Adv. Geosci., 64, 27–31, 2024
https://doi.org/10.5194/adgeo-64-27-2024

Advances in Geosciences
Open Access

Off-season irrigation as a climate adaptation strategy for future groundwater management in Northern Italy

Paolo Colombo, Pietro Mazzon, and Luca Alberti

Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, 20133, Italy

Correspondence: Paolo Colombo (paolo1.colombo@polimi.it)

Received: 13 May 2024 – Revised: 22 July 2024 – Accepted: 25 July 2024 – Published: 29 August 2024

Abstract. Northern Italy is a historically water abundant region. However, it was struck by a major meteorological drought recently, which caused many damages to agriculture and other sectors. Adaptation measures to a changing climate and to extreme events is thus a growing topic and measures have to be tested and planned to be able to avoid future water scarcity. Here, a possible adaptation measure is proposed and evaluated through field tests and numerical modelling: the flooding of fields during periods of water abundance as an additional aquifer recharge. Results show that the measure has a considerable potential in infiltrating high volumes of water. This work only shows the first achieved results, more data and improved numerical models are needed to sustain this consideration and assess the feasibility of the measure, both of which will be achieved in the next years.

1 Introduction

Across 2021 and 2022, Northern Italy suffered a harsh meteorological drought due to severe precipitation deficit, with a −33 % anomaly (SNPA, 2023). This strongly affected the pre-alpine lake levels as well as rivers discharge and soil moisture (Toreti et al., 2022, 2023). Groundwater levels were also impacted, resulting in decreased water table levels (Schiavo, 2024). Future climate scenarios predict increasing temperatures and increasing ice and snow-melt contribution in the region, leading to decreased water storage in alpine glaciers and icecaps (Casale et al., 2021; Fuso et al., 2021). Snow deficit also had an impact in 2022 drought (Avanzi et al., 2024), which combined with the other factors led to harsh consequences on agriculture, industrial and power generation sectors. A necessity to be more prepared for future droughts has emerged both from public institutions and citizens, going towards an increase of the water storage capacity through different methods.

In this study, we are considering harnessing the existing irrigation network to recharge aquifers in periods of water abundance by flooding available fields, to have an available aquifer storage when surface water becomes scarce. The overall goal is to test the use of the canal network as an already existing infrastructure for managed aquifer recharge (MAR) and assess its feasibility as a possible drought mitigation strategy in the area (Levintal et al., 2022; Oberto et al., 2018; Wendt et al., 2021).

The study is being carried out in the context of the MAURICE Interreg CE project, which first results are presented here.

2 Methodology

2.1 Study area framing and adaptation practice explanation

The study area is located in the western part of Lombardy region (Fig. 1a), an agricultural-urban area, where agriculture largely relies on flooding and surface irrigation methods using Ticino and Adda rivers' water, coming from the two main sub-alpine lakes of the region: Lake Maggiore and Lake Como. Historically, autumn and winter (October to February) are characterized by surface water exceedance, due to high precipitation and river water level. This behaviour is confirmed by the last 20 years precipitation observations in Milan and river level observations for river Ticino (Fig. 1b and c, respectively). The same behaviour was observed during the 2021–2022 dry years. This excess water can thus be distributed to the fields or kept in irrigation channels during autumn and winter, to let it infiltrate and percolate to-

Published by Copernicus Publications on behalf of the European Geosciences Union.

wards the water table, increasing groundwater storage and level. The slow groundwater velocity in the area (approximately 350 m yr^{-1}) would then result in water remaining stored in the subsoil below and around the irrigated areas. The "off-season" label of this practice comes from the fact the traditional irrigation season in the region is during spring and summer months (April to September), when precipitation alone is not enough for plants subsistence and growth. Positive feedback can emerge from this approach. Since the water infiltrated would come by Ticino river which is labelled of good chemical status (Bravetti et al., 2021), groundwater quality could improve as observed in other regions (Guo et al., 2023). In case of excessive precipitation, the excess water could be even distributed on the fields mitigating flood hazard alongside drought hazard (Ward et al., 2020). Local ecological systems can benefit from increased groundwater levels: the area is characterized by peculiar lowland springs (locally called "*fontanili*") in equilibrium with the water table, which serve as biodiversity hotspots as well as an additional source of irrigation water for surrounding fields and downstream. Due to decreasing groundwater levels some of these springs are not active anymore and increasing groundwater recharge could revive their ecosystems.

2.2 Methodological approach

The measure will be tested through two methodological components: field tests and scenarios evaluation through numerical modelling. A monitoring network of groundwater levels, spring and channel discharges has been established alongside area characterization activities, with monthly measurements of groundwater levels and seasonal measurements of canal and spring flow rates. Farmers have been involved to distribute water on known and monitored fields. Groundwater flow will be modelled through MOFLOW-USG (Panday et al., 2013) while the agricultural and recharge system will be modelled using IdrAgra (Gandolfi et al., 2011). Lastly, the models are used to evaluate multiple scenarios, harnessing the data collected and considering different climate change scenarios and adaptation measures configurations.

3 First results

During 2023/24 autumn and winter seasons, a first off-season irrigation field test was carried out distributing water in the irrigation network and over fields selected through the cooperation of farmers and the irrigation consortium "Est Ticino Villoresi". A total of 32.3 ha (0.323 km^2) were continuously flooded with constant water discharges, different for each field, as reported in Fig. 2a. Figure 2b shows the difference in the monitored groundwater levels (interpolated through ordinary kriging) between the end and the start of the field test, respectively February 2024 and November 2023. The observed data do not show a clear relationship between the groundwater head change and the irrigated fields. However, those fields are located in a transition zone where differences in groundwater level pass from negative to positive (Fig. 2b), suggesting an influence of the distributed water on the groundwater head variation. Prior to the field test, an additional recharge was also simulated through a transient-state simplified MODFLOW-USG local model over a reduced area, to assess the possible impacts of the off-season irrigation practice. The meteoric recharge was estimated though SWB2.0 (Westenbroek et al., 2018) with data from 2014 to 2018 and the porosity was set to 0.15, a representative value for the sandy gravel aquifer material found in the area. To consider a scenario that includes off-season irrigation, a provisional discharge provided to each field was divided by the area of that field and added to the meteoric recharge for the irrigation period. A cumulative volume of 991 000 m^3 was thus distributed over the same areas which have been flooded during the field test, for 187 d, namely from September to March. The results are presented in Fig. 2c, as differences between the scenario considering off-season irrigation and a scenario without it. At the end of the winter recharge period a visible groundwater level increase is observed across the area, with peaks of 26 cm in the proximity of the fields and a stored volume increase of 790 800 m^3. After three months (Fig. 2c, "Start of summer"), the increase is still present at an average of 2.2 cm over a 190 km^2 area, for a resulting remaining storage volume of 573 700 m^3. This results in 80 % and 58 % of the total infiltrated volume remaining available in the shallow aquifer at the end of winter and start of summer, respectively. Figure 2b and c show two different results in two different periods, and therefore they are not meant to be compared.

4 Conclusion and future developments

Distributing available water during the non-irrigation season on agricultural fields and channels can increase water storage for the following spring and summer through groundwater recharge. In the pilot area considered in this study, first model simulations and field tests sustain this assumption. The modelled stored volume for one season, using provisional discharges lower than the ones tested on the field, is comparable to 12 small surface water reservoirs of 25 000 m^3, without the need to build new infrastructure, since the existing network is exploited. However, considering the effect of lowland springs and other local conditions (such as pit-lakes) is necessary, along with the study of longer groundwater level time series. For this last point, four new continuous groundwater level and temperature monitoring points were built alongside the manual monitoring network, close to the experimentation fields, and a new test will be performed in winter 2024/25. The model will then be improved and updated to simulate the actual field-tested irrigation flow rates, and to include local peculiarities and new data. Simulation of climate change

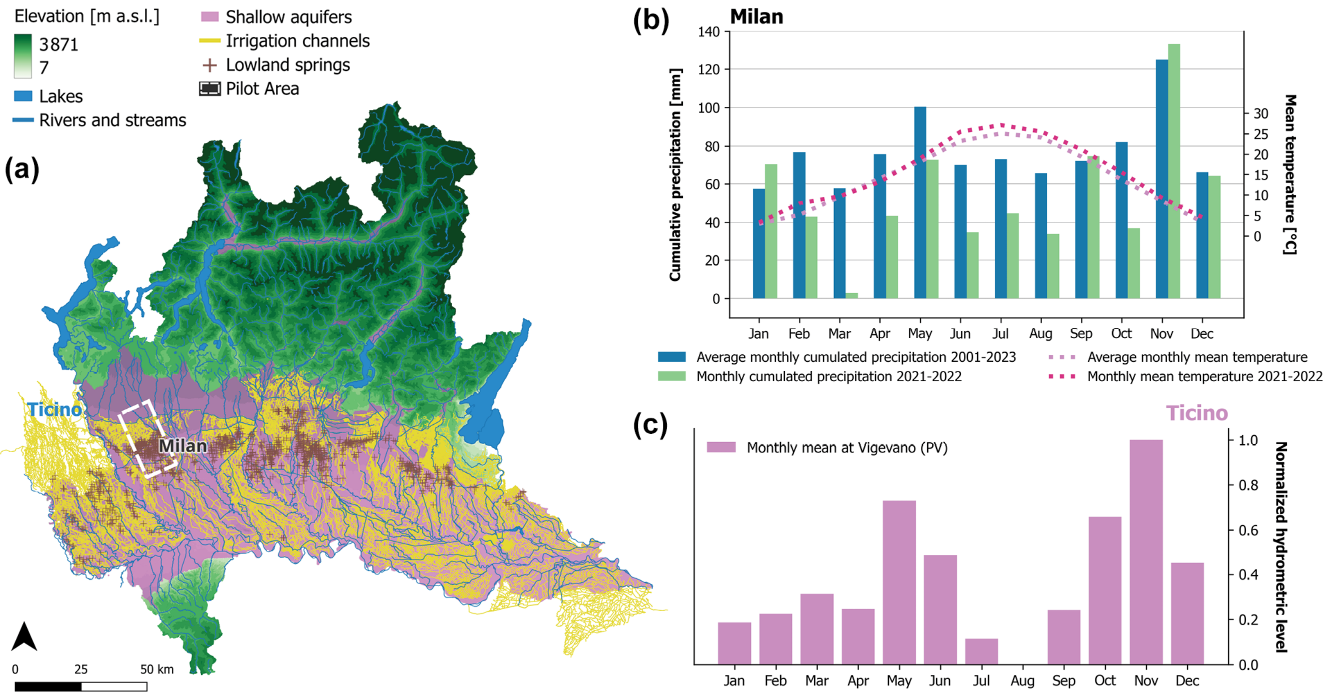

Figure 1. (a) Study area framing showing the hydrological network, the shallow aquifer system, the irrigation network and the lowland springs; **(b)** Monthly mean precipitation at Milano Lambrate station of the last 20 years; **(c)** Normalized monthly mean water level for river Ticino at Vigevano (PV) of the last 20 years.

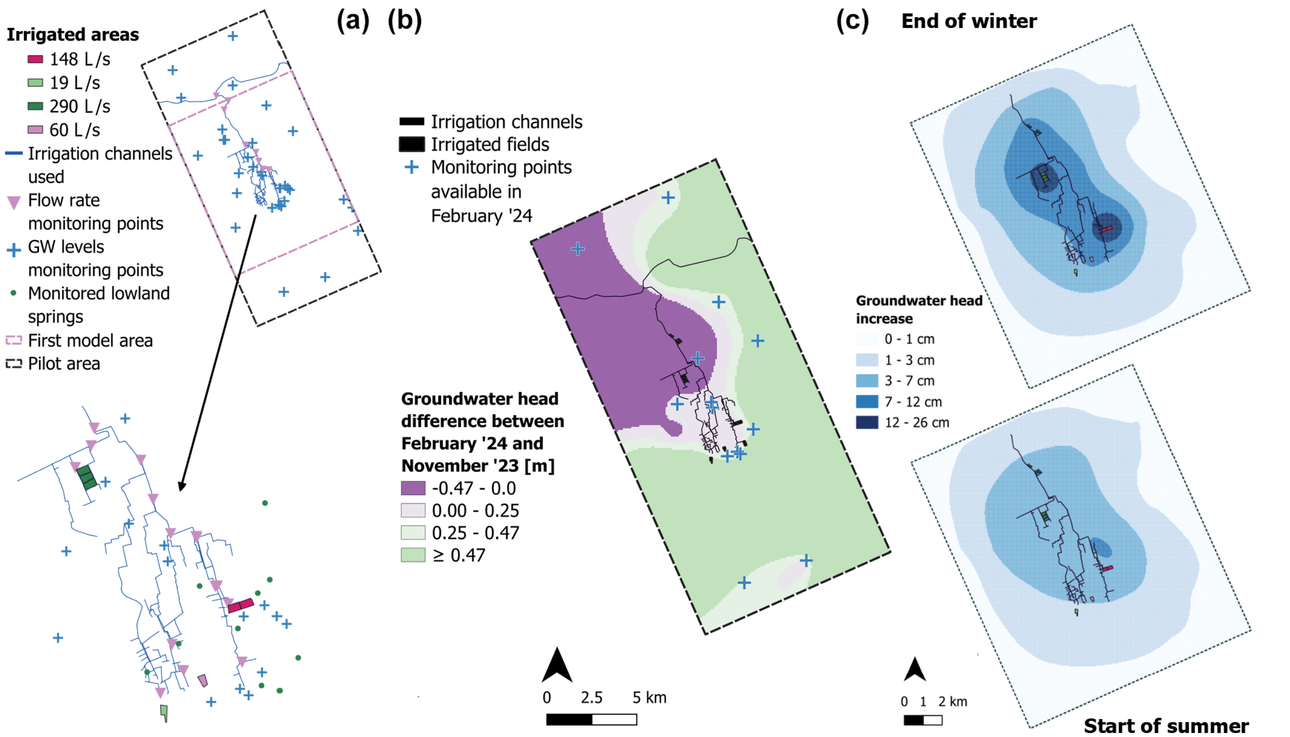

Figure 2. (a) Pilot Area with fields and monitoring network highlighted; **(b)** GW level differences between interpolated observations in February 2024 and November 2023; **(c)** GW level differences between model simulations in a winter irrigation scenario and a baseline scenario at the end of winter and at the start of summer.

and adaptation measures under different configurations will be produced, to be able to perform analyses on quantification of water storage and water deficit. Based on the test results, this adaptation measure could open opportunities and challenges to water management policies in the region and might be replicated in other areas with similar characteristics.

Code availability. The code used to generate Fig. 1b is available at Zenodo (https://doi.org/10.5281/zenodo.13378616, Colombo, 2024).

Data availability. Meteorological and hydrological data is publicly available on the Regional Environmental Authority (ARPA Lombardia) website following these instructions: https://www.dati.lombardia.it/stories/s/auv9-c2sj (ARPA Lombardia, 2024). Other data used is not publicly available at the moment since the project is still in progress.

Author contributions. PC: conceptualization, methodology, software, investigation, data curation, writing – original draft, writing – review and editing, visualization; PM: methodology, investigation, writing – review andediting; LA: conceptualization, methodology, investigation, writing – review and editing, supervision, funding acquisition.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Disclaimer. Publisher's note: Copernicus Publications remains neutral with regard to jurisdictional claims made in the text, published maps, institutional affiliations, or any other geographical representation in this paper. While Copernicus Publications makes every effort to include appropriate place names, the final responsibility lies with the authors.

Special issue statement. his article is part of the special issue "Groundwater management in the context of global change: integrating innovative approaches (EGU2024 HS8.2.1 session)". It is a result of the EGU General Assembly 2024, Vienna, Austria, 14–19 April 2024.

Acknowledgements. This research is funded by the Interreg Central-Europe programme, as part of Pilot Action Milan from MAURICE project (CE0100184): MAnagement of Urban water Resources In Central Europe facing climate change). The project involves other research and public administration entities from a total of 6 countries involved.

Financial support. This research has been supported by the Interreg (grant no. CE0100184).

Review statement. This paper was edited by Estanislao Pujades and reviewed by Thomas Riedel and one anonymous referee.

References

ARPA Lombardia: Dati di monitoraggio, https://www.dati.lombardia.it/stories/s/auv9-c2sj, last access: 9 April 2024.

Avanzi, F., Munerol, F., Milelli, M., Gabellani, S., Massari, C., Girotto, M., Cremonese, E., Galvagno, M., Bruno, G., Morra di Cella, U., Rossi, L., Altamura, M., and Ferraris, L.: Winter snow deficit was a harbinger of summer 2022 socio-hydrologic drought in the Po Basin, Italy, Commun. Earth Environ., 5, 1–12, https://doi.org/10.1038/s43247-024-01222-z, 2024.

Bravetti, E., Monti, C., Paleari, M., Tremolada, L., and Genoni, P.: Stato delle acque superficiali in Regione Lombardia – Corsi d'acqua – Rapporto sessennale 2014–2019, ARPA Lombardia, Milano, https://www.snpambiente.it/snpa/arpa-lombardia/stato-delle-acque-superficiali-in-regione-lombardia-corsi-dacqua-2014-2019/ (last access: 3 May 2024), 2021.

Casale, F., Fuso, F., Giuliani, M., Castelletti, A., and Bocchiola, D.: Exploring future vulnerabilities of subalpine Italian regulated lakes under different climate scenarios: bottom-up vs top-down and CMIP5 vs CMIP6, J. Hydrol. Reg. Stud., 38, 100973, https://doi.org/10.1016/J.EJRH.2021.100973, 2021.

Colombo, P.: paolchol/public, Zenodo [code], https://doi.org/10.5281/zenodo.13378616, 2024.

Fuso, F., Casale, F., Giudici, F., and Bocchiola, D.: Future hydrology of the cryospheric driven Lake Como catchment in Italy under climate change scenarios, Climate, 9, 1–24, https://doi.org/10.3390/CLI9010008, 2021.

Gandolfi, C., Facchi, A., and Ortuani, B.: Modello e codice di calcolo IdrAgra, https://hdl.handle.net/2434/300698 (last access: 27 August 2024), 2011.

Guo, Z., Fogg, G. E., Chen, K., Pauloo, R., and Zheng, C.: Sustainability of Regional Groundwater Quality in Response to Managed Aquifer Recharge, Water Resour. Res., 59, e2021WR031459, https://doi.org/10.1029/2021WR031459, 2023.

Levintal, E., Kniffin, M. L., Ganot, Y., Marwaha, N., Murphy, N. P., Dahlke, H. E., Bradford, S., and Ma, L.: Agricultural managed aquifer recharge (Ag-MAR) – a method for sustainable groundwater management: A review, Crit. Rev. Env. Sci. Tec., 53, 291–314, https://doi.org/10.1080/10643389.2022.2050160, 2022.

Oberto, G., Li, Y., Alberti, L., Soncini-Sessa, R., and Colombo, L.: Coupled irrigation-system/groundwater flow modelling for groundwater resource assessment in agricultural areas: a case study in northern Italy, Rendiconti Online Soc. Geol. Ital., 46, 2018, https://doi.org/10.3301/ROL.2018.58, 2018.

Panday, S., Langevin, C. D., Niswonger, R. G., Ibaraki, M., and Hughes, J. D.: MODFLOW–USG Version 1: An Unstructured Grid Version of MODFLOW for Simulating Groundwater Flow and Tightly Coupled Processes Using a Control Volume Finite-Difference Formulation, in: Book 6, Modeling Techniques, https://doi.org/10.3133/tm6A45, 2013.

Schiavo, M.: Spatial modeling of the water table and its historical variations in Northeastern Italy via a geostatistical approach, Groundw. Sustain. Dev., 25, 101186, https://doi.org/10.1016/j.gsd.2024.101186, 2024.

SNPA: Il clima in Italia nel 2022, 2023, Report SNPA, 36, ISBN 978-88-448-1168-6, 2023.

Toreti, A., Bavera, D., Avanzi, F., Cammalleri, C., De Felice, M., de Jager, A., Di Ciollo, C., Gabellani, S., Maetens, W., Magni, D., G., M., Masante, D., Mazzeschi, M., McCormick, N., Naumann, G., Niemeyer, S., Rossi, L., Seguini, L., Spinoni, J., and van den Berg, M.: Drought in northern Italy March 2022, JRC Publications Repository, Technical Report, https://doi.org/10.2760/781876, 2022.

Toreti, A., Bavera, D., Acosta, N. J., Arias-Muñoz, C., Avanzi, F., Barbosa, P., De, J. A., Di, C. C., Ferraris, L., Fioravanti, G., Gabellani, S., Grimaldi, S., Hrast, E. A., Isabellon, M., Jonas, T., Maetens, W., Magni, D., Masante, D., Mazzeschi, M., Mccormick, N., Rossi, L., and Salamon, P.: Drought in Europe June 2023, JRC Publications Repository, Technical Report, https://doi.org/10.2760/575433, 2023.

Ward, P. J., de Ruiter, M. C., Mård, J., Schröter, K., Van Loon, A., Veldkamp, T., von Uexkull, N., Wanders, N., AghaKouchak, A., Arnbjerg-Nielsen, K., Capewell, L., Carmen Llasat, M., Day, R., Dewals, B., Di Baldassarre, G., Huning, L. S., Kreibich, H., Mazzoleni, M., Savelli, E., Teutschbein, C., van den Berg, H., van der Heijden, A., Vincken, J. M. R., Waterloo, M. J., and Wens, M.: The need to integrate flood and drought disaster risk reduction strategies, Water Secur., 11, 100070, https://doi.org/10.1016/j.wasec.2020.100070, 2020.

Wendt, D. E., Loon, A. F. V., Scanlon, B. R., and Hannah, D. M.: Managed aquifer recharge as a drought mitigation strategy in heavily-stressed aquifers, Environ. Res. Lett., 16, 014046, https://doi.org/10.1088/1748-9326/abcfe1, 2021.

Westenbroek, S. M., Engott, J. A., Kelson, V. A., and Hunt, R. J.: SWB Version 2.0 – A Soil-Water-Balance Code for Estimating Net Infiltration and Other Water-Budget Components, 118 pp., https://doi.org/10.3133/tm6A59, 2018.