Editorial: Cold Arid Landscapes Ecological, Biological and Economic Significance

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Cold arid landscapes represent high-latitude deserts characterized by extreme cold, scarce precipitation, slow ecological processes, fragile soils, and sparse vegetation. Globally recognized examples of such regions include the high-altitude Trans-Himalaya, the Tibetan Plateau, the Arctic Tundra, the Andean Altiplano, and the Antarctic Dry Valleys. These areas are highly sensitive to climatic variations, permafrost dynamics, and land-use changes, resulting in limited livelihood options and the prevalence of transhumance, agro-pastoral systems, oasis-based farming, and seasonal water-dependent agriculture. While mountain ecosystems are increasingly being recognized in view of environmental challenges, biodiversity conservation, and developmental requirements (Purohit, 2021; Sharma and Chettri, 2021), cold arid regions still require focused attention (Gaur *et al*., 2025). Therefore, the present issue of *Annals of Arid Zone* (Volume 65, Issue 2) is dedicated to various thrust areas concerning cold arid regions.

The issue begins with the article by Sharma and Thapa, which elaborates on the importance of cold arid zones within global mountain systems as providers of ecosystem services essential for human well-being, with particular reference to the Hindu Kush Himalaya. The article highlights distinct and varying trends in key ecosystems of the region between 2000 and 2022, including alpine vegetation, the cryosphere, wetlands, and cold arid zones. Notably, the extent of cold arid zones declined by 2.75% during this period. Shakya and Sharma, complement this perspective by discussing the significance of nature-based solutions (NbS) through their design dimensions as an overarching and integrative framework. The six case studies presented in their article, incorporating NbS design elements, further illustrate socio-economic outcomes and provide insights into scalability across different cold arid biome types.

The unique high-altitude cold-arid hydrological system is discussed using examples from the Ladakh region. Garg *et al*. explain how various components, including seasonal snow, glaciers, perched aquifers, and a limited network of perennial rivers, collectively determine water availability for ecological and human systems. The article further evaluates implications for water security under a warming climate. Goyal and Gaur, while explaining the impacts of climate variability on water availability, agricultural productivity, and socio-economic

sectors in the region, emphasize the need to integrate traditional and modern strategies to safeguard Ladakh's fragile ecosystem.

Despite low vegetation cover, cold arid regions harbor rich floral and faunal diversity. This section begins with the article by Madhu Bala on sea buckthorn, a plant gaining increasing recognition for its remarkable economic, ecological, and pharmacological potential. Dey G. complements this topic by discussing the future prospects of sea buckthorn-based health-promoting products, while Shashni S. highlights its role in women's empowerment through entrepreneurial activities in the Trans-Himalayan region. The next three articles, also focused on the Ladakh region, address the diversity of medicinal plants (Jishtu and Goraya), wild and semi-wild edible plants (Gaur *et al*., 2025), and the distribution and climatic suitability of *Juniperus polycarpos* (Misra *et al*.). Two additional articles are dedicated to the improved propagation of important cold arid plant species. Dhavale *et al*., describe the effects of mulching and greenhouse structures on spinach production in Ladakh, while Dhiman B., discussing the cultural and medicinal significance of *Capparis spinosa* in the Spiti Valley (Himachal Pradesh) and its propagation constraints, proposes the use of in situ approaches for its multiplication and conservation.

Microbial communities (extremophiles) are well known for their ability to colonize extreme environments where higher plants and animals often fail to survive. Sawant *et al*., present a comprehensive conceptual article on harnessing microbial potential for sustainable biomanufacturing and bioeconomic growth, emphasizing their efficient process control, flexible substrate utilization, and ease of translation from laboratory to industrial-scale applications. This theme is further enriched by Kaur *et al*., who review the diversity of cold-arid microbiomes, their adaptation strategies, and emerging biotechnological applications. Gupta *et al*., strengthen this discussion through the characterization of a cold- and salt-tolerant hydrolase-producing bacterium isolated from Ladakh. Bioprospecting studies on microbial communities from other globally recognized cold arid regions, including the Arctic (Sai Maheshkumar *et al*.) and the Patagonian Andean ecosystems (Poveda S.L.), are valuable additions to this section.

Ecological processes, including nutrient cycling and decomposition in cold arid regions, are also addressed in this issue. Agnihotri, 2025 while discussing nutrient dynamics in thawing permafrost, highlights plant nutrient uptake, the contribution of microbial communities, and associated changes in hydrological processes. Goyal and Gaur emphasize the need for sustainable water management practices that support responsible tourism while ensuring long-term ecological resilience. Rai *et al*., describe ecological constraints in cold arid ecosystems, such as chronic water scarcity, extreme temperatures, intense solar radiation, and high evapotranspiration, which collectively limit biological productivity. The article concludes with approaches for soil fertility restoration, emphasizing the role of native microbial communities and their adaptive strategies in arid soils.

Two articles focusing on pastoralism provide valuable insights into its historical continuity as a human survival strategy across diverse geographical regions, particularly in the high-altitude Himalayas. The articles by Maikhuri *et al*. and Farooquee and Sasidhar, discuss issues related to pastoral communities engaged in grazing-based livelihoods, developmental challenges, and emerging pressures on these rangelands. Drawing upon examples of two major pastoral communities—the transhumance *Bhotiyas* and the forest-dwelling nomadic *Van Gujjars* of Uttarakhand, a state within the Indian Himalayan region—the discussion is further enriched by examining the political and socio-ecological dimensions of transhumance pastoralism.

The final section focuses on economic opportunities that can enhance the livelihoods of people living under these extreme environmental conditions. Gupta ***et al.,*** describe a variety of fermented foods from the cold desert regions of the Western Himalaya, highlighting their health benefits and bioactive properties with a view toward their wider popularization. Dey G. reviews the importance of yak milk and its products, including processing techniques, health benefits, and future prospects as a livelihood source for people inhabiting cold arid zones. Angmo ***et al***., propose a replicable

cultivation model for chamomile, a medicinally important crop of Ladakh, aimed at facilitating its market integration and commercial adoption.

The contributions to this issue collectively highlight diverse research themes relevant to cold arid regions, reflecting the growing emphasis on ecosystem-based approaches, nature-based solutions, and socio-ecological sustainability in these environmentally sensitive landscapes (Khan *et al.,* 2025). Ecological and hydrological processes in cold arid environments require continued research attention to generate new knowledge on ecosystem functioning under extreme climatic conditions (Changqing *et al.,* 2017; Ngaba *et al.,* 2024), particularly through the application of advanced methodologies such as those recently employed in studies of vegetation dynamics (Liu *et al.,* 2026). The articles further demonstrate the significance of these extreme environments as reservoirs of plant, microbial, and animal diversity with substantial potential for bioprospecting, climate resilience, and socio-economic development.

While Tewari and Kapoor (2013) previously documented the plant diversity of cold deserts in the context of ecological concerns, Agnihotri (2025) has recently emphasized the importance of quality and safety guidelines governing the trade and commercialization of these biological resources. Emerging knowledge on previously unexplored microbiomes, particularly regarding their taxonomic and functional diversity, will contribute significantly to understanding ecosystem functioning under changing climatic conditions (Mishra *et al.,* 2023). Similarly, the socio-ecological dimensions of transhumance pastoralism remain highly relevant in the context of contemporary climate-related pressures (Sheergojri *et al.,* 2026). The development of scientifically informed livelihood opportunities will be essential for improving socio-economic conditions in cold arid regions (Bhatt *et al.,* 2015). Expanding research within the thrust areas covered in this issue through advanced approaches and methodologies will be crucial for addressing future challenges and realizing the full potential of these unique ecosystems.

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