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Long-term water quality monitoring of the Sejnane reservoir in northeast Tunisia

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Abstract The Sejnane reservoir in northeast Tunisia provides drinking and irrigation water. Long-term water quality monitoring data including precipitation, evaporation, temperature, pH, conductivity, dissolved oxygen, turbidity, total suspended solids, major anions and cations, fluoride, BOD_5, NO_3^-, NO_2^-, NH_4^+, P_{tot}, fecal coliform bacteria, boron and heavy metals (Fe, Zn, Cu, Ni, Pb, Cr and Cd) are reported. The appropriateness for irrigation was estimated by the SAR and Na percentage and the water quality assessed using the Canadian Water Quality Index as good to excellent, which confirmed its suitability for drinking, aquatic life and irrigation purposes.

Keywords Water quality · Water Quality Index · Sodium adsorption ratio · Sodium percent · Irrigation · Principal component analysis

Résumé Le barrage Sejnane, situé au nord est de la Tunisie, a pour objectif de contribuer à la satisfaction des besoins en eau potable et l'irrigation des terres agricoles. L'article présente un suivi à long terme des paramètres de la qualité des eaux: précipitation, évaporation, température, pH, conductivité, oxygène dissous, turbidité, matières en suspension, Na^+, K^+, Ca_2^+, Mg^{2+}, Cl^-, F^-, $SO_4^=$, HCO_3^-, BOD_5, NO_3^-, NO_2^-, NH_4^+, P_{tot}, coliformes fécaux, bore et métaux lourds (Fe, Zn, Cu, Ni, Pb, Cr et Cd). La compilation de ces résultats a été réalisée avec une technique d'analyse multivariable pour la réduction des données. La convenance pour l'irrigation a été évaluée par les indices SAR et le pourcentage de sodium. Cette étude démontre la conformité des eaux aux règles de potabilité, de vie aquatique et d'irrigation. La qualité de l'eau a été évaluée via l'Indice canadien de qualité d'eau (WQI) et qualifiée de bonne à excellente.

Mots clés Qualité de l'eau · Indice de qualité de l'eau · Taux d'adsorption de sodium · Pourcentage de sodium · Irrigation · Analyse en Composantes Principales

Introduction

Surface water reservoirs are increasingly being developed in Tunisia to regulate the seasonal stream flows and to provide water to meet expanding demands for agriculture, energy development and domestic needs. For this reason, many reservoirs in central and north Tunisia have been extensively studied, e.g. Sidi Salem (Sternick 1990; Ben Othmen 2003), Sidi Saad (Bouden 1995), Bir M'cherga (Gaabab 1997). Most of their characteristics are relatively well known, except the Sejnane, Joumine and Sidi El Barrak reservoirs which are poorly understood.

This paper reports a water quality monitoring program for the Sejnane reservoir and discusses factors which may have caused some of the observed variations in water quality.

Study area and geological setting

The Sejnane reservoir is located in the northeast of Tunisia, 40 km west of Bizerte town (longitudes between 9°29′ and 9°22′30″ and latitudes between 37°8′ and 37°11′30″, Fig. 1). The earth dam of the reservoir was constructed in

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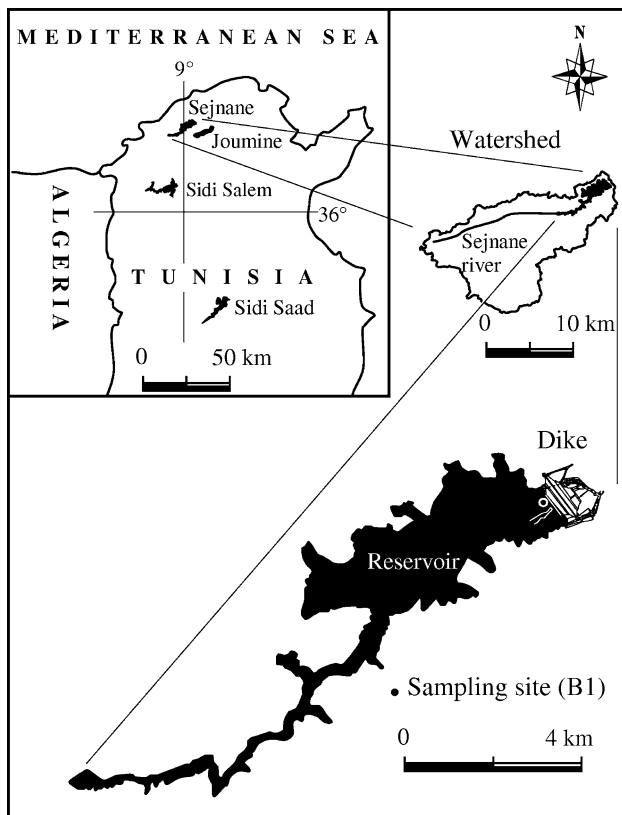e-mail: besma.zouabi@inbmi.edunet.tn

Fig. 1 Location of the study area and sampling site

Fig. 2 Geological settings of the Sejnane dam watershed area (Zouabi 2003)

the middle of the Sejnane River in 1994 to provide water for drinking and irrigation. The reservoir has a total surface area of about 7.35 km² and a storage capacity of 122 million m³ (Zouabi 2003).

The geology of the catchment includes Triassic to Quaternary deposits (Fig. 2). The Sejnane area is dominantly a succession of reddish sandstone and silty clays (Crampon 1971). Each sandstone horizon is approximately 100 m thick and consists of fine to medium grained sand with some lenses of coarse conglomerate (250–300 mm in diameter). The interbedded argillaceous layers are generally greenish to greyish in colour and about 300 mm thick (Castany 1953; Rouvier 1977).

The watershed receives an average annual rainfall exceeding 400 mm. From late autumn to early spring, the precipitation is equal to or exceeds the evaporation. During the rest of the year, the evaporation is significantly higher than the rainfall. Meteorological data of precipitation and atmospheric temperature were recorded by a weather station at the dam (see Fig. 3).

Materials and methods

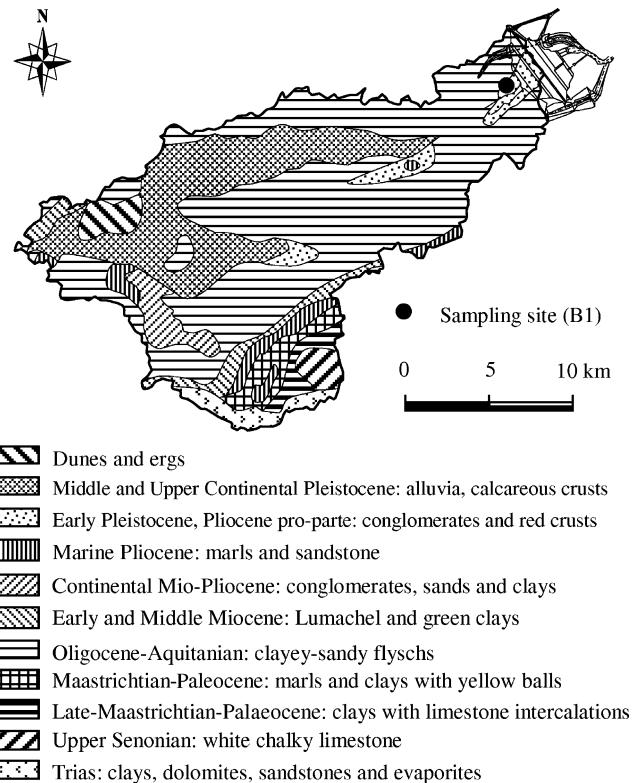Monthly monitoring of water quality parameters at the Sejnane reservoir was undertaken from 1995 to 2006
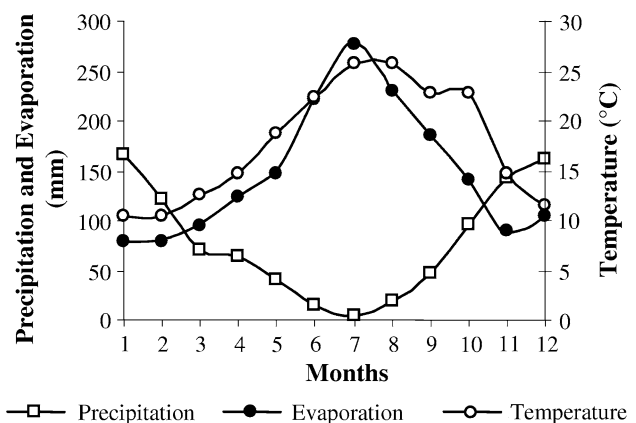

Fig. 3 Mean total monthly air temperatures, precipitation and evaporation recorded at the Sejnane reservoir for 1995–2006

inclusive. Of the nine sites routinely sampled, only site B1 is discussed here.

All samples were collected from the surface next to the riser on the principal axis of the reservoir (Fig. 1). Temperature, pH, conductivity and turbidity (expressed in nephelometric turbidity units (NTU)) were measured in the field using portable devices. In order to assess the water quality, separate samples for dissolved oxygen (DO) determination were taken in plain glass bottles; the acid

modification of the Winkler method was used to analyze the sample (APHA 1975). The samples were retained at a temperature of 4°C (Rodier 1978; Hounslow 1995) and analysis for the major elements (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^- and SO_4^{2-}) was undertaken. All nutrients were analyzed using colorimetric methods. Sodium and potassium concentrations were measured using the emission flame spectrophotometer. Calcium, magnesium and chloride were determined by titrimetry, while SO_4^{2-} was obtained by the gravimetric method. The fecal coliform (FC) bacterial densities were determined by a membrane filter technique. Potentiometry with ion-selective electrodes and emission flame photometry methods were used to determine whether specific toxic ions (such as fluoride and boron) were present while atomic absorption spectrophotometry (AAS) was used to analyze concentrations of the heavy metals iron, zinc, copper, nickel, lead, chromium and cadmium (APHA 1995).

The water sampling protocol was conducted according to the APHA standards (1995). Sample containers were carefully packed with an appropriate packing material and transported in a cooler. To measure the precision of the analytical process in the laboratory, intra-lab (blind-coded) duplicate samples were used.

Principal component analysis (PCA)

The PCA was used to analyze the water quality data (Davis 1986) using the XLStat-pro program (Addinsoft 1995–2002). The objective of PCA is both to achieve parsimony and to reduce dimensionality by extracting the smallest number of components p' ($p' \leq p$) that account for most of the variation in the original multivariate data and to summarize them by two or three transformed principal components (PCs) that can be displayed graphically with minimal loss of information (Davis 1986).

The 19 variables selected included chemical parameters (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, BOD_5, P_{tot}, NH_4^+, NO_2^- and NO_3^-), physical parameters (T, pH, conductivity, DO, turbidity and total suspended solids) and precipitation. The years in which the observations of each variable were carried out constitute the 12 individuals. The standard variations and correlation matrix used were those proposed by Chatfield and Collins (1980); the Pearson correlation matrix was then produced, as shown in Table 1.

Results of statistical analyses

Seven uncorrelated PCs are extracted in decreasing order of importance, so that the first PC accounts for as much of the variation as possible and each successive component

accounts for a little less (Chatfield and Collin 1980). An eigenvalue greater than 1 indicates that PCs account for more variance than one of the original variables in the standardized data. This is used as a cutoff point for which PCs are retained. Using this procedure, two components which account for a large proportion of the total data were identified (Table 2).

The first eigenvalue (E_1) equals 12.39 and represents an acceptable amount of the data variability of the first PC (65.24%). The percentage of variability represented by the first two PCs (F1 and F2) is very high (80.08%), indicating that the maps based on the first two PCs are a good quality projection of the initial multidimensional table. As a consequence, it was not necessary to complement the results with a third PC, as shown graphically in the scree test of Raymond B. Cattel (Fig. 4). The rate of decline tends to be fast first then levels off. The point corresponding to the curve-bend is considered to indicate the maximum number of PCs from which to extract PC1 and PC2.

The original data demonstrates relatively great redundancy particularly in precipitation and conductivity ($r = -0.946$), sodium and potassium ($r = 0.892$) and calcium and potassium ($r = 0.945$), hence some of those variables can be removed without a significant effect on the quality of interpretation. In this way the original data is reduced from 19 to only 7 factors associated with non-trivial eigenvalues.

The position of the variables relative to the correlation circle is shown in Fig. 5. This is consistent with the correlation matrix in Table 1 and indicates they are equally effective in modeling the variability of the dataset. The figures also indicate a high correlation between conductivity and most of the major ions: Mg^{2+} ($r = 0.952$), Ca^{2+} ($r = 0.947$), SO_4^{2-} ($r = 0.923$), temperature ($r = 0.911$), HCO_3^- ($r = 0.907$) and Na^+ ($r = 0.852$).

The F1 axis seems to be a factor of mineralization. It is defined by the conductivity and the concentrations of major anions and cations (Ca^{2+}, Mg^{2+}, Na^+, K^+ and SO_4^{2-}). Precipitation, temperature and evaporation play a key role in the temporal evolution of this phenomenon. Based on the squared cosines of the variables (Table 3), the F2 axis is defined by optic characteristics of the water body [turbidity (0.495), TSS (0.424), P_{tot} (0.48) and NH_4^+ (0.406)]. The amount of variability explained by the F1 and F2 axes is 80.08%, which is considered acceptable to describe the initial data without significant information loss.

Calcium and magnesium result from passage through or over limestones, dolomites of Middle and Upper Continental Pleistocene (alluvial and calcareous crusts) and Oligocene-Aquitanian (clayey-sandy flyschs) age.

Magnesium and sulphates are positively correlated ($r = 0.83$) which suggests that the magnesium originated not only from the Triassic dolomites but also from dissolution of the dolomitic limestones which frequently occurs.

Table 1 Pearson correlation matrix of selected water quality variables of Sejnane reservoir

	P	T	pH	BOD$_5$	Cond	DO	TSS	Turb	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	Cl$^-$	SO$_4^=$	HCO$_3^-$	P_{tot}	NH$_4^+$	NO$_3^-$	NO$_2^-$
P	1																		
T	**−0.895**	1																	
pH	**−0.633**	**0.758**	1																
BOD$_5$	**0.600**	**−0.609**	−0.559	1															
Cond	**−0.946**	**0.911**	**0.638**	**−0.596**	1														
DO	**−0.692**	**0.780**	**0.632**	−0.489	**0.864**	1													
TSS	0.375	−0.453	−0.360	−0.106	−0.518	−0.560	1												
Turb	0.514	−0.541	−0.316	−0.040	**−0.680**	**−0.746**	**0.849**	1											
Na$^+$	**−0.892**	**0.833**	**0.646**	**−0.828**	**0.852**	**0.614**	−0.184	−0.328	1										
K$^+$	**−0.866**	**0.844**	**0.674**	**−0.824**	**0.890**	**0.751**	−0.288	−0.452	**0.974**	1									
Ca^{2+}	**−0.879**	**0.857**	**0.604**	**−0.628**	**0.947**	**0.827**	−0.495	**−0.684**	**0.892**	**0.945**	1								
Mg^{2+}	**−0.883**	**0.866**	0.530	**−0.602**	**0.952**	**0.845**	−0.438	**−0.672**	**0.846**	**0.886**	**0.939**	1							
Cl$^-$	**−0.883**	**0.761**	**0.673**	**−0.781**	**0.793**	0.521	−0.056	−0.187	**0.951**	**0.898**	**0.800**	**0.732**	1						
SO$_4^{2-}$	**−0.823**	**0.819**	0.506	−0.388	**0.923**	**0.839**	**−0.628**	**−0.859**	**0.727**	**0.794**	**0.935**	**0.930**	**0.607**	1					
HCO$_3^-$	**−0.755**	**0.799**	0.512	−0.508	**0.907**	**0.945**	**−0.589**	**−0.798**	**0.711**	**0.829**	**0.921**	**0.898**	**0.579**	**0.918**	1				
P_{tot}	0.378	−0.517	**−0.800**	**0.656**	−0.407	−0.475	−0.067	−0.090	−0.501	−0.531	−0.397	−0.302	**−0.602**	−0.191	−0.315	1			
NH$_4^+$	0.227	−0.061	0.361	−0.403	−0.110	0.236	0.139	0.202	0.006	0.130	−0.055	−0.134	−0.008	−0.223	0.080	−0.560	1		
NO$_3^-$	−0.326	0.480	0.549	−0.380	0.546	**0.837**	−0.510	**−0.639**	0.380	0.572	**0.615**	0.515	0.264	**0.590**	**0.789**	−0.448	**0.586**	1	
NO$_2^-$	**0.636**	**−0.694**	**−0.579**	**0.706**	**−0.761**	**−0.854**	0.321	0.528	**−0.766**	**−0.881**	**−0.841**	**−0.788**	**−0.645**	**−0.714**	**−0.886**	0.489	−0.420	**−0.836**	1

In bold, significant values at the level of significance alpha = 0.050 according to two-tailed test

P precipitation, T temperature, $Cond$ conductivity, TSS total suspended solids, $Turb$ turbidity, DO dissolved oxygen, BOD_5 5-day BOD

Table 2 Eigenvalues and variance percentages

	F1	F2	F3	F4	F5	F6	F7
Eigenvalue (E)	12.39	2.82	2.06	0.85	0.30	0.198	0.12
%Variance (F)	65.24	14.84	10.82	4.50	1.61	1.04	0.65
Cumulative %	65.24	80.08	90.90	95.41	97.03	98.07	98.72

$$\%\text{variance } (F_i) = \frac{E_i}{\sum_{i=1}^{p'} E_i} \times 100$$
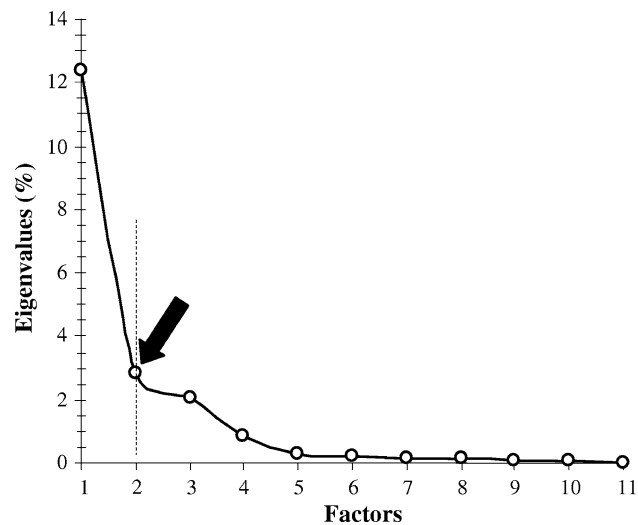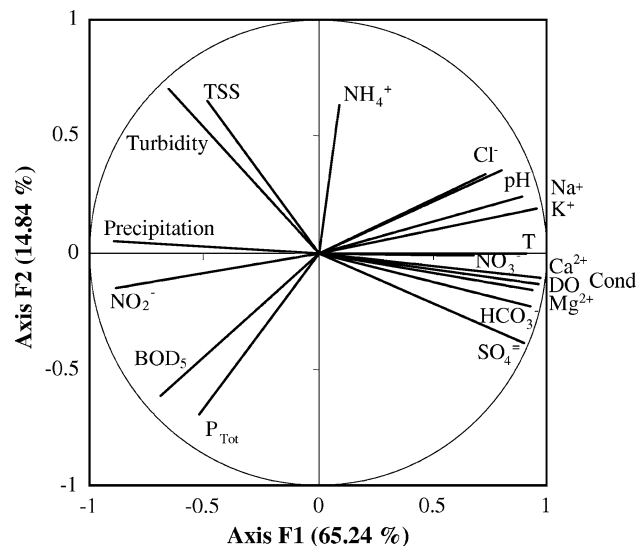

Fig. 4 Scree test of Raymond B. Cattel

Fig. 5 Correlation circle on F1 and F2 axes

This would also explain the high correlation recorded between Mg^{2+} and Ca^{2+} ($r = 0.939$). The high degree of correlation between HCO_3^- and Ca^{2+} ($r = 0.921$) confirms that the fluctuation of bicarbonate content is controlled by the level of saturation of the water with calcite and the variation in CO_2 pressure.

Table 3 Squared cosines of the variables according to the three-first factors

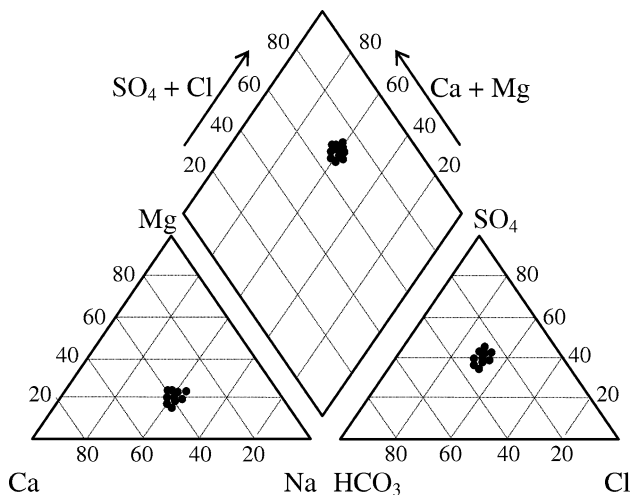|	F1	F2	F3
P	0.794	0.002	0.150
T	0.834	0.000	0.025
pH	0.532	0.111	0.025
BOD_5	0.473	0.379	0.015
Cond	0.931	0.019	0.022
DO	0.805	0.016	0.108
TSS	0.238	0.424	0.097
Turb	0.423	0.495	0.064
Na^+	0.791	0.057	0.113
K^+	0.906	0.036	0.018
Ca^{2+}	0.942	0.011	0.010
Mg^{2+}	0.876	0.027	0.029
Cl^-	0.652	0.126	0.172
$SO_4^=$	0.811	0.154	0.004
HCO_3^-	0.865	0.054	0.033
P_{tot}	0.271	0.480	0.037
NH_4^+	0.009	0.406	0.553
NO_3^-	0.468	0.000	0.502
NO_2^-	0.775	0.023	0.079

Fig. 6 Piper diagram showing major ion chemistry for Sejnane dam waters

Chloride, sodium and potassium result from the dissolution of Triassic evaporates, dominantly at the periphery of the watershed, and from the decomposition of aluminum silicates, potassium feldspar and similar minerals in the clay which are common in all the geological formations in the study area (Zouabi 2003). Not surprisingly, therefore, there was a high degree of correlation between sodium and potassium ($r = 0.98$), which suggests that a common mechanism is involved in the regulation of the concentrations of these two elements.
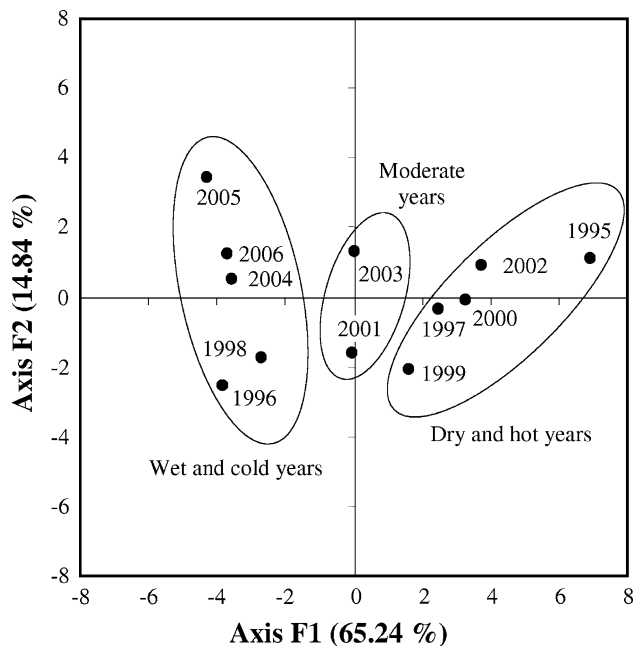
Fig. 7 Distribution of individuals according to F1 and F2 factors

The hydrochemical facies were determined using the Piper diagram (Piper 1944; Back 1961; Back and Hanshaw 1965). As seen in Fig. 6, based on the water classification scheme of Back and Hanshaw (1965) the water is characterized by the predominance of chlorinated–sulphated sodium–calcium facies.

The watershed is lithologically heterogeneous and composed typically of sedimentary rocks, with a relatively low salts content, always less than 0.5 g/l. This may to some extent be related to the climate and relief.

Three groups of climate scenarios occur in the Sejnane region: wet and cold; dry and hot; and moderate. As can be seen in Fig. 7, plotting the characteristics of the individual years against the F1 and F2 axes indicated they are strongly linked to precipitation and annual mean of temperature.

Water quality assessment

Calcium and magnesium

The average concentrations of calcium and magnesium are 52.18 mg/l and 9.77 mg/l, respectively, in the reservoir (Appendix 1). These values are well within the permissible limits for drinking-water prescribed by World Health Organization (WHO 1996, 2004) and do not damage boilers, pipes and cooking utensils (Brooks et al. 1997).

Sodium and chloride

Sodium concentrations of around 67.64 mg/l are acceptable, especially for the segment of the population that may be on severely restricted diets requiring limitation of their sodium intake. However, the low chloride concentration levels (75.65 mg/l) may affect domestic plumbing, water heaters and municipal waterworks equipment.

Nitrogen compounds and total phosphorus

Nitrate is the most abundant form of nitrogen compounds in the reservoir (0.489 mg/l) but still complies with WHO, CEC and FAO recommendations (Appendix 1). Ammonium was found in small amounts (0.025 mg/l) and also nitrite (0.007 mg/l). The sources of nitrate in the reservoir are mainly atmospheric and the geological formations containing soluble nitrogen compounds.

No agricultural fertilizers or domestic sewage were identified during the sampling period and there is no elevated health risk such as methemoglobinemia or blue baby syndrome (Antweiler et al. 1995).

Finally, a concentration of P_{tot} around 0.034 mg/l is consistent with healthy aquatic life in the water body (Brooks et al. 1997).

Dissolved oxygen

The average DO concentration level of about 7.78 mg/l complies with WHO and CEC standards and is considered good to sufficient for human consumption and most aquatic biota (Wilcock et al. 1995).

Specific conductivity

When acidic water flows over rocks containing calcite ($CaCO_3$), such as the calcareous shales of Maastrichtian age (Fig. 2), calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions will easily dissolve into the water and its specific conductivity will increase. However, as the water passes mainly over quartzose and other resistant rocks such as the Pliocene sandstone, this is unlikely to be important in the climatic conditions of the study area (Zouabi 2003).

During the present monitoring, the conductivity seems to vary related to the watershed lithology, precipitation, temperature and evaporation (Zouabi 2003). However, the conductivity is relatively low (621 µS/cm) indicating a high water quality.

Fecal coliform

Fecal coliform content is exemplified by the concentration of Escherichia coli (E. coli). Although FC were detected, their concentration is generally low (<25 E. coli counts per 100 ml) and presents little health risk (WHO 1996). However, as it does not meet the bacteriological standard purity for drinking-water (Appendix 1) the reservoir water

was treated with chlorine disinfection (chlorination), after which no FC was detected in distribution system.

Heavy metals and specific toxic elements

During the monitoring period, the measured concentrations of boron, iron, zinc, copper, nickel, lead, chromium and cadmium contents were considerably lower than the permitted international standards (Appendix 1) and hence, in this respect, the water is safe for drinking, irrigation and aquatic life.

Use for irrigation purposes

Excess amounts of sodium in irrigation waters may change the soil properties and reduce its fertility due to salinization and alkalization processes (Richards 1954; Cheverry 1972; Dehayer et al. 1997). The United States Salinity Laboratory Staff (1954) has determined that calcium and magnesium in water are important in modifying the effect of sodium on the soil and has introduced the sodium adsorption ratio (SAR) which expresses the relative activity of sodium ions in the exchange reaction with soil by

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+}]+[Mg^{2+}]}{2}}},$$

with [Na], [Ca] and [Mg] ion concentrations of sodium, calcium and magnesium. All concentration values are expressed in equivalents per million.

Data for water samples (Table 4) have been plotted in a Wilcox diagram for classification of irrigation waters (Wilcox 1948), based on specific conductance (at 25°C). As can be seen in Fig. 8, the water plots in the C2S1 class, i.e. with a medium salinity hazard (C2) and low sodium

Table 4 Annual mean of SAR and conductivity values

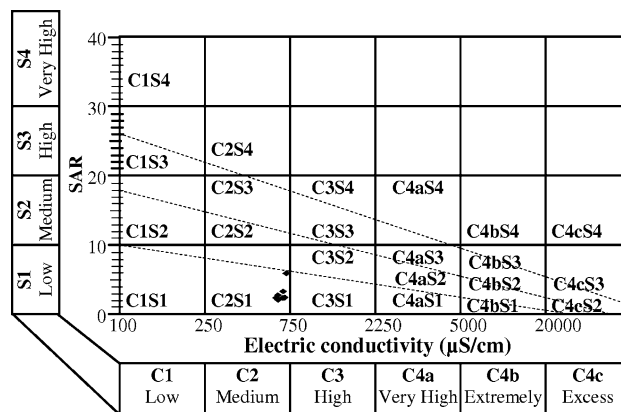| Year	SAR	Na (%)	Conductivity (μS/cm)
1995	3.93	50	750
1996	1.01	39	500
1997	3.30	45	730
1998	1.34	36	570
1999	2.28	43	680
2000	2.48	45	690
2001	1.85	43	640
2002	2.95	48	710
2003	4	47	620
2004	3.6	46	557
2005	2.39	49	455
2006	3.4	44	654

Fig. 8 The quality of water in relation to salinity and sodium hazard (after US Salinity Laboratory 1954)
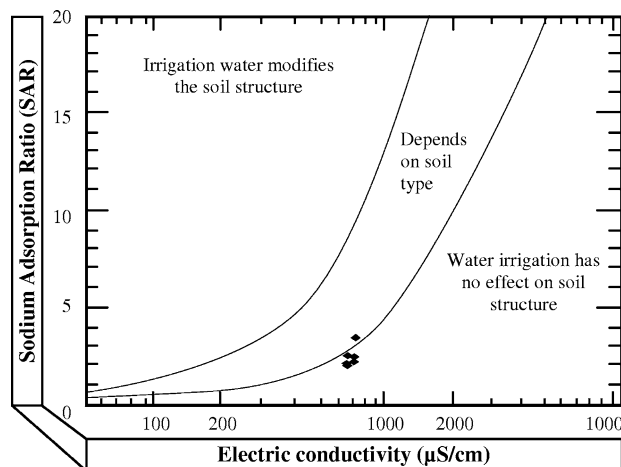

Fig. 9 Relationship between SAR and ECi of irrigation water for prediction of soil structure stability (after US Salinity Laboratory 1954)

hazard (S1). This indicates they are suitable for irrigation and can be used on almost all soil types with little danger of harmful levels of exchangeable sodium developing or a change in the soil structure (Fig. 9).

Percent sodium ratio (Na%)

The sodium percentage (Table 4) is plotted against conductivity in the Wilcox diagram in Fig. 10. This indicates an excellent to good water quality (Wilcox 1948).

Water quality trend

The Canadian Water Quality Index (WQI) is a 100 point scale which summarizes the variables of water quality (CCME 1999, 2001a, b). The WQI is used here to evaluate the overall quality of water in the Sejnane reservoir with respect to the guidelines for drinking-water (given in WHO
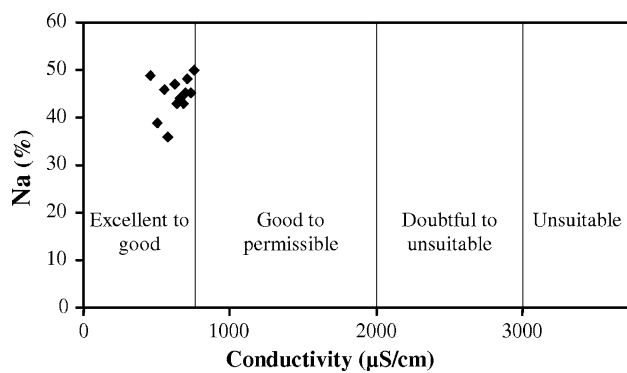
Fig. 10 The quality of water in relation to electrical conductivity and Na% (Wilcox 1948)
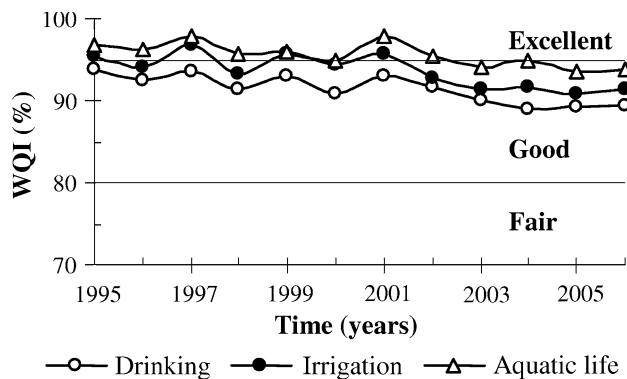

Fig. 11 Water quality trend of Sejnane reservoir

1996), irrigation (FAO 1994) and aquatic life (CEC 1978). As seen in Fig. 11, during the 10 year test period all the measured indices varied but showed good to excellent quality water.

(a) Fecal coliform and turbidity levels are slightly in excess of the good condition such that the natural raw water did not fully comply with the WHO guideline of excellent (Appendix 1).

(b) Turbidity, iron and to a lesser degree copper and chromium levels occasionally failed to comply with the CEC standard of excellent for aquatic life.

(c) The salinity status, expressed mainly by the relatively high sodium concentrations, seems to play a key role in the index fluctuation.

The water quality showed a marked stabilization for aquatic and irrigation indices although the drinking index trend is not as clear.

Although some heavy metals (boron, iron, zinc, copper, nickel, lead, chromium and cadmium) and specific toxic elements (fluoride and chloride) were identified in small amounts, they are to believed to be mostly of natural origins and do not pose a real threat to human consumption, aquatic life and irrigation.

Comparison with other reservoirs in Tunisia

Drinking-water supply

The untreated waters from the Sejnane, Joumine and Sidi Salem reservoirs have TSS and turbidity values of 7–12.43 mg/l) and 3.56–5.09 NTU, respectively. However, those from the Sidi Saad reservoir have high values of both TSS (23 mg/l) and turbidity (6.4 NTU). The mean concentrations of nitrate of all reservoirs are generally consistent with the WHO standard for drinking-water (Appendix 1); the lowest values being recorded at Sejnane (0.49 mg/l) and the highest at Joumine reservoir (3.93 mg/l).

Irrigation

The Sejnane and Joumine reservoirs have similar values of SAR (3 and 2.3) and conductivity (621 and 650 µS/cm), but for the Sidi Salem reservoir they were considerably higher (11.45 and 1,700 µS/cm) while the Sidi Saad reservoir gave values of 41.15 and 37,345 µS/cm.

Protection of aquatic life

Temperature, TSS, DO, pH, turbidity and to a lesser degree ammonium and nitrate levels recorded in all reservoirs are in the order of those required by the standards of the Commission of European Communities for aquatic life protection (Appendix 1). From the available data, the natural waters from the Sejnane and Joumine reservoirs are often of good quality and meet the standards established for drinking, irrigation and aquatic life protection. However, those from Sidi Salem and Sidi Saad do not always meet the irrigation standards especially for salts concentration. As a consequence, their use should be limited to only some soil types to avoid modification of the sediment structure.

Conclusions

The following conclusions can be drawn, based on the analysis and tests carried out during the study period:

1. The climatic conditions and the topographic and lithological characteristics of the watershed are the main controls on the water quality status in the reservoir. This explains why the waters have a unique chemical hydro facies type $Na^-(Ca)^-Cl^-(SO_4)$.

2. The measured physicochemical parameters (temperature, pH, dissolved O_2, NO_3^-, NO_2^-, NH_4^+, P_{tot}, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, F^-, SO_4^{2-}, HCO_3^-, etc), boron, heavy metals (Fe, Zn, Cu, Ni, Pb, Cr and Cd) and tests (FC, alkalinity, hardness and conductivity) confirm

that the water of the Sejnane reservoir generally conforms to international standards for drinkability, aquatic life and irrigation.

3. Based on Na%, SAR and ECi, the water has an excellent to good quality with no effect on the structure and stability of the soil when used for irrigation of arable lands.

4. According to the Canadian WQI, the Sejnane reservoir water is clean and rated as "good" to "excellent" throughout the 10 year study period. The water is able to support a high diversity of aquatic life without excessive algae growth. In addition, it is suitable for all forms of recreation, including those involving direct contact with the water (e.g. swimming).

5. To ensure this situation is maintained, a long-term program for preserving the water quality should be considered.

Appendix 1

See Table 5.

Table 5 Selected water quality variables of some reservoirs in Tunisia compared to international guidelines for drinking-water, aquatic life and irrigation uses

	Units	Average values				Drinking	Aquatic life	Irrigation
		Sidi Saad[a]	Sidi Salem[b]	Joumine[c]	Sejnane	WHO[d]	CEC[e]	FAO[f]
DO	mg/l	8.26	8.6	9.55	7.78	5	5–9	
Na^+	mg/l	506.09	220	75.30	67.64	<200		<70
K^+	mg/l	15.56	7.2	1.81	1.73			<2
Ca^{2+}	mg/l	386.87	167	61.57	52.18	100		<1,600
Mg^{2+}	mg/l	105.03	38	10.53	9.77	30		<10
HCO_3^-	mg/l	157.09	145	138.22	134.6			90–500
Cl^-	mg/l	742.30	237	72.83	75.65	250		<110
F^-	mg/l	NA	NA	NA	0.08	<0.5	<1.2	<1
P_{tot}	mg/l	0.027	0.1	0.027	0.034	3		
SO_4^{2-}	mg/l	1335.93	500	138.31	135.78	<250		
NO_3^-	mg/l	1.6	1.2	3.93	0.49	<50		<5
NO_2^-	mg/l	0.05	0.23	0.135	0.007	<0.1	0.01–0.03	
NH_4^+	mg/l	0.03	0.18	0.65	0.025	<0.5	0.04–1.0	
B	mg/l	NA	NA	NA	0.006	<1		<0.7
Fe	mg/l	NA	NA	NA	0.06	≤0.172	<0.03	<5
Zn	mg/l	NA	NA	NA	0.006	≤0.02	<0.03	<2
Cu	mg/l	NA	NA	NA	0.0072	≤0.01	<0.002	<0.2
Ni	mg/l	NA	NA	NA	0.0021	≤0.01	<0.025	<0.2
Pb	mg/l	NA	NA	NA	ND	≤0.01	<0.001	<0.2
Cr	mg/l	NA	NA	NA	0.0002	≤0.001	<0.001	<0.1
Cd	mg/l	NA	NA	NA	0.0003	≤0.0005		<0.01
FC	(Coli/100 ml)	NA	NA	NA	25	0	<200	<106
T	°C	23.97	20	20.3	20.54		<22	
Cond	µS/cm	3,734	1,700	650	621	400		<700
Turb	NTU	6.14	4.22	5.09	3.56	<5	<10	
pH	–	8.1	8.07	7.71	7.49	5–9	6.5–9	6.5–8.4
BOD_5	mg/l	NA	1.5	NA	2.99	3	3–6	
TSS	mg/l	23	7	12.43	12.25		<25	<2,000
SAR	–	41.15	11.45	2.3	3			<15

[a] Bouden (1995)

[b] Ben Othmen (2003)

[c] Hadj Zekri (2003)

[d] World Health Organization (WHO) (1996, 2004)

[e] Commission of European Committees (CEC) (1978)

[f] Food and Agriculture Organization (FAO) (1994)

FC fecal coliform, *NA* not available, *ND* not detected, *SAR* sodium adsorption ratio

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