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Editorial

Environmental Geotechnics

Editorial: Data, damage, and design: adaptive intelligence in environmental geotechnics

Josip Peranić PhD
Assistant Professor at the University of Rijeka, Faculty of Civil Engineering;
Editorial Board Member, Environmental Geotechnics
(josip.peranic@gradri.uniri.hr)

Environmental geotechnics stands at a crossroads—where the complexity of global environmental challenges meets the ingenuity of data-informed, interdisciplinary design. It is thus both a personal and professional privilege to write the editorial for this month's issue of *Environmental Geotechnics.* Having joined the editorial board at the beginning of 2024, I have quickly come to appreciate the depth and diversity of expertise that this journal embodies. As a young researcher who is just starting the academic career and a process of establishing a research group, the opportunity to interact and serve alongside leaders across so many subfields of geotechnical and environmental engineering has been invaluable. Environmental geotechnics is, by its very nature, a multidisciplinary field to an extent I could not comprehend until recently, requiring continuous engagement with advances in materials science, hydrology, microbiology, data science, climate modelling and many others. Through my involvement with the journal, I have not only broadened my technical horizon but also begun to realize how different sets of skills and some very specific expertise could be joined together in order to contribute meaningfully beyond traditional civil engineering, helping to cope with some of the emerging problems of the 21st century.

A multidisciplinary approach—essential for addressing the complex challenges faced by today's scientists and practitioners—is also deeply embedded in the journal's mission and reflected in this issue's five papers. From the microstructure of damaged soils to machine-learning-informed barrier design, the papers gathered here embrace complexity, uncertainty, and context as essential design parameters rather than constraints. These studies collectively advance what might be termed "adaptive intelligence" in environmental geotechnics—an approach where data, physics, chemistry, and societal needs converge.

The issue opens with the work by Yuan and Che (2025), who present a novel unit series–parallel electrical conductivity model for soils subjected to environmental loads. By linking soil resistivity to microstructural changes, such as porosity and fractal geometry under rainfall cycles, they propose a framework with direct application to slope stability monitoring and erosion assessment. Their work demonstrates the value of high-resolution sensing (via. X-ray microscopy) in capturing spatially distributed damage and translates this insight into a physically grounded predictive model. It exemplifies how small-scale processes can inform large-scale understanding, particularly in the face of climate-exacerbated hydrological cycles.

Li *et al*. (2025) then advance the conversation through data-driven design. Using a database of over 300 laboratory tests, they apply and compare machine learning algorithms—notably XGBoost and gene expression programming—to predict and classify the hydraulic conductivity of bentonite-polymer geosynthetic clay liners exposed to aggressive leachates. The sophistication of their approach lies not just in predictive accuracy but in interpretability: decision trees derived from their models can serve as practical tools in selecting liners for solid waste containment under specific leachates. In this way, the study moves beyond theoretical modelling to offer guidance for real-world geosynthetic barrier design, reaffirming the growing role of AI in geo-environmental material selection.

Complementing the micro- and data-driven focus of the previous papers, Lu *et al*. (2025) present a comprehensive bio-thermo-hydro-mechanical (BTHM) model for municipal solid waste degradation in anaerobic landfills. Their integrated modelling framework captures the interaction of temperature, leachate pressure, gas generation, and mechanical settlement—a level of coupling that mirrors the real-world complexity of landfill biogeochemistry. Particularly valuable is their sensitivity analysis, which quantifies the effects of waste composition and initial conditions on long-term landfill performance. As climate change alters surface and subsurface temperatures, and as global waste profiles continue to diversify, such multiphysics models will be indispensable for safe and efficient landfill management.

In a policy-relevant and circular economy-oriented contribution, Singh *et al*. (2025) present a comprehensive review of waste rubber tyre applications in geotechnical engineering. Conducted by world-leading experts in the field, the analysis spans diverse uses—from vibration damping to seismic isolation—while also addressing critical environmental concerns, including microplastic release and metal leaching. The paper serves as a timely reminder that sustainability in geotechnics hinges not merely on reuse, but on responsible reuse. As space and resources grow increasingly constrained, the geotechnical community must carefully balance innovation with environmental stewardship.

Finally, Bilardi *et al*. (2025) explore the influence of groundwater chemistry on the performance of permeable reactive barriers (PRBs), particularly those composed of zero-valent iron and lapillus. Through a series of laboratory experiments, they demonstrate how site-specific geochemical conditions—especially the presence of calcium carbonate—can significantly affect metal removal efficiency. Their findings not only highlight the non-universality of material behaviour in reactive barrier applications but also emphasize the importance of tailoring remediation strategies to local hydrochemical environments. This study reinforces the need for context-aware design, also exemplifying the kind of site-specific intelligence that future remediation technologies must embody in an era of climatic and geochemical variability.

Together, these five papers illustrate how environmental geotechnics is evolving from deterministic, single-variable approaches toward integrated, context-aware frameworks. This evolution is both a response to and a necessity of our times. In the face of a climate crisis, shrinking natural resources, and heightened public expectations for sustainable infrastructure, we are called upon to design systems that are as intelligent as they are resilient. I hope this issue inspires readers to see **environmental geotechnics** not just as a field of engineering, but **as a platform for interdisciplinary problem-solving in service of a sustainable future**.

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