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Using isotopic and hydrochemical data to investigate groundwater recharge and discharge in a highly impacted watershed: the Oglio River, northern Italy

Marco Rotiroti (1), Tullia Bonomi (1), Letizia Fumagalli (1), Sara Taviani (1), Gennaro A. Stefania (1), Chiara Zanotti (1), Martina Patelli (1), Valentina Soler (1), Elisa Sacchi (2), and Barbara Leoni (1)

(1) University of Milano-Bicocca, Department of Earth and Environmental Sciences, Milano, Italy (marco.rotiroti@unimib.it), (2) University of Pavia, Department of Earth and Environmental Sciences, Pavia, Italy

The investigation of groundwater recharge and discharge areas is crucial to define groundwater flowpaths and assess groundwater vulnerability to pollution. To this purpose, stable isotopes of the water molecule and hydrochemistry were used to investigate an area located in the Po Plain (N Italy) that is highly impacted by human activities, in particular, by agriculture.

The study area covers $\sim$1900 km^2 of the Oglio River basin, between the outflow from Lake Iseo and the confluence into Mella River. This area hosts a sandy mono-layer aquifer in its northern part (higher plain), that passes southwards into a multi-layer aquifer (lower plain) with increasing silt and clay contents. The transition between higher and lower plain is marked by a series of springs, the so called “spring belt". The area is crossed by hundreds of irrigation channels, fed by Oglio River water in its upstream stretch.

During 4 field surveys (November 2015, February, June and September 2016), groundwater, Oglio River and its main tributaries, Lake Iseo and springs were sampled. In each survey, up to 58 groundwater, 20 river water, 1 lake water and 7 spring water samples were collected. Rainwater was continuously collected between November 2015 and 2016 at 2 locations. All water samples were analysed for major ions, trace elements (Mn, Fe and As) and δ^{18}O/δ^{2}H in water.

Hydrochemical data showed that the higher plain is characterized by an oxidized *hydrofacies* with higher concentrations of NO_3 whereas the lower plain shows a reduced *hydrofacies* with higher concentrations of Mn, Fe, As and NH_4. This is mostly related to the aquifer permeability and suggests conditions open to surface recharge in the former. Indeed, water isotopes revealed that the aquifer in the higher plain is recharged by surface water (irrigation channels and Oglio River in its upstream stretch) and local precipitation, and discharges into springs, the Oglio River and through well abstractions; Lake Iseo does not directly recharge the aquifer. The strong impact of recharge by irrigation water is clearly observed during summer. The multi-layer aquifer in the lower plain is recharged by the upstream flow from the higher plain aquifer, and discharges into the Oglio River and its tributaries, and through well abstractions. In the lower plain, recharge by leaking irrigation channels is only seen for shallow aquifers, whereas deep aquifers are no or slowly recharged by irrigation water.

The present work confirms the use of stable isotope and hydrochemical data as powerful tools for identifying groundwater recharge and discharge. These results could be used for a future assessment of groundwater vulnerability to human pollution in the study area.

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