Abstract

Mountain regions and lowland agriculture are fundamental players in the hydrological cycle. Mountains act as water storage and regulators, supplying meltwater and rainwater to downstream communities, while lowland agriculture is one of the largest anthropogenic users of these water resources through irrigation withdrawals. Irrigated agriculture is responsible for 60–70% of total freshwater withdrawals with two-thirds depending directly on runoff originating in mountains. The link between mountain regions and lowland areas, however, is not limited to the supply of seasonal meltwater but expands to atmospheric moisture exchanges that contribute to local precipitation. In fact, evapotranspiration from mountain regions releases water vapour into the atmosphere, which is then transported by local winds and large-scale circulation and contributes to precipitation over lowland areas, influencing agricultural water availability. While the riverine connection depicts a giver upstream and a receiver downstream, in the atmospheric connection, the link is not unidirectional: lowland agriculture can act as a source of atmospheric moisture contributing to precipitation on the Alps.

Despite the growing attention and identification of the existing interactions between mountains and lowlands through atmospheric pathways, the connections remain poorly quantified and understood, especially for what concerns lowland agriculture. At the same time, even though riverine linkages have been more extensively studied, quantifying regional-scale agricultural dependence on irrigation water remains challenging. In the context of projected changes in river water availability, these knowledge gaps limit the effectiveness of water management and policy planning. This highlights the need for reliable agro-hydrological modelling approaches to support water governance strategies in sustainable water allocation and reducing agricultural vulnerability to climate changes.

To shed light on these gaps, we investigated mountain–lowland interdependencies through three complementary approaches: (i) the development and application of a physically-based agro-hydrological model to quantify crop irrigation water requirements; (ii) assessment of lowland dependence on alpine evapotranpiration through the quantification of Alpine contributions to lowland precipitation thanks to the coupling of moisture-tracking data and high-resolution reanalysis; and (iii) evaluation of the atmospheric moisture fluxes from lowland agriculture to high alpine catchments through the combined analysis of glacier ice samples and moisture tracking

Our results assessed the performance of the here-presented and newly developed agro-hydrological model WaterCROPv2 in evaluating irrigation water demands. We show how it is able to provide reliable estimates of irrigation water demand consistent with independent datasets and previous local studies. Applying it to the Italian maize cultivation, we proved its suitability and the advantages of using it as a decision-support tool for water management at the regional scale. The analysis identified regions where maize production is climatically sustainable and others where it is highly water-demanding, showing the application as a tool to define better water allocations. Furthermore, thanks to the flexibility of the model to test alternative irrigation strategies, simulations evaluated that a complete transition to micro-irrigation could reduce irrigation water use by an average of 21% with potential savings of up to 30–40% in areas with currently low efficiency irrigation systems. Beyond these riverine dependencies, the results also highlight the importance of atmospheric pathways linking mountain and lowland systems. Atmospheric analysis revealed that Alpine evapotranspiration contributes, on average, approximately to 5% of annual precipitation over agricultural land in the Pianura Padana, increasing to up to 7% in localized hotspots. Single sink locations highlighted the local nature of agricultural dependency from Alpine evapotranspiration, hinting at the existence of stronger convective seasonal fluxes. Furthermore, even though moisture transport from the Pianura Padana back to the Alps is weaker, localized feedbacks exist, especially between the western plain and the central Southern Alps. We show the relevance of moisture transport from lowland agricultural land to the Alps providing evidences on the detection of pesticide, agriculture-born pollutants, in the water of the high alpine SteinWasser stream. Specifically, we report the results from the field work carried out to collect ice and snow samples from the surface of Steingletscher, the glacier upstream of SteinWasser, to determine whether the glacier acts as a secondary source of pollutants or pesticide inputs are ongoing. Moisture tracking analysis showed the marked atmospheric link to the surrounding areas, depicting potential sources of pollution.