Water Rock Interaction [WRI 14]

Groundwater salinization in hard-rock aquifers: impact of pumping and vertical transfers

Hélène Pauwels*a, Luc Aquilina, Philippe Negrel, Olivier Bour, Jérôme Perrin, Shakeel Ahmed

*BRGM, avenue Claude Guillemin 45060 Orléans, France
bCAREN, Univ Rennes 1 - Campus de Beaulieu, 35042 Rennes, France
ICFGR-NGRI Uppal road, Hyderabad, India

Abstract

Evolution of groundwater quality and salinization induced by exploitation of crystalline aquifers under two different climatic and socio-economic conditions, in France and India, is investigated. Irrigation return flow and high evaporation rates, or mixing with a saline fossil fluid mobilized by pumping, are shown to result in an increase in groundwater salinization.

© 2013 The Authors. Published by Elsevier B.V. Open access under CC BY-NC-ND license. Selection and/or peer-review under responsibility of the Organizing and Scientific Committee of WRI 14 – 2013

Keywords: groundwater, salinization, isotopes.

1. Introduction

Groundwater from crystalline aquifer is a natural resource of major importance in many parts around the world. It represents a valuable resource as an alternative to surface water which availability or poor quality are often limiting factors. However, it is also a resource highly vulnerable to change in agricultural practices and land use because of the rapid circulation of waters, and preferential flows can act as a rapid transporter of contaminants. This gives rise to numerous environmental impacts, such as a dramatic decline of piezometric levels, groundwater contamination, and salinization. Through a 2 site-based study, this paper addresses environmental consequences and particularly evolution of the chemical composition of water in response to several years of pumping. The sites are located in France where exploitation of this alternative resource is increasing, and in India where from the 1960’s, exploitation of

* Corresponding author. Tel.: +33238643406; fax: +33238643446.
E-mail address: h.pauwels@brgm.fr.
this resource has increased drastically and has contributed to a radical change known as the Green Revolution.

2. Studied areas

The Maheshwaram watershed and the deep-water plant of Ploemeur are located 35 km south of Hyderabad in Andhra Pradesh, Southern India and in western France, respectively. Their geology is representative of the regional situation, being composed of crystalline rocks; Archean granite in Maheshwaram and Hercynian granitic rocks in Ploemeur. The deep-water plant of Ploemeur has been exploited as the principal source of tap water for a medium sized city (15,000 inhabitants) since 1991 with an annual water production of about 10^6 m^3. As common in French Brittany, the surroundings are characterized by intensive agriculture inducing diffuse pollution [1]. Maheshwaram is a typical Indian rural watershed with a population of 15,000 inhabitants whose principal occupation is agriculture: rice, vegetables and flowers being the main crops. With an annual potential evapotranspiration close to 2000 mm and an annual rainfall of 700 mm over a 4- to 5-month monsoon period, the region’s climate is classified as semi-arid. Agricultural activity has been developing continuously since the beginning of the 1980s, leading to a drastic lowering of the water table and an endhoreism of the basin with a quasi-null groundwater flow towards neighboring basins [2]. The irrigation return-flow is highly variable in the area, being a function of the land use (i.e. higher in rice paddies than in flower or vegetable plots). Water samples were regularly collected from observation bore wells and pumping well in Ploemeur and farming wells in Maheshwaram. These sampling allowed determining the concentration of major and trace elements, as well as isotopes contents.

3. Results and discussion

3.1. Evolution of chemical composition

At both sites, an evolution of the chemical composition has been observed over time. In Ploemeur, a strong variation has been noticed during the first 200 days after pumping start, with a decrease of NO₃ concentration from 13 mg/L to around a value of 5 +/- 1 mg/L and then stabilization. Sulfate and chloride concentrations initially at 15 and 50 mg/L increased rapidly during the 200 first days and then more moderately. Presently, concentrations exceed 60 and 70 mg/L respectively, showing a significant and steady salinization of pumped water.

At Maheshwaram, chloride concentrations are very variable from few mg/L to more than 500 mg/L and increased with time. Initial concentrations before pumping start (in 1997) can be derived from the mean weighted value of chlorides content in rainwater (close to 1.9 mg/L) and factor F, which represents the concentration effect due to evapotranspiration. This factor is related to the total quantity of rainwater P (in mm) and the evapotranspiration E (in mm) by the equation F=P/(P - E). Chloride concentration in 1997 is then estimated at 8 to 20 mg/L. Since chloride data have been acquired only recently, electrical conductivity (EC), which field data are available since 2001–2002, is used as a proxy for the aquifer solute concentration. For this study, a selection of 25 irrigation wells located away from villages and quite widespread over the watershed has been chosen. The 25 selected wells were away from anthropogenic sources of solute (e.g., sewers, poultry farms) so as to capture EC trends mainly due to solute recycling. The mean EC trend shows a significant increase with time. Chloride trend is then extrapolated from the good correlation established between TDS or chloride and EC on samples collected in 2006. It appears
that from 20 mg/L or less in 1997, the mean chloride concentration increased to about 38 mg/L in 2002 and 58 mg/L few years later in 2009.

3.2. Processes of salinization

Although the geological contexts are very similar with aquifers characterized by a high vulnerability, it may be clearly stated that processes leading to salinization are different. In both cases, recharge water acts as transporter of contaminants, which explains in Maheshwaram the spots with several hundred mg/L of chlorides. But away from the sources of contamination, a regular increase of salinization is observed. Actually, solute recycling by Irrigation Return Flow is known for its negative impact on groundwater quality because it increases the overall salinity of water. In the catchment, the recycling is very important at the scale of paddy fields and accounts for 70-90 mm/year, i.e. in the same range as natural recharge from rainfall even though the total irrigated area covers only 4-9% of the total watershed. [2]. The high evaporation in relation to paddy fields is supported by the isotopes of the water molecule and particularly by ‘D-excess’ values. The ‘D-excess’ values in groundwater samples, calculated from $\delta^D - 7.64 \times \delta^{18}O$, are mainly in the range of -4 to +8. ‘D-excess’ values of around 7-8 in groundwater may be inherited from precipitation during the monsoon with a minor evaporation. ‘D-excess’ values of less than 5, however, suggest significant evaporation. A contrast is observed according to the activity in the vicinity of the sampling point (Fig.1). ‘D excess’ of groundwater closed to paddy fields present the lowest values, showing that water recycled during irrigation underwent a strong evaporation.

![Fig. 1. Deuterium excess in Maheswahram groundwater catchment vs fluoride concentration for different land uses.](image)

Since the fertilizers applied to the paddy fields have a negligible Cl content, and as isotopes values highlight the strong evaporation, the increase of Cl concentration between 20 and 58 mg/L from the beginning of pumping is assumed to be due to irrigation return flow in paddy fields. These observations are in agreement with the results of a solute recycling model that includes the reservoir geometry and hydraulic properties, the pumping rate and the irrigation surface area of the watershed and which simulates an increase in concentration of any mobile element by 2.8 over the last 13 years [3],

In Ploemeur, diffuse pollution of agricultural origin also alters the chemical composition of groundwater. Pyrite present in rocks induces denitrification, namely a strong abatement of NO$_3$ but a SO$_4$ increase [1].
Denitrified waters are then characterized by low $\delta^{34}$S and $\delta^{18}$O of SO$_4$. However, despite the high SO$_4$ content in pumped water, the SO$_4$ isotopes values do not match with pyrite as a single origin (Fig.2). Isotope values plots along a mixing line between denitrified groundwater and deeper saline fluids [4] evidenced at the scale of the Brittany [5]. As in Maheshwaram, vertical transfers induced by pumping are at the origin of groundwater salinization, but from the surface in one case and from depth in the other. In Ploemeur, according to the temperature monitoring, this deep circulation is expected to occur at 300m depth or more. A mass balance calculation made from major elements show that during the last 20 years, the contribution of this deep fluid increased regularly to reach nearly 50 % of the pumped water.

Fig. 2. SO$_4$ isotopes in groundwater at Ploemeur, showing the mixing between denitrified GW and old saline GW.

3.3. Further impacts

Salinization is known to modify the chemical composition of waters, several processes such as ions exchange being involved. Detrimental components can thus be released from the rock and mobilized in water. No detrimental effect has been recorded in Ploemeur. On the other hand, high fluoride concentrations are spread around the Maheshwaram watershed with concentration increase with evaporation and when the hydrochemical facies evolves from Na-Ca-HCO$_3$ to Na-HCO$_3$-(Cl), namely salinization. Moreover, a survey conducted through a population of schoolchildren revealed the recent emergence of dental fluorosis evidencing the recent increase of F concentration in waters and its relationship with salinization.

Acknowledgements

This work has been supported by the French National Research Agency (ANR) through the VMC program (MOHINI project N° ANR-07-VULN-08).

References

[1] Tarits C et al. Oxido-reduction sequence related to flux variations of groundwater from a fractured basement aquifer (Ploemeur area, France). Appl Geochem 2006; 21(1): 29-34.
[2] Maréchal C et al. Combined estimation of specific yield and natural recharge in a semi-arid groundwater basin with irrigated agriculture. J Hydrol 2006; 281-293.
[3] Perrin J et al. Solute recycling: an emerging threat to groundwater quality in southern India? J Hydrol 2011; 398: 144-154.
[4] Pauwels H. et al. Input of sulphate isotopes to the understanding of nitrogen and sulphur behaviour in the groundwater of hard-rock aquifers (Brittany, France). *Appl Geochem* 2010; 25: 105-115.

[5] Aquilina et al. Evidences for a saline fluid component at shallow depth in the Armorican basement. *This volume*. 