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Mountain soils and threats

Devastation after earthquake. Kathmandu, Nepal (Flickr/ReSurge International)

Soil degradation in mountain environments is a worldwide problem. Mountain soils are intrinsically vulnerable and therefore very sensitive to degradation processes such as water erosion, loss of chemical and physical quality, and desertification. Degradation processes result from a combination of factors: low soil formation rates and slow pedogenesis; steep slopes favouring profile erosion and even topsoil truncation; limited organic matter inputs; extreme climate affecting the soil biological communities and the organic matter turnover.

In addition, mountains are particularly sensitive to climate change. For example, the impact of climate change on the snowpack duration, rainfall regime and frequency of extreme meteorological events can heighten soil erosion and degradation, often leading to non-tolerable soil losses.

In particular, when marginal areas are abandoned, they become even more prone to natural hazards such as shallow slope failures and heightened erosion. Besides localized events, the impact of climate change on mountain soils may also have off-site effects. For example, glacial retreat in mountains is followed by a consistent reduction in glacial runoff water, which will affect the availability of most of the world's freshwater resources for domestic, agricultural and industrial consumption. Climate change will also affect vegetation, as it can induce altitudinal shifts of plant species, threatening biodiversity. The interactions of soils, biosphere and water cycle can be therefore seriously compromised.

In arid zones, populations are heavily dependent on ecosystem services provided by highland areas. One-third of the global population in lowlands survives thanks to water flowing from frequently far-off highland areas. In semi-arid and arid regions, mountains may be the only areas with sufficient precipitation to generate runoff and groundwater recharge, serving as water towers for millions of people living in surrounding lowland areas. Mountains play a key role in the hydrological cycle of dryland regions, and are the source of many of the world's greatest rivers including the Nile, Colorado, Yangtze and Mekong. Unfortunately, over-exploitation of natural resources and land conversion, as well as the spread of invasive alien species and climate change, are altering hydrological and fire regimes, leading to land degradation and desertification, and impacting mountains' abilities to deliver key ecosystem services such as water.


Soil degradation in Tres Molinos
(UNCCD/Jorge Valenzuela)

Mountain agricultural soils face several limitations related to severe slopes, limited accessibility and mechanization. Since ancient times, terracing has been widely used to guarantee agricultural quality and to prevent natural hazards. For example wide areas in Europe have been subject to recent land reclamation and reshaping operations, carried out in order to make agriculture more profitable and to allow mechanization.

Mountain soil degradation includes a variety of processes, strictly related to soil hydrology and watershed management. Recently, Alewell proposed to group all hazards that induce mountain soil loss in the wide category of "soil erosion", including for example shallow landslides and mudflows that involve the first decimeters of soil.

In particular in drylands, sustainably managed land resources – such as those that employ organic, ecological or conservation agriculture – can significantly increase soil water retention and filtration to help ensure improved availability. Sustainable land management (SLM) and ecosystem restoration represent "win-win" investments that benefit multiple sectors and stakeholders operating within the nexus of food and water security.

Soil vulnerability to erosion can be assessed through a wide set of lab methods such as direct field measurements with sediment collection (*e.g.* sediment traps); radionuclides measurements (both field and lab applications); estimate models such as the revised universal soil loss equation (RUSLE) applied at plot, catchment and regional scales.

Among the recently used methods for soil erosion estimation, RUSLE-derived models are widely applied in heterogeneous mountain environments. However, validations for non-agricultural systems are scarce, and the performance of the methods is still controversial. Recently, discrepancies have been noted between estimation models and radionuclide measurements (*e.g.* 137Cs) on mountain slopes – differences attributed to erosion processes that take place in winter such as snow-induced erosion from snow gliding and full-depth avalanches.


Land slips are common in Ecuador's eastern Andes.
Upper Mazar watershed, Cañar, Ecuador
(Fundación Cordillera Tropical)

Gallreide (Austrian Service for Torrent and Avalanche)

A correction factor for RUSLE estimates accounting for snow-driven erosion has been proposed in the last years for the Alps by Konz *et al.* and by Stanchi *et al.* Sets of indicators of physical vulnerability have been introduced and tested for mountain soils by several authors in a variety of environments, from the Mediterranean to the Alps for Europe, giving promising results. These indicators are related to soil aggregate stability (*e.g.* aggregate breakdown curves), and soil liquid and plastic limits, describing soil consistence and resistance. Applications are available for both natural ecosystems and agro-ecosystems, and can be adapted to different environmental contexts.

Considering the wide range of processes affecting mountain soils, and their potential on-site and off-site effects, hazard and risk assessment are essential. Linking soil properties with extreme event thresholds is fundamental for improving knowledge of soils and mountain ecosystems, and would be a relevant step in mountain hazard studies.

Moreover, civil protection and preparedness are becoming fundamental for mountain populations. Best practice and management suggestions that target local conditions are needed to mitigate soil vulnerability and to cope with the issues of anthropogenic impacts and climate change. In particular in drylands, the sustainable management of natural resources must be ensured in order to promote conservation and rehabilitation of land as well as of freshwater resources. This will lead to the enhancement of community drought resilience and increase understanding of other risks associated with water scarcity and land degradation in mountainous areas and related lowlands. Furthermore, sustainable landscape management over large territorial units is required to maintain the functionality and sustainability of highlands and lowlands in dryland systems.

The United Nations Convention to Combat Desertification (UNCCD) promotes a wide range of such measures with the aim of enhancing sustainable environmental and natural resource management. This work is based on the understanding that the conservation, protection and rehabilitation of land together with freshwater resources are essential components of any policy that targets the protection of natural resources and the environment. This also incorporates the enhancement of community resilience to drought and other risks associated with water scarcity and land degradation.

Rotational grazing in Tajikistan

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During the Soviet era the steep mountain slopes in the Faizabad district were intensely cultivated, which led to severe soil degradation. Rotational grazing is an option for sustainable land use in these areas. Farmers near the Karsang and Tshinoro mountains applied a rotational scheme of 10 to 14, dividing a grazing day into a grazing period of four hours in the early morning and a later period in the afternoon. The dung left by the animals enhances soil fertility. The dung favours palatable species and compensates for the fertilizers that used to be applied in the Soviet era. The applied rotational scheme also has the advantage of having fewer trampled paths than the overgrazed village pastures.

A farmer cultivating soil for fruit crops of grapes and pomegranates. Hosilot, Tajikistan (@FAO/Vasily Maximov)

Large-scale hydrological and agricultural water harvesting

Sven Walter and Luisa Vanderwegen

Many mountain peoples have developed large-scale hydrological and agricultural water-harvesting infrastructure to overcome water constraints. Water harvesting by early farmers was probably pivotal in the emergence and diversification of food production, the domestication of plants and animals, and the shaping of ecocultural landscapes. For example, the Inca civilization in the central Andes had a social organization based on water management and work sharing and cooperation. Irrigated terraces play an important role in protecting soil against erosion and in maintaining agricultural fertility, but they are also cultural and landscape elements that provide a strong identity for numerous mountain landscapes in the Mediterranean basin from North Africa to southern Europe and the Levant area of Southwest Asia.

Dry lands. Purulia, West Bengal, India (@UNCCD/Aniruddha Pal)