

# Evaluating the Vulnerability of Mountain Springs: A Case Study in Italy to Prioritize Conservation and Management Strategies

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## INTRODUCTION, AIM and METHODS

This research introduces a methodology for evaluating the protection zone of vulnerable mountain springs using a hydrogeochemical approach. These resources frequently serve as the primary freshwater supply in numerous mountainous regions. In this study, we assess the vulnerability of two small mountain springs named **Laron** and **Canchero**, situated in Northern Italy. These two springs are situated in the Cansiglio-Cavallo Massif, a vast karst area situated in Veneto region (Fig. 1).

The main goal is to assess the geochemical and hydrological processes that control the springs water quality and use them for formulating effective springs protection measures.

The two springs were monitored for about three years (2019-2021). Continuous hydrological data (CTD) and water samples for chemical, physical, and isotopic analyses ( $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ ) were collected. In addition, monthly average isotopic composition of precipitation of the area was monitored through the installation of two rain gauges: Vittorio Veneto (VIT, 147 m) and the other at Pian Cansiglio (CLR, 1065 m). Additionally, hourly meteorological data were acquired from two ARPAV stations.

$\delta^{18}\text{O}$  and  $\delta^2\text{H}$  of the samples were determined by IRMS ( $\text{CO}_2\text{-H}_2\text{/water}$  equilibration method) and about 5% of samples were analyzed by CRDS.

To assess the vulnerability of the springs we used the Vespa index [1], which is based on the joint use of flow, temperature, and specific electrical conductivity measurements obtained from monitoring the spring for at least one hydrological year and with hourly or bi-hourly frequency. Additionally, the VESPA index was calculated to define the protection zones of the two springs. The index is defined as  $V = c(\rho) \cdot \beta \cdot \gamma$ . The VESPA index was computed based on hourly data gathered by CTD probes throughout the entire monitoring period for both springs. The values of  $V \geq 10$ ,  $1 \leq V < 10$ ,  $0.1 \leq V < 1$  and  $0 \leq V < 0.1$ , are assigned for a very-high, high, medium and low vulnerability, respectively.

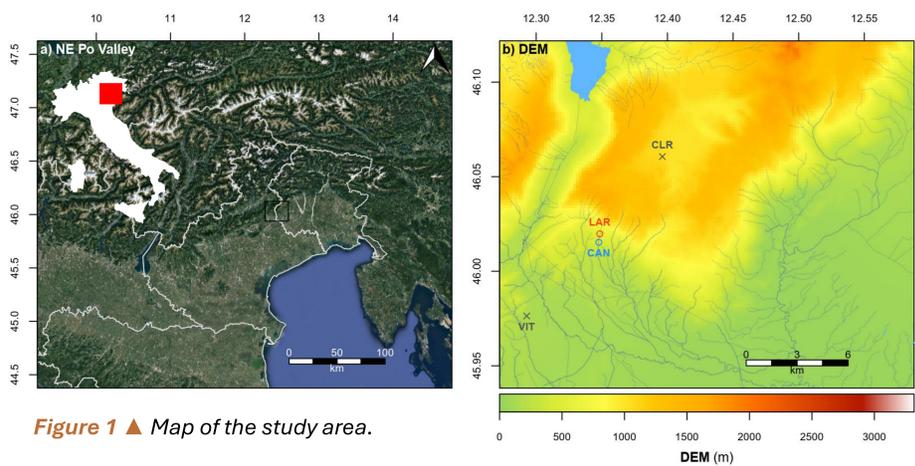


Figure 1 Map of the study area.

## HYDROLOGICAL DATA of the SPRINGS

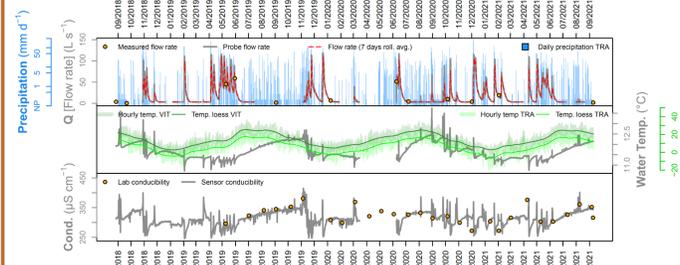


Figure 2 Hydrographs of Laron spring.

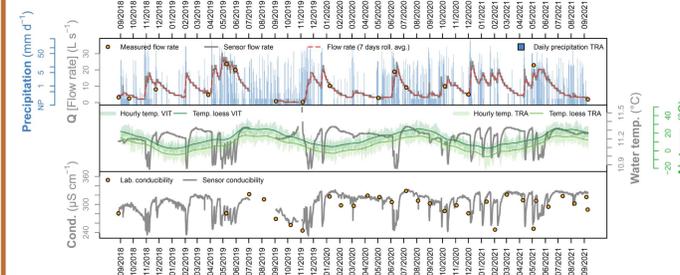
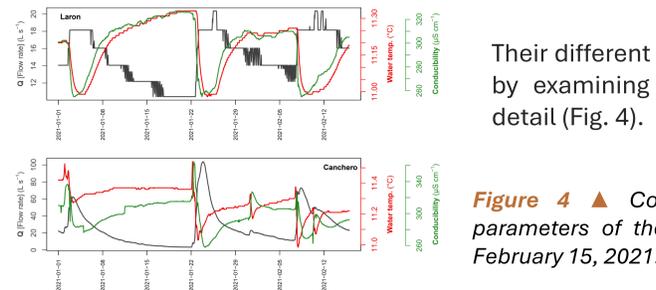


Figure 3 Hydrographs of Canchero spring.



Their different behavior is particularly clear by examining a specific period more in detail (Fig. 4).

Figure 4 Comparison of the hydrological parameters of the two springs for January 1 to February 15, 2021.

## HYDROGEOCHEMICAL DATA of the SPRINGS

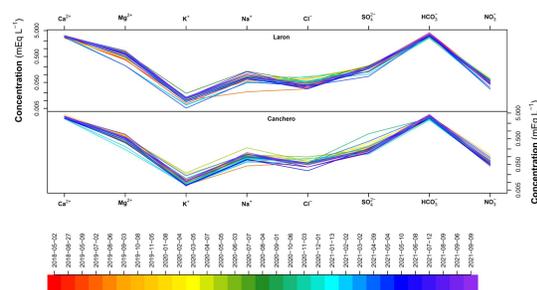


Figure 5 Major ions composition of Laron and Canchero springs

The peaks discharge of both Laron and Canchero springs are pronounced in response to significant precipitation events (Figure 2 and 3). However, the hydrographs show some differences in the recession curves. Laron exhibits a less steep slope compared to the Canchero's recession phases, suggesting a deeper aquifer circuit feeding Laron compared to Canchero.

## ISOTOPIC DATA of PRECIPITATION and SPRINGS

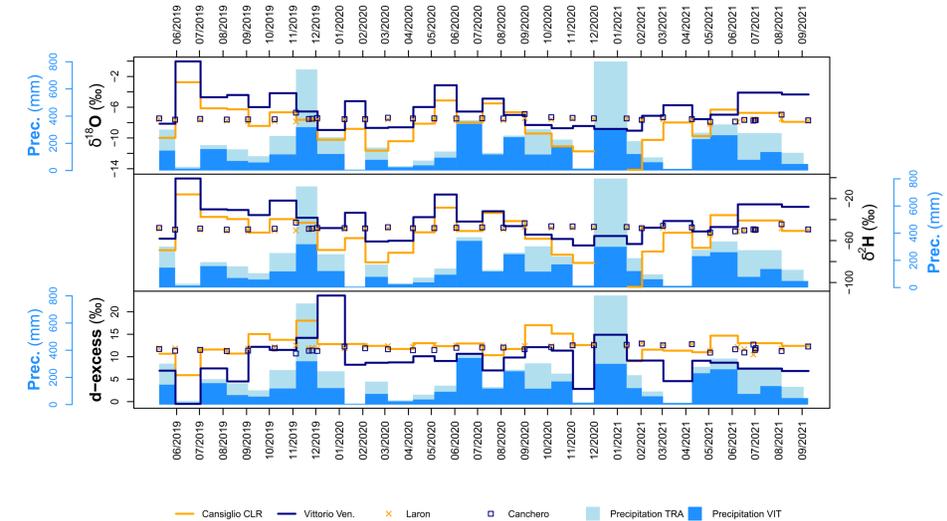
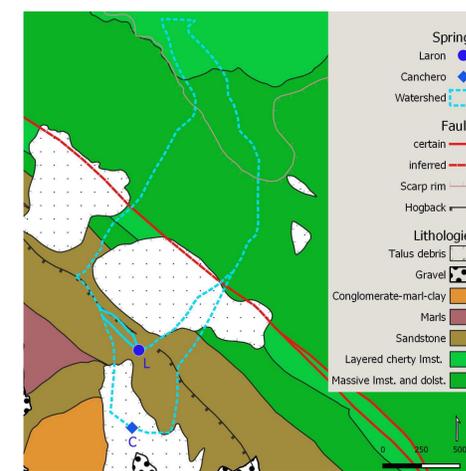


Figure 6 Temporal variation of  $\delta^{18}\text{O}$ ,  $\delta^2\text{H}$ , and  $d$ -excess measured in Laron and Canchero springs together with the monthly amount and isotopic composition of the precipitation sampled in the rain gauges in CLR and VIT.

## SPRING RECHARGE ELEVATIONS and VULNERABILITY

Table 1 VESPA index's results.

|                 | $\beta$ | $\gamma$ | $\rho$ | $V$  |
|-----------------|---------|----------|--------|------|
| <b>Laron</b>    | 0.51    | 3.37     | -0.33  | 0.56 |
| <b>Canchero</b> | 9.11    | 6.51     | -0.59  | 35.2 |



The mean  $\delta^{18}\text{O}$  values of Laron (-7.7 ‰) and Canchero (-7.5 ‰), along with an elevation gradient of -0.17 ‰/100m, suggests a mean recharge elevation of 630m and 550m, respectively.

Laron spring had a  $V$  value of 0.56, indicating a medium vulnerability. Canchero spring had a  $V$  value of 35.2, indicating a high vulnerability level.

Figure 7 Map of the areas for Laron spring delineated using VESPA index and evaluating the drainage basin.

Both springs have a bicarbonate-calcium geochemical facies. The small differences between the two springs are detected in the average concentrations of  $\text{Mg}^{2+}$  and  $\text{K}^{+}$  that in Laron are slightly higher compared to Canchero (Figure 5), whereas the average concentration of  $\text{Ca}^{2+}$  and  $\text{Na}^{+}$  cations is lower.