Securing Drinking Water Supplies: The Role of Organic Matter on Water Treatability

Second-Year Student Progress Report

Submitted to the Sue White Fund (SWF)

By

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Research Context

Globally, one in four cities is water-stressed, and the projected demand for water in 2050 is set to increase by 55% (Organisation for Economic Co-operation and Development (OECD), 2012). This project considers two different geographical locations of the globe with water resource management issues. In the east of the UK, there is an acute water supply-demand balance due to low rainfall and rapid population growth, leading to an expected 35 million litres of water per day (MLD) regional water deficit by 2025. In western Ghana, illegal mining has polluted about 60% of drinking water sources, reducing the quality and quantity of water available for abstraction, treatment, and supply to local inhabitants. Water transfer from water-surplus to water-deficit regions is an increasingly used mechanism to improve the resilience of drinking water supplies. However, limited attention has been paid to how this complex water movement affects water quality and treatability.

Regardless of location, all source waters contain natural organic matter (NOM) that changes temporally and spatially. Therefore, water transfers will inevitably result in water mixtures containing NOM of different characteristics, resulting in different removal potentials by conventional coagulation and sorption processes. If inadequately removed, NOM can react with disinfectants (e.g., chlorine) during the disinfection stage to produce potentially carcinogenic disinfection by-products (DBPs). NOM can also serve as food for bacterial growth, affecting the biostability of water in distribution systems. Therefore, understanding the characteristics of NOM is vital for effectively managing and treating new water resources and blends.

The revision of abstraction licenses is forcing water utilities to use new sources of lower water quality to meet demand, which has increased reliance on surface waters. All surface waters east of the UK and western Ghana regions are from lowland catchments. NOM has been extensively characterised in water resources from upland areas, which has enabled a better link to treatability. For example, UK upland sources have higher proportions of hydrophobic organic matter, which is known to be effectively treated by coagulation processes used in drinking water treatment. In contrast, inputs of recycled wastewater and algal organic matter are more pronounced in lowland areas, making NOM more hydrophilic and less amenable to coagulation. To date, there is limited understanding of the characteristics of NOM in lowland surface waters that control their removal in drinking water treatment processes. Therefore, this project will identify these characteristics and match them with appropriate treatment mechanisms to enable enhanced removal of NOM in the UK and Ghanaian lowland surface waters.

Aims and Objectives

This project aims to determine the features of organic matter in lowland surface waters that control their removal in drinking water treatment processes. This will allow for proactive management of water treatment systems to make more informed decisions on water blending and transfer and future water treatment works (WTWs) operation and treatment process selection. Specific objectives are:

I. To identify and select the most appropriate methods of characterisation for source waters.

II. To characterise and assess the spatial and temporal variability of NOM in the UK and Ghana lowland surface waters.
III. To Understand the mechanisms of treatment processes (coagulation, ion exchange, oxidation, adsorption) and conditions required for effective NOM removal.
IV. To determine the features of NOM that can/can't be removed by different treatment processes and understand the influence of residual NOM on DBP formation.
V. To identify the similarities and differences in NOM in the UK and Ghana lowland surface waters and understand how this might influence water resource management planning, respectively.

Progress to date and future work

This project is part of the EPSRC Centre for Doctoral Training (CDT) called Water Infrastructure and Resilience (WIRe) at Cranfield University. As part of this programme, I completed my first-year introductory semester by taking the Science and Engineering Principles of Water and Wastewater Treatment, Water in Cities and Water Resilience modules. I have also participated in the WIRe Summer Challenges (2022 and 2023), where I exhibited my research as a poster (**Figure 1**). I must complete two additional modules (10 credit hours each) as part of the WIRe CDT. I took my first one on Data Analysis and Interpretation at Newcastle University (November 2023).

I did background reading during the first year to understand the project setting and elements. I focused on identifying appropriate methods for characterising NOM in surface water. The characterisation methods considered included bulk parameters (e.g., UV_{254}, alkalinity, anions, cations, turbidity, dissolved organic carbon (DOC)), XAD resin fractionation to distinguish hydrophobic (HPO), transphilic (TPI) and hydrophilic (HPI) character of the NOM, Liquid chromatography with organic carbon detector (LC-OCD) to fractionate NOM into biopolymers (BP), humic substances (HS), building blocks (BB), low molecular-weight acids (LMWA), low molecular-weight neutrals LMWN) based on their molecular size, zetasizer and autotitrator for charge load and density determination using polydiallyldimethyl ammonium chloride (PDADMAC) as an indicator and fluorescence spectrometer to determine the fluorescence excitation and emission matrix in order to classify NOM into humic-like, fulvic-like and protein-like compounds.

Following the background reading, I developed detailed plans for my first experimental chapter, which aims to understand the selective removal potential of NOM by coagulation and ion exchange (IEX) and to identify the potential synergies between the two that could benefit lowland surface water treatment and operations (workflow presented in **Figure 2**) based on a good assessment of characterisation methods discussed earlier. Training on laboratory equipment was received at Cranfield University (FTIR, TOC analyser, Ion chromatography, Fluorescence spectrometer) and Heriot-Watt University in Edinburgh (XAD resin fractionation, introduction to coagulation jar testing, charge density and molecular weight determination) (**Figure 3**).

In my second year, I conducted bench-scale studies on water samples collected from the Eastern UK according to the workflow presented in (**Figure 4**). All experiments were run in triplicates. This study aimed to investigate the influence of pH, hydrophobicity, and molecular weight to understand better the removal of NOM by IEX and coagulation for high-alkalinity surface water. Preliminary results showed that when coagulation has not been optimised for charge neutralisation, the bulk of organic matter is more amenable to IEX removal (see Table 1 for a summary). These findings were presented at the 8th International Water Association (IWA) Conference on Natural Organic Matter (NOM 8) held on the 3rd - 8th of December 2023 in South Africa (**Figure 5**).

Table 1. Summary of preliminary results

	IEX	**Coagulation**
Dissolved organic carbon (DOC) removal	59 %	At Raw water pH: 8% At optimised pH: 51%
Hydrophobicity	Efficiently removed natural organic matter (NOM) of all hydrophobicity than coagulation	Targeted tarnspilic (TPI) and hydrophobic (HPO) fractions
Molecular weight	~1kDa fractions control DOC removal	
	Better removal and less sensitivity to pH	pH-sensitive

Arrangements have been made with the University of Mines and Technology, Ghana, for an international placement from February 2024 to July 2024. During this period, samples from Ghana will be subjected to coagulation and IEX studies following the workflow presented in **Figures 2 and 4**. We expect that the results will highlight how the characteristics of NOM in water from different geographical locations influence the performance of these two processes.

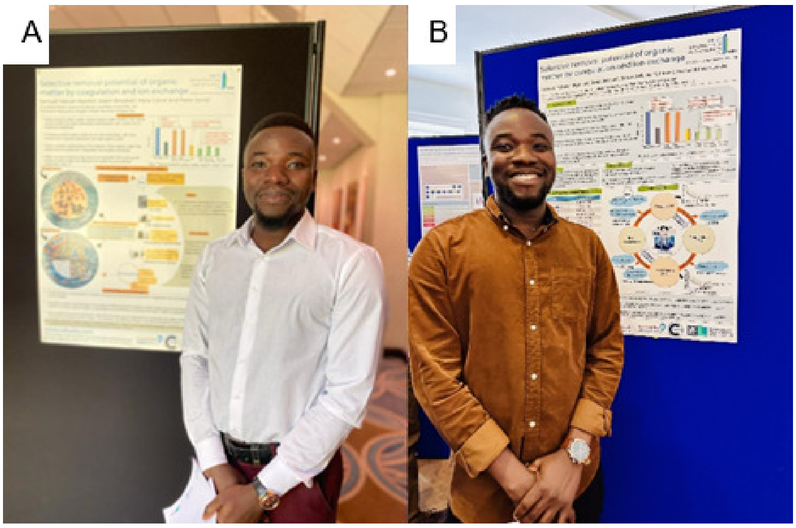

Figure 1. WIRe summer challenge (A) 2022, and (B) 2023

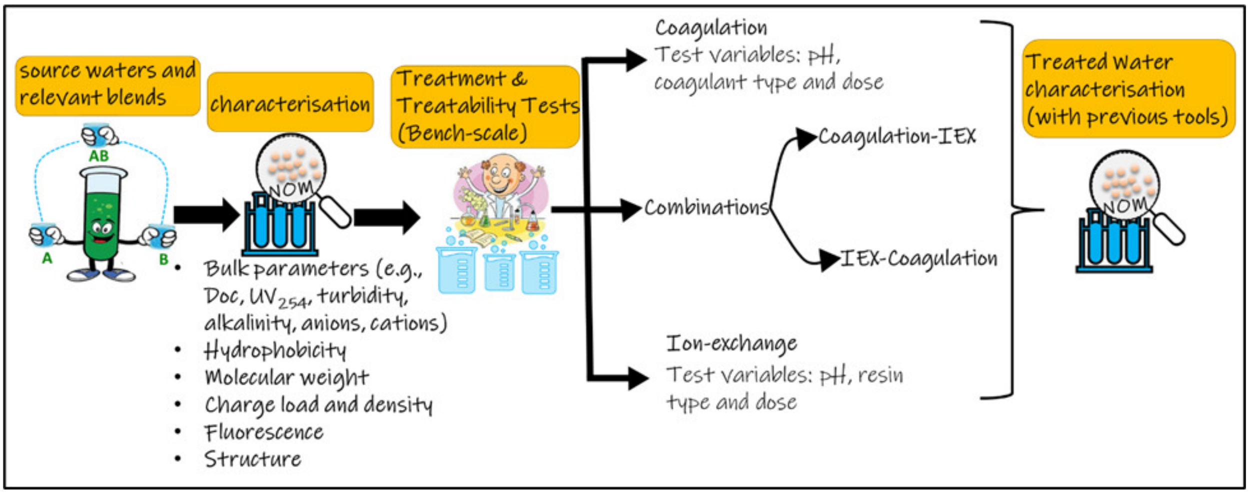

Figure 2. Diagrammatic representation of the workflow for the first experimental chapter

Figure 3. Laboratory training at Cranfield and Heriot-Watt University

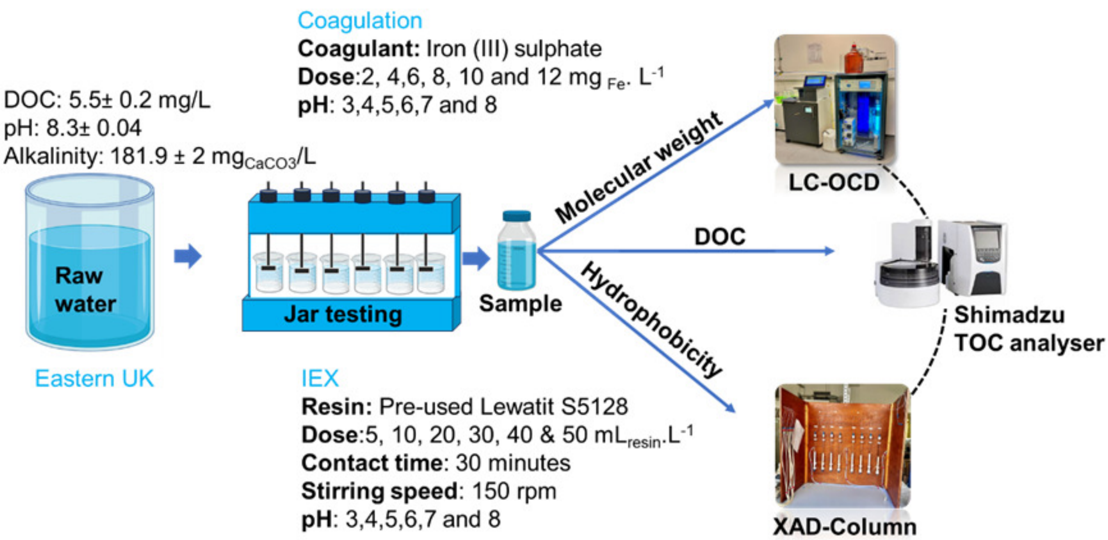

Figure 4. Diagrammatic representation of the workflow for coagulation and ion-exchange

bench-scale experiments

Figure 5. Research work presentation at the IWA NOM8 conference

Anticipated impact of the research project

Overall, the project outputs will provide Anglian Water and the Ghana Water Company Ltd with the necessary tools to manage planned water movements within their active region(s). These tools will help develop strategies to adapt the current and future operation of water treatment works (WTWs) by selecting the most appropriate treatment techniques to treat these water sources effectively. This will ensure the continued production and supply of quality drinking water to all people, as called for in the sixth Sustainable Development Goal (SDG), as the quality of source water changes. Furthermore, this approach can be replicated in other regions in the UK, Ghana and other parts of the world undergoing similar water resource planning. The project will also be helpful to stakeholders such as the Environment Agency in the UK and the Ghana Water Resources Commission, which are leaders in water resource planning but do not necessarily consider the impact on water treatability when developing these plans.

This research has been an invaluable opportunity for me as an individual. Funding from the Sue White Fund (SWF) paved the way for me to undertake a PhD on the EPSRC Water Infrastructure and Resilience (WIRe) CDT programme at Cranfield - an opportunity not usually afforded to African students. This programme has provided me with additional technical and transferable skills, including communication, business development, academic writing, responsible research and innovation, equality, diversity, and inclusion. Since undertaking this research, I have interacted with researchers and experts in water resource management - an experience that will benefit me throughout my career. I will use the knowledge and experience I have gained from this project to alleviate water-related issues in Ghana and beyond through consultations, workshops, and outreach programmes I plan to run after graduation. So, this research and SWF funding will fast-track my career and network. Most importantly, this will maximise my chances to implement and deliver the research effectively in Ghana. I am sincerely grateful to the Sue White Fund for providing me with this lifelong opportunity.

References

Organisation for Economic Co-operation and Development (OECD). (2012). OECD Environmental Outlook to 2050 : the Consequences of Inaction. OECD Pub. HYPERLINK "https://www.oecd.org/env/indicators-modelling-outlooks/oecdenvironmentaloutlookto2050theconsequencesofinaction-keyfactsandfigures.htm"https://www.oecd.org/env/indicators-modelling-outlooks/oecdenvironmentaloutlookto2050theconsequencesofinaction-keyfactsandfigures.htm