Complementary use of hydrodynamic and hydrochemical tools to infer groundwater-surface water interactions in rivers located in alpine karst environments. The Segura and Zumeta rivers (Jaén province, SE Spain)

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Knowledge of surface water / groundwater interactions in high mountain karst regions is crucial for enhancing the protection and management of water resources. This is particularly relevant when dealing with mountainous areas located in the Mediterranean region, such as Sierra de Segura (SE Spain), one of the largest carbonate outcrops (3000 km^2) in the Iberian Peninsula. This region acts as headwater of rivers flowing eastward (Mediterranean Sea) and westward (Atlantic Ocean) over Cretaceous-Tertiary limestones and dolostones. However, information on the surface water-groundwater interactions in rivers and streams found in the area is still limited, as well as their role in the functioning of the carbonate aquifers. This research shows the preliminary results obtained from hydrological (flow-rate) and hydrochemical records (electrical conductivity -EC-, temperature, major ions, total organic carbon -TOC-, dissolved gases -O_2 and ^{222}Rn-) measured along two of the main rivers in the area (Segura and Zumeta). 218 discharge and physico-chemical parameter measurements were carried out during the hydrological year 2022/23 in 24 points spread along 20 km of each river.

In general, a progressive increase of flow-rate is observed in Segura and Zumeta rivers, from 240 to 1915 l/s and 11 to 784 l/s, respectively. Water chemistry evolves from calcium-bicarbonate *facies* to calcium-magnesium bicarbonate along the Segura and Zumeta valleys. In this sense, the carbonate substratum and the different incision degrees in the fluvial network (deeper in the Segura River) result in a distinct chemical behaviour for each river, particularly near the gaining river stretches (up to 3 in Segura and 2 in Zumeta). Moreover, stream-path evolutions of flow and physico-chemical parameters show a certain relationship in both rivers, with three stretches in Segura and one in Zumeta where values of temperature, EC, and dissolved oxygen (O_2) strongly decrease due to groundwater inputs to the riverbeds. Increases in ^{222}Rn activity (up to 700 Bq/m^3) also occur simultaneously in the same areas. However, rises in water mineralisation, Cl^-, (from 2.6 to 6.1 mg/l), and radon activity were found in one stretch in Zumeta River with low O_2 concentration (6.2 mg/l), indicative of groundwater discharges with higher residence times into the aquifer and from slightly drier recharge areas (soil evapo-concentration). In this last stretch, groundwater is diffusely discharged to riverbed throughout alluvial sediments, causing more inertial variations in flow-rate than in other locations with higher O_2 concentrations.

Hydrodynamic tools combined with the spatial distribution of physical-chemical parameters, including dissolved gases have allowed us to understand the different dynamics of surface water / groundwater interactions in the studied rivers. Thus, hydrological evolution of Zumeta River is related to the inertial behaviour and the higher residence times of groundwater. In the Segura valley, the higher incision rate, the carbonate rocks, and the karstic gaining river stretches result in active fluvial dynamics with strong hydrochemical changes. In this sense, geomorphological / hydrodynamic setting, groundwater–rock interaction, recharge, or a different combination of these processes are responsible for the location of gaining river stretches but also for the different hydrochemical evolution in both rivers.