Recharge of alluvial aquifers by mediterranean hill reservoirs. Multidisciplinary approach.

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Abstract The functioning of an infiltrating hill reservoir is investigated using geochemical, pedological and geophysical data. The basin groundwaters define three chemical types (calcium-bicarbonate, sodium-chloride and calcium-sulphate). Meteoric groundwater and evaporated reservoir water are the poles of a mixing process revealed by the downstream groundwater chemistry. Groundwater outflows are calculated above (300 m^3 j^{-1}) and below (170 m^3 j^{-1}) the 4.5 m reservoir water level and are counterbalanced by a 50 m^3 j^{-1} groundwater inflow. Sandstone weathering and erosion formed a shallow sandy drain which partly leads to the mixture of reservoir water and alluvial groundwater, and the alluvial aquifer recharge. A hill reservoir function, like groundwater recharge, must be assigned before contruction in order to find the suitable sites.
Key words: applied geophysics; water chemistry; groundwater; hill reservoir; Tunisia.

INTRODUCTION

Water scarcity, owing to low and erratic rainfall, always posed problems to farmers and herders. In the last century, world-wide population has tremendously grown increasing the pressure on water resources. To secure water supply and intensify agricultural production, water harvesting are traditionnally used under varying rainfall rates and population densities (Prinz, 1999; Nasri, 2002). In Tunisia, the Government has undertaken since the early 1990's the implementation of the "*National Strategy of Surface Runoff Mobilization*" which aims at building numerous large dams, small earth dams and other works for irrigation and water table recharge (Albergel et Rejeb, 1997; Berndtsson, 1999). For some reservoirs, the water balance is highly negative and suggests a water loss by infiltration leading to a reservoir leakage and an alluvial aquifer recharge. The goals of our study are: (a) using a geochemical approach, characterizing the waters and quantifying the reservoir leakage; (b) using geophysical and pedological approaches, clarifying if the leakage is due to a dam defect or superficial deposits.

MATERIALS AND METHODS

Two water samplings were carried out in may 1998 (almost emty reservoir) an in March 1999 (almost full reservoir) (Fig. 1a). Respectively 14 and 21 samples were analyzed for major elements (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-} and HCO_3^{-}) and water stable isotopes (^2H and ^{18}O). Applied geophysics is a useful tool preserving the structure and the functioning of soils, and providing a spatialized and well sampled information. Based on surface measurements, the principle is to determine the physical properties of a soil volume, and the vertical and horizontal variations. The measured variables are (a) the apparent soil resistivity for the 2-D imaging survey of the two soil toposequences Z3L3 and Z3L4; (b) the apparent soil conductivity for the EM31 (Geonics™) imaging survey of the reservoir vicinity. Eight soil pits were dug and described for the calibration of the geophysical measurements (Fig. 1b).

RESULTS

Water chemistry and groundwater recharge

The chemical composition of surface and underground waters are provided in Montoroi et al., 2002 and 2003. Three groundwater types can be distinguished in relation with the bedrock (limestone, marl, gypsiferous marl, gypsiferous argillite, sandstone). The first type, weakly concentrated, is represented by 3 wells from limestone outcrop (w6, w8 and w11). Bicarbonate and calcium are the major ions and result from limestone weathering. The second type of groundwater includes 5 wells (w4, w5, w7, w9 and w10), located in the marly lowlands between the limestone outcrops, is characterized by a lower rate of calcium and bicarbonate coupling with a higher rate of magnesium, and by a dominance of sodium (w9 and w10) and chloride ions (w4, w5, w7 and w9). In the lower part of the watershed, the third type of groundwater is draining gypsiferous deposit and is dominated by calcium and sulphated ions. No significant variation of the groundwater types is noticed between the two sampling periods: the ion concentrations varied in a short range and the reservoir water, which is calcium sulphated, has a concentration factor of 2.6. The groundwater is less concentrated in the downstream part of the dam suggesting that an upstream groundwater flow is diluted by reservoir water.

This is confirmed by the water isotope data which show, in dry period, a mixing process between a meteoric groundwater and an evaporated reservoir water. According to hydrological and isotopic modelling, 300 $m^3\,j^{-1}$ and 170 $m^3\,j^{-1}$ groundwater outflows are calculated above and below the 4.5 m reservoir water level. They are counterbalanced by a 50 $m^3\,j^{-1}$ groundwater inflow (GRÜNBERGER *et al.*, 2003).

Localization of reservoir leakage

Physical and pedological clues prove that the reservoir is leaking. A sandy layer (over 70 g $100g^{-1}$ of sand), situated at the left side embankment and in the sediment of the reservoir, is nearly 1.5 m thick with a bottom elevation above the reservoir bottom ranging from 3 to 5 m. The layer forms an aquifer resulting from the weathering of the sandstone outcrop and is connected with the downstream alluvial aquifer. The high permeability of the sandy layer explains partly the high water loss of the reservoir (MONTOROI *et al.*, 2000; 2002).

The pedological data are used to interpret the geophysical data which reveal the spatial features of the soils and deposits. The EM31 imaging shows the horizontal extension of electricaly resistant bodies corresponding to the upstream sandy layer, previously described, and the downstream alluvial aquifer (Fig. 2a). The 2-D images indicate the vertical morphology of the clayey soils formed from marl deposits and the sandy soils. Colluvium deposit and reservoir sediment can be distinguished (Fig. 2b).

CONCLUSION

Using geochemical, pedological and geophysical approaches, a case study of a highly infiltrating hill reservoir, located in an Mediterranean environment, highlights the following points: (a) a chemical caracterization of basin waters shows 3 types (calcium-bicarbonate, sodium-chloride and calcium-sulphate); (b) a quantification of the groundwater inflow and outflow leading to a water mixing with the reservoir water and a recharge of the alluvial aquifer; (c) the likely leakage is due to soil and rock characteristics in the hill rerservoir vicinity.

Such a study can be transfered to others infiltrating hill reservoirs and must be initiated before the construction of a hill reservoir. A good adequation of the site and the water uses is requested. Thus, the recharge of a downstream aquifer needs the presence of permeable deposits.

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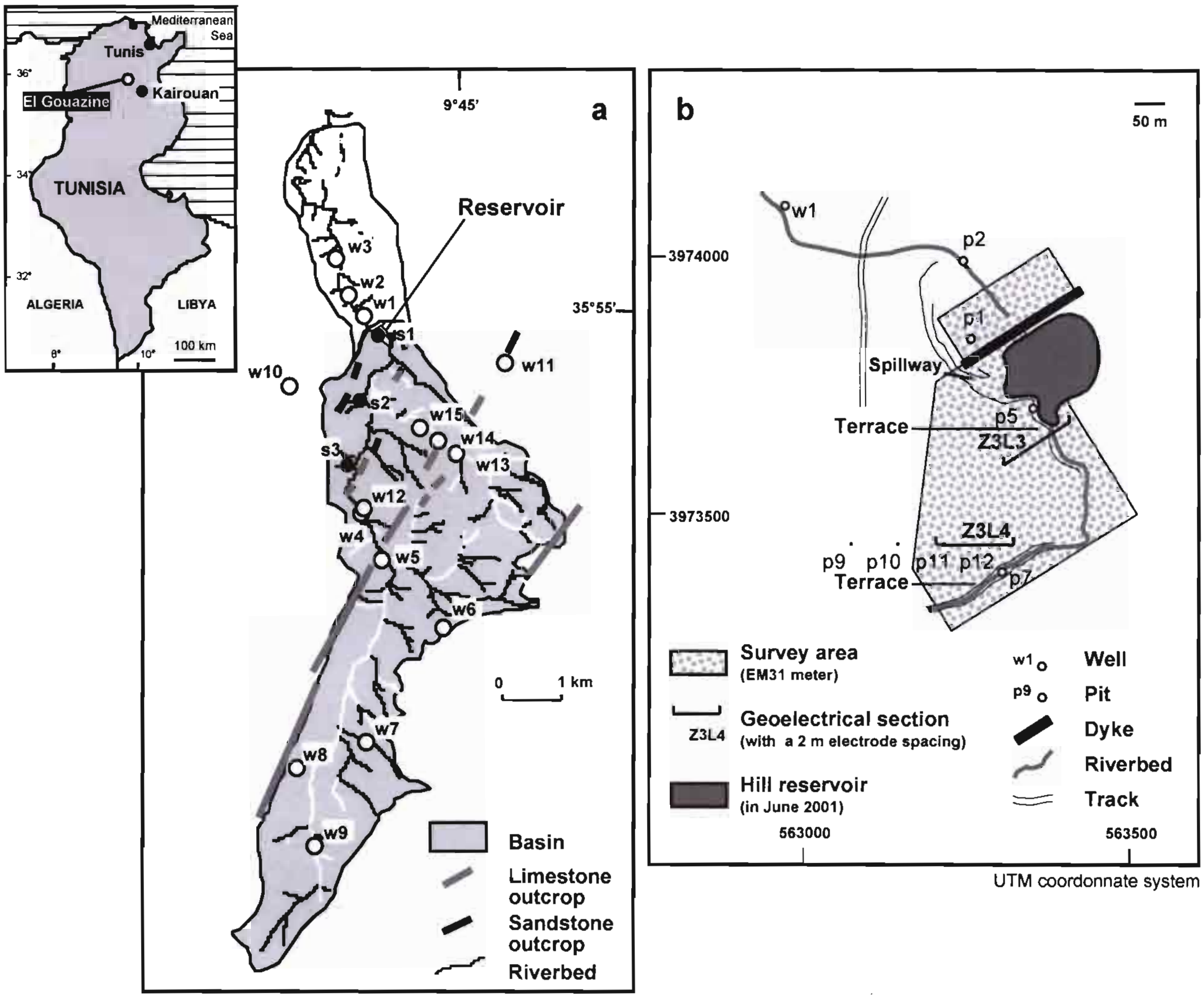
FIGURE CAPTIONS

Fig. 1 Localization of the El Gouazine hill reservoir. a: Map of the basin showing the main geological features and the sampling points location for waters. O = ground waters for wells (w), ● surface waters (s). b: Map of the reservoir vicinity showing the location for geophysical measurements.

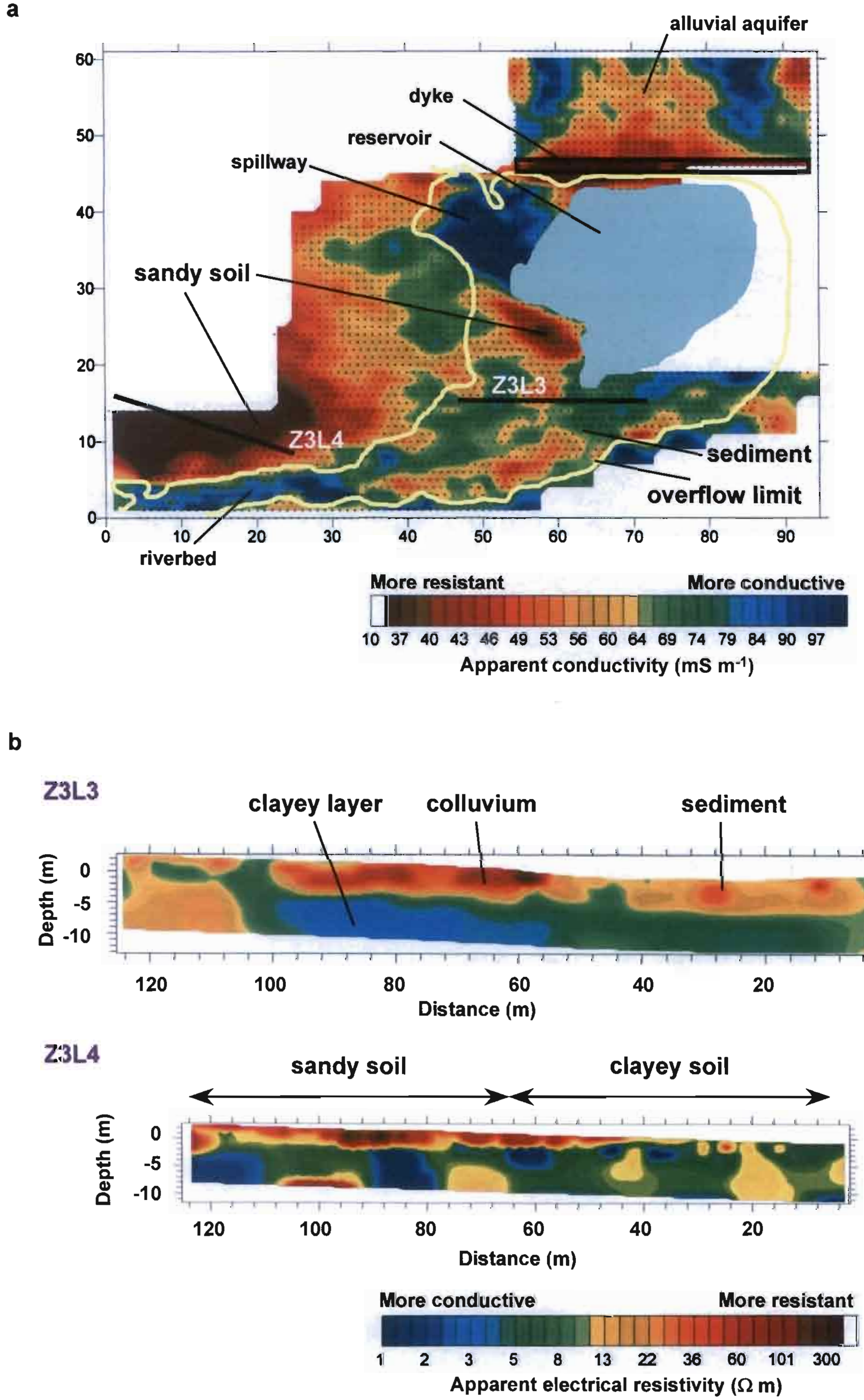
Fig. 2 Geophysical data. a: Map of the reservoir vicinity showing the apparent conductivity units and the corresponding soil formations. b: Geoelectrical sections showing the apparent resistivity units and the corresponding soil formations.

Fig. 1



Mediterranean Sea
Tunis
36°
El Gouazine
Kairouan
34°
TUNISIA
32°
ALGERIA
LIBYA
100 km
8°
10°
9°45'
a
Reservoir
35°55'
w1
w2
w3
w4
w5
w6
w7
w8
w9
w10
w11
w12
w13
w14
w15
s1
s2
s3
0
1 km
Basin
Limestone outcrop
Sandstone outcrop
Riverbed
b
50 m
3974000
3973500
w1
p2
p1
Spillway
Terrace
p5
Z3L3
Z3L4
p9
p10
p11
p12
p7
Terrace
Survey area
(EM31 meter)
Z3L4
Geoelectrical section
(with a 2 m electrode spacing)
Hill reservoir
(in June 2001)
563000
w1
Well
p9
Pit
Dyke
Riverbed
Track
563500
UTM coordonnate system

Fig. 2


a
alluvial aquifer
dyke
reservoir
spillway
sandy soil
Z3L3
Z3L4
sediment
overflow limit
riverbed
More resistant
More conductive
10 37 40 43 46 49 53 56 60 64 69 74 79 84 90 97
Apparent conductivity (mS m-1)
b
Z3L3
clayey layer
colluvium
sediment
Depth (m)
Distance (m)
Z3L4
sandy soil
clayey soil
Depth (m)
Distance (m)
More conductive
More resistant
1 2 3 5 8 13 22 36 60 101 300
Apparent electrical resistivity (Ω m)

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