frontiers
in Sustainability

TYPE Editorial
PUBLISHED 24 March 2026
DOI 10.3389/frsus.2026.1766036

EDITED BY
Spyridon Ntougias,
Democritus University of Thrace, Greece

REVIEWED BY
Eli Jamilah Mihardja,
Bakrie University, Indonesia
Oleksandra Trokhaniak,
National University of Life and
Environmental Sciences of
Ukraine, Ukraine

*CORRESPONDENCE
Azade Deljouei
✉ azade.deljouei@nau.edu

RECEIVED 11 December 2025
REVISED 02 March 2026
ACCEPTED 10 March 2026
PUBLISHED 24 March 2026

CITATION
Deljouei A, Cislaghi A and Abdi E (2026) Editorial: Nature-based solutions for managing soil erosion and enhancing soil stability. *Front. Sustain.* 7:1766036. doi: 10.3389/frsus.2026.1766036

Editorial: Nature-based solutions for managing soil erosion and enhancing soil stability

Azade Deljouei[1]*, Alessio Cislaghi[2,3] and Ehsan Abdi[4]

[1]School of Forestry, Northern Arizona University, Flagstaff, AZ, United States, [2]Department of Agricultural and Environmental Sciences, University of Milan, Milan, Italy, [3]Centre of Applied Studies for the Sustainable Management and Protection of Mountain Areas, University of Milan, Edolo, Brescia, Italy, [4]Department of Forestry and Forest Economics, Faculty of Natural Resources, University of Tehran, Karaj, Iran

KEYWORDS

biodegradable geotextiles, governance and land tenure, hydrological regulation, nature-based solutions (NBS), root reinforcement, soil bioengineering, soil erosion, soil stabilization

Editorial on the Research Topic
Nature-based solutions for managing soil erosion and enhancing soil stability

Soil erosion and shallow slope instabilities continue to challenge forest, rangeland, and multi-use landscapes worldwide (Xiong and Leng, 2024; DiBiagio et al., 2024; Yosef et al., 2025). Beyond the direct loss of soil, these processes disrupt hydrological regulation, compromise infrastructure stability, degrade downstream water quality, and reduce long-term land productivity (Tao et al., 2023; Flores et al., 2020; Roy, 2023; Martin et al., 2020). As climate extremes intensify and land-use pressures increase, the frequency and magnitude of these destabilizing processes are expected to rise, amplifying risks across coupled ecological and socio-economic systems. This escalating exposure highlights the need for strategies that enhance the intrinsic stabilizing capacity of landscapes rather than relying exclusively on hard-engineering solutions (Phillips et al., 2023). In this regard, Nature-Based Solutions (NBS) provide a compelling framework, using vegetation, soils, and natural materials to diminish erosion risks and strengthen slope resilience (Deljouei et al., 2023).

Yet despite their growing prominence, NBS are frequently discussed as collections of individual techniques rather than as integrated systems (Lei and Saeed, 2024). In practice, components such as vegetation-based reinforcement (Deljouei et al., 2020; Bordoni et al., 2026), biodegradable materials (Song et al., 2022; Shalchian and Arabani, 2023), soil diagnostics (Bouzouidja et al., 2021; Calfapietra et al., 2025), stand management (Rodrigues et al., 2021; Ma et al., 2022), and governance mechanisms (Martin et al., 2021) are typically addressed separately within their respective disciplines. Such compartmentalized evaluation obscures the interdependencies among these components. Durable erosion control depends on the coordinated interaction of ecological processes, structural configuration, material performance, monitoring systems, and institutional continuity.

Recognizing these limitations, this Research Topic seeks to move beyond technique-specific discussions and instead frame NBSs as coordinated socio-ecological systems operating across scales. Rather than providing an exhaustive review of the broader literature, this Editorial synthesizes the conceptual threads that connect the included contributions and situates them within the broader challenge of implementing erosion-oriented NBS under intensifying climatic and land-use pressures. Building on this integrative perspective, this Research Topic brings together contributions that demonstrate how stabilization processes operate across interacting spatial and institutional scales. Although the studies differ in spatial scope and methodological focus—ranging from root–soil interactions (Marzini et al.) to natural-fiber geotextiles (Holanda et al.), mineral indicators of soil development (Zhang et al.), stand structural effects on soil condition (Luo et al.), and national-scale erosion governance strategies (Teku and Derbib)—their findings converge on a central conclusion: soil stability emerges from the alignment of biophysical mechanisms and socio-institutional frameworks rather than from isolated technical interventions.

At the scale of plant–soil interaction, Marzini et al. examine how root-system architecture governs slope stabilization processes. By jointly evaluating root area ratio (RAR) and saturated hydraulic conductivity (K_S), they show that dense and well-distributed root networks enhance both infiltration capacity and subsurface mechanical reinforcement in forested slopes of Italy and Switzerland. Hydraulic performance declines with depth and distance from tree stems, demonstrating that root distribution actively regulates subsurface water movement rather than merely reflecting stand structure. This mechanistic linkage positions vegetation as a controllable design component in stabilization planning, since configuring root architecture can influence runoff redistribution and reduce shallow landslide susceptibility. However, root-mediated reinforcement operates under the hydrological conditions established at the soil surface. Before rainfall reaches the ground, a portion is intercepted by leaves, branches, and litter layers (Sadeghi et al., 2020, 2026)—meaning it is temporarily stored or evaporated within the canopy—thereby altering both the amount and the intensity of water delivered to the soil. By reducing raindrop kinetic energy, delaying through fall timing, and preserving litter structure (Levia et al., 2011; Sadeghi et al., 2020, 2024), interception moderates splash erosion and controls the initial phase of runoff generation. These changes directly affect infiltration patterns and subsurface flow redistribution (Friesen, 2020), thereby influencing the effectiveness of root reinforcement (Kong et al., 2025). In this way, canopy interception and root architecture function as coupled controls over slope hydrology, regulating both water input at the surface and its redistribution belowground. This vertical coupling is not confined to slope-stabilization contexts. A study conducted in a virgin old-growth forest used as a structural benchmark (Azaryan et al., 2026), integrating canopy structure, understory composition, soil physical properties, and root traits, likewise demonstrates how vertically organized forest components jointly regulate soil moisture redistribution and structural soil condition. Together, these findings reinforce the need to evaluate forest systems as vertically integrated ecological strata rather than as isolated functional components.

Extending the stabilization framework beyond biological controls, Holanda et al. examine another dimension of NBS performance: material durability. Their evaluation of natural-fiber geotextiles derived from *Syagrus coronata* demonstrates that treatment intensity critically influences strength retention under field exposure. A single waterproofing-resin application sustained fiber performance for 120 days, while untreated materials degraded rapidly and double-treated fibers became brittle. These results show that the structural reliability of biodegradable materials depends not only on ecological compatibility but also on their temporal performance under environmental stress. Accordingly, biodegradable geotextiles must be aligned with rainfall regimes (de Souza Batista et al., 2024) and vegetation establishment timelines (Álvarez-Mozos et al., 2014) to remain effective during critical stabilization windows.

While material durability determines whether structural interventions persist, effective implementation also requires reliable monitoring of soil condition over time. Zhang et al. address this need by introducing magnetic susceptibility (χlf) as a diagnostic indicator of soil development and iron-oxide transformations in humid forest systems. Variations in χlf reflect changes in nutrient status and soil structural stability, providing a rapid and non-destructive monitoring tool for assessing soil condition. Such indicators enhance the feedback loop between intervention and evaluation, particularly in heterogeneous landscapes where repeated soil sampling is logistically challenging (Ouallali et al., 2025). By strengthening monitoring capacity, these tools support adaptive management and enable earlier detection of soil degradation before visible erosion occurs.

Moving from subsurface and material controls to forest-scale configuration, Luo et al. examine how stand structure influences soil condition. They demonstrated that canopy openness, stand density, and understory composition directly shape soil physical and chemical properties. Their findings show that moderately dense stands with healthier understories tend to support more favorable soil conditions, suggesting that structural complexity contributes to soil resilience. This reinforces a central silviculture principle: stand structure is not merely a determinant of timber yield or species composition, but a management lever capable of strengthening soil stability and mitigating erosion (Hakimi et al., 2018). When stand-level decisions are explicitly aligned with soil-health objectives, silvicultural interventions can function as proactive components of watershed protection (Hawthorne et al., 2013). Stand management thus represents a bridge between ecological processes and landscape-scale stabilization outcomes.

At the broadest spatial scale, stabilization outcomes are shaped not only by ecological design but also by institutional structure. Teku and Derbib therefore highlight the necessity of coupling technical interventions with governance frameworks, policy alignment, and community participation. Their systematic review of 129 studies from the highly erosion-prone Ethiopian Highlands shows that physical measures such as terracing, agroforestry, and stone bunds are most effective when embedded within supportive local institutions and long-term stewardship arrangements. Their synthesis makes clear that NBS implementation cannot rely on technical soundness alone; durable erosion-control outcomes depend on coherence among engineering design, local land-tenure systems, and governance capacity. In many contexts, these institutional conditions ultimately determine whether technically robust interventions persist or fail over time. By situating stabilization within governance and land-tenure systems, this contribution links slope-scale ecological processes—such as root reinforcement, canopy-mediated rainfall partitioning, material durability, and soil monitoring—to institutional arrangements. These arrangements ultimately determine whether such interventions are maintained and remain effective over time.

Cross-cutting scientific insights and research priorities

Across the articles included in this Research Topic (Luo et al.; Tekua and Derbib; Holanda et al.; Zhang et al.; Marzini et al.), several shared scientific patterns emerge. Vegetation characteristics—particularly root-system architecture and canopy-mediated rainfall regulation—function as measurable design variables that influence both hydraulic redistribution and mechanical soil reinforcement. Structural elements, including biodegradable materials and stand configuration, determine whether stabilization measures retain functional integrity under field conditions. Monitoring tools, such as soil diagnostic indicators, provide the feedback necessary to evaluate performance and guide adaptive management. Finally, institutional coherence and long-term stewardship determine whether technically robust interventions persist beyond initial implementation.

Future research should therefore prioritize long-term performance assessment under intensifying climate variability, advance integrative models that couple biophysical measurements with socio-institutional datasets, and develop standardized performance metrics for evaluating stabilization outcomes across eco-regions. Advancing these directions will strengthen both scientific understanding and the practical implementation of integrated stabilization systems.

From biophysical mechanisms to institutional architecture

Taken across scales, the contributions define a stabilization continuum extending from root-scale ecological processes to institutional governance. Marzini et al. analyze root-mediated reinforcement at fine spatial resolution, whereas Tekua and Derbib evaluate institutional arrangements at national scales. The linkage between these levels is functional rather than merely conceptual: biophysical stabilization processes depend on sustained long-term land-use continuity, while governance frameworks must account for the ecological mechanistic that underpin slope resilience.

Holanda et al., Zhang et al., and Luo et al. occupy intermediate layers within this continuum. Material durability defines temporal compatibility between engineering interventions and vegetation establishment. Diagnostic indicators such as χlf enhance monitoring intelligence, linking implementation with adaptive management. Stand structural configuration determines how forest management decisions influence hydrological and mechanical reinforcement processes.

Despite their complementarity, common constraints emerge. Most analyses rely on short- to medium-term field observations, limiting insight into long-term system performance under intensifying climate variability. Geographic specificity constrains immediate transferability across eco-regions. Moreover, integration between socio-economic datasets and biophysical measurements remains partial. Addressing these limitations will require interdisciplinary models that explicitly couple ecological reinforcement processes with institutional decision-making frameworks.

On this basis, erosion-oriented NBS can be conceptualized as a multi-layer stabilization framework composed of four interdependent component:

(1) a biophysical reinforcement layer (canopy processes, litter layers, soil structure, and roots),

(2) a structural and material layer (stand configuration, and geotextile performance),

(3) a monitoring layer (soil diagnostics and mineral indicators), and

(4) an institutional layer (policy coherence, tenure systems, and stewardship capacity).

Durable soil stability depends on the coordinated integration of these layers, such that biophysical reinforcement, structural interventions, monitoring systems, and governance arrangements function in mutual support rather than as isolated components.

Implications for management and implementation

For practitioners and land managers, the findings synthesized in this Research Topic suggest that NBSs should be designed and evaluated as coordinated systems rather than as isolated interventions. Vegetation selection must be based on measurable root density, rooting depth distribution, root tensile strength, and hydraulic influence rather than solely on species availability or aesthetic criteria. Stand density and canopy structure should be intentionally managed to regulate canopy rainfall partitioning, particularly in erosion-prone slopes and infrastructure corridors. Biodegradable geotextiles and stabilization blankets must be selected and treated according to projected rainfall intensity, exposure duration, slope gradients, and the anticipated vegetation establishment timelines, ensuring that material degradation does not precede biological reinforcement. Monitoring programs should include repeatable soil diagnostic indicators capable of detecting early declines in soil structure or hydrological performance—such as infiltration capacity, bulk density, or soil cohesion—before visible erosion occurs.

At the institutional and policy scale, effective implementation requires integrating stabilization planning with land-tenure clarity, long-term maintenance responsibilities, and secured multi-year funding mechanisms. Technical installations such as terracing, agroforestry systems, or slope plantings should be embedded within governance structures that guarantee continuity beyond initial project cycles. Agencies and local authorities should align engineering design standards with ecological performance metrics. Project approval and post-implementation audits should therefore require measurable indicators such as infiltration capacity, vegetation cover persistence, and soil stability. Cross-sector coordination among forestry departments, watershed managers, infrastructure planners, and community organizations is essential to prevent fragmentation of responsibilities. Durable erosion control through NBSs depends on sustained operational alignment between ecological processes, performance monitoring, and institutional accountability.

Author contributions

AD: Project administration, Writing – review & editing, Writing – original draft, Conceptualization. AC: Conceptualization, Writing – review & editing, Writing – original draft. EA: Writing – original draft, Conceptualization, Writing – review & editing.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author AD declared that they were an editorial board member of Frontiers at the time of submission. This had no impact on the peer review process and the final decision.

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

References

Álvarez-Mozos, J., Abad, E., Goñi, M., Giménez, R., Campo, M. A., Díez, J., et al. (2014). Evaluation of erosion control geotextiles on steep slopes. Part 2: influence on the establishment and growth of vegetation. *Catena* 121, 195–203. doi: 10.1016/j.catena.2014.05.015

Azaryan, M., Vajari, K. A., Marcu, M. V., and Sadeghi, S. M. M. (2026). Integrating multiscale ecological indicators to assess ecosystem functioning in virgin Hyrcanian beech forests. *Front. Forests Global Change* 8:1726336. doi: 10.3389/ffgc.2025.1726336

Bordoni, M., Giganti, M., Gambarani, A., Vivaldi, V., Rossi, G., Bazzano, P., et al. (2026). Quantification of the mechanical reinforcement of roots of olive trees and their contribution to shallow slope stability. *Catena* 266:109929. doi: 10.1016/j.catena.2026.109929

Bouzouidja, R., Béchet, B., Hanzlikova, J., Sněhota, M., Le Guern, C., Capiaux, H., et al. (2021). Simplified performance assessment methodology for addressing soil quality of nature-based solutions. *J. Soils Sed.* 21, 1909–1927. doi: 10.1007/s11368-020-02731-y

Calfapietra, C., Di Lonardo, S., Peruzzi, E., Doni, S., and Masciandaro, G. (2025). Perspectives from nature-based solutions to restore soil and ecosystems. *Eur. J. Soil Sci.* 76:e70134. doi: 10.1111/ejss.70134

de Souza Batista, G. E., Bressane, A., Motta, M. F. B., de Castro Medeiros, L. C., Negri, R. G., and Urban, R. C. (2024). Nature-based solution using a bioengineering strategy for soil erosion control in tropical climate with intense rainfall patterns. *Nat. Based Solut.* 5:100130. doi: 10.1016/j.nbsj.2024.100130

Deljouei, A., Abdi, E., Schwarz, M., Majnounian, B., Sohrabi, H., and Dumroese, R. K. (2020). Mechanical characteristics of the fine roots of two broadleaved tree species from the Temperate Caspian Hyrcanian Ecoregion. *Forests* 11:345. doi: 10.3390/f11030345

Deljouei, A., Cislaghi, A., Abdi, E., Borz, S. A., Majnounian, B., and Hales, T. C. (2023). Implications of hornbeam and beech root systems on slope stability: From field and laboratory measurements to modelling methods. *Plant Soil* 483, 547–572. doi: 10.1007/s11104-022-05764-z

DiBiagio, A., Capobianco, V., Oen, A., and Tallaksen, L. M. (2024). State-of-the-art: parametrization of hydrological and mechanical reinforcement effects of vegetation in slope stability models for shallow landslides. *Landslides* 21, 2417–2446. doi: 10.1007/s10346-024-02300-1

Flores, B. M., Staal, A., Jakovac, C. C., Hirota, M., Holmgren, M., and Oliveira, R. S. (2020). Soil erosion as a resilience drain in disturbed tropical forests. *Plant Soil* 450, 11–25. doi: 10.1007/s11104-019-04097-8

Friesen, J. (2020). "Flow pathways of throughfall and stemflow through the subsurface," in *Precipitation Partitioning by Vegetation: A Global Synthesis* (Cham: Springer International Publishing), 215–228. doi: 10.1007/978-3-030-29702-2_13

Hakimi, L., Sadeghi, S. M. M., Van Stan, J. T., Pypker, T. G., and Khosropour, E. (2018). Management of pomegranate (*Punica granatum*) orchards alters the supply and pathway of rain water reaching soils in an arid agricultural landscape. *Agric. Ecosyst. Environ.* 259, 77–85. doi: 10.1016/j.agee.2018.03.001

Hawthorne, S. N., Lane, P. N., Bren, L. J., and Sims, N. C. (2013). The long term effects of thinning treatments on vegetation structure and water yield. *For. Ecol. Manage.* 310, 983–993. doi: 10.1016/j.foreco.2013.09.046

Kong, K., Deng, Z., Chen, F., Wang, Z., and Chen, Y. (2025). Numerical analysis of the effect of vegetation root reinforcement on the rainfall-induced instability of loess slopes. *Sci. Rep.* 15:23233. doi: 10.1038/s41598-025-06400-3

Lei, W., and Saeed, L. (2024). Climate-resilient geotechnics: unsaturated soils, bio-mediated ground improvement, and nature-based solutions. *Multidisc. Eng. Sci. Open* 1, 1–12.

Levia, D. F., Keim, R. F., Carlyle-Moses, D. E., and Frost, E. E. (2011). "Throughfall and stemflow in wooded ecosystems," in *Forest Hydrology and Biogeochemistry: Synthesis of Past Research and Future Directions* (Dordrecht: Springer Netherlands), 425–443. doi: 10.1007/978-94-007-1363-5_21

Ma, S., Wang, H. Y., Zhang, X., Wang, L. J., and Jiang, J. (2022). A nature-based solution in forest management to improve ecosystem services and mitigate their trade-offs. *J. Clean. Prod.* 351:131557. doi: 10.1016/j.jclepro.2022.131557

Martin, D. A., Osen, K., Grass, I., Hölscher, D., Tscharntke, T., Wurz, A., et al. (2020). Land-use history determines ecosystem services and conservation value in tropical agroforestry. *Conserv. Lett.* 13:e12740. doi: 10.1111/conl.12740

Martin, J. G., Scolobig, A., Linnerooth-Bayer, J., Liu, W., and Balsiger, J. (2021). Catalyzing innovation: governance enablers of nature-based solutions. *Sustainability* 13:1971. doi: 10.3390/su13041971

Ouallali, A., Bouhsane, N., Bouhlassa, S., Spalevic, V., Kader, S., Michael, R., et al. (2025). Exploring soil pedogenesis through frequency-dependent magnetic susceptibility in varied lithological environments. *Euro-Mediterr. J. Environ. Integr.* 10, 887–900. doi: 10.1007/s41207-024-00663-4

Phillips, C., Bloomberg, M., Marden, M., and Lambie, S. (2023). Tree root research in New Zealand: a retrospective 'review'with emphasis on soil reinforcement for soil conservation and wind firmness. *New Zeal. J. Forest. Sci.* 53, 1–34. doi: 10.33494/nzjfs532023x177x

Rodrigues, A. R., Marques, S., Botequim, B., Marto, M., and Borges, J. G. (2021). Forest management for optimizing soil protection: a landscape-level approach. *Forest Ecosyst.* 8:50. doi: 10.1186/s40663-021-00324-w

Roy, S. (2023). "Transportation infrastructure, slope instability, and soil erosion," in *Disturbing Geomorphology by Transportation Infrastructure: Problem, Prospect, and Solution* (Cham: Springer International Publishing), 109–133. doi: 10.1007/978-3-031-37897-3_4

Sadeghi, S. M. M., Aghajani, H., Jalilvand, H., Ahmady-Asbchin, S., Sadati, S. M., Coenders-Gerrits, M., et al. (2026). Canopy vitality drives rainfall redistribution in an old-growth temperate beech forest. *For. Ecol. Manage*. 606:123552. doi: 10.1016/j.foreco.2026.123552

Sadeghi, S. M. M., Epstein, J. M., Deljouei, A., Gorora, F. J., and Cohen, M. J. (2024). Stand age controls canopy and soil rainfall partitioning in slash pine forests. *For. Ecol. Manage.* 572:122307.

Sadeghi, S. M. M., Gordon, D. A., and Van Stan II, J. T. (2020). "A global synthesis of throughfall and stemflow hydrometeorology," in *Precipitation Partitioning by Vegetation: A Global Synthesis* (Cham: Springer International Publishing), 49–70. doi: 10.1007/978-3-030-29702-2_4

Shalchian, M. M., and Arabani, M. (2023). Application of plant-derived fibers in soil reinforcement on experimental, numerical, and case study scales: a review. *Bull. Eng. Geol. Environ.* 82:19. doi: 10.1007/s10064-022-03029-8

Song, G., Song, X., He, S., Kong, D., and Zhang, S. (2022). Soil reinforcement with geocells and vegetation for ecological mitigation of shallow slope failure. *Sustainability* 14:11911. doi: 10.3390/su141911911

Tao, H., Lei, S. W., Gong, L., Shi, X., Zhang, M. M., and Yang, G. Q. (2023). Study on erosion and stability of the ecological slope. *Front. Earth Sci.* 10:1071231. doi: 10.3389/feart.2022.1071231

Xiong, M., and Leng, G. (2024). Global soil water erosion responses to climate and land use changes. *Catena* 241:108043. doi: 10.1016/j.catena.2024.108043

Yosef, B. A., Gomi, T., and Ohira, M. (2025). Soil erosion modeling in forested watersheds: a comprehensive review. *J. Sediment. Environ.* 10, 1101–1116. doi: 10.1007/s43217-025-00259-0