

Impacts of at-site wastewater disposal systems on the groundwater aquifer in arid regions: case of Sfax City, Southern Tunisia

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Abstract Groundwater in Sfax City (Tunisia) has been known since the beginning of the century for its deterioration in quality, as a result of wastewater recharge into the aquifer. An average value of $12 \times 10^6 \text{ m}^3$ of untreated wastewater reaches the groundwater aquifer each year. This would result not only in a chemical and biological contamination of the groundwater, but also in an increase of the aquifer piezometric level. Quantitative impacts were evaluated by examining the groundwater piezometric level at 57 surface wells and piezometers. The survey showed that, during the last two decades, the groundwater level was ever increasing in the urban area with values reaching 7 m in part; and decreasing in Sidi Abid (agricultural area) with values exceeding -3 m . Groundwater samples for chemical and microbial analysis were collected from 41 wells spread throughout the study area. Results showed significantly elevated levels of sodium, chlorides, nitrates and coliform bacteria all over the urban area. High levels (NO_3 : 56–254 mg/l; Na $>1,500 \text{ mg/l}$; Coliforms $>30/100 \text{ ml}$) can be related to more densely populated areas with a higher density of pit latrine and recharge wells. Alternatively results showed a very variable chemical composition of groundwater, e.g. electrical conductivity ranges from 4,040 to 19,620 $\mu\text{s/cm}$ and the dry residual varies between 1.4 and 14 g/l with concentrations increasing downstream. Furthermore a softening of

groundwater in Set Ezzit (highly populated sector) was observed.

Keywords Groundwater · Wastewater · Recharge · Water quality · Southern Tunisia

Introduction

Rapidly increasing urban population growth rates over the last few decades have been responsible for the production of huge quantities of wastewater, often disposed of in on-site sewage disposal systems without any particular treatment (Beaudry 1992; Edline 1998). On-site sewage disposal encompasses cesspools, septic tanks and pit latrines. It is estimated that in the United States approximately one-third of its sewage is disposed of by septic tanks (Harman et al. 1996). Septic tanks are also common in other countries such as Canada and Australia, as well as in developing countries (Whelan 1988). In Sana'a, Yemen, it is estimated that 80% of the urban recharge is wastewater from cesspits (12.5 Mm^3 in 1993) (Alderwish and Dottridge 1999) and in the city of Amman, Jordan, $8 \text{ Mm}^3/\text{year}$ from cesspool leakages are recharging the aquifer (Salameh et al. 2003). Conversely, in the UK only 5% of the population is not served by mains sewerage and most of these are served by septic tank systems (Payne and Butler 1993).

Leakage from such sewer system provides the highest percentage of water recharge to aquifer underlying many cities throughout the world (Lerner 1986; Yang et al. 1999). Therefore, this usually results in affecting the water quality of the receiving water bodies by bringing in different types of pollutants (physical, chemical, biological, etc...) (Jeong 2001; Zingoni and Love 2005; Wakida and Lerner 2005). The density of systems is the most important

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factor in groundwater contamination by on-site sewage disposal system. A minimum lot size of 0.4–0.6 ha is needed to prevent groundwater contamination (Bicki and Brown 1991). Other factors that can contribute to the hazard of groundwater pollution by this system are improper design, poor maintenance and depth of the water table (Yates 1985).

Tunisia was engaged in large-scale investments for the collection and safe disposal of wastewater (Arar 1991). The ever-increasing development of urbanization, tourism and industrial activities resulted in undertaking the necessary measures to protect wastewater-receiving sites from eventual pollution. The number of wastewater treatment plants increased from 26 in 1989 to 61 in 2000 and is expected to exceed 120 plants by 2010 (Kouri 1992). The annual treated wastewater volume produced by treatment plants spread all over the country is estimated to be 170 millions of cubic meters, 25% of which are used in agriculture (Grabi 2001). In spite of all of these efforts in terms of wastewater treatment and safe disposal, rural and suburban regions are usually devoid of wastewater collection and treatment facilities. As an alternative, people adopt systems composed of septic tanks and recharge wells generally reaching the groundwater aquifer for the disposal of their domestic wastewaters. Such systems usually result in contaminating the groundwater, especially if they are poorly studied and badly monitored. This study evaluates quantity and quality impacts of such systems on the groundwater aquifer of the city of Sfax, the second largest city in Tunisia.

Study area

Characteristics of the city

Covering 170 km², Sfax City is located in the South East of Tunisia on the Mediterranean Sea (Fig. 1). It is characterized by an arid to semi-arid Mediterranean climate. Average temperature varies from 11.3°C in January to 26.5°C in August, with an annual average of 19°C. Mean annual precipitation observed over a period of 30 years is ~230 mm.

Sfax City has been characterized by an important spatial extension since the beginning of the nineteenth century to the detriment of agricultural lands and by reclamation of important sea zones, with relatively low water depths. This important spatial expansion of the city was accompanied by extensions of the water distribution system to supply potable water to almost all the inhabitants of the region. Nevertheless, extension of the wastewater collection system was rather limited. Nearly half of the homes in Sfax City are located in unsewered areas and must rely on

individual household disposal systems, composed of septic tanks and recharge wells. This latter generally reaches the groundwater aquifer, and therefore wastewater does not take advantage of the soil purification potential.

Characteristics of the aquifer

The examined groundwater aquifer is formed of Mio-plio-quadernary clastic deposits, essentially composed of sand and clayey sand levels. The lithology of the aquifer is characterized by lenticular structures with lateral shift of facies (Fig. 2). The aquifer, composed of two levels, is characterized by a variable thickness (1–9 m) and a depth varying between 10 and 35 m (Chalbaoui 1989).

The aquifer permeability is characterized by an important spatial variation. Horizontal permeability values oscillate between 2.4×10^{-7} cm/s within a salt marsh and 4×10^{-4} cm/s within a sandy level in downtown Sfax. Measured vertical permeability values varied between 1.3×10^{-6} and 4.8×10^{-4} cm/s (Chalbaoui 1989). The aquifer-specific discharge is relatively low. Computed discharges varied between 1.8×10^{-5} and 1.8×10^{-4} m²/s. Measured transmissivity values varied between 4×10^{-6} and 4.6×10^{-4} m²/s.

Besides natural recharge, important quantities of domestic wastewater have been injected into the aquifer over the last 30 years. Previous studies conducted in the region showed that both hydrodynamics and groundwater quality were extremely influenced by domestic wastewater recharge (Njim 1988; Beny Akhy 1994).

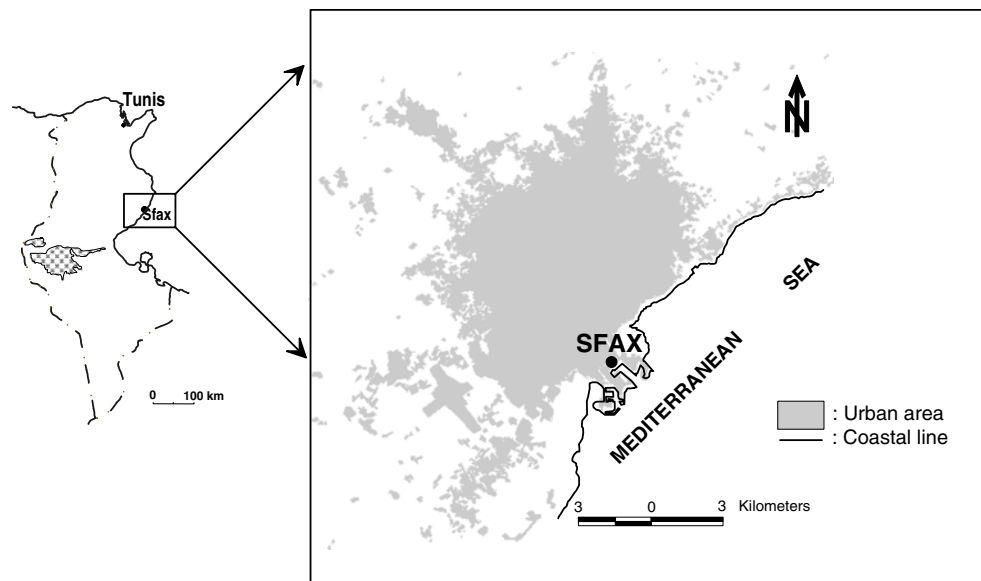
Materials and methods

The present piezometric status of the aquifer was characterized through a survey of surface wells (57 wells) spread all over the study area (Fig. 3). Data obtained were used to develop piezometric maps. Time evolution of the piezometric level was assessed by comparing piezometric maps established over a period of 22 years, extending from January 1983 to January 2005. Maps showing piezometric differences over a given period of time were also established to achieve this objective.

Groundwater samples were taken from 41 wells, 2–3 m below the water table, by using mobile pumping stations. Two samples from each well were collected for microbial and chemical analysis. In order to obtain groundwater directly from the aquifer, samples were collected after a period of pumping when the field parameters (e.g. conductivity, pH) showed constant values.

Groundwater samples for microbial analysis were taken aseptically in sterile glass containers and placed

Fig. 1 Location map of the study area



immediately in a refrigerator and kept at 4°C. Detailed information on temporal variation of the groundwater microbial quality was obtained through an extensive sampling program (three times over a 6-month period). Laboratory analysis was conducted within 24 h. The collection of samples was carried out from the 17 to 26 January, 2005. The analytical methods used to evaluate the water chemical and microbial composition are reported in Table 1.

The software ACCESS was used to develop a database and ARC VIEW GIS 3.2 was used to establish maps.

Results and discussions

Piezometric behaviour

The piezometric map established in January 2005 (Fig. 4) shows values varying between -5 and 28 m, with a NW-SE flow direction. Groundwater flow is locally deviated from North to South and from East to West, towards the agricultural area of Sidi Abid, where the aquifer is exploited by a number of wells (around 900 wells), mainly used for irrigation purposes.

By comparing the different piezometric maps established since 1983, the aquifer is shown to have a persistent morphologic behaviour (Chalbaoui 1989; Beny Akhy 1994). In fact, groundwater flow usually followed a NW-SE direction. The piezometric map of 2005, established in the present study, confirmed this particular morphologic behaviour of the aquifer. The map also showed the persistent piezometric cavity in the vicinity of Sidi Abid region because of the aquifer overexploitation. Hydraulic gradients were shown to be relatively small (<2 m/km) for the central area of Sfax City. However, they were shown to be much more important (with values reaching 6.5 m/km) in the vicinity of the upstream zones in the north and northwest of the city.

Based on measurements of groundwater depths in the survey of January 2005, a map of isodepths of the aquifer was also established (Fig. 5). The map shows water depths <2 m in the vicinity of the downtown area. Maximum depths were observed upstream of the study area, with values reaching 36 m.

Figure 6 shows the difference of piezometric levels over the period 1993–2005. This variation is not uniformly distributed over the study area. Two piezometric domes

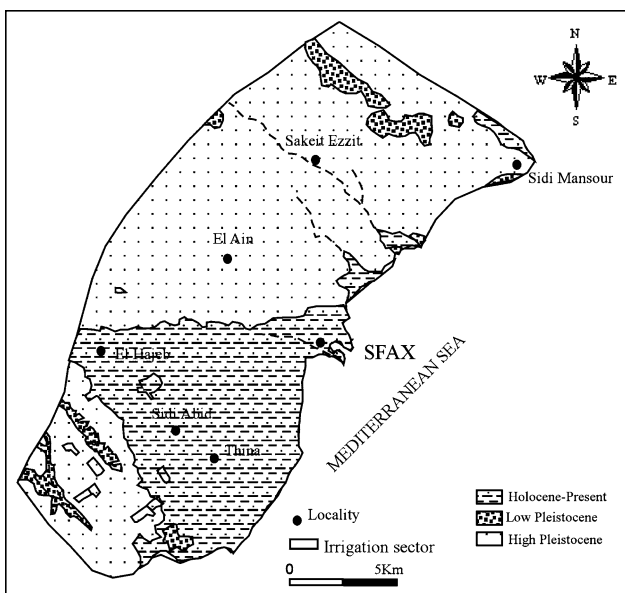
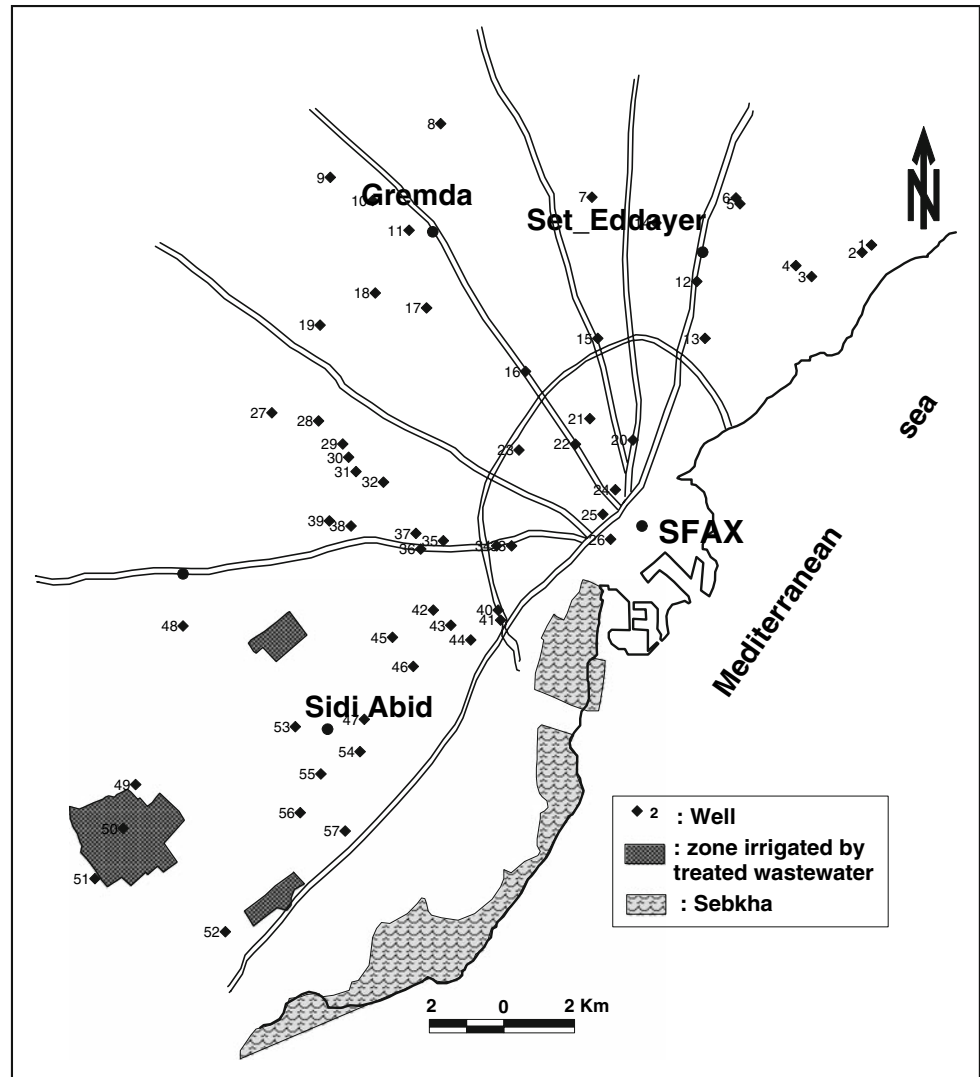


Fig. 2 Simplified geological map of the study area

Fig. 3 Location of wells used in the survey



separated by a piezometric cavity were observed. The maximum rise of groundwater level was observed in two different sectors:

- A highly urbanized area in the northwest of the city, where increases in the aquifer level of 6 m were

Table 1 Used analytical methods

Element	Analytical method
HCO ₃ ⁻	Titration with HCl
SO ₄ ²⁻	Chromatography liquid phase
Cl ⁻	Titration with AgNO ₃
Ca ²⁺	Titration with EDTA
Mg ²⁺	Atomic absorption spectrometer
Na ⁺	Atomic absorption spectrometer
NO ₃ ⁻	Atomic absorption spectrometer
Coliform bacteria	Membrane filtration

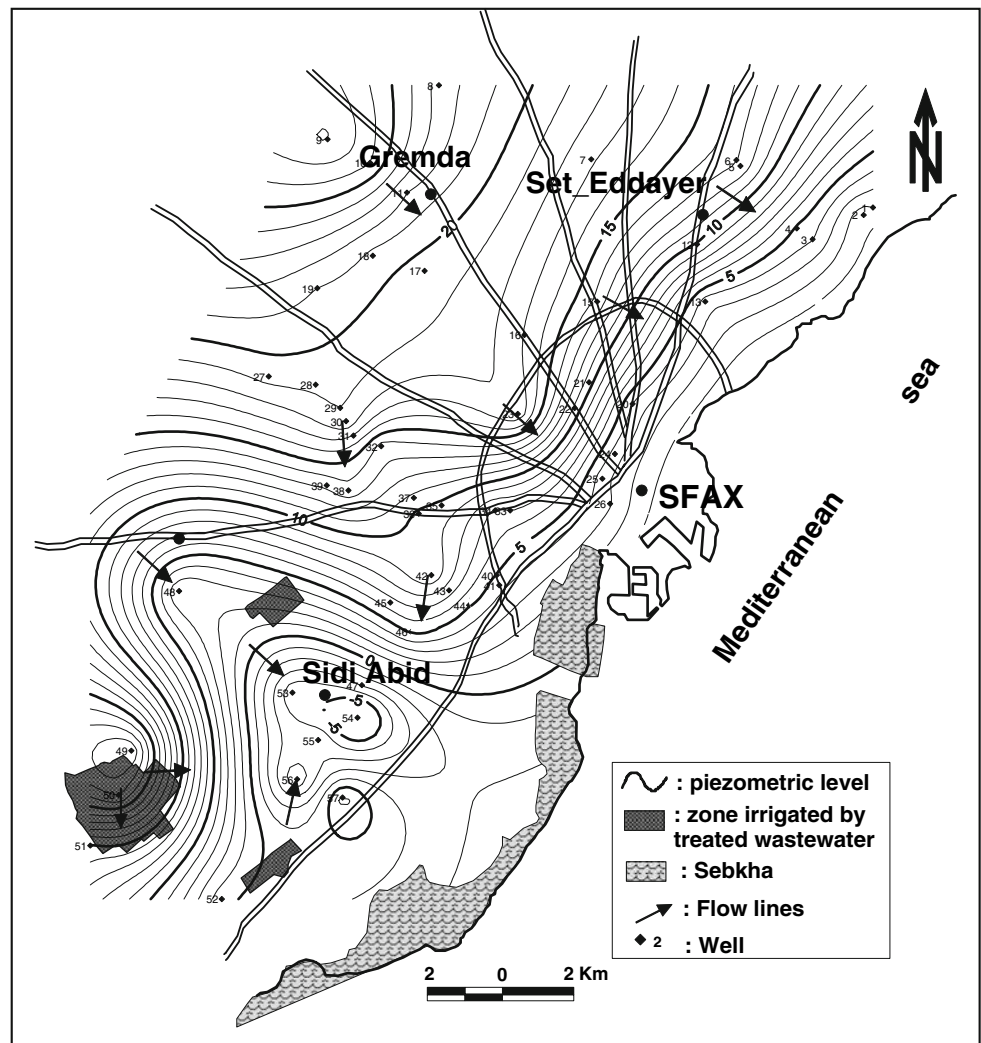
registered. This is the result of the injection of significant quantities of untreated domestic wastewaters in the aquifer through recharge wells.

- An agricultural zone in the extreme south of the study area, in which the groundwater level increase is believed to be related to artificial recharge through irrigation with treated wastewaters largely practiced in this particular zone.

Regarding the piezometric cavity, it is the result of the groundwater aquifer overexploitation for agricultural purposes in Sidi Abid, where groundwater level drop reached -5 m. The same structure was observed along the period extending from 1987 to 2005 with an increase of piezometric level reaching 7 m in the urban area (Fig. 7).

Groundwater level rises were also confirmed by simple simulations based on injected volumes and the aquifer properties. Figure 8 shows the evolution of wastewater injected quantities over the period 1983–

Fig. 4 Piezometric map of Sfax Aquifer (January 2005)

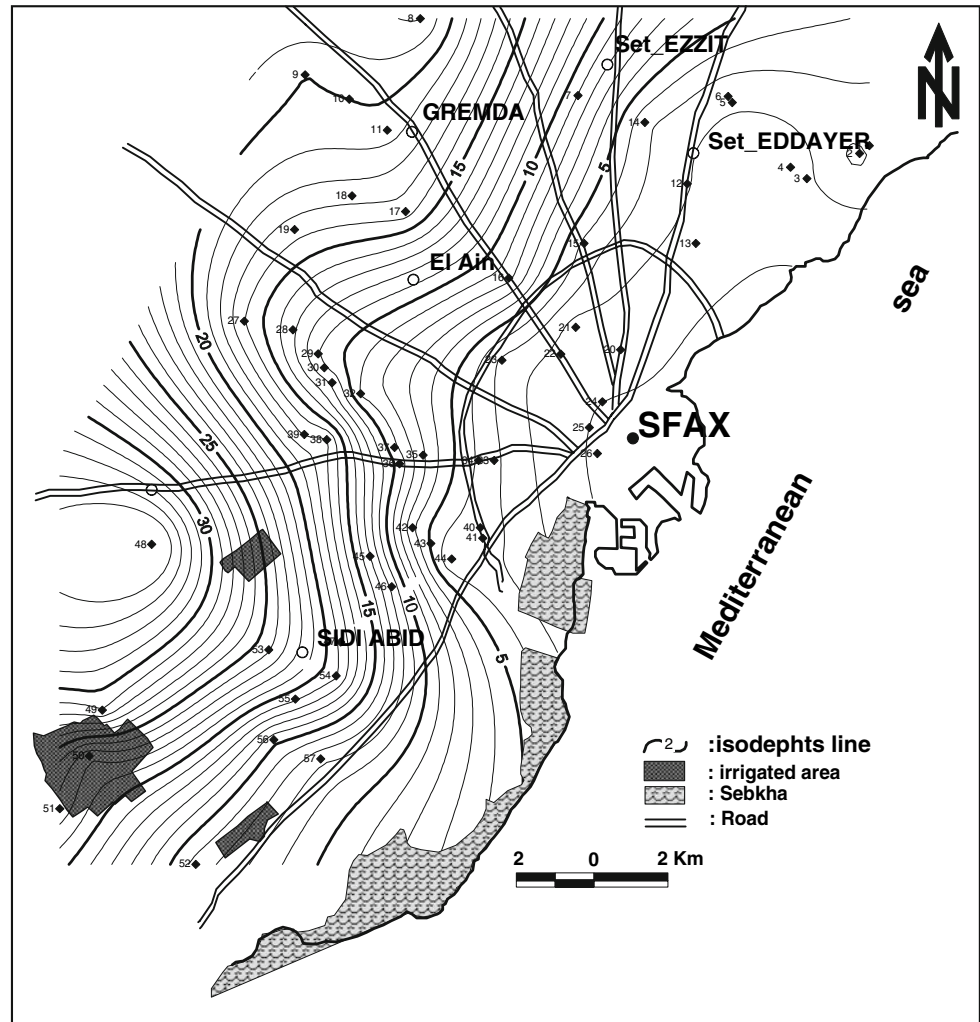


2005. These latter were computed as the differences between annual water consumption and collected wastewater quantities in the city, which are also displayed in the same figure (Fig. 8). It has to be mentioned at this stage that a coefficient of 0.8 was applied to water consumption volumes to account for any losses that may occur, mainly by evaporation. The ever increasing wastewater volume injected in the aquifer was shown to exceed $12 \times 10^6 \text{ m}^3/\text{year}$.

The annual rate of water table rise (h_i) was estimated as: $h_i = V_i / (A \times S)$, where V_i is the annual injected wastewater volume, A the city surface area and S is the aquifer specific yield. This simple modelling procedure was first suggested by Sophocleous (1991) to relate groundwater recharge to water-table fluctuations (WTF) in wells. In general, the WTF method was proved to be particularly appropriate when water levels show a quick response in areas with a relatively thin vadose zone (Moon et al. 2004), which is the case for the examined aquifer.

The WTF method estimates total groundwater recharge (natural and artificial) as the product of specific yield and the annual rate of water-table rise, including the total groundwater draft. Nevertheless, both groundwater draft and natural recharge were assumed to be negligible within the study area. In fact, Sfax citizens do not rely on groundwater for their domestic use and the city is characterized by a relatively high imperviousness ratio, which limits natural recharge. Regarding the specific yield, an average value of 0.25 was considered. It was obtained from a long duration pump test (72 h) and later confirmed by values given in the literature (Chow 1964; Castany 1982) based on soil type. Table 2 shows computed h_i values over the period 1987–2005, which oscillate around an average value of 0.35 m/year, depending on water consumption and the city surface area. The computed total groundwater rise over the period 1987–2005 was shown to be $\sim 6.8 \text{ m}$, which compares quite well with the measured piezometric fluctuations displayed in Fig. 7.

Fig. 5 Isodepths map for Sfax Aquifer (January 2005)



Groundwater quality

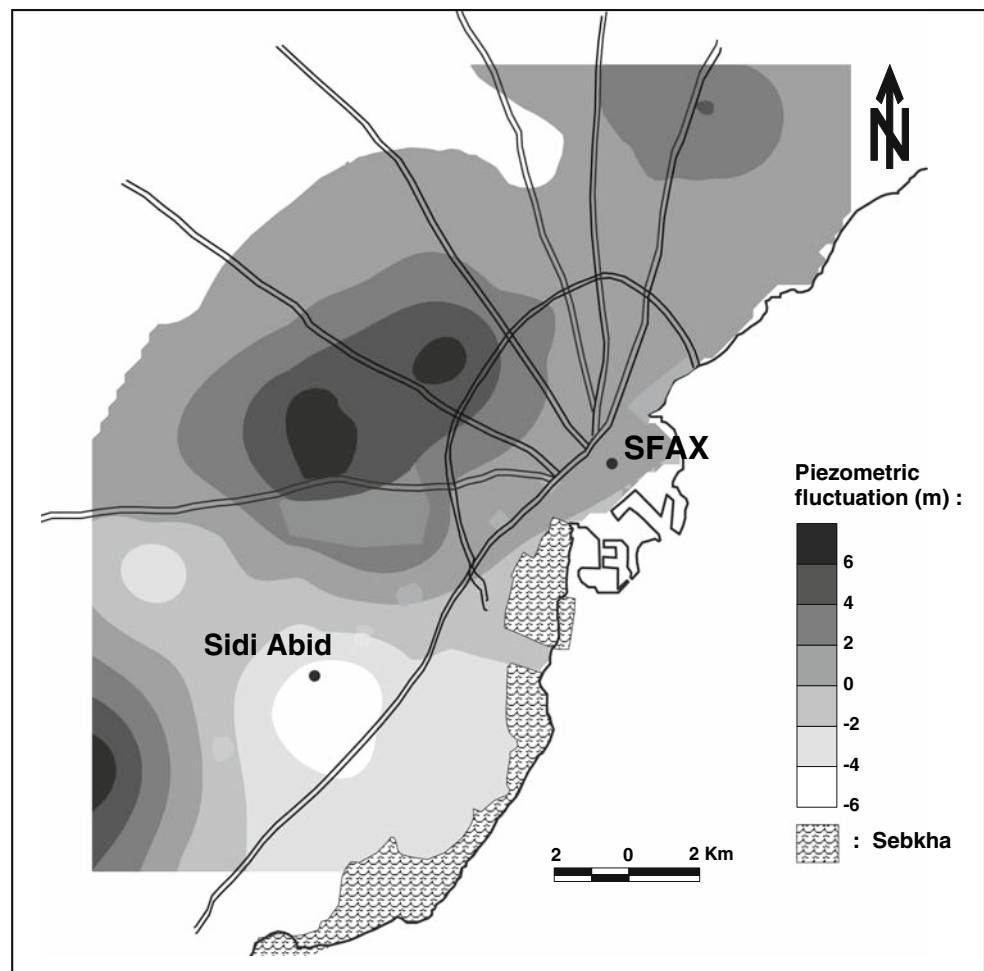
Groundwater quality was characterized through the analysis of water samples drawn from 41 surface wells spread all over the urban area.

Groundwater chemical behaviour

Table 3 shows the groundwater chemical composition. Results obtained are quite variable, but generally exceed by far the World Health Organization standards (WHO 2004). Water has almost neutral conditions, with pH values ranging from 7.5 to 8. Electrical conductivity ranged from 4,040 to 19,620 $\mu\text{s}/\text{cm}$ and maximum values were observed along the coastal zone. Results of the chemical analysis were presented on Piper Diagram (Fig. 9). This latter shows a global chemical homogeneity with a sulphated-sodic facies and an enrichment of chloride.

Salinity map of January 2005 shows that salinity tends to increase downstream (Fig. 10). Dry residual varies between 1.4 and 14 g/l, with an average value of 5.7 g/l. Salinity is relatively high along the coastal zone, where dry residual generally exceeds 8 g/l. This might be explained by the evaporation process, which tends to be quite important in zones of low groundwater depths. A salinity rate of <4 g/l is observed in the vicinity of stream of Set-Ezzit in the north of the study zone. This is probably the result of infiltration of rainwater and the injection of significant quantities of wastewaters in this highly populated sector. Compared to the salinity map developed by Beny Akhy (1993), the same evolution of salinity from upstream to downstream is observed. However, a restriction of the area that corresponds to high salinity (exceeding 8 g/l) and an increase of that corresponding to relatively lower salinity (between 4 and 6 g/l) are observed. This clearly shows the softening effect of groundwater, possibly caused by the injection of significant quantities of domestic

Fig. 6 Piezometric fluctuations in Sfax Aquifer (1993–2005)



wastewaters characterized by a salinity varying between 2 and 4 g/l.

Groundwater contamination by nitrogen compounds is a generalized phenomenon (Table 3), which extends almost all over the aquifer. The highest concentrations were registered in the northeast and the suburban areas, where the sanitary sewer system is not well developed. Concentration values vary between 32 and 240 mg/l, with an average of 117 mg/l. The highest concentrations were observed in the northeast of the city (wells no. 1, 2, 3, 4, 5, 6 and 13), characterized by shallow groundwater depths (<2 m) and recharge wells communicating directly to the aquifer. Nevertheless, relatively high nitrate concentrations (above 100 mg/l) were also registered in the southwest (wells no. 38, 39 and 40), a suburban region where bovine breeding is practiced.

Groundwater microbiological characteristics

Microorganisms are slightly present in the examined groundwater because of the anaerobic conditions and the

small quantities of available nutrients. Organic matter transfer to the aquifer enhances their multiplication. Pathogenic germs are generally associated to coliforms and fecal streptococci. The presence of these latter implies pollution by domestic wastewaters.

Total coliforms are widely distributed throughout the study area. It was detected in 27 of 30 (90%) wells sampled in the urban area (Fig. 11). An assessment level of more than 1,100/100 ml was registered in the highly urbanized area (North of the city) throughout the study period (6 months). This would imply a continuous supply of polluted waters to the groundwater aquifer. Distribution of fecal coliforms and streptococci coliforms shows a heavy concentration along the coastline and the southern suburban zone.

Groundwater contamination in the north (Set-Ezzit zone) is explained by the high concentrations of wastewater recharge wells. Contamination in the southern region is much more important. The wastewater collection system is not widespread all over this region. Moreover, this zone is characterized by the existence of bovine breeding farms. Therefore, groundwater contamination in this zone may be

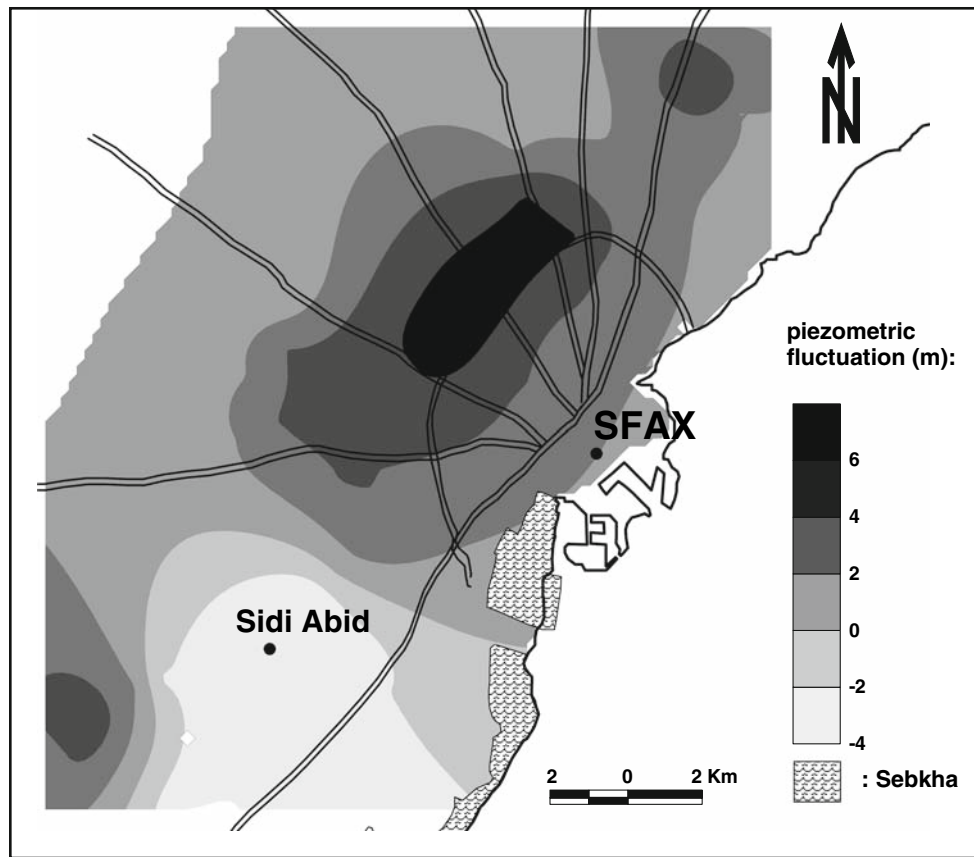


Fig. 7 Piezometric fluctuations 1987–2005

attributed to domestic and/or animal origins by infiltration of polluted waters through the soil or by direct contamination via unprotected wells.

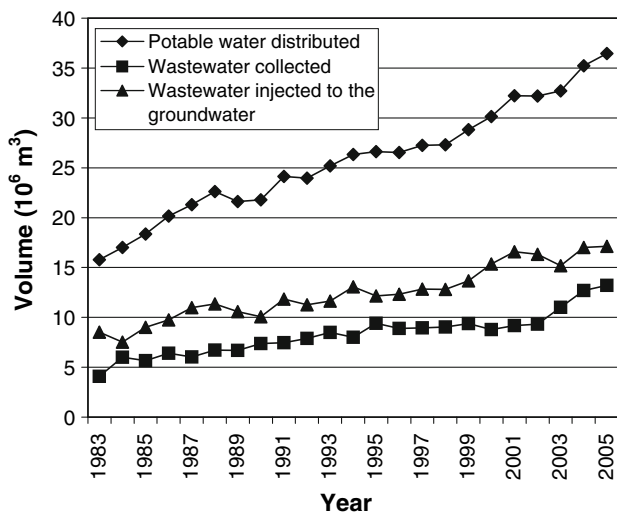


Fig. 8 Evolution of wastewater volumes injected in the groundwater aquifer of Sfax city

Table 2 Estimation of the groundwater increase

Year	Injected volume $10^3 \text{ m}^3/\text{year}$	Surface (km^2)	Groundwater increase (m)
1987	10,986	120	0.36
1988	11,355	120	0.37
1989	10,589	120	0.35
1990	10,061	120	0.33
1991	11,850	120	0.39
1992	11,273	140	0.32
1993	11,655	140	0.33
1994	13,062	140	0.37
1995	12,162	140	0.34
1996	12,338	140	0.35
1997	12,857	160	0.32
1998	12,807	160	0.32
1999	13,676	160	0.34
2000	15,344	160	0.38
2001	16,595	160	0.41
2002	16,432	170	0.38
2003	15,169	170	0.36
2004	16,132	170	0.38
2005	16,245	170	0.38
Total (m)			6.78

Table 3 Groundwater chemical analysis data

Well-number	NO ₃ ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	Na ⁺ (mg/l)	Cl ⁻ (mg/l)	pH	Electrical conductivity (μS/cm)	S (g/l)
1	32	2,500	3,727	5,600	7.6	19,620	14.8
2	254	1,300	736	1,120	7.55	8,000	5.8
3	100	1,420	819	1,600	7.62	8,670	6.3
4	212	1,340	989	2,140	7.67	8,240	6.1
5	188	1,600	1,564	2,500	7.85	13,140	9.92
6	163	1,500	758.8	1,336	7.92	7,750	5.8
7	56	1,160	528.8	806	7.88	5,370	4.02
8	114	1,100	920	1,350	7.82	7,100	5.35
9	97	360	184	267.5	7.75	1,930	1.45
10	47	1,120	552	900	7.92	5,130	3.8
11	135	1,320	589	910	7.94	5,350	4.1
12	93	1,950	690	1,064	7.6	7,350	5.5
13	185	1,640	1,812	2,920	7.61	11,870	8.9
14	40	1,100	298	435	7.5	4,400	3.35
15	175	1,500	1,218	1,884	7.91	9,880	7.44
16	76	1,160	1,840	2,550	7.7	11,780	8.85
19	90	1,860	469	760	7.88	5,110	3.8
20	87	1,950	621	1,002	7.5	6,410	4.8
21	67	1,350	1,494.1	2,016	7.1	9,550	7.2
22	165	1,820	458.8	1,200	7.85	8,540	6.43
23	134	1,580	390.8	590	7.67	4,800	3.6
24	138	1,580	782	2,150	7.85	6,390	4.8
27	55	1,920	874	1,485	7.68	7,240	5.4
28	87	2,180	758.8	1,245	7.79	6,570	4.95
30	130	1,420	690	1,040	7.85	5,840	4.4
31	77	1,720	758.8	1,465	7.82	7,260	5.5
32	69	2,260	920	1,155	7.78	6,840	5.2
33	125	2,720	942.8	1,250	7.59	5,320	6.3
34	90	2,700	1,678	1,169	7.95	11,220	8.4
35	111	2,900	1,150	1,740	7.89	8,850	6.62
36	112	2,640	690	1,414	7.82	6,500	4.9
37	92	2,000	515	740	7.9	5,000	3.8
38	200	1,200	368	566	7.78	4,040	3.1
39	185	1,400	469	675	7.8	4,780	3.6
40	205	1,860	358.5	477	7.5	5,230	3.92
41	105	1,480	335.7	495	7.9	4,220	3.18
42	85	1,600	690	937	7.25	6,000	4.52
43	101	2,720	691	921	7.85	6,800	5.2
44	85	2,570	312	840	7.9	6,810	5.2
45	90	3,260	1,066	1,600	7.94	9,460	7.1

Conclusion

Quantity and quality impacts of wastewater recharge on groundwater in Sfax City (Tunisia) were evaluated. Detailed mapping of the present state of the urban aquifer and the study of its evolution since 1983 showed a general

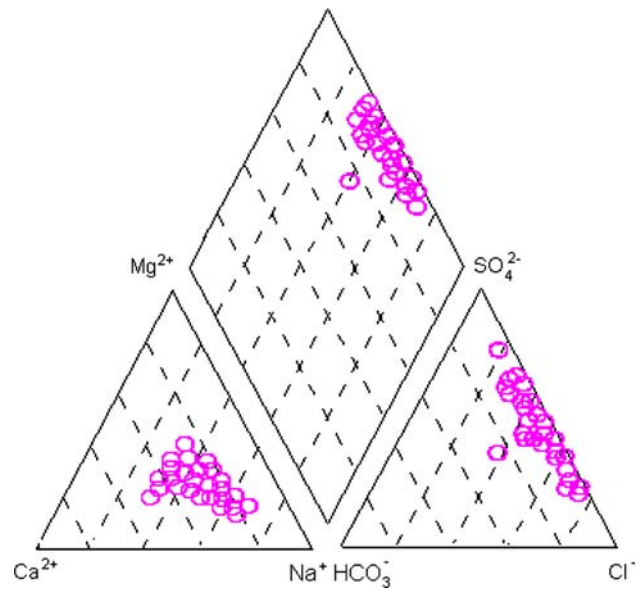


Fig. 9 Piper diagram of Sfax groundwater

northwest to southeast flow direction. In the south, the groundwater flow is highly disturbed. It adopts different directions converging into the cavity of Sidi Abid, a region characterized by an overexploitation of the aquifer for agricultural purposes. In the highly urbanized northern zone, the groundwater level increased continuously over the last two decades because of the lack of an appropriate wastewater collection system. In fact, almost $12 \times 10^6 \text{ m}^3$ /year of wastewaters are injected to the aquifer via recharge wells.

The chemical facies of the examined groundwater is sulphated sodic, with an enrichment of chloride. Salinity of the aquifer varies between 1.4 and 14 g/l, with an average of 5.7 g/l. The highest values were registered along the coastal zone. Concentrations of the different analysed elements were shown to exceed by far the WHO. High nitrate concentrations are attributed to the continuous injection of untreated domestic wastewaters via recharge wells, directly related to the aquifer. The most polluted zones correspond to the coastal line and the suburban region. This particular distribution of the groundwater pollution is explained by a high density of recharge wells and the presence of specific agricultural activities (bovine breeding).

Groundwater microbial analysis showed a high fecal contamination. Important concentrations of fecal streptococci and *Escherichia coli* were registered along the entire observation period. Most of the contaminated wells were found in the northeast of the city.

All of these obtained results can be considered in the management of the local water resources for domestic and/or agricultural use. Furthermore, the observed ever

Fig. 10 Salinity map (January 2005)

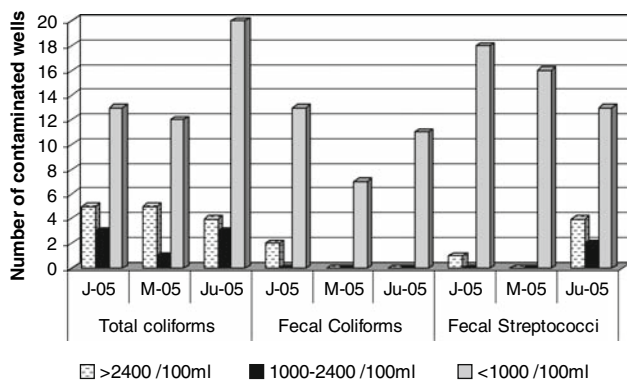
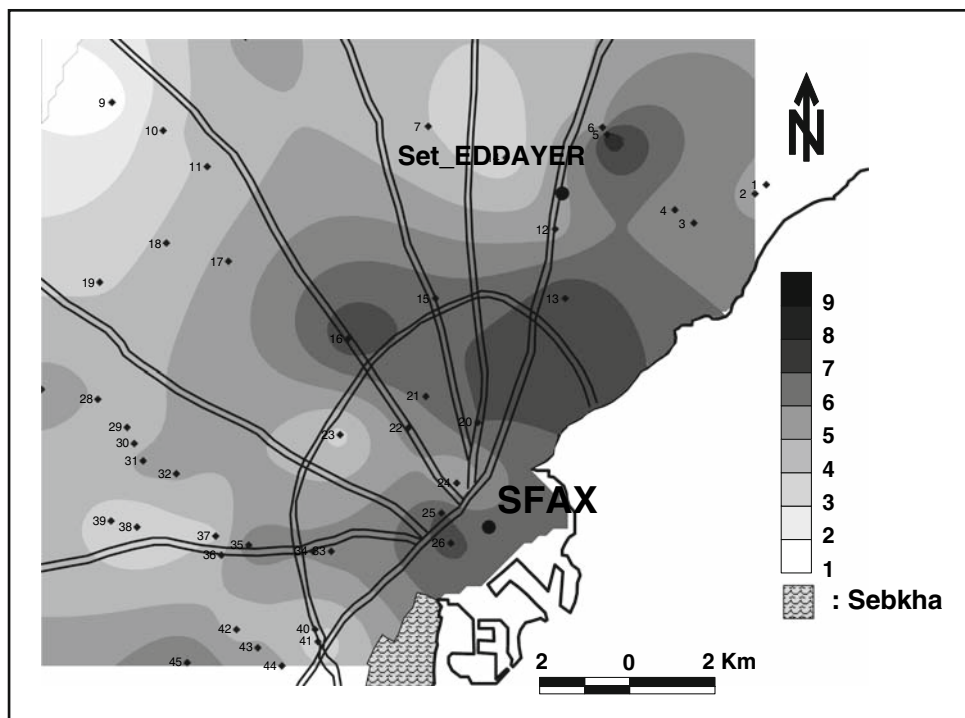


Fig. 11 Detection frequency of Coliforms bacteria in 30 urban wells in January, March and June 2005 (Sfax City groundwater)

increasing groundwater levels may lead to special building and construction measures for foundation stability.

References

- Alderwish AM, Dottridge J (1999) Urban recharge and its influence on groundwater quality in Sana'a, Yemen. In: Chilton J (ed) Groundwater in the urban environment. Selected City Profile, Balkema, Rotterdam, pp 85–90
- Arar A (1991) Wastewater reuse for irrigation in the Near East Region. *J Water Sci Technol* 23:2127–2134
- Beaudry JP (1992) Traitement des eaux. Edition de Griffon d'Argile, pp 187–206
- Beny Akhy R (1994) Etude de l'évolution et modélisation mathématique de la nappe phréatique urbaine de Sfax. D.E.A. Fac. Sc. de Tunis
- Bicki TJ, Brown RB (1991) On-site sewage disposal—the influence of system density on water-quality. *J Environ Health* 53:39–42
- Castany G (1982) Principe et méthodes de l'hydrogéologie. Edition BORDAS, Paris, 238pp
- Chalbaoui M (1989) Etude de l'hydrogéologie et de l'hydrologie urbaine de la ville de Sfax. Thèse de troisième cycle. Faculté des Sciences de Tunis, Tunisie
- Chow VT (1964) Handbook of applied hydrology. Edition McGraw-Hill Book Company, New York
- Edline F (1998) L'épuration biologique des eaux (Théorie et technologie des réacteurs), 4^{ème} édition CEBEDOC. Lavoisier, 297p
- Grabi A (2001) Eaux usées, quel traitement pour quel usage ou quel usage pour quel traitement. *Revue de l'environnement en Tunisie*, 8, juin, pp 36–38
- Harman J, Robertson WD, Cherry JA, Zanini L (1996) Impacts on a sand aquifer from an old septic system nitrate and phosphate. *Ground Water* 34:1105–1114
- Jeong C (2001) Effects of land use and urbanization on hydrochemistry and contamination of ground water from Taejon area, Korea. *J Hydrol* 253(1–4):194–210
- Kouri N (1992) Wastewater Reuse implementation in selected countries of the Middle East and North Africa. *Canadian Journal of Development Studies, Special issue on sustainable water resources management in arid countries*. International Water Resources Association, pp 131–144
- Lerner DN (1986) Leaking pipes recharge ground water. *Ground Water* 24:654–662
- Moon SK, Woo NC, Lee KS (2004) Statistical analysis of hydrographs and water-table fluctuation to estimate groundwater recharge. *J Hydrol* 292:198–209
- Njim S (1988) Contribution à l'étude de la pollution hydrique de la nappe phréatique de la ville de Sfax. D.E.A. Fac. Sc. de Tunis
- Payne JA, Butler D (1993) Septic tanks and small sewage treatment works. A guide to current practices and common problems. Technical note 146, in F. Wakida, 2005

- Salameh E, Alawi M, Batarseh M, Jiries A (2003) Determination of trihalomethanes and the ionic composition of groundwater at Amman City, Jordan. *Hydrogeol J* 10:332–339
- Sophocleous MA (1991) Combining the soil water balance and water-level fluctuation methods to estimate natural groundwater recharge: practical aspects. *J Hydrol* 124:229–241
- Wakida F, Lerner D (2005) Non agricultural sources of groundwater nitrates: arc view and case study. *Water Res* 39(1):3–16
- Whelan BR (1988) Disposal of septic tank effluent in calcareous sand. *J Environ Qual* 17:272–277
- WHO (World Health Organization) (2004) Guideline for drinking water quality, recommendations, vol 1, 3rd edn. WHO, Geneva, Switzerland
- Yang Y, Lerner DN, Barrett MH, Tellam JH (1999) Quantification of groundwater recharge in the city of Nottingham. *UK Environ Geol* 38:183–198
- Yates MV (1985) Septic-tank density and groundwater contamination. *Ground Water* 23:586–591
- Zingoni E, Love D (2005) Effects of a semi formal urban settlement on groundwater quality, Epworth (Zimbabwe): case study and groundwater quality zoning. *Phys Chem Earth* 30(11–16):8