Ion-exchange-based methods of fluoride extraction from Tanzanian groundwater and the community health issues that stem from overexposure to fluoride

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Introduction

Groundwater in Tanzania often contains fluoride levels far above the WHO limit of 1.5 mg/L, with some sources >30 mg/L. Chronic exposure causes dental and skeletal fluorosis and has been linked to neurodevelopmental deficits in children.

Current defluoridation methods, such as reverse osmosis, are costly and poorly suited to rural settings.

This project, part of the TUDAY (Tanzania-UK collaboration on Defluoridation by Adsorption and recoverY) initiative, develops an ion-exchange and precipitation process to reduce fluoride to safe levels while recovering it as valuable calcium fluoride. The approach also emphasizes social acceptance and sustainability, including the future use of locally sourced biomass as ion-exchange media.

Graduate Research Seminar Presentation at NM-AIST

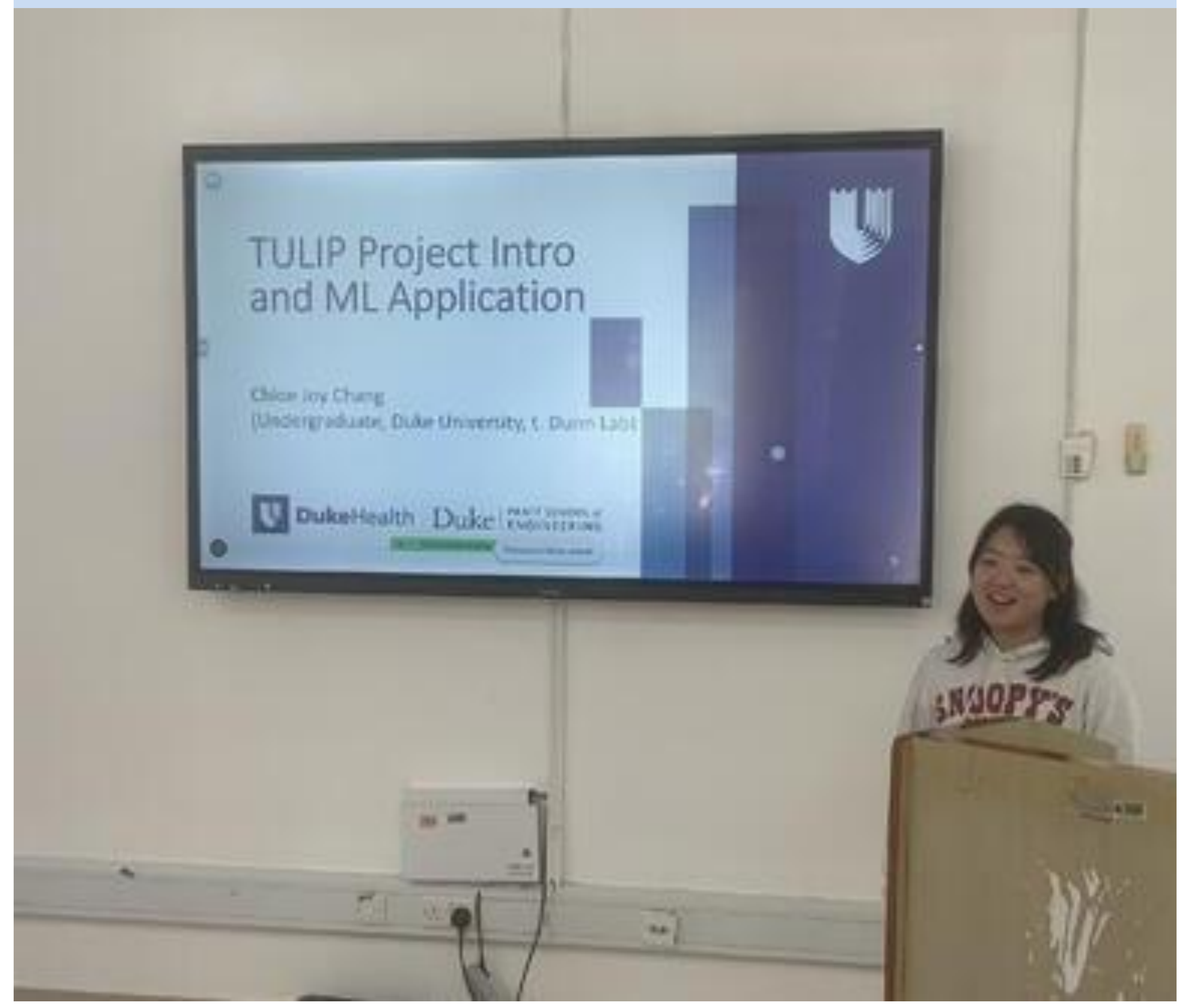

Fig 1: Research Pitch Presentation during Tanzania Trip

Results

1. Ion-Resin Screening

- Tested AMPA, IDA, and SULF ligands with Al^{3+}, La^{3+}, and Ce^{3+} ions.
- **Low-fluoride samples**: IDA–Al^{3+} showed the highest adsorption (qe ≈ 0.13).
- **High-fluoride samples**: IDA–Al^{3+} strongly outperformed all others (qe ≈ 4.5), followed by AMPA–Al^{3+} (qe ≈ 3.7).
- Other systems showed negligible adsorption.

2. Community Feedback (Field Visit, July 2025)

- **Bone char**: technically moderate but rejected due to cultural perceptions, animal source reliance, and poor sustainability.
- **Ion-exchange resins**: viewed as modern, neutral, and scalable.

3. Conclusion

- **IDA–Al^{3+}** selected as the lead system for further development due to:
  - Superior adsorption capacity across concentrations.
  - Scalability and robustness.
  - Strong community acceptance compared with bone char.

Methods and Processes

Phase 1 of the TUDAY project was divided into **four work packages**, combining lab studies with stakeholder engagement:

1. Adsorbent Chemistry – Tailored ion-exchange resins were developed by testing different metals and functional groups to improve fluoride binding capacity and selectivity.

2. Dynamic Operations – System performance was optimized through breakthrough experiments, flow rate testing, regeneration screening, and comparing a packed column with an agitated tubular reactor.

3. Fluoride Recovery – Batch precipitation experiments optimized conditions for recovering fluoride as CaF_2, with protocols for purity assessment and large-scale testing at Leeds' Multiform facility.

4. Stakeholder Engagement – Mapping and strategy development were informed by case studies on social acceptance and direct fieldwork in Tanzania.

A **field visit (July 6–10, 2025)** to NM-AIST and local communities provided insights into water management practices, infrastructure challenges, and cultural acceptance. These findings directly shaped the stakeholder engagement strategy and ensured that technical solutions were aligned with community needs and long-term sustainability.

Bar graph of average qe vs. ion-resin exchange system

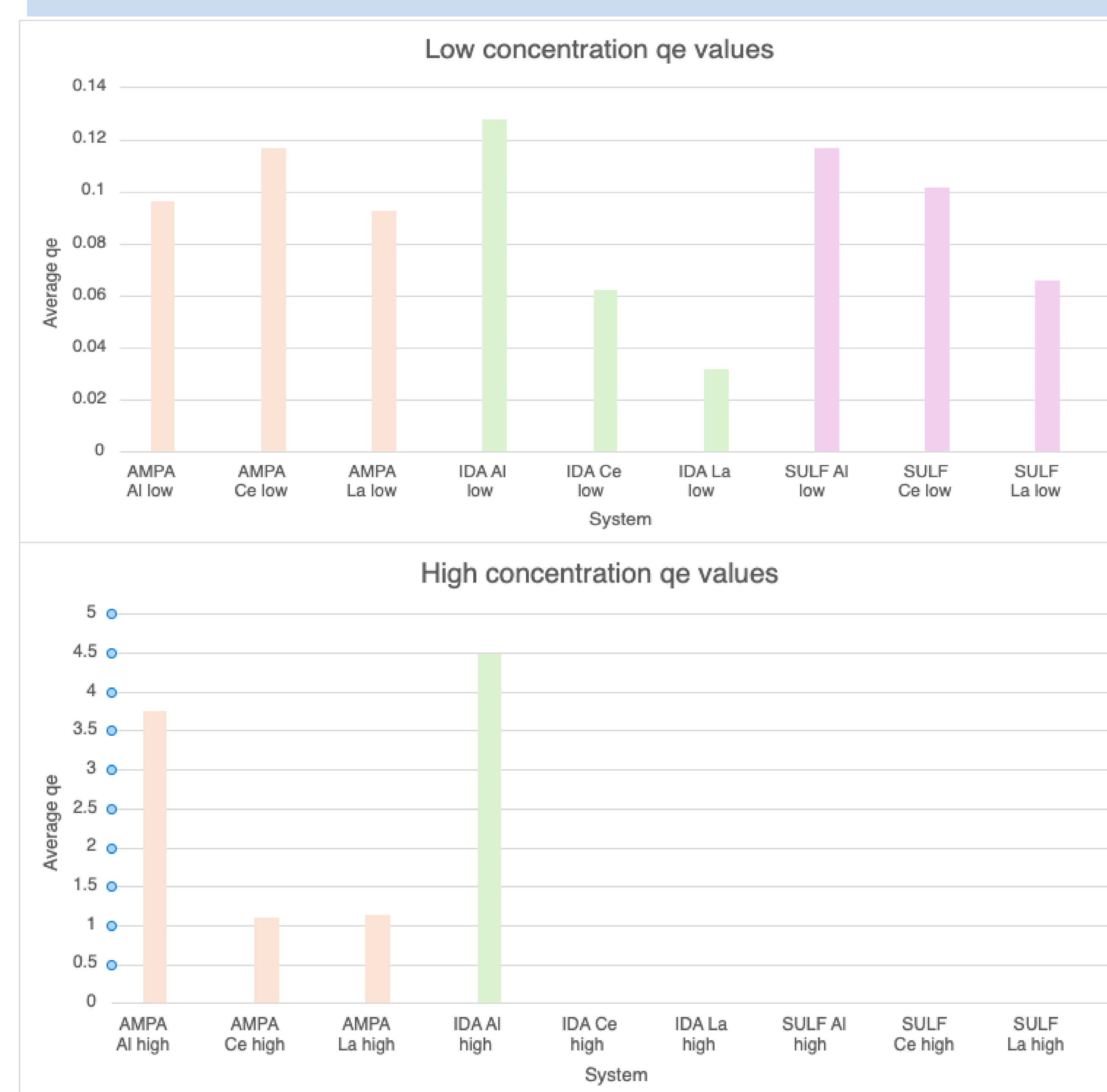

Fig 2,3: Bar graph of qe results for ligand-ion coupled systems

Conclusion

1. Why IDA–Al^{3+}?

Fluoride (a hard Lewis base) binds strongly with Al^{3+} (a hard Lewis acid).

IDA ligand provides stable chelation, preventing metal leaching and enabling strong Al–F interactions.

Outperformed La^{3+} and Ce^{3+} systems due to higher charge density and favorable coordination geometry.

2. Future Directions

Dynamic column experiments and regeneration testing.

Valorisation of fluoride as CaF_2 to improve sustainability and offset costs.

Continued stakeholder engagement to ensure cultural acceptance and long-term adoption.

3. Significance

Provides a **scalable, socially viable solution** for defluoridation in Tanzania.

Directly addresses health risks: skeletal/dental fluorosis and neurodevelopmental deficits in children.

Advances both **scientific innovation** and **health equity** in fluoride-affected regions.