



Infiltration-driven transport of quarry suspended material in the karst aquifers of the Apuan Alps (Tuscany, Italy)

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Introduction

- Quarrying of the famous **Carrara marble** developed across the centuries starting from the Etruscan age and has hugely increased in the last decades.
- Nowadays, the **Apuan Alps quarry district** produces about **1.5 Mt of marble** and about **3 Mt of quarrying by-products** and **wastes** which cause several environmental issues: water and air pollution, increase of hydrogeological risks.
- The Regional Environmental Agency of Tuscany (ARPAT) and the DST-UNIFI are carrying out a project to assess the infiltration dynamics and transport mechanism of the marble powder ("*marmettola*") which causes **severe pollution episodes** (Fig. 1) in the Apuan karst aquifers.



Fig. 1. Tana dei Tufi spring before (top) and after (bottom) a pollution event.

Results and Discussion

- Cartaro** is the spring that has most frequently exceeded the **300 NTU** threshold during the monitored years (20-30 events/year). Relationships between rainfall and turbidity is evident (Fig. 3).

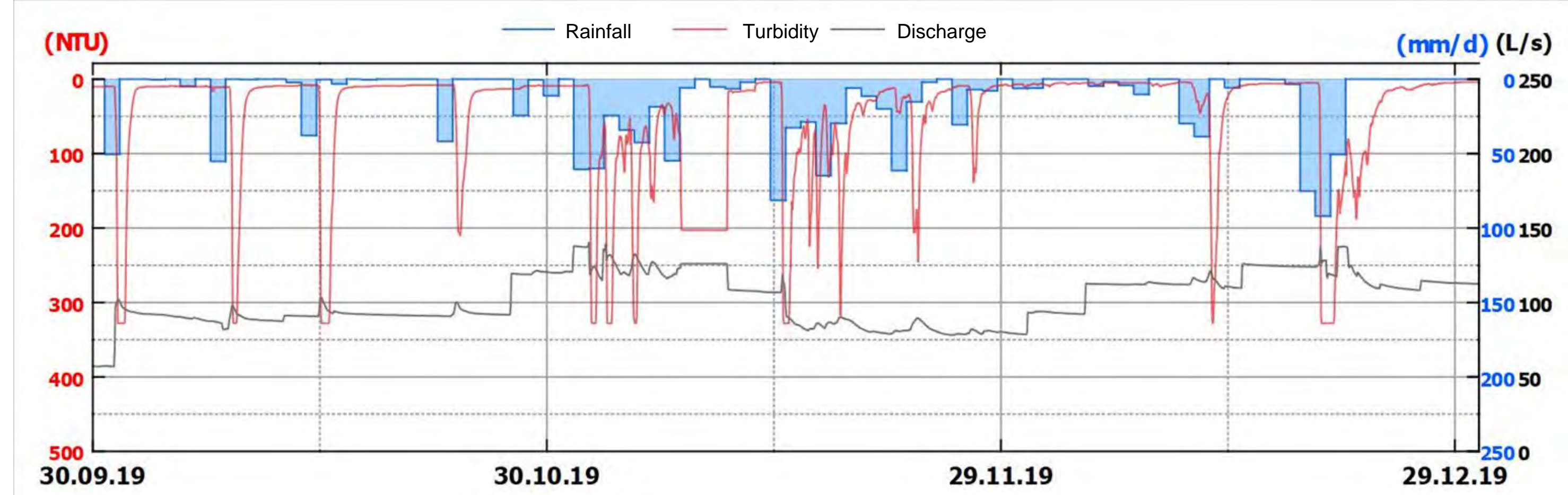


Fig. 3. Turbidity (red line) peaks occurred in the period 23/09 - 24/12/2019 (reversed scale) at Cartaro spring, compared to rainfall and discharge of water sent to the capturing plant .

- Other springs have a more complex behaviour due to the wider catchment area and to a complex groundwater system. In these cases, although turbidity is still associated with flood events, a direct correlation between total rainfall and the number and the amount of turbidity threshold events is not evident.
- At the Equi Terme spring** (Fig. 4), major turbidity events occur during or shortly after the strongest rainstorms, but turbidity can easily exceed 100 NTU also during low discharge phases, demonstrating a direct connection between quarry sites and springs.

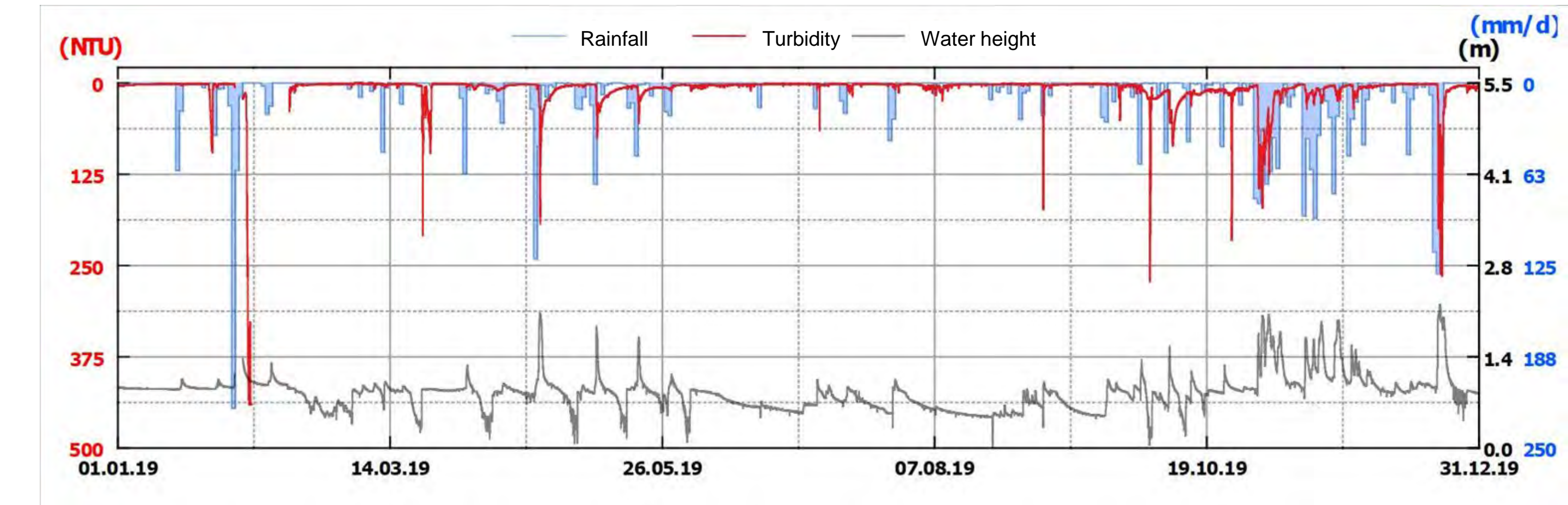


Fig. 4. Turbidity (red line) peaks occurred in the year 2019 (reversed scale) at Equi spring, compared to rainfall and discharge.

- At Equi spring (Fig. 5), higher turbidity peaks occurred after a period with low rainfall. Conversely, long lasting rains do not always cause turbidity events probably because deposits have been washed away from the aquifer by previous rainfall.

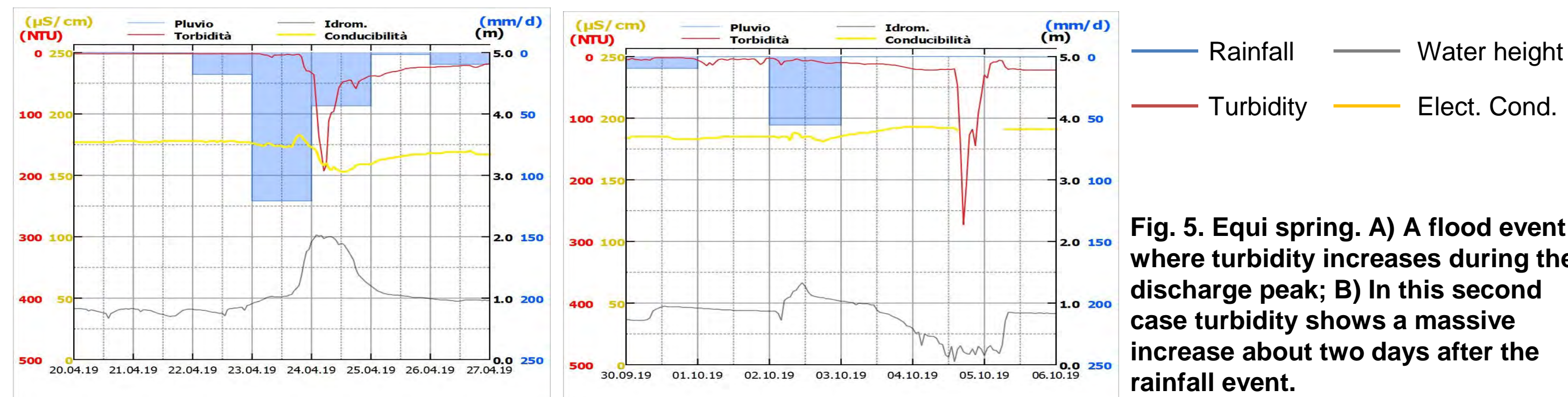


Fig. 5. Equi spring. A) A flood event where turbidity increases during the discharge peak; B) In this second case turbidity shows a massive increase about two days after the rainfall event.

Study area and methods

The Apuan Alps (Fig. 2)

- One of the most relevant karst areas of Italy (approx. 140 km²), more than 1400 caves.
- Total karst discharge is about 6 m³/s. Spring discharges range from 20 L/s (Q) to 1.6 m³/s, average 80-100 L/s.
- About 150 active quarries nowadays.
- Marble quarrying, block squaring and transport produce a huge amount of slurry that represents about 4.3% of total production.

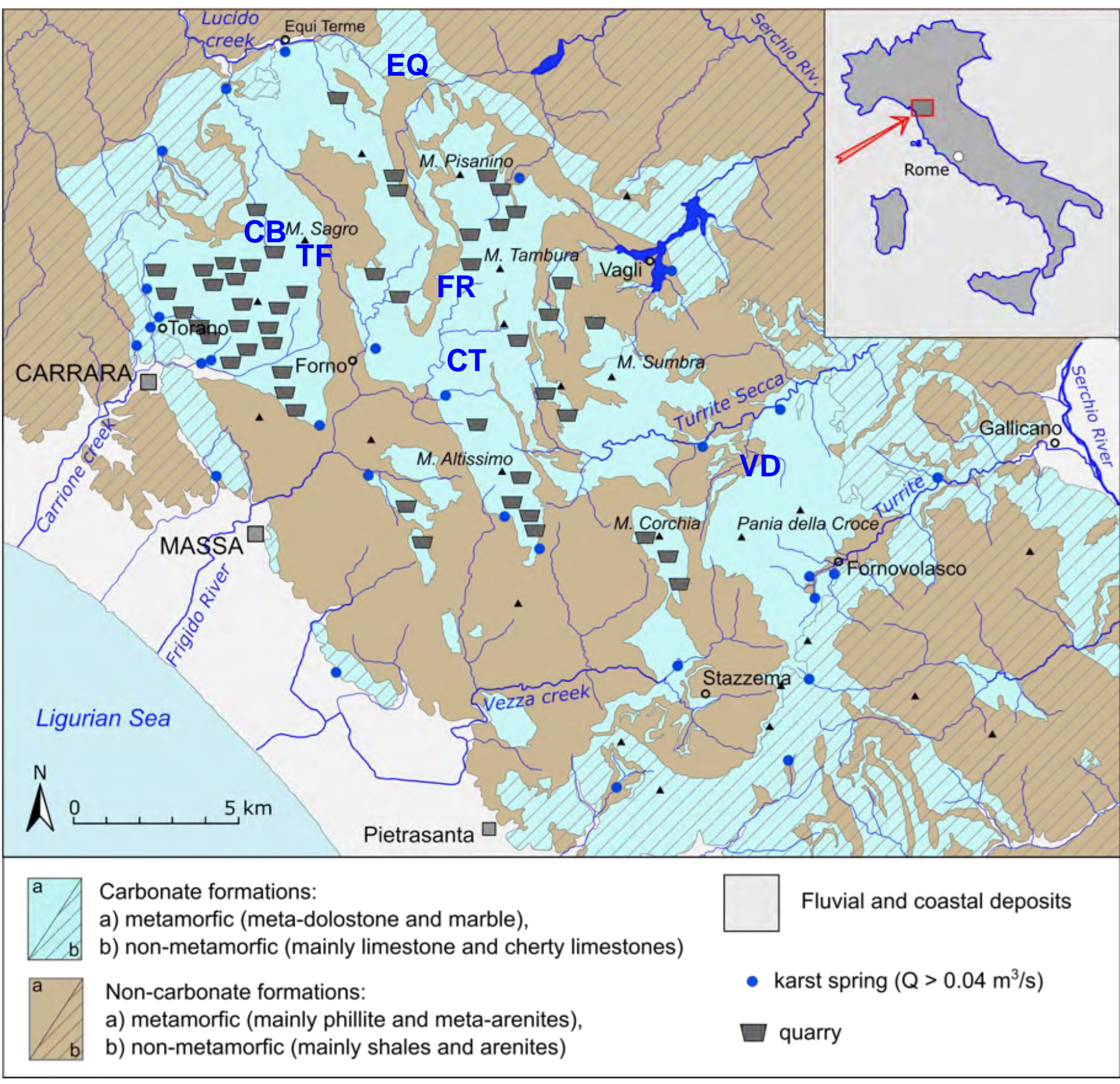


Fig. 2. Simplified hydrogeological map of the Apuan Alps, the monitored karst springs are highlighted (Piccini et al., 2019)

Methods

- Analysis of the monitoring data collected from 2019 to 2024 in some of the main Apuan karst springs (Fig. 2): Equi Terme (EQ), Forno (FR), Cartaro (CT), Carbonera (CB), and Tana dei Tufi (TF), and the underground river of the Monte Corchia karst system (VD).
- Monitored parameters: water level (wl), turbidity (NTU), temperature (T), and specific electrical conductivity (EC_{sp}).
- Definition of turbidity thresholds for pollution investigation: 10 ≤ NTU < 50, 50 ≤ NTU < 100, 100 ≤ NTU < 300, 300 ≤ NTU.
- Conversion of NTU to transported mass when Q data available (after Drysdale et al. 2001).

Concluding remarks

- Among the monitored springs, Cartaro, Carbonera and Tana dei Tufi fall within areas of high quarrying activity. Since these springs are fed by small karst systems (1-6 km²) and characterized by a relatively simple structure, a close relationship is observed between turbidity and infiltration, and therefore high turbidity events are frequent.
- The Equi and Frigido springs have much larger catchment areas (25-35 km²) and are fed by complex karst systems. Different behaviours are observed depending on rainfall regime and flow rate. Sediment transport is particularly abundant during the first heavy autumn rainfall.

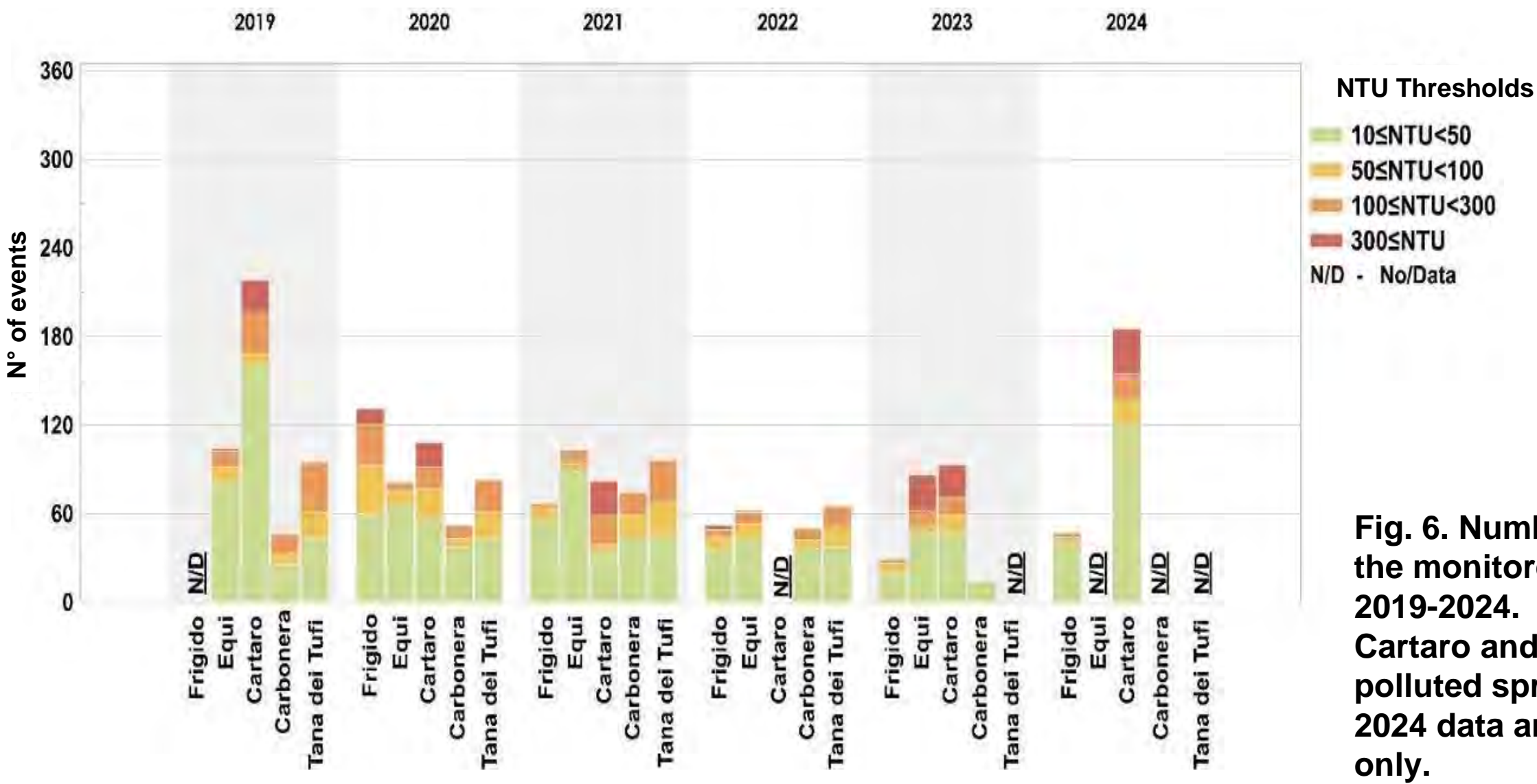


Fig. 6. Number of turbidity events at the monitored springs in the years 2019-2024. Cartaro and Equi are the most polluted springs. 2024 data are available for two springs only.

References

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