Rain water harvesting and management of small reservoirs in arid and semiarid areas

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Water chemistry characteristics in small reservoirs of semiarid Tunisia

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Abstract

The variation of water quality in 24 small reservoirs of semiarid Tunisia was studied in relation to catchment and hydrological context during two successive and contrasting hydrological years. Measured salinities generally satisfied the various uses. Three geochemical groups were identified based on the water quality during the inflow period. Calcium sulphate water types characterize reservoirs located in Zeroud and Merguellil catchments. They have the greatest dissolved salt contents and an increase of salinity by evaporation may limit their suitability for irrigation. Calcium bicarbonate dominated waters, especially observed in the Medjerda sub-catchments, are far more diluted and present less constraints. Two reservoirs located in Cap Bon are made conspicuous by sodium chloride dominated waters with a low ionic content. The salinity of this kind of water increases more quickly with evaporation and can then impose constraints for irrigation use.

Introduction

As part of a decennial strategy (1990-2000) for water resources mobilization, Tunisia has undertaken the creation of a thousand hillside-reservoirs, half of which will be located in the semiarid zone of the country. Hillside reservoirs (from 10 000 to 500 000 m^3) are used for surface water control, in order to support groundwater recharge and to combat erosion and silting of dams located downstream. Besides, this allows the creation of water resources in deprived remote areas (Talineau et al., 1994). The use and valorisation of this new resource through micro-irrigation are then encouraged (Selmi, 1996). However, the quantitative and qualitative characteristics of the water have to be known to ensure its optimal exploitation and management. Therefore, a survey of hillside-reservoirs is conducted by the Water and Soil Conservation Service and Orstom (Smaoui et al., 1996). In respect of water quality, salinisation concern may be significant since strong evaporation in the semiarid context favours salt concentration in water, that can limit the resource availability for irrigation. This paper presents the geochemical characteristics of 24 hillside-reservoirs of semiarid Tunisia and an analysis of the water quality evolution during evaporation.

Material and methods

The mentioned 24 hillside-reservoirs were studied. Their geographical distribution covers the entire semiarid Tunisia, from Cap Bon to the Algerian frontier. The topography of this area is structured by limestones and Cretaceous and Eocene marls.

Reservoirs were created between 1989 and 1993 with capacities between 15 000 and 235 000 m^3. Maximum water surfaces vary from 1 to 10 ha. Catchments extend from 85 to 1800 ha, they mainly consist of cultivated areas and grazing grounds, and sometimes of forested areas when slopes are not degraded. The reservoir water is used for small irrigation, feeding livestock, and domestic needs but not for drinking water supply.

Water samples were collected seasonally during the hydrological year 1994-1995, and more frequently for some reservoirs during the hydrological year 1995-1996. Electric conductivity (E.C.) and pH were measured and major ions were analysed (Rahaingomanana, 1998). The PCwateq model (Plummer et al., 1976; Rollins, 1988) was used to determine solute activity. The EXPRESO model (Rieu et al., 1998) was used to carry out evaporation simulation of water, assuming that solutions are in equilibrium with:

- calcite	$CaCO_3$	pKs = 8.37 (Hegelson, 1969);
- gypsum	$CaSO_4$	pKs = 4.85 (Robie et al., 1968).

Results

Identification and characterization of geochemical groups

Identification of geochemical groups is based on the analysis of water observed during reservoir filling. Consequently, indications about runoff water composition is given by the Piper diagram (Fig. 1). Three geochemical groups are noticed: calcium sulphate (12 reservoirs), calcium bicarbonate (10), and sodium chloride (2) dominant water. Inflow (runoff) water composition is related to catchment characteristics. Bicarbonate dominant water comes from slopes where limestone prevail while sulphate water results from marl and groundwater drainage. Figure 2 indicates that hillside reservoirs located in Zeroud and Merguellil catchments present sulphate runoff water while hillside reservoirs in the southest part of Medjerda catchment present bicarbonate dominant runoff water. Chloride dominant runoff water is localised in Cap Bon.

We evaluate water quality for irrigation with E.C. and Sodium Adsorption Ratio[1] (SAR). The E.C. indicates the salinity level of the water. In Tunisia, water salinity is considered suitable for all crops up to 1.5 g l^{-1}. The SAR is related to the sodium proportion in the water and indicates alkalinization risks for irrigated soils. For a SAR value, this risk depends on the water salinity. The values for runoff water are shown in Table 1. Sulphate runoff water presents a higher level of salinity: E.C. ranging between 0.6 and 3.0 dS m^{-1} is equivalent to salt concentrations of 0.4 to 2.0 g l^{-1}.

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[1] SAR = $Na^+ / (Ca^{2+} + Mg^{2+})^{1/2}$ ($mmol^{1/2}\ l^{-1/2}$)

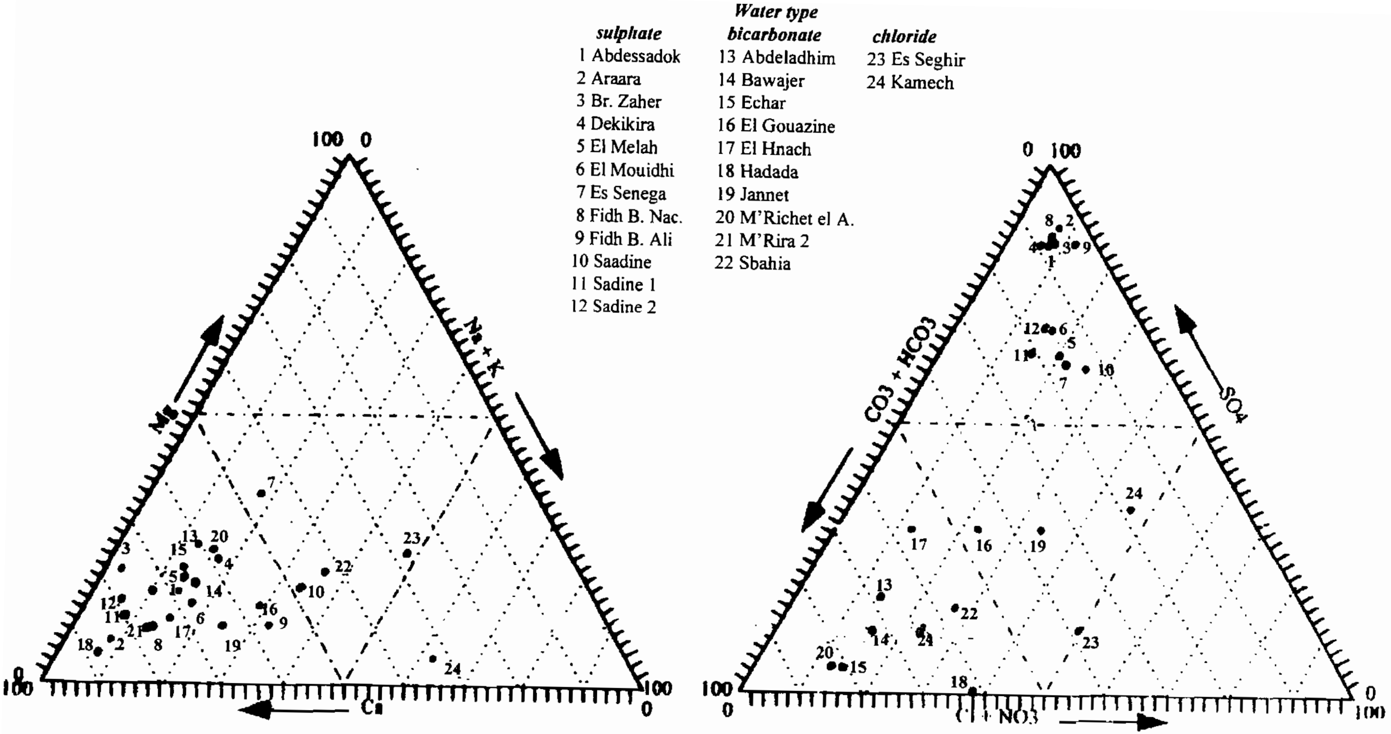

Figure 1 Hill-side reservoir flood water in a Piper diagram.

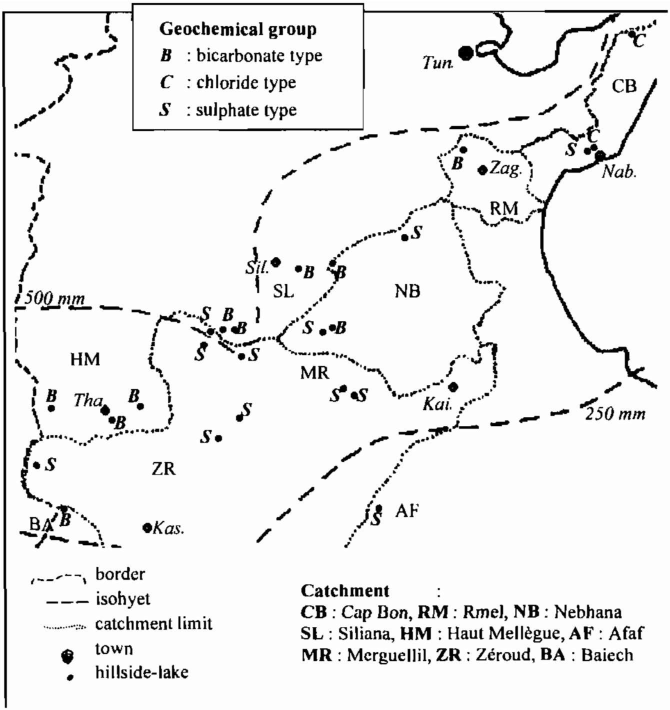

Figure 2. Localisation of hillside reservoirs and geochemical groups.

The lowest level of salinities is observed in bicarbonate dominant runoff water which has an E.C. <0.5 dS m^{-1} (0.3 g l^{-1}). Runoff water with chloride dominant type has intermediate salinity levels, up to 0.8 dS m^{-1} (0.5 g l^{-1}). Since the water is dominated by calcium, the SAR is low. A slight risk related to SAR exists for water of bicarbonate and chloride type which has SAR>1 whereas E.C. is <0.7 dS m^{-1}. Beside this and slightly saline sulphate water, runoff water displayed a good quality for irrigation.

Table 1. E.C. and SAR ranges of hillside reservoirs storing runoff water.

Flood waters	E.C. (dS m^{-1})	SAR
Sulphate type	0.62 - 3.10	0.3 - 2..9
Bicarbonate type	0.16 - 0.45	0.3 - 1.0
Chloride type	0.51 - 0.78	2.7 - 3.3

Water geochemical evolution

The salinity variation observed in the geochemical groups is indicated in Table 2. The salinity variation is small in water which is of sulphate type. Nevertheless, salinity reaches a maximum level in this group since runoff water contains the highest amounts of dissolved salts. An E.C. of 8.1 dS m^{-1} observed at Fidh Ben Ali reservoir indicates a salinity around 5.5 g l^{-1}. Salinity variations are greatest in the group with bicarbonate dominant runoff water which is the most diluted. The maximum E.C. observed was 3.1 dS m^{-1} at the El Hnach reservoir and corresponds to a salinity around 2 g l^{-1}. Salinity variations are moderate for the group with chloride dominant runoff water but the maximum E.C. observed is also 3 dS m^{-1} at the Es Seghir reservoir.

Table 2. E.C. variations observed in hillside reservoirs.

Geochemical group	E.C. variation factor	E.C. max
Sulphate type	1.3 to 3.8	8.1 dS.m^{-1} *Fidh Ben Ali*
Bicarbonate type	1.5 to 11.7	3.1 dS.m^{-1} *El Hnach*
Chloride type	3.0 to 4.1	3.1 dS.m^{-1} *Es Seghir*

The increase in salinity for reservoir water is mainly related to evaporation but the time evolution of the water composition also depends on inflow and outflow. The time evolution also depends on geochemical processes of salt precipitation and dissolution during water concentration or dilution. Ion exchange processes with sediment can occur too. The smallest salinity variation was observed at the El Mouidhi (Fig. 3a) reservoir which runoff water of a calcium sulphate type had an E.C. of approximately 1.2 dS m^{-1} (0.8 g l^{-1}). Percolation is significant and induces a fast decrease of the water volume which limits salts accumulation in the reservoir by evaporation. On the other hand, the greatest salinity variation was observed at the M'Richet el Anze reservoir (Fig. 3b): during the hydrological year 1994-95, inflows are very limited and measured E.C. is approximately 1 dS m^{-1} until the beginning of spring. The E.C. reached 2 dS m^{-1} at the beginning of the summer, before end of the wet season. The reservoir filled up at the beginning of the hydrological year 1995-96 and then, E.C. fell to 0.2 dS m^{-1}. The high salinity during the first period was favoured by the low water volume that increased the evaporative effects. In addition, we observed a spring discharge near the reservoir, presenting a greater salinity than the runoff water. During the first period, this kind of contribution could have influenced the geochemical evolution of the stored waters.

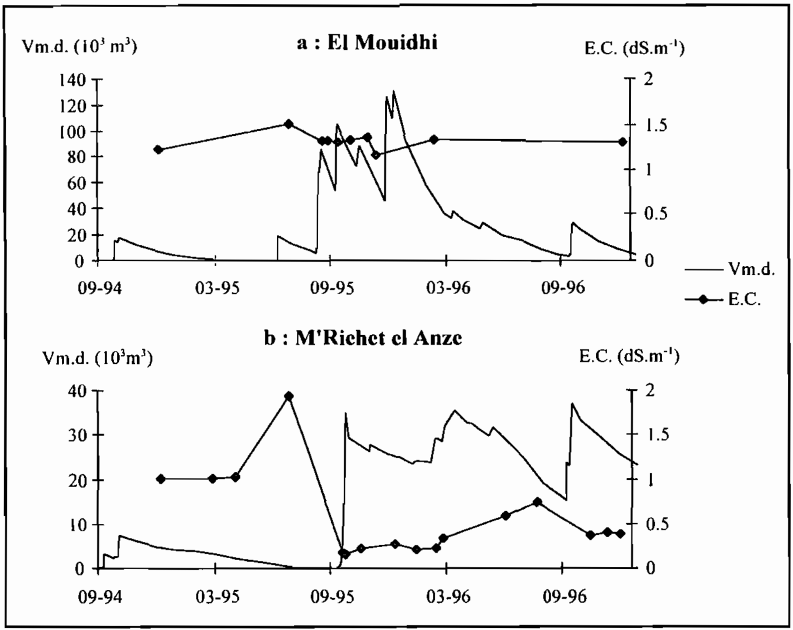

Figure 3. The E.C. and mean daily volume (Vm.d.) variations at El Mouidhi (a) and M'Richet el Anze (b) hillside reservoirs.

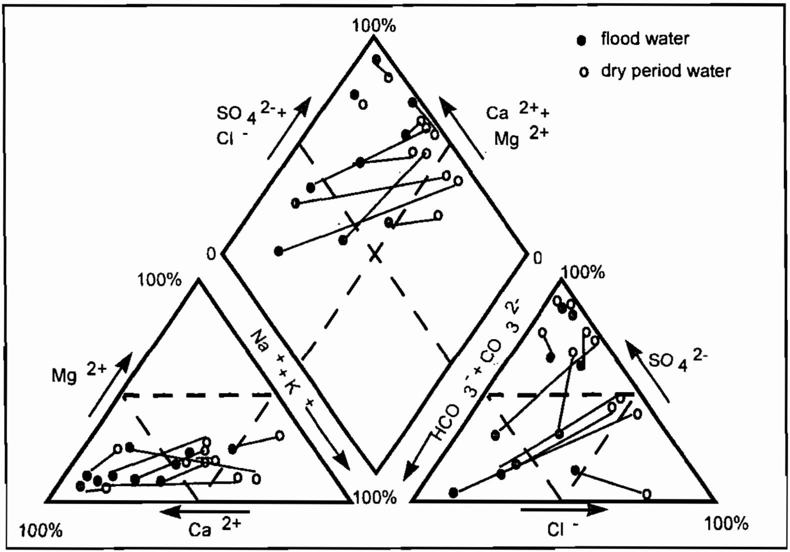

Figure 4. Most significant water type evolution in the hillside reservoirs.

The geochemical evolution related to the most important salinity variations are shown in Fig. 4. For the sulphate runoff group, we observed similar or increased sulphate proportions during the dry period. In the same way, chloride proportions increased in the case of the chloride dominant runoff group. On the other hand, we observed important changes the for bicarbonate dominant runoff group since the water observed during the dry period can present a sulphate or a chloride dominant type. For cations, a decrease in calcium generally occurs. This evolution can be related to calcite and gypsum precipitation when water is evaporated. Indeed, Fig. 5a shows that water in hillside reservoirs can be over-saturated compared to calcite equilibrium, so that calcite can precipitate and decrease the calcium and carbonate proportion in the water. The hillside reservoirs water are under-saturated compared to gypsum equilibrium but (Ca^{2+}) and (SO_4^{2-}) activities increase jointly until saturation (Fig. 5b).

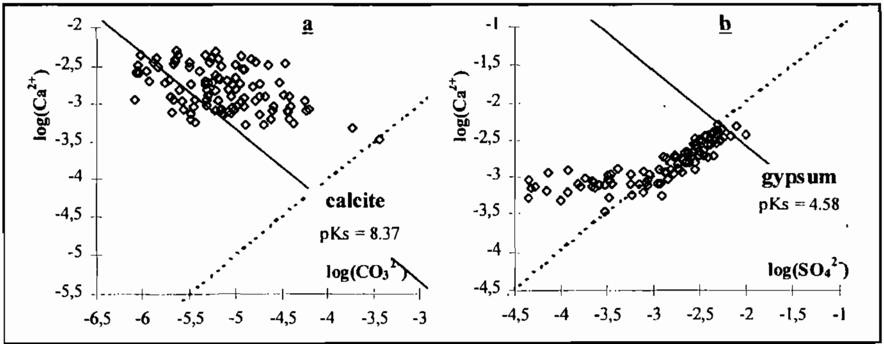

Figure 5. Calcite (a) and gypsum (b) equilibrium diagrams for the hillside reservoir water.

Evaporation simulations

Although the water chemical evolution is not only determined by evaporation processes, we compared the observed geochemical evolution with evaporation simulations for Fidh Ben Ali, M'Richet el Anze, and Es Seghir reservoirs which represent the three different geochemical groups. We considered periods where salinity increased. In Fig. 6, we can note differences between the observed and the simulated evolution regarding concentration for Fidh Ben Ali. These differences could be expected since, as mentioned before, the actual water evolution may be influenced by secondary inflow, coming from groundwater for example. Moreover, the simulations assume that thermodynamic equilibrium regarding calcite is realised as over-saturation was often observed. In spite of these differences, the measured and simulated E.C. evolutions are rather close (Fig. 7a). On the other hand, SAR tends to be over-estimated in the model compared to observations (Fig. 7b). This may result from the greater precipitation of calcium in the model, as a result of calcite and gypsum thermodynamic equilibrium. Differences are all the more significant since the water is over-saturated regarding these minerals. The M'Richet el Anze water is quite diluted and only slightly over-saturated regarding calcite, thus, no difference between observations and simulations appears.

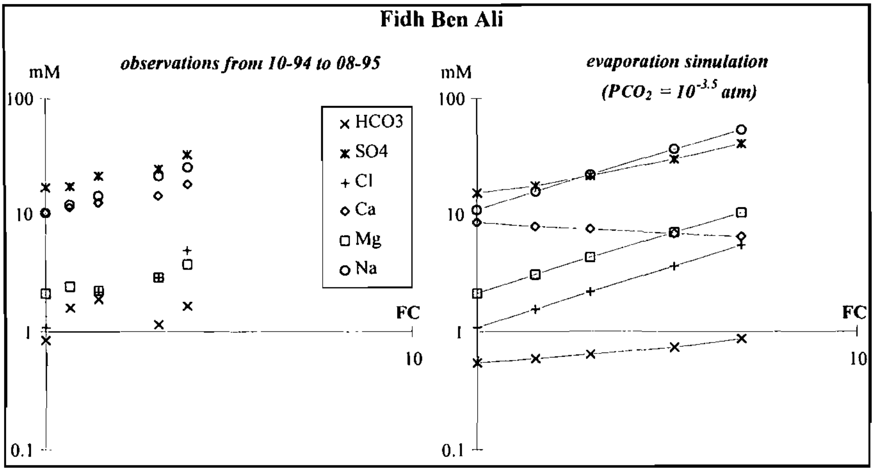

Figure 6. Water composition evolution with increase of the concentration factor (FC): observations and Expreso evaporation simulation for Fidh Ben Ali hillside reservoir water.

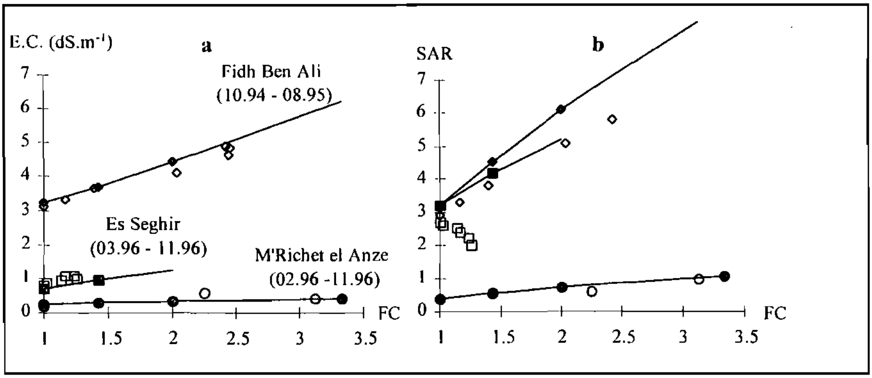

Figure 7. E.C. (a) and SAR (b) evolutions with increase of the concentration factor (FC): observations (*empty symbols*) and Expreso evaporation simulation (*full symbols*) for Fidh Ben Ali, Es Seghir, and M'Richet el Anze hillside reservoirs water.

Evaporation simulations allow to determine the theoretical evolution of water quality during dry periods if we assume that no inflow occurs during this period. We carried out evaporation simulations for water with specific initial compositions that allow to delimit the risks related to E.C. and SAR increase. A concentration factor of 5 was considered, it can for example be reached at the end of the summer, in a reservoir having a water level below 2 m at the beginning of the dry season.

Results are shown in Table 3 where E.C. values are expressed as quality grades for crops and SAR is presented according to the risk for irrigated soils. As we noted before sulphate dominated runoff presents the greatest salinity and some constraints can exist for irrigation. During the concentration process, the increase in salinity can be limited by gypsum precipitation. Indeed, initial constraints can only be increased and salinity reaching a concentration factor of 5 may be unsuitable for irrigation. Salinity of bicarbonate and chloride dominant runoff is low and entirely satisfactory for irrigation. For a concentration factor of 5, E.C. remains very satisfactory for the bicarbonate dominant water. In the case of the chloride dominant water, E.C. at a concentration factor of 5 indicates that problems may occur for salt sensitive crops. In this group, E.C. is initially higher than for the bicarbonate dominant water and it increases more quickly since Cl and Na do not take part in the salt precipitation. The evolution of the SAR related risk depends on the relative evolution of the cationic proportions and salinity of water. For sulphate water, a high salinity prevents the SAR related risk. For bicarbonate and chloride dominant water, the lowest salinity favours a slight risk, especially in the case of sodium chloride dominant water.

Table 3. Hillside-reservoirs water quality evolution during evaporation simulation.

Geochemical group	E.C. class*		SAR related risk	
	FC = 1	FC = 5	FC = 1	FC = 5
Sulphate type	A to B	B to D	Without	
Bicarbonate type	A^+	A^+ to A^-	without to slight	
Chloride type	A^+	A^- to B^-	Slight	

* Tunisian E.C. classes for irrigation : A = all uses (< 1.5 g l^{-1})
B = not for sensitive crops (1.5 to 3 g l^{-1})
C = tolerant crops only (3 to 5 g l^{-1})
D = unsuitable for crops (> 5 g l^{-1})

Conclusion

The geochemical characterization of water in the hillside reservoirs of semiarid Tunisia put highlighted different major geochemical groups with indications about localization and quality of water during the reservoir filling period. The observations made during different hydrological periods helped us to understand the actual geochemical evolution of water and confirmed the importance of reservoir hydrology for this evolution. Expreso simulations were used to detail the risk of water quality deterioration under evaporation for each group. The geochemical and hydrological information acquired for Tunisian hillside reservoirs can now be integrated to bring around concrete actions necessary for the reservoir management. According to above, it would be useful to investigate the nature and volume of secondary inflows. Moreover, exchange phenomena between water and sediments needs to be studied to better understand the geochemical evolution of the stored water. This may be significant for hillside reservoirs where particle transport is important. It may also be interesting to analyse the impact of the reservoirs on the groundwater quality.

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