Microbiological, physicochemical, and heavy metals assessment of groundwater quality in the Triffa plain (eastern Morocco)

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Abstract The focus of this study is the physicochemical and bacteriological characteristics of groundwater in the Triffa plain, Morocco. In total, 34 groundwater samples were analyzed for major elements (Tp, pH, EC, K⁺, Na⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻, NO₃⁻, NO₂⁻, NH₄⁺, H₂PO₄⁻, CO₃, and HCO₃⁻) and trace metal (Al, Cd, Cu, Fe, and Zn) content. The results show that the pH values range between 6.7 and 8.9, electrical conductivity ranges between 740 and 7340 µS/cm, and nitrate content ranges between 1.7 and 212 mg/l. Hydrochemical facies represented using a Piper diagram indicate an Na–K–Cl type water. All the trace metal concentrations are within the admissible standard range except for Cd. The bacteriological analysis showed that the majority of groundwater samples are contaminated. Generally, the content of total coliforms, fecal coliforms, and fecal streptococci ranged from 0 to 140, 0 to 125, and 0 to 108 CFU/100 ml, respectively. The samples are grouped according to three factors. Factor 1 shows strong positive loadings of EC, Mg, Cl, Na and K with 51.91% of total variance (TV); factor 2 shows strong negative loadings of NO₃, SO₄ and Ca with 17.98% of TV; and factor 3 shows

strong negative loading of HCO₃ with 15.56 of TV. We conclude that the quality of this groundwater is suitable for irrigation and domestic use (cleaning house, ect).

Keywords Groundwater · Hydrochemistry · Trace metal · Bacteriological analysis · Triffa · Morocco

Introduction

The deterioration of groundwater quality by nitrate and microbial contamination has been the subject of a number research papers (Lamrani Alaoui et al. 2008; Bahri and Saibi 2012; Douagui et al. 2012; Saber et al. 2013; Merghem et al. 2016; Al-Barakah F et al. 2017; Mallick 2017; Unnisa S and Zainab Bi 2017). The World Health Organization (WHO 2000) has set a limit of 50 mg/l on nitrates in drinking water based on the formation of methemoglobinemia in red cells (Douagui et al. 2012). In Morocco, the local economy is based on agriculture, which consumes 92% of the total water use. Currently, water resources are under serious pressure and agricultural practices often have negative impacts on groundwater quality (Chettouani and Damou 1993; Benkaddour 1997; Fetouani et al. 2008; Fekkoul et al. 2013). The scenarios of possible climate change impact on groundwater in the north of Africa are alarming (IPCC 2007; Jilali 2014). The decrease in the recharge of the aquifers is due to the decrease in precipitation and an increase in temperature (IPCC 2007). Consequently, the groundwater quality is strongly affected (Baba 2012; Jilali et al. 2015a).

Most of the previous studies in this region focused on groundwater quality (nitrate and salinity). This paper illustrates the impacts of irrigated agriculture and wastewater as well as physico-chemical and bacteriological

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Fig. 1 Geographical and geological location of the study area (Fetouani et al. 2008), modified. Points numbered in *red* highlight the location of groundwater samples

Fig. 2 Abundance of TC in groundwater (vertical axis), as sampled in June and November 2013 (horizontal axis)

Fig. 3 Abundance of FC in groundwater (vertical axis) as sampled in June and November 2013 (horizontal axis)

Fig. 4 Abundance of FS in groundwater (vertical axis) as sampled in June and November 2013 (horizontal axis)

factors and metal content on the quality of groundwater in the unconfined Triffa aquifer in different periods of time. The wastewater of the city of Berkane is rejected in the upstream of the Triffa basin (Cheraa wadi). Piezometric maps show that the direction of groundwater is from SE to NW (Fekkoul et al. 2013). For this reason, most of the contamination takes place in this direction. To assess this, 34 wells have been selected from the entire Triffa plain area (unconfined aquifer) to identify the spatial extent of contamination and evaluate the groundwater quality.

Study area

The Triffa aquifer basin is located in the north-eastern part of Morocco and has a surface area of 750 km². It is limited in the north by the Ouled Mansour hills, in the west by the Kiss and Moulouya rivers, in the south by the Beni Snassen Mountains, and in the east by the Kiss River. It lies between latitudes 35°05' N and 34°55' N, and longitudes 2°23' W and 2°11' W (Fig. 1). Geologically, the plain is formed by Tertiary and Quaternary formations consisting of alluvial material, silt, sandstone, limestone, and clay (Fetouani et al. 2008). In this region two aquifers are

present: (1) an unconfined aquifer hosted by the Tertiary and Quaternary formations; (2) a confined aquifer hosted by the Liasic formation (limestones and dolostones) (DGH 1997; El Mandour 1998; El Idrysy and Smedt 2006, 2007).

The climate of the region is semi-arid and total rainfall does not exceed 327 mm/year. The yearly average temperature is 17.4 °C, but seasonal variability is high, with a minimum of 11 °C and a maximum of 25 °C. The average annual evapotranspiration is about 300 mm/year (Fekkoul et al. 2013).

Materials and methods

Chemical analyses were run on 34 groundwater wells located in different parts of the study area during the months of March, June, and November 2013. Measurements of pH, temperature, electric conductivity (EC) (using ORION STAR A111 and WATER PROOF CC-411), and piezometric level were taken in situ. All water samples were collected in polyethylene bottles and stored in the absence of light at 4 °C. Major ions were analyzed in the laboratory for K⁺, Na⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻, NO₃⁻, NO₂⁻, NH₄⁺, H₂PO₄⁻ (SKALAR method), and HCO₃⁻

Table 1 Total Coliforms (TC), Fecal coliforms (FC), and Fecal Streptococci (FS) as colony forming units per 100 ml values measured in June 2013 and November 2013

Well	June 2013			November 2013		
	TC	FC	FS	TC	FC	FS
1	35	23	13	20	12	28
2	30	25	0	28	16	0
3	38	30	0	10	8	0
4	72	62	16	20	12	58
5	27	24	0	46	34	6
6	140	125	0	124	112	30
7	–	–	–	86	50	22
8	–	–	–	0	0	0
9	–	–	–	12	0	0
10	–	–	–	56	14	40
11	–	–	–	24	8	94
12	80	3	0	72	2	6
13	50	3	2	–	–	–
14	31	20	2	50	46	6
15	25	13	3	22	12	0
16	23	14	0	24	0	0
17	0	0	0	30	12	0
18	73	23	0	62	16	0
19	32	0	13	98	76	108
20	85	61	0	78	50	24
21	50	0	0	122	82	30
22	20	3	0	66	36	66
23	41	34	0	84	66	0
24	45	5	0	42	0	106
25	10	0	0	14	12	0
26	102	62	0	96	50	4
27	43	25	0	34	0	0
28	108	28	1	104	94	0
29	17	4	50	0	0	10
30	21	20	3	0	0	0
31	17	13	0	10	8	0
32	60	53	20	44	0	56
33	0	12	0	0	0	0
34	102	88	4	68	64	2
Minimum	0	0	0	0	0	0
Maximum	140	125	50	124	112	108
Average	47.48	26.66	4.38	46.85	27.03	21.09

The values above 0 indicate potential contamination

(Rodier 1984). Nitric acid was added to 50 ml of water to produce a 10% nitric acid concentration for the analysis of Al, Cd, Cu, Fe, and Zn, which were determined by atomic emission spectroscopy (ICP-AES; Ultima 2, JobinYvon: equipped with an optical system with two thermo-regulated networks of 4343 and 2400 rev/mm back to back, covering

the spectral range 120–800 nm with a nitrogen sweep) in the National Center for Scientific and Technical Research, Rabat-Morocco. A database was then created on the geographic information system (GIS) integrating.

Bacteriological analysis was conducted in the same groundwater wells of the study area in June and November

Fig. 5 EC ($\mu\text{S}/\text{cm}$) measured in the Triffa plain in **a** March, **b** June, and **c** November 2013, highlighting the changes in EC concentration between one period and another. The blue lines are the wadis

2013. All measurements were conducted on the same day in the quality control laboratory (University of Mohammed 1st, Morocco). Pathogens analyzed in this study include total coliforms (TC), fecal coliforms (FC), and fecal streptococci (FS: Intestinal Enterococci). Water samples of 100 ml each were filtered (pore size: $0.45 \mu\text{m}$) and then transferred onto triphenyl-tetrazolium chloride (TTC) and tergilactose agar (AFNOR 1998), which were used as selective media for FC. The FC and TC were counted after 24 h incubation at $44 \pm 1^\circ\text{C}$. For FS, the selective medium of Slanetz and Bartley was used. The FS were counted after incubation at 37°C for 24 h. The total number of bacteria was determined as colony forming units per 100 ml (CFU/100 ml).

The principal component analysis (PCA) multivariate statistical technique was used in our research. This method is a quantitative and independent approach for the classification of groundwater samples according to their geochemical characteristics and may simplify and organize large data sets to make useful groupings of similar samples (Kumar et al. 2013; Jilali et al. 2015b). The STATISTICA software was used to process the November 2013 vintage data analyses. For this, the analyses of EC, K^+ , Na^+ , Ca^{2+} , Mg^{2+} , HCO_3^- , Cl^- , SO_4^{2-} and NO_3^- were used as variables.

Results and discussion

Groundwater bacteriological quality

Figures 2, 3, and 4 show the abundance of TC, CF, and FS in groundwater sampled in June and November 2013.

- TC abundance varied from 0 to 140 CFU/100 ml in June and from 0 to 124 CFU/100 ml in November (Fig. 2);
- FC abundance varied from 0 to 125 CFU/100 ml in June and from 0 to 112 CFU/100 ml in November (Fig. 3);
- FS abundance varied from 0 to 50 CFU/100 ml in June and from 0 to 108 CFU/100 ml in November (Fig. 4).

The results that show the contamination of groundwater affects nearly the whole region (Table 1; Figs. 2, 3, 4). Generally, the highest numbers of these bacteria groups were recorded in June, which is the dry period. One well, however, (no. 17) shows no contamination during the dry period. Otherwise, in the humid period (November) three

Table 2 Physicochemical parameters of groundwater sampled in the wells in March 2013 (NS: Static level)

Well	Tp (°C)	pH	NS (m)	EC (μS/cm)	NO ₃ [−] (mg/l)	Ca ²⁺ (mg/l)	Mg ²⁺ (mg/l)	K ⁺ (mg/l)	Na ⁺ (mg/l)	Cl [−] (mg/l)	SO ₄ ^{2−} (mg/l)	HCO ₃ [−] (mg/l)
1	19	7.4	16.4	4970	100.7	270	255.2	7.8	529	1666.1	312	305
2	19.5	7.41	10.5	3870	60.5	130	200.5	11.7	540.5	974.9	547.2	427
3	20.3	7.2	13	3380	115.6	140	145	6.6	517.5	833.1	470.4	396.5
4	18.7	7.5	12	2520	118.9	110	127.6	5.5	322	390	470.4	366
5	20.8	7.3	18.5	3290	72.3	150	145.8	6.6	345	780	432	396.5
6	19	7.38	3	4070	78	160	182.3	9	540.5	957.1	672	457.5
7	19.7	7.32	4.5	3480	107.6	200	151.9	9.4	322	797.6	624	396.5
8	22	7.34	12	2820	55	150	133.6	3.1	322	673.6	259.2	366
9	20	7.64	16.5	2390	80	80	133.6	4.3	322	460.8	288	396.5
10	22.8	7.37	22	2080	44	80	109.4	3.1	276	425.4	163.2	396.5
11	20	7	5	3390	32.1	200	127.6	9	448.5	744.5	–	–
12	19.5	7.22	11.5	2600	85	150	115.4	5.5	379.5	514	–	–
13	23.5	7.13	3		135.7	170	127.6	12.5	460	638.1	–	–
14	20.3	7.42	3.5	2400	63	170	60.7	10.1	345	478.6	–	–
15	20	7.31	3	3570	130.7	170	170.1	11.3	368	833.1	672	396.5
16	23	7.3	12	5380	48	300	164	13.3	483	329.4	–	–
22	20.3	7.3	11	2940	97.8	180	145.8	19.5	345	620.4	–	–
24	20.4	7.63	12	3140	31.6	160	133.6	6.8	379.5	709	470.4	427
Minimum	18.7	7	3	2080	31.6	80	60.7	3.1	276	329.4	163.2	305
Maximum	23.5	7.64	22	5380	135.7	300	255.2	19.5	540.5	1666.1	672	457.5
Average	20.49	7.34	10.52	3311.18	80.92	165.00	146.09	8.62	402.50	712.54	448.40	393.96

Accuracy: Tp ± 0.1 °C, pH ± 0.01, EC ± 0.25%, and ICP-AES ± 0.5%

uncontaminated wells were observed (wells no. 8, 30, and 33). In addition, the abundance of bacteria was lower than in the dry period (June). The highest numbers of bacteria were recorded in Madarh region (Fig. 1). On the other hand, a correlation between pH values and bacteria has been established for the months of June (dry period) and November (humid period): with an increase in pH, the TC and FC values were generally lower (e.g., in the case of wells no. 5, 16, 19, 21, 22, 23, 31 and 34 located in the north of Hassi Smia flexure), whereas the FS values were higher (e.g., in the case of wells no. 15, 29, 30 and 34 located in the south of Hassi Smia flexure). The fecal contamination is due to the injection of fecal organic matter in septic tanks. Therefore, the abundance of bacteria depends on the richness of nutrients from human waste and animals (Al-Barakah F et al. 2017; Bahri and Saibi 2012; Merghem et al. 2016).

Hydrochemistry of groundwater quality

According to Table 1, the pH values of the analyzed samples varied from 7 to 7.64 in March, from 6.7 to 8.9 in June, and from 6.75 to 9.62 in November. These values

indicate that the groundwater is slightly acid to alkaline water. The temperature of groundwater ranged between 18.5 and 23.5 °C. The EC values of groundwater samples range from 740 to 5380 μS/cm in March, from 1170 to 4120 μS/cm in June, and from 1590 to 7340 μS/cm in November. The highest EC was recorded in the west part of the study area (Fig. 5; Tables 2, 3).

The hydrogeochemical facies of groundwater and the relationship between different dissolved ions can best be understood by plotting geochemical data on a Piper diagram, which indicates an Na–K–Cl type water (Fig. 6). The diagram shows the evolution of major ions for two periods (March and November). According to the Ca²⁺, Mg²⁺, Na⁺, and K⁺ triangle, an increase in the concentration of Mg²⁺ and decreases in Na²⁺ and K⁺ were registered.

The results of plots of major ions with EC show that chloride and sodium were strongly correlated with EC with R² = 0.95 and 0.836, respectively (Fig. 7). These values indicate that the groundwater salinities were mainly controlled by these ions. The possibility that salinization could have been caused by seawater intrusion is not plausible, because Triffa is an unconfined aquifer, with no inflow in its north part. Thus, a plot of chloride versus sodium shows

Table 3 Physicochemical parameters of groundwater sampled in the wells in June 2013 and November 2013 (NS: Static level)

Well	June 2013										November 2013												
	Wp	pH	NS	EC (μS/cm)	NO ₃ ⁻ (mg/l)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	Wp	pH	NS	EC (μS/cm)	Na ⁺ (mg/l)	K ⁺ (mg/l)	Mg ²⁺ (mg/l)	Ca ²⁺ (mg/l)	NH ₄ ⁺ (mg/l)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	CO ₃ ²⁻ (mg/l)	HCO ₃ ⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	H ₃ PO ₄ ⁻ (mg/l)
1	20.9	7.04	16	3730	146.5	1114.7	-	19.4	7.75	16.15	4100	426.7	8.5	116.57	188.94	0.06	856.12	367.71	0	228.8	38.76	0.06	<0.02
2	21	7.42	3	3750	44	731.3	-	18.9	7.22	9.6	5000	607.56	5.86	118.33	223.94	<0.02	1018.69	581.99	0	326.4	89.28	0.07	<0.02
3	21.1	7.05	16	3300	48.4	-	-	20.6	7.63	13.5	4220	577.26	4.76	95.78	150.05	0.09	895.47	450.22	0	326.4	96.21	0.1	<0.02
4	19.9	7.6	12	2380	52.1	340.8	152.5	19.4	7.78	12.8	2880	396.45	3.23	61.45	106.19	0.07	364.12	453.58	0	289.8	168.28	<0.04	<0.02
5	21	6.7	18.5	3000	35.3	624.8	437.5	21.2	7.07	18	3660	338.38	6.87	109.49	218.65	0.08	730.86	389.38	0	255.64	84.91	<0.04	<0.02
6	20.7	7.05	2.6	3380	39.7	663.85	-	19.9	7.12	2.8	4790	602.71	6.51	119.58	216.1	0.08	953.41	597.05	0	426.44	94.55	<0.04	<0.02
7	19.8	7.12	4.5	3420	176	738.4	782.5	20.4	7.53	3	4280	414.56	8.43	108.42	261.04	0.08	764.81	559.67	0	289.8	114.05	<0.04	<0.02
8	22	7.34	12.5	2100	-	-	-	21	7.44	-	3380	346.27	2.95	74.29	185.89	0.07	620.9	337.77	0	216.6	69.93	<0.04	<0.02
9	21.4	7.25	17	2330	68.5	447.3	347.5	20.8	7.27	16.7	2770	334.67	6.04	57.57	106.67	0.09	444.82	307.8	0	241	87.5	<0.04	<0.02
10	21.5	7.5	25	2060	15.8	337.25	252.5	23.1	7.22	22	2410	300.18	2.18	44.78	96.21	0.06	411.78	214.98	0	236.12	48.04	<0.04	<0.02
11	20.5	7.2	5.1	3410	-	-	-	20.2	7.39	3.2	3670	417.16	6.06	88.97	184.89	0.07	665.27	490.24	0	209.28	62.1	<0.04	<0.02
12	22.4	6.97	14	2480	20.7	401.15	420	19.1	6.75	11	2890	336.8	3.84	62.74	128.64	0.04	465.84	320.88	0	372.76	54.13	<0.04	<0.02
13	20	7.29	3	3030	31	450.85	475	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	20.8	7.67	4.5	1200	10.5	113.6	472.5	20.8	7.15	4.8	2140	191.89	7.64	52.9	131.24	0.08	324.7	327.22	0	233.68	47.26	<0.04	<0.02
15	20.3	7.24	3.5	3380	212.9	653.2	497.5	20.5	7.02	3.8	4120	402	10.73	91.08	247.51	0.08	762.24	483.84	0	299.56	117.54	<0.04	<0.02
16	21.4	6.75	11.5	1170	40.3	869.75	402.5	21.3	6.99	11.6	5520	538.35	12.12	138.38	281.39	0.05	1317.31	396.79	0	216.6	79.83	<0.04	<0.02
17	21.4	7.14	30	3000	-	514.75	85	20.4	7.57	26	2250	317.08	6.95	50.03	79.3	0.09	193.85	363.11	0	519.16	16.18	<0.04	<0.02
18	20.7	8.9	11.9	3960	121	1345.45	73.75	20.6	9.62	12	5060	789.44	18.81	93.82	7.66	5.79	1401.5	23.63	14.4	304.44	1.69	<0.04	0.09
19	20.7	7.25	12	3130	22.3	631.9	275	18.5	7.28	7.9	2860	280.86	2.45	94.37	125.58	0.09	408	387.77	0	302	34.92	<0.04	<0.02
20	22	7.27	16	2270	33.8	379.85	252.5	20.5	7.23	13.5	2660	286.26	3.62	55.12	142.33	0.09	458.62	268.79	0	253.2	91.87	<0.04	<0.02
21	20.6	7.37	3	1400	17.9	358.55	335	20.6	7.33	3	3410	338.77	13.42	72	138.36	0.07	595.43	365.36	0	282.48	107.71	<0.04	<0.02
22	20.8	7.08	15	1420	34.4	447.3	230	21	7.37	14.3	3020	263.05	6.08	79.07	178.05	0.07	506.35	349.69	0	299.56	79.37	0.05	<0.02
23	21	7.14	5	1520	13.6	1480.35	347.5	20.8	7.05	5.4	7340	1031.5	15.29	198.59	199.85	0.03	1806.19	509.04	0	465.48	82.41	0.24	<0.02
24	19.7	7.37	7	2080	12	355	147.5	21.3	7.24	6	2940	252.69	15.03	75.78	168.07	0.07	485	379.26	0	323.96	56.51	<0.04	<0.02
25	21.8	7	14	4120	33.2	681.6	197.5	20.9	6.99	14.2	5230	611.02	15.17	125.21	265.07	0.08	1214.54	461.77	0	223.92	79.03	0.05	<0.02
26	21	7.05	8	3570	23.8	766.8	162.5	20.6	7.57	8	4690	460.67	10.4	98.86	234.85	0.08	994.07	427.14	0	209.28	91.28	<0.04	<0.02
27	20.4	7.7	20.5	2600	122.9	383.4	37.5	20.1	7.24	20	3260	451.25	3.33	45.73	92.76	0.07	439.07	419.81	0	392.28	149.38	<0.04	<0.02
28	19.8	7.27	34	1630	79.4	195.25	97.5	19.5	7.06	33.7	1955	177.57	1.82	53.5	129.65	0.37	191.22	302.93	0	314.2	82.41	<0.04	<0.02
29	21.6	7.01	40	1290	17.9	-	-	20.5	7.1	43.1	1590	151.47	1	38.7	74.83	0.11	159.31	148.21	0	282.48	83.35	<0.04	<0.02
30	19.9	6.8	36	2200	15.8	294.65	60	21.5	7.66	37	2620	392.91	0.99	37.78	73.4	0.05	330.41	313.29	0	443.52	118.19	<0.04	<0.02
31	21.1	7.04	23	3970	38.7	926.55	105	20.3	7	22	5110	677.84	5.66	123.57	166.21	0.07	1111.02	398.13	0	309.32	157.9	<0.04	<0.02
32	22.8	7	14	2190	35	355	90	20.4	7.4	11.8	2700	284.87	5.48	44.83	117.64	0.12	436.15	242.19	0	358.12	67.26	<0.04	<0.02
33	22.7	7.14	27.5	1960	30.2	-	-	23.2	7.08	27.5	3870	410.87	2.57	92.92	181.46	0.04	775.72	311.45	0	294.68	67.34	<0.04	<0.02
34	20.5	7.6	39.1	4010	-	-	-	20.7	7.21	40	3860	578.32	1.03	57.98	76.84	0.12	565.22	464.85	0	463.04	86.6	<0.04	<0.02
Minimum	19.7	6.7	2.6	1170	10.5	113.6	37.5	18.5	6.75	2.8	1590	151.47	0.99	37.78	7.66	0.03	159.31	23.63	0	209.28	1.69	<0.04	<0.02
Maximum	22.8	8.9	40	4120	212.9	1480.35	782.5	23.2	9.62	43.1	7340	1031.5	18.81	198.59	281.39	5.79	1806.19	597.05	14.4	519.16	168.28	0.24	0.09
Average	20.98	7.24	15.43	2660.00	53.12	592.98	269.45	20.55	7.34	15.45	3644.09	423.86	6.81	84.19	156.95	0.26	686.91	376.23	0.44	309.39	81.99	0.07	<0.02

Accuracy: TP ± 0.1 °C, pH ± 0.01, EC ± 0.25%, and ICP-AES ± 0.5%

Fig. 6 Piper diagram for groundwater samples showing the hydrogeochemical facies and changes in the concentration of major ions between March and November 2013

a high correlation coefficient of 0.797 (Fig. 8), indicating that these ions have the same origin: the dissolution of halite present in: (1) sedimentary rocks (DGH 1997; El Mandour 1998; El Idrysy and Smedt 2006) or (2) saline surface deposits (Chettouani and Damou 1993; Benkaddour 1997). The plot of SO_4 versus EC (Fig. 7) shows a good correlation, indicating that the sulfate participates in water mineralization. On the other hand, a plot of SO_4 versus Ca (Fig. 8) indicates that the sulfate has the same origin as Ca. A plot of HCO_3 versus EC (Fig. 7) shows no linear correlation between them and indicates that the bicarbonate participates in the transfer reaction. On the other hand, the plot of HCO_3 versus Ca (Fig. 8) indicates the ionic association between them (Saber et al. 2013; Mallick 2017).

The concentrations of NO_3^- in March, June, and November are in the range of: 31.6–135.7, 10.5–212.9, and 1.7–168.3 mg/l, those of Cl^- are in the range of 329.4–1666.4, 113.6–1480.3, and 159.3–1806.2, and those of SO_4^{2-} are in the range of 163.2–672, 37.5–782.5, and 23.6–672 mg/l, respectively (Fig. 9; Tables 2, 3). The high concentrations result from the presence of cultivation zones, where ammonium nitrate is used as a chemical fertilizer. This observation is similar to those made in other studies carried out in the Triffa plain (Fetouani et al. 2008; Fekkoul et al. 2013). The increases in other anions and cations occur due to the concentration of these ions by recycling the groundwater as irrigation water (Bahri and Saibi 2012). Comparing the concentration of nitrate, chloride, and

Fig. 7 Major ion concentration (vertical axis) versus EC (horizontal axis). The linear correlation between them is shown by R^2

Fig. 8 Concentration of various major ions. The linear correlation between them is shown by R^2

Fig. 9 Concentration of nitrates recorded in **a** March, **b** June, and **c** November 2013, highlighting the changes in NO_3^- concentration between one period and another. The blue lines are the wadis

sulfate with the depth of the aquifer suggests that high concentrations takes place in the dry period. On the other hand, the plots of HCO_3^- versus SO_4 and SO_4 versus Cl (Fig. 8) show that the pollutants are inputs from the soil surface and their origin is the same: from fertilizers and from animal and human wastes (Saber et al. 2013; Mallick 2017; Unnisa S and Zainab Bi 2017).

According to WHO standards, the admissible levels of Cu, Zn, Al, Cd, and Fe in potable water are 2, 3, 0.2, 0.003, and 0.2 mg/l, respectively. The concentrations of trace metals in groundwater are generally within the admissible standard range, with the exception of Cu, Zn, Al for wells 24 and 26 measured in June, and wells 1 and 17 measured in November, and Fe for wells 12 and 26 measured in June, and wells 1, 18, 27, and 33 measured in November. For Cd, all samples of groundwater present contamination with a concentration higher than 0.003 mg/l (Table 4). This contamination comes probably from the pesticides used for irrigation and the discharge located in the southern part of Berkane.

PCA

The data were processed by the STATISTICA software package. The variables of Mg, Ca, Na, K, Cl , HCO_3^- , SO_4 , NO_3 and EC were used for the PCA test (Table 5). Three factors were extracted; factor 1 shows strong positive loadings of EC, Mg, Cl , Na and K with 51.91% of Total Variance (TV: 85.45%); factor 2 shows strong negative loadings of NO_3 , SO_4 and Ca with 17.98% of TV; and factor 3 shows a strong negative loading of HCO_3^- with 15.56 of TV. The spatial distribution of the variables and individuals in the axes system F1-F2 and F1-F3 are showed in Figs. 10 and 11.

Considering the spatial distribution of the variables and individuals in the axe systems of F1-F2 we can conclude the presence of two groups of waters. Group 1 corresponds to the waters from the south-west part of the study area. This group which is located in a fractured zone suggest that the area of recharge (Oued Cherrâa) and the mixture of groundwater between unconfined and confined aquifers facilitated by faults. Group 2 consists of the waters of wells situated in the center of Triffa plain (an intensive irrigation zone), where agricultural activities take place.

Table 4 Metal concentrations of groundwater sampled in the wells in June 2013 and November 2013 (mg/l)

Well	June 2013					November 2013				
	AL	Cd	Cu	Fe	Zn	Al	Cd	Cu	Fe	Zn
1	–	0.022	0.026	0.062	0.386	0.22	0.03	0.05	0.44	0.22
2	0.061	0.027	0.13	0.06	0.078	0.03	0.02	0.03	0.03	0.01
3	–	0.022	0.028	0.049	0.18	0.06	0.02	0.04	0.03	0.04
4	0.189	0.023	0.12	0.095	0.074	0.13	0.02	0.04	0.12	0.21
5	–	0.021	0.031	0.046	0.01	≤0.006	0.02	0.04	0.08	0.06
6	–	0.02	0.025	0.141	0.189	0.25	0.02	0.04	0.08	0.63
7	0.056	0.02	0.028	0.069	0.02	0.11	0.03	0.05	0.15	0.12
8	0.062	0.024	0.12	0.116	0.114	0.02	0.02	0.04	0.08	0.12
9	–	0.02	0.25	0.083	0.08	≤0.006	0.04	0.04	0.06	0.02
10	–	0.021	0.025	0.388	0.162	≤0.006	0.09	0.06	0.07	0.08
11	–	0.02	0.024	0.032	0.01	0.07	0.03	0.04	0.06	0.08
12	0.1	0.023	0.121	0.493	0.107	≤0.006	0.02	0.04	0.09	0.09
13	0.172	0.027	0.122	0.045	0.077	–	–	–	–	–
14	–	0.021	0.025	0.066	0.01	0.07	0.02	0.03	0.12	0.03
15	–	–	–	–	–	0.02	0.02	0.03	0.03	0.07
16	0.352	0.028	0.122	0.042	0.05	0.02	0.07	0.03	0.03	0.08
17	0.093	0.026	0.125	0.082	0.157	0.46	0.05	0.03	0.34	0.43
18	0.548	0.034	0.129	0.05	0.471	0.33	0.04	0.04	4.07	0.06
19	0.059	0.034	0.122	0.119	0.078	0.06	0.03	0.03	0.16	0.06
20	0.062	0.026	0.122	0.062	0.058	0.16	0.02	0.03	0.23	0.06
21	0.072	0.025	0.121	0.074	0.076	0.05	0.02	0.03	0.07	0.03
22	0.473	0.029	0.12	0.076	0.003	0.06	0.03	0.03	0.09	0.06
23	0.073	0.043	0.123	0.091	0.027	0.1	0.03	0.03	0.14	0.04
24	0.146	0.029	0.12	0.118	0.031	0.04	0.03	0.03	0.09	0.05
25	0.168	0.43	0.127	0.049	0.059	≤0.006	0.07	0.06	0.04	0.16
26	0.291	0.033	0.122	0.453	0.039	0.02	0.06	0.04	0.07	0.32
27	–	–	–	–	–	0.17	0.02	0.03	0.25	0.09
28	–	–	–	–	–	0.18	0.05	0.03	0.19	0.15
29	–	–	–	–	–	≤0.006	0.02	0.02	0.06	0.01
30	–	–	–	–	–	≤0.006	0.02	0.02	0.11	0.14
31	–	–	–	–	–	0.1	0.04	0.03	0.15	0.1
32	–	–	–	–	–	0.13	0.02	0.03	0.13	0.11
33	–	–	–	–	–	≤0.006	0.03	0.03	0.5	0.05
34	–	–	–	–	–	≤0.006	0.03	0.03	0.06	0.09
Minimum	0.056	0.02	0.024	0.032	0.003	≤0.006	0.02	0.02	0.03	0.01
Maximum	0.548	0.43	0.25	0.493	0.471	0.46	0.09	0.06	4.07	0.63
Average	0.18	0.04	0.10	0.12	0.10	0.07	0.03	0.04	0.25	0.12

The values above the admissible range indicate potential contamination

Table 5 Correlation coefficients of physicochemical parameters of well groundwater

	EC	Na	K	Mg	Ca	Cl	SO ₄	HCO ₃	NO ₃
EC	1.00	0.91	0.60	0.92	0.55	0.98	0.47	0.05	0.12
Na		1.00	0.48	0.75	0.20	0.89	0.34	0.29	0.12
K			1.00	0.57	0.33	0.67	0.05	−0.13	−0.23
Mg				1.00	0.67	0.90	0.51	−0.05	0.03
Ca					1.00	0.49	0.66	−0.36	0.20
Cl						1.00	0.29	−0.05	0.00
SO ₄							1.00	0.17	0.44
HCO ₃								1.00	0.04
NO ₃									1.00

The values close to 1 indicate a good correlation

Conclusions

The results obtained from the 34 analyzed samples show that groundwater quality in the Triffa aquifer is poor. High concentrations of nitrates and EC were recorded in the western part of the Triffa plain, and in over half of the tested wells exceeded the standard level set for drinking water by the WHO (50 mg/l). The bacteriological data (TC, FC, and FS) showed that almost all of the samples were contaminated. The contamination came from septic tanks and the wastewater dumped in the Charaa wadi (river). In general, the results for metals (Cu, Zn, Al, Fe) were within the acceptable range for drinking water, except for Cd, a contamination that could be dangerous for human life. Multivariate statistical analysis undertaken using PCA of major hydrochemical ions identified three major geochemical processes with 85.45% of TV. Thus, the groundwater from the Triffa plain is recommended for irrigation and domestic use (house cleaning, etc.).

Fig. 10 Spatial distribution of the variables in the axes system **a** F1-F2 and **b** F1-F3

Fig. 11 Spatial distribution of the individuals in the axes system **a** F1-F2 and **b** F1-F3

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