level with the most amount of data possible. This group includes all data available. To be able to look at trends, data has been extracted based on time, rather than location. This includes data that has been gathered from the same measuring station several times over a time period, and has been categorized as trend-data.

3.4.2. TFA on a national scale

With the use of each measurements assigned county code, all measurements have been divided and processed individually to form boxplots for each county. With lack of data from Södermanland County and Gotland County, nineteen counties have been processed for TFA concentrations. For each county, the minimum, maximum, median and mean concentrations have been presented in boxplots. The upper and lower quartile represent the concentrations within the 25th and 75th percentile, with upper and lower whiskers representing maximum and minimum concentrations measured within the county. The median is represented by a yellow line horizontally fixed in the box, with a blue dot showing the mean concentration. Additionally, the number of measurements for each boxplot is represented as the letter (n).

3.4.3. TFA trend analysis

The concentrations of TFA in different waters vary with tenfold magnitudes. Some measuring stations display concentrations exceeding 2000 ng/l, while others hover around 100 ng/l. It would then be wrong to assume a common average concentration when displaying trends in change of concentrations over time. To display these trends with varying initial concentrations, two model approaches have been used on log-transformed data. The first, a Linear Mixed Model (LMM) has been applied to all trend-data. This model incorporates fixed and static effects on TFA concentrations allowing for visualization of a general trend for all observed stations even though concentrations can differ much in magnitude. The LMM is based on the following equation:

$$Y_{ij} = \beta_0 + \beta_1 \cdot Year_{ij} + u_i + \epsilon_{ij} \qquad \textbf{(eq. 3.1)}$$

Where Y_{ij} is the normal logarithmic concentration measured at station i and time j. β_0 is the fixed intercept, β_1 is the fixed effect of time (year) representing the overall temporal trend. u_i is the random intercept for station i, assumed to follow a normal distribution $u_i \sim N(0, \sigma^2_{\text{station}})$. ϵ_{ij} is the residual error, assumed $\epsilon_{ij} \sim N(0, \sigma^2)$. This model accounts for variability between the stations while estimating a common temporal trend across all stations.

To account for, and evaluate the sensitivity of the LMM, a Robust Linear Model (RLM) was also fitted to downweigh observations with large residuals.

This can reduce the influence of outliers or extreme values on the estimated trend from the LMM. The RLM is based on the following equation:

$$Y_{ij} = \beta_0 + \beta_1 \cdot Year_{ij} + \gamma_i + \epsilon_{ij} \qquad \textbf{(eq. 3.2)}$$

The variables are defined as for the LMM, but with the exception for γ_i that represents station-specific fixed effects, implemented as dummy variables.

Further visualisation in trends were made using linear regression for each station with normalised initial natural logarithmic concentrations. This shows potential trends for each station, represented with red for trend lines showing increase in TFA concentrations, and blue for decreasing concentrations.

3.4.4. Pesticide Indicators

For each year, 2000 to 2024, the total sales of the active substance present in pesticides were compiled for each of the substances presented in section 2.2.3. The data is presented through a graph showing yearly input of each substance as the mass of each active substance converted to TFA-equivalents. The conversion stems from the relationship between the molar mass of the substance in relation to the molar mass of TFA, to create a theoretical maximum yield of TFA each year. For the case of degradation from Fluazinam and Fluopyram to TFA, the molar yield of TFA is doubled due to the substances containing two fluorinated methyl groups that could theoretically degrade into two TFA molecules.

Due to TFAs accumulative effects in groundwater, two model approaches have been done to look at potential accumulation of TFA due to input of pesticides.

The first model displays a total accumulated mass of TFA in the form of TFA-equivalents. It shows how much accumulated potential TFA could be leached into Swedish groundwaters if no extraction or degradation occurs from the year 2000-2024. This model assumes that all pesticides have a 100% molar yield of TFA every year and no degradation of TFA occurs.

The second model is based on a mass balance, where the pesticides have a factor of degradation, i.e., a certain amount of the mass of pesticides form TFA each year. The formed TFA has accumulative effects, but in the model different potential half-lives are implemented for the accumulated TFA. The given half-lives are 50, 100, 200 and 500 years as well as no degradation, i.e., no half-life. The factors of degradation are based on the percentual degradation of pesticides to TFA illustrated in *Figure 4*. Since different soil types will be expected for agricultural areas on a national scale, the geometric mean has been applied to the noted pesticides. Due to lack of information on the remaining pesticides not tested for in the report, a mean value has been estimated based on the geometric means of the ones listed. The mass balance for TFA formed and degraded is as follows:

$$E_i^{in}(t) = v_i \frac{I_i(t) \cdot 10^6}{MW_i} \qquad \textbf{(eq. 3.3)}$$

Where $E_i^{in}(t)$ is the potential TFA-equivalent input in moles each year t, for each pesticide i. v_i is the stoichiometric yield in moles TFA per mole parent, i.e. 2 for Fluazinam and Fluopyram and 1 for all other pesticides. $I_i(t)$ is the pesticide applied in year t and MW_i is the molar mass of each pesticide. The TFA-equivalents are then converted to TFA according to:

$$F_i(t) = f_i E_i(t) \qquad \textbf{(eq. 3.4)}$$

Where $F_i(t)$ Is the formed TFA in moles from the factor f_i applied to each pesticide. The TFA-equivalent stock is then depleted from formation of TFA, while enriched from addition of new pesticide each year according to:

$$E_i(t+1) = E_i(t) - F_i(t) + E_i^{in}(t) \qquad \textbf{(eq. 3.5)}$$

The total amount of moles of TFA formed is the sum of all TFA formed from each pesticide and is converted to metric tonnes according to:

$$M_{TFA}(t) = \frac{F(t) \cdot MW_{TFA}}{10^6} \qquad \textbf{(eq. 3.6)}$$

The actual amount of TFA present each year due to half-life degradation is described as follows:

$$T(t+1) = (1-k)T(t) + M_{TFA}(t) \qquad \textbf{(eq. 3.7)}$$

Where $T(t)$ is the actual TFA stock at the start of year t, and k is the annual TFA loss fraction.

In summary, a mass-balance model was used to estimate the potential formation and accumulation of TFA from pesticide precursors. Annual pesticide inputs were converted into TFA-equivalents using molar masses and stoichiometric yields, after which a degradation factor was applied to estimate the fraction forming TFA each year. The remaining precursor stock was carried forward, while newly formed TFA was added to the accumulated TFA stock. Different TFA half-life scenarios were then applied to assess how persistence affects long-term accumulation. The model therefore describes both the yearly formation of TFA and its potential build-up over time with degradation assumptions.

3.5. Computational Tools

The main data processing and statistical analysis were conducted using Python. For data handling and numerical operations, the libraries *pandas* and *numpy* were used. When conducting statistical trend analyses for TFA, *statsmodels* were utilised to compute the LMM and RLM with figures being produced using *matplotlib*. In the case of mapping TFA concentrations on a national level, *geopandas* and *shapely* were used for geographical processing to convert station coordinates into spatial objects so that map visualisation through *matplotlib* and *contextily* could be performed.

Some Additional standard Python libraries were used, more specifically *math, os, sys* and *pathlib*. These were helpful in numerical functions and file handling.

3.6. Uncertainty and Limitations

The models used and analyses conducted are based on several fundamental assumptions and affected by lack of knowledge in the field. The limitations and uncertainties are important to keep in mind when evaluating the strength of the models and the conclusions that can be drawn.

3.6.1. National mapping of TFA trends & concentrations

When looking at concentrations for municipalities, there is a clear lack of data coverage. There are 290 municipalities in Sweden and collected data only covers 111 of these, meaning that only 38 percent of all municipalities have data coverage. This can be further misleading when looking at concentrations on a county level, since 90% of counties, 19 out of 21, are accounted for. Furthermore, several counties and especially municipalities are only represented by a few, and sometimes as little as one measurement. In many cases, one county can be represented by data collected in 2024, while a neighbouring county is predominantly represented by data collected in 2025. This has been done to be able to visualise concentrations on a national scale to the fullest extent, but assuming that concentrations differ too little over one year to actually create a significant misrepresentation.

An even larger gap in data coverage is found when analysing trends in concentration change over time. The LMM and RLM are based on trend-data collected from 29 measuring stations. Out of these, the mean group size is 4.4, a minimum of 2 and a maximum of 12. It is worth noting that only one measuring station has done 12 measurements, while the second largest group size is 5. In total, there are 128 observations represented by the trend-stations. Evaluating concentration change over time is also impeded due to the time scale. Since the earliest measurement was made in 2023 and the latest in 2026, long-term patterns in concentration changes are not obvious.

A notable factor when evaluating concentrations measured is the measurement uncertainty. TFA measurements done by SGU has a Limit of Quantitation

(LOQ) of 50 ng/l using an internal method of measuring (Häggqvist & Rosenqvist, 2025). The LOQ indicates that the lowest concentration of TFA in a sample that can be measured with acceptable precision and accuracy is 50 ng/l. This means that data valued at 0 in concentration, could in fact be positive and in theory affect the analyses. Furthermore, the internal method of measuring used by SGU does not indicate the level of measurement uncertainty. However, for other PFAS measured at the same sites, the measurement uncertainty lies at 31 %. This value could roughly be applicable to TFA, as measurements of TFA in Vombsjön conducted by Eurofins in 2024 had a measurement uncertainty of 38% (Sydvatten, personal communication, 6th of February 2026).

The title of this thesis could be misleading since majority of measurements of TFA have been taken from groundwater rather than surface water. However, since some measurements of TFA come from lake Mälaren, it would be wrong to not claim surface water as being part of the mapping. It is also assumed in this case that groundwater behaves much like surface water in respect to concentrations of TFA. Since most groundwater measurements by SGU have been taken in shallow gravel and sand aquifers, it is assumed that water retention times correspond well to surface waters.

3.6.2. Knowledge on Pesticides

Data on pesticides sold in Sweden stretch back to 1976 and the earliest accessible data comes from 1986. However, a time frame of the year 2000-2024 has been chosen to model. This is due to data from 1999 and earlier not being in digital format but rather scanned paper documents. Extraction could be possible from these documents, but would require extensive manual work. The data available is subject to knowledge gaps for certain pesticides. If one pesticide has sold less than 100 kg, it is denoted as zero tonnes sold that year. Due to market reasons, KEMI is not able to collect all data on sold pesticides from distributers some years, since the companies do not consider it possible to make the data public due to market reasons (KEMI, 2024). In the model, this has led to the assumption that years without data is considered as zero tonnes sold. Due to lack of knowledge on the factor of degradation for most pesticides, it is highly uncertain how much TFA is actually produced from pesticides that have been used in Sweden. Furthermore, the factor of degradation changes depending on soil type, while the model used has assumed a geometric mean for all of Sweden. It is also unknown if all pesticides bought each year are actually used or stored to be used in later years.

4. Results

The models developed and used are here presented in the order of concentrations for counties and municipalities, followed by boxplots for each county's concentration. Afterwards, TFA concentration trends for all trend stations are presented and finally potential accumulation of TFA from pesticide use is shown.

4.1. Swedish concentrations of TFA

The following *Figure 5* shows how the mean concentration of TFA varies between Swedish counties. Other than Värmland County to the east, the mean concentrations seem to have somewhat of an increase in the southward direction, with the highest in Skåne County. Södermanland County and Gotland County have no recorded measurements, hence no concentration gradient colour present. Blekinge- and Östergötland County are also presented with no concentration gradient colour, even though measurements have been made there. This is due to the measurements being treated as zero in concentration since they fall below the LOQ.

Figure 6 follows the exact same principle as *Figure 5*, but shows the mean concentration for the Swedish municipalities rather than counties. Here, the lack of measurements becomes more apparent as the number of grey municipalities exceed the number of coloured ones. Still, an overall increase in TFA concentrations in a southward direction can be seen, but it becomes clear that few individual measurements can represent, or rather misrepresent, large areas.

Since the concentrations presented in both figures are on a logarithmic scale, they are not excellent when looking at the actual TFA concentrations. The figures rather serve as indicators to showcase the gradient change between regions. As for the actual concentrations, they are presented with greater depth in boxplot *Figures 7* to *14*. The boxplots for the 19 counties are divided into three counties per figure with the exception of Skåne County. All figures are shown in a descending order of highest to lowest mean concentration of TFA.

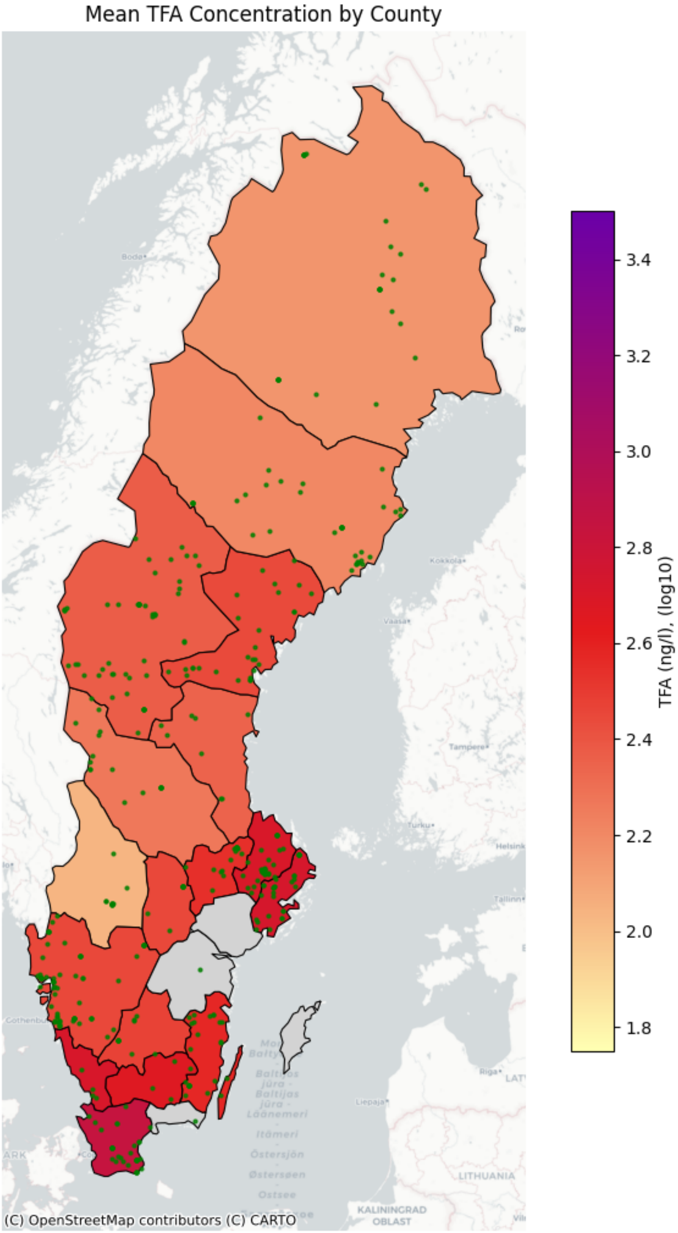


Figure 5: Mean concentration of TFA for each county. Measurements made illustrated as green dots. Concentrations are shown on a $\log_{10}$ scale, with original concentrations measured in ng/l.

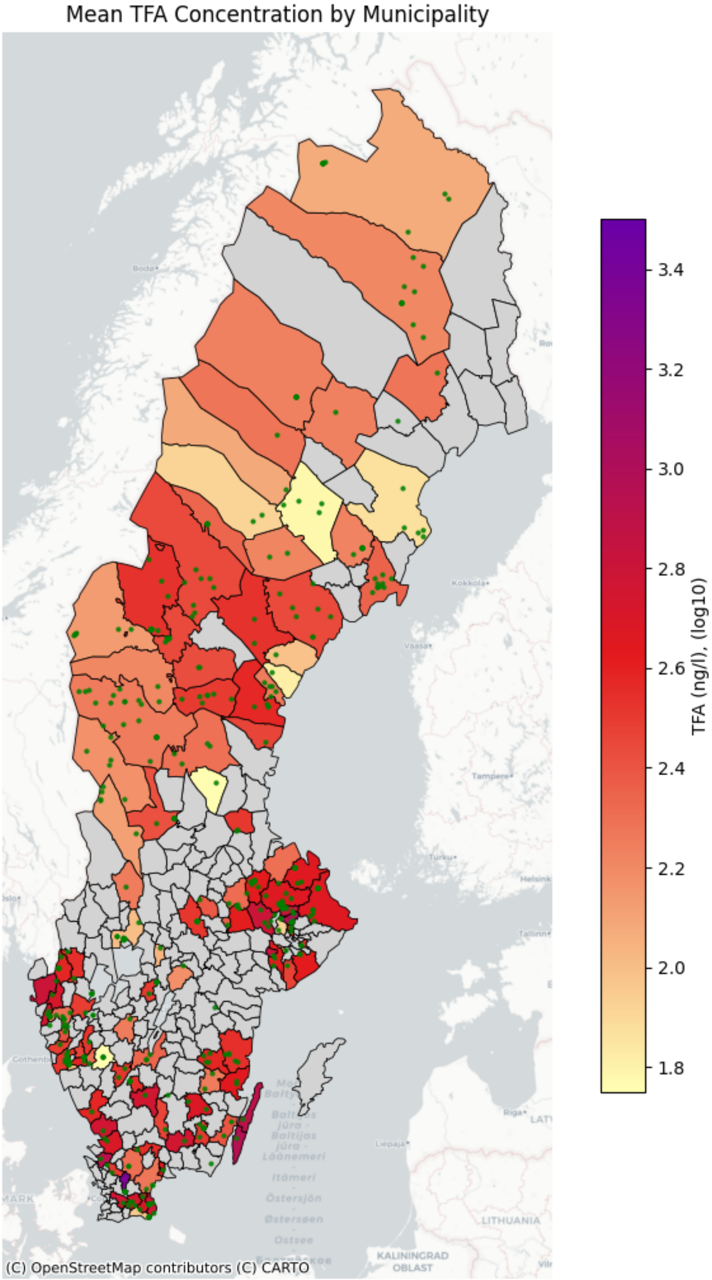


Figure 6: Mean concentration of TFA for each municipality. Measurements made illustrated as green dots. Concentrations are shown on a $\log_{10}$ scale, with original concentrations measured in ng/l.

In *Figure 7* it can be seen that the counties of both Stockholm and Uppsala have had a significant number of measurements made, 45 and 43 respectively, compared to Halland that has only had 5. However, the mean concentration is still between roughly 450 and 500 ng/l for all three counties. Stockholm has a maximum concentration of 1400 ng/l, while Uppsala and Halland have a maximum of 1300 and 650 ng/l respectively. The median corresponds fairly well to the mean value, indicating that the mean value is not overly weighted by extreme outliers in neither county.

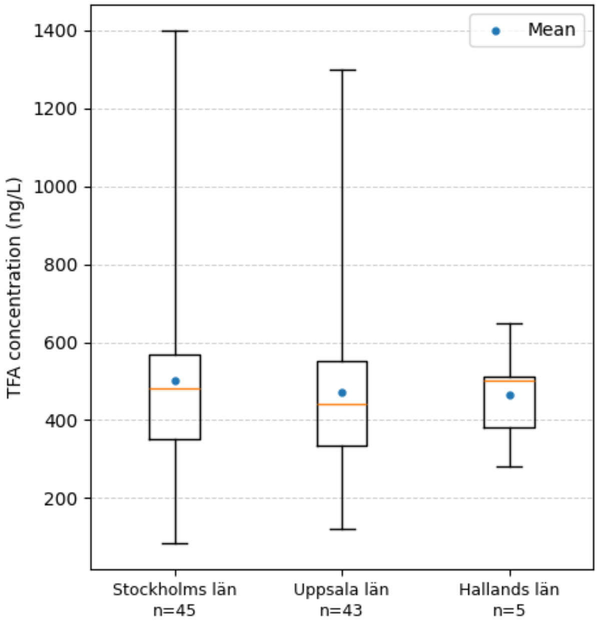


Figure 7: Boxplots showing the mean, median, 25- and 75-percentiles for the county's TFA concentrations with number of measurements represented as (n) for the counties Stockholm, Uppsala and Halland. The mean is shown with a blue dot and the median with a yellow line.

In *Figure 8* the boxplots for counties Kronoberg, Kalmar and Västmanland are shown. The number of measurements is low for both Kronoberg and Kalmar, only amounting to 4 and 6 respectively. Kalmar has had 25 measurements made, with large quartile groups one and four. Kronoberg has few extreme outliers, with a maximum of roughly 560 ng/l. Kalmar has a maximum of 920 ng/l and Västmanland a maximum of 720 ng/l. The mean concentration of Västmanland is situated in quartile group four, suggesting a weighted mean due to extreme outliers of high concentrations.

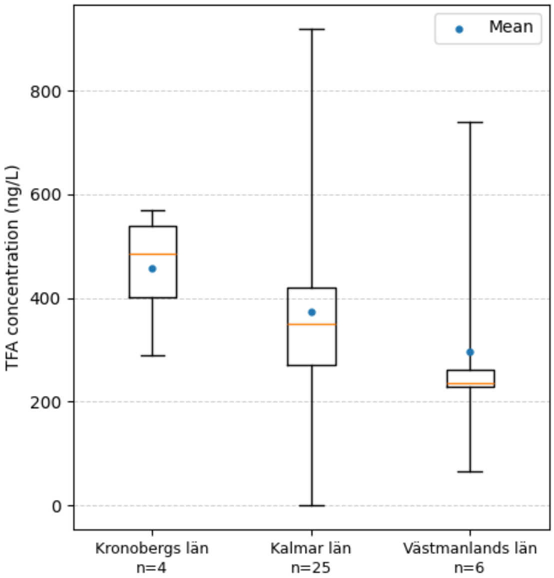


Figure 8: Boxplots showing the mean, median, 25- and 75-percentiles for the county's TFA concentrations with number of measurements represented as (n) for the counties Kronoberg, Kalmar and Västmanland. The mean is shown with a blue dot and the median with a yellow line.

The concentration boxplots for counties Örebro, Västra Götaland and Västernorrland are presented in *Figure 9*. Worth noting is that Västra Götaland is the one county that has had the largest number of measurements made, 67, out of all 19 counties studied. This has resulted in a mean value close to the median. For Örebro and Västernorrland, 8 and 28 number of measurements have been made respectively. All counties share somewhat the same mean concentration of roughly 280 ng/l, with a maximum concentration of 400 ng/l for Örebro, 1100 ng/l for Västra Götaland and 1000 ng/l for Västernorrland. Interestingly, Västra Götaland has several low concentrations below 100 ng/l with a lower whisker reaching 0 ng/l resulting in a lower quartile situated below 100 ng/l.

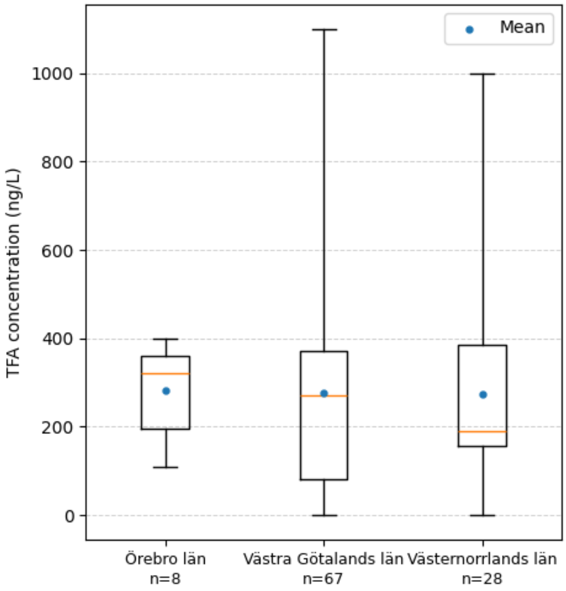


Figure 9: Boxplots showing the mean, median, 25- and 75-percentiles for the county's TFA concentrations with number of measurements represented as (n) for the counties Örebro, Västra Götaland and Västernorrland. The mean is shown with a blue dot and the median with a yellow line.

In *Figure 10* the concentration boxplots for counties Jönköping, Jämtland and Gävleborg are presented. Jämtland has had the second largest number of measurements made out of all counties, reaching 53 in total. Jönköping and Gävleborg have had 11 and 9 measurements made respectively. The mean concentration of the three counties corresponds fairly well to their median, with a mean between 270 and 210 ng/l in a decreasing order from Jönköping to Gävleborg. In the same order, the maximum concentrations measure 560, 950 and 450 ng/l for the three counties, with 0 ng/l in the lower whisker for both Jönköping and Jämtland.

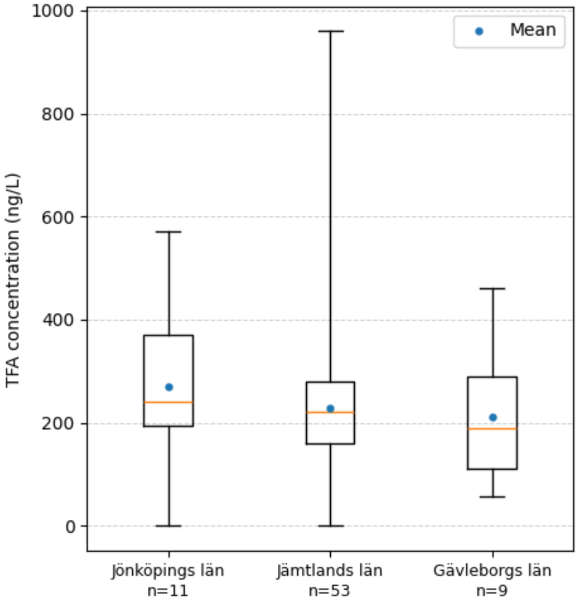


Figure 10: Boxplots showing the mean, median, 25- and 75-percentiles for the county's TFA concentrations with number of measurements represented as (n) for the counties Jönköping, Jämtland and Gävleborg. The mean is shown with a blue dot and the median with a yellow line.

Figure 11 illustrates the concentration boxplots for counties of Dalarna, Västerbotten and Norrbotten. Common for all three counties is that they display mean concentrations below 200 ng/l. The number of measurements made for Dalarna, Västerbotten and Norrbotten is 17, 36 and 28 respectively. From the previous order the three counties have maximum concentrations of 300, 490 and 240 ng/l. Interestingly, Norrbotten displays the lowest maximum concentration of all Swedish counties that has had more than one measurement made.

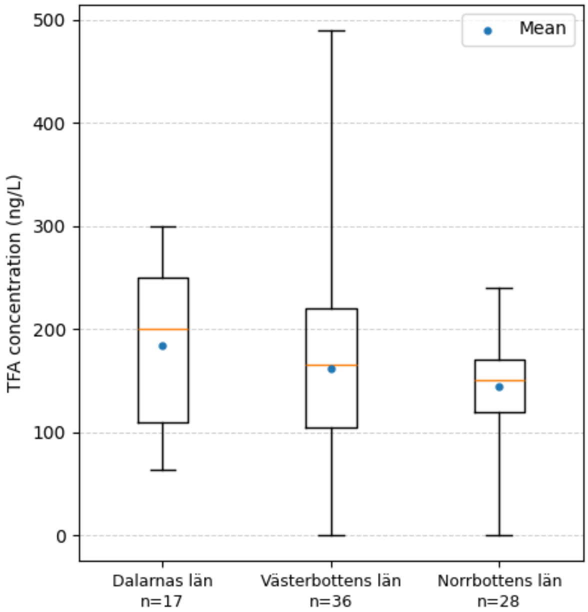


Figure 11: Boxplots showing the mean, median, 25- and 75-percentiles for the county's TFA concentrations with number of measurements represented as (n) for the counties Dalarna, Västerbotten and Norrbotten. The mean is shown with a blue dot and the median with a yellow line.

Figure 12 differs much from the previous boxplots due to the lack of data available resulting in some uninformative boxplots. The counties illustrated are Värmland, Blekinge and Östergötland, with the three having 11, 1 and 1 number of measurements made respectively. The boxplot with more than one data point, representing Värmland, displays a mean value slightly above 100 ng/l, but with a median, lower whisker and lower quartile all situated at 0 ng/l. Värmland has a maximum concentration of just under 600 ng/l. Both Blekinge and Östergötland only have a single measurement each at 0 ng/l, resulting in degenerate boxplots.

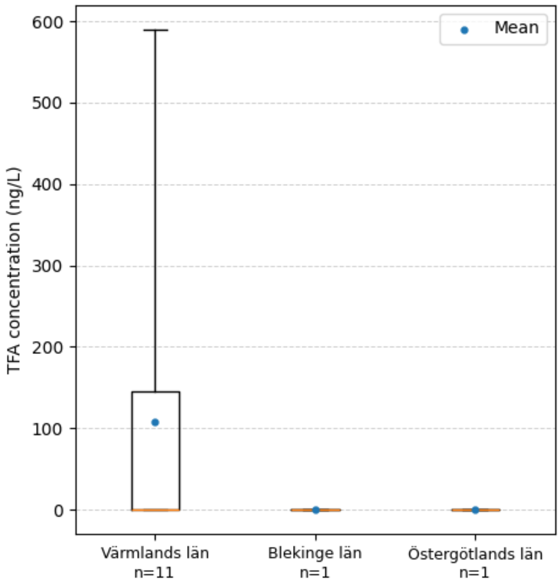


Figure 12: Boxplots showing the mean, median, 25- and 75-percentiles for the county's TFA concentrations with number of measurements represented as (n) for the counties Värmland, Blekinge and Östergötland. The mean is shown with a blue dot and the median with a yellow line.

The final county with an associated boxplot for its TFA concentrations is Skåne County, illustrated in *Figure 13*. This county displays the highest maximum concentration of all counties in Sweden, reaching 2700 ng/l. It also displays the highest mean concentration of all counties at 600 ng/l. The number of measurements made are 38, with a median value of roughly 350 ng/l. This difference between median and mean could suggest a weighted mean due to extreme outliers in quartile group four.

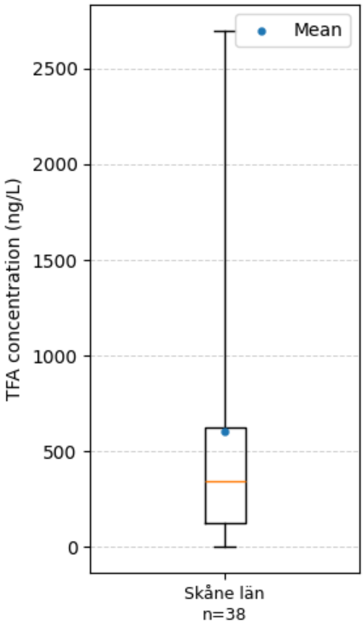


Figure 13: Boxplot showing the mean, median, 25- and 75-percentiles for the county's TFA concentrations with number of measurements represented as (n) for Skåne County. The mean is shown with a blue dot and the median with a yellow line.

A side-by-side comparison of the 19 Swedish county's boxplots is illustrated in *Figure 14.* What becomes clear is the extreme maximum concentration measured in Skåne County compared to all other counties that seem to congregate well in their span of concentrations. Even though the minimum and maximum concentrations of all counties can differ in the magnitude of thousands, the mean value for all counties level fairly well on a national scale, differing in size of between roughly 600 and 100 ng/l at the extremes, with a national mean concentration of about 360 ng/l.

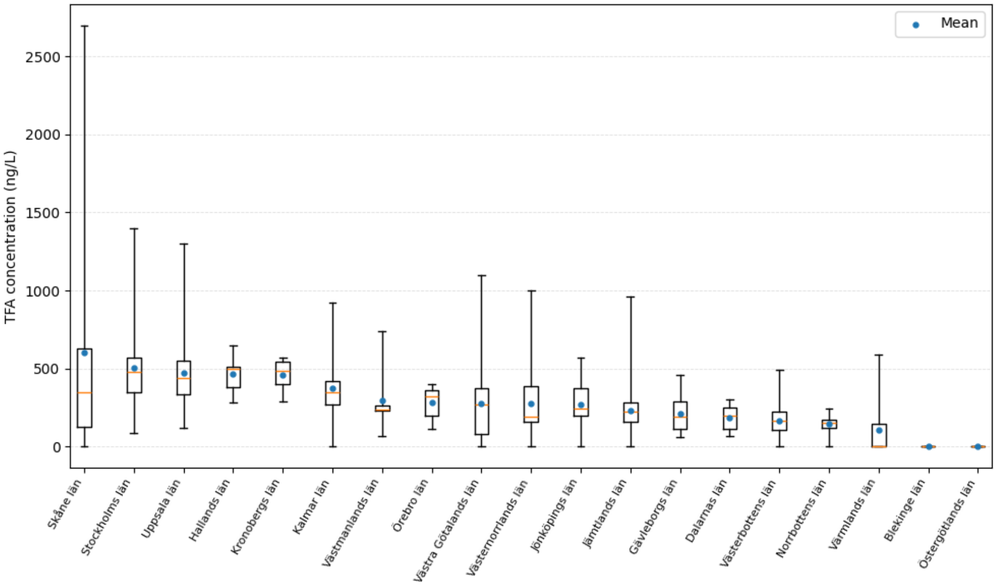


Figure 14: Boxplot showing the mean, median, 25- and 75-percentiles for the county's TFA concentrations with number of measurements represented as (n) for 19 out of all 21 Swedish counties. The mean is shown with a blue dot and the median with a yellow line.

4.2. Concentration trends

From the 29 stations that have had more than one measurement done in time, an LMM and RLM have been conducted and the two trend lines are presented in *Figure 15* below. The time scale shows that measurements were taken as early as the latter half of 2023, with the latest single measurement done in early 2026. Majority of measurements are clumped for each year. For instance, there are three major gaps, or rather four major clumps, where many of the measurements are taken. The slopes of the LMM and RLM result in a yearly increase change in concentration of 19.65- and 16.86 percent respectively as can be seen in Appendix Table 3 and Table 5. The actual value of the TFA concentration on the y-axis gives no information on the trendlines, but what is of essence is the slope of the lines.

The RLM downweighs outliers and reduces the influence of trend stations with observed extreme high or low measurements, which in the case of this model results in a slightly lower percentual increase in concentration compared to the LMM. Comparatively, it could be said that some high or extreme observations contribute to a steeper increase in the LMM. However, both models show with certainty a positive trend in concentration increase over the whole time-scale. As presented in Appendix Table 4 and Table 6, the p-value associated with the year coefficient was <0.001, suggesting that the observed increase is unlikely to arise from random sampling variability under the assumptions of the model.

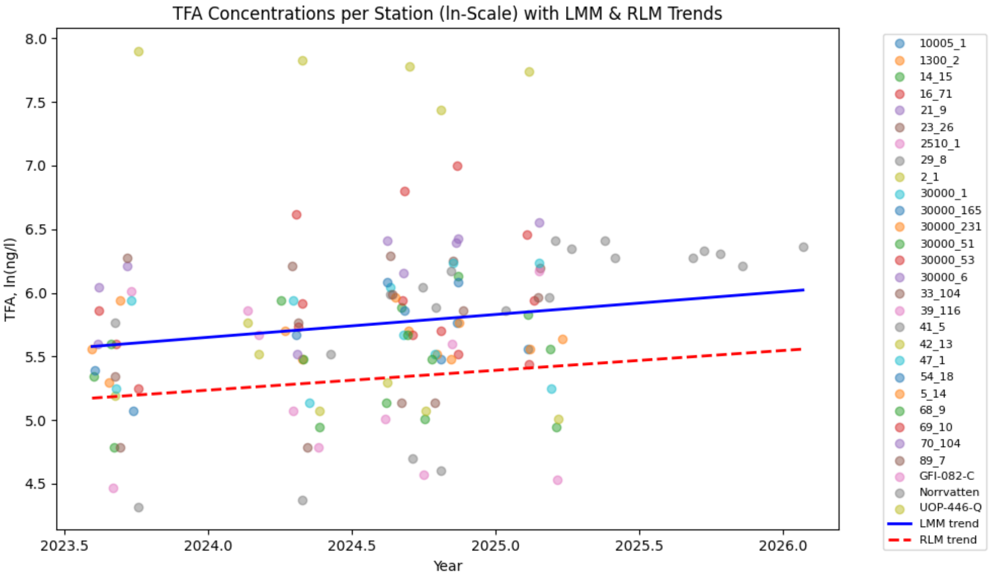


Figure 15: Linear mixed model fitted for all trend stations. Includes LMM and RLM trend lines as well as station values on ln-scale for all trend station measurements, represented by the colour of each station presented in the right-hand corner.

The national trend fitted for all trend stations as illustrated in *Figure 15* assume the same rate of change in concentration across all stations. In the real world this is unlikely to be the case, and so individual trend lines and change in concentration is illustrated in *Figure 16* and *Figure 17*. The first figure shows the percentual change relative to the first measurement normalised for each station. Even though each station is colour coded, it can be quite hard to follow the concentration change between measurements for one individual station. What is clear from *Figure 16* however, is that most measurements taken after the very first measurement for each station, is located above the index line, showing an increased change in concentration for the majority of trend stations.

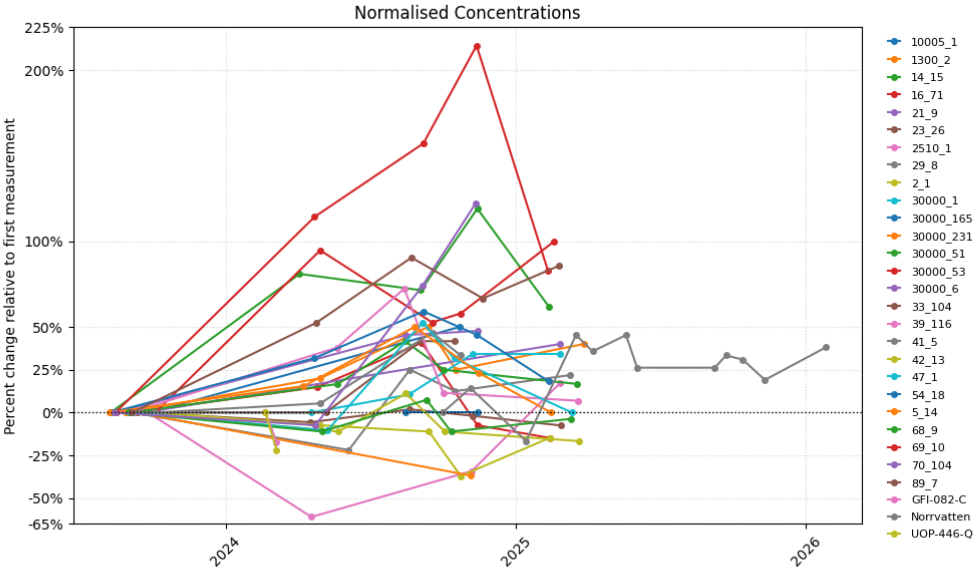


Figure 16: Percentual change in concentration for measurements in time at all trend stations. The dots represent each measurement done with interconnecting lines showing the slope of change between measurements. All normalised around each station's first measurement.

Based on the same normalised concentrations as in *Figure 16*, a visual representation of the rate of change for all trend stations is shown in *Figure 17*. Worth noting in the figure is that the y-axis does not correlate its values to the trendlines very well, and the initial value from which each trendline starts gives no valuable information. The purpose of the trend lines is to give an overview of the general trend for each individual trend station rather than giving information on the rate of change. What becomes clear from the figure is that 6 out of 29 stations have, under the time by which measurements have been taken, shown a decrease in TFA concentration. 3 stations have shown close to zero change, and the remaining stations have shown in increase in TFA concentrations. This is well visualised by the colour coding of the trend lines and the majority of them, coloured red, show this increase in concentrations.

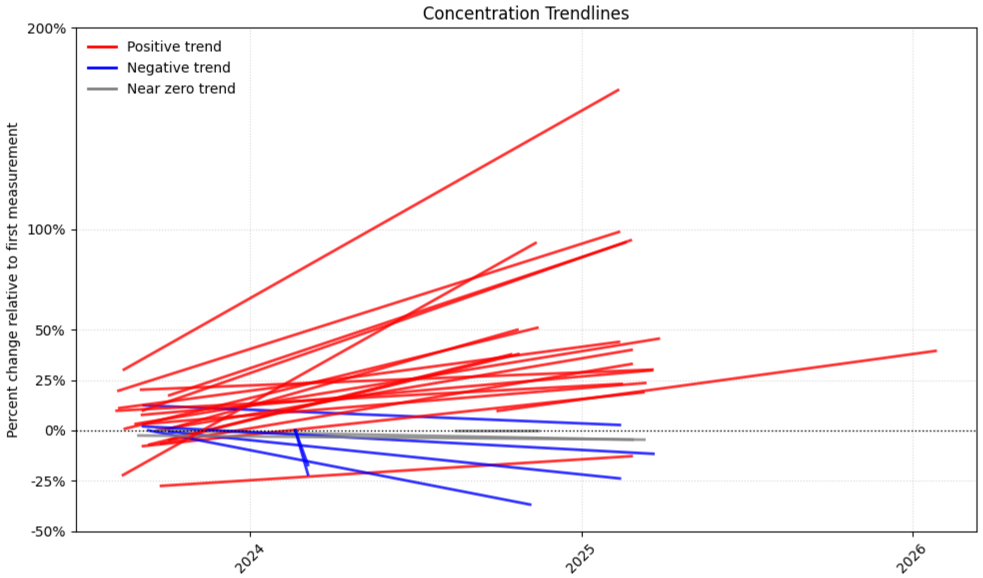


Figure 17: Basic fitted trend lines for the normalised concentration changes illustrated in Figure 16. Trend lines are assuming a linear increase in concentration change.

4.3. TFA from pesticides

Figure 18 shows the amount of theoretical TFA-equivalents from active substances in pesticides sold for each year 2000-2024. What it does not show, is the amount of pesticides sold. The true amount of active substances has undergone a molar conversion to TFA, so that the potential maximum amount of TFA derived from each pesticide can be illustrated. What can be seen in the figure is that the active substance Fluazinam has had a large impact on the amount of TFA-equivalents during the early 2000's, with a decrease in impact somewhere around, and after, 2009. The number of active substances categorised as TFA-equivalents has seen an increase in the past ten years, with substances such as Fluopyram, Tau-fluvalinate and Diflufenican dominating in tonnes of TFA-equivalents sold.

The total amount of TFA-equivalents sold shows numbers between 15 and 20 tonnes a year in the 00's, with a dip in sales during the 10's and a steep increase in the last ten years. In 2023, TFA-equivalents sold reached the largest number of tonnes since 2001, and in 2024, this number was surpassed, reaching an all-time high over the studied period.

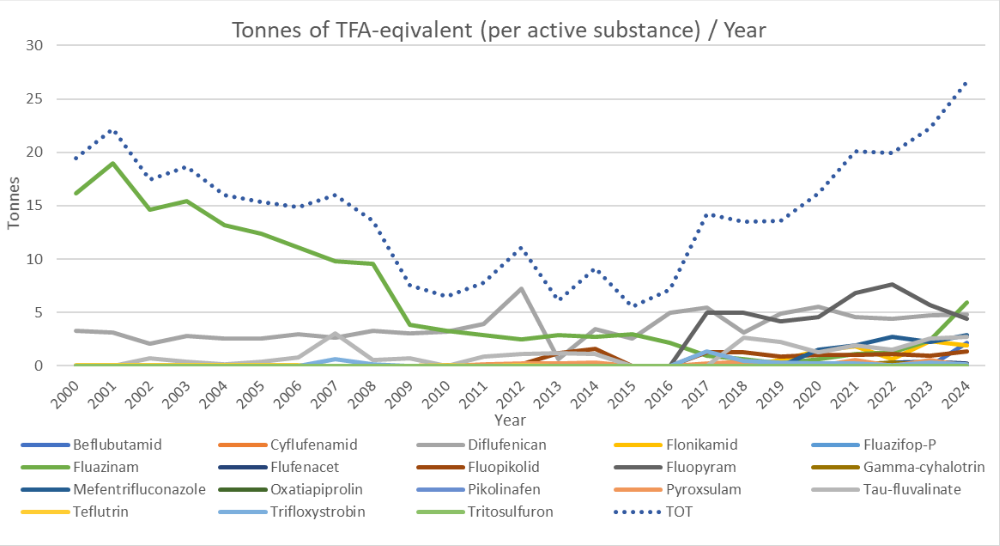


Figure 18: Tonnes of pesticides sold (as TFA-equivalents) for each year 2000-2024. The total amount of TFA-equivalents illustrated with a dotted line.

The total amount of TFA-equivalents sold during the period 2000-2024 is illustrated through a cumulative graph in *Figure 19*. The graph is based on the exact same total amount of TFA-equivalents illustrated as the dotted line in *Figure 18*. It shows how much potential TFA could be released into the natural environment and accumulate. The graph is primitive, and it must be noted that if it were to be interpreted as pure TFA released and accumulated in Swedish natural waters, many unrealistic assumptions are made. To further investigate a more realistic approach to potential accumulation of TFA, a flux-based system is illustrated in *Figure 20*.

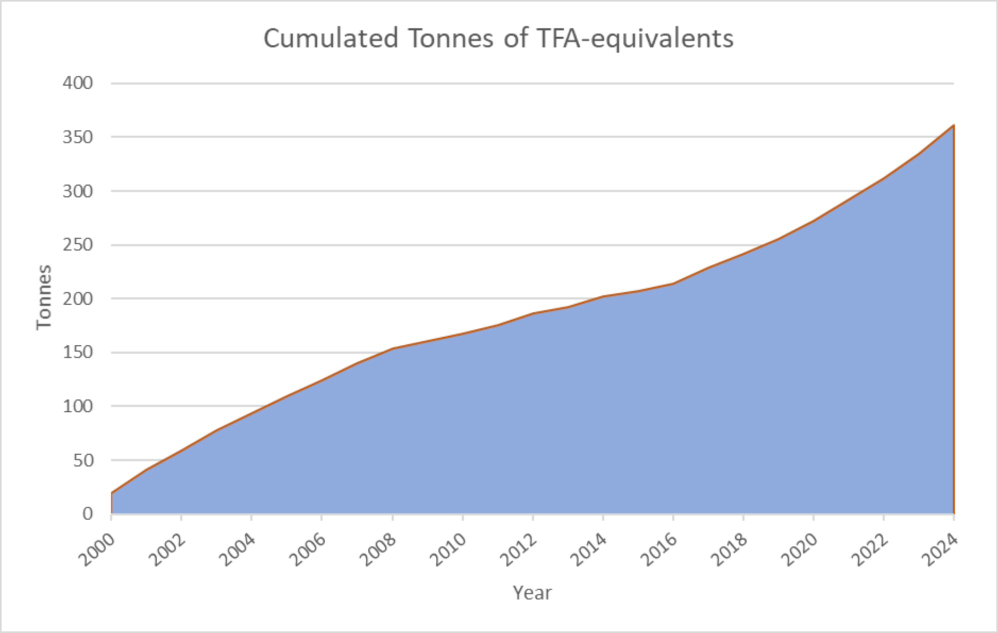


Figure 19: Theoretical cumulated tonnes of TFA-equivalents from 2000-2024.

By assuming the conditions explained in section 3.4.4, a mass balance approach was used to create a more realistic model of accumulation of TFA in Swedish groundwaters illustrated in *Figure 20*. In contrast to the theoretical accumulation illustrated in *Figure 19*, this model does not assume that all TFA-equivalents from pesticides actually become TFA instantly. Furthermore, the model assumes an out-flux of TFA from the system through degradation of the TFA-molecule itself. What can be seen in the figure is a steady, slightly increasing addition of TFA to the system over the whole period. Notable is that the potential degradation of TFA as it is released to the natural environment does not considerably change the total amount of TFA accumulated in the system. Even if TFA would have a half-life of 50 years, accumulation would still occur, though slightly faster than in the cases of longer half-lives. From the figure, it can be seen that with a half-life of 50 years, the addition of TFA-equivalent pesticides from 2000-2024 would lead to an accumulation of roughly 130 tonnes present in 2025. With no half-life, roughly 150 tonnes are expected.

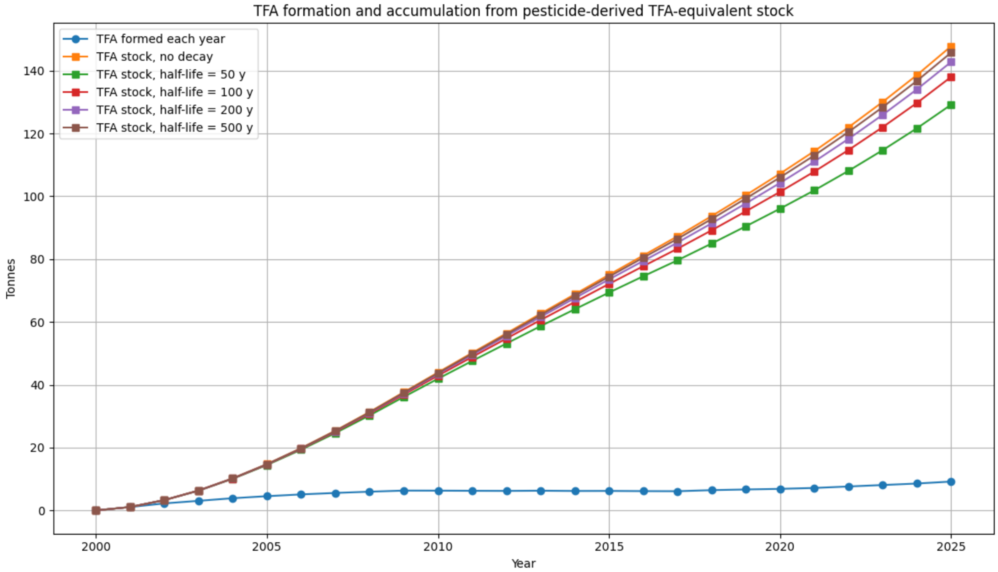


Figure 20: Potential accumulated tonnes of TFA in Swedish groundwater systems years 2000-2025 based on pesticide-derived TFA-equivalents. Lines representing different half-lives as well as amount of TFA formed each year.

5. Discussion and Conclusions

5.1. Main Findings on TFA Occurrence in Swedish Waters

TFA has been detected to some extent across much of Sweden but with lack of consistency in geographical coverage. Counties such as Jämtland and Västra Götaland has had many measurements made, while other regions such as Blekinge and Gotland have had one or even zero measurements taken. Since the majority of data sets used come from SGU, complementary data from measurements taken by external stakeholders could possibly help create a more even geographical distribution of measurements in regions not included in the models used.

The results however indicate a southward concentration gradient, with higher mean concentrations generally found in southern Sweden. This claim is backed by Häggqvist & Rosenqvist (2025). Both the highest maximum and highest mean concentration was detected in Skåne County at 2700 ng/l and 600 ng/l respectively. On a national scale, the mean concentration lies at around 360 ng/l with county means ranging from about 100 ng/l to 600 ng/l depending on region and data availability. Due to the LOQ when sampling, paired with measurement uncertainty, the actual concentrations could in some cases differ with several hundreds of ng/l while measurements treated as 0 ng/l could in fact be positive in concentration, and influence the true regional concentrations.

Several measurements have been treated as 0 ng/l in concentration, but with an LOQ of 50 ng/l and a measurement uncertainty of potentially 38%, the results may give a slightly misleading representation of regions. The LOQ and measurement uncertainty could in theory lead to a measurement of 69 ng/l be treated as 0 ng/l.

The counties of Gotland and Södermanland have not been tested for TFA by the data gathered from SGU. This gives an underrepresentation of the regions since TFA would highly likely be present in the counties' ground- and surface waters when looking at the neighbouring regions. This further highlights the fact that monitoring of TFA is not evenly distributed geographically.

5.2. Temporal Trends and Indications of Increasing Concentrations

The trend analysis conducted has been subject to small data sets and a short time period. With 29 trend-stations, 128 measurements, a mean group size of 4.4 and a time period just shorter than three years, it would be hard for the model to give a precise measure of the actual change in TFA concentrations over time. The reliability of the model further decreases due to the LOQ and measurement uncertainty as mentioned in section 5.1.

What was found in the trend analysis conducted however, is a positive trajectory with increasing concentrations for a clear majority of trend-stations. The LMM and RLM shows an approximate national yearly increase in concentrations of 19.65% and 16.86% respectively. Due to the limitations of the LMM and RLM, the resulting percentual increases should be interpreted cautiously, and serve rather as good indicators that an increase in concentrations of TFA in Swedish waters is occurring. Since the LMM and RLM are based of log-transformed values of concentrations, the modelled yearly increase in concentrations is exponential. Important to note is that the trend lines fitted for the normalised concentrations are based on concentrations that have not been log-transformed. This means that they do not indicate an exponential yearly increase, but rather a linear relationship. However, since the trendlines are fitted for each and every trend-station, it would be hard to see if there is a linear or exponential relationship to concentration change due to the very small group sizes. Therefore, they are not used to interpret actual concentration change, but rather just indicators of the projection in concentration change. So, even if an exponential increase or a linear increase is assumed for trend-stations, both scenarios indicate increasing concentrations.

Since SGU and other Swedish authorities have not conducted testing for TFA concentrations in natural waters earlier than 2023, little is known about changes in concentration. To further estimate the change in concentrations, older water samples that have not been subject to contamination of TFA or TFA-precursor substances could be tested. Measurements of such samples could give additional information on how concentrations of TFA in extracted ground- and surface water looked like in prior years. With such additional information, similar trend analyses could give stronger certainty in trends, while also give more precise indications of possible future concentrations in Swedish waters.

5.3. Pesticides as a Potential Long-Term Source of TFA

Several pesticides containing 18 different active substances approved or historically used in Swedish practices contain a fluorinated methyl group. As shown by Johnsen et al. (2026) at least seven of these, with similar properties and all containing the fluorinated methyl group, have proven to produce TFA as a product of degradation in agricultural soils in less than a year after application. If the remaining active substances could degrade to TFA and follow similar paths of degradation, it would be possible for pesticides containing fluorinated methyl groups to be large contributors to increasing TFA concentrations in natural waters.

The mass balance approach to an accumulation model of TFA as a product of degradation from different active substances showed large accumulations of TFA. However, the model lacks in knowledge of the true factor of degradation for majority of the active substances. The factors differ between soil type, and only a geometric mean was applied. Furthermore, different crops require different pesticides which in turn could cause different amounts of TFA production depending on the type of agricultural practice.

Since no mass balance has been carried out on the actual groundwater fluxes in Sweden in relation to agriculture, the numbers created by the model are hard to apply in a real context. If TFA were to have no half-life and could permanently accumulate, there could have been an accumulation of 150 tonnes of TFA in Swedish waters. However, the dispersion of these 150 tonnes is not known, so to make the claim that a certain percentage of a concentration of TFA in a sample would be the result of pesticide derived degradation is practically impossible. It is also unlikely that all TFA from pesticide use actually accumulates in groundwater aquifers. Some groundwater will eventually exit to oceanic sources of water and some might be extracted and removed from the groundwater cycle in other anthropogenic processes. Due to TFAs ability to spread through atmospheric deposition, it could also be possible for TFA to leave surface waters through evaporation. The above mentioned, and other potential sources of outflow, will most likely make the model create higher values of accumulated TFA than is true in a real context.

Agricultural practices that use active substances containing fluorinated methyl groups however, as proven by Johnsen et al, (2026) and as claimed by KEMI (n.d.), will lead to the release of TFA into the soil. Skåne County, with the largest amount of agricultural land, both in percentual land coverage, and also in number of hectares, shows the highest concentrations of TFA in all of Sweden.

The location of the highest ever measured concentration is in the south of the municipality of Höör. Located at the edge of several active agricultural fields, the trend-station is highly likely subject to sampling of water that is in direct contact with the fields. Through personal communication with the owner of these agricultural fields (26th of February, 2026) it was relayed that 18 different pesticides have been used there during the last four years, 2021-2025. Out of these 18 pesticides, six of them contain active substances with fluorinated methyl groups. Without other obvious anthropogenic sources of contamination, it would be likely that the high concentrations of TFA measured at the site come from the degradation of pesticides in the soil reaching the groundwater.

For future research, it would be of high interest if connections between fluorinated pesticides and TFA concentrations in nature waters were investigated further. By creating in-depth mass balances of groundwater fluxes in connection to TFA-precursor substances used in agricultural practices, it could become more apparent how big of a TFA contaminator pesticide use is. This could either rule out, or strengthen the assumption that atmospheric deposition of TFA is the major contamination source.

As of now, it is quite hard to show clear correlations between the results from TFA concentration dispersion and changes, to the input of pesticides as TFA precursors. A suggested possible way of proving the magnitude of the correlation between the concentrations of TFA modelled and the potential formation of TFA from pesticides would be a comparison of the two with older water samples. If TFA concentrations were to be tested for in old water samples under at least the period 2000-2024, it could be possible to see a correlation between the decline in TFA precursors in the 2010s and the increase in the 2020s to actual TFA concentrations. If concentrations of TFA in water samples from this time period follow the same trajectory as the input of the pesticides, meaning a dip in the 2010s, with possible lag, it could further prove that pesticides are possible major contributors of TFA to groundwater and surface water.

5.4. Regulatory Implications and the Swedish Context

The Swedish Drinking Water Directive, LIVSFS 2022:12, today only regulates PFAS-parameters where TFA is excluded since the Swedish National Food Agency (2026a) has in principle chosen to adopt the “Sum of PFAS” parameter from the EU’s DWD (2020). Since the DWD (2020) allows for member states to comply with either both, or one of the parameters “Sum of PFAS” and

"PFAS Total", TFA would not be necessary to regulate according to EU-law if only "Sum of PFAS" were to be applied on a national scale within member states.

From the European Commission notice C/2024/4910 (2024), it also becomes clear that applying TFA to the definition of "PFAS Total", would make the parameter pointless in many cases, since it is regulated at a maximum of 500 ng/l. This statement is of high interest in contrast to the concentrations measured in Sweden, reaching 2700 ng/l at the highest maximum concentration and mean concentrations reaching above 500 ng/l in several counties. Furthermore, the parameters PFAS 21 and PFAS 4 from LIVSFS 2022:12 are regulated at 100 and 4 ng/l respectively. PFAS 4 for instance, regulates the four PFAS: PFOS, PFOA, PFNA and PFHxS. Out of these, PFOA is the PFAS that Dutch authorities have based their proposed maximum TFA concentrations on. Under Dutch regulations, PFOA may not reach more than 4.4 ng/l, and with a potency factor of 0.002 for TFA, they reached a proposed maximum concentration for TFA in drinking water of 2200 ng/l. Had the Dutch model been applied to the Swedish conditions according to PFAS 4, TFA would have a proposed maximum concentration in drinking water under 2000 ng/l.

The German and Danish proposed permissible levels of TFA reach a broader spectrum of waters, including groundwater, surface water and drinking water. However, most of the suggested permissible levels of TFA are based on existing framework, such as general pesticide framework for groundwaters, and internal assessments on pelagic communities. The only case in which TFA has been studied at as an individual substance of interest, is in German drinking water. The recommended maximum concentration of 10 000 ng/l is based on one single study conducted between 2018 and 2019, on rats. This can be compared to the Dutch evaluation that has not conducted their own study on rats, but rather based their models of several prior studies conducted. Furthermore, the Danish proposed permissible levels on TFA in drinking water is based on the German proposed levels, with an added 10% safety margin, reaching 9000 ng/l. Interestingly, the German concentration of 10 000 ng/l has already undergone an added safety margin from 60 000 ng/l. This means that the proposed Danish permissible level of TFA in drinking water has had two safety margins added to it, while the original concentration was practically based of a single study conducted in Germany.

5.5. Recommendations for Monitoring, Research and Policy

It has become clear that TFA is a widespread substance that is present in majority of ground-, surface- and drinking water samples worldwide. It is by many means excluded from most parameters of regulated PFAS, even though it is considered by definition a PFAS as of the 2021 technical revision by OECD. Even if one could argue that TFA, at least according to EU-law, could be regulated by the standard practices applied to PFAS today, it seems action is yet to be taken to regulate TFA in European waters. However, this is quite unsurprising as the knowledge on the effects of TFA on human health and ecological systems are little compared to not only other PFAS, but other environmental toxins in general.

The overall toxicological view on TFA is that is poses little to no threat on neither human nor animal health with regards to the concentrations tested for in studies highly exceeding concentrations found in the natural environment. Still, results showed for instance cases of liver dystrophy in rat populations exposed to higher doses of TFA. It however becomes clear that long-term effects of TFA on human health is much understudied. Even though TFA has little to no accumulative effects in the human body, it is unknown if the daily exposure of TFA through drinking water and food will lead to negative implications further on.

As seen in the trend-analysis conducted from trend-stations in Sweden, concentrations of TFA in Swedish waters are increasing. New pesticides containing substances that could be potential precursors to TFA present in the environment have, at least since the year 2000, increased by around 13 additional active substances in pesticides. Additionally, 2024 marked the year by which the highest amount of potential TFA-precursor pesticides was sold on the Swedish market since the year 2000.

The World Health Organisation is set to develop harmonized health-based guideline values for drinking water and food exposure by 2027, and this includes values for TFA. A final statement on TFA from EFSA with a deadline on the 31st of July 2026 will set an Acceptable Daily Intake and an Acute Reference Dose for TFA. Until EFSA and WHO have concluded their knowledge on TFA, there is no clear or generally accepted view on TFA regarding its effects on human health or ecosystems in relation to concentrations found in different types of water. Furthermore, no authority today has set any clear regulated limits to the concentration of TFA in natural waters apart from Denmark and their 9000ng/l TFA limit in drinking water.

Even though this thesis mainly investigates pesticides as potential precursors of TFA input to the environment, pharmaceuticals and refrigerants are also known precursors. However, due to the limitations of this work, the degradation pathways and possible input of TFA to the environment from these external sources has not been further investigated. Several scholars still assume them to be major contributors, and further research into these could reveal a possible need to regulate them as well as pesticides.

5.6. Final Comments

As of now, policy makers await extended knowledge on TFA, which causes a high interest in expanding the monitoring of TFA that is currently taking place. Measurements of TFA are scarce, and the need for additional measurements are needed both at trend-stations to monitor the change in concentrations, but also at more locations to better understand the geographical distribution of TFA. The connections between the use of pesticides and their effect on concentrations of TFA in natural waters are scarce, and as potential point sources of TFA, regulation and better pesticide framework is needed along with deeper understanding of the general mechanisms that form TFA from pesticides. Some steps are being taken in Sweden, as re-evaluations of certain pesticides by KEMI will have decisions made by 2028. Worth noting is that TFA has other known anthropogenic sources, such as the use of the refrigerant HFO-1234yf, which calls for further investigation into the spreading of such substances and their pathways through atmospheric deposition.

The need to monitor and regulate TFA in the environment is based on the assumption that it can be harmful for the human health and the ecosystem. Even though concentrations of TFA in natural waters are seemingly quite harmless following the results of several studies, the long-term effects are mostly unknown. Removing TFA from water in conventional water treatment plants would be costly and highly energy intensive, and since TFA is long-lived and accumulates easily in groundwaters, not taking action towards decreasing concentrations from contamination sources now, could lead to future action being too late.

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Appendix

Table 3: Summary statistics for the Linear Mixed Model (LMM) trend analysis.

Metric	Value
Model	LMM
Dependent Variable	LogConc
No. Observations	128
Method	REML
No. Groups	29
Scale	0,044
Min. group size	2
Log-Likelihood	-35,869
Max. group size	12
Converged	Yes
Mean group size	4,400
Annual change per year	19.65%

Table 4: Fixed-effect estimates and variance component from the Linear Mixed Model (LMM).

Parameter	Coef.	Std.Err.	z	P>|z|	CI lower [0.025]	CI upper [0.975]
Intercept	-357,536	76,753	-4,658	0,000	-507,970	-207,102
Year	**0,179**	**0,038**	**4,733**	**0,000**	**0,105**	**0,254**
Group Var	0,372	0,552				

Table 5: Summary statistics for the Robust Linear Model (RLM) trend analysis.

Metric	Value
Model	RLM
Dependent Variable	LogConc

No. Observations	128
Df Residuals	98
Df Model	29
Method	IRLS
Norm	HuberT
Scale Est.	mad
Cov Type	H1
No. Iterations	47
Annual change per year	16.86%

Table 6: Parameter estimates from the Robust Linear Model (RLM), including station-specific effects.

Parameter	coef	std err	z	P>|z|	CI lower [0.025]	CI upper [0.975]
const	-310,181	75,691	-4,098	0,000	-458,532	-161,830
Year	**0,156**	**0,037**	**4,168**	**0,000**	**0,083**	**0,229**
station_1300_2	0,208	0,173	1,206	0,228	-0,130	0,547
station_14_15	0,541	0,173	3,132	0,002	0,202	0,879
station_16_71	0,339	0,173	1,962	0,050	0,000	0,677
station_21_9	1,080	0,206	5,239	0,000	0,676	1,484
station_23_26	0,928	0,173	5,372	0,000	0,589	1,266
station_2510_1	0,460	0,179	2,576	0,010	0,110	0,810
station_29_8	0,521	0,173	3,018	0,003	0,183	0,860
station_2_1	2,436	0,173	14,106	0,000	2,098	2,775
station_30000_1	0,760	0,173	4,399	0,000	0,421	1,098
station_30000_165	0,735	0,207	3,556	0,000	0,330	1,141

station_30000_231	0,433	0,206	2,102	0,036	0,029	0,837
station_30000_51	-0,354	0,173	-2,051	0,040	-0,693	-0,016
station_30000_53	0,398	0,173	2,305	0,021	0,060	0,737
station_30000_6	1,002	0,188	5,323	0,000	0,633	1,370
station_33_104	-0,332	0,178	-1,861	0,063	-0,682	0,018
station_39_116	-0,666	0,173	-3,859	0,000	-1,005	-0,328
station_41_5	-0,800	0,179	-4,479	0,000	-1,150	-0,450
station_42_13	-0,188	0,173	-1,087	0,277	-0,526	0,151
station_47_1	0,032	0,173	0,183	0,855	-0,307	0,370
station_54_18	0,335	0,173	1,939	0,053	-0,004	0,673
station_5_14	0,403	0,173	2,334	0,020	0,065	0,741
station_68_9	0,240	0,173	1,390	0,164	-0,098	0,579
station_69_10	1,284	0,173	7,439	0,000	0,946	1,623
station_70_104	0,617	0,178	3,458	0,001	0,267	0,967
station_89_7	0,487	0,173	2,820	0,005	0,148	0,825
station_GFI-082-C	0,504	0,206	2,447	0,014	0,100	0,908
station_Norrvatten	0,804	0,163	4,929	0,000	0,484	1,123
station_UOP-446-Q	0,385	0,206	1,869	0,062	-0,019	0,789