Universiteit Utrecht

Writing assignment

Evaluation of water quality for livestock with a focus on PFAS

Master: Health and Environment
Student: Rafaella Christodoulou
Supervisor: Milou Dingemans (KWR Water Research Institute)

Contents

Abstract 2

  Layman’s Summary 2

1) Introduction 3

2)Methods 6

  2.1) Literature search 6

3)Water Quality and Contaminants 7

  3.1) Management of Water Quality in the Netherlands for livestock 7

  3.2) Polluted water pathways for livestock 9

  3.2.1) Factors of water quality 11

    3.2.2) TDS and Salinity: 11

    3.2.3) Hardness 12

    3.2.4) Ph 13

    3.2.5) Nitrate and Nitrite 14

    3.2.6) Heavy metals: 14

    3.2.7) Ammonium in Water 15

    3.2.8) Blue-green algae toxins: 16

    3.2.9) Bacterial Contamination 17

    3.3.1) Antibiotics in Water 17

4) Emerging contaminants 18

  4.1) PFAS in drinking water for livestock 20

  4.2.) Water pathways of PFAS in livestock 21

  4.3)PFAS Regulations in the Netherlands 22

5) Results and discussion 24

6)References 29

Abstract

Clean water is indispensable for animal health, yet the regulations governing water quality for livestock lag behind emerging contaminants. This assignment aims to report on the current regulatory landscape regarding water quality for livestock, emphasizing its broader implications for the overall health of livestock. Recognizing the pivotal role of clean water in augmenting the well-being and productivity of animals, our primary objective is to explore the existing regulatory measures governing water quality for livestock.

Crucial questions guide our inquiry: What factors currently manage water quality for livestock? What are the pathways and sources of water pollution in livestock environments, and how do they vary across regions and livestock types? Additionally, we probe into the potential health impacts of emerging contaminants, particularly perfluoroalkyl substances (PFAS), on livestock.

The literature review employs an approach, using publications from the past decade associated with water quality for livestock. These publications serve as valuable resources, offering insights into the regulatory landscape and pollution dynamics in livestock environments.

A notable emphasis is placed on emerging contaminants, especially PFAS, due to the absence of established limits in water quality regulations for livestock. The study critically reports recent updates in risk limits for PFAS in Dutch surface waters for humans. Furthermore, the exploration of existing literature reveals knowledge gaps, particularly in understanding the impact of PFAS on livestock. To address these gaps, proposed research projects aim to provide deeper insights into water quality for livestock, establish maximum residual limits for PFAS for drinking water for livestock, and investigate potential effects associated with elevated PFAS concentrations in water.

In conclusion, while this assignment reports factors and pathways of contaminants in water for livestock, the specific health effects of PFAS on livestock remain uncertain. Future research is recommended to encompass comprehensive studies on air and feed consumption, feed storage, and their correlation with water quality. A meticulous examination of PFAS exposure implications on livestock is imperative, necessitating the determination of maximum residual limits, assessment of potential effects, and the formulation of strategies to limit exposure. The assignment underscores the importance of ongoing research in this evolving issue, making substantial contributions to the welfare of animals and the production of safe, high-quality food.

Layman's Summary

This assignment is about an important issue: that often is underestimated. We often research water quality for humans but forget about keeping up to date on the water quality of emerging contaminants for livestock. First, we want to understand which factors are polluting drinking water and how they affect the health of the animals. Clean water is highly important for animals to stay healthy and do well, so we're exploring the existing regulations that control water quality for them.

The questions of this assignment are: What manages water quality for animals right now? How does polluted water enter where the animals live, and does it vary in different types of animals? We're also looking into possible health issues caused by new contaminants in the water, such as perfluoroalkyl substances (PFAS).

The approach is to evaluate research from the last ten years that is about water quality for animals. The reason that we focused on PFAS (a new contaminant), is because there aren't clear rules for them in water quality regulations for animals. We're checking recent updates in rules for PFAS in Dutch waters for humans. But we still don't know a lot about how PFAS might affect animals. To fill in the gaps, we're proposing new studies to learn more about water quality for animals, set safe limits for PFAS, and investigate for effects of high PFAS levels in the drinking water.

In conclusion, there is an identification of the factors and the paths that polluted water can enter livestock and what are the effects for livestock, we're still not sure about the specific health problems caused by PFAS in animals. We suggest more research to look at how animals eat, drink water and store food, and how it connects to water pollution by PFAS. It's really important to carefully study how PFAS might affect animals, so we can set safe limits, figure out effects, and make sure animals stay healthy.

1) Introduction

Domesticated animals grown in an agricultural context to offer labor and diverse consumer items, including meat, eggs, milk, fur, leather, and wool, are referred to as livestock (Brittanica, 2023). Water is a vital nutrient essential for sustaining life and optimizing milk production, growth rate, and reproduction in livestock (Beeder, 2005, 2006, 2009; Sajid et al., 2014). However, water quality remains a poorly studied topic (Schlink et al. 2010). Guidelines for drinking water quality for humans are developed with a high degree of specificity and detail, ensuring that the quality of water intended for human consumption is tightly regulated and safe (World Health Organization, 2022). These guidelines include precise procedures and specific threshold values meticulously designed to safeguard human health. However, it is worth noting that the water quality standards for animals may vary and may be less stringent or detailed than those for humans. This is because animal health and well-being may tolerate a broader range of drinking water conditions than that of humans (WHO, 2022). Nevertheless, guidelines for animal water quality should be kept to date to maintain the health and productivity of livestock, although with different criteria and tolerances compared to human standards as it being discussed later for pfas minimum residual limits for livestock.

Water quality is a multifaceted concept determined by a combination of physical, chemical, and biological factors(table 1) (Omer, 2019). Physically, the temperature and turbidity of water play crucial roles, influencing its ability to support life and maintain clarity. Chemically, parameters such as pH, dissolved oxygen, nutrients like nitrogen and phosphorus, and the presence of heavy metals are key indicators of water quality(Omer, 2019). Biological factors, including bacteria, pathogens, and the diversity of aquatic life, provide insights into the overall health of ecosystems (Omer, 2019). Additionally, the sedimentation process, the presence of toxic substances, and salinity levels contribute to the comprehensive evaluation of water quality.

Table 1 Water quality factors (Omer, 2019)

TYPES OF WATER QUALITY FACTORS

Physical factors	Chemical factors	Biological factors
Turbidity	pH	Bacteria
Temperature	Acidity	Algae
Colour	Alkalinity	Viruses
Taste and odour	Chloride	Protozoa
Solids	Chlorine residual	
Electrical conductivity	Sulfate	
	Nitrogen	
	Fluoride	
	Iron and manganese	

Livestock health and well-being depend on various factors such as Nutrition (Balanced diet, Feed Quality), Housing and Shelter(Comfortable environment and adequate space), Healthcare (Vaccinations, Parasite Control, Regular Health checks), Sanitation and Cleanliness(Clean living Spaces, Manure management), Climate control(Ventilation, Temperature Control) as well as climate change (Abubakar et al., 2020). Climate change presents a dual-edged impact on animal health, offering both positive and negative consequences. The effects manifest through direct, indirect, and environmental alterations. Specifically, rising temperatures and heat waves stand out as a direct consequence of climate change(Lacetera, 2018; Abubakar et al., 2020). Animals exposed to prolonged heat may experience heat stress, triggering metabolic issues, immunosuppression, and oxidative stress. Regrettably, these complications may culminate in the demise of the affected animals (Akbarian et al., 2016; Abubakar et al., 2020).

Drinking water is often forgotten when discussing nutrient requirements for livestock (Meehan, Stokka and Mostrom, 2021). Drinking water plays a pivotal role in intracellular metabolism and is an abundant constituent of living organisms (Rizwan et al., 2023). At birth, it constitutes about 70-80% of an animal's body and remains at 65-70% of adult live weight, subject to age, fat cover, and physiological condition (Lardner et al., 2005; Rizwan et al., 2023). It also has a substantial presence in milk, ranging from 78-90%, with a high percentage, accounting for 98% of all molecules (Rizwan et al., 2023). Water serves a multitude of functions in the body, encompassing thermoregulation, lubrication, acting as a medium for chemical reactions, aiding in digestion and absorption, supporting lactation, acting as a carrier and cushion, maintaining mineral balance, and facilitating the functions of other nutrients (Lardner et al., 2005; Hersom & Crawford., 2008; Rizwan et al., 2023).

Water quality and water availability are critical factors when evaluating the nutritional aspects of livestock (Hersom & Crawford., 2008; Sajid et al., 2014, Rizwan et al., 2023). While it may not provide nutrients, such as carbohydrates, proteins, fats, vitamins, or minerals, its role is indispensable. Livestock requires water for several essential functions (Rizwan et al., 2023). It aids in the digestion of feed, softening, and breaking down particles for effective nutrient absorption. Water is also vital for temperature regulation, ensuring that animals can cool down under hot conditions, maintain a stable body temperature, and support metabolic processes(Rizwan et al., 2023). In lactating animals, water is a significant component of milk production (Sajid et al., 2014). General health and well-being rely on adequate water intake because dehydration can lead to health issues, reduced feed intake, and susceptibility to diseases. Extensive research has demonstrated that providing animals with clean drinking water elevates disease resistance and leads to improved performance (Marschalko et al., 2022).

This assignment embarks on a comprehensive exploration of the underestimated yet profoundly significant issue of water quality in livestock environments. The result of this underestimation is the lack of research papers with the main scope to investigate water quality for livestock and not only for human consumption. The primary objective is to address the critical role that clean and safe drinking water plays in the well-being and productivity of livestock.

Table 2 Effects from drinking polluted water in livestock. The table includes the main issues that lead to adverse effects of drinking polluted water for livestock. (FAO, 2022)

EFFECTS FROM POLLUTED DRINKING WATER IN LIVESTOCK

Issue	Cause	Effect
Waterborne diseases	Bacterial, viral, and parasitic infections in water	Illnesses and reduced productivity
Reduced feed and water intake	Poor water quality or taste	Inadequate nutrition and no growth and productivity,
Digestive	Toxins or contaminants in drinking water	The issue with nutrient absorption, Diarrhea, decreased weight gain, poor feed conversion
Reproductive	Water contaminants may affect fertility, gestation, and the health of offspring	Reduced reproductive efficiency
Respiratory	Pollutants such us gases or matters in drinking water	Respiratory issues with coughing, nasal discharge, and distress
Decreased immunity	Exposure to pollutants in water	Susceptible to diseases, increased morbidity, and mortality
Impact on milk and meat quality	Contaminants in drinking water accumulate in animal tissues, posing risks to human health	Decrease in milk and meat quality
Stress and behavioural changes	Poor water quality	Restlessness, aggression, or lethargy

Pollution in water sources poses significant risks to livestock health and productivity. According to table 2, potential consequences include the spread of waterborne diseases, impacting the well-being of animals. Contaminated water may lead to reduced feed and water intake, hindering nutrition and normal growth (FAO, 2022). Moreover, digestive issues, reproductive challenges, and respiratory problems can arise due to pollutants in water, affecting overall livestock health (FAO, 2022). Additionally, compromised immunity increases susceptibility to diseases, raising morbidity and mortality rates(FAO, 2022). Poor water quality can also impact the quality of milk and meat, posing potential health risks for consumers. Furthermore, livestock may exhibit stress-induced behavioural changes, affecting overall well-being and productivity(FAO, 2022).

Throughout this investigation, we investigated various water contaminants. The selection and prioritization of the later mentioned water contaminants is from their significance and multiple times reported in various research papers. Furthermore, we explored the potential adverse outcomes of compromised water quality from different perspectives(salt, chemicals, pathogens, metals, emerging chemicals). We focus on identifying the main water pollutants and checking how updated are the contaminants compared to humans. Importantly, reporting emerging contaminants, such as PFAS, that may affect the health and performance of livestock when present in drinking water and other exposure routes.

Several key questions will be answered.

- What are the existing regulatory mechanisms that manage 1) exposure of environmental contaminants to livestock?
  That is addressed in chapter 3.1.
- What are the pathways and sources of water pollution in livestock environments?
  Addressed in chapter 3.2.
- Can PFAS exposures in water have health effects on livestock?
  Addressed in chapter 4.

2)Methods

2.1) Literature search

The approach of this review is to identify several publications over the past years (2013-2023), that describe scientific findings related to water quality for livestock. The literature databases used are Scopus and Web of Science. Firstly, ‘water quality AND livestock,’ at Scopus, led to 2724 hits, by limiting the search areas to ‘Veterinary’ and ‘Pharmacology, Toxicology and Pharmaceutics’ leading to 211 hits. Using other keywords such as ‘water pollution paths AND livestock’ led to 22 hits on Scopus and 24 on Web of Science. The use of the keywords ‘’Water and Quality’’ AND ‘PFAS’ AND ‘’livestock’’ generated 22 hits on Scopus and 9 hits on Web of Science. All abstracts were screened, and relevant research papers were selected. The relevance was measured according to the research questions that need to be answered.

Table 3 Search items that were used for the literature search to Scopus and Web of Science

Combination of search items	Number of articles: Web of Science	Scopus
Water AND Quality AND Livestock	262	211
Water AND Pollution AND paths and Livestock	24	22
Water AND Quality AND livestock AND PFAS	9	22
Water AND pollution AND Livestock	291	93

A second step was to search other significant government and European authorities as databases with search terms “water quality for livestock” or “water quality” or “PFAS in water” “water and contaminants” including EFSA (European Food Safety Authority) which generated multiple hits but one was relevant, “water quality guidelines”, “water and contaminants” WHO (World Health Organization) who generated multiple hits and one was relevant, search for “PFAS AND water”, “PFAS AND Livestock” that had multiple hits but 3 of them were relevant in RIVM (National Institute for Public Health and the Environment), search items of “water” with hits 160 but only the relevant for answering the question 1 and 2 were kept in KNMvD (Royal Dutch Veterinary Association), search items in Rijkswaterstaat (RWS, Ministry of Infrastructure and Water Management in the Netherlands) were “water management” that helped answering the current situation of Netherlands of water managing companies, search items in KWR (Water Research Institute, Netherlands) were “water and contaminants”, “water and PFAS” with more than 4000 hits that were less because only the most recent ones until 2013 were considered and 2 research papers helped by answering the first question about the Dutch water situation and waste water treatments as well as part of third question of how much is the prevalence of PFAS in Dutch waters, in Vewin (Association of drinking water companies, Netherlands) helped with the first question of Dutch management of water and the association in each region in the Netherlands, European Water Framework Directive (WFD) website helped with the Drinking Water Directive on regulations with knowledge about water quality factors, Royal GD (Animal Health Service, Netherlands) answered a majority of first question on which are the water contaminants in livestock. The final set of documents in the second part was screened based on relevance and geographical location (Europe and Netherlands).

3)Water Quality and Contaminants

3.1) Management of Water Quality in the Netherlands for livestock

In the Netherlands, the assurance of water quality across various sources, including surface water (rivers, lakes, and streams), groundwater, and riverbank groundwater, is of paramount importance. Approximately 40% (500 million m3/year) of the annual Dutch tap water is sourced from surface water, notably from the Rhine and the Meuse (rivers) and the Ijsselmeer (lake) (Vewin, 2023). Nine intake points, predominantly situated in the western region, facilitate this abstraction. While 40% of the drawn surface water undergoes immediate treatment to meet drinking water standards, the remaining portion is transported to western coastal dunes for pre-treatment, infiltration, and subsequent abstraction from the subsoil—a process conducted at 11 infiltration sites (Vewin, 2023).

Surface water quality is influenced by a range of factors, including river discharge, discharges from sewage and industrial wastewater treatment plants, atmospheric deposition, drift, and runoff. Climate scenarios, as outlined by the Royal Netherlands Meteorological Institute (KNMI), predict increased climate extremes, impacting substance leaching and runoff. Instances of temporary failure to meet water quality requirements for drinking water production prompt water companies to suspend surface water intake. In contrast to groundwater, surface water necessitates more intensive treatment technologies to adhere to drinking water quality standards. The Water Framework Directive (WFD) mandates European Member States to prevent water quality deterioration and reduce treatment intensity, emphasizing the significance of comprehensive water management.

In the Netherlands, 55% of drinking water is derived from groundwater, abstracted from approximately 200 sites in the east and south regions (van Berkel et al., 2022). Groundwater, characterized by more consistent quality and slower changes compared to surface water, remains under increasing pressure (van Berkel et al., 2022). Riverbank groundwater, constituting 5% of drinking water production, is abstracted at 14 sites from areas adjacent to rivers. Livestock use of drinking water is approximately 110 million cubic meters of groundwater and surface water each year, allocated for irrigation (71 million m3) and livestock watering (37 million m3) (Fraters et al., 2021). Moreover, an additional 46 million cubic meters of drinking water are utilized for livestock watering and stall cleaning (Fraters et al, 2021). Irrigation water usage is notably weather-dependent, exhibiting variation between 23 million m3 (2012) and 265 million m3 (2018) over the period 2001-2018, as reported by Van der Meer in 2020.

Water quality standards in the Netherlands play a crucial role in safeguarding animal health, as emphasized by Royal GD and the National Institute for Public Health and the Environment (RIVM). These stringent regulations ensure that water provided to livestock meets specific quality criteria, tailored to the unique needs of various animal species, while effectively mitigating the risks associated with waterborne pathogens and contaminants. The European Water Framework Directive (WFD) (WFD, 2023) is a guiding authority within the European Union, including the Netherlands, aimed at achieving ecological water quality by 2027 and protecting chemical water quality. Even though water quality for livestock is not part of the WFD regulations, by ensuring good chemical quality we ensure better quality for water use for livestock. The Environmental Management Act in the Netherlands further reinforces water quality maintenance by prohibiting waste discharge into surface or groundwater (Zaken, 2011).

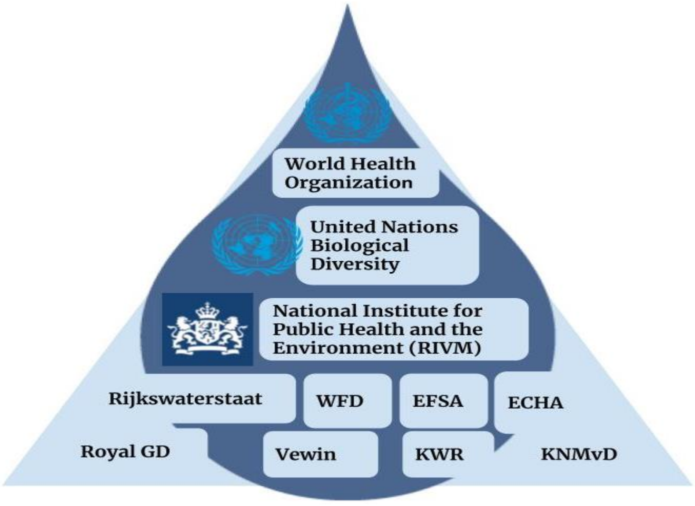


Figure 1 Water Management and Quality Hierarchy in the Netherlands. First, we have the World Health Organization and the United Nations, Moving up with National Institute for Public Health. Rijkswaterstaat (Water management in the Netherlands), WFD (European Water Framework Directive), EFSA (European Food Safety Authority), ECHA (European Chemicals Agency), Royal GD (Animal Health Service, Netherlands), Vewin (Association of Drinking Water Companies, Netherlands), KWR (Water Research Institute), KNMvD

In figure 1, each of the authorities, agencies and regulations contribute to keeping water quality standards in the Netherlands. The National Institute for Public Health and the Environment (RIVM) ensures adherence to international health and environmental standards in the Netherlands, aligning with organizations like the World Health Organization (WHO) and the European Food Safety Authority (EFSA) about water contaminants that can be transferred to livestock. The Ministry of Economic Affairs oversees veterinary medicine regulation, emphasizing animal welfare, public health, and food safety. Rijkswaterstaat collaborates with other water management entities to maintain clean and healthy water in major water bodies for various purposes, including drinking water, agriculture, fishing, industry, environmental conservation, and recreation. The Trade Association of Drinking Water Companies (Vewin) plays a pivotal role in the production of safe and healthy drinking water.

Despite challenges, comprehensive water management remains pivotal to ensuring a safe and sustainable water supply in the Netherlands (Vewin, 2017; Brunsch et al., 2018). Good water quality for livestock encompasses two essential facets: ecological and chemical water quality (Royal GD, 2009). Water quality assessments are multifaceted, encompassing not only microbiological parameters like E. coli and other pathogens but also an array of chemical parameters, including ammonium, cadmium, carbon components, chloride, and hardness (RIVM, 2023). Concurrently, chemical water quality addresses the presence of waste products and chemical contaminants in water sources, while ecological water quality is a measure of the water temperature and the amount of nutrients, plants, and animals.

Veterinary medicine professionals should consider while livestock producers in the Netherlands diligently adhere to these stringent water quality standards, particularly in settings like dairy farms where disease transmission risks are notably high (Royal GD, 2009). Poor water quality can contribute to the persistence and, transmission of diseases among animals because dairy farms typically share facilities and equipment for milking, feeding, and other activities (Royal GD, 2009). If proper hygiene and sanitation practices are not followed, these shared resources can become sources of contamination and transmission. Since dairy farms often have a high density of animals, creating an environment where infectious diseases can spread more easily.

3.2) Polluted water pathways for livestock

When viewing the water pollution factors for livestock is important to acknowledge the pathways where it enters the livestock. Contaminated water can reach livestock through various pathways. Some of the common pathways through which contaminated water can affect the animals at a farm.

A) Surface Water Runoff: During heavy rainfall, water can carry contaminants from surrounding areas and deposit them on neighbouring areas, which can be animal farm premises (FAO, 2013; Mateo-Sagasta, Zadeh & Turral, 2017). This runoff can bring pollutants such as fertilizers, pesticides, animal waste, and other chemicals to the farm because of the presence of industrial factories close to animal farms. Especially in the Netherlands where flooding is a common issue (FAO, 2013; Mateo-Sagasta, Zadeh & Turral, 2017). With a significant portion of its landmass situated below sea level, the susceptibility of the Netherlands to potential flooding is notably high (Brunsch et al., 2018). The Netherlands faces susceptibility to flooding from both coastal areas and significant rivers. In 2018, the Netherlands experienced the impact of a drought, while in 2019, challenges arose due to diminished groundwater levels (Eurostat, 2019).

Data analysis reveals that the quality of surface water, a crucial source for drinking water production, is primarily affected by factors such as pesticides, salinization, pharmaceutical residues, and industrial substances (Brunsch et al., 2018). This has resulted in the exceeding of signalling values and standards for surface water at intake points. Consequently, the quality requirements essential for maintaining a good condition of drinking water sources, as outlined in the Water Framework Directive (WFD), are not always met in cases related to the mentioned contaminants (Brunsch et al., 2018). The heightened likelihood of extreme precipitation may lead to increased leaching and runoff of substances. Conversely, during periods of minimal precipitation, concentrations of various contaminants may rise in surface water (Brunsch et al., 2018).

B) Irrigation Water: If irrigation water sources are contaminated, the water used for crop irrigation can carry contaminants onto the farm, affecting both irrigation water to crops and the animals that consume them(livestock feed) and then to livestock (Borah & Bera, 2004). Currently, there is no explicit EU regulation about irrigation water. Despite recent progress, the EU Council has adopted a proposed regulation for the direct reuse of domestic wastewater for irrigation (European Commission, 2018), currently pending approval by the European Parliament (European Council, 2020; Dingemans et al., 2020). This regulation integrates standardized minimum quality requirements, risk management protocols, and specific permit-related procedures, accompanied by obligations for transparent information sharing (Dingemans et al., 2020).

However, assessments conducted by independent experts (Rizzo et al., 2018) have identified certain deficiencies in the proposed regulation (Dingemans et al., 2020). While it incorporates crucial elements regarding water quality requirements, some significant aspects remain inadequately addressed, such as contaminants of emerging concern, the potential spread of antibiotic resistance, disinfection by-products, and the efficacy of effect-based bioanalytical tools (Dingemans et al., 2020). The need for improved clarity in selecting minimum quality requirements is also emphasized (Dingemans et al., 2020).

It's important to recognize that domestic wastewater carries diverse pathogens, including bacteria, viruses, protozoa, and helminths (Dingemans et al., 2020). Primarily originating from infected individuals, enteric pathogens cause gastrointestinal diseases to enter wastewater. Notably, pathogens are currently not subject to monitoring in wastewater(Dingemans et al., 2020).

C) Groundwater Contamination: Contaminated groundwater can be pumped for various farm uses, including drinking water for animals. Pollutants such as heavy metals, nitrates, or microbial pathogens can affect the quality of the water (FAO, 2006; FAO, 2013).

D) Cross-Contamination from Adjacent Areas: Farms located near industrial or urban areas may be at risk of contamination from neighbouring sources. Polluted water can migrate onto the farm and affect the water supply for animals (FAO, 2013; Mateo-Sagast, Zadeh & Turral, 2017).

E) Manure Storage and Disposal: Improper handling and disposal of manure can lead to surface and groundwater contamination on the farm. Manure lagoons or storage areas that leak or overflow can release contaminants into the environment (FAO, 2013; Mateo-Sagasta, Zadeh & Turral, 2017).

F) Floodwaters: During floods, animal farms may become inundated with contaminated water from nearby rivers, streams, or sewer systems. Floodwater can carry a wide range of pollutants and pathogens onto the farm (FAO, 2013).

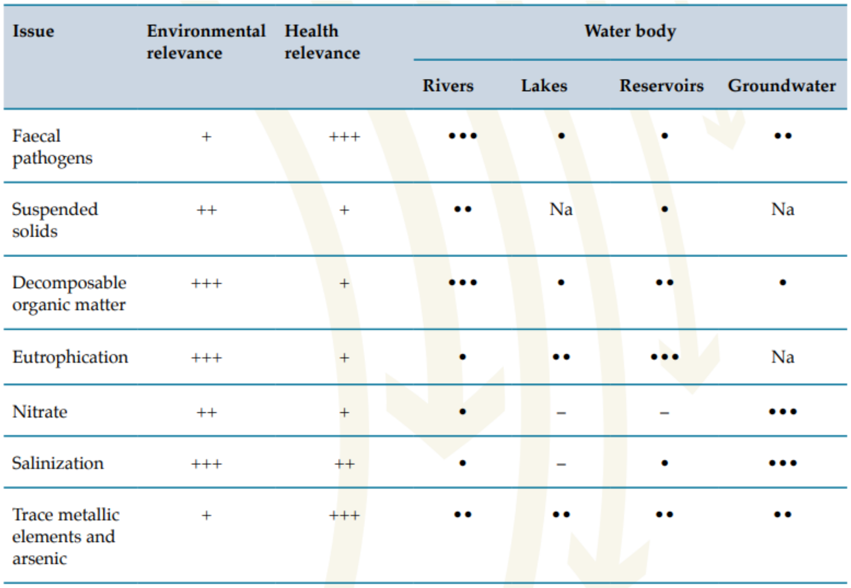
G) Inadequate Infrastructure: Aging or damaged infrastructure on the farm, such as leaking pipes or inadequate storage systems for drinking water, can introduce contaminants into the water supply used for animals (FAO, 2013).

H) Transportation and Supply: Water contaminated during transportation or while being supplied to the farm can also pose a risk. This can occur if the water source used for animal consumption is not properly monitored or treated. However, in Europe, water transportation is being shifted to rail and inland waterways. (FAO, 2013).

Understanding the various pathways through which water contamination can enter livestock farms is essential for effective risk mitigation, safeguarding animal health, ensuring environmental sustainability, and complying with regulations. The most important pathways include specifically Surface Water Runoff, Irrigation Water, Surface, and Groundwater Contamination. We will focus on the different contaminants as well as emerging contaminants.

3.2.1) Factors of water quality

Water quality is a critical factor in livestock environments as it directly affects the health and well-being of animals. Several types of pollutants contribute to water pollution in these settings, and understanding their impacts is crucial for maintaining livestock health. Figure 2 summarizes the types of Water bodies that are polluted due to agriculture parameters. Of course, the issues are related to livestock health as livestock water consumption can lead to a decrease in health status.



Issue	**Environmental relevance**	**Health relevance**	**Water body**			
			Rivers	**Lakes**	**Reservoirs**	**Groundwater**
Faecal pathogens	+	+++	•••	•	•	••
Suspended solids	++	+	••	Na	•	Na
Decomposable organic matter	+++	+	•••	•	••	•
Eutrophication	+++	+	•	••	•••	Na
Nitrate	++	+	•	–	–	•••
Salinization	+++	++	•	–	•	•••
Trace metallic elements and arsenic	+	+++	••	••	••	••

Figure 2 The primary issues that might arise because of agricultural practices may result in contamination in different waterways and have environmental and health importance(livestock). (B. Fraters et al., 2021).

3.2.2) TDS and Salinity:

Salinity in water, often measured as Total Dissolved Solids (TDS), reflects the cumulative amount of soluble salts present (Carson, 2000). However, Total Dissolved Solids (TDS) is a measure of the combined content of all inorganic and organic substances present in a liquid in molecular, ionized, or micro-granular suspended form. It is typically expressed in parts per million (ppm) or milligrams per litre (mg/L)(Omer, 2020). TDS in water mainly consists of minerals, salts, metals, cations (positively charged ions), anions (negatively charged ions), and other organic matter. High TDS levels can affect the taste and quality of water, and they are often used as an indicator of water purity (Omer, 2020). Rapid fluctuations in water salinity can harm animals, necessitating the consistent provision of low-salinity water to prevent health issues (Bagley and Kotuby-Amacher, 1997; Abdelsattar et al., 2020). Varied salinity levels have different effects on animals. Abdelsattar et al. (2020) found that animal performance (which could include factors like growth rate, reproductive success, or overall health) improves in low salinity conditions but declines with increased salinity. This suggests that high mineral concentrations, particularly NaCl, in saline water can significantly affect livestock productivity. In cattle, pigs, sheep, and goats, the ideal chloride concentration in drinking water is below 250 mg/L, but it can differ if it is above 2000 mg/L. However, in poultry, the ideal chloride concentration in drinking water is below 200 mg/L, and it's out of the limit above 200 mg/L(Royal GD, 2009). Ideal sodium concentration in drinking water for cattle is below 800 mg/L, for pigs below 400 mg/L and for poultry below 150 mg/L. Sodium can differ between 800-1500 mg/L for cattle, sheep, and goats, 400-800 mg/L for pigs, and 150-200 mg/L for poultry, (Royal GD, 2009).

In reality, salinity can be impacted by pollution in different ways. Firstly, industrial discharges can significantly impact water salinity by releasing pollutants into water bodies, with brine or chemicals from industrial processes contributing to increased salinity (Azadi, Ashofteh and Loáiciga, 2018). Similarly, agricultural runoff, stemming from the use of fertilizers and pesticides, can alter salinity levels in nearby water bodies, particularly when fertilizers containing salts are involved. Thirdly, urban areas contribute to water pollution through runoff containing road salts, heavy metals, and various contaminants, potentially affecting the salinity of adjacent water sources (Azadi, Ashofteh and Loáiciga, 2018). Fourthly, oil spills introduce hydrocarbons and pollutants, influencing water quality, including salinity. Furthermore, improper disposal of domestic or industrial wastewater is another source of salinity alteration, as it can introduce salts and other pollutants into water bodies (Azadi, Ashofteh and Loáiciga, 2018). Additionally, climate change-induced factors such as changes in precipitation patterns and rising sea levels can influence salinity, with increased evaporation and reduced freshwater input potentially elevating salinity levels in certain regions(Azadi, Ashofteh and Loáiciga, 2018).

3.2.3) Hardness

Water hardness is associated with elevated levels of minerals, such as magnesium and calcium, and is known as permanent hardness (Bagley et al., 1997).

Found in water as bicarbonates, sulfates, and occasionally as chlorides and nitrates (APHA, 2005), these ions contribute to two forms of hardness. Temporary hardness, stemming from carbonates and bicarbonates, can be eliminated through boiling. On the other hand, permanent hardness persists after boiling and is primarily caused by sulfates and chlorides (Tchobanoglous et al., 2003).

In general, groundwater tends to be harder than surface water. Water is considered hard if it contains more than 300 mg/L of hardness, noticeable to most individuals at levels exceeding 150 mg/L, while water with less than 75 mg/L is classified as soft (APHA, 2005).

Permanent hardness can be problematic in industrial processes, as it can lead to the buildup of scale in pipes and equipment (APHA, 2005). Unit D is the degree of hardness, 1 D equals 10 mg/L Cao the unit used to measure the degree of water hardness is usually expressed in parts per million (ppm) or milligrams per litre (mg/L) of calcium carbonate (CaCO3). The determination of hardness typically involves titration with ethylene diamine tetra acidic acid (EDTA) and Eriochrome Black and Blue indicators, expressed in terms of mg/L of CaCO3 (APHA, 2005).This unit is commonly referred to as "ppm as CaCO3" or "mg/L as CaCO3" (Tchobanoglous et al., 1985). The measurement is based on the equivalent concentration of calcium carbonate, which helps standardize the reporting of water hardness.

Excessive water hardness can, however, lead to a range of digestive problems in livestock, including diarrhea, reduced feed utilization, and a decline in both water and feed intake (Bagley and Kotuby-Amacher, 2000). Feed utilization refers to how efficiently animals convert their diet into growth and other productive outcomes. Key measures include the Feed Conversion Ratio (FCR), which calculates the amount of feed consumed per unit of weight gain. Efficient feed utilization is crucial for economic and environmental sustainability in livestock production (DeZuane, 1997).

The ideal hardness for cattle, sheep, goats, pigs, poultry, and horses is below 15 D and a maximum of 20 D for poultry and 25 for the rest of the livestock (Royal GD, 2009).

Water hardness, influenced by calcium and magnesium ions, can indeed be affected by pollution. Industrial discharges, agricultural runoff with calcium-containing fertilizers, urban runoff carrying diverse contaminants, and improper wastewater disposal all have the potential to introduce substances that alter water hardness. The specific impact depends on the nature and concentration of pollutants introduced.

3.2.4) Ph

The pH level of water is a critical parameter for measuring acidity or alkalinity. This metric is essential to understanding the suitability of water for livestock consumption (Royal GD, 2009). The pH ranges from 0 to 14, with 7 being considered neutral. A pH value of less than 7 indicates acidity, whereas a value greater than 7 reflects alkalinity(Royal GD, 2009). When considering livestock health and production, it is crucial to identify the optimal pH range for different livestock.

For dairy animals, such as cows, the preferred pH range typically falls between 6.0 and 8.0 (Royal GD, 2009). This range ensures that the water consumed is not overly alkaline, which can lead to digestion issues. For other livestock, including poultry, pigs, and various ruminants, the acceptable pH range spans from 5.5 to 8.3 (Royal GD, 2009). Adhering to these pH guidelines is essential to maintain the health and productivity of livestock.

Water with a significantly high alkaline pH can adversely affect animals. For this reason, water levels must be between 4 and 9. It is worth noting that pH levels outside the recommended ranges can lead to imbalances in the digestive system of animals, affecting nutrient absorption and overall health (Royal GD, 2009).

Overall, ph levels in water can be significantly impacted by pollution. Pollution, particularly from various sources such as industrial discharges, agricultural runoff, and untreated sewage, can introduce acidic or alkaline substances into water bodies (Hahne & Kroontje, (1973), Wei et al., 2016). This can lead to changes in the pH of the water.

3.2.5) Nitrate and Nitrite

Nitrate (NO_3) and nitrite (NO_2) are chemical compounds commonly found in water sources that pose potential risks to livestock health (Royal GD, 2009). Nitrate, which is considered less toxic than nitrite, can still be harmful at elevated concentrations. Within the digestive systems of ruminants and herbivores, nitrate has the potential to be converted to nitrite through bacterial processes, thereby increasing the risk of health issues in animals (Bagley & Kotuby-Amacher, 2000). This conversion process is problematic because it causes health problems which in turn result in decreased milk production, as documented by Bagley and Kotuby-Amacher (2000). Nitrate levels must be below 0.1 mg/L and a maximum of 1.0 mg/L for all livestock animals. However, nitrite levels must be below 100 and a maximum of 200 mg/L(Royal GD, 2009).

Nitrate and nitrite levels in water are susceptible to pollution from various sources. Agricultural runoff, resulting from the application of nitrogen-based fertilizers, can lead to increased nitrate levels. Improper disposal of wastewater, including untreated sewage or industrial effluents, contributes to the contamination of water sources with nitrogen compounds (Mahvi & Nouri & Babaei, 2005). Livestock manure and runoff from intensive farming areas further introduce nitrates into water bodies. Certain industrial discharges and atmospheric deposition of nitrogen oxides also play a role in elevating nitrate and nitrite levels (Arauzo & Martínez-Bastida, 2015)

3.2.6) Heavy metals:

Water sources can contain various elements, some of which are toxic at elevated levels. Iron, aluminium, beryllium, boron, chromium, cobalt, copper, iodine, manganese, molybdenum, and zinc are examples of such elements (Lardner et al., 2005). Although these elements are important micronutrients at low doses, excessive exposure can harm livestock and must be monitored and controlled in drinking water (Carson, 2000). For instance, ideal iron levels must be below 0.5 and a maximum of 10 mg/L for almost all livestock. However, maximum iron levels for poultry are 5.0 mg/L. Furthermore, manganese levels must be below 1.0 and a maximum of 2.0 mg/L for livestock except for poultry which must be below 0.5 and a maximum of 1.0 mg/L (Royal GD, 2009). The health effects of various elements in water for livestock can vary depending on the concentration of the elements and the specific needs of the animals. Some of the most common elements found in water for livestock:

Iron: Low to moderate levels of iron are generally acceptable and may even be beneficial for livestock. However, excessively high levels can lead to iron toxicity, causing gastrointestinal issues, reduced feed intake, and potential interference with the absorption of other minerals (Hart, 1982; Galvin, 1996; ANZG, 2023)

Aluminium: Elevated levels of aluminium in water are generally considered undesirable for livestock. Chronic exposure to high aluminium concentrations may lead to neurological and skeletal issues, impacting overall health(Hart, 1982; Galvin, 1996; ANZG, 2023).

Beryllium: Beryllium is not typically found in water at concentrations that pose health risks to livestock. However, excessive exposure can lead to respiratory and gastrointestinal issues(Hart, 1982; Galvin, 1996; ANZG, 2023).

Boron: High levels of boron in water can be toxic to livestock, causing symptoms such as decreased feed intake, weight loss, and potential reproductive issues(Hart, 1982; Galvin, 1996; ANZG, 2023).

Chromium: Elevated levels of hexavalent chromium (Cr(VI)) can be toxic to livestock, leading to digestive issues, respiratory problems, and potential carcinogenic effects(Hart, 1982; Galvin, 1996; ANZG, 2023).

Cobalt: Cobalt is an essential trace element, and deficiencies can lead to health issues. However, excessive cobalt intake may result in toxicity, causing gastrointestinal and neurological problems(Hart, 1982; Galvin, 1996; ANZG, 2023).

Copper: Copper is an essential mineral, but excessive levels can lead to copper toxicity. Symptoms include digestive disturbances, liver damage, and hemolysis (breakdown of red blood cells) (Hart, 1982; Galvin, 1996; ANZG, 2023).

Iodine: Iodine is essential for thyroid function, but excessive intake can lead to iodine toxicity, causing goitre, weight loss, and potential reproductive issues(Hart, 1982; Galvin, 1996; ANZG, 2023).

Manganese: Manganese is an essential nutrient, but excessive levels can lead to manganese toxicity, impacting the nervous system and causing reduced growth and reproduction(Hart, 1982; Galvin, 1996; ANZG, 2023).

Molybdenum: Excessive molybdenum intake can lead to molybdenum toxicity, causing symptoms such as diarrhea, joint abnormalities, and potential interference with copper metabolism(Hart, 1982; Galvin, 1996; ANZG, 2023).

Zinc: Zinc is an essential trace element, but excessive intake can lead to zinc toxicity, causing gastrointestinal issues, reduced feed intake, and potential interference with copper absorption(Benson, 2022).

3.2.7) Ammonium in Water

Ammonium is produced as a breakdown product of protein-containing substances. Ammonium can be found also in wood and most fertilizer products (Royal GD, 2009). During the winter months, leaves in ditches are slowly converted into ammonium, and all kinds of products that are released called amines can be toxic (Royal GD, 2009). Ammonium is formed when little or no oxygen is present (anaerobic degradation) (Royal GD, 2009). If ammonium meets oxygen, the opposite effect will take place under the influence of an excess of oxygen (Royal GD, 2009). Aerobic bacteria will convert ammonium via nitrite and nitrate into proteins. All kinds of toxic intermediate substances can be formed (nitrosamines). Nitrosamines, a group of chemical compounds formed under specific conditions involving nitrites and secondary amines, pose potential health risks for livestock. While limited research exists on the specific impact of nitrosamines on livestock health, their recognized carcinogenic properties raise concerns (Royal GD, 2009). Prolonged exposure to nitrosamines may contribute to the development of tumors, and livestock may experience gastrointestinal disturbances, reproductive and developmental issues, compromised immune function, and liver damage. Nitrosamine exposure in livestock can occur through contaminated water or feed, emphasizing the importance of monitoring and preventive measures.

Livestock producers should implement practices to reduce nitrosamine formation in feed and water sources, seek veterinary guidance, and employ strategies to ensure the overall health and well-being of their animals. Ammonium can also be produced in the rumen of ruminants. The rumen is one of the stomach compartments in ruminant animals, which are a subgroup of mammals that includes cattle, sheep, goats, deer, and others. Subsequently, ruminants can tolerate higher ammonium concentrations. However, deep groundwater should generally contain ammonium less than 2 mg/L and a maximum of 10 mg/L. For pigs and poultry ammonium-pH combination is especially important. At a higher pH of more than 8, the ammonium concentration must be lower than ph 8, since free ammonia is formed at a higher ph in the rumen (Royal GD, 2009). Free ammonia can promote the colonization of bacteria in the respiratory tract of poultry and pigs. In the drinking water for poultry and pigs ammonium should be above 1.0 and below 2 mg/L as above 5 mg/L there is ammonia formation from the water (Royal GD, 2009). Ammonium levels in water can be impacted by pollution. Ammonium is a form of nitrogen that can be introduced into water through various sources, including agricultural runoff, industrial discharges, and untreated sewage. Excessive levels of ammonium in water can result in water pollution and have detrimental effects on aquatic ecosystems (Beede, 2006).

3.2.8) Blue-green algae toxins:

Under specific weather (hot temperature) and water conditions (higher humidity), typically occurring during late summer or early fall, there is a risk of blue-green algae, also known as cyanobacteria, rapidly proliferating to form a concerning "bloom." (Royal GD, 2009). This phenomenon predominantly affects livestock that rely on ponds and water bodies in temperate regions for drinking. These algal blooms are often wind-driven, pushing them toward the shores of ponds, and making them accessible to animals along with water (Beede, 2009). While many algal blooms are innocuous, an increase in water temperature and various unknown factors can trigger the production of potent neurotoxins or hepatotoxins by these algae, posing a severe threat to animals consuming water (Bagley & Kotuby-Amacher, 1997). Diagnosing such cases typically involves a clinical evaluation of affected animals, identifying potentially toxic algal cells in the water or gastrointestinal contents of the animals, and more recently, using chemical detection methods to identify algal toxins (Royal GD, 2009). The consumption of toxic algae, such as certain species of cyanobacteria (blue-green algae), can lead to a condition known as harmful algal bloom (HAB) poisoning or cyanobacterial intoxication. Here are some potential health impacts observed in livestock: a) Liver Damage: Hepatotoxicity: Hepatotoxins target the liver, causing damage to liver cells and impairing liver function. This can lead to liver failure (Beede, 2006).

b)Neurological Symptoms: Neurotoxic Effects: Some cyanobacteria produce toxins that can have neurotoxic effects, affecting the nervous system and leading to symptoms such as muscle tremors, convulsions, and incoordination (Beede, 2006). c) Gastrointestinal Issues Digestive Disturbances: Livestock may experience gastrointestinal issues, including abdominal pain, diarrhea, and vomiting. d)Respiratory Distress: Respiratory Issues: In severe cases, ingestion of certain toxins produced by algae can lead to respiratory distress (Beede, 2006). e) Death: Fatal Consequences: HAB poisoning can be fatal, especially if a significant number of toxic algae is ingested. f) Reduced Growth and Productivity: Impact on Livestock Performance: Even sublethal exposure to hepatotoxins can result in reduced growth rates, decreased reproductive performance, and overall compromised livestock productivity (Beede, 2009).

It's important to note that the specific health impacts can vary depending on the type of toxin, the concentration of toxins in the water, the duration of exposure, and the susceptibility of the livestock species. Nutrient pollution, stemming from excessive nitrogen and phosphorus inputs through agricultural runoff, sewage discharges, and industrial effluents, fuels the process of eutrophication. This nutrient influx stimulates the rapid growth of algae, including harmful species capable of producing toxins (Beede, 2006). Urban runoff, laden with heavy metals and nutrients from roads and urban areas, contributes to nutrient enrichment in water bodies, fostering conditions conducive to algal growth and toxin production. Industrial discharges introduce chemical contaminants that interact with algae, promoting the proliferation of toxin-producing species (Beede, 2009). Climate change further exacerbates the issue through temperature and precipitation changes, creating environments favouring the growth of harmful algae. Additionally, poor agricultural practices, marked by pesticide and herbicide runoff, contribute to water pollution, impacting both aquatic ecosystems and algal communities.

3.2.9) Bacterial Contamination

Bacterial contamination of livestock drinking water is a significant concern, with far-reaching consequences for livestock health. Elevated bacterial levels in the water are associated with infertility, foot rot, for most of the livestock species and reduced milk production(cows) (Janse et al., 2018).. This contamination often arises from the presence of animal excreta, particularly manure, in stagnant water bodies.

Microbiological parameters for drinking water:

E. coli levels are assessed to determine water contamination, while Salmonella and Clostridium are examined as potentially harmful pathogens for animals (Janse et al., 2018). The maximum level of *E. coli* is 100 cfu/mL(less than 100 colony-forming units per millilitre) for drinking water for humans (Janse et al., 2018). The numbers represent the maximum allowable bacterial count per mL of drinking water to ensure that it is safe for consumption.

Contaminated drinking water can lead to livestock diseases, such as botulism, salmonellosis, tularemia, and *Listeria* infection (Janse et al., 2018). Additionally, *Listeria* species naturally exist in the environment and can be found in various sources, including surface waters (Rothrock et al., 2017).

3.3.1) Antibiotics in Water

Antibiotics are medicines that fight bacterial infections in people and animals (MedlinePlus, 2022). Antibiotics are widely used in human and animal healthcare but, once in the body, the drugs are not completely metabolized or eliminated and a percentage ranging from 30% to 90 % is excreted unchanged into the wastewater system. Antibiotics can be detected in both groundwater and surface water, as evidenced by multiple studies (Kümmerer, 2009a; Carvalho and Santos, 2016; Binh et al., 2018; Danner et al., 2019; Felis et al., 2020; Kovalakova et al., 2020; Lyu et al., 2020; Anh et al., 2021). The most common antimicrobials found in the wastewater treatment plan in a research project in Portugal were the antibiotics sulfamethoxazole, ciprofloxacin, and erythromycin (de Jesus Gaffney et al., 2017). Regrettably, in many European Union (EU) countries, there is a lack of official oversight of antibiotics in water supply systems. Notably, data from a published study indicated that antibiotics (doxycycline, enrofloxacin or amoxicillin) were present in 52% of the analyzed water samples (Małgorzata Gbylik-Sikorska et al., 2015) (Saleh et al., 2023).

When water supply systems are compromised by contamination, there is a risk of unintended antibiotic exposure in the farm environment. Specifically, certain physicochemical properties of antibiotics, such as tetracyclines, fluoroquinolones, and sulfonamides, enable them to adhere to the inner surfaces of water supply system pipes, becoming embedded in the biofilm that lines these pipes (Sumano et al., 2004). This scenario gives rise to several concerns: the biofilm may detach from the pipe's inner surface and be consumed by animals such as broilers or pigs, thereby contributing to the spread of antibiotic resistance among the bacteria contained within the biofilm. The higher usage of antibiotics leads to the spread of drug-resistant pathogens in animals and infections left untreated.

4) Emerging contaminants

In this writing assignment, the focus is on emerging contaminants (ECs) that are not typically recognized as significant factors in the water quality of livestock but for human consumption. Public health organizations tend to prioritize human health, sometimes overlooking the interconnectedness of the environment, human health, and animal well-being as part of the One Health concept(CDC, 2023).

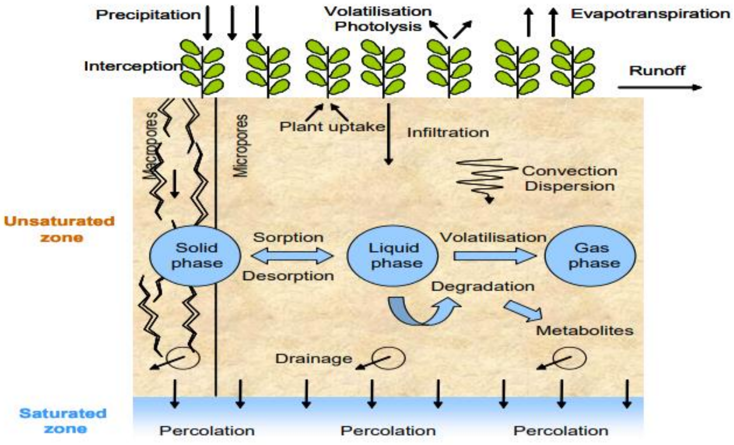


Figure 3 Fate and transport processes for contaminants in the agricultural soil environment (OECD, 2012)

Emerging contaminants or Environmental contaminants (ECs) are Biocidal active substances (AS) and their metabolites/transformation products, when present in the water abstracted for drinking water production, can be a source of harmful substances generated during the processing of water to produce drinking water (ECHA & EFSA, 2023). Additionally, often unknown substances, with uncertainty about their (hazardous) properties and that they are unregulated(ECHA & EFSA, 2023). Specifically, some examples of these substances found in the environment originate from a wide range of consumer products, such as pharmaceuticals, personal care products (PCPs), and plastics (Johnson and Bell, 2022). These substances are released into the environment at various stages of the life cycle. Entry points for ECs include wastewater discharge, leachate from landfills, and surface water runoff, as evidenced by studies conducted by Lapworth et al. (2012) and Liu and Wong (2013) (Johnson and Bell, 2022). Remarkably, the fate of emerging contaminants in the environment is demonstrated in Figure 4. The degradation of EC (environmental contaminants) can occur through biological, physical, or chemical processes (FAO IMWI, 2017). Additionally, EC may adhere to soil particles, be absorbed by plants, leach into groundwater, or be carried to surface waters via runoff and drainage water(OECD, 2012). The occurrence of these processes is contingent upon the inherent physical characteristics of the EC, encompassing its solubility in water, affinity for organic matter and other soil components, and volatility (OECD, 2012). The properties of the soil and prevailing climatic conditions also play a crucial role in determining the extent of these processes. What further complicates the management of ECs is the widespread usage and presence of product categories responsible for their release. Pharmaceuticals, PCPs, and plastics have diverse applications in various industries. The multitude of sources and pathways through which ECs can enter the environment underscores the complexity of addressing and mitigating their impacts (OECD, 2012). Effective strategies and heightened awareness are essential for managing the presence of ECs and their potential consequences for both environmental and public health (OECD, 2012).

Current concerns related to emerging contaminants in livestock drinking water encompass various categories, including Pharmaceuticals and Veterinary drugs, pesticides, and herbicides, per- and polyfluoroalkyl substances (PFAS), endocrine-disrupting compounds (EDCs), and heavy metals.

Reversely, food system activities also affect water resources by depleting groundwater, non-point source pollution from agriculture (FAO IMWI, 2017) or discharges of untreated or poorly treated wastewater. Thus, sustainable management of water resources is crucial, and many challenges exist to realize the level of sustainable water resources as suggested by the Clean Water Sustainable Development Goal (SDG6) (Damania et al., 2019). For instance, water quality issues negatively affect the production processes of drinking water and water use in the food industry. As the food system and the water system are interlinked, this should also be reflected in managing both systems. One of the solutions to coping with water scarcity while producing enough food is the use of (un)treated wastewater for irrigation (Qadir et al., 2007; Al Evans et al., 2019), which creates a dilemma if inadequate quality water is used. Poor quality wastewater might simultaneously disrupt crop growing, leave traces of foodborne diseases or residues of toxic substances, which cause animal diseases for livestock, fish and sea life in the short and/or long run, and affect human health (Amoah, 2011; Woldetsadik et al., 2017), which has a negative impact on food security.

Per- and polyfluoroalkyl substances (PFAS), such as perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), raise considerable apprehension due to their persistent nature and potential consequences for both the environment and human health (Centers for Disease Control and Prevention, 2019). Their resistance to environmental degradation results in long-lasting presence, while their ability to traverse soils poses a risk of contaminating drinking water sources. (National Toxicology Program, 2016). Furthermore, PFAS exhibits bioaccumulation, concentrating in the tissues of fish and wildlife, thereby amplifying potential ecological and human health concerns. These substances have been identified in rivers, lakes, and various animal species in both terrestrial and aquatic ecosystems (National Toxicology Program, 2016). While the exact health effects on humans from low-level environmental PFAS exposure remain uncertain, studies involving laboratory animals exposed to higher concentrations suggest possible impacts on growth, development, reproduction, thyroid function, the immune system, and liver health (National Toxicology Program, 2016).

The focus on per- and polyfluoroalkyl substances (PFAS) in livestock settings is driven by their distinctive characteristics that pose potential risks to animal health. PFAS exhibits high toxicity even at low concentrations, making them a cause for concern in livestock environments(Death et al., 2021). Additionally, their exceptional persistence in the environment means that PFAS can accumulate in water sources over time, raising the likelihood of prolonged exposure for livestock (Death et al., 2021). Widespread contamination of water bodies globally further underscores the relevance of PFAS in livestock contexts. The bioaccumulative nature of PFAS in animal tissues, coupled with their potential adverse effects on liver function, immune systems, and development, heightens the importance of monitoring and managing PFAS contamination in livestock environments. Furthermore, the transfer of PFAS to livestock products, such as meat and milk, raises concerns about potential human exposure, emphasizing the interconnectedness of environmental and public health in addressing this emerging contaminant (Figure 5, Death et al., 2021).

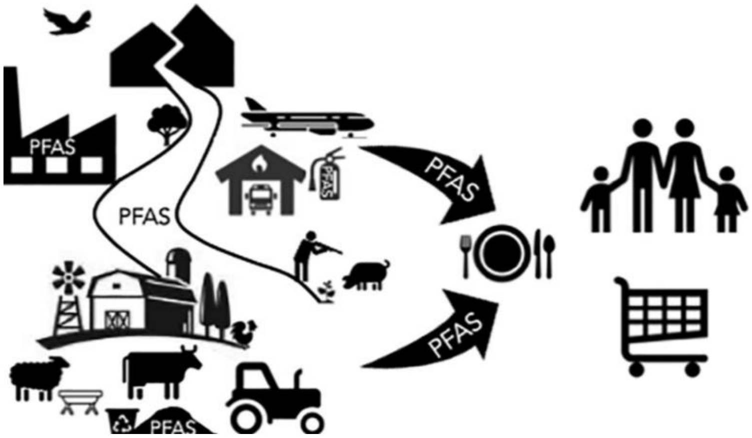


Figure 4 The image depicts how PFAS pollution is connected with the environment, animals, and humans. (Death et al., 2021)

4.1) PFAS in drinking water for livestock

PFAS was first identified as PFOA-containing compounds used in Teflon production and since then they have been detected everywhere (Death et al., 2021). PFOA is restricted by European law. As a response to the growing awareness of their adverse effects, there has been a notable trend toward imposing wide restrictions on PFAS usage and disposal. The persistence of PFAS in the environment, coupled with their bioaccumulative nature, has led to their classification as emerging contaminants of global concern (ECHA, 2023). Governments and regulatory bodies worldwide are increasingly acknowledging the potential risks associated with PFAS, leading to stringent restrictions on their production, use, and release (ECHA, 2023). This broad regulatory approach aims to limit the environmental burden of PFAS and mitigate their impact on ecosystems, including livestock settings. However, because of the high usage of the products in the past, there is long-term environmental exposure and presence. There is no reported evidence of detrimental health effects in livestock, even at high maximum observed blood plasma PFOS concentrations. Studies have indicated concentrations up to 0.24 mg/L in sheep (Kowalczyk et al., 2012), 0.25 mg/L in pigs (Kowalczyk, 2014), and varying levels between 2.46 mg/L (Kowalczyk et al., 2013) and 76.3 mg/L (Lupton et al., 2015) in cattle. The absence of reported adverse health impacts suggests a need for further research to comprehensively assess the potential implications of PFOS exposure in livestock.

Drinking water contaminated with PFASs has been identified in many countries, and several biomonitoring studies have observed elevated concentrations of PFASs in the blood of the general population drinking contaminated water (Hölzer et al., 2008; Frisbee et al., 2009; ATSDR, 2013; Gyllenhammar et al., 2015; Ingelido et al., 2018).

While the studies referenced above highlight similarities in the overall tissue distribution of PFAS across various species, distinctions exist that are influenced by species, dosage, and to a lesser extent, by gender. In cattle, for instance, PFHxS and PFBS, shorter-chain PFAS, exhibit lower accumulation potential compared to longer-chain compounds like PFOS (Lupton et al., 2011, Lupton et al., 2014). Conversely, in chicken eggs, PFHxS demonstrates greater accumulation potential than PFOS (Wilson et al., 2020), with ongoing exposure potentially explaining observed variations. Across multiple livestock studies involving experimental exposure in cattle (Kowalczyk et al., 2013; Lupton et al., 2014; Lupton et al., 2015), pigs (Numata et al., 2014; Guruge et al., 2016), and chickens (Guruge et al., 2008; Yeung et al., 2009; Yoo et al., 2009), PFAS concentrations in muscle—typically the most consumed animal product—consistently proved lower than those measured in offal, primarily liver, blood, and kidney. These findings underscore the nuanced and species-specific dynamics of PFAS distribution in livestock.

4.2.) Water pathways of PFAS in livestock

The introduction of PFAS into livestock environments involves multiple entry routes and pathways, potentially affecting both animal health and the food chain. PFAS and derivatives can infiltrate animals through various means, including atmospheric deposition, freshwater sources, and terrestrial environments (Modified from Ramachandraiah et al., 2022). The transport and deposition of PFAS are facilitated by processes such as wind dispersal, rainfall, and snowfall, increasing exposure to animals and humans (Modified from Ramachandraiah et al., 2022). Especially for livestock animals, routes of exposure include the consumption of PFAS present in contaminated water and feed.

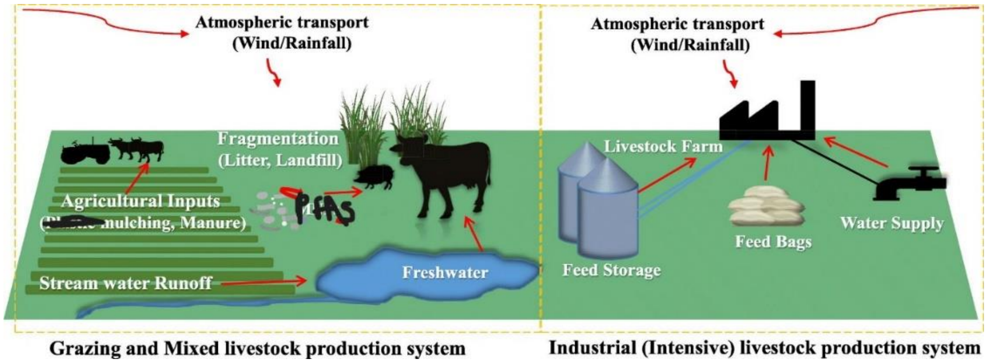


Figure 5 Pathways through which PFAS can enter livestock though water. (Modified from Ramachandraiah et al., 2022).

PFAS can infiltrate agricultural fields and farmland through multiple pathways, including agricultural practices involving material inputs and manure, fragmentation of larger plastics associated with sewage sludge, landfill, and litter, as well as stormwater runoff and deposition, as noted in studies by Hurley and Nizzetto (2018), Piehl et al. (2018), and Wu et al. (2021). More than 90% of European rivers investigated have detected one or more PFASs, and these substances have been found in drinking water (Ahrens and Bundschuh, 2014).

Regarding water exposure, examinations of ambient PFOS concentrations in drinking water across different regions, including Japan (Guruge et al., 2008), Australia (Thompson et al., 2011), and Europe (EFSA, 2018), have revealed a range from <0.1 to 51 ng/L. Comprehensive global reviews of PFAS concentrations in drinking water have been conducted by Rahman et al. (2014) and Domingo and Nadal (2019). PFAS presence has been identified in sediments of bays, lakes, rivers, and effluents from sewage treatment plants (OECD, 2002; Ahrens et al., 2009; Möller et al., 2010). For instance, downstream from wastewater treatment facilities in Japan, PFOS concentrations have been measured up to 157 ng/L (Guruge et al., 2008). Elevated concentrations are observed downstream of PFAS production sites (Boiteux et al., 2017), areas with the historical use of aqueous film-forming foams for fire-fighting purposes (D'Agostino and Mabury, 2017), and downstream of landfills (leachate concentrations from an Australian study were PFOA max. 48 ng/L and PFOS max. 240 ng/L; Gallen et al., 2017). PFOS and PFOA exhibit long surface water half-lives of 41 years and 92 years, respectively (DoER, 2016), with the potential need for nanofiltration to eliminate PFAS from treated water (Domingo and Nadal, 2019). Different livestock production systems, such as grazing-based, mixed, and industrial systems, exhibit varying reliance on external resources and have distinct implications for resource consumption and pollution levels (Mekonnen and Hoekstra, 2012).

4.3)PFAS Regulations in the Netherlands

There are different regulations about water designated for human consumption, particularly in the context of surface water quality, where distinctions are made between saltwater and other surface waters. Specifically, the Annual average environmental quality standard' (JG-MKN) has set a stringent limit, at 40 times on Maximum Residue Levels (MKN) value, for the cumulative presence of per- and polyfluoroalkyl substances (PFAS) in surface water (van der Aa, Hartmann & Biesebeek, 2021).

Table 4 Maximum Acceptable Limits of the main four PFAS categories in Dutch Waters. Information obtained from RIVM 2023 (Am et al., 2019)

Pfas	Surface water drinking water	Salt surface water	Fresh surface water
Sum of pfas	0.10 µg/l	48 ng/l	48 ng/l
Pfos and derivatives	1.1 µg/l	7.2 µg/l	48 ng/l
Pfoa	87.5 ng/l	48 ng/l	48 ng/l
Pfna	No limit	No limit	No limit
Pfhxs	No limit	No limit	No limit

Zooming in on PFAS, a risk limit of 0.10 µg/l for drinking water intended for human consumption has been set, representing a notably low threshold (van der Aa, Hartmann & Biesebeek, 2021). However, the permissible concentration is higher at 48 ng/l for both salt and fresh surface water, considering human fish consumption (Rijksinstituut voor Volksgezondheid en Milieu [RIVM], 2017). RIVM (Dutch National

Institute for Public Health and the Environment) an authoritative body providing water quality standards, including for perfluorooctanoic acid (PFOA), considers chronic exposure scenarios, including PFOA accumulation in fish. Based on this assessment, a protective concentration of 48 nanograms per litre in water has been calculated, safeguarding the lifetime consumption of fish by humans and wildlife(Am et al., 2019).

Table 5 Maximum Residual Levels of PFAS on livestock products in the Netherlands

	Maximum residual levels (µg/kg fresh weight)				
Food	PFOS	PFOA	PFNA	PFHS	Sum
Eggs	10	0.30	0.70	0.30	1.7
Meat from cattle, pigs, and poultry	0.30	0.80	0.20	0.20	1.3
Sheep meat	1.0	0.20	0.20	0.20	1.6
Offal from cattle, sheep, pigs, and poultry	6.0	0.70	0.40	0.50	8.0

Despite European restrictions on PFOA usage, historical PFOA-containing products contribute to ongoing environmental exposure. The persistent nature of PFOA leads to its prolonged presence in the environment. Preliminary analysis, aligned with monitoring data, indicates that the safe concentration established by RIVM is not exceeded in Dutch surface waters. It is pertinent to note, however, that RIVM's considerations are confined to human fish consumption and drinking water regarding PFOA, neglecting animals' drinking water consumption, especially given variations in body mass index and physiology among livestock (Am et al., 2019).

For perfluorooctane sulfonic acid (PFOS) and its derivatives, the limit for drinking water is 1.1 mg/L, while Perfluorononan-1-oic acid (PFNA) and perfluorohexane-1-sulfonic acid (PFHxS) lack explicit restrictions in RIVM guidelines. Notably, RIVM applies restrictions on PFAS as a collective entity, recognizing that instances of PFAS contamination typically involve multiple substances rather than a singular compound (table 4).

Considering only the average body weight and water intake of one of the livestock animals (cattle) comparable with human average body weight and water intake.

Water Intake per kg (human)=3.0 litres/70kg≈ 0.043 litres/kg

Water Intake per kg (cattle)≈700kg/56.778liters =0.081 litres/kg

Cattle water intake of litres/kg is almost double the number of humans. Meaning that the drinking water standards for humans are not very closely related to drinking water standards for livestock and this example for cattle.

Adjusting drinking water standards for livestock compared to humans involves considerations of body weight, metabolic rates, and species-specific sensitivities. Variations in water consumption patterns, nutritional needs, and potential impacts on health and productivity guide the development of standards tailored to the specific characteristics of each livestock species.

In a study conducted in 2019 (EFSA, 2020), (Table 6) a high prevalence and distribution of PFAS compounds were observed in animal products and drinking water. Fish meat exhibited a particularly elevated prevalence, with more than one thousand occurrences for each PFAS compound, while the prevalence in drinking water, although half the number found in fish, remained substantial. Importantly, livestock meat showed a total of 1490 occurrences, indicating a significant incidence of PFAS in livestock. This underscores the pervasive nature of PFAS compounds in various environmental compartments, necessitating ongoing monitoring and regulatory considerations.

Table 6 The four (PFHxS, PFNA, PFOA, PFOS) more often distributed PFAS along with their concentration in meat, fish products and drinking water in Europe in 2019 (Schrenk et al., 2020 EFSA)

PFAS	**PFHXS**	**PFNA**	**PFOA**	**PFOS**	**GRAND TOTAL**
Category					
Animal and vegetable fats and oils	53	36	38	38	165
Drinking water (water without any additives except carbon dioxide; includes water ice for consumption)	449	449	452	451	1801
Eggs and egg products	107	124	177	174	582
Fish meat	1718	2134	2273	2637	8762
Fish offal	202	204	208	208	822
Fruit and fruit products	94	98	144	143	479
Grains and grain-based products	80	87	86	93	346
Livestock meat	222	348	459	461	1490
Meat and meat products (including edible offal)	23	23	23	23	92
Poultry	130	170	185	169	654
Preserved meat	38	38	43	43	162
Sausages	36	36	43	43	158
Cheese	53	53	115	115	336
Cream and cream products	12	12	13	13	50
Fermented milk products	63	64	65	66	258
Liquid milk	126	111	236	235	708
Milk and dairy products	13	13	13	13	52
Vegetables and vegetable products (including fungi)	274	275	489	477	1515
	4745	5594	8197	8498	27034

5) Results and discussion

Firstly, the research questions need to be answered.

- What are the existing regulatory mechanisms that manage 1) exposure of environmental contaminants to livestock?

  Chapter 3.1 discusses the existing regulatory mechanisms related to the exposure of environmental contaminants to livestock.

Regulatory frameworks aim to monitor and control the presence of contaminants in the environment and their potential impact on livestock and human health. These mechanisms involve guidelines, standards, and monitoring protocols to ensure the safety of livestock products and minimize human exposure to harmful substances.

- What are the pathways and sources of water pollution in livestock environments,

Chapter 3.2 explores the pathways and sources of water pollution in livestock environments, examining variations across different types of livestock. Livestock environments can contribute to water pollution through factors such as runoff from agricultural areas, discharges from industrial facilities, and untreated sewage. The chapter delves into the specific ways these pollution sources can affect water quality and how variations in livestock practices impact pollution levels.

- Can PFAS exposures in water have health effects on livestock?

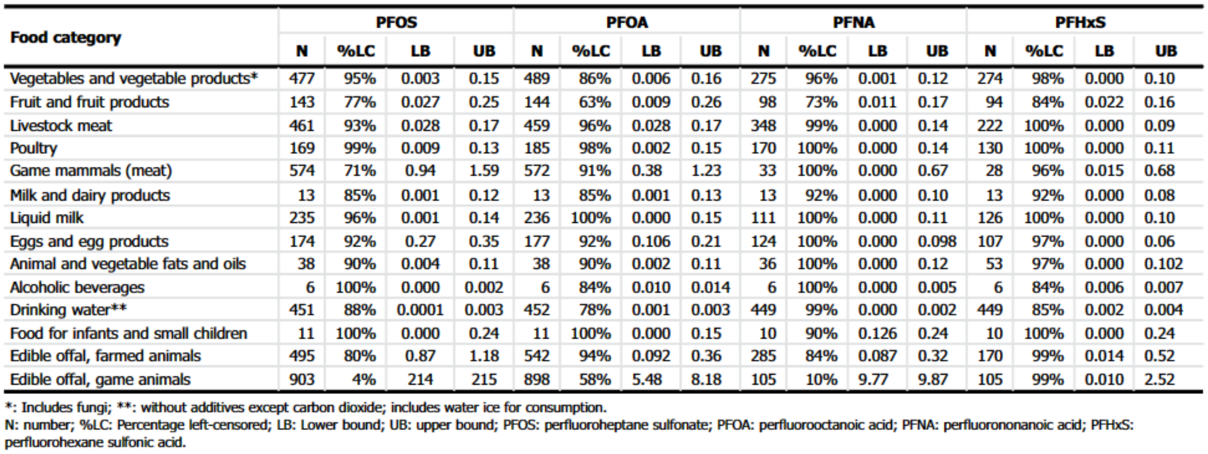
In Chapter 4, the focus shifts to PFAS exposures in water and their potential health effects on livestock. PFAS, being a group of persistent and bioaccumulative substances, can have implications for animal health when present in water sources. This section discusses the existing scientific knowledge regarding the impact of PFAS exposure on livestock, including potential health risks and concerns related to the consumption of PFAS-contaminated water by livestock.

The Rijksinstituut voor Volksgezondheid en Milieu (RIVM) has instituted updated risk limits for perfluoroalkyl substances (PFAS) in surface water, aligning with health-based limit values proposed by the European Food Safety Authority (EFSA) in 2020. These revised risk limits hold substantial implications for water quality assessments, particularly in the context of human PFAS intake through fish consumption. The new risk limits for three prevalent PFAS in Dutch surface waters are stipulated as follows: 0.3 nanograms per litre for PFOA, 7 picograms per litre for PFOS, and 10 nanograms per litre for HFPO-DA (GenX). This significant reduction from existing water quality standards reflects heightened toxicity considerations as evaluated by EFSA.

PFAAs (per- and poly-fluoroalkyl substances) generally exhibit high absorption from the gastrointestinal tract, with examples like PFOA and PFOS showing over 90% absorption in rats, and they undergo minimal metabolism (Kudo, 2015; Pizzurro et al., 2019). Due to their non-volatile and metabolically inert nature, the elimination of PFAAs from the body primarily occurs through urine and faeces (Pizzurro et al., 2019). The enterohepatic circulation, involving excretion into bile, can extend the half-life of PFAAs (Kudo, 2015). Notably, PFOS and longer-chain PFAS tend to bioaccumulate and persist in protein-rich compartments such as the liver and blood, with the partitioning between blood and liver being specific to each animal species (Kelly et al., 2009; Guruge et al., 2008). Evidence from studies on humans and experimental mammals indicates that PFOA, PFOS, and PFBS preferentially distribute to the liver, while PFBA and PFHxS exhibit a preference for serum distribution (Pizzurro et al., 2019). Despite being proteinophilic, PFAS concentrations in tissues show a positive correlation with protein content rather than fat content (Kelly et al., 2009). While health effects related to these patterns have not been explored in livestock or game species, the variability observed in experimental animals emphasizes the need for comprehensive studies considering a range of exposure doses and time frames. Due to significant differences in PFAS toxicokinetics among species, blood serum (or plasma) PFAS concentrations serve as a more reliable indicator than the external dose for comparing adverse effects across different species (Pizzurro et al., 2019).It is crucial to acknowledge the diversity of PFAS compounds alongside PFOA, PFOS, and GenX. Given the anticipated similar modes of action and potential cumulative toxicity, comprehensive assessments of discharges and surface water samples should encompass a broad range of PFASs to thoroughly evaluate both environmental and health implications (Schrenk et al., 2020).

The dynamic nature of risk limits set by the RIVM and being kept up to date underscores ongoing research and evolving understanding of PFAS. This necessitates a proactive approach to mitigate potential risks, especially concerning food-producing animals. Vigilant control of water supply during animal production emerges as a cornerstone in this preventive strategy.

Table 7 Mean levels (µg/kg) of PFOS, PFOA, PFNA and PFHxS in selected food categories(except fish) (Schrenk et al., 2020)



Food category	PFOS				PFOA				PFNA				PFHxS			
	N	%LC	LB	UB	N	%LC	LB	UB	N	%LC	LB	UB	N	%LC	LB	UB
Vegetables and vegetable products*	477	95%	0.003	0.15	489	86%	0.006	0.16	275	96%	0.001	0.12	274	98%	0.000	0.10
Fruit and fruit products	143	77%	0.027	0.25	144	63%	0.009	0.26	98	73%	0.011	0.17	94	84%	0.022	0.16
Livestock meat	461	93%	0.028	0.17	459	96%	0.028	0.17	348	99%	0.000	0.14	222	100%	0.000	0.09
Poultry	169	99%	0.009	0.13	185	98%	0.002	0.15	170	100%	0.000	0.14	130	100%	0.000	0.11
Game mammals (meat)	574	71%	0.94	1.59	572	91%	0.38	1.23	33	100%	0.000	0.67	28	96%	0.015	0.68
Milk and dairy products	13	85%	0.001	0.12	13	85%	0.001	0.13	13	92%	0.000	0.10	13	92%	0.000	0.08
Liquid milk	235	96%	0.001	0.14	236	100%	0.000	0.15	111	100%	0.000	0.11	126	100%	0.000	0.10
Eggs and egg products	174	92%	0.27	0.35	177	92%	0.106	0.21	124	100%	0.000	0.098	107	97%	0.000	0.06
Animal and vegetable fats and oils	38	90%	0.004	0.11	38	90%	0.002	0.11	36	100%	0.000	0.12	53	97%	0.000	0.102
Alcoholic beverages	6	100%	0.000	0.002	6	84%	0.010	0.014	6	100%	0.000	0.005	6	84%	0.006	0.007
Drinking water**	451	88%	0.0001	0.003	452	78%	0.001	0.003	449	99%	0.000	0.002	449	85%	0.002	0.004
Food for infants and small children	11	100%	0.000	0.24	11	100%	0.000	0.15	10	90%	0.126	0.24	10	100%	0.000	0.24
Edible offal, farmed animals	495	80%	0.87	1.18	542	94%	0.092	0.36	285	84%	0.087	0.32	170	99%	0.014	0.52
Edible offal, game animals	903	4%	214	215	898	58%	5.48	8.18	105	10%	9.77	9.87	105	99%	0.010	2.52

*: Includes fungi; **: without additives except carbon dioxide; includes water ice for consumption.
N: number; %LC: Percentage left-censored; LB: Lower bound; UB: upper bound; PFOS: perfluoroheptane sulfonate; PFOA: perfluorooctanoic acid; PFNA: perfluorononanoic acid; PFHxS: perfluorohexane sulfonic acid.

Considering the impact of water, animals, and human health to comprehensively address the limited research on PFAS in livestock, it is imperative to embrace a One Health approach as depicted in Figure 7. This interdisciplinary strategy underscores the interconnected impact of water on the health of both animals and humans. Initiatives should expand through collaborative efforts among experts from various fields, aiming to assess exposure pathways, evaluate risks to both livestock and human health and implement holistic strategies for effective and comprehensive solutions. Initiatives should focus on regularly consumed food categories contributing most to PFAS exposure (table 7, Schrenk et al., 2020). For PFOS, high mean levels were observed in various fish species, eggs, egg products, livestock meat, fruit, and fruit products. PFOA, in addition to fish, exhibited relatively high levels in drinking water, fruit, vegetables, and their respective products(Schrenk et al., 2020). Considering the interconnected nature of livestock and agricultural products, PFAS interference is pervasive, emphasizing the need for a comprehensive approach.

Research challenges arise from the lack of studies on PFAS in livestock, necessitating a focus on water quality, especially in the context of food-producing animals. Pathways of PFAS entry into water for livestock should be thoroughly investigated, considering the surroundings of livestock farms, potential residual PFAS products, contaminated feed, and the origin of water. Understanding how PFAS enters water for livestock is crucial for evaluating environmental impacts.

Significantly the pathways in which water polluted with PFAS enter livestock have an enormous interest in how the environment is also affected by PFAS. I would like to propose certain pathways including: 1) Surroundings of livestock farms, multiple industrial companies have been using PFAS- products for hundreds of years. Even though PFAS use is no longer used, PFAS derivatives can be found around industries (soil, water) and streams where livestock uses water. 2) it needs to be investigated that farmers can still own products that can be still contaminated with PFAS that are used for supplying water to animals. 3) As we discussed above, a variety of food products was found with PFAS, the same probably occurs with livestock feed that water is used to prepare the feed. Eventually, this leads to contamination with PFAS.

Our hypothesis posits that livestock feed may become contaminated with PFAS through the utilization of water in the feed preparation process, mirroring findings in various food products discussed previously. To substantiate this hypothesis, a focused investigation is imperative. Rigorous testing of livestock feed is paramount, aiming to identify and quantify the presence of specific PFAS compounds. Concurrently, the water sources employed in the preparation of livestock feed demand scrutiny to ascertain their PFAS content and contribution to feed contamination. Elucidating the transfer mechanisms from water to feed, including the influence of feed composition and processing methods, is crucial. Additionally, an assessment of livestock exposure to PFAS through contaminated feed, coupled with the monitoring of PFAS levels in livestock tissues, will offer insights into potential bioaccumulation. The investigation should also consider farm-specific factors, encompassing feed storage conditions, source variability, and water quality fluctuations. 4) An important aspect is where water's origin is. The pipes that it used to be transferred, The whole transfer of water to livestock. How much infected is soil with PFAS and how water is influenced by that?

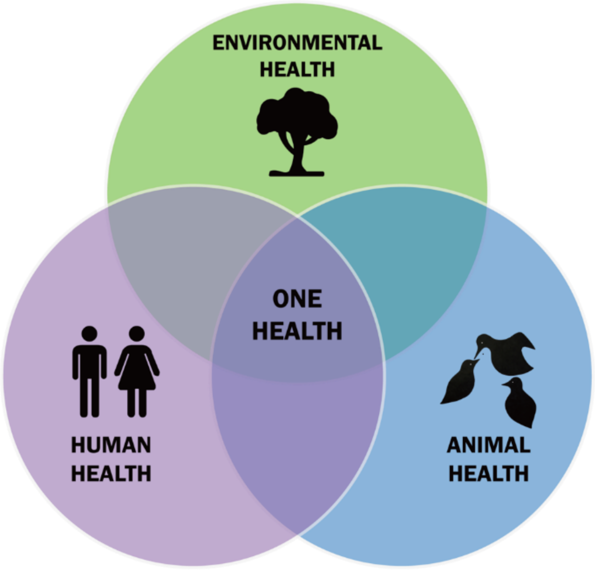


Figure 6 The One Health Approach: Shows how One Health relates to animals, humans, and the environment. By Thddbfk - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=81872126

An imperative facet in deciphering PFAS contamination within livestock environments hinges on scrutinizing the origin of water sources and the entire transfer process to livestock. The conduits, encompassing pipes and the intricate water transfer mechanisms, are pivotal in shaping PFAS concentrations. This scrutiny is of paramount importance, given the interconnectedness of soil contamination with water sources and its potential influence on PFAS dispersion. Soil contamination studies, involving rigorous sampling and analysis, become crucial for gauging PFAS levels and identifying contamination hotspots.

The complex interplay between soil and water necessitates hydrological investigations to unravel the transport dynamics of PFAS. Additionally, assessing the historical land use, particularly industrial activities, provides insights into potential PFAS sources. The main impact on PFAS concentrations is anticipated to stem from the historical use of PFAS-containing products in both industrial and on-farm applications. This comprehensive investigation, incorporating water source analysis, infrastructure assessment, soil contamination studies, hydrological investigations, and historical land use analysis, is essential for delineating specific pathways of PFAS contamination in livestock environments. Such insights are foundational for formulating effective management strategies and mitigating potential risks to environmental and animal health. Given the potential risks associated with PFAS exposure through food consumption, the question arises: should people modify their diets to reduce PFAS exposure? While dietary adjustments are possible, the regulatory framework, employing Maximum Acceptable Concentration Environmental Quality Standards (MAC-EQS), serves as a safeguard for aquatic ecosystems and is more relevant for human health protection(Am et al., 2019). MAC-EQS, based on direct ecotoxicity considerations, focuses on liver toxicity as the most sensitive parameter, but variations in bioaccumulation patterns between experimental animals and humans underscore the need for comprehensive studies (Am et al., 2019).

The risk limit, in this context, is predicated on liver toxicity, identified as the most sensitive parameter in laboratory animals. Notably, there are substantial variations in bioaccumulation patterns between experimental animals and humans for perfluorooctanoic acid (PFOA) and other perfluorinated compounds. (ATSDR, 2018). These differences arise from distinct kinetic behaviours in the two groups. While experiments involving mice, rats, and monkeys have been conducted a new laboratory study is underway at the US Army Public Health Center (Gunpowder, MD) with a wild species of mouse (Peromyscus spp.) and PFOS, PFOA, PFBS, and PFHxS. Additional studies encompassing rabbits, chickens, and quails reveal no pertinent systemic effects while effects were observed in mice, rats and monkeys (ATSDR, 2018). The latter investigations, focusing on specific effects such as immune response, or lacking observed dose-response effects on general toxicity outcomes like body weight, contribute to the overall understanding of the potential impacts of PFAS (ATSDR, 2018).

Despite the indications of adverse effects of PFAS in human consumption and the detection of PFAS in animal organs, the specific impact of these emerging contaminants on livestock remains an unanswered research question. That’s why more research on toxicology testing on livestock water is needed. Notably, PFAS is found in surface water, but the currently available maximum residual limits and toxicology testing are tailored exclusively to human consumption. This highlights a critical gap in our knowledge concerning the effects of PFAS on livestock.

To address this gap, proposed research projects are essential in elucidating the multifaceted aspects of PFAS exposure in livestock. Firstly, toxicology testing conducted by RIVM for water consumption in livestock is pivotal. This involves determining the maximum residual limits for PFAS in drinking water for livestock and investigating potential effects associated with high PFAS concentrations in such water sources. Recognizing that PFAS exposure goes beyond water consumption, it is imperative to extend investigations to air and feed consumption, as well as the storage of feed. A comprehensive understanding of PFAS consumption in all these dimensions is crucial for a holistic assessment of its impact on livestock.

Furthermore, research projects should aim to identify effective strategies for limiting PFAS exposure in livestock. This involves testing various pathways through which PFAS enters surface water intended for livestock consumption. Implementing measures to decrease the presence of PFAS in these pathways is essential for mitigating potential adverse effects on animal health.

In conclusion, the proposed research projects aim to provide a thorough understanding of the implications of PFAS exposure on livestock, including the determination of maximum residual limits considering animal health, assessment of potential effects, and identification of strategies to limit exposure. These efforts will contribute significantly to ensuring the well-being of animals and the production of safe, high-quality food.

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