



Journal of Applied Sciences

ISSN 1812-5654

science
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Assessment of Groundwater Quality in the Al-Butana Region of Sudan

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Abstract: The quality of drinking groundwater of Al-Butana region of Sudan was investigated. In this study a total of 209 well water samples belonging to previous Construction Analysis (CA) and a total of 121 well water samples belonging to the Current Study (CS) were compared and statistically analyzed. The comparison indicated that there are obvious differences between the CA and the CS with respect to their chemical constituents. The TDS concentration levels tend to decrease by excessive pumping in the investigated boreholes of the study area. Almost, all of the examined boreholes (with the exception of 6.2% CS and 2% CS) revealed TDS concentrations well below the maximum permissible level of 1000 mg L⁻¹ adopted by the Sudanese Standards and Metrology Organization. Generally, the measurements of pH, EC, TH, cations and anions of the investigated well water samples seemed to be unstable and fluctuating up-and-down with a whole decrease in TDS during well water pumping. The fluctuation of well water constituents is submitted to the natural physicochemical equilibrium that termed by this study.

Key words: Groundwater quality, construction analysis, ground water, metrology

INTRODUCTION

Groundwater constituents are greatly affected by many factors; the intensive evaporation of effluent surface irrigation water that led to the precipitation of evaporites, especially affecting the groundwater at shallow depth (Subyani, 2005), local hydrogeological conditions and the chemical makeup of minerals. Some chemicals are more soluble than others, making them more likely to become dissolved in water (Harrington *et al.*, 2008), proximity of groundwater to seacoast (Nassereddin and Mimi, 2005) and direct contact of seawater to the aquifers (Shaaban, 2001), internal movement of groundwater (Mehta *et al.*, 2000), intensive evaporation of effluent surface irrigation water that led to the precipitation of evaporites, especially affecting the groundwater at shallow depth (Subyani, 2005), increase of groundwater discharge increases groundwater salinity (Munday and Andrew, 2008), climatic season (total dissolved solids of groundwater decrease at the beginning of the rainy season and increase after the rainy season (Shanyengana *et al.*, 2004), over exploitation of coastal aquifers (Ramkumar *et al.*, 2010) and anthropogenesis also affect fresh water resources (Humphries and Wood, 2004).

The continuous changes in groundwater chemical constituents necessitate a frequent examination of

groundwater quality before being used. Therefore, periodical analysis for drinking water wells is very important; therefore, this study is conducted to investigate the following objectives:

- To compare between the current analyses conducted by the current study with the routine chemical analysis that usually done after well drilling
- To compare the results obtained (both CA and CS) with the local, regional and international standards and guidelines

MATERIALS AND MATHOD

Study location: The study area was divided, administratively, into three regions as follows:

- The whole area of East of Gezira Locality, Gezira State
- The Western Administrative Units area of Umelghura Locality, Gezira State
- The Eastern Administrative Units area of Shark-el-Neel Locality, Khartoum State (Fig. 1)

Samples and data collection: A total of 121 groundwater samples were collected from different boreholes of various communities using 250 mL plastic bottles, each bottle was rinsed with the targeted water 3-4 times before filling.

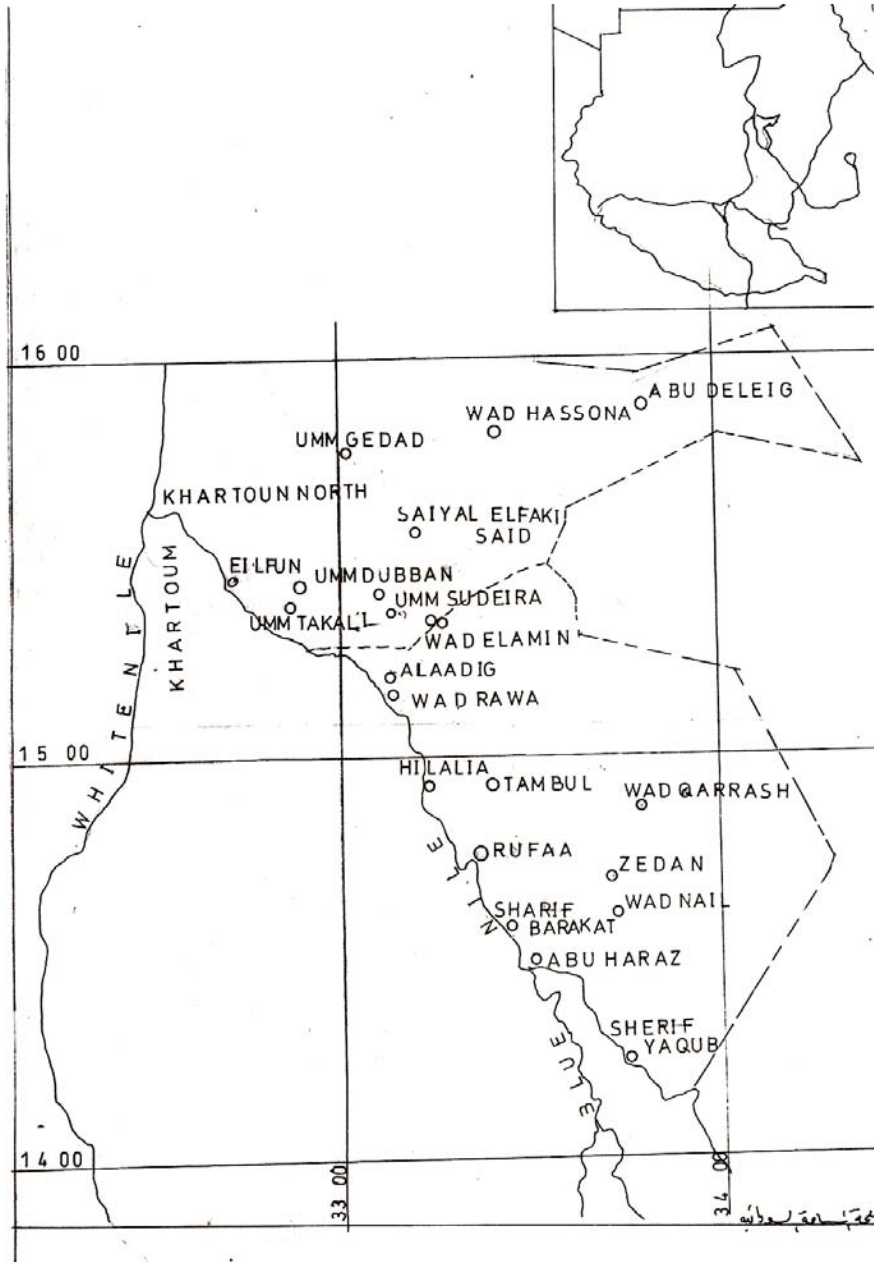


Fig. 1: Location map of the study area, Al-Butana region of Sudan. Source: Sudan National Survey Authority, prepared for the current study, 1 cm = 18 km

Samples were collected directly from the outlet points of the well, where and when possible. In boreholes without outlet point, samples were collected from reservoirs or from the nearest water-tap to the groundwater source. The hydro-meteorological data (climate elements) are available at Wed-Medani

Meteorological Station. The CA data of boreholes were obtained from the Information Center archives of Groundwater Directorate in Khartoum-Kilo A'shara and from the National Institute for Drilling at Wad-Medani and Water Corporation of East Gezira Locality; Rufaa' Town.

Statistical analyses of data: Basic statistics program (Microsoft Excel Spreadsheet) was used to calculate mean, range and standard deviation of the obtained data.

Chemical analyses: The determinations were carried out according to the standard methods for the examination of Water and Wastewater APHA (1998) and Rhoades (1982). In these determinations, pH was measured by a meter ohm pH-meter, India (Model 632). The pH meter was first adjusted using standard buffer solutions having pH of 4 and 9.2. Electric conductivity (EC) (dS m^{-1} at 25°C) in groundwater samples was measured by Beckman Solu Bridge type equipment. To convert the EC readings to TDS, the results for the EC dS m^{-1} were multiplied by 640. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined by complex metric titration using Ethylene Diamine Tetra Acetic Acid (EDTA). Sodium (Na^+) and potassium (K^+) were determined photo metrically by flame photometer (Model: PFP7, Serial No. 15027, Jenway-England). Chloride (Cl^-) was determined by titration using standard silver nitrate solution and potassium chromate (5% solution) as an indicator. Bicarbonates (HCO_3^-) were determined by titration against 0.05 N standard sulphuric acid (H_2SO_4) to pH 4.5 using phenolphthalein and methyl orange as indicators. Fluoride (F^-) was determined by Alizarin Visual method. Nitrate (NO_3^-) was determined by cadmium reduction method according to APHA (1998). Nitrate (NO_3^-) is reduced almost quantitatively to nitrite NO_2^- in the presence of cadmium. The NO_2^- thus obtained is determined colorimetrically using instrument Model specord 40-analytikjena spectro-photometer (Germany).

RESULTS AND DISCUSSION

Distribution of the TDS, the TH and the cations: For study convenience, the data of the TDS, the TH and the cations for both CA and CS were statistically analyzed and categorized in Table 1. Analyses of the data revealed obvious variations in the TDS level among boreholes. The TDS concentration levels in the CA range between 110 and 6400 mg L^{-1} , the mean value is 498 mg L^{-1} , thus resulting in a high SD of 665 mg L^{-1} . In the CS, the TDS levels ranged between 115 and 1070 mg L^{-1} , the mean value is 322 mg L^{-1} , thus resulting in SD of 165 mg L^{-1} . The magnitude of the SD (665) in the CA data is higher than that for the CS (SD 165). This indicates that there is, comparatively, a little variation in the TDS magnitude in well water samples analyzed recently during this study.

The levels for the TDS in the CA and the CS samples were compared with the local, regional and international standards and guidelines for TDS in drinking water. The data indicates that 71.3% (CA) and 87.6% (CS) of the

groundwater samples have TDS levels lying well below the maximum level of 500 mg L^{-1} recommended by USEPA (1976). Only 28.71% (CA) and 12.4% (CS) of the investigated samples have TDS levels well above 500 mg L^{-1} , 93.8% (CA) and 98.4% (CS) of samples have TDS levels well below the maximum level of 1000 mg L^{-1} set by each of GCCS (1993), WHO (1993) and SSMO (2002) while only 6.2% (CA) and 1.56% (CS) of the investigated samples have TDS levels in excess of the maximum recommended level of 1000 mg L^{-1} . Moreover, 97.6% (CA) and 100% (CS) of the samples lie well below the maximum level of 1500 mg L^{-1} set by each of EEC (1992) and SASO (1984) whereas, only 2.4% (CA) and none of the investigated samples (CS) exceeded the above-mentioned level. Therefore, according to the respective standards and guidelines limits for drinking water listed in Table 1, high salinity drinking water with TDS levels violating the maximum recommended levels is considered unsuitable for drinking but could be used for irrigation of crops with good salt tolerance (Al-Redhaiman and Abdel Magid, 2002). TH value ranged between 7 and 156 and between 8 and 138 for the CA and CS analysis, respectively. The mean value of TH is 64 mg L^{-1} (CA) and 57 mg L^{-1} (CS) and the SD value is 23 mg L^{-1} (CA) and 21 mg L^{-1} (CS). The SSMO (2002) did not set any guideline value for TH. The SASO (1984) and the GCCS (1993) guideline value for the maximum permissible hardness is 500 mg L^{-1} . None of the investigated boreholes of both CA and CS exceeded the level of 500 mg L^{-1} adopted by GCCS and SASO guideline value as a maximum permissible level for TH in drinking water. According to Viessman and Hammer (1985) water hardness of more than 300-500 mg L^{-1} is considered excessive for public water supply. However, many consumers object to water hardness above 150 mg L^{-1} (Al-Redhaiman and Abdel Magid, 2002). Therefore, according to the classification suggested by USGS (2009), the groundwater quality pertaining to TH in the study area may be classified as soft water. No remarkable difference exists between CA and CS analyses with respect to their Ca^{2+} content. In the CA, the mean value of Ca^{2+} level is 39 mg L^{-1} , the range is between 0.0 and 90 mg L^{-1} and the SD is 19 while in the CS analyses, the mean value is 37 mg L^{-1} , the range is between 6 and 88 mg L^{-1} and the SD is 17. All Ca^{2+} levels of the investigated well water samples fall below the maximum permissible level of 200 mg L^{-1} set by the GCCS (1993) and SASO (1984) standards. No standard and guideline value was set for Ca^{2+} level in drinking water by USEPA (1976), SSMO (2002) and WHO (1993). The Blue Nile has a high concentration of Ca^{2+} which may be attributed to the weathering of basaltic rocks in the ethiopia

Table 1: The TDS, TH and the cations of well drinking water samples for CA analysis (n = 209) and CS analysis (n = 121) in the study area

Data used	Constituent/ property	Mean	Range	S.D	SSMO	% of	SASO	% of	GCCS	% of	WHO	% of	USEPA	% of	EEC	% of
					standard (2002)	sample above	standard (1984)	sample above	standard (1993)	sample above	guidelines (1993)	sample above	regulation (1976)	sample above	standard (1992)	sample above
CA	TDS	498	110-6400	665	1000	6.2	1500	2.4	1000	6.2	1000	6.2	500	28.7	1500	2.40
	TH	64	7-156	23	NS	-	500	0	500	0	NS	-	NS	-	NS	-
	Ca ²⁺ (mg L ⁻¹)	39	90	19	NS	-	200	0	200	0	NS	-	NS	-	200	0.00
	Mg ²⁺ (mg L ⁻¹)	20	90	13	NS	-	150	0	150	0	NS	-	NS	-	50	0.96
	Na ⁺ (mg L ⁻¹)	65	775	98	200	5.3	NS	-	200	5.3	200	5.3	NS	-	175	8.61
	K ⁺ (mg L ⁻¹)	6	90	12	NS	-	NS	-	NS	-	NS	-	NS	-	12	11.96
CS	TDS	322	115-1070	165	1000	1.6	1500	0	1000	1.6	1000	1.6	500	12.4	1500	0
	TH	57	8-138	21	NS	-	500	0	500	0	NS	-	NS	-	NS	-
	Ca ²⁺ (mg L ⁻¹)	37	82	17	NS	-	200	0	200	0	NS	-	NS	-	NS	-
	Mg ²⁺ (mg L ⁻¹)	20	56	10	NS	-	150	0	150	0	NS	-	NS	-	NS	-
	Na ⁺ (mg L ⁻¹)	52	309	56	200	2.84	NS	-	200	2.48	200	2.48	NS	-	200	2.84
	K ⁺ (mg L ⁻¹)	5.6	66	10	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-

NS: No standard

highlands. Therefore, the Blue Nile which is considered as the main source of aquifers' recharge in the study area, may have replenished groundwater, thus resulting in an increased concentration of Ca²⁺ in boreholes close to the river. Away from the Blue Nile, the level of Ca²⁺ tends to decrease due to ion exchange (Abdel-Salam, 1966). High concentration of Ca²⁺ in groundwater may be attributed to weathering of silicate minerals (Ramkumar *et al.*, 2010). In Erude City, India, the groundwater Ca²⁺ ranged between 28 and 188 (Ramkumar *et al.*, 2010). According to the data embodied in Table 1, in the CA, the mean value of Mg²⁺ is 20 mg L⁻¹, the range is between 0.0 and 90 mg L⁻¹ and the SD is 13, similarly, in the CS, no significant differences exist, the mean value is also 20 mg L⁻¹, the range is between 2 and 58 mg L⁻¹ and the SD is 10. Only 3 of the examined boreholes (1.4%) in the CA exceeded the level of 150 mg L⁻¹ set by SASO (1984) and GCCS (1993) for Mg²⁺ in drinking water and none of the boreholes in the SA exceeded the level of 150 mg L⁻¹. No standard and guideline value was set by SSMO (2002), WHO (1993) and USEPA (1976) for the maximum permissible level of Mg²⁺ in drinking water. Regarding the EEC (1992) only 9 samples (4.3% CA) and 2 samples (1.7% CS) of the examined boreholes are in excess of the permissible level of 50 mg L⁻¹ set for magnesium. The international standards set the limits for Mg²⁺ not to be more than 30 mg L⁻¹ if there is 250 mg L⁻¹ of sulfate, if there is less sulfate, Mg²⁺ up to 150 mg L⁻¹ may be allowed (Al-Redhaiman and Abdel Magid, 2002). The Mg²⁺ levels in fresh water is usually below that of Ca²⁺, this is probably due to the lower geological abundance of Mg²⁺ in the study area groundwater aquifer (El-Nazeer, 1987). The Mg²⁺ levels in the groundwater of Gezira formation generally varies from 5 to 45 mg L⁻¹ and the average is 15 mg L⁻¹ while the Nubian Sandstone formation contains a low amount of Mg²⁺ varying from 9 to 27 mg L⁻¹ (Abdel-Salam, 1966). In Erude City, India, the groundwater Mg²⁺ ranged between 5 and 209 mg L⁻¹ (Ramkumar *et al.*,

2010). The Na⁺ mean value of the CA data is 65 mg L⁻¹, the range is between 0.0 and 775 mg L⁻¹ and the SD is 98 while in the CS data, the Na⁺ mean value is 52 mg L⁻¹, the range is between 2 and 310 mg L⁻¹ and the SD is 56. Only 13 boreholes out of 209 (6.2%) in the CA exceeded the maximum level of 200 mg L⁻¹ adopted by the SSMO (2002), GCCS (1993) and WHO (1993), whereas in the CS only 3 boreholes out of 121 (2.5%) exceeded the previously mentioned level. The EEC (1992) standard adopted a maximum allowable level of 175 mg L⁻¹ for Na⁺ in drinking groundwater. The number of samples exceeding the EEC guideline is 20 boreholes (10%) and 7 boreholes (5.8%) in the CA and CS, respectively. No standard has been set by SASO (1984) and USEPA (1976) for sodium. In Erude City, India, the groundwater Na⁺ ranged between 6 and 437 mg L⁻¹ (Ramkumar *et al.*, 2010). The K⁺ concentration in the CA analysis ranged between 0.0 and 90 mg L⁻¹, mean 6 mg L⁻¹ and the SD is 12 while in the CS, K⁺ ranged between 1.0 and 45 mg L⁻¹, mean 5.6 and the SD is 10. The SSMO (2002) did not set any guideline value for potassium. The unique standard that was set for K⁺ is 12 mg L⁻¹ which is adopted by EEC (1992) to be the maximum limit for this element. A total of 26 boreholes (11.96%) in the CA and 12 boreholes (9.92%) in the CS exceed the maximum level that set by the EEC standard (Table 1). In general, K⁺ concentration in the groundwater of the study area is very low; however, some boreholes showed high K⁺ levels. Potassium ion tends to be fixed again through sorption on clay minerals but, in general, the concentration of K⁺ is predicted by the theoretical dissolution of potassium feldspars. The relative immobility of K⁺ as related to Na⁺ is due to the fact that K⁺ enters into the structure of certain clay minerals and also due to the lesser rate of disintegration of K⁺ minerals compared to Na⁺ minerals (El-Nazeer, 1987). The relatively low levels of K⁺ in the study area, however, may be due to its greater resistance to weathering and its fixation in the formation of clay mineral (Ramkumar *et al.*,

2010). In Erude City, India, the groundwater K⁺ concentration level ranged between 4 and 76 mg L⁻¹ (Ramkumar *et al.*, 2010).

Distribution of the TH and the anions: Table 2 summarizes the data of the TH and the anions for both CA and CS. The pH value ranges are (6.5 and 9.1 CA), (7.1, 8.4 CS). The mean pH value 7.8 (CA) and 7.7 (CS) indicates the alkaline nature of groundwater samples studied. The SSMO (2002) and WHO (1993) range for pH level in drinking water is 6.5-8.5. None of the pH levels of the drinking water samples studied was below or above this level in both CA and CS. Nearly; all of the groundwater samples investigated in the study area are alkaline. Alkalinity is due to the presence of high levels of NaHCO³ and Ca (HCO₃)₂ (Abdel-Salam, 1966). In Erude City, India, the groundwater pH level ranged between 7 and 8.2 (Ramkumar *et al.*, 2010). The Cl⁻ level in the CA varies between 0.0 and 930 mg L⁻¹ with a mean of 70 mg L⁻¹ and SD of 108 while in the SA analysis the Cl⁻ concentration level ranged between 21 and 369 mg L⁻¹ with a mean of 114 mg L⁻¹ and a SD of 66. A level of 250 mg L⁻¹ has been recommended by SSMO (2002), WHO (1993), USEPA (1976) and GCCS (1993) guidelines to be the maximum recommended level for this element. A total of 11 boreholes (5.3%) and 6 boreholes (5%) exceeded this level in the CA and CS, respectively. Only 3 boreholes (1.4%) in the CA exceeded the maximum level of 600 mg L⁻¹ set by SASO (1984) while none of the boreholes in the CS analysis exceeded this level. The number of the boreholes exceeding the 200 mg L⁻¹ set by the EEC (1992) guidelines jumped to 18 boreholes CA (8.6%) and 17 boreholes CS (14%). In Erude City of India, the groundwater Cl⁻ ranged between 28 and 759 mg L⁻¹ (Ramkumar *et al.*, 2010). In general, Cl⁻ content in the Gezira formation varies between 10 to 105 mg L⁻¹ with an average of 28 mg L⁻¹ while in the Nubian formation the Cl⁻ ion content varies between 4 to 78 mg L⁻¹ with an average of 40 mg L⁻¹ (Abdel-Salam, 1966). According to

the data presented in Table 2, in the CA analysis, the HCO₃⁻ level ranged between 0.0 and 610 mg L⁻¹, with a mean of 66 mg L⁻¹ and SD of 119. In the CS analysis, the HCO₃⁻ level ranged between 41 and 464 mg L⁻¹, with a mean of 114 mg L⁻¹ and SD of 73. No standard and guideline limit has been set for HCO₃⁻ by any of the standards used for comparison in this study. Obviously, most of the investigated boreholes in the CA showed mean HCO₃⁻ levels less than that found in the CS Obiefuna and Sheriff (2011) reported that HCO₃⁻ concentrations in drinking water of Pindiga and Tudun Wada, Nigeria, ranged between 0.0 and 217 mg L⁻¹. In general, the amount of HCO₃⁻ content in the Gezira formation is more than that found in the Nubian Sandstone formation (Abdel-Salam, 1966). The mean value of NO₃⁻ ion concentration is 6.7 and 3.0 mg NO₃⁻ with a range between 0.0 and 750 mg L⁻¹ and between 0.0 and 26 mg L⁻¹ for CA and CS, respectively. It may be observed that the SD of the CA data (55 mg L⁻¹) is higher than that of the CS data (3.7 mg L⁻¹). In aquifers underlying the agricultural area of Canada Bonton *et al.* (2010) reported NO₃⁻ levels ranging between 6 and 125 mg L⁻¹. Nitrate concentration level for the groundwater samples investigated in this study (CA and CS) revealed that only 1.91% of the investigated groundwater samples in the CA exceeded the maximum permissible limit of 45 mg L⁻¹ guideline set by SASO, GCCS and USEPA standards and the guideline limit of 50 mg L⁻¹ set by the SSMO, WHO and EEC standards while none of the CS samples investigated exceeded the maximum recommended level of either 45 mg L⁻¹ or 50 mg L⁻¹ and therefore, pose no health hazards with respect to their NO₃⁻ ion consent. The mean value of F⁻ level is 0.7 in both CA and CS with a range from 0.0 to 7 mg L⁻¹ and from 0.0 to 2.6 mg L⁻¹ for CA and CS, respectively. As manifested and judged by the magnitude of the SD, negligible variation exists between CA and CS data. Yasir (2004) reported that groundwater F⁻ concentration levels in the study area ranged between 0.2

Table 2: The pH and the anions of well drinking water samples for CA analysis (n = 209) and SA analysis (n = 121) in the study area

Data used	Constituent/properties	Mean	Range	S.D	SSMO	% of	SASO	% of	GCCS	% of	WHO	% of	USEPA	% of	EEC	% of
					standard (2002)	sample above	standard (1984)	sample above	standard (1993)	sample above	guidelines (1993)	sample above	regulation (1976)	sample above	standard (1992)	sample above
CA	pH	7.8	2.6	0.5	8.5	0	6.5-8.5	0	6.5-8.5	0	6.5-8.5	0	6.5-8.5	0	6.5-8.5	0
	F ⁻ (mg L ⁻¹)	0.7	0-7	0.7	1.5*	5.8	0.6-1	12	0.6-1	12	1.5*	5.8	4*	1	0.7-1.5	5.8
	NO ₃ (mg L ⁻¹)	6.7	0-750	55	50	2	45	2	45	2	50	2	45	2	50	2
	Cl (mg L ⁻¹)	70	930	108	250	3.4	600	1	400	2	250	3.4	250	3.4	200	7.7
	HCO ₃ (mg L ⁻¹)	66	610	119	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-
CS	pH	7.7	1.3	0.3	8.5	0	6.5-8.5	0	6.5-8.5	0	6.5-8.5	0	6.5-8.5	0	6.5-8.5	0
	F ⁻ (mg L ⁻¹)	0.7	0-2.6	0.6	1.5*	11.6	0.6-1	19	0.6-1	19	1.5*	11.6	4*	0	0.7-1.5	11.6
	NO ₃ (mg L ⁻¹)	3.0	0-26	3.7	50	0	45	0	45	0	50	0	45	0	50	0
	Cl (mg L ⁻¹)	114	348	66	250	5	600	0	400	0	250	5	250	5	250	5
	HCO ₃ (mg L ⁻¹)	283	435	73	NS	-	NS	-	NS	-	NS	-	NS	NS	NS	-

NS: No standard, *: No lower limit

and 0.8 mg L⁻¹. Birkeland *et al.* (2005) reported that F⁻ concentration levels in Abu-Deleig area ranged between 1 and 2 mg L⁻¹. Li *et al.* (2011) found that the F⁻ levels in sandstone aquifers of Taiyuan basin of China ranged between 1.5 and 2 mg L⁻¹. Fluoride concentration levels for both CA and CS revealed that 94.26 and 88.43% of the well water samples analyzed are lying well below the maximum permissible limit of 1.5 mg L⁻¹ set by both of the SSMO (2002) for CA and CS, respectively. On the other hand, it may observe that 5.75% (CA) and 11.58% (CS) of the well water samples are violating the maximum permissible limit of 1.5 mg L⁻¹ set by SSMO (2002) and WHO (1993). With respect to the Economic European Community EEC (1992) standards and guidelines for F⁻ in drinking water (0.7-1.5 mg L⁻¹), 64.11 and 61.15% of the well water samples examined have F⁻ concentration level lying well below the minimum recommended limit of 0.7 mg L⁻¹ set by the EEC (1992), 30.14 and 27.27% are lying within the 0.7-1.5 mg L⁻¹ guideline limit set by the respective standard while only 5.75 and 11.58% of the well water samples are above the maximum permissible limit of 1.5 mg L⁻¹ for CA and CS, respectively. Only 27.75 and 27.27% of the samples are within the recommended level of 0.6-1 mg L⁻¹, set by both SASO (1984) and GCCS (1993), in CA and CS, respectively. A total of 60.29 and 53.71% of the investigated samples are lying below the minimum recommended level while only 11.96 and 19% (23 boreholes) are above the maximum recommended guideline level in both CA and CS, respectively. Percentages of 99.04 and 100% are well below the maximum recommended level of 4 mg L⁻¹ set for F⁻ in drinking water by the USEPA (1976) in both CA and CS, respectively. It may be observed that only 0.96% in the CA are in excess of the maximum recommended level of 4 mg L⁻¹ while none of the well water samples in CS have exceeded the maximum recommended level of 4 mg L⁻¹ set by the USEPA (1976) standard.

CONCLUSIONS

Based on the results of the present investigation, the following conclusions may be drawn:

- Only 6.2% (CA) and 1.6% (CS) of the investigated boreholes were found to be in excess of the TDS level of 1000 mg L⁻¹ set by SSMO (2002) and WHO (1993)
- Due to the excessive pumping and extraction, TDS concentrations of groundwater in the study area are continuously decreasing during withdrawal-time in accord with the daily pumping rate and aquifer geological formation
- Most of the groundwater constituents levels obtained in this study exhibited compliance to the standards and guidelines set by SSMO (2002) and WHO (1993).

RECOMMENDATIONS

- The study recommends that the respective authorities should encourage population groups in the study area to live in areas where groundwater is of an acceptable quality. Moreover, it is advisable to build water-treatment plants close to the Blue Nile instead of the high-cost installing and operating wells
- Groundwater directorates throughout the study area should closely monitor the activities of the private drilling companies and force them to prepare precise composite log files for each of the boreholes fixed and posted in a visible position at the borehole site
- The concern authorities should have to re-analyze well drinking water periodically and data should be kept properly in well-knit composite logs
- The study recommends SSMO to prepare drinking water standards independent of WHO guidelines according to environmental conditions and the prevailing climate temperature

ACKNOWLEDGMENT

The authors acknowledge the assistance of all those who contributed to this study.

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