Adaptation to climate change induced water stress in major glacierized mountain regions

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Mountains are a critical source of water and home to a large proportion of the world's population. Cryospheric and hydrological changes combined with increasing water demand are impacting water availability, livelihoods and cultural values, threatening long-term water security of downstream populations. Here, we present a global systematic review in which 83 peer-reviewed articles were critically evaluated to unravel and assess different types of adaptation measures that have been undertaken to manage water stress. We observe that changes in glacier extent and snowfall amount are the main cryospheric changes motivating adaptations. However, changes in precipitation patterns, such as increasing extremes or alterations of the rain-snow line, which lead to both increasing water stress and seasonal flooding or glacier lake outburst floods (GLOFs), and are also observed to be important motivators of adaptive actions. The main sectors affected by hydrological and cryospheric changes are agriculture, tourism, hydropower generation and health and safety. To reduce risks of water scarcity and water-related disasters, and to enhance the resilience of human and natural systems, a broad set of adaptation measures have been implemented in the world's mountain regions. Such adaptations include crop diversification, new irrigation practices, dams and water storage infrastructure, training programs and the establishment of Early Warning Systems, artificial snow making, shifts to non-snow-based tourism, and changes to cultural practices. We find that globally the most commonly used adaptation practices correspond to the improvement of water storage infrastructure, agricultural and irrigation practices, economic diversification and water governance and laws. However, our systematic review reveals these and other adaptation actions have strong regional variation. For example, adaptation in the agricultural sector is most prevalent in Africa, Asia and South America; while in Europe, Australia and New Zealand responses in the tourism sector are more common. Socio-ecological trade-offs associated with adaptations are often reported. For example, the promotion of snow-making reduces socio-economic vulnerability but adds pressure on water resources and environment.
However, successful implementation of adaptation measures are limited by a diverse set of factors. This includes reduced capacities and resources in infrastructure maintenance, mismanagement, conflicts and mistrust in government together with lack of funding and insufficient collaboration between stakeholders as well as delayed implementation of laws and mountain development programs. Moreover, extreme events and climate change impacts together with discontinuities and errors in climate data need to be considered. In order to address or overcome these limitations, it is important to raise awareness of local communities about climate change and to demonstrate the positive effects of adaptation measures and environmental laws; increase funding for mountain programs and motivate combined activities of governments and stakeholders to build their trust on each other.