Managed Aquifer Recharge (MAR) to reduce aquifer vulnerability to climate change and to control groundwater declining yields

Introduction

Owing to increasing domestic, agricultural, and industrial demand, groundwater resources are under immense pressure (Siebert et al., 2010). Populations in arid and semi-arid regions of the world are highly dependent on groundwater to meet their freshwater needs because of insufficient surface water resources (Boretti & Rosa, 2019). Moreover, extreme events, such as floods and droughts caused by climate change, often result in scarcity of water when required and vice versa. These climate extremes are expected to further intensify by climate change (Scanlon et al., 2016).

Similarly, water demand in Europe has increased gradually over the last 50 years due to climate change (frequent drought events), increased agricultural demand, urbanization, and growing tourism, etc. In the year 2020, Italy emerged as the leading country within the European Union (Eu27) in terms of the absolute volume (9.2 billion m^3) of fresh groundwater abstracted for public water supply (Figure 1). In terms of per capita, there was a significant gap between member states. Italy secured its first position with 129 m3 per inhabitant, followed by Croatia (100), Slovenia (82), Austria (77), Greece (70), Denmark (68), Bulgaria (63) and France (53), etc (Istat Water Statistics, 2021).

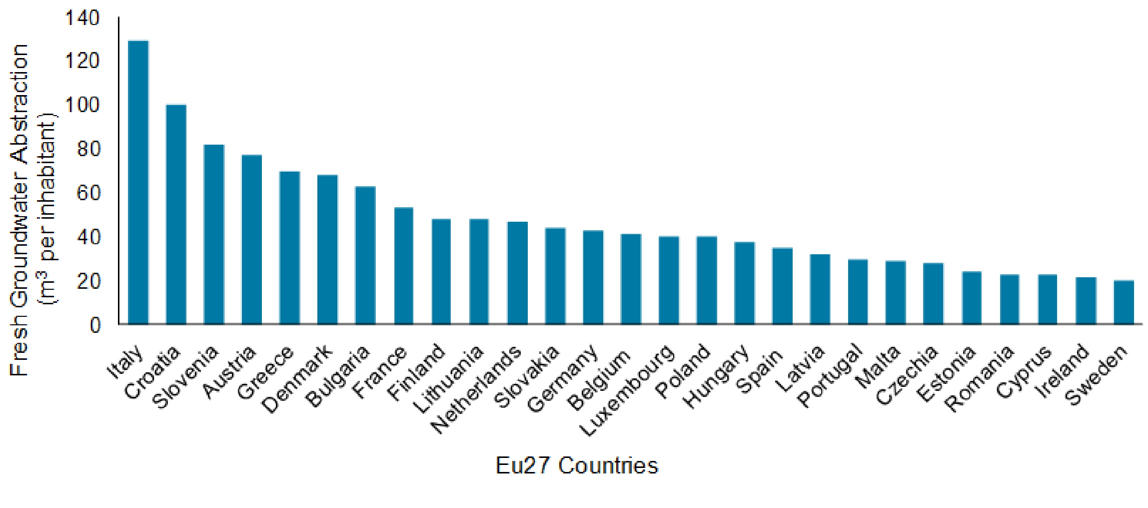

Fig. 1: Fresh groundwater abstraction rate (m^3 per inhabitant) as of 2020 in Eu27 countries (Istat Water Statistics, 2021).

Managed Aquifer Recharge (MAR)

To overcome the impact of extreme climate events and the current pattern of groundwater depletion, water management strategies need to be changed. Managed aquifer recharge (MAR) is being increasingly practiced worldwide as a water management strategy to increase surface water infiltration and storage in underground space. The idea of MAR is to infiltrate water into partially depleted aquifers to enhance sustainable groundwater supply from aquifers (Dillon et al., 2019). In contrast to the other methods of management of water resources, the MAR technique offers important advantages for protecting the aquifers from the impact of hydrological and climate changes, restoring depleted aquifers, decreasing evaporation loss, improving water quality, controlling land subsidence, and preventing saline intrusion (Dillon & Arshad, 2016). An integral part of a MAR project is the availability of high-quality source water.

Hydrogeological Setting of the Friuli Venezia Giulia (FVG) Region

The FVG region in northeastern Italy has also experienced an imbalance in its hydrogeological system over the years, resulting in a decrease in groundwater levels. The Friuli Plain covers an area of approximately 2900 km^2 and contains a thick, unconfined, and multilayer aquifer system. Several rivers, i.e., Torre, Natisone, Cormor, Tagliamento, Meduna, and Cellina, flow through the Friuli plain. The sediment distribution resulting from the flow of currents from north to south towards the Adriatic Sea divides the Friuli region into two distinct zones:

- **High plain**: An unconfined aquifer system comprising mainly gravels with some fractured conglomerates, which mainly relies on precipitation and surface water as its water sources.
- **Low plain**: Consists of silty-clayey and sandy deposits forming the multilayer confined aquifer system, which is primarily fed by the water released from the unconfined aquifer of the high plain.

The transition between the two aquifers is highlighted by the “springs line” that extends in an east–west direction for about 100 km (Martelli & Granati, 2010; Teatini et al., 2015).

Evidence of Groundwater Decline

The lowering of piezometric levels in the phreatic aquifers of the FVG plain resulted mainly from climate change impacts, including reduced and variable precipitation patterns and temperature increases (Figure 2). The analysis of piezometric data, conducted on three wells of the regional monitoring network (Ufficio Idrografico) in the Mereto di Tomba area for the period 1976–2022, showed an average decrease in piezometric levels of 3 m.

The analysis of climate data collected by the regional network for the FVG plain and processed by ARPA FVG—OSMER (ARPA FVG, 2018) for the 1974–2022 period shows the average temperature increase was 0.3 °C every 10 years, with a clear accelerating trend in the most recent decades, with a summer rate of increase of 0.4°C per decade.

The precipitation data showed a statistically significant average decrease in eastern areas (Udine district). For these areas, a decrease in precipitation of up to 15–20% can be estimated for the period. Considering the Udine weather station, the analysis of climate indicators shows with regard to precipitation, a decreasing trend with values of—90 mm in the period 1961–2022, an increase in the frequency of negative deviations from the average of the 30-year reference period 1991–2020, a reduction in spring and summer precipitation, an increase in intense rainfall, and long drought periods (WMO, 2015). These changes in the hydrologic regime have resulted in a decrease in direct infiltration and an increase in the surface runoff and evapotranspiration rate, thus affecting both the surface and groundwater resources in the region.

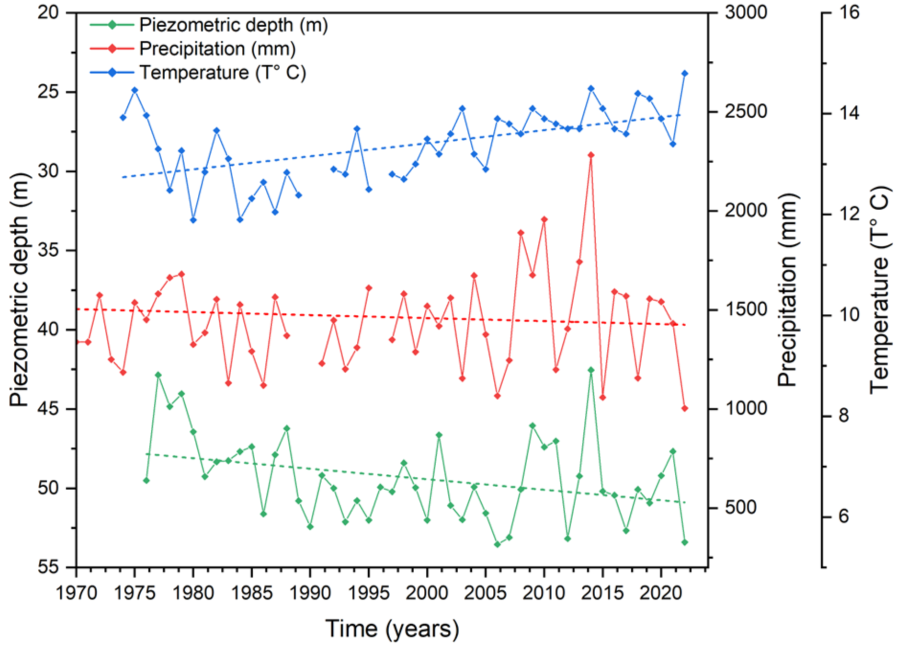

Fig. 2: Historical trends of piezometric levels, temperature, and precipitation in FVG region (ARPA FVG, 2018; WMO, 2015).

MAR Perspective in the Friuli-Venezia Giulia Region of Italy

To deal with the declining water resources and enhance the underground storage of high-quality surface waters, three recharge plants (Carpeneto, Mereto di Tomba, and Sammardenchia, located to the east of Tagliamento River in the upper FVG plain, were built by the local water reclamation authority in 2001. However, the systems could not become functional because of a lack of reference legislation (DM 100/2016) on MAR at that time, which now provides the possibility of implementing controlled recharge practices to sustain groundwater resources in the region.

The potential of MAR in this pre-Alpine region is characterized by the availability of high-quality surface waters (mainly by rivers), a number of existing structures, i.e., pits and large-diameter wells, and a highly permeable, thick aquifer system, primarily comprising gravels cemented irregularly into conglomerate layers and interbedded sand and very few clay layers (Teatini et al., 2020).

Present Study

This study focuses on the Sammardenchia area of the upper Friuli plain and employs a modeling-based approach to evaluate MAR effectiveness. First, a large-scale steady-state model was developed to reproduce the natural groundwater flow regime. This was followed by the construction of a more detailed local-scale model, in which recharge through an infiltration pond and a recharge well was simulated.

In the model, different hydraulic heads were applied to both the infiltration pond and the recharge well. The simulations were designed to assess the infiltration rates achievable from each structure and to evaluate the corresponding rise in groundwater levels within the aquifer system.

Key Findings

Results provide insight into the spatial and temporal distribution of recharge, highlighting the potential effectiveness of combining pond infiltration with well recharge for sustaining groundwater resources. The simulations highlight the potential of MAR to counteract piezometric decline and support groundwater sustainability in the high plain.

Conclusions and Future Work

The study demonstrates that MAR can effectively mitigate groundwater depletion in the Friuli Venezia Giulia region. The favourable hydrogeological setting, availability of good quality surface water, and existing infrastructure provide strong potential for future MAR projects.

Future work will extend the modeling framework to include water quality dynamics, addressing potential hydrochemical changes associated with surface water infiltration. This integrated assessment will provide a more comprehensive evaluation of MAR feasibility, ensuring both the sustainability and safety of groundwater resources in the region.

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