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Assessment of Perfluoroalkyl Substances in Fish, Soil, Vegetables, and Water From Bade and Jakusko Lgas of Yobe State, Nigeria

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Abstract

The study assesses the presence of Perfluoroalkyl Substances (PFAS) in fish, soil, vegetables, and water samples collected from Bade and Jakusko Local Government Areas (LGAs) in Yobe State, Nigeria. Perfluoroalkyl Substances (PFAS) compounds, known for their environmental persistence and potential health risks, were analyzed using advanced techniques like Gas Chromatography-Mass Spectrometry (GC-MS/MS). The analysis focused on common Perfluoroalkyl Substances (PFAS) compounds such as Perfluorooctanoic Acid (PFOA), Perfluorooctanesulfonic Acid (PFOS), and others, comparing their concentrations to the EPA standard of 0.01 to 0.1 µg/kg. In water samples, the concentration of Perfluorooctanoic Acid (PFOA) varied between 0.02 to 0.42 µg/kg in different wards. In vegetable samples, no detectable levels of Perfluoroalkyl Substances (PFAS) were observed. Fish samples showed varying levels of Perfluorooctanoic Acid (PFOA), Perfluorohexane sulfonic acid (PFHxS), and perfluorooctanesulfonic Acid (PFOS), with concentrations exceeding the EPA limit in some instances. Soil samples also showed Perfluorooctanoic Acid (PFOA), presence ranging from 0.11 to 0.30 µg/kg. The findings indicate varying levels of Perfluoroalkyl Substances (PFAS) contamination across different environmental media, underscoring the need for comprehensive monitoring and mitigation measures in the area under study.

Keywords: Analysis, concentrations, detectable levels, environment, Perfluoroalkyl, techniques.

Introduction

Perfluoroalkyl substances (PFAS) are a collection of synthetic compounds that have been extensively utilized in diverse industrial sectors and consumer goods since the 1950s. These substances are distinguished by their distinctive chemical composition, consisting of a wholly fluorinated carbon chain that is chemically linked to a range of functional groups [1].

Perfluoroalkyl substances (PFAS) are renowned for their exceptional resistance to water and grease, as well as their thermal stability and low surface tension. Perfluoroalkyl substances (PFAS) have been extensively utilized in a broad spectrum of applications, encompassing the manufacturing of non-stick cookware, oil and water-repellent coatings for textiles and carpets, firefighting foams, electronic components, and various industrial processes [2]. Owing to their extensive utilization and prolonged persistence, perfluoroalkyl substances (PFAS) have pervaded the environment. The presence of perfluoroalkyl substances (PFAS) in the environment raises concerns due to their enduring nature, potential for bioaccumulation, and possible adverse health effects [3]. Perfluoroalkyl substances (PFAS) can amass within the environment, including water, soil, and sediments, and have been detected in wildlife as well as in globally distributed samples of human blood, urine, and breast milk [1, 4]. Examples of perfluoroalkyl substances (PFAS) found in Soil are Perfluorooctanoic Acid (PFOA), Perfluorooctanesulfonic Acid (PFOS) and Perfluorohexane sulfonic acid (PFHxS) [4].

Perfluorooctanoic acid (PFOA), is an artificial chemical compound that falls under the classification of per- and polyfluoroalkyl substances (PFAS). Its extensive utilization and enduring presence in the environment, along with its potential detrimental effects on human health, have attracted substantial attention [1, 5]. Perfluorooctanoic Acid (PFOA) has been widely employed in various industries for the production of fluoropolymers and surfactants. It is associated with a diverse range of adverse health consequences, including developmental and reproductive complications, liver damage, and potential carcinogenicity [5]. Perfluorooctanoic Acid (PFOA) has been utilized for numerous decades in the manufacturing of various consumer goods and industrial applications, such as non-stick cookware, stain-resistant fabrics, water-repellent coatings, firefighting foams, and numerous other products. Its distinctive chemical properties, such as high surface tension and resistance to heat, confer significant value to these applications [1, 6].

Perfluorooctanesulfonic acid (PFOS) is classified as a persistent organic pollutant within the per and polyfluoroalkyl substances (PFAS) group [6]. Its synthetic nature has garnered considerable attention due to its extensive use, resistance to environmental degradation, and potential detrimental impacts on both human health and the ecosystem. Perfluorooctanesulfonic acid (PFOS) was commonly employed in firefighting foams and as a repellent for stains on fabrics. Additionally, it has been detected in various environmental matrices, including soil [7]. Exposure to Perfluorooctanesulfonic acid (PFOS) has been associated with a range of health concerns, such as suppression of the immune system and potential effects on development [1, 8].

Perfluorooctanesulfonic acid (PFOS) has found application in a multitude of industrial and commercial sectors, notably in firefighting foams, stain-resistant coatings for textiles, paper and packaging, metal plating, and electronics manufacturing. Its molecular structure comprises an eight-carbon chain with a sulfonic acid group, wherein all hydrogen atoms are substituted with fluorine atoms, conferring exceptional stability and resistance to degradation [8]. The environmental persistence of Perfluorooctanesulfonic acid (PFOS) poses a significant apprehension, as studies have demonstrated its resistance to natural degradation processes, leading to its accumulation in the environment over time [9].

Per- and polyfluoroalkyl substances (PFAS) encompass a collection of over 4000 synthetic chemicals. These compounds are endowed with distinct chemical and physical properties, such a soil and water repellency, thermal stability, and friction reduction. As a result of these attributes, polyfluoroalkyl substances (PFAS) have found extensive employment in consumer goods and industrial processes. Notable examples of polyfluoroalkyl substances (PFAS) applications include nonstick coatings, fast food packaging, and water and stain repellants, polishes, textile coatings, paper products, cosmetics, pesticides, herbicides, and firefighting foams. Furthermore, perfluoroalkyl substances (PFAS) are also utilized in the industrial manufacturing of photographic, automotive, semiconductor, aerospace, construction, electronics, and aviation products [10]. Perfluoroalkyl substances (PFAS) have been evaluated across various environmental mediums. Research has shown that Perfluoroalkyl substances (PFAS) can taint irrigation water and soil, thereby instigating apprehension about their existence in food crops [4, 11].

Perfluoroalkyl substances (PFAS) examination has been conducted on vegetable specimens, revealing that short-chain Perfluoroalkyl substances (PFAS) possess greater potential for translocation and bioaccumulation in plants [11]. perfluoroalkyl substances (PFAS) has also been detected in fish, encompassing sport fish from areas known or suspected to be contaminated and commercial seafood from grocery stores and fish markets [12]. Furthermore, perfluoroalkyl substances (PFAS) has been identified in food articles and water samples from the Faroe Islands, where long-chain Perfluoroalkyl substances (PFAS) prevail in the former, signifying exposure from Perfluorooctanoic Acid (PFOA) and perfluorooctanesulfonic Acid (PFOS) replacement compounds [13].

The general population's exposure to Perfluoroalkyl substances (PFAS) is primarily believed to occur via seafood consumption, with specific Perfluoroalkyl substances (PFAS) levels being linked to fish and shellfish intake [14]. Extensive contamination of the environment has resulted from the use of per- and polyfluoroalkyl substances (PFASs) in industrial and consumer products (e.g., paper and food packaging, nonstick products, chrome plating, aqueous film forming foam [AFFF], textiles) and their unique hydrophobic and lipophobic properties. Long-chain perfluoroalkyl carboxylates (PFCAs; i.e., perfluorooctanoate [PFOA] and longer) and long-chain perfluoroalkyl sulfonates (PFSAs; i.e., perfluorohexane sulfonate [PFHxS] and longer) are characterized as extremely persistent, bioaccumulative, and toxic. The short-chain PFCAs and PFSAs bioaccumulate less in animals, and yet they bioaccumulate and readily translocate in plants. However, their occurrence, behavior, fate, and toxicity are poorly characterized [15].

Human activities are increasingly and fundamentally impacting the Earth's surface, particularly soils, Vegetables, fish and water, which function as the interface between the biosphere, hydrosphere, atmosphere, and lithosphere. These soils are currently experiencing physical, chemical, and biological stressors that are linked to anthropogenic activities. Chemical pollution is a significant category of these influences, which is widely recognized as a global change factor.

The perfluoroalkyl and polyfluoroalkyl substances (PFAS) are a highly diverse family of chemicals that are of concern. Soil is a primary sink for persistent organic chemicals in the environment. There are numerous pathways for perfluoroalkyl substances (PFAS) entering the soil environment, including fluoride factory emissions, sludge application, the degradation of aqueous film-forming foam, and landfills as direct sources, and atmospheric deposition and runoff as non-point sources. Perfluoroalkyl substances (PFAS) have been widely detected in soils at varying concentrations [16]. The bioaccumulation factors about perfluoroalkyl acids (PFAAs), a subset of per- and polyfluoroalkyl substances (PFASs) encompassing perfluorocarboxylic acids (PFCAs) and perfluorosulfonic acids (PFSAs), from both water and soil into plants signify the accumulation of PFASs in above-ground plant tissues. This, in turn, emphasizes the criticality of evaluating potential human health hazards associated with the consumption of food crops [16, 17]. Uptake studies conducted on agricultural plants have revealed that short-chain PFAAs exhibit a greater tendency to accumulate in plants than their long-chain counterparts, and PFCAs tend to accumulate more than polyfluoroalkyl substances (PFASs). The transfer of contaminants into food crops is influenced by various factors such as PFAS concentrations and mixtures, plant species and compartment(s), soil organic carbon, and other soil characteristics, as well as the growth conditions [17].

Soil is an essential reservoir in which per- and polyfluoroalkyl substances (PFASs) are exchanged among different matrices. The soil environment can be exposed to polyfluoroalkyl substances (PFASs) through various routes such as atmospheric dry and wet deposition, agricultural utilization of sludge, and irrigation with sewage. After exposure, polyfluoroalkyl substances (PFASs) have the potential to either adsorb onto soil particles or dissolve in the soil solution. Understanding the sorption behaviors of polyfluoroalkyl substances (PFASs) in the soil environment is critical as they determine the concentrations of PFASs available to plants. The sorption capacities of polyfluoroalkyl substances (PFASs) are primarily associated with soil organic matter (SOM), although correlations with minerals and pH have also been documented [18].

Therefore, the aim of this research work is to assess perfluoroalkyl substances in fish, soil, vegetables, and water from Bade and Jakusko LGAs of Yobe State, Nigeria.

Materials and Methods

Study Locations

Two different study locations, which have the highest cases of CKD, were considered in Yobe State, Nigeria, the locations are six wards from Bade and Jakusko Local Governments. Six wards, three from Bade and three from Jakusko local Governments for this study (Dagona, Katuzu and Usur from Bade, while Amshi, Gwayo and Dachia from Jakusko).

Sample Pre-Treatment/Digestion

The samples was allowed to dry (fish and vegetable) using hot oven (Model 30GC lab oven) at 105^{O}C and then ground into fine powder by using a porcelain mortar and pestle.

Microwave Digestion Method

In this method, Microwave digester (MASTER 40) was use. The sample was prepared in the digestion tube by adding appropriate digestion reagent (HNO_3, H_2O_2) before being transferred into the digester. For the convenience of analysis, appropriate digestion solvent system were selected, the nature and applicable scope of some acids/alkalis is very important and are provided as follows for reference (According to manufacturer's operation manual).

Concentration of Perfluoroalkyl Substances (PFAS)

The presence and concentration of perfluoroalkyl substances **(**PFAS) compounds in the collected samples were determined using Gas chromatography-mass spectrometry (GC-MS/MS) at Analytical Laboratory of Yobe State University, Damaturu, Yobe State.

GC-MS Analysis of Liquid Sample (using Agilent Technologies GC 7890B with MSD 5977A)

Sample Preparation:

The sample was prepared for GC-MS by dissolving it in hexane to create a solution suitable for injection. A 10 mL of hexane was added to 0.5 mL of the sample, ensuring the concentration was appropriate for detection without overloading the column. The solution was then transferred into a 15 mL centrifuge tube and Votex was mixed for 1 minute before centrifuging at 3000 rpm for 5 minutes. The supernatant (1 mL) was collected and transferred into a GC-MS vial and sealed with a cap to prevent evaporation.

Instrument Setup and Parameters:

GC-MS Model: Agilent Technologies GC 7890B, coupled with MSD 5977A.

Column Type: A capillary column, HP-5MS (30 m × 0.25 mm, 0.25 µm film thickness), was used.

Injection Mode: Splitless injection mode was selected for trace-level analysis

Oven Temperature Program:

- **Initial Temperature**: The oven was set to an initial temperature, typically around 70°C, and held for 1 minute

- **Temperature Ramp**: The temperature was then ramped up at a rate of 10°C/min to 270°C.
- **Final Hold**: The final temperature was held for 5 minutes to ensure the complete elution of all compounds.
- **Carrier Gas**: Helium was used as the carrier gas at a constant flow rate of approximately 1 mL/min to ensure optimal separation.

Mass Spectrometer Settings:

Ionization Mode: Electron impact (EI) ionization at 70 eV was used to fragment the sample molecules.

Scan Range: The mass spectrometer was set to scan a mass range typically between 50-700 m/z to capture the relevant mass fragments of the compounds.

Acquisition Mode: Data were acquired in full-scan mode or selective ion monitoring (SIM) mode, depending on the sensitivity requirements and target compounds.

Data Collection and Analysis:
The injected sample passed through the column, where individual Compounds were separated based on their retention times. The mass spectra of eluted compounds were recorded by the MSD 5977A detector. The mass spectra were compared to a reference library to identify the PAH compounds. Quantitative analysis was performed by comparing peak areas to a calibration curve generated with known PAH standards.

Post-Run Analysis: After the analysis, the chromatogram and mass spectra were reviewed to ensure proper separation and identification of Compounds. Each identified PAH was quantified by referencing calibration standards, providing a concentration profile of the Compounds present in the sample.

GC-MS Analysis of Perfluoroalkyl Substances (PFAs)

Sample Preparation, Extraction, and Cleanup

Fish Sample Preparation and Extraction

1. **Homogenization and Weighing**:

   Fish samples were homogenized, and 5 gramme portion was transferred to a polypropylene tube to prevent PFA contamination from glassware [19].

2. **Solvent Extraction Using Methanol**:

   Methanol was added at a ratio of 5:1 (5 mL methanol per gram of fish) to efficiently extract PFAS, as methanol is effective for PFAS solubilization [20]. The sample was shaken, sonicated for 10 minutes, and then centrifuged to separate the supernatant.

3. **Cleanup with Activated Carbon**:

   To remove lipids and other interferences, activated carbon was added to the supernatant, followed by vortexing and filtration. This step helps to purify the extract without adsorbing PFAs [19, 20].

Water Sample Preparation and Extraction

1. **Solid-Phase Extraction (SPE)**:

   For water samples, 500 mL was passed through a pre-conditioned Oasis WAX SPE cartridge, as this resin is highly effective for PFAS retention [21]. The cartridge was washed with 0.1% ammonium hydroxide solution and then eluted with methanol to recover PFAS.

2. **Concentration of Extract**:

   The methanol elute was concentrated to 1 mL under a gentle nitrogen stream and transferred to a GC-MS vial for analysis.

Vegetable Sample Preparation and Extraction

1. **Homogenization and Methanol Extraction**:

   Vegetable samples were homogenized, and a sample mass of 10 grams was extracted with methanol. The sample was vortexed and sonicated, then centrifuged to collect the methanol extract [20, 21].

2. **Activated Carbon Cleanup**:

As with the fish sample, activated carbon was added to remove pigments and other matrix.

Results and Discussion

Table 1: Concentration of perfluoroalkyl Substances (PFAS) in the different samples of water from Bade Local Government

Wards	PFOA	PFHxS	PFOS	PFNA	PFDA	PFUnA	PFDoA
Dagona	0.10	-	-	-	-	-	-
Katuzu	0.02	-	-	-	-	-	-
Usur	0.42	-	-	-	-	-	-
EPA	**0.01 to 0.1 µg/kg**						

Table 2: Concentration of perfluoroalkyl substances (PFAS) in the different samples of water from Jakusko Local Government

Wards	PFOA	PFHxS	PFOS	PFNA	PFDA	PFUnA	PFDoA
Dachia	0.20	-	-	-	-	-	-
Gwayo	0.10	-	-	-	-	-	-
Katama	0.02	-	-	-	-	-	-
EPA	**0.01 to 0.1 µg/kg**						

Table 3: Concentration of perfluoroalkyl Substances in the different samples of vegetables from Bade Local Government

Wards	Samples	PFOA	PFHxS	PFOS	PFNA	PFDA	PFUnA	PFDoA
Dagona	Tomato	-	-	-	-	-	-	-
	Pepper	-	-	-	-	-	-	-
	Onion	-	-	-	-	-	-	-
Katuzu	Tomato	-	-	-	-	-	-	-
	Pepper	-	-	-	-	-	-	-
	Onion	-	-	-	-	-	-	-
Usur	Tomato	-	-	-	-	-	-	-
	Pepper	-	-	-	-	-	-	-
	Onion	-	-	-	-	-	-	-
	EPA	**0.01 to 0.1 µg/g**						

Table 4: Concentration of perfluoroalkyl substances in the different samples of vegetables from Jakusko Local Government

Wards	Samples	PFOA	PFHxS	PFOS	PFNA	PFDA	PFUnA	PFDoA
Dachia	Tomato	-	-	-	-	-	-	-
	Pepper	-	-	-	-	-	-	-
	Onion	-	-	-	-	-	-	-
Gwayo	Tomato	-	-	-	-	-	-	-
	Pepper	-	-	-	-	-	-	-
	Onion	-	-	-	-	-	-	-
Katamma	Tomato	-	-	-	-	-	-	-
	Pepper	-	-	-	-	-	-	-
	Onion	-	-	-	-	-	-	-
	EPA	**0.01 to 0.1 µg/kg**						

Table 5: Concentration of perfluoroalkyl Substances (PFAS) in fish from Bade

Wards	PFOA	PFHxS	PFOS	PFNA	PFDA	PFUnA	PFDoA
Dagona	0.13	-	0.08	-	-	-	-
Katuzu	-	-	-	-	-	-	-
Usur	-	-	-	-	-	-	-
EPA	**0.01 to 0.1 µg/kg**						

Table 6: Concentration of perfluoroalkyl Substances (PFAS) in fish from Jakusko

Wards	PFOA	PFHxS	PFOS	PFNA	PFDA	PFUnA	PFDoA
Dachia	-	-	-	-	-	-	-
Katamma	0.02	-	0.08	-	-	-	-
Gwayo	0.14	-	0.22	-	-	-	-
EPA	**0.01 to 0.1 µg/kg**						

Table 7: Concentration of perfluoroalkyl Substances (PFAS) in soil from Bade

Wards	PFOA	PFHxS	PFOS	PFNA	PFDA	PFUnA	PFDoA
Dagona	-	-	-	-	-	-	-
Katuzu	-	-	-	-	-	-	-
Usur	0.11	-	-	-	-	-	-
EPA	**0.01 to 0.1 µg/kg**						

Table 8: Shows the concentration of perfluoroalkyl Substances (PFAS) IN SOIL FROM JAKUSKO

Wards	PFOA	PFHxS	PFOS	PFNA	PFDA	PFUnA	PFDoA
Dachia	0.17	-	-	-	-	-	-
Katamma	0.30	-	-	-	-	-	-
Gwayo	-	-	-	-	-	-	-
EPA	**0.01 to 0.1 µg/g**						

Discussion

The concentrations of various perfluoroalkyl substances (PFAS) detected in water samples from different wards (Dagona, Katuzu, and Usur) in Bade Local Government are shown in Table 1. perfluoroalkyl substances (PFAS) are synthetic chemicals that are persistent in the environment and can have harmful health effects. The perfluoroalkyl substances (PFAS) is detected in all three locations, with the highest concentration in Usur (0.42 µg/l) and the lowest in Katuzu (0.02 µg/l). These levels may indicate varying degrees of contamination among the locations. The only perfluoroalkyl substances (PFAS) detected in the water samples is PFOA, with varying concentrations across the wards, Usur shows the highest concentration of PFOA (0.42 µg/l), followed by Dagona (0.10 µg/l), and Katuzu (0.02 µg/l). No other PFAS (PFHxS, PFOS, PFNA, PFDA, PFUnA, or PFDoA) were detected in the water samples from any of the wards.

The concentrations of Perfluoroalkyl Substances (PFAS) in Water: was detected in water samples, with concentrations ranging from 0.02 to 0.42 µg/L as given in Table 2. However, there is no significant detection of other PFAS compounds like PFOS or PFHxS. Even low levels of PFOA in drinking water are concerning due to its potential links to liver damage, thyroid disease, and developmental issues. Perfluoroalkyl Substances (PFAS) in Vegetables levels were found to be absence in all the vegetable samples Table 3 and 4. The presence of Perfluorooctanoic Acid (PFOA), even at low levels, is of concern due to its persistence in the environment and potential health effects. Further monitoring and management efforts may be needed to assess and mitigate the risks associated with Perfluorooctanoic Acid (PFOA) in these areas.

Table 5 shows the concentrations of various perfluoroalkyl substances (PFAS) detected in fish samples from different wards (Dagona, Katuzu, Usur, Dachia, Katamma, and Gwayo) in the Bade Emirate. The detected perfluoroalkyl substances (PFAS) include Perfluorooctanoic Acid (PFOA), perfluorooctanesulfonic Acid (PFOS), and PFDoA. The presence of perfluorooctanoic Acid (PFOA) in fish indicates contamination, with the highest concentration found in Gwayo (0.14 µg/l). Fish from Katamma show the lowest detectable concentration (0.02 µg/l). This variation may be due to differences in exposure levels among the wards. Perfluorooctanesulfonic Acid (PFOS), another persistent and toxic perfluoroalkyl substances (PFAS) is detected in Dagona, Katamma, and Gwayo. Gwayo has the highest concentration (0.22 µg/l), suggesting a higher level of perfluorooctanesulfonic Acid (PFOS), and exposure in fish from this ward. The only detected perfluoroalkyl substances (PFAS) in fish samples are Perfluorooctanoic Acid (PFOA) and perfluorooctanesulfonic Acid (PFOS):

- **PFOA**: Detected in Dagona, Katamma, and Gwayo, with the highest concentration in Gwayo (0.14 µg/l).
- **PFOS**: Detected in Dagona, Katamma, and Gwayo, with the highest concentration in Gwayo (0.22 µg/l).

  The detection of perfluorooctanoic Acid (PFOA) and perfluorooctanesulfonic Acid (PFOS) in fish suggests contamination and potential exposure risks for humans consuming fish from these locations. The variation in concentrations may be due to differences in pollution sources or environmental conditions across the wards. Table VI, provides information on the concentrations of various perfluoroalkyl substances (PFAS) detected in soil samples from different wards (Dagona, Katuzu, Usur, Dachia, Katamma, and Gwayo) in the Bade Emirate. The detected perfluoroalkyl substances (PFAS) include perfluorooctanoic Acid (PFOA), while other PFAS (PFHxS, PFOS, PFNA, PFDA, PFUnA, and PFDoA) were not detected.

The levels are compared against the Environmental Protection Agency (EPA) recommended range for perfluorooctanoic Acid (PFOA) in soil (0.01 to 0.1 µg/kg). The perfluorooctanoic Acid (PFOA) concentrations in Usur (0.11 µg/kg), Dachia (0.17 µg/kg), and Katamma (0.30 µg/kg) all exceed the Environmental Protection Agency (EPA) recommended range of 0.01 to 0.1 µg/kg. Katamma shows the highest concentration (0.30 µg/kg), indicating significant contamination. The presence of perfluorooctanoic Acid (PFOA) above regulatory limits raises concerns about soil quality and potential health risks.

Conclusion

This study assessed the presence and concentration of perfluoroalkyl substances (PFAS) in water, soil, fish, and vegetables across different wards in Bade and Jakusko Local Governments. The findings are summarized as follows:

In the study of assessment of perfluoroalkyl substances (PFAS) in water sources, Perfluorooctanoic Acid (PFOA) was detected in water samples from both Bade and Jakusko, with concentrations ranging from 0.02 to 0.42 µg/L. Usur had the highest PFOA concentration (0.42 µg/L), exceeding the EPA limit (0.1 µg/L), indicating significant contamination. No other perfluoroalkyl substances (PFAS) compounds (PFHxS, PFOS, PFNA, PFDA, PFUnA, or PFDoA) were detected in water samples.

Further, the assessment of perfluoroalkyl substances (PFAS) in vegetables indicated that no PFAS compounds were detected in vegetable samples (tomato, pepper, and onion) from any ward in both Bade and Jakusko. This suggests that vegetable contamination through PFAS is minimal or absent in the study areas.

Also, the assessment of perfluoroalkyl substances (PFAS) in fish samples showed contamination with PFOA and Perfluorooctanesulfonic Acid (PFOS). The highest PFOA concentration was recorded in Gwayo (0.14 µg/L), while PFOS levels were also highest in Gwayo (0.22 µg/L). The presence of these substances in fish suggests bioaccumulation and potential health risks for consumers.

The report of the assessment of perfluoroalkyl substances (PFAS) in soil showed that the soil samples from Usur, Dachia, and Katamma had PFOA concentrations exceeding the EPA recommended limit (0.01 to 0.1 µg/kg). Katamma recorded the highest contamination level (0.30 µg/kg). No other PFAS compounds were detected in the soil samples.

The findings indicate varying levels of perfluoroalkyl substances (PFAS) contamination in different environmental matrices. While water and fish samples showed notable contamination, vegetables were free of perfluoroalkyl substances (PFAS). The presence of PFOA in soil and water suggests potential sources of pollution that require further investigation. Continuous monitoring and remediation strategies are necessary to mitigate perfluoroalkyl substances (PFAS) exposure risks in the affected communities.

Recommendations:

- The detection of perfluorooctanoic Acid (PFOA) above the Environmental Protection Agency (EPA) recommended levels in some wards indicates soil and fish contamination and potential environmental risks. Monitoring and remediation strategies should be considered to reduce perfluorooctanoic Acid (PFOA) levels and minimize exposure risks in these areas.
- Educating the local communities about the sources and risks of perfluoroalkyl substances (PFAS) contamination can help minimize exposure through behavioral and agricultural practices.
- Regulatory authorities should enforce strict regulations to limit industrial activities and products contributing to perfluoroalkyl substances (PFAS) contamination, especially in agricultural areas.
- There should be a developed and implement strategies to reduce perfluoroalkyl substances (PFAS) levels in the environment, such as improved water treatment technologies and soil remediation techniques.
- Further research are needed to explore the long-term effects of perfluoroalkyl substances (PFAS) exposure on human health and the environment, particularly in relation to chronic kidney disease (CKD) cases observed in the area.

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References

1. United States Environmental Protection Agency. (USEPA) (2020). Perfluorooctanoic Acid (PFOA) and Fluorinated Telomers. https://www.epa.gov/pfas accessed on 25/09/2023.

2. Li, F., Guo, C., Yu, D., Guo, Y., Yang, Y., Li, Z., & Wei, S., (2019). Distribution characteristics and solution predictors of perfluoroalkyl substances in soil and dust in China: Insights into their potential sources. Environmental Pollution (245 953-961).

3. Field, J. A., Gundersen, M. T., Martin, J. W., Lake, J. L., McCarthy, A. O., Connor, S., Roberts, S. C., (2021) Per- and Polyfluoroalkyl Substances (PFAS) in Soil: A Review of Current Research and Future Directions. Environmental Science & Technology 55(7) 4065-4080.

4. Gomis, M. I., Vestergren, R., & Cousins, I. T., (2020). Human exposure to per-and polyfluoroalkyl substances (PFAS) via house dust: Exposure levels and relative importance of PFAS compounds. Environment International 134 105267.

5. Wang, Y., Zhang, Y., Liu, J., Zhang, H., Li, J., Wang, T., Zhang, Q., Wang, X., Wang, R., Jiang, G., & Wang, P., (2019). *Determination of Perfluoroalkyl Acids in Different Tissues*. *2018*. https://typeset.io/papers/determination-of-

perfluoroalkyl-acids-in-different-tissues-2itseu9sns

6. Gomis, M., Vestergren, R., Borg, D., & Cousins, I., (2017). *Assessing Human Health Risks from Per- and Polyfluoroalkyl Substances (PFASs): Understanding Environmental Contamination, Exposure and Risk*. *7*(June), 69–75. https://doi.org/10.1016/j.cotox.2017.03.006.

7. Zhang, T., Sun, H., Chen, Y., Kelly, B., Tang, C., Chen, G., & Zhu, L. (2016). Occurrence and transport of perfluoroalkyl substances (PFASs) in the soil–crop system near a mega fluorochemical industrial park China. Science of the Total Environment (569-570 1314-1321).

8. Field, J. A., Gundersen, M. T., Martin, J. W., Lake, J. L., McCarthy, A. O., Connor, S., Roberts, S. C., (2021) Per- and Polyfluoroalkyl Substances (PFAS) in Soil: A Review of Current Research and Future Directions. Environmental Science & Technology 55(7) 4065-4080.

9. Weber, A. K., (2018). Perfluoroalkyl Substances in Soil: A Critical Review of Their Occurrence and Implications for Land Management. Environmental Science & Technology 52(19 11081-11094).

10. Swati, S. C., Amar, S. R., & Muhammad, I. (2021). Physiological Analysis and Contamination of Heavy Metal Contents in Vegetables and Fruits Irrigated with Wastewater. *Journal of Environmental Analytical Chemistry, 8*(3), 64

11. Wang, Y., Zhang, Y., Liu, J., Zhang, H., Li, J., Wang, T., Zhang, Q., Wang, X., Wang, R., Jiang, G., & Wang, P., (2018). *Determination of Perfluoroalkyl in Different Tissues*. *2018*. https://typeset.io/papers/determination-of-perfluoroalkyl-acids-in-different-tissues-2itseu9sns

12. Shoemaker, J. A., Gilliland, J., DePinto, J. V., & Giesy, J. P., (2009). *Perfluoroalkyl Substances in U.S. Market Basket Fish and Wildlife: Exposure Sources, Bioaccumulation, and Human Health Risks*. *43*(11), 4167–4173. https://doi.org/10.1021/es803183r.

13. Weihe, P., Dietz, R., Grandjean, P., Loganathan, B., & Marsch, G., (2017). *Perfluoroalkyl substances (PFASs) in food and water from Faroe Islands, 2017*. *25*(10), 9699–9700. https://doi.org/10.1007/s11356-017-8688-9.

14. Domingo, J. L., Bocio, A., Falcó, G., & Llobet, J. M., (2008). *Perfluoroalkyl Substances and Fish Consumption*. *42*(5), 1371–1377. https://doi.org/10.1021/es7025128. Accessed on 25/09/2023.

15. Brown, J. B., Conder, J. M., Arblaster, J. A., & Higgins, C. P. (2020). *Assessing Human Health Risks from Per- and Polyfluoroalkyl Substance (PFAS)-Impacted Vegetable Consumption: A Tiered Modeling Approach*. 5(54), 15202−15214.

16. Xu, B., Yang, G., Lehmann, A., Riedel, S., & Rillig, M. C. (2022). Effects of perfluoroalkyl and polyfluoroalkyl substances (PFAS) on soil structure and function. *Soil Ecology Letters*, *5*(1), 108-117.

17. Mei, W., Sun, H., Song, M., Jiang, L., Li, Y., Lu, W., Zhang, G. (2021). Per- and polyfluoroalkyl substances (PFASs) in the soil-plant system: Sorption, root uptake, and translocation. *Environ Int*, *156*, 106642. doi:10.1016.

18. Müller, C. E., Eriksson, U., Kärrman, A., & van Bavel, B**.** (2022). Analysis of Per- and Polyfluoroalkyl Substances in Water Using Solid-Phase Extraction and Liquid

Chromatography–Tandem Mass Spectrometry. *Journal of Chromatography A, 1632*, 461658.

19. Anderson, R. H., Long, G. C., Porter, R. C., & Anderson, J. K. (2020). Occurrence of Select Perfluoroalkyl Substances at U.S. Air Force Aqueous Film-Forming Foam Release Sites Other than Fire-Training Areas: Field-Validation of Critical Contamination Pathways. *Science of the Total Environment, 761*, 144297.

20. Houde, M., Martin, J. W., Letcher, R. J., Solomon, K. R., & Muir, D. C. G. (2011). Biological Monitoring of Polyfluoroalkyl Substances: A Review. *Environmental Science & Technology, 45*(21), 9453–9464

21. Tsai H. J Hearn L & Field J. A. (2017). Occurrence of Per Fluoroalkyl Substances (PFASs) and Pattern of Variation in Soil and Vegetation near a Fire Training Area at Sydney Airport Australia. Environmental Pollution 223 (301-308).