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Insight from surface water-groundwater interactions in an alluvial aquifer: contributions of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ of water, $\delta^{34}\text{S}_{\text{SO}_4}$ and $\delta^{18}\text{O}_{\text{SO}_4}$ of sulfates, $^{87}\text{Sr}/^{86}\text{Sr}$ ratio

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Abstract

Understanding water exchange between streams and groundwater, or surface water-groundwater interactions, is of primary importance for solving conflicts related to water use and for restoring water ecosystems. The main goal of this study was to demonstrate that combination of classic geochemical tools and isotopic tools ($\delta^2\text{H}$ and $\delta^{18}\text{O}$ of water, $\delta^{34}\text{S}_{\text{SO}_4}$ and $\delta^{18}\text{O}_{\text{SO}_4}$ of sulfates, $^{87}\text{Sr}/^{86}\text{Sr}$) can lead to a better understanding of surface water - groundwater interactions for a main alluvial aquifer in the Alps mountains (Isère River alluvial aquifer) used for drinking water supply. We report here the results that identified 3 aquifer units based on groundwater recharge.

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Keywords: alluvial aquifer; surface water-groundwater interactions; $\delta^2\text{H}$ and $\delta^{18}\text{O}$ of water; $\delta^{34}\text{S}_{\text{SO}_4}$ and $\delta^{18}\text{O}_{\text{SO}_4}$ of sulfates; $^{87}\text{Sr}/^{86}\text{Sr}$ ratio

1. Introduction

Interactions between groundwater and surface water play a fundamental role in the functioning of ecosystems. In the context of sustainable river basin management it is crucial to understand and quantify exchange processes and pathways between groundwater and surface water. Alluvial aquifer exchange processes can proceed in two ways: groundwater flow through the streambed into the stream (gaining stream), and stream water infiltrates through the sediments into the groundwater (losing stream). Often, a stream is gaining in some reaches and losing in other reaches. Knowledge of these exchange processes is fundamental to understand the quality, the flow, the stage and the water temperature of both rivers and groundwater. This can be of crucial importance for implementation of restoration measures and to develop new ways of efficiently using water resources at a basin scale. Numerous methods are currently applied and described in the literature for estimating interactions between groundwater and

surface water^{1,2}, but only few studies have combined isotopic approach with “classical” methods (measurement of water table, pumping test, incremental streamflow...). Here, we present a combined approach in order to constrain the recharge of the Isère River alluvial aquifer which is expected to be connected with the Isère River flow. Hydrogeological, hydrogeochemical, geological, geophysical data were acquired and combined to study the Isère River alluvial aquifer at the neighborhood of Albertville city (French Alps). The main objective is to test whether isotopic tools are relevant or not for tracing multiple and complex groundwater/surface-water relationships.

2. Characteristics of the Isère River alluvial aquifer and Isère River basin

In this study we focused investigations on Isère River alluvial aquifer located in the neighborhood of Albertville city (Fig. 1). The studied area covers the Isère River alluvial aquifer expansion for the administrative limits of the local council of Albertville district (SCOT Arlysère: Schéma de COhérence Territoriale Arlysère). For the studied area, alluvial aquifer is used mainly for drinking water supply. The Isère alluvial aquifer corresponds to a sequence of unconsolidated to moderately consolidated sand and gravel deposits. The thickness of these deposits may be highly variable (from 10 m up to 300 m) but this information is not well documented, especially on our studied area where the deepest borehole (70-80 m) drilled into the alluvial deposits did not reach the underlying bedrock. The expected recharge of the alluvial aquifer is from precipitation, through surface water-groundwater interactions with the Isère River and/or through other aquifers (groundwater flows from the Beaufortain and Belledonne hillsides, mountain ranges surrounding the studied area, see Fig. 1)³.

The Isère River is a 286 km long river in southeastern France. Its source is in the Alps on the border with Italy.. It flows into the Rhône River (left bank) in Pont-de-l'Isère, a few km north of Valence. Its upper valley is called Tarentaise, and its middle valley Grésivaudan. Upstream of the studied area (Fig. 1), the Isère River basin includes mountain ranges (Belledonne and Beaufortain massif) that in a geological and structural context belong to the External Crystalline Massifs (ECM). The ECM form the backbone of the Alpine arc and represent the Hercynian-age basement of the European plate that was uplifted during the collisional stage of the Alpine orogeny^{4,5}. The External Crystalline Massifs (ECM) are in particular noted for occurrences of elevated concentrations of arsenic and antimony in groundwater. Arsenic-bearing sulfide minerals, such as pyrite, arsenian pyrite, and arsenopyrite, are the most likely sources of As leached within the crystalline ECM rocks. Upstream of the studied area, the Isère River also flows on evaporite formation (mainly gypsum) of Triassic age along the Synclinal Median Fault⁵ that results in locally high sulfate concentration in river water⁶. Thus, due to local context, groundwater from Isère alluvial aquifer may display high concentrations in arsenic, antimony or sulfate that could lead to higher production cost for drinking purpose (due to water treatments involved to reach concentrations below French drinking water guidelines).

3. Materials and Methods

3.1. Hydrogeological data

Elevation of the groundwater table of the Isère River alluvial aquifer and of the stream stage of the Isère River were measured for 114 points (99 bore wells and 15 stream stage see Fig. 1), for 2 different water stages (low flow period in September 2011 and high flow period in April 2012).

3.2. Hydrogeochemical data

Groundwater from the Isère River alluvial aquifer (10 sampling points) and inputs of water and dissolved elements that could be involved in the recharge of the Isère alluvial aquifer (8 sampling points including springs from the hillsides and river water) were sampled during two sampling campaigns (September 2011 and April 2012). The concentrations of major cations (Ca^{2+} , Na^+ , K^+ , Mg^{2+} by ICP-AES); major anions (Cl^- , NO_3^- , SO_4^{2-} , PO_4^{2-} by ion chromatography) and trace elements (As, Sb by ICP-MS) were measured. H and O isotope compositions of water ($\delta^2\text{H}_{\text{H}_2\text{O}}$, $\delta^{18}\text{O}_{\text{H}_2\text{O}}$), Sr isotope compositions of dissolved Sr ($^{87}\text{Sr}/^{86}\text{Sr}$), S and O isotope compositions of dissolved sulfate ($\delta^{18}\text{O}_{\text{SO}_4}$, $\delta^{34}\text{S}_{\text{SO}_4}$) were measured respectively with a Finnigan MAT 252 (IRMS), Finnigan MAT 262 (TIMS) and a Delta+XP mass spectrometer coupled in continuous-flow mode to a Thermo elemental analyser.

3.3. Geophysical data

Electrical Resistivity Tomography and High-Resolution Seismic Reflection were carried out, upstream Albertville, to constrain the geometry of the detrital deposits in the Isère alluvial valley (Fig. 1).

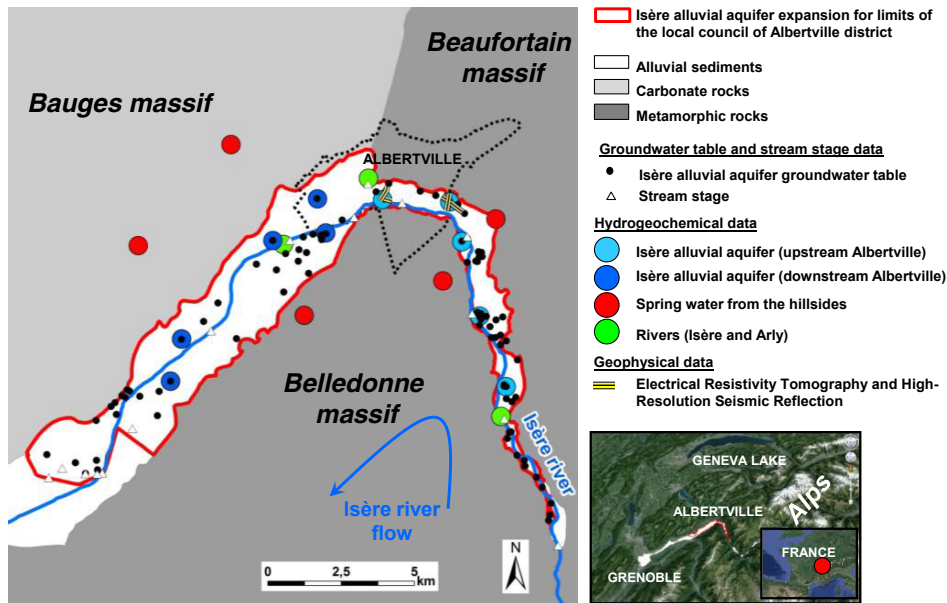


Fig. 1. Location of the studied area and data acquired.

4. Results and discussion

Upstream Albertville city, combining all the approaches, strong exchanges between groundwater of the Isère River alluvial aquifer and the Isère River have been evidenced. This is supported by (1) comparable flow direction for the aquifer and the Isère River, (2) environmental tracers suggesting that a significant proportion of water is provided by the Isère River and (3) geometry of the sedimentary deposits suggesting that stream is gaining in some reaches (rock bar) and losing in other reaches (overdeepened glacial basin). Isotope data provided decisive information. All the isotopic tracers investigated ($\delta^2\text{H}_{\text{H}_2\text{O}}$, $\delta^{18}\text{O}_{\text{H}_2\text{O}}$, $\delta^{18}\text{O}_{\text{SO}_4}$, $\delta^{34}\text{S}_{\text{SO}_4}$, $^{87}\text{Sr}/^{86}\text{Sr}$) justify that the main groundwater recharge is coming from Isère River. As an example, S and O isotopes of dissolved sulfates in groundwater (see $\delta^{34}\text{S}_{\text{SO}_4}$ values on Fig. 2) are marked by Triassic gypsum deposits occurring on the Isère River watershed upstream Albertville city.

Downstream Albertville city, surface water - groundwater interactions are limited and two aquifer units are distinguished (Fig. 2). One on the left river bank of the Isère River where hydrogeological data revealed that Arly River and Isère River alluvial aquifer are disconnected. Groundwater stages of the alluvial aquifer suggest that exchanges with Isère River could occur but environmental tracers evidenced that groundwater recharge involves mainly Beaufortain and Belledonne hillsides (arsenic and antimony inputs due to weathering of metamorphic rocks). On the right river bank of the Isère River, all data suggest that the recharge of the alluvial aquifer is mainly controlled by water coming from the Bauges hillsides. The key role played by the hillsides downstream Albertville is supported by the geometry of alluvial fans documented in the literature. Here, isotope data also provided decisive information. Groundwater display different $^{87}\text{Sr}/^{86}\text{Sr}$, $\delta^{18}\text{O}_{\text{SO}_4}$ and $\delta^{34}\text{S}_{\text{SO}_4}$ signatures depending on the location of the alluvial aquifer (left/right river bank of the Isère River). As an example (see Fig. 2), groundwater one the left river bank of the Isère River is marked by the isotopic signature of the Beaufortain and Belledonne hillsides. Whereas, groundwater one the right river bank of the Isère River is marked by the isotopic signature of the Bauges hillsides.

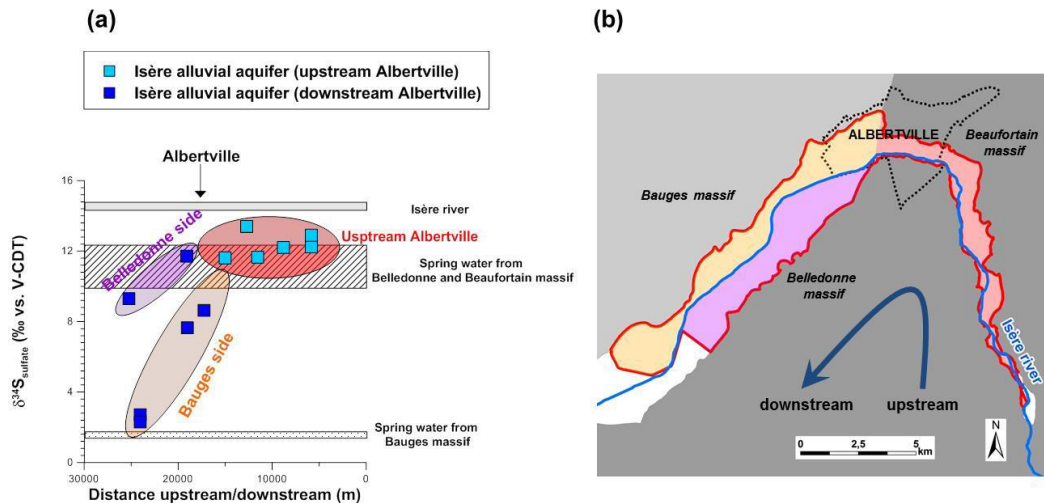


Fig. 2. (a) $\delta^{34}\text{S}_{\text{sulfate}}$ vs. distance upstream/downstream for the Isère alluvial aquifer groundwater; (b) aquifer units individualized.

5. Conclusion

Understanding of the recharge of the Isère River alluvial aquifer and quantification of the part coming from surface water - groundwater interactions have been significantly improved combining geological data, hydrogeological data and hydrogeochemical data, including isotope data. The result of this study is now the new technical reference used by water resource policy makers for the implementation of preservation measures. In agreement with the Water Framework Directive (2000/60/EC), areas of the Isère River alluvial aquifer that present outstanding interests regarding quality and quantity for drinking use (in our case, low content of As and Sb) have been listed and mapped. For present or future use, water policy makers are now focusing their water protection measures on these areas. Similar approach can be applied to other areas/contexts. In particular this approach could be helpful to constrain the key processes and pathways between groundwater and surface water that should be taken into account, for instance in hydrological forecast models of river streamflow.

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