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*Original*

Characterizing Recharge Dynamics of Mountain Springs in Aosta Valley (NW Italy): A Combined Harmonic and Isotopic Investigation / Gizzi, Martina; Biamino, Luca. - ELETTRONICO. - EGU25-6491:(2025). ( EGU General Assembly 2025 Vienna 27 April - 2 May 2025) [10.5194/egusphere-egu25-6491].

*Availability:*

This version is available at: 11583/2998365 since: 2025-03-18T14:39:36Z

*Publisher:*

EGU

*Published*

DOI:10.5194/egusphere-egu25-6491

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(Article begins on next page)

EGU25-6491, updated on 18 Mar 2025

<https://doi.org/10.5194/egusphere-egu25-6491>

EGU General Assembly 2025

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## Characterizing Recharge Dynamics of Mountain Springs in Aosta Valley (NW Italy): A Combined Harmonic and Isotopic Investigation

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Mountain hydrology and hydrogeology in the European Alps have been impacted by climate change, land use modifications, and evolving water consumption patterns. These factors have affected drought and flood dynamics, evapotranspiration, snow-to-rainfall ratios, and spring recharge mechanisms, introducing new rainfall patterns linked to increased average air temperatures. Consequently, understanding balance fluctuations in alpine aquifers is critical for predicting future water availability in mountain regions.

This study investigates hydrogeological dynamics at the catchment scale through the analysis of selected mountain springs in the Aosta Valley Region (northwestern Italy), specifically Promise Spring (1580 m a.s.l.), and Entrebin Spring (981 m a.s.l.). Given the complexity of contextualizing spring behavior within a rapidly changing climatic framework, innovative methodologies are required for a more detailed characterization of the inputs feeding the aquifers. Fast Fourier Transform (FFT) analysis of hydrograph signals was applied to decompose environmental variables, enabling the identification of physical relationships between flow rate, temperature, and precipitation signals. Additionally, isotopic analyses of water samples, conducted according to V-SMOW2 standards, provided valuable insights into the origin and flow paths of groundwater recharge, leveraging the utility of Oxygen-18 and Deuterium for hydrogeological applications. The altitude of rainfall or snowfall deposition was subsequently determined using empirical relationships derived from the literature.

The integration of these two independent analysis techniques facilitated a comprehensive understanding of the nature and origin of water inputs feeding the springs. Moreover, the study elucidates the influence of climate change on the variability of spring discharge over both short- and long-term timescales. The findings contribute to a more detailed understanding of aquifer recharge dynamics and provide critical insights for the sustainable management of water resources in alpine regions. Their application to drinking water sources holds significant social implications, fostering more effective resource management strategies in the face of climate-sensitive variations.