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Editorial: Women in critical zone science

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Editorial on the Research Topic
Women in critical zone science

1 Introduction

The Critical Zone (CZ) is defined as the Earth's living skin extending from the impermeable bedrock upward through the porous bedrock, the unsaturated and saturated zones, rhizosphere to the top of the vegetation canopy (NRC, 2001; Brantley et al., 2007; Arora et al., 2023). CZ is where interactions between the atmosphere, water, soil, rock, and living organisms occur, influencing the availability of water resources, the formation and properties of soils, and the overall health of ecosystems. Over the past 2.5 decades, research interest on CZ has increased with research foci including high-frequency monitoring, novel sensing and tracing techniques, high-fidelity biogeochemical modeling, development of AI/machine learning approaches, data harmonization and repository building, and other multidisciplinary integrative approaches that can capture the dynamic and interconnected nature of the CZ. The collection of articles in this Research Topic features contributions led by women scientists who have made substantial contributions to the study of CZ science. These contributions cover a wide spectrum of topics, including a mini-review on application of nuclear magnetic resonance (NMR) in near-surface environments, a perspective piece on recognizing CZ as a CZ ecosystem, and other articles that focus on drivers of riverine exports of dissolved organic carbon and nitrogen, land/crop heterogeneity impacts on eddy covariance flux measurements, as well as recent streamflow trends in permafrost environments. These topics also involved novel method development, high fidelity hydrological and ecohydrological modeling, and the use of machine learning approaches. Below, we briefly synthesize these contributions.

2 Overview of publications in this Research Topic

Out of the 6 publications in this Research Topic, some deal with climate change impacts on streamflow quantity and quality. Bennett et al. investigated long-term streamflow trends within 74 gaged sites in North America affected by varying amounts of permafrost coverage. They used multiple statistical tools along with machine learning methods to examine the drivers of change in streamflow trends within the basins. They suggested that streamflow trends are largely driven by precipitation, followed by temperature, and then by

static drivers such as permafrost coverage. Ruckhaus et al. investigated long-term stream concentration-discharge (C-Q) datasets to understand how changes in acid deposition and precipitation have influenced dissolved organic carbon and nitrogen loading to streams. Their work focused on Sleepers River Research Watershed, a forested headwater catchment in northeastern Vermont, which has experienced increases in precipitation and decreases in acid deposition. Their long-term stream data showed increasing trend in dissolved organic carbon concentrations and generally decreasing trend in dissolved inorganic nitrogen, such that stream C:N ratios will likely continue to increase. This finding has important implications for stream metabolism and biogeochemical processes in watersheds recovering from acid deposition.

Beyond studying long-term datasets, there is a need to develop strategies to instrument watersheds impacted by climate disturbances such as droughts and wildfires. In this regard, Wainwright et al. combined remote sensing data products with a hydrological model to identify distinct hillslope zones that exhibit varying sensitivity to drought and divergent eco-hydrological responses. Analyzing three life zones across four catchments near Crested Butte, Colorado, the authors concluded that predictions of drought sensitivity can be improved with including hydrological variables (e.g., differences in soil moisture across wet and dry years) in a machine learning approach as compared to including static explanatory variables (e.g., elevation, geology) alone.

Other studies investigated the impact of spatial heterogeneity on well-established methods used in CZ science. Hernandez Rodriguez et al. explored how spatial heterogeneity of row crop agriculture contributes to observations of land-atmosphere exchange and the interpretation of eddy covariance measurements. The authors quantitatively showed that the spatial structure of the land cover, characterized by the mosaic of maize and soybean fields, can result in a >10% difference in flux magnitudes as compared to assuming an equal distribution of crop types within the flux footprint. Bravo and Zhang review application of NMR tools in heterogeneous subsurface materials with dual or multimode pore systems. Their work summarizes existing approaches used to investigate pore coupling effects using NMR, describe the two factors controlling pore coupling: surface geochemistry and network connectivity, and highlight future research opportunities, particularly for expanding NMR applications in the vadose zone and karst aquifers.

A perspective article in this Research Topic had a broader look at viewing the critical zone as an ecosystem. The author suggests that this definition allows CZ science to delve into deeper spatial and temporal scale questions than addressed by domain science alone. The author further opines that CZ science operates at the intersections of disciplines, allows for analyzing problems using multiple perspectives in a place-based science setting and therefore, enables making new discoveries.

3 Conclusion

It is encouraging to see contributions from women scientists and women led teams being recognized and celebrated in recent times (Tetzlaff et al., 2021; Ali et al., 2023; Turner, 2024; https://www.cee.psu.edu/events/women-advancing-river-research.aspx). However, we still have far to go to make science more equitable (e.g., https://www.nature.com/articles/d41586-024-00640-5; Arora et al., 2022; Staniscuaski, 2024). Led by women scientists, the publications in this Research Topic offer guidance on possible future directions of CZ research, ranging from expanding the applicability of NMR tools in heterogeneous vadose zone environments to broadening the definition of CZ to CZ ecosystem. Finally, we believe that increased representation of women in leadership roles, editorial boards and outreach activities within the field would not only advance CZ science, but also contribute to significant access to, and support within, CZ science.

Author contributions

BA: Writing – original draft, Writing – review & editing. ES: Writing – original draft, Writing – review & editing. LJ: Writing – original draft, Writing – review & editing.

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Conflict of interest

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