Food and Agriculture Organization of the United Nations

GLOBAL SYMPOSIUM on SOILS and WATER

02-05 October, 2023

Soil and water: a source of life

LINKING EMERGING CHEMICALS IN SOIL TO WATER CONTAMINATION: The Specific case of the ‘Forever Chemicals’ - PFAS

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Project Lead, PFAS *In Situ Immobilisation in Soil and Groundwater*

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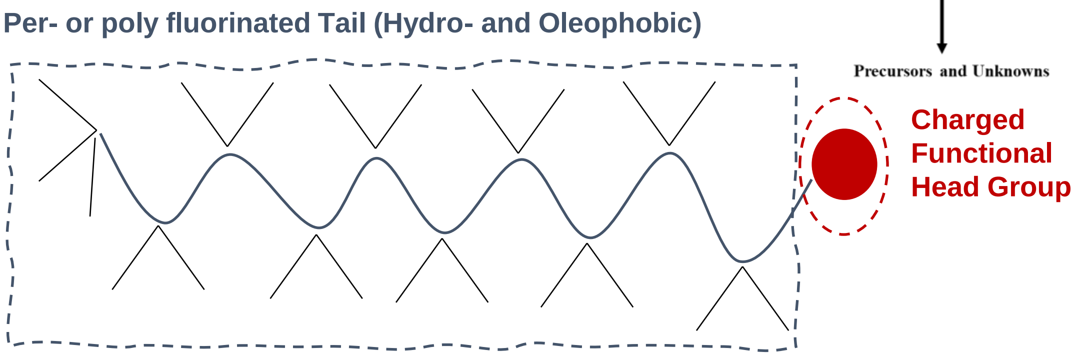
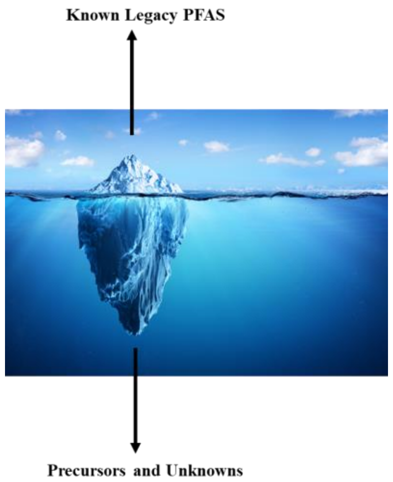
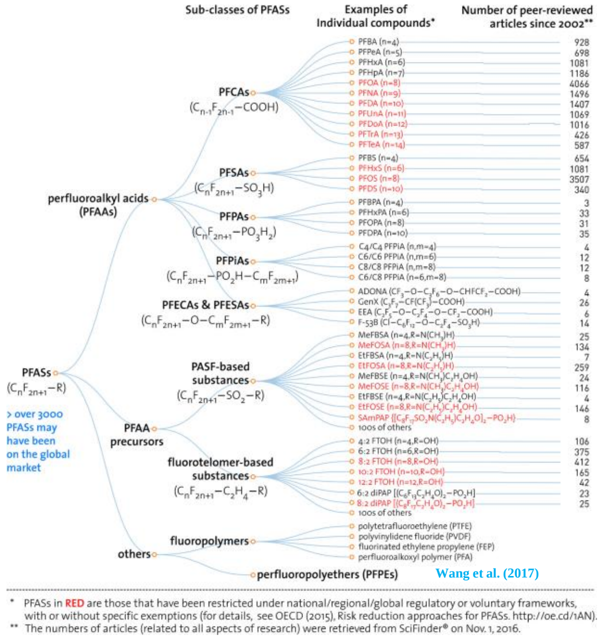
PFAS Chemistry and Properties

- > 1000 compounds
- Lipid and water repellent
- Persistent, Stable – C-F Bond
- Ionic state (anion, cation, zwitterion)
- Different composition, sizes, structure, and functions
- Widely used, ubiquitous

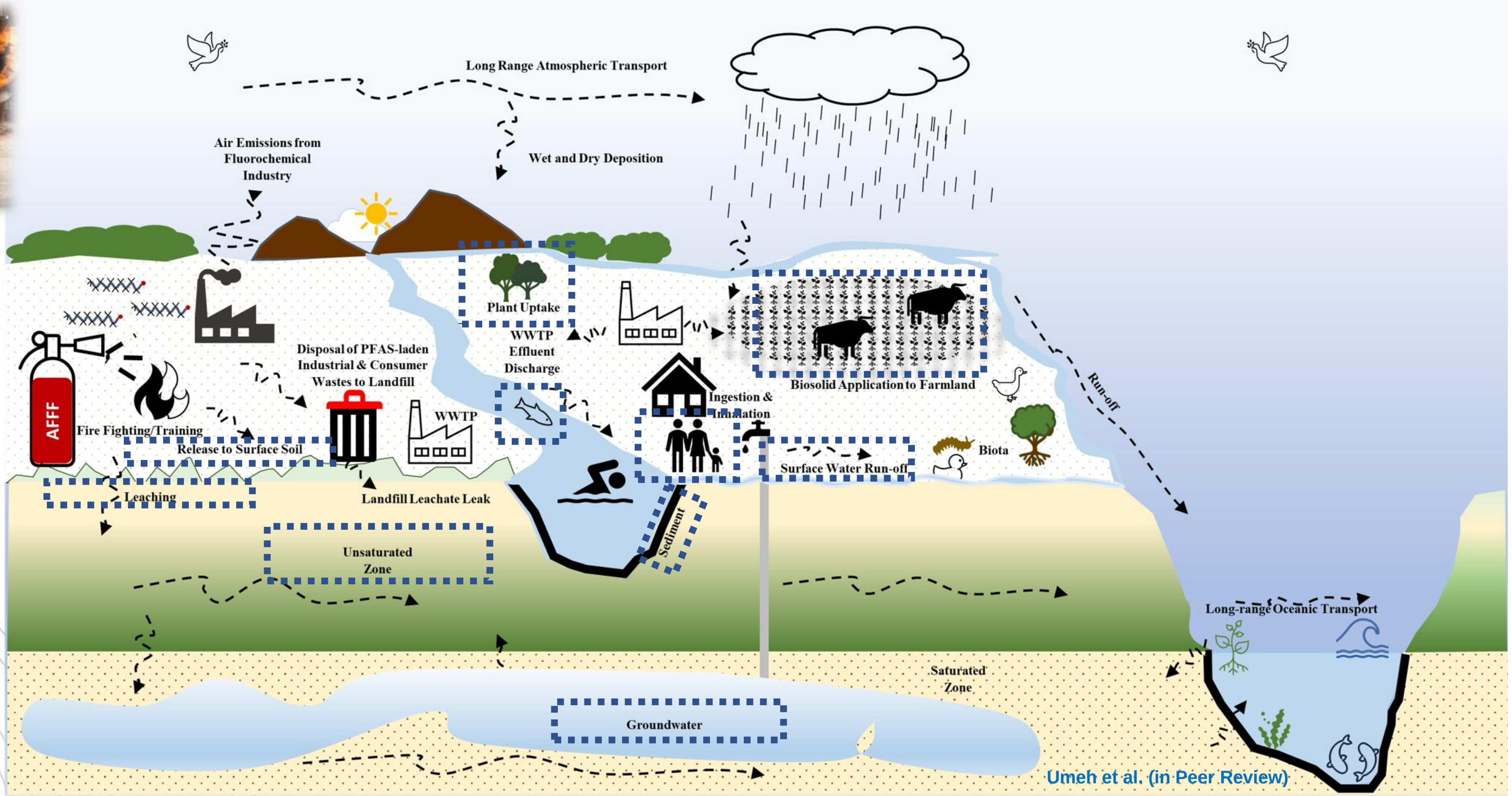






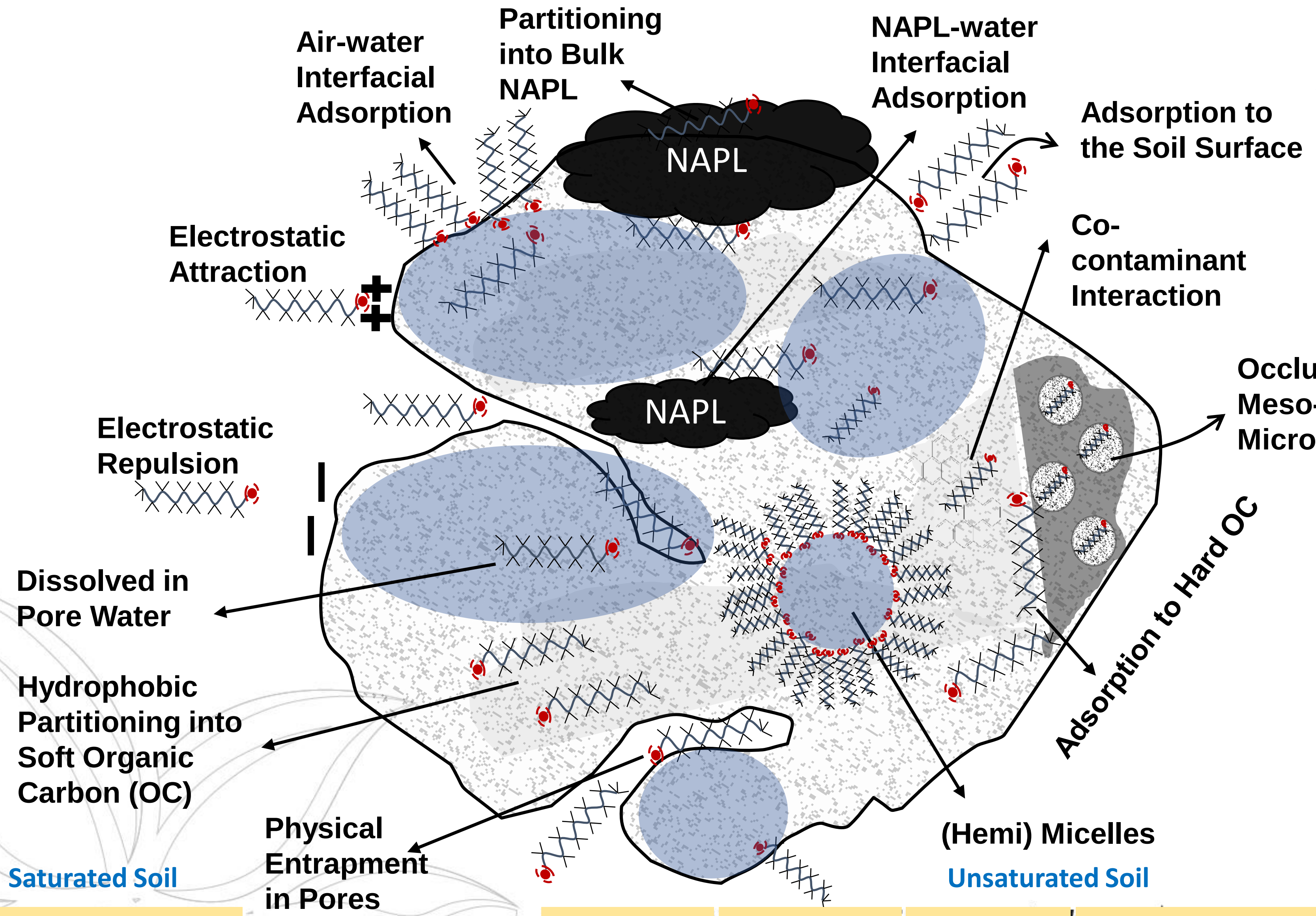
PFAS Fate in the Environment

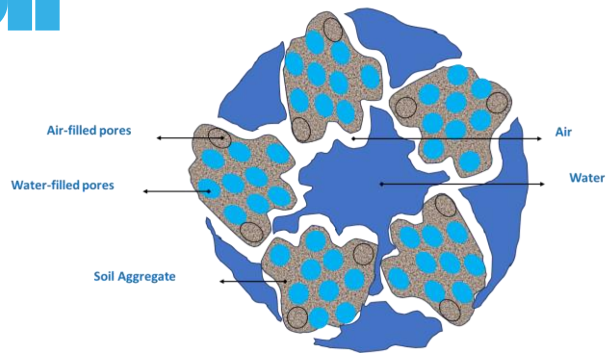
- ❑ AFFF has been widely used for fire-fighting by the military and municipal fire departments
- ❑ Complex mixture: fluorocarbon and hydrocarbon surfactants, solvents
- ❑ "Limited knowledge on the complete constituent and chemistry of AFFF



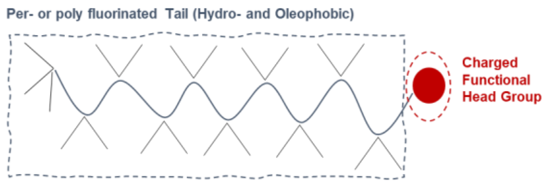
- ✓ Occurrence, nature and Extent
- ✓ Leaching and Surface Transport
- ✓ Subsurface Transport
- ✓ Exposure and Risk Assessment
- ✓ Risk Management

PFAS Retention Mechanisms in Soil





Umeh et al. (unpublished)



Saturated Soil

$$R = 1 + K_d * \frac{\rho_b}{\theta_w}$$

Solid Phase

Unsaturated Soil

$$K_{aw} * \frac{A_{aw}}{\theta_w} \quad K_{nw} * \frac{A_{nw}}{\theta_w} \quad K_{an} * \frac{A_{an}}{\theta_w} \quad H * \frac{\theta_a}{\theta_w} + K_n * \frac{\theta_n}{\theta_w}$$

AWI | NAPL-Water | NAPL-Air | Air | NAPL

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Typical AFFF-contaminated Site

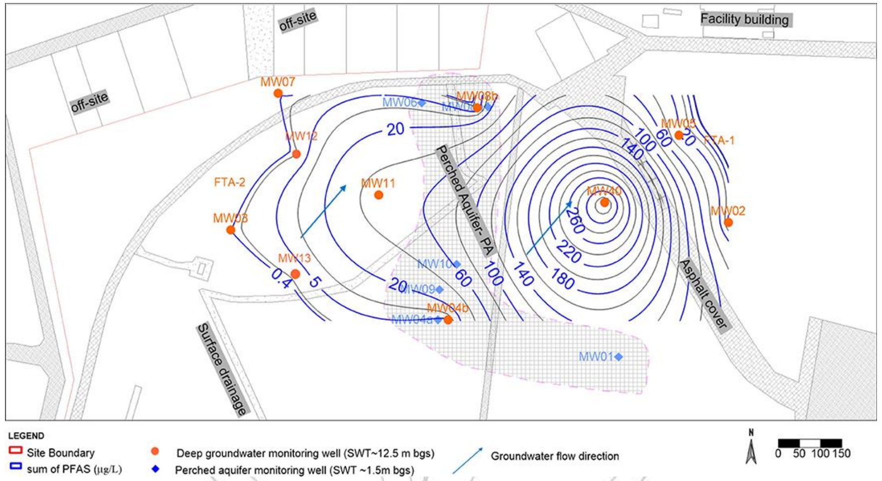
frontiers in Water

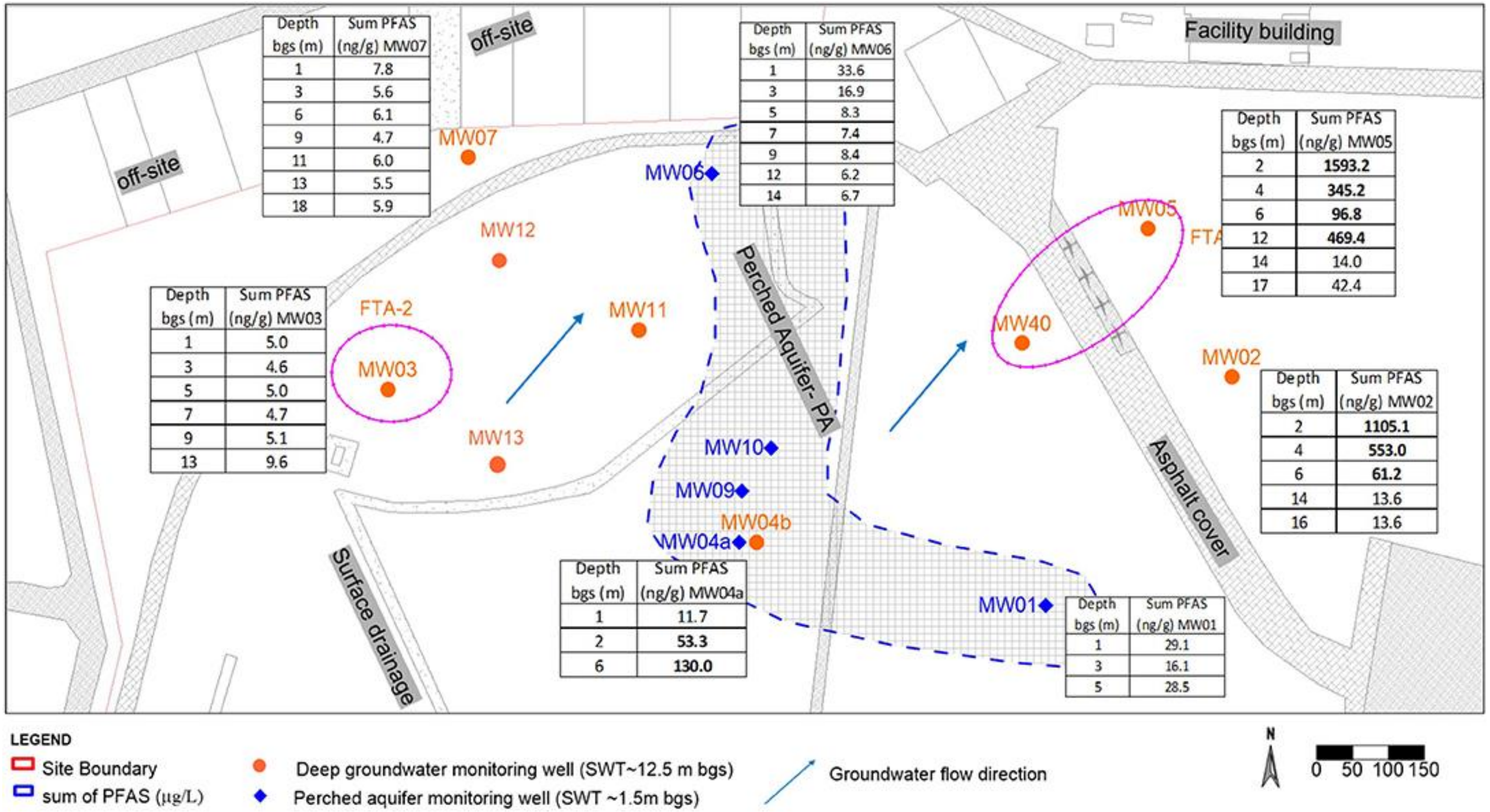
ORIGINAL RESEARCH
published: 23 December 2020
doi: 10.3389/frwa.2020.597810

Check for updates

Separation and Lithological Mapping of PFAS Mixtures in the Vadose Zone at a Contaminated Site

Dawit N. Bekele[1,2], Yanju Liu[1,2], Mark Donaghey[2], Anthony Umeh[1,2], Chamila S. V. Arachchige[1], Sreenivasulu Chadalavada[1,2] and Ravi Naidu[1,2]**





Bekele,….., Umeh et al. 2020

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Soil Properties Influence PFAS Retention

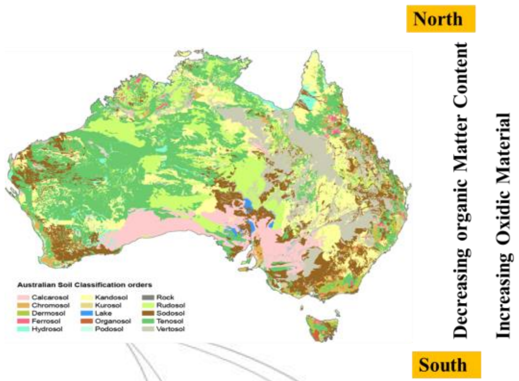
Environmental Science & Technology
pubs.acs.org/est
Article

Sorption of PFOS in 114 Well-Characterized Tropical and Temperate Soils: Application of Multivariate and Artificial Neural Network Analyses

Anthony C. Umeh,* Ravi Naidu,* Sonia Shilpi, Emmanuel B. Boateng, Aminur Rahman, Ian T. Cousins, Sreenivasulu Chadalavada, Dane Lamb, and Mark Bowman

Cite This: https://dx.doi.org/10.1021/acs.est.0c07202 Read Online

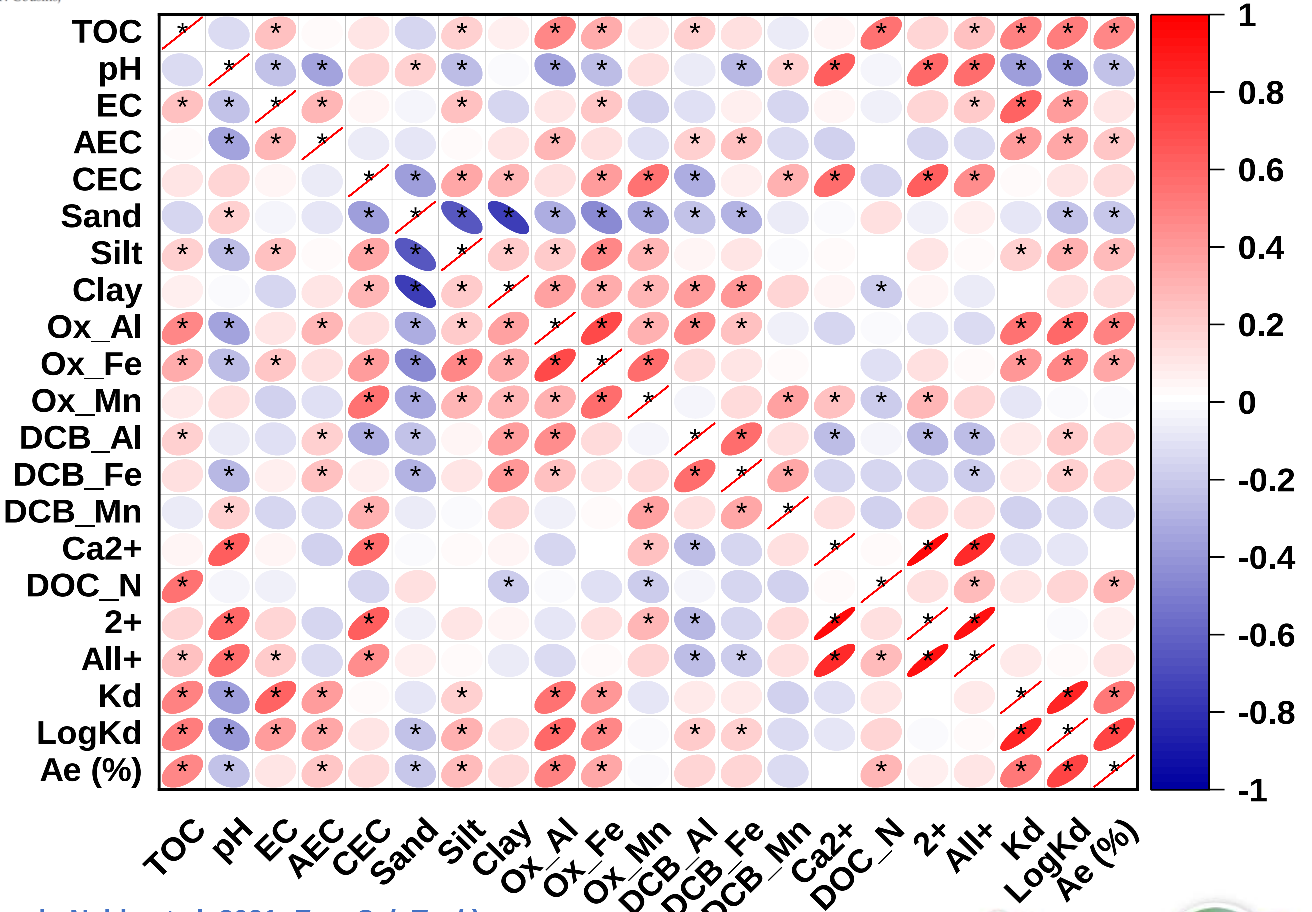
Adapted from Naidu et al. 2020



Heterogeneity

- Soil properties
- Organic Matter
- Clay mineralogy
- Salinity
- Hydrogeology

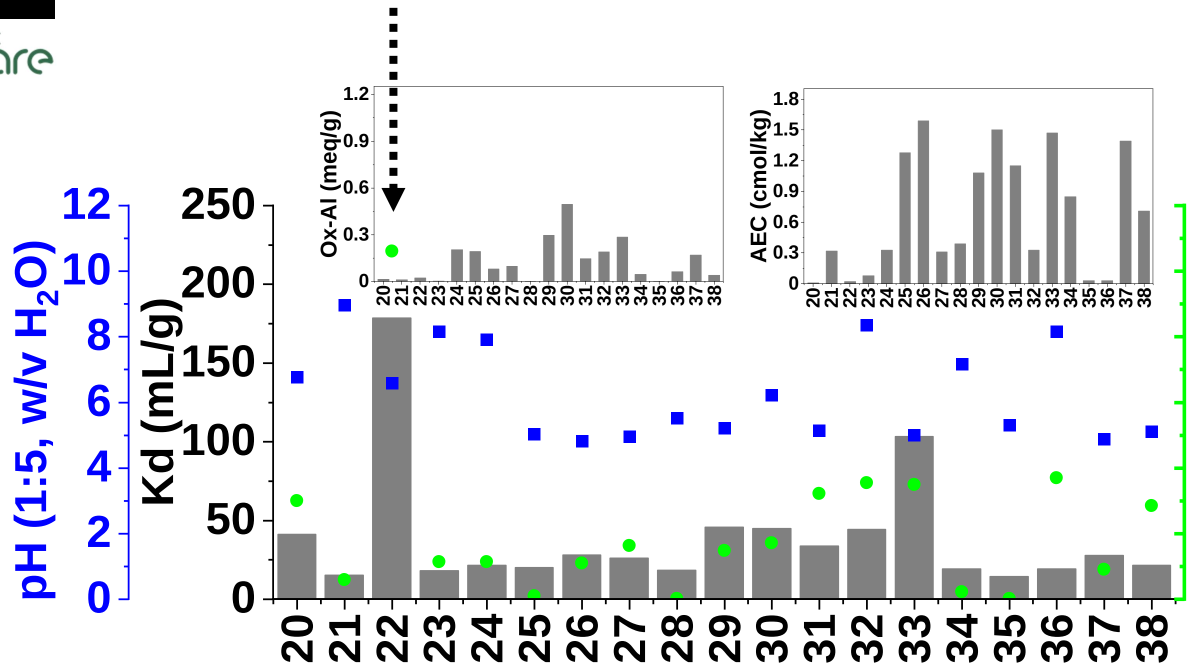
- Soil from over 40 sites in Australia and Fiji
- Australia:
  - Queensland
  - New south Wales
  - Victoria
  - South Australia
- Fiji:
  - Highly weathered, low activity clay minerals, variable charged
  - Collected from uncultivated and cultivated lands

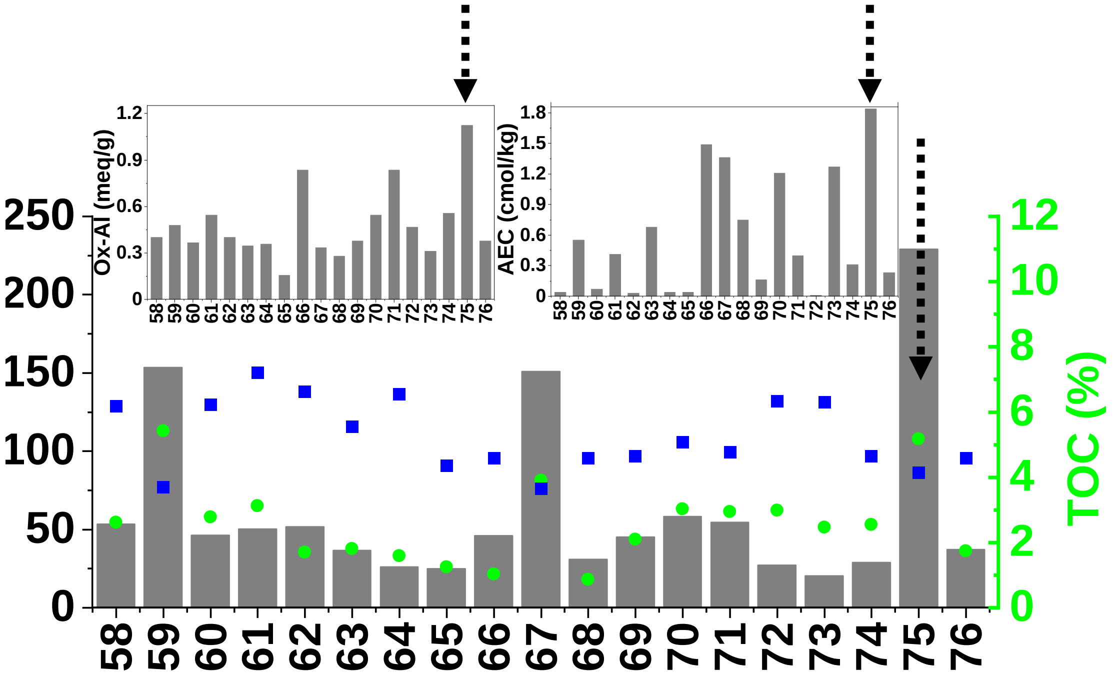


(Umeh, Naidu et al. 2021, *Env. Sci. Tech*)

Soil Organic Carbon and Surface Chemical Properties Influence PFAS Retention in Soils

Soil Properties Influence PFAS Retention



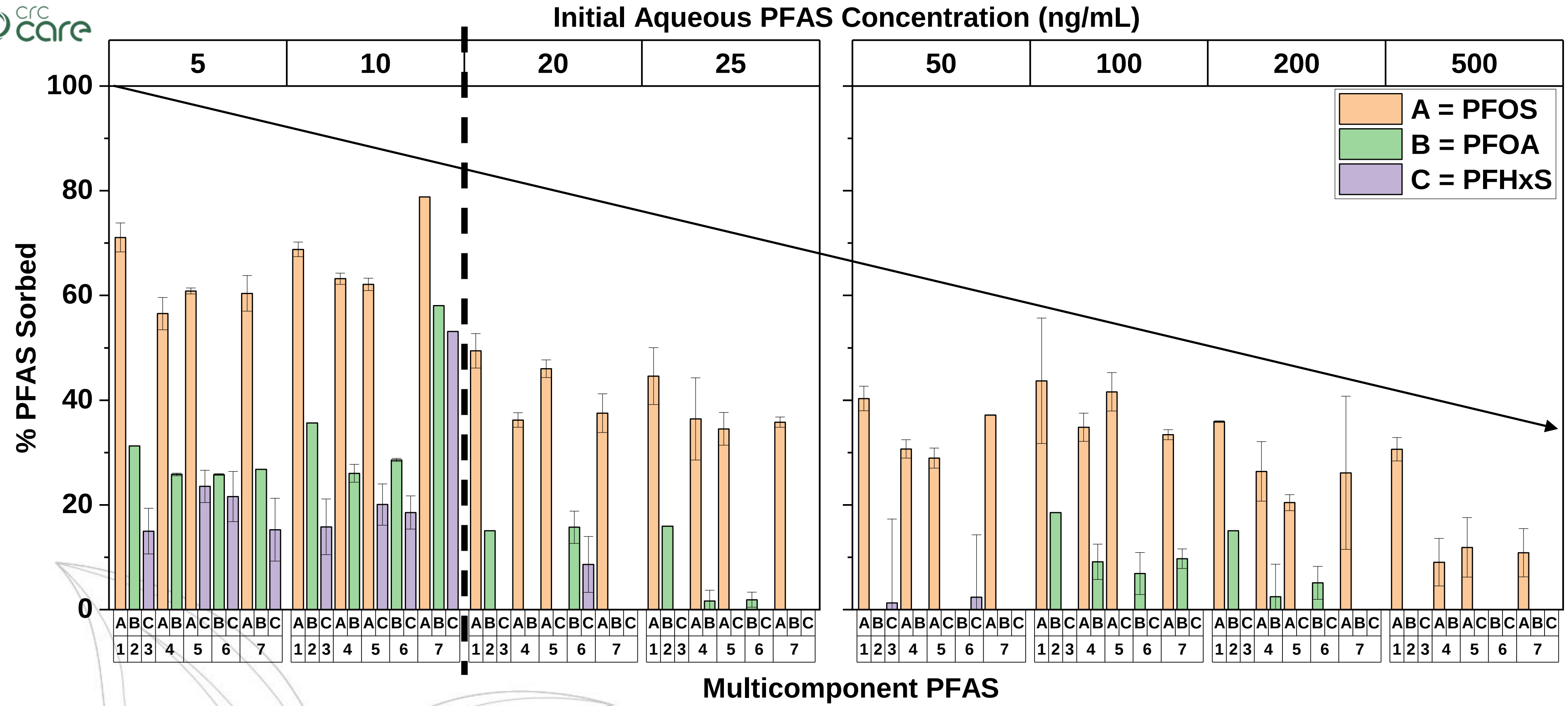


Key Points

- **PFOS sorption range from 36.5− 95.3% (median: 69.3 in soils)**
- **<u>Nonlinear</u> sorption isotherms**
- **Soil Organic Carbon (TOC) alone explained only 35% of the variations in K_d.**
- **Key influencing soil properties include:**
  - **TOC, AEC, Oxalate-extractable Al & Fe oxides, pH and Silt content of soils**
  - **A sole K_{OC} approach is error-prone**

(Umeh, Naidu et al. 2021, *Env. Sci. Tech*)

Mixture Effects on PFAS Retention



Legend

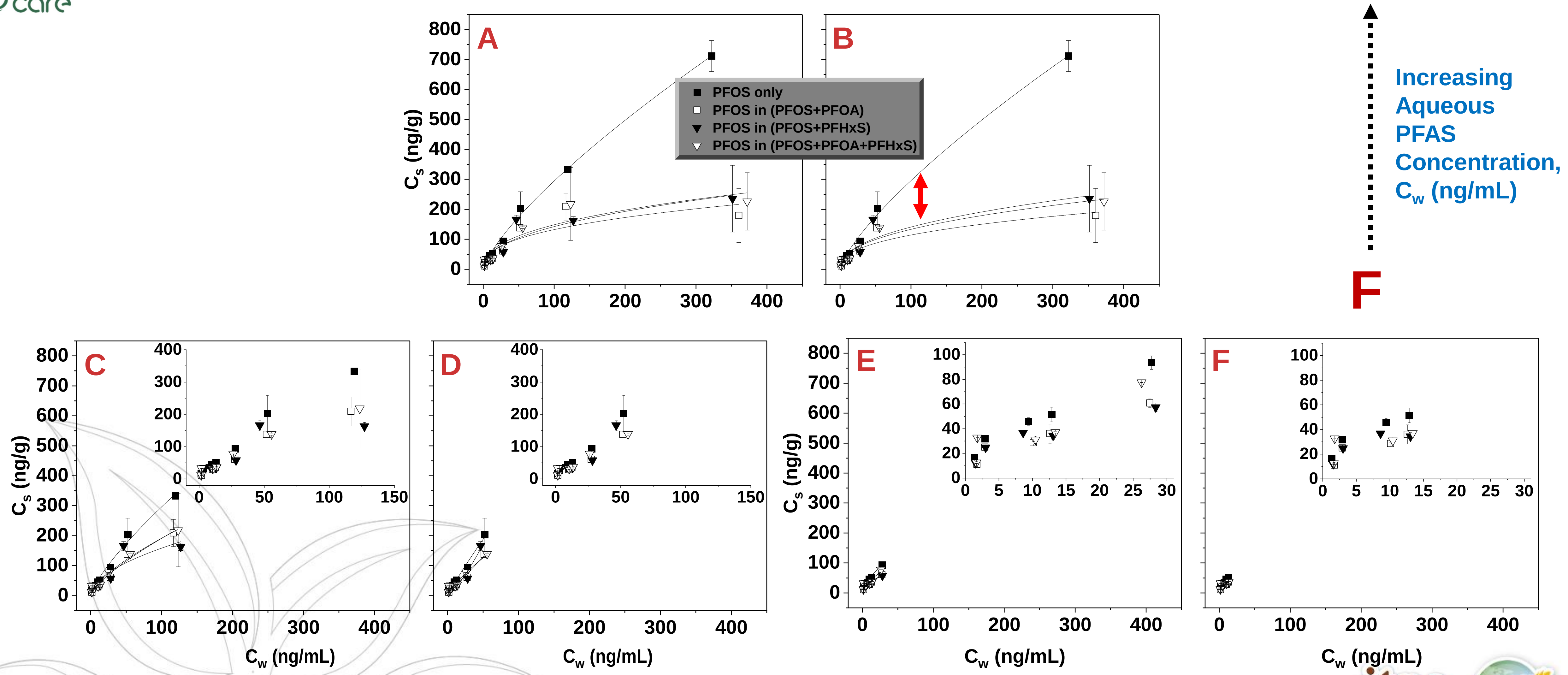
- 1 = A = PFOS
- 2 = B = PFOA
- 3 = C = PFHxS
- 4 = A+B: Ab, aB
- 5 = A+C: Ac, aC
- 6 = B+C: Bc, bC
- 7 = ABC: Abc, aBc, abC

Umeh et al. (in Peer Review)

KEY POINTS:

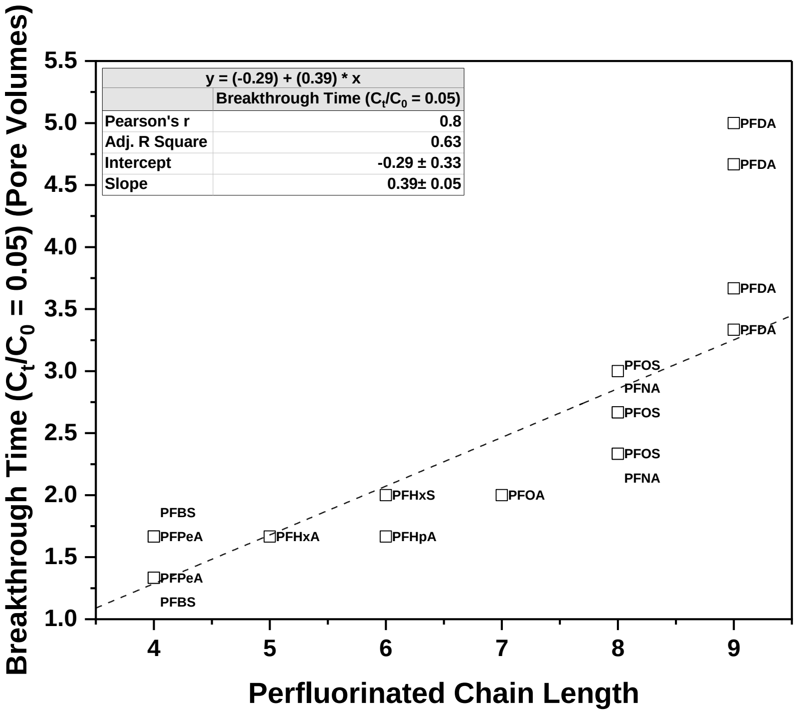
- Sorption followed PFOS > PFOA > PFHxS
- Generally decreasing % sorption as initial aqueous phase PFAS concentration increases
- % PFAS sorbed decreased in the presence of mixtures, especially for PFOA and PFHxS
- The influence of mixture interactions (competitive effects) on leachable and sorbed PFAS will be significant in saturated soils around source zone areas where PFAS concentrations are elevated, especially for PFOA and PFHxS.

Mixture Effects on PFAS Retention



Umeh et al. (in Peer Review)

PFAS Retention/Release in Soil Dependent on PFAS Properties



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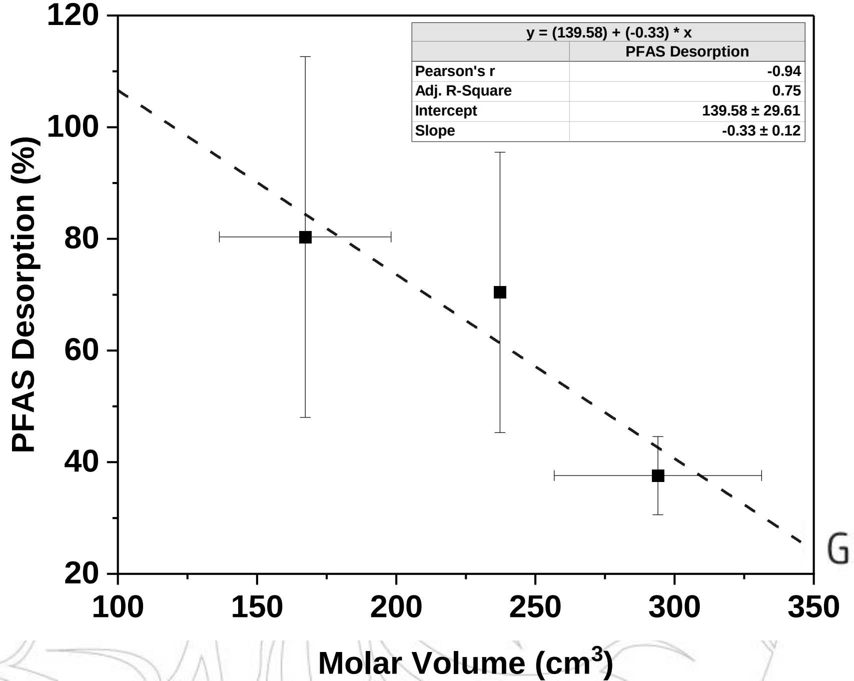

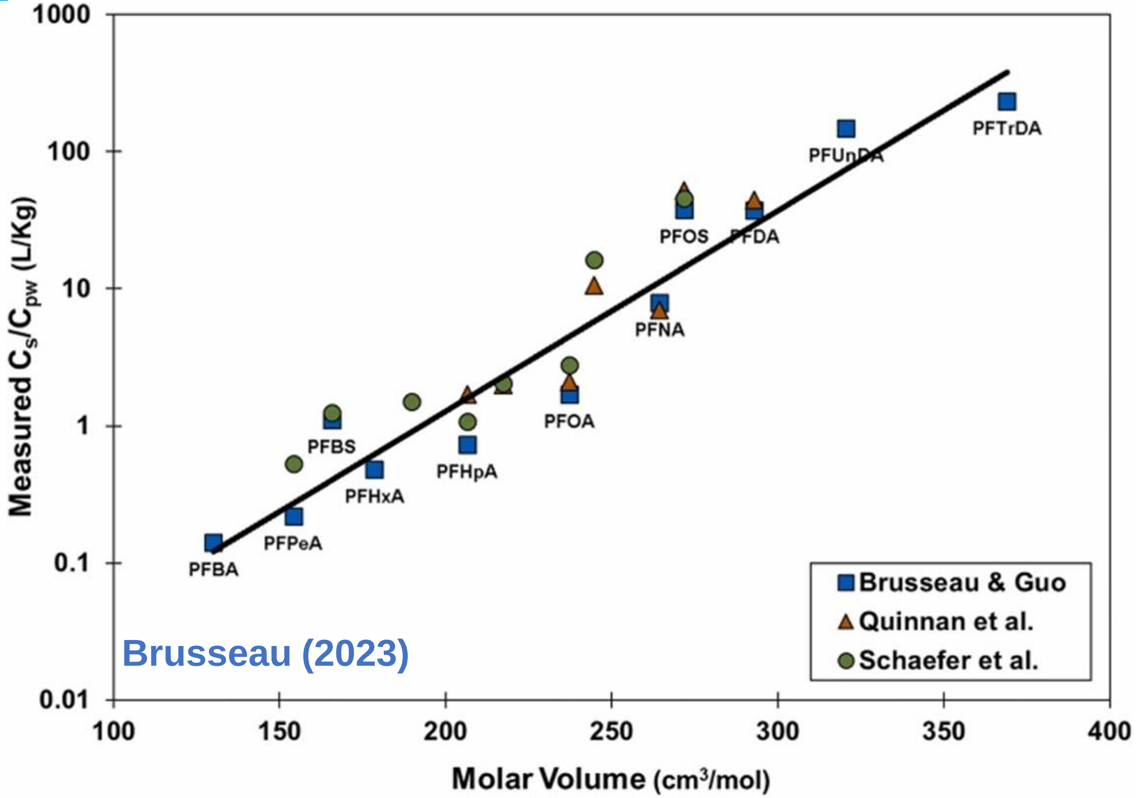

‘Forever Chemicals’ – PFAS – in Drinking Water

Environment International 178 (2023) 108033

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Full length article

Per- and polyfluoroalkyl substances (PFAS) in United States tapwater: Comparison of underserved private-well and public-supply exposures and associated health implications

Kelly L. Smalling[a,*], Kristin M. Romanok[a], Paul M. Bradley[b], Mathew C. Morriss[c], James L. Gray[d], Leslie K. Kanagy[d], Stephanie E. Gordon[e], Brianna M. Williams[a], Sara E. Breitmeyer[a], Daniel K. Jones[c], Laura A. DeCicco[f], Collin A. Eagles-Smith[g], Tyler Wagner[h]

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Public-supply
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Sources
Health effect

ABSTRACT

Drinking-water quality is a rising concern in the United States (US), emphasizing the need to broadly assess exposures and potential health effects at the point-of-use. Drinking-water exposures to per- and poly-fluoroalkyl substances (PFAS) are a national concern, however, there is limited information on PFAS in residential tapwater at the point-of-use, especially from private-wells. We conducted a national reconnaissance to compare human PFAS exposures in unregulated private-well and regulated public-supply tapwater. Tapwater from 716 locations (269 private-wells; 447 public supply) across the US was collected during 2016–2021 including three locations where temporal sampling was conducted. Concentrations of PFAS were assessed by three laboratories and compared with land-use and potential-source metrics to explore drivers of contamination. The number of individual PFAS observed ranged from 1 to 9 (median: 2) with corresponding cumulative concentrations (sum of detected PFAS) ranging from 0.348 to 346 ng/L. Seventeen PFAS were observed at least once with PFBS, PFHxS and PFOA observed most frequently in approximately 15% of the samples. Across the US, PFAS profiles and estimated median cumulative concentrations were similar among private wells and public-supply tapwater. We estimate that at least one PFAS could be detected in about 45% of US drinking-water samples. These detection probabilities varied spatially with limited temporal variation in concentrations/numbers of PFAS detected. Benchmark screening approaches indicated potential human exposure risk was dominated by PFOA and PFOS, when detected. Potential source and land-use information was related to cumulative PFAS concentrations, and the number of PFAS detected; however, corresponding relations with specific PFAS were limited likely due to low detection frequencies and higher detection limits. Information generated supports the need for further assessments of cumulative health risks of PFAS as a class and in combination with other co-occurring contaminants, particularly in unmonitored private-wells where information is limited or not available.

1. Introduction

The quality and sustainability of drinking-water are rising concerns in the United States (US) because of population-driven water demands, increasing contamination of drinking-water resources, and a growing understanding of potential human-health consequences associated with

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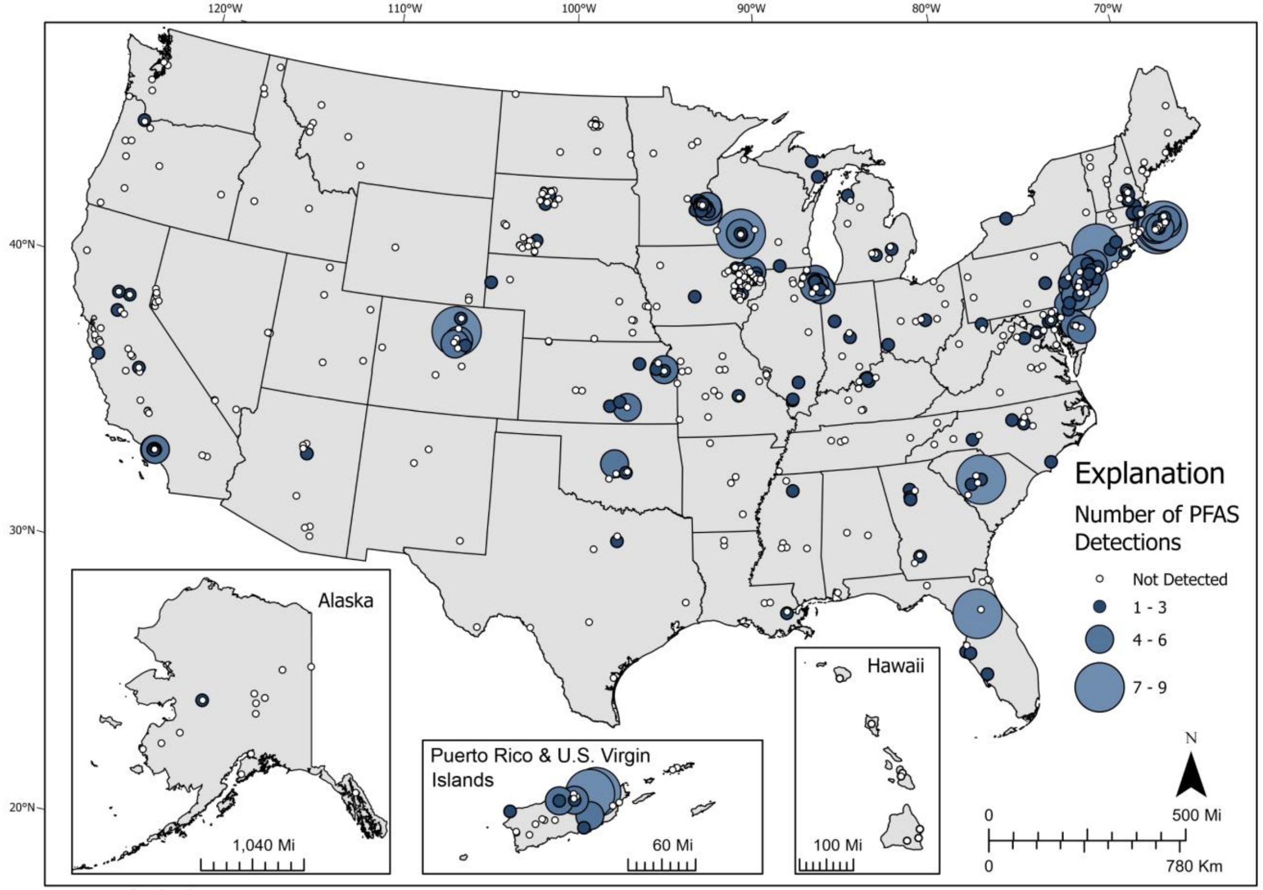
CNN health | Life, But Better | Fitness | Food | Sleep | Mindfulness | Relationships

Nearly half of the tap water in the US is contaminated with ‘forever chemicals,’ government study finds

Per- and Polyfluoroalkyl Substances (PFAS) in Select U.S. Tapwater Locations



USGS science for a changing world

Map represents all sampling locations not the only locations where PFAS was observed.

Smalling et al. (2023)

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Management of PFAS-contaminated Soil and Water

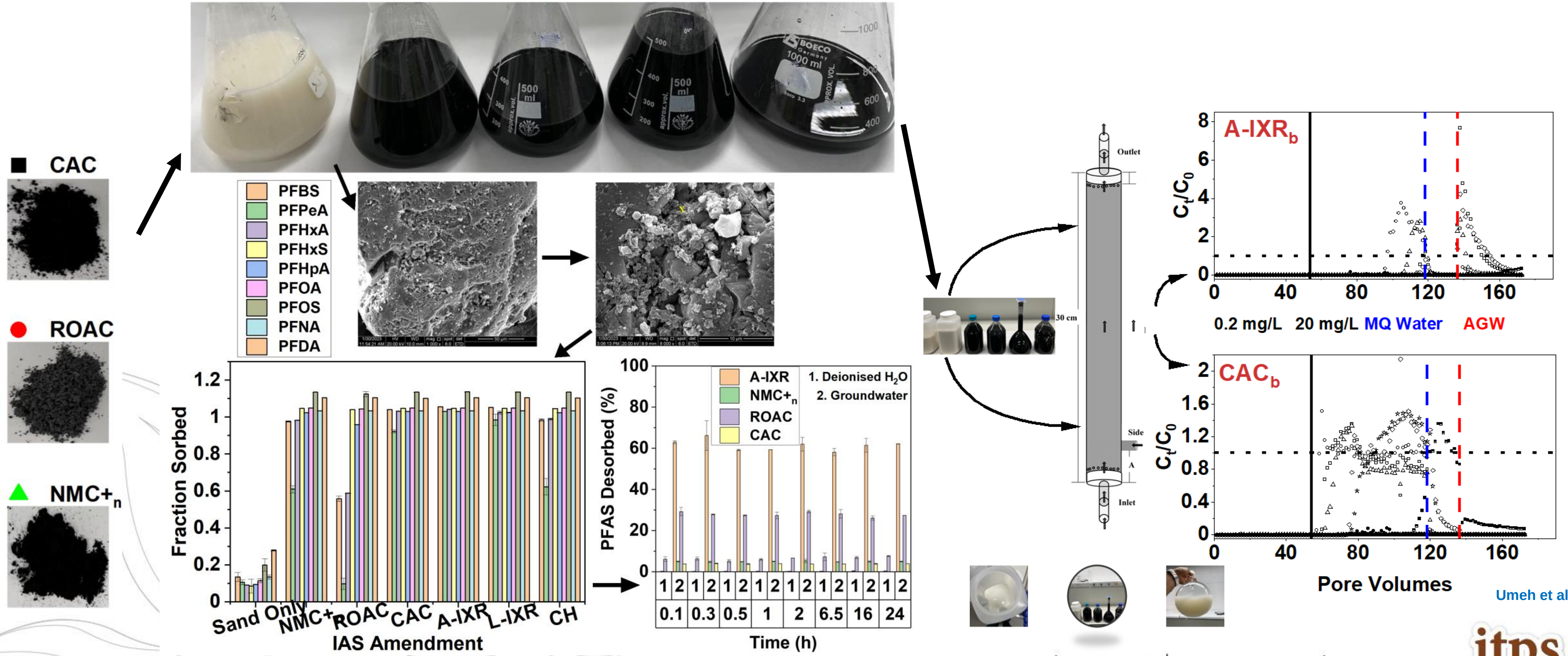
ISOLATE
SEPARATE

AND/OR

STABILIZE
IMMOBILISE

AND/OR

DISPOSE
DESTROY
PARTIAL or FULL



Umeh et al. (in Peer Review)

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Groundwater pH Influences PFAS Retention

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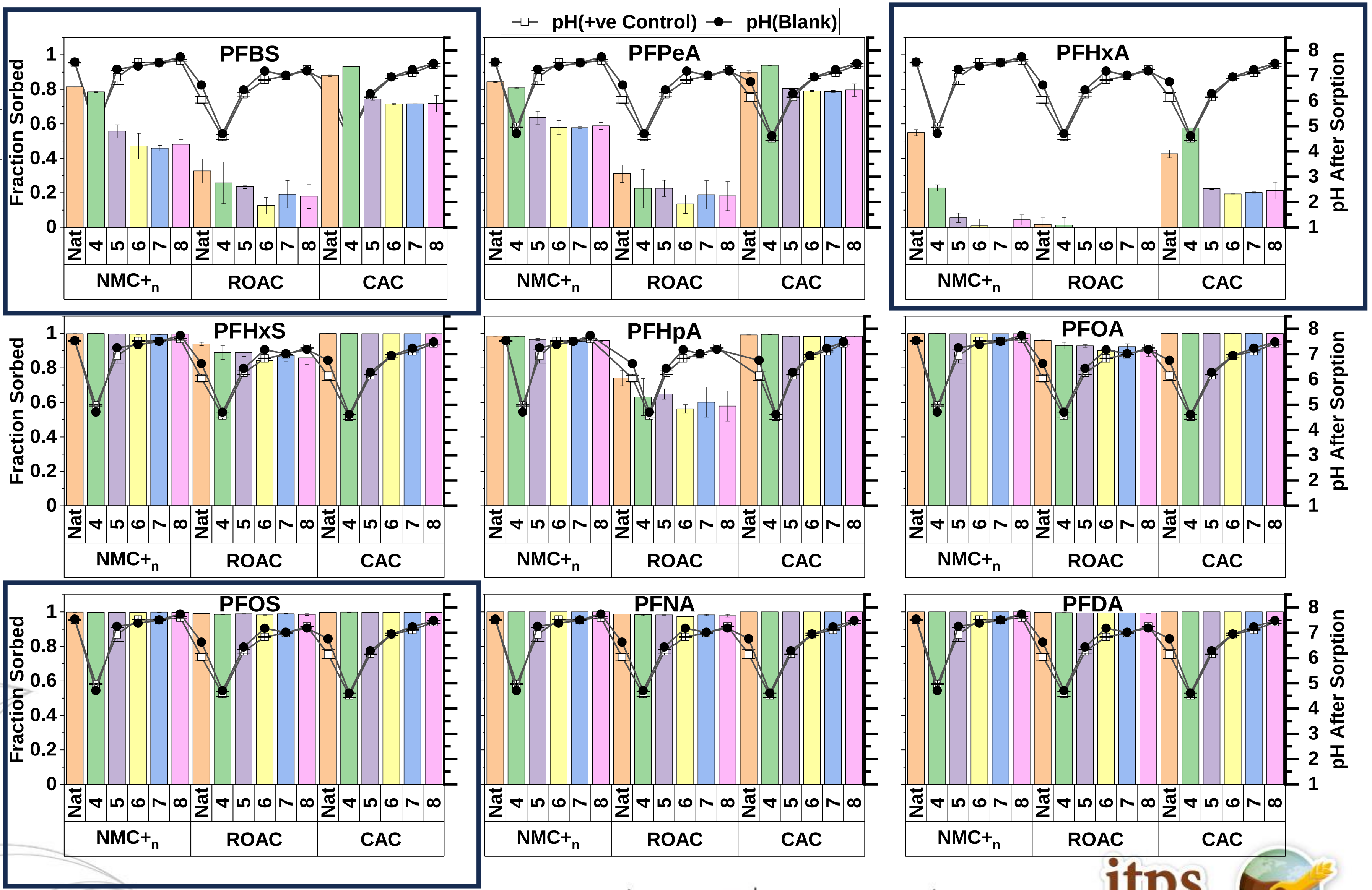
Science of The Total Environment
Available online 24 August 2023, 166568
In Press, Journal Pre-proof What's this?

Multicomponent PFAS sorption and desorption in common commercial adsorbents: Kinetics, isotherm, adsorbent dose, pH, and index ion and ionic strength effects

Anthony C. Umeh [a] [b], Masud Hassan [a], Maureen Egbuatu [a], Zijun Zeng [a], Md. Al Amin [a], Chamila Samarasinghe [a] [b], Ravi Naidu [a] [b]



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Ionic Composition of Groundwater Influences PFAS Retention

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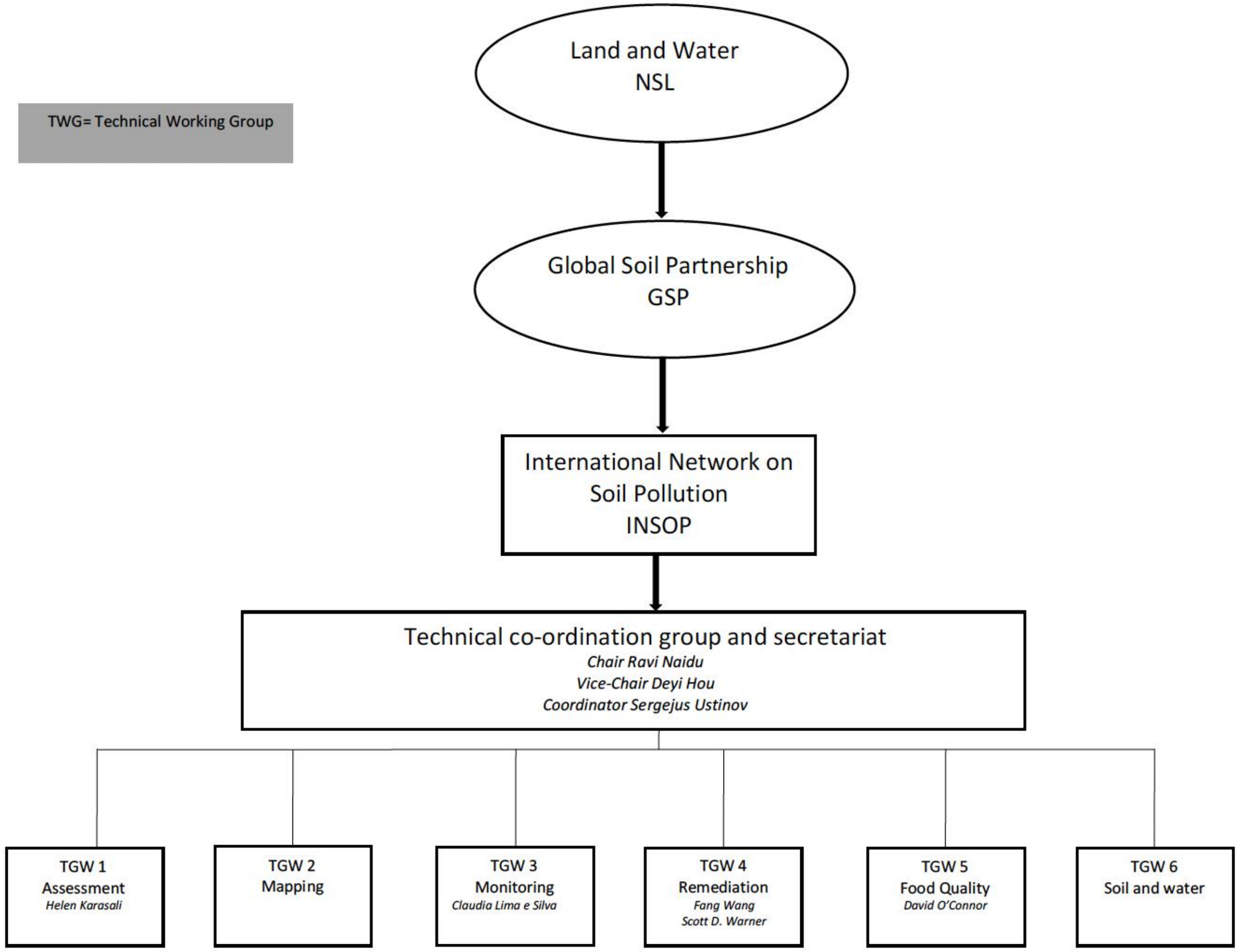
International Network on Soil Pollution (INSOP)



INSOP WA approach: Soil and Water

Soil and water Working Group scope

International Network on Soil Pollution (INSOP)

Channelling collective action towards Zero Pollution

The Network

The International Network on Soil Pollution (INSOP) has the overall aim of stopping soil pollution and achieve the global goal of zero pollution. To this end, INSOP works to improve knowledge on the full cycle of soil pollution, from assessment to remediation, as well as on the effect on environmental and human health and the provision of soil ecosystem functions and services. It also aims to strengthen technical capacities and legislative frameworks for the prevention of soil pollution, and promotes the exchange of experiences and technologies for the sustainable management and remediation of polluted soils.

The scope

Most contaminants in aquatic ecosystems come from anthropogenic land-based sources. Therefore, soil management can have an enormous impact on water quality, including pollution. The overall objective of the soil and water Working Group (WG) is to raise awareness on the effects different contaminants of terrestrial origin could have on marine and aquatic ecosystems. Contaminants of concern such as plastic pollution of which 80% entering the ocean has a land origin, eutrophication and other land-based contaminants reaching the fresh and marine environments will be discussed and knowledge gaps addressed.

In collaboration with the assessment WG, the WG will create a knowledge exchange platform on the environmental and associated ecotoxicological risks on soil and water pollution. In addition, joint experts from the monitoring and remediation WG will work together to create a stronger regulation and policies which will protect and reduce the soil pollution impact on the aquatic environment.

Other tasks of interests and feasibility will be defined and agreed during the upcoming 'brainstorm' meeting which will be held in autumn 2022.

- Objective:
  - Strengthen knowledge on the environmental and associated ecotoxicological risks, environmental fate and behaviour of soil and water pollutants

CHANNELLING COLLECTIVE ACTION TOWARDS ZERO POLLUTION

INSOP WA approach: Soil and Water

Activity	Deliverable
SOPs for measuring leaching potential of soil pollutants	Globally harmonized SOP protocol for soil pollutants leaching potential
Assessment of soil pollutants prone to leaching and risks they have to groundwater pollution	Report publication and training on leached pollutants and their risks to aquatic health
Identification of indicators relevant to the groundwater assessment affected by soil pollutants	Publication of posters to raise awareness on direct and indirect groundwater pollution indicators
Address and strengthen environmental components of the One Health approach	Preparation of a publication and guidelines that reviews state-of-the-art knowledge of antimicrobial resistance (AMR) to enhance One Health action plan

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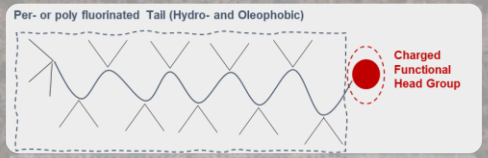
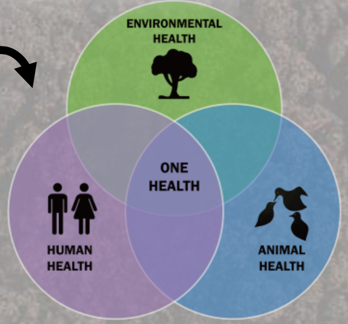
Key Conclusions And Looking Ahead

- **Soil is an important reservoir for emerging chemicals, such as PFAS.**
- **Understanding the fate and behaviour of PFAS in soils is important for preventing extensive water contamination.**
- **The environmental behaviour of PFAS is dependent on physicochemical properties of soil, water, and PFAS.**
- **More research is required focusing on uncommon and short chain PFAS**
- **Need for more investments into research and testing of innovative technologies to cleanup PFAS in soil and water.**
- **Exposure to emerging chemicals, such as PFAS, can adversely impact the actualisation of the UN SDGs, if not effectively and quickly managed.**
- **Need for national, regional, and global cooperation to effectively understand the extent of PFAS contamination in soils and water, and to manage PFAS-contaminated sites, including capacity development in developing countries.**





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- Dr. Md. Aminur Rahman
- Dr. Masud Hassan
- Dr. Chamila Samarasinghe
- Danidu Kudagamage
- Abhishek Sharma

Questions/Comments

"To forget how to tend soils is to forget ourselves"

Mahatma Gandhi

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