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

Lund University, Sweden, 29 June – 2 July, 1998

Water chemistry of small reservoir catchments in central Tunisia

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Water chemistry of a small reservoir catchment in central Tunisia, preliminary results of water-soil-rock interactions

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Abstract

Numerous small hill reservoirs have been constructed in Tunisia since the early 1990's. The water chemistry of a representative small reservoir catchment was investigated to elucidate water-soil-rock interactions. The groundwater and surface water of the calcareous and marly watershed were characterized by field chemical investigations and pedological observations. The reservoir water was alkaline, with a low concentration, highly oxygenated and weakly carbonated while the groundwater was neutral, displayed higher concentration, weakly oxygenated and highly carbonated. Field observations have shown that the reservoir water is infiltrating and supplying a downstream aquifer and that the groundwater is flowing downstream under and inside reservoir sediments. Reservoir water loss was estimated using a conservative tracer and daily water balances. With regard to the chemical composition and the volume of water reservoir, it can be concluded that (i) the reservoir has a minimum infiltration rate of 126 $m^3 d^{-1}$, (ii) above a 4.5 m water level, the daily infiltration rate mostly ranges from 200 to 300 $m^3 d^{-1}$, below a 4.5 m level infiltration approximately ranges from 50 to 150 $m^3 d^{-1}$. Further chemical and isotopic analyses will allow to better understanding of the geochemical processes of the watershed and possibilities to model the water-soil-rock interactions.

Introduction

At present, approximately 450 hill reservoirs have been constructed in northern and central Tunisia since the early 1990's. The Direction of Water and Soil Conservation at the Ministry of Agriculture has assigned different aims for these reservoirs: decreasing of soil losses, reducing of dam sedimentation, and replenishing groundwater tables (Albergel and Rejeb, 1997). Water reservoirs should give an opportunity for nomadic families to settle and to find water supplies for agriculture and domestic uses (Talineau et al., 1994; Selmi, 1996).

The widespread use of agricultural practices, such as extraction of groundwater for irrigation and use of fertilizers, leads to a modified groundwater quality. This is particularly the case in Mediterranean climate, where high water demands during the growing season coincides with the dry period (Stigter et al., 1998).

At present, thirty reservoirs are monitored and allow the calculation of water budgets and modelling of catchment water flows (Fig. 1). Most reservoirs receive water from surface runoff. The subsurface component of the water balance is usually not a dominant term. From a chemical transport perspective, however, subsurface flows can be important as mechanism of transport for chemicals to and from reservoirs (Winter, 1995).

Although hydrochemical investigation combined or not with hydrogeological inventory is well established throughout the Mediterranean basin (Armengol et al., 1994; Marc et al., 1996; Ben Othman et al., 1997; Petelet et al., 1997; Stigter et al., 1998), little is known in Tunisia about the influence of hill reservoirs on groundwater. A chemical and regional typology of hill reservoir water, recently performed by Rahaingomanana (1998), gives a general framework to more detailed studies such as the present one included in the EU sponsored project Hydromed.

The main objectives of our work consisted in characterizing spatial water chemistry at a given time (flow and dry periods), in identifying geochemical tracers explaining the relationships between reservoir water and groundwater table and, *in fine*, in modelling the water-soil-rock interactions. In this paper, we report the preliminary results of a field study carried out during a dry period within and beyond a hill reservoir watershed.

Study site

The El Gouazine hill reservoir was chosen among five test sites of the Hydromed project because the water balance is highly negative suggesting an important water loss by infiltration (Fig. 1). The catchment is situated in the Ousseltia province, 50 km northwest of Kairouan and more precisely between the Ousseltia and Ksar Lamsa villages (Fig. 2). El Gouazine river is an affluent of Maarouf river and belongs to the endoreic basin of Nebhana river (central Tunisia). The basin outlet forms the Kelbia sebkha located few kilometers north of Kairouan.

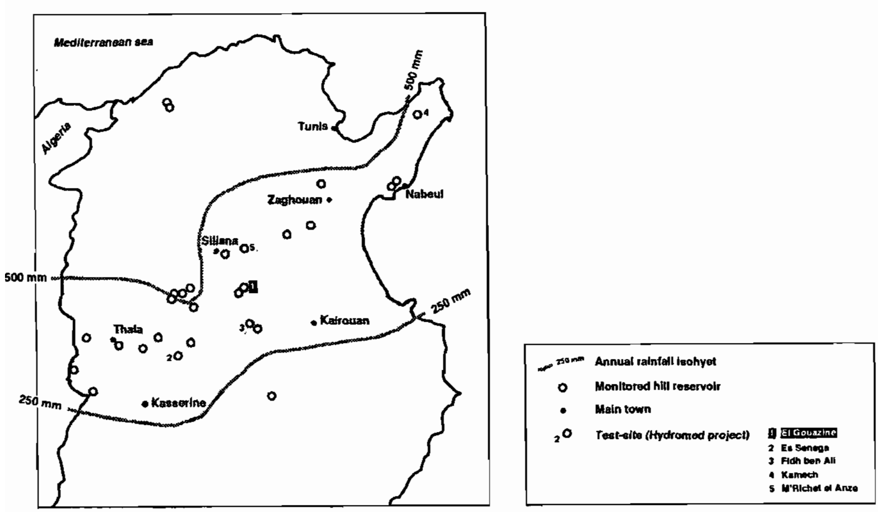

Figure 1. Localization of El Gouazine hill reservoir in central Tunisia.

The watershed is approximately 18.1 km^2 in area and bordered by SW-NE orientated hills. Elevations decrease from 575 m above sea level for the highest hills to 375 m above sea level near the reservoir (Fig. 2). With a topographic variation of 200 m and a main river length of 11 km, the average slope is approximately 1.8% or 18 m km^{-1}. This value is higher than 5% in the upper parts of the valley cross-sections.

The El Gouazine region is characterized by a Mediterranean climate with a warm and dry summer, a cool and rainy winter, and highly variable rainfall in autumn and in spring. Mean annual precipitation was 395 mm at Ousseltia during the 1962-1989 period (Bocquet, 1993) and 355.8 mm at El Gouazine during the 1994-1997 period (Guiguen and Ben Younes, 1994; CES/ORSTOM, 1996a; 1996b; 1997). Mean annual air temperature is 19.1°C, with a minimum of 10.4°C in January and a maximum of 28.6°C in August (Bocquet, 1993). Potential evapotranspiration strongly exceeds precipitation and is approximately 1680 mm at Kairouan during the 1964-1982 period (Karray and Fakhfakh, 1998) and 1460 mm at Ousseltia during the 1993-1995 period (Riou, 1980; Pernin, 1998).

Vegetation originally consisted of Alep pines and Carob trees. Owing to increasing agricultural activities, a large part of the original vegetation has been replaced by rainfed cereals and by irrigated agriculture (mainly tomatoes, peppers, cucumbers, watermelons, almond trees, and olive trees). Alep trees are found only on poor calcareous soils at the top of the hills.

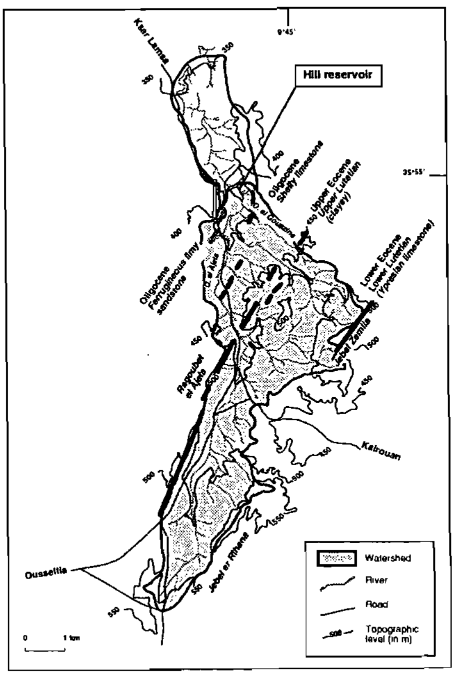

Figure 2. Study site of El Gouazine catchment with geological outcrops.

Geology and hydrogeology

El Gouazine watershed is located on the east edge of a SW-NE orientated syncline, known as Ousseltia syncline and characterized by marly calcareous and gritty deposits (Fournet, 1969). These deposits were raised by tectonic movements in the eastern part of the watershed with a southeastern and nearly vertical dip (Castany, 1951; Jauzein, 1967). The southeastern part of the basin is formed by Eocene sediments which include a mostly carbonated deposit composed of marl and nummulitic limestone from Ypresian or lower Lutetian, and a mostly clayey deposit composed of marl and shelly limestone from upper Lutetian. The northwestern part is formed by Oligocene sediments whose detrital facies is mostly gritty and known as *Fortuna formation*. Filled up at Quaternary, the syncline deposits have been cut by the rivers (locally known as oued). Gravelly and pebbly colluviums were extensively deposited and calcreted. Layers of shelly limestone (containing Oyster and/or Gastropod fossils), limy sandstone and marl outcrop in some catchment places (Fig. 2).

A regional aquifer is flowing towards the eastern endoreic lowlands (locally known as sebkhas) of the Kairouan plain and is discerned in El Gouazine catchment (Karray and Fakhfakh, 1998).

Soils

Most of the watershed soils are highly calcareous and clayey (Brunisso, 1967; Albouy et al., 1995; Bellier et al., 1997; Montoroi et al., 1997; Bellier et al., 1998). Calcreted horizons are observed on the summit of most hills. On the hillslope, colluvium is found with a high stone content.

According to the World Reference Base for Soil Resources (ISSS Working group RB, 1998), the main soils include calcrete calcisols and calcaric cambisols. Cambisols are mainly formed from marl deposits and locally from limy sandstone deposits.

Dam characteristics

The earth and embankment dam was built in 1990. The dyke is 232 m long, 56 m wide, and 10.6 m high, and the spillway overflows at a maximum water level of 8.28 m. The reservoir surface in overflow situation is of $9.597\ 10^{-2}$ km^2 for a 18.1 km^2 watershed surface defining a surface rate of 0.53% and a maximum capacity of 233 370 m^3 (Guiguen and Ben Younes, 1994).

In 1997, the reservoir capacity was lower owing to sedimentation, the value being 217 340 m^3. The reservoir capacity loss of 16 030 m^3 in 7 years corresponds to a mean annual loss of 2 290 m^3 and approximately to a maximum 3 m thick sediment deposit (CES/ORSTOM, 1996a;1996b; 1997).

Methods

Water sampling

In May 1998, systematic water sampling was done within the catchment and beyond (Fig. 3). Surface water, groundwater, and reservoir water were sampled and filtered using a 0.2 μm mesh size. Electrical conductivity at 25°C ($EC_{25°C}$), pH, and dissolved oxygen were measured in field before and after water filtration with WTW devices (LF 330 conductivimeter, pH 340 pHmeter, and OXY 330 oxymeter). Bicarbonate content was assessed in field by complete alcalimetry titration (CAT) with 0.1 N HCl. Filtered water was analyzed at laboratory for major and isotopic elements.

Soil and rock sampling

The reservoir was almost empty in May 1998 and bottom sediments were drying. Four pits were dug in the reservoir bottom and two others at the dowstream side of the dam. Soil profiles were described and samples were collected for chemical analysis. Rocks were collected at different places of the catchment close to the wells where groundwater was sampled.

Other data

The water level of the reservoir was automatically recorded using an Elsyde device (Guiguen and Ben Younes, 1994). Data were stored in the Hydromed database using Hydrom software (CES/ORSTOM, 1996a; 1996b; 1997).

Chemical analyses, carried out by Job et al. (1995) and by Rahaingomanana (1998) for different periods during 1994 and 1995, were used for calculation.

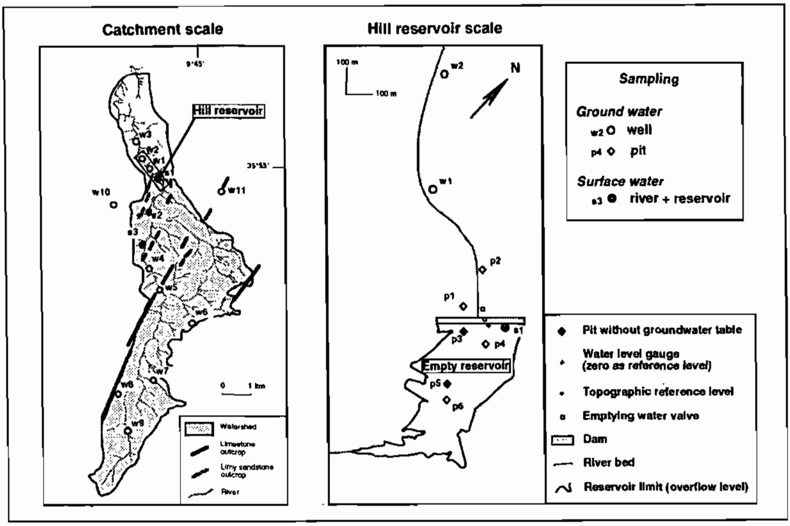

Figure 3. Sampling localization of surface waters and ground waters in El Gouazine watershed.

Results

Water chemistry

Surface water and groundwater are highly contrasting in the catchment and the reservoir. The reservoir water is alkaline (pH > 10), weakly concentrated (EC < 1 dS m^{-1}), highly oxygenated (> 120 %; range from 9 to 12 mg L^{-1}), and weakly carbonated (CAT < 2 $mmol_c$ L^{-1}) (Table 1). The chemical characteristics of El Gouazine reservoir water are consistent with those of other reservoirs belonging to the same geological environment.

In turn, groundwater is close to neutral, more concentrated (2 < EC < 8,5 dS m^{-1}), weakly oxygenated (< 80 %; range from 3 to 8 mg L^{-1}), and highly carbonated (4 < CAT < 11 $mmol_c$ L^{-1}) (Table 2).

The groundwater is less concentrated in the downstream part of the dam suggesting that an upstream groundwater flow is diluted by reservoir water.

Table 1. Chemical data of surface waters in El Gouazine watershed (data are given for filtered (F) and nonfiltered (NF) samples).

Date	Sample label	Sample location	Depth (m)	$EC_{25°C}$ ($dS\ m^{-1}$)	pH	T (°C)	Dissolved O_2 ($mg\ L^{-1}$)	Dissolved O_2 (%)	CAT ($mmol_c\ L^{-1}$)	
14/05/98	s1	lake 1	- 0.1	0.859	10.13	28.7	12.28	161.8	2.00	(NF)
			- 0.1	0.901	9.76	27.2	-	-	1,22	(F)
		lake 2	- 0.1	0.878	9.93	29.2	9.05	122.8	1.90	(NF)
			- 0.1	0.862	10.00	24.3	-	-	1.12	(F)
14/05/98	s2	marsh	- 0.2	2.845	6.88	20.2	3.85	43.8	1.72	(NF)
			- 0.2	2.840	7.23	25.6	-	-	1.90	(F)
14/05/98	s3	seepage	- 0.2	7.665	7.03	22.5	7.55	93.9	10.15	(NF)
			- 0.2	7.700	7.43	23.0	-	-	9.20	(F)

$EC_{25°C}$ electrical conductivity measured at 25°C CAT complete alcalimetry titration

Table 2. Chemical data of groundwater in El Gouazine watershed (data are given for nonfiltered samples).

Date	Well (w) or pit (p) label	location	Depth(1) (m)	$EC_{25°C}$ ($dS\ m^{-1}$)	pH	T (°C)	Dissolved O_2 ($mg\ L^{-1}$)	Dissolved O_2 (%)	CAT ($mmol_c\ L^{-1}$)	Depth(2) (m)
Dam downstream										
17/05/98	w1	River bed	- 1.0	2.220	7.06	19.5	4.40	56.4	5.20	3.30
			- 15.0	2.450	7.15	18.1	7.15	80.3	6.20	
21/05/98	w2	River bed	- 1.0	2.130	7.04	17.8	2.94	33.3	6.30	2.70
			- 2.5	2.130	7.08	17.3	2.54	27.4	6.60	
21/05/98	w3	River bed	- 1.0	2.990	7.10	17.7	4.57	42.9	6.80	1.70
			- 2.3	2.990	7.11	17.7	4.18	45.5	7.10	
21/05/98	p1	Footdyke	-	1.888	7.38	18.7	3.87	43.4	4.00	2.50
21/05/98	p2	River bed	-	2.720	7.05	17.2	3.73	41.2	6.20	1.85
Within the watershed										
16/05/98	w4	River bed	- 1.0	8.300	7.02	17.0	6.45	66.5	10.65	2.70
			- 4.0	-	-	-	-	-	-	
16/05/98	w5	Calcareous outcrop	- 1.0	2.240	6.98	20.0	3.80	42.5	6.15	1.45
			- 4.5	-	-	-	-	-	-	
16/05/98	w6	El Aafou	- 1.0	1.212	7.34	16.1	2.60	26.7	4.50	8.40
			- 1.6	-	-	-	-	-	-	
23/05/98	w7	Souk	- 1.0	3.240	7.13	19.3	7.48	84.8	5.30	?
			- 5.5	3.250	7.10	18.1	6.92	78.1	5.00	
16/05/98	w8	Fountain	- 1.0	0.753	7.61	21.7	8.75	108.0	3.70	-
21/05/98	w9	Head	- 1.0	3.230	7.26	17.1	5.56	62.1	6.90	3.15
			- 8.3	3.230	7.30	17.2	7.54	83.2	6.00	
23/05/98	p4	Sediment	-	2.020	7.72	25.6	5.28	70.2	5.20	2.00
22/05/98	p6	Sediment	-	4.910	6.85	16.8	1.26	14.8	8.40	2.30
Beyond the watershed										
17/05/98	w10	Bou Haleb	- 1.0	4.180	7.23	18.4	5.51	65.7	5.60	3.35
22/05/98	w11	Larbi	- 1.0	0.833	7.26	17.0	3.30	37.2	6.50	4.00
			- 4.0	0.835	7.25	16.8	3.74	39.8	5.70	

$EC_{25°C}$ electrical conductivity measured at 25°C CAT complete alcalimetry titration
(1) sampling depth below groundwater level (2) groundwater level referencing to soil surface

Pedological observations

Reservoir sediments are composed of fine clayey layers alternating with coarse sandy layers. They are overlying the old river bed deposits composed mainly of coarse calcareous gravel and pebble. The sediment thickness is approximately 3 m at the p4 pit confirming the measurements carried out by sounding the reservoir water (CES/ORSTOM, 1996a; 1996b; 1997). Within the gravelly and pebbly layer, a groundwater table is observed at about 2.5 m depth (Fig. 4).

As shown at the two upstream reservoir cross-sections, a sandy layer is situated at the left side embankment of the reservoir and was overlying the gravelly and pebbly layer. Concerning the reservoir cross-section situated more upstream, the sandy layer is nearly 1.5 m thick, the base being at a 5 m level. In turn, concerning the wider reservoir cross-section, a sandy layer of 1 m thickness is present in the sediments. According to these facts, we can assume that the high permeability of the sandy layer explains partly the high water loss of the reservoir, especially when the water level amounts to more than 4 m.

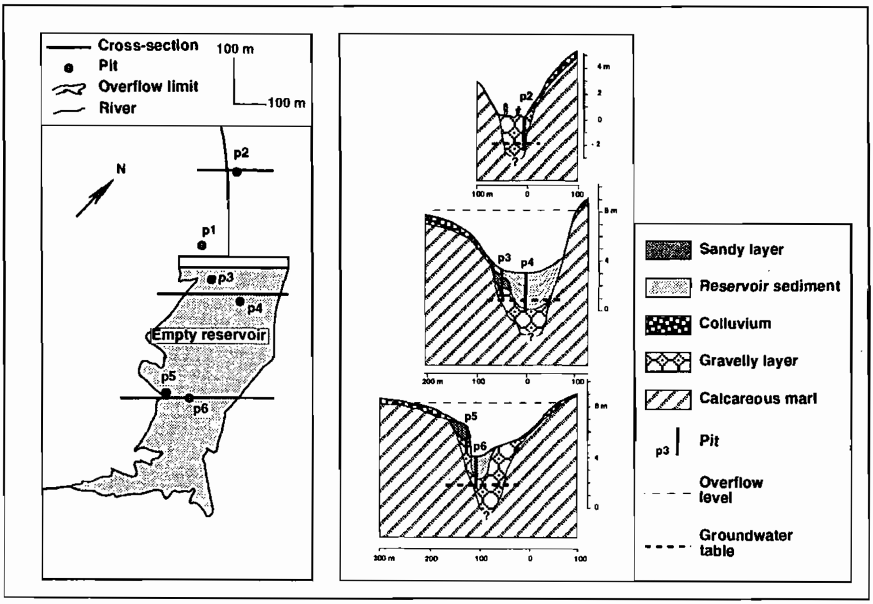

Figure 4. Deposit structure of El Gouazine hill reservoir (May 1998).

The measurements of water level, carried out in the pits and the wells, define a hydraulic gradient from upstream to downstream (Fig. 5). It seems relevant to conclude that an upstream groundwater table is flowing downstream under and inside the sediments confirming the assumption suggested by the chemical data.

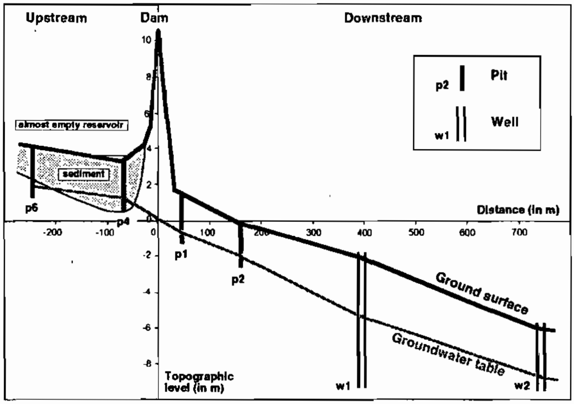

Figure 5. Groundwater level in upstream and downstream parts of El Gouazine dam (May 1998).

Infiltration rate estimation of reservoir water by chemical tracer method

During a dry period, we considered the temporal evolution of the reservoir volume (V) and the concentration of a conservative element (Cl^-). We compared the reducing volume factor Fv and the concentration factor Fc calculated from an initial given time (i) to a final given time (f) by the relationships $Fv = V_i / V_f$ and $Fc = Cl^-_f / Cl^-_i$. If both factors are equal, there is no infiltration or the groundwater inflow compensates the groundwater outflow. In turn, the reservoir loses water if Fc>Fv (outflow) and gains water if Fc<Fv (inflow).

If we assume, for the last two cases, that there is no infiltration during the considered period, we can calculate a theorical concentration Cl^-_{th} by the relationship $Cl^-_{th} = Fv\ Cl^-_i$ and a theorical volume by the relationship $V_{th} = V_i / Fc$. The deviation from the theoretical volume V_{th} and the measured volume V_i gives an estimation of the groundwater balance. A negative value corresponds to a volume of water outflow while a positive one corresponds to a volume of water inflow.

This method was applied to 1994 and 1995 data for which 5 simultaneous measurements of reservoir volume and chloride concentration were available as shown in Fig. 6 (Rahaingomanana, 1998). The calculations showed that the hill reservoir had no infiltration or gained water from December 1994 to April 1995 while it lost 7068.7 m^3 from April to June 1995 corresponding to an infiltration rate of 126.2 m^3 per day (Table 3).

However, the calculated volumes did not exactly represent the groundwater flow because a non-negligible amount of rainfall occurred during the four considered periods. During the first three periods, the rainfall ranged from 9 to 14.5 mm while the amount was 57.3 mm for the last one. The water inflow led to a decrease in Cl^-_f concentration by dilution during the given period. Thus, the calculated concentration factor Fc was underestimated while the calculated theorical volume V_{th} and deviation $V_{th} - V_i$ were overestimated.

Taking into account this approximation, we can only assert that, from April to June 1995, the hill reservoir had a minimum infiltration rate of 126 m³ per day.

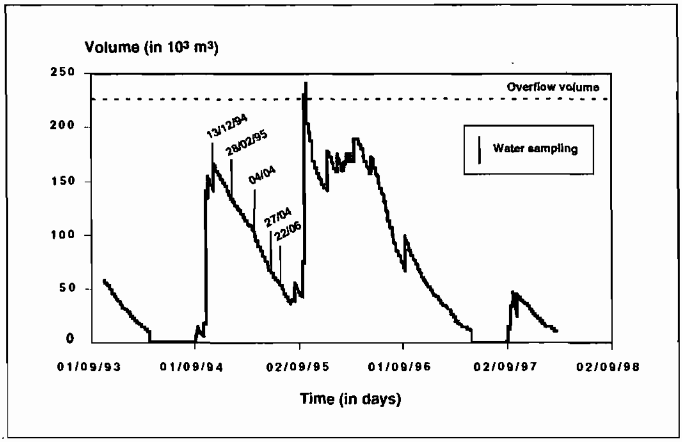

Figure 6. Daily reservoir volume versus time for El Gouazine hill reservoir.

Table 3. Infiltration rate of El Gouazine reservoir water during the 1994-1995 period.

Period	V_i	V_f	Cl^-_i	Cl^-_f	Fv	Fc	Cl^-_{th}	V_{th}	$V_{th} - V_i$	N	Rate
	m^3		$(mmol_c\ L^{-1})$				$(mmol_c\ L^{-1})$	m^3		d	$m^3\ d^{-1}$
13/12/94 28/02/95	146000	114000	0.91	1.10	1.28	1.21	1.17	121047.3	7047.3	77	91.5
28/02/95 04/04/95	114000	96500	1.10	1.30	1.18	1.18	1.30	96461.5	-38.5	35	-1.1
04/04/95 27/04/95	96500	81600	1.30	1.32	1.18	1.02	1.54	95037.9	13437.9	23	584.3
27/04/95 22/06/95	81600	53900	1.32	2.30	1.51	1.74	2.00	46831.3	-7068.7	56	-126.2

Water loss evolution

Water level data were recorded when water level variation was higher than 1 cm and were converted into volume by a relationship calculated for El Gouazine reservoir. As data were too numerous, only those recorded at 8.00 am were selected for processing. They were smoothed by a six-day running average for a series of 130 days starting from 1/1/1997.

The observed volume variations between two given dates correspond either to a water inflow if the variation is positive or to a water outflow if the variation is negative. Taking into account the measured evaporation, rainfall, and runoff volumes, we can estimate the groundwater inflow and outflow volumes. The values are compared to the water level data in Fig. 7.

A change was observed in groundwater balance at the 4.5 m water level. Above this value, the infiltration rate of groundwater mostly ranged from 200 to 300 m³ per day. Below the 4.5 m level, infiltration rate approximately ranged from 50 to 150 m³ per day. For the lower water level, there is either no infiltration or a water supply. It is quite interesting to notice that the level change corresponds nearly to the sandy layer position previously described.

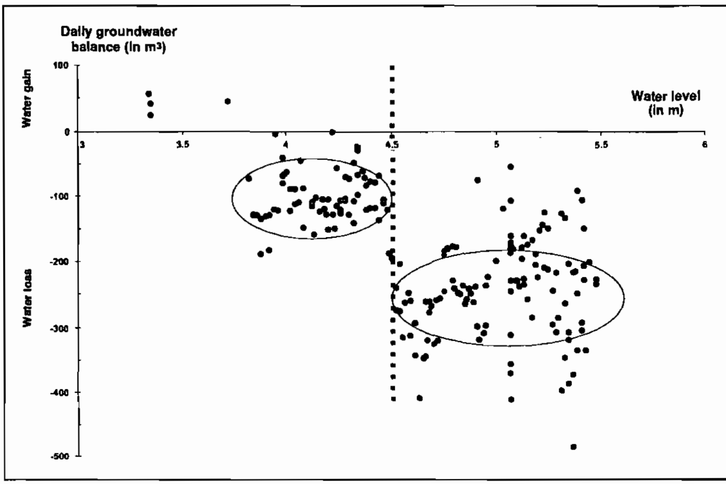

Figure 7. Water loss by infiltration for El Gouazine hill reservoir (plotted data correspond to a series of 130 days starting from 1/1/1997).

Conclusion

The water chemistry and pedological observations confirm that the El Gouazine reservoir can infiltrate and supply a downstream aquifer. We need more information to assess the permeability of porous deposits. It seems that a general (maybe regional) aquifer flows in the watershed, temporarily supplying the hill reservoir and maintaining an alluvial aquifer.

The laboratory analyses will allow to distinguish the different chemical composition of waters defining different water types and to determine the interactions of subsurface water with surface water features such as reservoir and river. Geochemical modelling will lead to an evaluation, on the one hand, how the different geological and pedological parts of the watershed contribute to the chemistry of the reservoir water and, on the other hand, how reservoir water contributes to aquifer recharge.

Acknowledgments

The authors are grateful to Dr. Jean Albergel and Yannick Pépin who kindly provided access to the hydrological database of El Gouazine hill reservoir. We also thank Nathalie Rahaingomanana for the chemical analyses of surface water which were extracted from her thesis.

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Proceedings of the International Seminar
Rain water harvesting and management of small reservoirs in arid and semiarid areas

an expert meeting within the EU-INCO collaboration HYDROMED (Program for research on hill reservoirs in the semiarid zone of the Mediterranean periphery).
Lund University, 29 June - 2 July, 1998

Editor Ronny Berndtsson

Sponsoring organizations: ORSTOM/HYDROMED, Swedish International Development Cooperation Agency (SAREC), Swedish Natural Science Research Council (NFR), and Lund University

Report 3222
Lund 1999