A framework for evaluating thaw settlement in permafrost regions

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This research improves the evaluation of thaw settlement in permafrost regions through a unified, multi-scale framework. By consolidating dispersed laboratory data, refining empirical models for coarse-grained and organic soils, and introducing new regional hazard indices, the work bridges a critical gap between scientific understanding and engineering application. The Thaw Settlement Evaluation Framework integrates regional hazard mapping with site-specific prediction workflows, supporting informed decision-making from feasibility studies to detailed design.

Research summary

This research addressed the lack of integrated, practitioner-ready tools for evaluating thaw settlement across spatial scales in permafrost regions. A Thaw Settlement Evaluation Framework was developed, combining regional hazard assessment with site-specific thaw strain estimation. We compiled and standardized a large dataset of thaw settlement tests, evaluated existing empirical models, and developed new predictive tools for coarse-grained and highly organic soils.

Regional hazard mapping methods were advanced through the Thaw Settlement Potential Index (*TSPI*) and the Thaw Settlement Hazard Index (I_{TSH}). The framework provides four structured workflows for evaluating thaw settlement at different stages of a project. These workflows give engineers and planners practical, evidence-based resources for designing and managing infrastructure in permafrost regions. By centralizing methods and guiding users through consistent evaluation steps, the framework supports more resilient infrastructure development in northern regions under changing climatic conditions.

Taking action

Implementation of the Thaw Settlement Evaluation Framework can directly support proactive infrastructure planning in permafrost regions. At the regional scale, hazard mapping using the *TSPI* and I_{TSH} could be used in early project screening to flag high-susceptibility areas and guide field investigations. At the site scale, the new empirical tools for coarse-grained and organic soils can be applied with readily available index property data, improving settlement estimates without extensive lab testing. Open-access datasets and standardized workflows could be adopted to ensure consistency and reproducibility. Ongoing collaboration among researchers, engineers, and planners will refine these methods as new climate projections, ground ice mapping, and test data emerge. Adoption of the framework can extend infrastructure service life, lower maintenance costs, and strengthen resilience in northern communities.

Connections to other projects

This project is part of Theme 1 — *Characterisation of permafrost* and directly relevant to Theme 5 — *Adaptation to permafrost thaw*.

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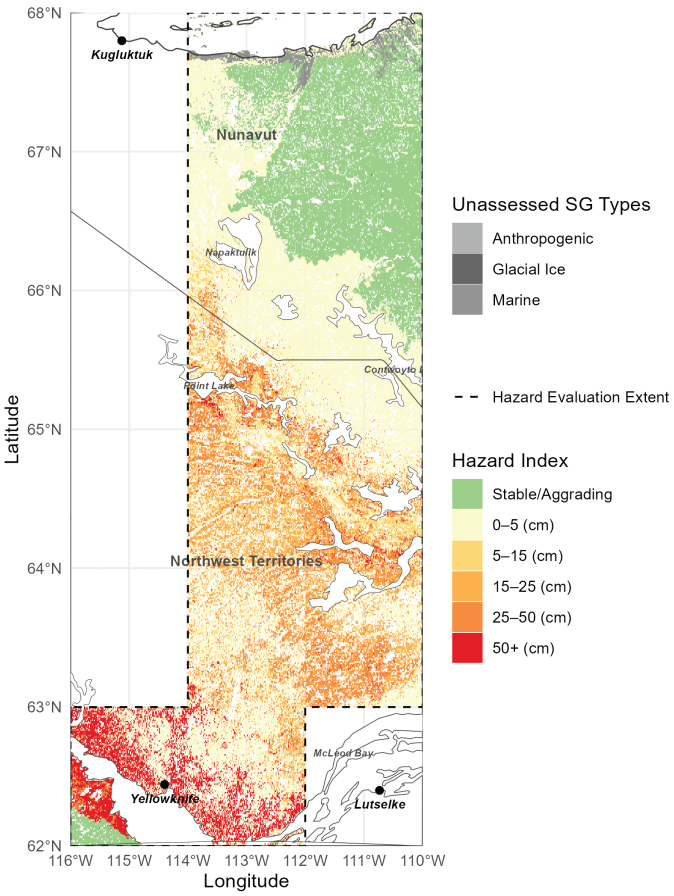

Figure 1. Thaw settlement hazard map of the Slave Geological Province, created using the Thaw Settlement Hazard Index (I_{TSH}). The index combines projected thaw depth (expressed as changes in active layer thickness ΔALT) with the Thaw Strain Potential Index ($TSPI$) to identify areas most susceptible to thaw-related settlement.

Partners, team members and support

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References

Mohammadi, Z., and Hayley, J. L. (2023). 'Qualitative evaluation of thaw settlement potential in permafrost regions of Canada'. *Cold Regions Science and Technology*, 216, 104005. Available at https://doi.org/10.1016/j.coldregions.2023.104005

Mohammadi, Z., and Hayley, J. L. (2024). Permafrost thaw settlement dataset (Version 1.2.1) [Data set]. Zenodo. Available at https://doi.org/10.5281/zenodo.14538524

Mohammadi, Z., and Hayley, J. L. (2024). 'Estimating thaw settlement of coarse-grained permafrost sediments'. *Canadian Geotechnical Journal,* 62(1), 1–18. Available at https://doi.org/10.1139/cgj-2023-0492

Mohammadi, Z., and Hayley, J. L. (2025). 'Compilation and analysis of thaw settlement test results: Implications for prediction tools and stress–strain characterization in permafrost'. *Earth System Science Data,* 17, 3921–3947. Available at https://doi.org/10.5194/essd-17-3921-2025

Mohammadi, Z., and Hayley, J. L. (2025). Regional evaluation of thaw settlement hazard in the Slave Geological Province. In GeoManitoba 2025 Conference, Winnipeg, MB, Canada.

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